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TETRAPOD BIODIVERSITY THROUGH THE PERMO-TRIASSIC BEAUFORT GROUP (KAROO SUPERGROUP) OF SOUTH AFRICA.

Volume I

Merrill Victoria Mary Nicolas

A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2007.

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DECLARATION

I declare that this thesis is my own, unaided work, except where specific acknowledgement is made to the work of others. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

_____

(Signature of candidate)

_____ day of _____ 2006

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"The pounding of the cylinders increased: ta-pocketa-pocketa-pocketa-pocketa-pocketa. The Commander stared at the ice forming on the pilot window. He walked over and twisted a row of complicated dials. "Switch on No. 8 auxillary!" he shouted. "Switch on No. 8 auxillary!" repeated Lieutenant Berg. "Full strength in No. 3 turret!" shouted the commander. "Full strength in No. 3 turret!" The crew, bending to their various tasks, in the huge eight-engined Navy hydroplane, looked at each other and grinned. "The Old Man'll get us through," they said to one another. "The Old Man ain't afraid of hell!"… He took one last drag of his cigarette and snapped it away. Then, with that faint, fleeting smile playing about his lips, he faced the firing squad: erect and motionless, proud and disdainful, Walter Mitty the Undefeated, inscrutable to the last."

From: The Secret Life of Walter Mitty

by James Thurber

Peter Frederick Nicolas. My Father.

1947-2000

Oh! You have slipped the surly bonds of earth

and dance the skies on laughter-silvered wings;

You tread the high untrespassed sanctity of space,

put out your hand and touch the face of God.

Adapted from: High Flight

by Pilot Officer Gillespie Magee

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ABSTRACT

The rocks of the Beaufort Group of South Africa record a remarkably complete depositional sequence incorporating a rich fossil tetrapod succession from the mid-Permian to mid-Triassic. This represents one of the best preserved ecological assemblages of pre-mammalian terrestrial tetrapods documenting the stem lineages of both mammals and dinosaurs.

For more than a century large collections of fossils from the Beaufort Group have been built up at various museums in South Africa. With the co-operation of all the South African museums curating collections of Karoo fossils, a single standardised database has been compiled for the fossils collected from the Beaufort Group as well as a GIS system incorporating all the South African databases of fossil records.

Major problems which had to be overcome related largely to the non-standardised nature of different databases, locality, and taxonomic information. Particularly problematic was entering ambiguous and vague locality information onto the GIS database, so that it would still be useful for qualitative evaluation. The created GIS database is a useful analytical tool, but requires streamlining to make it accessible to all users. Completion of the foundation phase of the GIS database has highlighted problems which need to be addressed in the future to make the database an effective tool for research purposes.

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Incorporation of datasets from the various museums required rigorous standardisation, quality testing and manipulation. This unique dataset now, for the first time, provides a record of fossil continental vertebrate biodiversity from the Middle Permian to the Middle Triassic of Gondwana, including accurate numbers of specimens of the various taxa which have been collected from the rocks of the Beaufort Group.

Establishment of this dataset has enabled the determination of the diversity and numeric abundance of tetrapods from the rocks of the Beaufort Group; faunal biodiversity changes through time; ecological representation of the faunal assemblage within and across biozones of the Beaufort Group; trends in generic diversity within and across biozones showing particularly the decline in generic diversity by the close of the *Cistecephalus* Assemblage Zone, as well as the extent of survivorship and extinction within each biozone of the Beaufort Group.

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ACKNOWLEDGEMENTS

Many people have contributed to this study. I am indebted to numerous people whose input was invaluable. My gratitude is therefore extended to the following persons and Institutes for their assistance and guidance:

Firstly, to Riaan van der Walt. Your support, encouragement and respect are rare gifts. How can I even attempt to thank you?

Above all - to my most beautiful children: Dieudonné, Daniel-Peter and to the as yet unborn joy that we wait eagerly for.

I am forever indebted to my mother, my sisters and my brother who did not think for a single moment that I may find this journey daunting or difficult.

I am indebted to my supervisor, Prof. B.S. Rubidge (Bernard Price Institute for Palaeontological Research), for his guidance and critical analysis during the course of this project. His wealth of experience and support was especially valued.

I would like to acknowledge the financial support provided by the Palaeontological Scientific Trust (PAST), without whose support I would never have enjoyed this academic journey and would instead, still be teaching mathematics to surly teenagers.

I would like to acknowledge the financial support and academic freedom provided by the Satellite Applications Centre (CSIR) for this project and the contribution and insight of Anthony Cooper and Karen Wentzel.

I would like to acknowledge the financial support provided by National Research Foundation of South Africa (NRF).

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I am indebted to Inge Netterberg for her huge contribution, practical insight and sheer endurance. She laid down the keystone. Thank you.

I am eternally grateful to Derek Dent whose assistance went above and beyond. Your meticulous attention to detail and impeccable dedication to the task at hand is rare and inspiring. Your unfailing patience and many hours spent on graphs and tables is sincerely appreciated.

Special thanks to Dr. B. de Klerk (Albany Museum), Dr. M. Raath (Bernard Price Institute), Dr. J. Neveling (Council for Geoscience), Ms. E. Butler (National Museum), Prof. B. Rubidge (Rubidge Collection), Ms. S. Kaal (South African Museum) and Ms. S. Potze (Transvaal Museum) for allowing such generous access to their museum records of fossil collections from the Beaufort Group, Karoo Supergroup of South Africa.

I am indebted to Dr. F. Abdala, Dr. A. Yates, Dr. R. Govender, Dr. A. Renaut, Mr. J. Cisneros and Prof. B.S. Rubidge for their efforts in explaining various aspects of vertebrate taxonomy and anatomy as well as various (complex) aspects of Karoo sedimentology and geology. What is impressive is how unselfishly they shared their knowledge and insight.

I have greatly benefited from numerous discussions had with other researchers. Impromptu conversations with Dr. M. Raath, Prof. L. Berger, Dr. R. Damiani, Mr. C. Vasconcelos, Dr. R. Prevec, Dr. R. Renaut, Dr. A. Renaut, Dr. L. Backwell, Ms. L. Periera, Ms. C. Steininger, Ms. R. Pickering, Ms. C. McCrae, Ms. H. Mocke, Mr. M. Blackbeard, Mr. J. Cisneros, Dr. I. McKay, Dr. E. Bordy and Dr. F. Abdala have steered me (often unknowingly) onto the correct path when I was distinctly veering off.

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Tables; Figures; Appendices; DVD

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Chapter 1: Introduction

Section 1: Literature Review

1.1.1 Biostratigraphy of the Beaufort Group

The rocks of the Beaufort Group (Adelaide and Tarkastad subgroups) of the Karoo Supergroup cover a large percentage of the surface of South Africa (Smith, 1990) and comprise an approximately 3000m thick sequence of predominantly sedimentary rocks that are richly fossiliferous. The absolute age of the Beaufort Group is not well constrained, with current dates based mainly on faunal correlations. The oldest stratigraphic units are considered Middle Permian (Kazanian) (Rubidge, 1995), and the uppermost strata as Middle Triassic (Anisian) (Ochev & Shishkin, 1989; Hancox *et al.*, 1995; Hancox & Rubidge, 1996; Hancox, 1998).

The global relevance of the Beaufort Group is largely due to its remarkable assemblage of tetrapod fossils and the succession is held by many to be the global biostratigraphic standard for the non-marine Permo-Triassic (e.g. Shishkin *et al.*, 1995; Lucas, 1998). Furthermore, the rocks of the Beaufort Group preserve one of the most complete and best-studied non-marine Permo-Triassic (PT) boundary sequences globally (Smith, 1995; Ward *et al.,* 2000; Smith & Botha, 2005; Botha & Smith, 2006). These boundary sections preserve the terrestrial record of the Permo-Triassic

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extinction event - the greatest mass extinction event experienced on Earth to date (Erwin, 1993, 1994; 2006).

The fossils of the Beaufort Group represent one of the best preserved ecological assemblages of pre-mammalian terrestrial vertebrates in the world (Keyser & Smith, 1979). This is a pivotal time in evolutionary history because during this period the stem lineages to both mammals and dinosaurs arose (Broom, 1932; SACS, 1980), and the rocks of the Beaufort Group contain many significant fossils that document these evolutionary milestones (Hancox *et al.*, 2001).

The abundance of fossils has proved particularly useful to understanding the tectonic controls of the Karoo Basin during deposition of the Beaufort Group (Hancox & Rubidge, 1997). Tetrapod fossils (particularly therapsids) have long been used for the biostratigraphic subdivision and correlation of the group which is especially useful because of the scarcity of basin-wide lithostratigraphic marker beds (Broom, 1907, 1909; Haughton, 1924b, 1963, 1969; Kitching, 1970, 1972, 1977, 1984; Keyser & Smith, 1979; Keyser, 1979; Rubidge, 1995; SACS, 1980). The few major lithological boundaries that have been traced throughout the basin have been shown to be diachronous (Keyser, 1979), whereas the biozones more closely approximate time lines. Different genera of the infra-order Dicynodontia are the most abundant fossil tetrapod taxa in the Beaufort Group, and for this reason they are used as index fossils for the majority (five of the eight) of the currently recognised vertebrate biozones (Hancox & Rubidge, 1997). Moreover, due to their abundance, dicynodonts have

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great potential for global correlation and have therefore been used in a number of previous biogeographic studies and biochronological schemes (Cooper, 1982; Cruickshank, 1985, 1986; Lucas, 1990, 1993, 1995, 1998; De Fauw, 1993; Shishkin & Ochev, 1992).

Following is a summary of the history of work on the biostratigraphy of the Beaufort Group since Seeley proposed the first biostratigraphic subdivision back in 1892.

Seeley (1892) divided the Beaufort into three biostratigraphic zones:

(3) Zone of "highly specialized group of theriodonts" (uppermost zone).

(2) Zone of "Dicynodonts".

(1) Zone of "Pareiasaurians" (lowermost zone).

Broom (1907b; 1909) proposed a new biozonation of the Beaufort "Series":

(6) *Cynognathus* Zone (uppermost zone)

(5) *Procolophon* Zone

(4) *Lystrosaurus* Zone

(3) *Cistecephalus* Zone

(2) *Endothiodon* Zone

(1) *Pareiasaurus* Zone (lowermost zone)

Watson (1914) agreed with Broom's subdivision and was the first to indicate the distribution of these units (which he termed "zones") on a map. Later he replaced the

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Pareiasaurus Zone with the *Tapinocephalus* Zone (Watson 1914c). An updated biozone distribution map was published by Von Huene (1940). Hotton and Kitching (1963) pointed out that *Procolophon* occurs throughout the *Lystrosaurus* Zone and that a separate overlying *Procolophon* zone was not valid.

Kitching (1970; 1977) introduced the *Daptocephalus* Zone to encompass the strata between the level where *Cistecephalus* became extinct and the first appearance of *Lystrosaurus,* and discarded Broom's *Endothiodon* and *Procolophon* Zones. Kitching (1977) also produced a map showing zone-defining fossil localities (Figures 1.2 & 1.3).

Keyser and Smith (1979) proposed a new vertebrate biozonation (and accomanying biozone map) for the Beaufort Group and linked the assemblage zones to the new lithostratigraphy, proposed by S.A.C.S (1980). The Beaufort assemblage zones as proposed by Keyser & Smith (S.A.C.S., 1980) are:

(7) *Kannemeyeria-Diademodon* Assemblage Zone (uppermost zone)

(6) *Lystrosaurus-Thrinaxodon* Assemblage Zone

(5) *Dicynodon lacerticeps-Whaitsia* Assemblage Zone

(4) *Aulacephalodon-Cistecephalus* Assemblage Zone

(3) *Tropidostoma-Endothiodon* Assemblage Zone

(2) *Pristerognathus-Diictodon* Assemblage Zone

(1) Dinocephalian Assemblage Zone (lowermost zone)

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The discovery of a tetrapod fauna from below the *Tapinocephalus* Assemblage Zone (Rubidge, 1984; Rubidge *et al.,* 1994; Rubidge *et al.,* 1983), led to the erection of an additional vertebrate biozone at the base of the Beaufort Group (Rubidge, 1990). This biozone, the *Eodicynodon* Assemblage Zone is the oldest vertebrate biozone of the Beaufort Group (Rubidge, 1984; Rubidge *et al.,* 1983; Rubidge, 1995).

Following the recommendations of the International Stratigraphic guide (ISSC, 1976) the names of the assemblage zones that were accepted by SACS (1980) incorporated two generic names. The most recent biostratigraphic scheme of the Beaufort Group (Rubidge, 1995b) follows the most recent nomenclatorial practise of the ISSC (1994) and uses only one taxon name in defining a biozone. The current biozonation (Figure 1.1) is:

(8) *Cynognathus* Assemblage Zone

(7) *Lystrosaurus* Assemblage Zone

(6) *Dicynodon* Assemblage Zone

(5) *Cistecephalus* Assemblage Zone

(4) *Tropidostoma* Assemblage Zone

(3) *Pristerognathus* Assemblage Zone

(2) *Tapinocephalus* Assemblage Zone

(1) *Eodicynodon* Assemblage Zone

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A faunal based subdivision of the *Tapinocephalus* Assemblage Zone, based on the relative abundances of dinocephalians and dicynodonts, was first suggested by Boonstra (1969). He proposed a threefold subdivision, which included an upper subzone in which dinocephalians were absent. This upper subzone was later re-named the *Pristerognathus-Diictodon* Assemblage Zone by Keyser & Smith (1979). Loock *et al.*, (1994) were able to tie the ranges and abundances of this proposed subdivision to the local lithostratigraphy in the southern Karoo Basin. They correlated the contact between the lower dinocephalian rich and upper dicynodont abundant zones of the *Tapinocephalus* Assemblage Zone with the contact between the Wilgerbos and Koornplaats Members of the Abrahamskraal Formation. Further refinement of the taxonomy of tapinocephalid dinocephalians could enhance the biostratigraphic subdivision of this part of the lower Beaufort Group (Hancox *et al.*, 2001).

The beginning of the Triassic Period in the Karoo Basin has traditionally been defined by the first appearance of the dicynodont genus *Lystrosaurus* (Broom, 1932; Kitching, 1968; 1977) and has been stratigraphically placed at the base of the Katberg Formation. Smith (1995) and Smith and Ward (2001) confirmed the long-reported observation that *Lystrosaurus* fossils actually first appear in association with Permian taxa (Hotton, 1967; Keyser & Smith, 1979). This means that the base of the *Lystrosaurus* Assemblage Zone occurs in the Permian. According to Smith (1995) the range of *Lystrosaurus* overlaps *Dicynodon* zone fossils in an “overlap” zone of as much as 41m. For this reason there is, as yet, no vertebrate taxon whose first occurrence can be used to define the base of the Triassic. Additional confirmation of

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this is provided by work on the Permo-Triassic boundary in the south of the basin (Smith & Macleod, 1999; Macleod *et al.*, 1999) where again an overlap in the ranges of *Dicynodon* and *Lystrosaurus* is observed. Further evidence of this overlap is demonstrated by Neveling (1998; 2002), Neveling *et al.*, (1999, 2000) and Smith & Ward (2001). These studies dispel the long held belief that *Lystrosaurus* had a narrow stratigraphic range and was restricted to the very earliest Induan (Battail, 1993). Neveling (2002, 2004) now considers the range of this genus to extend from the Changhsingian until well into the Olenekian.

Recent research has revealed an increase in procolophonid abundance towards the top of the *Lystrosaurus* Assemblage Zone, above the last appearance of *Lystrosaurus* (Neveling, 2004). There may therefore be some merit in re-instating the *Procolophon* Zone of Watson (1914), between the last appearance of *Lystrosaurus* and the first appearance of *Kestrosaurus* (Neveling *et al.*, 2000; Neveling, 2002). The first appearance of *Kestrosaurus* marks the base of the overlying *Cynognathus* Assemblage Zone (subzone A of Hancox *et al.*, 1995; Hancox, 1998; Shishkin *et al.*, 2004).

The faunal association of the uppermost subzone (subzone C of Hancox *et al.*, 1995) occurring exclusively above the last appearance of *Xenotosuchus africanus* and *Kannemeyeria simocephalus*, is dominated by large capitosaurid amphibians assigned to the Mid-Triassic genus *Paracyclotosaurus* (Hancox *et al.*, 2000a;b; Damiani & Hancox, 2003); stahleckeriid and shansiodontid dicynodonts (Hancox & Rubidge,

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1994, 1996; Hancox, 1998) and, as yet undescribed advanced gomphodont cynodonts (Hancox, 2000). Although no formal subdivision of the *Cynognathus* Assemblage Zone is accepted at present, current research (Hancox & Rubidge, 1996; Hancox, 1998; Damiani, 1999; Neveling *et al.*, 1999, 2000; Damiani *et al.*, 2000a;b; Hancox *et al.*, 2000a;b) has strongly reinforced the proposed subdivision of Hancox *et al*. (1995). Following on the work of Welman *et al*. (1991), these research activities have shown that subzone A occurs across the entire basin, and that most of the fauna is more primitive than previously known for the *Cynognathus* Assemblage Zone (Groenewald & Kitching, 1995).

The proposal that the *Cynognathus* Assemblage Zone be subdivided into three distinct subzones is based on the distribution of diagnostic amphibian taxa. Hancox *et al.*, (1995) subdivided the *Cynognathus* Assemblage Zone into three aforementioned subzones (A, B and C), based on the tested hypothesis that the mastodonsaurids: *Kestrosaurus dreyeri*, *Xenotosuchus africanus* and *Paracyclotosaurus morgani* (Hancox *et al.*, 2000a;b) do not overlap chrono-stratigraphically.

Trematosuchus from the *Cynognathus* Assemblage Zone is viewed as the closest relative of *Trematosaurus* from the middle Buntsandstein Zone (Upper Olenekian) of Western Europe (Shishkin & Welman, 1994). This relationship has long been used as evidence for the Early Triassic age for the entire *Cynognathus* Assemblage Zone (Watson, 1942), an opinion previously adopted by the majority of researchers (Shishkin & Welman, 1994). However, it has been shown that the tetrapod

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assemblage of this biozone is typically Middle Triassic in age (Ochev & Shishkin, 1989; Shishkin & Ochev, 1992). This contradiction is resolved by the study of Hancox, *et al.* (1995) who suggested that *Trematosuchus* belongs to the earliest faunal assemblage considered as Lower Triassic in age, while the rest of the *Cynognathus* Assemblage Zone, containing the typical faunal assemblage of this zone, corresponds to the Anisian.

The biostratigraphic subdivision of the *Cynognathus* Assemblage Zone (Hancox, *et al.*, 1995), as a result of the clear partitioning of its faunal content, has allowed for the refinement of the relative ages of the subdivided *Cynognathus* Assemblage Zone (Hancox & Rubidge, 1997). This refinement was accomplished by comparison of the fauna comprising the various subzones with fossil faunas from other better dated rock successions of Gondwana, Russia and China (Hancox & Rubidge, 1997). Accordingly, the age of the *Cynognathus* Assemblage Zone has been refined, with subzone A considered to be latest Early Triassic (Late Olenekian), and subzones B and C, extending across the Early-Middle Triassic boundary into the Middle to Late Anisian (Hancox *et al.*, 1995; Hancox *et al.*, 2001; Neveling, 1998; Abdala *et al.*, 2005).

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1.1.2 Karoo Basin development

Modelling the Karoo Basin as a retro-foreland basin [related to subduction of the Palaeo-Pacific plate underneath the Gondwana plate (Pysklywec & Mitrovica, 1999; Veevers *et al.*, 1994; Johnson, 1991; Cole, 1992)] has seen refinements in the past few years and the effects of basin flexure in relation to thrust advance, sedimentary loading and source unloading had a great influence on the basin infilling (Beaumont, 1981; Quinlan & Beaumont, 1984; Johnson & Beaumont, 1995).

The stratigraphic fill of this foreland basin is controlled by interaction between tectonism, sediment flux and climate (Johnson & Beaumont, 1995). The abundance of fossils in the Karoo Basin provides evidence supporting these parameters, particularly with regard to the timing and duration of tectonism and climatic changes within the basin (Hancox & Rubidge, 1997). Apart from their usefulness in biostratigraphy, fossils also assist in relative age determination – this is particularly important for defining time lines and mapping different strata of the same age throughout the basin. Fossils have therefore proved useful in the development and refinement of basin models for the deposition of the rocks of the Karoo Supergroup (Rubidge, 1988; Hancox *et al.*, 1995; Catuneanu *et al.*, 1998a) and have solved problems that lithological studies alone could not. The recent application of the reciprocal flexure model to explain the Karoo stratigraphy (Catuneanu *et al.*, 1997, 1998b) has relied on fossils for the dating of certain stratigraphic units.

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Fossils have played an important role in re-evaluating the accumulation of the Karoo Supergroup (Hancox *et al.,* 1995; Hancox, 1998; Catuneanu *et al.,* 1998b) by providing evidence for synchronous, spatially separate depositional settings and by the demarcation of chronostratigraphically significant surfaces (Hancox & Rubidge, 1997). Research progress has clearly revealed the benefits of multidisciplinary studies in earth sciences and particularly the role of fossils (Hancox *et al.*, 2001). These have resulted in major refinements to basin development models (Catuneanu *et al.,* 1998b).

1.1.3 Vertebrate taxa from the Beaufort Group

Although the vertebrate fauna of the Beaufort Group has been collected and studied for over 150 years, new taxa continue to be discovered (eg. Hancox *et al.,* 2001; Gow, 2000; Damiani *et al.,* 2000b; Modesto, Sues & Damiani, 2001b; Damiani & Hancox, 2003; Sidor *et al.,* 2004; Sidor & Smith, 2004; Abdala *et al.,* 2006; Smith *et al.,* 2006).

1.1.3.1 Fish

A number of freshwater fish taxa are described from the Beaufort Group (Rubidge, 2005), and where present are useful indicators of aquatic palaeoenvironments (e.g. Keyser, 1966) with biostratigraphic potential (Jubb, 1973; Bender *et al.,* 1991; Murray, 2000; Bender & Hancox, 2000; 2004; Bender, 2005). The majority of the

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fossil fish documented are palaeoniscid fish [with 25 species (Bender, 2000; Jubb & Gardiner, 1975)], but hybodid sharks, coelacanths and lungfish have also been identified. Beaufort Group fish have received scant attention for more than two decades since the work of Jubb and Gardiner (1975), but research on fossil fish has recently resurged with the investigating of two well-preserved occurrences of actinopterygian fish from the *Tapinocephalus* and *Dicynodon* Assemblage Zones (Bender *et al.,* 1991; Bender, 2000).

Recent research on palaeoniscid fish from the Permian Beaufort Group has shown that these faunas are much more diverse than previously recognised (Bender, 2000; Bender & Hancox, 2000; Hancox & Rubidge, 1997), comprising seven genera. Five of the seven taxa are common to both the *Tapinocephalus* and *Dicynodon* Assemblage Zones, but two appear to have possible biostratigraphic significance. *Atherstonia scutata* and *Blourugia* are present throughout the lower Beaufort, while two genera are of significance as biostratigraphic indicators (Bender, 2000) - *Westlepis kempeni* is limited to the *Tapinocephalus* Assemblage Zone and *Kompasia delaharpi* is recognised only from the *Dicynodon* Assemblage Zone (Bender *et al.*, 1991; Bender, 2002). The mid Triassic Bekkerskraal occurrence (*Cynognathus* Assemblage Zone) has been comprehensively documented (Brough, 1931, 1934; Jubb & Gardiner, 1975; Hutchinson, 1973, 1975, 1978) and has yielded 14 lower actinopterygian taxa (Bender, 2001), in addition to a limited number of chondrichthyians. Several specimens of *Lissodus africanus,* a fresh water hybodontid

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shark have been discovered in the Burgersdorp Formation (*Cynognathus* Assemblage Zone) (Broom, 1909; Brough, 1935).

Coelacanths are represented by a few specimens from the Beaufort Group (Rubidge, 2005). A specimen from Permian rocks was placed in the genus *Rhabdoderma* (Rubidge, 2005), and Triassic rocks have yielded specimens of *Whiteia africana*, described from the Bekkerskraal occurrence (Broom, 1909, Brough, 1931). Ceratodontid lungfish are known from the upper Beaufort Group (Kitching, 1995).

Work on the actinopterygians and lungfish of the *Cynognathus* Assemblage Zone has revealed their potential for environmental interpretation, biostratigraphy and Gondwanan strata age correlation (Bender & Hancox, 2000) as well as an aid to understanding the infilling of the Karoo Basin (Hancox & Rubidge, 1997).

1.1.3.2 Amphibia

The Beaufort Group preserves one of the most diverse temnospondyl amphibian faunas in the world. This assemblage includes representatives of the families Amphibamidae, Trematosauridae, Tupilacosauridae, Brachyopidae, Chigutisauridae, Laidleriidae, Lydekkerinidae, Mastodonsauridae, Rhinesuchidae and Rhytidosteidae (Damiani & Rubidge, 2003). Only the Rhinesuchidae, the earliest capitosaurid family is present in the Permian, and are known only from Gondwanan countries (Damiani & Rubidge, 2003). The greatest diversity of rhinesuchids is in South Africa (Damiani

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& Rubidge, 2003), with the family ranging through the Middle to Late Permian (Schoch, 2000). Rhinesuchids are generally considered the most primitive stereospondyl amphibians and the ancestors of the advanced Mesozoic stereospondyls (Schoch & Milner, 2000; Yates & Warren, 2000). Apart from *Broomistega,* a rhinesuchid representative from the Early Triassic of South Africa (Shishkin & Rubidge, 2000), rhinesuchids are known only from the Permian.

Dramatic changes in the composition of amphibian faunas during the Permo-Triassic biotic turnover have been documented (Shishkin & Rubidge, 2000) with the number of taxa increasing greatly in the Triassic (Shishkin & Welman, 1994; Shishkin *et al.*, 1996; Latimer, 1998; Warren, 1998, 1999; Damiani, 1998, 1999; Hancox *et al.*, 2000a;b; Schoch, 2000; Shishkin & Rubidge, 2000; Hancox & Rubidge, 2001; Schoch & Rubidge, 2005). The *Lystrosaurus* Assemblage Zone contains seven higher-level taxa, the Amphibamidae, Tupilacosauridae, Rhinesuchidae, Lydekkerinidae, Rhytidosteidae, Mastodonsauridae and Trematosauridae (Damiani & Rubidge, 2003). The most common amphibian genera of the assemblage are *Lydekkerina, Micropholis,* and *Broomistega,* which are represented by small or medium-sized forms (Shishkin *et al.*, 1996).

The overlying *Cynognathus* Assemblage Zone hosts four, with a suspected fifth family - the Mastodonsauridae, Trematosauridae, Brachyopidae, Laidleriidae, and, possibly the Rhytidosteidae (Damiani & Rubidge, 2003; Shishkin & Welman, 1994).

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Many of these families have a global distribution and are useful as biogeographic indicators (Shishkin & Welman, 1994).

1.1.3.3 Amniota

The clade Amniota is defined as the most recent common ancestor of extant mammals and reptiles, and all its descendants (Gauthier *et al.*, 1988) and is divided into two stem-based taxa: Synapsida (mammals and their extinct relatives) and Sauropsida (reptiles and their fossil relatives). Sauropsida is defined as reptiles plus all other amniotes more closely related to them than they are to mammals (Gauthier *et al.*, 1988). Reptilia are defined as the most recent common ancestor of extant turtles and saurians, and all of its descendants (Gauthier *et al.*, 1988). The origin of mammals and saurians from early synapsids and early diapsids respectively is generally accepted, but the origin of turtles is problematic (Gauthier *et al.*, 1988; Gow, 1997; Laurin & Reisz, 1995; Debraga & Reisz, 1996)

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1.1.3.3.1 Parareptilia

The primary dichotomy in reptilian evolution, the branching into anapsid and eureptilian lineages must have occurred no later than the earliest Westphalian, when the oldest known diapsid, *Hylonomus lyelli* was present in what is present day Nova Scotia (Carroll, 1963). The ancestral anapsid reptile may well have dispersed into Gondwana by this time, as Euramerica and Gondwana had joined to form Pangaea by the early Late Carboniferous (Li *et al.*, 1993). The clade Parareptilia as presently defined (Laurin & Reisz, 1995) includes the Millerettidae, Pareiasauria, Procolophonoidea and testudines.

The tree topology for anapsid reptiles suggests that a distribution in Gondwanan Pangaea is ancestral for anapsid reptiles (Gauthier *et al.*, 1988) and phylogenetic calculations suggest that they were diversifying in Early Permian Gondwana as early as the Sakmarian (Modesto, 2000). This hypothesis is presented without the support of actual palaeontological evidence as mesosaurs and parareptiles have as yet no known fossil record prior to the Middle Permian (Gow, 1997).

Mesosaurs are the oldest known anapsid reptiles (Gauthier *et al*. 1988; Modesto, 1999, 2000). According to Modesto (2000), mesosaurids, millerettids, and *Eunotosaurus* are therefore the descendants of an ancestor that dispersed into Gondwana sometime during the Late Carboniferous or earliest Permian. There are

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two equally parsimonious interpretations for the palaeobiogeographic distributions of anapsid reptiles, crownwards of *Eunotosaurus* (i.e. the procolophonomorphs) (Modesto, 1999; 2000). The first interpretation hypothesises that lanthanosuchoids and nyctiphruretians dispersed from Gondwana to colonise Euramerica separately, with pareiasaurs and procolophonoids evolving in Gondwana because their recent common ancestral procolophonian had arisen there. The second scenario suggests that the ancestral procolophonomorph dispersed from Gondwana into Euramerica, from which lanthanosuchoids, nyctiphruretians, and the ancestral procolophonian evolved. The ancestral procolophonian then migrated back into Gondwana, subsequently giving rise to procolophonoids and pareiasaurs (Modesto, 2000).

Following mesosaurs, the next oldest anapsids in Gondwana are *Eunotosaurus*, millerettids, pareiasaurs, and procolophonoids (Gow & Rubidge, 1997), which appear in the *Tapinocephalus* Assemblage Zone (Smith & Keyser, 1995). The *Tapinocephalus* Assemblage Zone is either latest Kazanian or earliest Tartarian in age, which subsequently creates a substantial temporal gap between the disappearance of mesosaurs and the first appearance of parareptiles in Gondwana (Modesto, 2000). During this Early Permian time gap, acleistorhinids are present in western Euramerica (Modesto, 2000). Using Acleistorhinidae as the first appearance datum for Parareptilia, minimum divergence times suggest for at least four lineages (but of specific relevance in South Africa - two endemic Gondwanan lineages, Millerettidae and *Eunotosaurus*) can be extended well into the Early Permian (Modesto, 2000) prior to Beaufort times. The phylogeny and the biostratigraphy of

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anapsid reptiles provide support for the hypothesis that there was a preservational vacuity of terrestrial vertebrates in Early Permian Gondwana (Modesto, 2000). This paucity was only alleviated with the onset of continental sedimentation represented by the Beaufort Group in South Africa (Modesto & Rubidge, 2000).

The rare parareptile, *Eunotosaurus africanus* has been the focus of several recent papers (Gow, 1997; Gow & deKlerk, 1997; Rubidge *et al.*, 1999; Modesto, 2000), and is significant as it is the earliest and possibly most primitive member of the Parareptilia Olsen, 1942 (Debraga & Reisz, 1996). Furthermore, Gow (1997), suggested that *Eunotosaurus* was related most closely to the millerettids among parareptiles, and together they constitute the sister taxon to Ankyramorpha (Debraga & Reisz, 1996). The hypothesis that *Eunotosaurus* is a parareptile related most closely to millerettids (Gow, 1997) was rejected by Modesto (2000), who considered procolophonomorphs rather than millerettids as the closest relatives of *Eunotosaurus*.

Eunotosaurus was probably a slow moving terrestrial animal (the unmodified limbs, broad, imbricating ribs and the long whip-like tail support this suggestion (Gow, 1997). Furthermore, the limbs were short and powerful and thus quite capable of some degree of digging ability (Gow, 1997). In modern ecosystems utilisation of pre-existing burrows is common - perhaps *Eunotosaurus* made use of abandoned therapsid burrows (Smith, 1987).

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Procolophonia is defined as the most recent common ancestor of pareiasaurs, procolophonids, and testudines (Chelonia), and all its descendants (Laurin & Reisz, 1995). The Procolophonoidea, the group which unites the Procolophonidae and Owenettidae, occur in Permian to Late Triassic strata (Benton, 1993) are important as these tetrapods are one of two major reptilian groups that survived the end-Permian extinction and subsequently radiated significantly during the Triassic Period (Modesto *et al.*, 2001; Erwin, 1993). The oldest known procolophonoid is recognised from the *Tapinocephalus* Assemblage Zone (Gow & Rubidge, 1997), but in the Beaufort Group the taxon is most abundant in the Triassic *Lystrosaurus* and lower *Cynognathus* Assemblage Zones (Neveling, 2002).

Procolophonoid phylogeny has not been addressed in any great detail in the past but a recent discovery of a new specimen of procolophonoid reptile from the *Lystrosaurus* Assemblage Zone (Modesto & Damiani, 2000) provided the catalyst for a thorough investigation of the interrelationships of Procolophonoidea (Modesto *et al.*, 2001), which should result in an assessment of the diversity of the lineage (Norell, 1992). Because of their cosmopolitan distribution, they are of importance for use in biostratigraphy (Sues *et al.*, 2000; Gow & Rubidge, 1997) and in studies of the evolution of herbivory (Ruben, 1986; Sues, 2000).

Recently much new research has been undertaken on the Triassic procolophonoids of South Africa and currently five genera are recognised from the *Lystrosaurus* Assemblage Zone. In South Africa *Owenetta*, of the family Owenettidae, proposed by

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Reisz and Laurin (1991) as the sister taxon of turtles, is known from the Late Permian *Cistecephalus* and *Dicynodon* and the Early Triassic *Lystrosaurus* Assemblage Zones (Kitching, 1995, Groenewald & Kitching, 1995, Smith & Keyser, 1995). This genus was until recently considered to have been restricted to the Permian Period (Modesto, *et al.*, 2001), however, a Triassic species of *Owenetta* is now known (Reisz & Scott, 2001). The oldest species is *Owenetta rubidgei* from the *Cistecephalus* Assemblage Zone (Gow & Rubidge, 1997) and the youngest *Owenetta kitchingorum* (Reisz & Scott, 2001) from the *Lystrosaurus* Assemblage Zone.

A further four new Triassic procolophonoid genera from the *Lystrosaurus* Assemblage Zone have been described; *Sauropareion anoplus* (Modesto & Damiani, 2000), *Coletta seca* (Gow, 2000), *Saurodectes rogersorum* (Modesto *et al.*, 2003; Smith & Botha, 2005) and a new genus and species of procolophonid (Cisneros, 2006). Procolophonoid phylogenetic analysis reveals that *Sauropareion* is the sister taxon of the clade Procolophonidae (Laurin & Reisz, 1995; Modesto *et al.*, 2001) and *Coletta seca* (Gow, 2000), belongs to the family Procolophonidae (Gow, 2000). The new taxon is a basal form, being the sister group of all procolophonids to the exclusion of the owenettids, *Coletta seca* and *Sauropareion anoplus* (Cisneros, 2006). Currently the only genus recognised from the *Cynognathus* Assemblage Zone is *Thelegnathus* (Laurin & Reisz, 1995).

Lee (1997a;b) published a phylogeny for pareiasaurs. Subsequent optimisation of Gondwanan and Euramerican pareiasaurian distributions using Lee's (1997b)

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phylogeny strongly suggests that pareiasaurs diversified initially in Gondwana and that northern Pangaea was colonised by more recently derived taxa on at least two separate occasions (Modesto & Rybczynski, 2000).

Lee's (1997b) phylogeny of pareiasaurs reveals that *Bradysaurus* and *Embrithosaurus* (both from Gondwana) are the most basal members. Battail (2000) has shown that *Embrithosaurus schwartzi* and *Bradysaurus seeleyi* from South Africa are the earliest known pareisaurs, and Lee (1997a) considers *Bradysaurus* (from the *Tapinocephalus* Assemblage Zone) the most basal pareiasaurid.

Lee (1997a) undertook a taxonomic revision of the pareiasaurs and suggested that previous estimates of pareiasaurid biodiversity in the lower Beaufort Group were over-inflated. Pareiasaurs appear to be restricted to the Permian (Lee, 1997a,b). Of the 16 recognised species, ten are from the Karoo (Lee, 1997a). Lee (1997a) showed that pareiasaurs suffered two major extinctions within the Permian, one at the end of the *Tapinocephalus* Assemblage Zone and the other at the Permo-Triassic extinction event.

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1.1.3.3.2 Diapsida

The bulk of reptiles fall into the Diapsida, which comprise the Lepidosauromorpha and Archosauromorpha (Gower & Sennikov, 1997; Gower & Sennikov, 2000; Gower & Weber, 1998; Welman, 1995).

In South Africa the oldest diapsid is the younginid *Youngina* from the *Tropidostoma* Assemblage Zone (Smith & Evans, 1995), and *Youngina* is the only diapsid representative from the Permian Beaufort Group (Rubidge, 2005). The specimen from the *Tropidostoma* Assemblage Zone is important as it increases the biostratigraphic range of this form by some three million years (Smith & Evans, 1995), as all specimens collected previously had been assigned to the *Dicynodon* Assemblage Zone (Keyser & Smith, 1995).

Captorhinids do not have temporal openings, but are considered more closely related to Diapsida (deBraga & Rieppel, 1997). Recently the skull of a small captorhinid *Saurorictus australis* was discovered from the lower Beaufort *Tropidostoma* Assemblage Zone, and is the first captorhinid discovered in South Africa (Modesto & Smith, 2001c). *Saurorictus australis* is the southern most representative of a radiation of Late Permian captorhinids which are known from Russia, India and Zimbabwe, Zambia and Niger (de Ricqlès & Taquet, 1982; Gow, 2000b; Modesto & Smith, 2001).

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In the Triassic there was an increase in the number of diapsid taxa. The oldest archosaurs from the Beaufort Group appear at the beginning of the Triassic with genera such as *Prolacerta* and *Proterosuchus* from the *Lystrosaurus* Assemblage Zone (Welman & Flemming, 1993). Previously four proterosuchid species belonging to three genera were recognised from South Africa (Broom, 1903, 1946; Haughton, 1924; Broili & Schröder 1934; Charig & Reig, 1970; Charig & Sues 1976; Cruickshank, 1972), namely *Proterosuchus fergusi* Broom 1903, *Chasmatosaurus vanhoepeni* Haughton 1924, *Elaphrosuchus rubidgei* Broom 1946 and *Chasmatosaurus alexandri* Hoffmann 1965. Subsequent taxonomic revision considers them all in the species *Proterosuchus fergusi* (Cruickshank, 1972; Welman & Flemming, 1993). In Olenekian rocks of the Beaufort, a new form, strikingly similar to the genus *Garjainia* from Russia has recently been discovered (Hancox & Rubidge, 1997) and appears to be phylogenetically between *Proterosuchus* and *Erythrosuchus*, both of which are from slightly younger Anisian rocks of the *Cynognathus* A Assemblage Zone (Hancox *et al.*, 1995; Hancox, 2000). A significant genus from the *Cynognathus* B Assemblage Zone (Hancox *et al.*, 1995; Hancox, 2000) is *Erythrosuchus* (Gower, 1997; Welman, 1995), and *Euparkeria* is also present in this biozone (Welman, 1995).

Broom (1906) described the small diapsid reptile, *Palacrodon browni* from the *Cynognathus* Assemblage Zone. Gow (1999) re-described this enigmatic genus and showed that this taxon is not a rhynchocephalian, a member of the Sphenodontidae

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(Hoffstetter, 1955), an anomalous procolophonid or a lizard (Malan, 1963; Gow, 1999), but rather a basal diapsid archosauromorph.

Dilkes (1995, 1998) re-described the rhynchosaurs *Howesia browni* and *Mesosuchus browni* from the *Cynognathus* Assemblage Zone and showed that *Howesia* is a probable sister taxon to the clade of *Rhynchosaurus, Stenaulorhynchus, Scaphonyx* and *Hyperodapedon*, whereas *Mesosuchus* is the most primitive member of the Rhynchosauria (Dilkes, 1995).

1.1.3.3.3 Synapsida

Mammals are the only living representatives of an umbrella group of amniotes called Synapsida, which has a history extending back approximately 310 million years (Damiani & Rubidge, 2003). Non-mammalian synapsids, particularly therapsids, are the dominant amniotes in the Beaufort Group (Rubidge, 1995) and their fossilised remains have made these rocks internationally prominent (Broom, 1907, 1909; Haughton, 1924b, 1963, 1969; Kitching, 1970, 1972, 1977, 1984; Keyser & Smith, 1979; Keyser, 1979; Rubidge, 1995; SACS, 1980).

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1.1.3.3.3.1 Pelycosauria

The initial stages of synapsid (i.e. pelycosaur) diversification are recorded best in the Late Carboniferous and Early Permian rocks of North America (Romer & Price, 1940). Initially Cope (1881), thereafter resuscitated by Broom, 1938, proposed a close affinity between the palaeoequatorial (e.g. North American pelycosaurs-Early Permian) and the earliest therapsids known from the Middle Permian holarctic (South Africa and Russia) (Broom, 1938, Rubidge, 2005). The lack of temporal and geographic overlap between these two groups has been interpreted as indicative of a physiological advance of therapsids, thus allowing for their geographic dispersal (McNab, 1978; Parrish *et al.,* 1986). The presence of the varanopsid *Elliotsmithia* (Dilkes & Reisz, 1996; Modesto *et al.,* 2001b; Reisz *et al.,* 1998), which is known from two localities in the *Tapinocephalus* Assemblage Zone, has enhanced the degree of overlap between these two groups right into the Middle Permian (Dilkes & Reisz, 1996; Modesto *et al.*, 2001b; Reisz *et al.*, 1998).

1.1.3.3.3.2 Therapsida

The discovery of new basal therapsid fossils from the *Eodicynodon* Assemblage Zone has significantly extended the phylogenetic and stratigraphic range of synapsids from South Africa (Rubidge, 1995) and suggests a Gondwanan origin for several therapsid

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clades (Rubidge, 1995; Modesto *et al.*, 1999; Rubidge & Sidor, 2001; Rubidge & Kitching, 2003).

1.1.3.3.3.2.1 Biarmosuchia

The Biarmosuchia include a number of primitive and little-known Middle and Late Permian basal therapsid genera, which have been considered the most primitive post-sphenacodont synapsids (Hopson & Barghusen, 1986).

Recently a number of well preserved specimens have been described and these add greatly to our knowledge of this paraphyletic clade (Sidor & Welman, 2003; Sidor *et al.*, 2004; Rubidge *et al.*, 2006). Biarmosuchians are known only from Russia, Malawi and South Africa (Ivakhenko, 1999; Rubidge & Sidor, 2001; Rubidge, 2005), but the greatest number of taxa comes from the Permian Beaufort Group of South Africa. These are the "ictidorhinids" (*Ictidorhinus*, *Hipposaurus*, *Lycaenodon* and *Rubidgina*) and a derived subclade, Burnetiamorpha (*Burnetia* and *Paraburnetia*) (Rubidge & Sidor, 2001; 2002). The Burnetiamorpha, whose skulls have numerous bony protrusions, has six described genera, *Paraburnetia* from Russia, *Lobalopex* from the *Tropidostoma* Assemblage Zone (Sidor *et al.*, 2004), *Paraburnetia* from the *Cistecephalus* Assemblage Zone (Smith *et al.*, 2006), *Burnetia* from the *Dicynodon* Assemblage Zone (Rubidge & Sidor, 2002) and *Bullacephalus* together with

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Pachydectes from the *Tapinocephalus* Assemblage Zone of South Africa (Rubidge & Kitching, 2003; Rubidge *et al.,* 2006).

A comprehensive list of biarmosuchian representation in the Beaufort Group, which includes classification to genera level and numbers of genera representatives is summarised in Chapter 3, Synthesis of Data (Folder 5: Specimen Count – Biarmosuchia).

1.1.3.3.3.2.2 Dinocephalia

Dinocephalians were a group of medium to large therapsids which had amongst its members the largest terrestrial animals to have existed up to the Late Permian (Rubidge, 1991). They became extinct by the close of the *Tapinocephalus* Zone times (Rubidge, 1991), leaving no descendent groups (Boonstra, 1971; Kemp, 1982). The dinocephalians are an ancient group and their ancestry is not clear. It is assumed that they must have evolved during the onset of the Middle Permian, or even Early Permian, but no trace supporting this assumption has as yet been found.

A cladistic approach has only recently been used to classify the Dinocephalia, such as the cladistic analysis of King (1988) and Rubidge & Sidor (2001). Kemp (1982) was the first to adopt the cladistic approach but did not provide characters relating to the sister groups contained in his cladogram. Hopson and Barghusen (1986) undertook a

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cladistic analysis of therapsid relationships and included various dinocephalian infraorders. The infra-order Dinocephalia was considered to consist of six families, namely: Estemmenosuchidae, Brithopodidae, Anteosauridae, Titanosuchidae, Tapinocephalidae and Styracocephalidae (Boonstra, 1963; Kemp, 1982). More recently, King (1988) reclassified the abovementioned families as subfamilies of the three families Estemmenosuchidae, Brithopodidae, and Titanosuchidae, and regarded *Styracocephalus*, the only genus in the family Styracocephalidae, as *incertae sedis* (Rubidge, 1991). *Styracocephalus* however, has been re-described by Rubidge & van den Heever (1997), resulting in the resurrection of the family Styracocephalidae. Present taxonomical review reveals that only the Estemmenosuchidae (Russia) have not yet been found in Africa (Rubidge, 1991).

South Africa has the most diverse dinocephalian fauna, including representatives of the families Anteosauridae, Titanosuchidae, Tapinocephalidae and Styracocephalidae (Rubidge & van den Heever, 1997). The Anteosauridae are the most primitive (Boonstra, 1965), the Tapinocephalinae (large and specialised herbivores) the most derived, with the Titanosuchidae (large, cumbersome herbivores or omnivores) falling between the two (Rubidge, 1991).

Recent discoveries from the lowermost Beaufort Group include the basal predatory anteosaurid *Australosyodon* (Rubidge, 1994) and the basal tapinocephalid *Tapinocaninus* (Rubidge, 1991). These two finds are highly significant from a palaeobiogeographic perspective as they represent the most basal forms of the

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Anteosauridae (Rubidge, 1991) and Tapinocephalidae (Rubidge, 1994) respectively. Until now, the only anteosaurid from Gondwana has been the most derived genus *Anteosaurus* (from the family Anteosauridae) from the *Tapinocephalus* Assemblage Zone (Rubidge, 1994).

A comprehensive list of dinocephalian representation in the Beaufort Group, which includes classification to genus level and numbers of genera representatives is summarised in Chapter 3, Synthesis of Data (Folder 5: Specimen Count – Dinocephalia).

1.1.3.3.3.2.3 Gorgonopsia

Gorgonopsians, known only from southern Africa and Russia, were the dominant tetrapod carnivores of the Permian and became extinct at the end of that period (Kitching, 1995). Gorgonopsians were extensively studied by Sigogneau (1970), but have received scant attention since, apart from a cranial kinetic study by Laurin (1998) and a discussion of Gorgonopsian taxonomy by Maisch (2002). In the rocks of the lower Beaufort Group, from where they are most abundantly known, more than 25 genera are currently recognised (Sigogneau-Russell, 1989). A comprehensive list of gorgonopsian representation in the Beaufort Group, which includes classification to generic level, and numbers of genera representatives, is summarised in Chapter 3, Synthesis of Data (Folder 5: Specimen Count – Gorgonopsia).

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The unsatisfactory state of gorgonopsian taxonomy has severely hindered a broader understanding of the group (Rubidge & Sidor, 2001). As a result of the poor taxonomy within Gorgonopsia, an evaluation of their diversity, faunal and biogeographical patterns, as well as their representation within an ecological community could not accurately be assessed.

1.1.3.3.3.2.4 Therocephalia

The earliest therocephalians were contemporaneous with the most primitive therapsids in the lowermost Beaufort Group (Rubidge *et al.*, 1983). The Therocephalia are at least as ancient as the gorgonopsians, and in fact, outlasted them (making it through to Early Middle Triassic times) (Rubidge *et al.*, 1983). The earlier therocephalians, despite being present in the lowermost rocks of the Beaufort Group, already manifest considerable enlargement of the temporal opening (van den Heever, 1994). Later therocephalians included the advanced bauriamorphs, which carried certain theriodont characters to a high degree of specialisation. Advanced therocephalians parallel the development of several cynodont features (Rubidge & Sidor, 2001; Sidor, 2003).

A remarkable aspect of therocephalians is that from their first appearance in the *Tapinocephalus* Assemblage Zone with *Glanosuchus* and *Allopecodon* (Rubidge *et*

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al., 1983), they are the only theriodont group present in all the assemblage zones of the Beaufort Group (Fourie, 2001).

There is a possibility that the taxonomic diversity recorded in the therocephalians has been inflated. The fragmentary nature of some of the therocephalian fossils, and the enthusiasm of early workers in the field to give each scrap of bone a new taxonomic designation, has led to the description of numerous taxa. Only the early therocephalians have been reviewed over the last fifteen years (van den Heever, 1994), but research on the more derived forms as well as phylogenetic studies in general have been neglected.

A comprehensive list of currently accepted therocephalian genera within the Beaufort Group of South Africa is summarised in Chapter 3, Synthesis of Data - Folder 5: Specimen Count - Therocephalia.

1.1.3.3.3.2.5 Cynodontia

Cynodonts are the therapsid group that gave rise to mammals (Battail, 1991; Hopson, 1991, 1994; Sidor & Hopson, 1998; Jenkins, 1971; Crompton, 1995). Beaufort rocks contain a rich diversity of cynodonts, extending over a long stratigraphic range. These include the Late Permian *Procynosuchus* and *Cynosaurus* (Rubidge & Sidor, 2001) and the recently discovered *Charassognathus* (Botha *et al.*, 2007), as well as a wide

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variety of Triassic forms, of which *Galesaurus* and *Thrinaxodon* were the dominant Early Triassic (*Lystrosaurus* Assemblage Zone) genera (Rubidge & Sidor, 2001; Rubidge, 1995b). A new galesaurid cynodont, *Progalesaurus* increases the diversity of Early Triassic cynodonts (Sidor & Smith, 2004). A number of genera such as *Cynognathus*, *Diademodon* and *Trirachodon* are known from the Middle Triassic *Cynognathus* Assemblage Zone (Hopson, 1984; Gow & Hancox, 1993; Neveling, 2002).

By the beginning of the Middle Triassic, cynodonts were diversifying and had diverged phylogenetically into two main subgroups: Probainognathia and Cynognathia (Rubidge & Sidor, 2001). Hopson and Kitching (2001) described *Lumkia fuzzi* from the *Cynognathus* Assemblage Zone, as the oldest probainognathid and the first member of the family from South Africa – a clade previously known only from the Middle and Upper Triassic of Argentina (Martinez *et al.,* 1996). Other new forms from the *Cynognathus* Assemblage Zone include a new species of *Trirachodon* from the lower part of the biozone (Neveling *et al.,* 2001) and a new taxon from the upper part of the zone (Abdala *et al.,* 2005).

Cynodonts have been the subject of recent research projects and their taxonomy is generally better understood than the Gorgonopsia and Therocephalia. In addition they have been the focus of many phylogenetic studies (e.g. Battail, 1991; Hopson, 1991, 1994; Sidor & Hopson, 1998) and more recently both physiological and behavioural studies (Ray *et al.,* 2004; Botha & Chinsamy, 2005).

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A comprehensive list of cynodont representation in the Beaufort Group, which includes classification to generic level and numbers of genera representatives is summarised in Chapter 3, Synthesis of Data (Folder 5: Specimen Count – Cynodontia).

1.1.3.3.3.2.6 Dicynodontia

Dicynodonts, the dominant herbivores of the mid-Permian – mid-Triassic, were the most successful family of the therapsids in terms of phylogenetic longevity, numbers of individuals [they are by far the most abundant therapsid group from terrestrial Permo-Triassic strata worldwide (King, 1988)], and the extent of distribution throughout Gondwana (King, 1988; Rubidge & Sidor, 2001).

Basal anomodont relationships were greatly elucidated with the recognition that *Patranomodon* (Rubidge & Hopson, 1990, 1996) and *Anomocephalus* (Modesto *et al.*, 1999; Modesto & Rubidge, 2000) from the lowermost Beaufort are the most basal anomodonts. These finds suggest that Anomodontia originated in Gondwana rather than Laurasia as previously hypothesised (Modesto *et al.*, 1999; Modesto & Rubidge, 1999, 2000).

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The diversity and long stratigraphic record of dicynodonts from the Beaufort Group has resulted in phylogenetic work to determine interrelationships of the various genera (Angielczyk, 2001; Cluver & King, 1983; Cox, 1998; King, 1988; Vega-Dias *et al.,* 2004). "Until recently, the vast number of named dicynodont species clouded the understanding of the group's evolutionary history. However, as a result of the efforts of several workers (Cluver & Hotton, 1981; Cluver & King, 1983; King, 1988; King & Rubidge, 1993), the number of valid taxa has been greatly reduced" (Rubidge & Sidor, 2001: p.473). Accordingly, the number of recognised dicynodont genera from the *Tapinocephalus* Assemblage Zone has been reduced to only *Robertia*, *Pristerodon, Chelydontops* and *Diictodon* (King & Rubidge, 1993), with the recent additions of two new basal genera *Colobodectes* (Modesto *et al.,* 1999) and *Lanthanostega* (Modesto *et al.,* 1999; Modesto & Rubidge, 2000), from the base of the Beaufort Group.

The dicynodonts were greatly reduced by the increasingly harsh conditions of the terminal Permian, and only two genera, the medium-sized *Lystrosaurus* (Rubidge & Sidor, 2001) and the tiny *Myosaurus* (Battail, 1993; Groenewald & Kitching, 1995), are represented in the Early Triassic *Lystrosaurus* Assemblage Zone (Battail, 1993). *Lystrosaurus* spread throughout Pangeae, having been described from Russia, China, India, Antarctica, South America and Africa (King, 1988).

"Dicynodonts underwent a second, relatively minor radiation during the Middle Triassic, with taxa such as *Kannemeyeria* becoming common" (Rubidge & Sidor,

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2001: p.464). Previous authors have disagreed as to the exact stratigraphic range of *Kannemeyeria* (e.g. Watson, 1942; Kitching, 1977; Keyser & Smith, 1979) however new stratigraphic studies have shown that this genus is restricted to only the middle reaches of the biozone (Hancox *et al.,* 2001). Renaut (2001) confirmed that only one species of *Kannemeyeria* is present in South Africa, with further suggestion that *Kannemeyeria* is congeneric with *Rabidosaurus* and *Uralokannemeyeria* from Russia, and *Shaanbeikannemeyeria* from China (Renaut, 2001). In addition, Govender (2006) has suggested the presence of stahleckeriids in subzone B of the *Cynognathus* Assemblage Zone, making this the earliest appearance of this family globally. Hancox (1998) and Hancox & Rubidge (1997) identified a form similar to the Chinese genus *Shansiodon* from the uppermost *Cynognathus* Assemblage Zone. This find has important ramifications for the correlation and refinement of the age assignment of this biozone (Catuneanu *et al.,* 1998b). Also included in this subzone is the presence of *Angonisaurus* (Hancox & Rubidge, 1996).

A comprehensive list of dicynodonts from the Beaufort Group, which includes classification to generic level and numbers of specimens of individual genera is summarised in Chapter 3, Synthesis of Data (Folder 5: Specimen Count – Dicynodontia).

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1.1.4 Biodiversity Patterns

The rocks of the Beaufort Group, which were deposited over a period of at least 40 million years from the Middle Permian to Middle Triassic, preserve the most unbroken record of non-marine tetrapod biodiversity trends and evolution across this interval (Anderson, 1999; Rubidge, 2005).

Current collecting activities have revealed distinct faunal changes along the Ecca-Beaufort boundary as one proceeds northwards in the Karoo (Modesto *et al.,* 2001a; Rubidge *et al.,* 1999; Welman *et al.,* 2001). What is observed is that the vertebrate fossil assemblages become progressively younger, with the most primitive forms being restricted to the Middle Permian *Eodicynodon* Assemblage Zone along the southern margin of the basin, and in the north, genera from the latest Permian *Dicynodon* Assemblage Zone are present just above the basal contact (Kitching, 1977, 1995). Diagnostic tetrapod fossils have thus demonstrated that the palaeo shoreline of the Beaufort Group, along the Ecca-Beaufort contact, is highly diachronous, becoming younger from south to north (Rubidge *et al.,* 2000). Furthermore, recent work has shown that for the Permian there is the possibility that the *Tapinocephalus* Assemblage Zone, the thickest biozone of the Beaufort Group, can be divided into a lower unit where dinocephalians are more abundant than dicynodonts and an upper unit where dicynodonts greatly outnumber dinocephalians (Boonstra, 1969; Loock *et al.,* 1994; Rubidge *et al.,* 1999; Modesto *et al.,* 2001a).

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The Permo-Triassic extinction event which is regarded as the most severe biological crisis to have occurred during the last 600 million years of earth history (Smith, 1995; Erwin, 1993; 1994; 2006; Benton & Twitchett, 2003) is documented in the rocks of the Beaufort Group (Ward, *et al.,* 2000; Smith & Ward, 2001; Botha & Smith, 2006). The hypothesised causes of the extinction are numerous and include global cooling (Stanley, 1988), volcanism (Campbell *et al.,* 1992), oceanic anoxia (Wignall & Twitchett, 1996; Hotinski *et al.,* 2001), oceanic overturn (Knoll *et al.,* 1996), excessive methane release (Krull *et al.,* 2000; Sheldon & Retallack, 2002) and extraterrestrial impact (Becker *et al.,* 2001; 2004). Recent estimates suggest that *ca.* 90% of marine species were eliminated by this extinction event (Stanley & Yang, 1994), while figures for terrestrial groups range from 60% to almost 80% (Olson, 1989; Maxwell, 1992; Erwin, 2006).

The palaeontological record of this event in sections of marine strata, located in China, reveals the extinction event was sudden rather than protracted (Jin, *et al.*, 2000), with the major pulse of extinction being constrained to an interval of 10^4 to 10^5 yr (Bowring, *et al.,* 1998). Far less is known about the pattern and duration of the event in the terrestrial environment (Retallack, 1995; Smith & Ward, 2001; Smith & Botha, 2005; Botha & Smith, 2006). Until recently, pinpointing the Permo-Triassic boundary in terrestrial rocks has proven problematic because of incomplete and/or low-resolution sampling around the boundary (Smith & Ward, 2001). This difficulty in quantifying the boundary, points to the assertion, quite rightly that estimates of

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terrestrial vertebrate extinction at the Permo-Triassic boundary can be questioned on the basis that such studies used these low stratigraphic and taxonomic resolutions (Modesto *et al.,* 2001b).

This situation has been refined due to the recognition of a "fungal spike" at many non-marine and shallow marine Permo-Triassic sections around the world (Eshet *et al.,* 1995; Visscher *et al.,* 1996), and through the use of new terrestrial ecosystem event stratigraphy markers (Ward *et al.,* 2000). Smith and Ward (2001) document the stratigraphic ranges of fossil vertebrate taxa spanning the Permo-Triassic interval at multiple stratigraphic sections in the Karoo Basin, concluding that the pattern of species extinction and recovery is similar in all studied sections.

The Permo-Triassic boundary in the Beaufort Group is considered to be immediately overlain by an event bed (Ward *et al.*, 2000). The first appearances of Early Triassic recovery fauna comprise proterosuchian archosauromorphs (*Proterosuchus*), amphibians (*Micropholis* and *Lydekkerina*), procolophonoids (*Owenetta* and *Procolophon*), dicynodonts (*Lystrosaurus*) and cynodonts (*Galesaurus, Thrinaxodon* and *Progalesaurus*) (Smith & Ward, 2001; Smith & Botha, 2005). Smith and Ward (2001) propose that the extinction occurred during (or created) an environmental changeover from wet flood-plain to dry flood-plain environments, bringing about a faunal change to a recovery fauna composed of drought-tolerant taxa in the Early Triassic.

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The hypothesis–testing of whether the extinction event was sudden or protracted, was first attempted by King (1990) for the Karoo, resulting in an interesting interpretation. King (1990) examined the diversity of tetrapod genera from the Karoo Basin using the generic data in Kitching (1977) and his biostratigraphic scheme of land vertebrate assemblage zones. She concluded that the renowned low diversity of the earliest Triassic *Lystrosaurus* Assemblage Zone was merely the final chapter in a gradual reduction in the numbers of Karoo genera that had begun well before the end of the Permian Period (Modesto *et al.*, 2001b). This conclusion is strengthened by the work of Smith & Ward (2001), which showed that although only 101 stratigraphically controlled identifiable fossils were collected at the boundary, when plotted on a single composite section, they form a pattern suggesting a gradual extinction. King's (1990) conclusions are drawn from a literal reading of the fossil record of the Karoo and it is possible that a different picture of the diversity patterns of the Karoo fauna could have emerged if her data had been examined from a phylogenetic perspective (Norell, 1992). What is concrete though is that the end-Permian extinction event brought a catastrophic drop in dicynodont numbers, so that by the beginning of the Triassic only two dicynodont genera, *Lystrosaurus* and *Myosaurus* are represented in South Africa (Battail, 1993; Groenewald & Kitching, 1995; Botha & Smith, 2006).

The question of whether there was a steady decline in fauna or whether the mode of extinction was sudden or protracted is addressed by Modesto *et al* (2001b). Four taxa (Procolophonidae, *Coletta*, *Sauropareion* and the Triassic species of *Owenetta*) of the six terminal procolophonoid taxa that originated during the later part of the Late

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Permian Period, extended into the Triassic Period. This translates into a survival rate of 67% for procolophonids through what has commonly been described as the greatest mass extinction in earth's history (Modesto *et al.,* 2001b). This implies a surprisingly low level of extinction (33%) for these reptiles when the consensus has been that relatively few Permian tetrapod lineages survived into the Triassic Period (e.g. Rubidge *et al.,* 1995; Modesto *et al.,* 2001b).

The findings of Modesto *et al* (2001b) of high procolophonoid survivorship across the Permo-Triassic boundary compare favourably with the results of recent phylogenetic work, which suggests that diapsid reptiles, particularly the archosauromorphs, similarly experienced a relatively low extinction level (*ca.* 22%) (Dilkes, 1998).

The two uppermost biozones of the Beaufort Group, the *Lystrosaurus* and *Cynognathus* Assemblage Zones, provide an ideal opportunity to study Early Triassic therapsid faunal biodiversity patterns of Gondwana following the effects of the Permo-Triassic extinction. The *Lystrosaurus* and overlying *Cynognathus* Assemblage Zones have in the past been interpreted as consisting of distinct faunal assemblages that neither overlap nor share any common genera (Kitching, 1977; Rubidge, *et al.*, 1995). In order to explain the sharp evolutionary differences between the two faunas, Anderson and Cruickshank (1978) proposed the existence of a time-gap between the two zones, while Keyser and Smith (1979) considered a palaeontologically barren zone to be present between the *Lystrosaurus* and *Cynognathus* Assemblage Zones.

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Recent intensive fossil collecting in the stratigraphic interval between the *Lystrosaurus* and *Cynognathus* Assemblage Zones has shown that although fossils are scarce in this stratigraphic interval, they are indeed present and that there is no time gap between the two biozones (Neveling, 1998).

The stratigraphic interval between the *Lystrosaurus* and *Cynognathus* (A) Assemblage Zones is the only interval in the Beaufort Group characterised by an absence of dicynodonts, following the disappearance of *Lystrosaurus* at the end of the *Lystrosaurus* Assemblage Zone. Furthermore, both the continuation of the genus *Thrinaxodon* from the *Lystrosaurus* Assemblage Zone into this transitionary interval as well as the appearance of a new amphibian fauna, marking the start of the *Cynognathus* Assemblage Zone is characteristic of this interval. The index fossil of the *Cynognathus* subzone A, the amphibian *Kestrosaurus,* is the most common genus within the interval and shows a wide stratigraphic range (Hancox *et al.,* 2001; Shishkin *et al.,* 1995; Hancox *et al.,* 1995; Neveling, 1998).

While the majority of *Kestrosaurus* fossils have been collected in the Burgersdorp Formation in the northern part of the Karoo Basin, the *Kestrosaurus* material collected by Neveling (1998) in the southern part of the Karoo Basin was from the Katberg Formation. The presence of *Kestrosaurus* in the Katberg Formation in the south has important implications for the development of the Karoo Basin and suggests time-equivalence between the Katberg Formation in the south and the Burgersdorp Formation in the north (Neveling, 1998).

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Section 2: Aims

1.2.1 Aims

This review has highlighted recent taxonomic, biogeographic and stratigraphic advances which have been achieved on the rocks and fossils of the Beaufort Group. Much of the stratigraphic advances have been made possible by relatively small scale detailed studies which were achieved by recent collecting activities of a limited number of researchers (e.g. Smith, Hancox, Neveling and Rubidge). However large collections of fossils exist in various museums and information pertaining to these collections would greatly advance studies on the biodiversity and biostratigraphy of the Karoo, and ultimately lead to more refined basin development and biogeographic models.

This project aims to synthesise and analyse available data from collections pertaining to the vertebrate fauna of the Beaufort Group, of the Karoo Supergroup of South Africa. This has required the setting up of a computer database to incorporate information pertaining to all the Beaufort Group fossil tetrapod faunas in South African museum collections (refer to Volume II). This is the first time a study of this nature has been undertaken specifically on the rocks of the Karoo Supergroup, but more importantly on tetrapod faunas in a sequence which has such an extensive

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temporal record from the Middle Permian to the Middle Triassic. An auxillary aim of this project involved completing the groundwork for establishing a useable GIS database which can be utilised by future researchers working on the vertebrate fauna of the Beaufort Group (Refer to Chapter 6), while the main *aim* of this project concentrate on the following issues which have not been fully addressed in the past:

(1) Quantify the taxonomic representation, diversity and numeric abundance of Beaufort Group tetrapod fossils.
(2) Plot the changes in faunal biodiversity through time in the Beaufort Group.
(3) Discuss the ecological representation within the faunal assemblage of the Beaufort Group.
(4) Evaluate the collecting bias of each collection.

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Chapter 2: Materials and Methods

The setting up of a palaeontological GIS database which will be useful to future researchers has been a daunting task and has required addressing numerous aspects which are not required for this project, but are essential for future studies. In this thesis data is presented in Volume II in three formats:

(a) Appendices

(b) Figures

(c) Tables

The following technical aims are addressed in this chapter:

(1) Incorporation of all recorded fossil specimens in South African museum collections found to date from the Beaufort Group (Karoo Supergroup) of South Africa onto a single standardised database for use as an analytical tool.

(2) Incorporation of all recorded fossil specimens in South African museum collections found to date within the Beaufort Group (Karoo Supergroup) of South Africa onto a Geographical Information System (GIS).

(3) Standardising of data procedure. A preliminary scheme for the standardisation and organisation ('cleaning') of the data of the contributing museums.

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(4) Gap and Neighbourhood Analysis of the distribution pattern of the fauna of the Beaufort Group.

(5) Subdivision of the quality of Beaufort Group Data – a collated study of the seven contributing museums.

(6) Museum faunal content (specimen representation and numbers) – a comparative study.

2.1 Materials

Collections of vertebrate fossils have been amassed in South Africa for more than a century and are housed in seven large collections. The catalogues of these collections, which are all available digitally, have been utilised to address the aims of this project which are listed in Chapter 1. Before interpretive work could be performed on these datasets, it was necessary to analyse the quality of the data presented from a statistical perspective. The assessment and subsequent subdivision of the data available for use into viable or non-viable categories was based on the degree of detail and the reliability of the information pertaining to each record. Relegation to a viable or non-viable category was not a fixed subdivision, as certain records were considered viable for certain aspects of the study, but deemed non-viable for another issue to be analysed.

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2.1.1 Analysis of original data

The following databases from South African museums have been analysed and interpreted for this study:

(a) Council for Geoscience, Tshwane

(b) Transvaal Museum, Tshwane

(c) Bernard Price Institute for Palaeontological Research, University of the Witwatersrand, Johannesburg

(d) National Museum, Bloemfontein

(e) Albany Museum, Grahamstown

(f) Rubidge Collection, Wellwood, Graaff-Reinet

(g) South African Museum, Iziko Museum, Cape Town

The original datasets provide a *theoretical potential* of 26 837 specimens prospectively usable for analysis and trend interpretation (Table 2.1). The *theoretical potential* of 26 837 is the sum of the original, unaltered records of each contributing museum. After careful investigation of the recorded contents of each museum, criteria for the elimination of certain records were established (Table 2.2). Motivation for the elimination of records includes the removal of data pertaining to fossils not from the Beaufort Group of the Karoo Supergroup, specimens which are not vertebrate, or specimens which could not be identified. After this initial round of data elimination, the *actual potential of analysable vertebrate specimens* in the Beaufort Group amounted to 20 968 (Table 2.1).

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The figure of 20 968 calculated for those specimens that may be used for further analysis and interpretation did not remain constant during the course of this study. The number of usable records fluctuated depending on what specific data was required to fulfil the particular aspect being addressed. The number of viable vertebrate specimens for use decreased significantly in the analysis of biodiversity across time, for example, as many records did not possess accompanying assemblage zone information. Addressing the quality of data available for analytical purposes for the Beaufort Group is discussed in detail in the section that follows.

2.1.2 Analysis of the quality of Beaufort Group data

2.1.2.1 Neighbourhood and Gap Analysis

Before determining the distribution patterns and biodiversity of vertebrate fauna in the Beaufort Group, the 'validity' of the collecting which has been undertaken needed to be established. In order to ascertain the degree of 'usefulness' of the Beaufort Group data for analytical purposes it was necessary to determine the even-handedness of the distribution of fossil localities and hence fossil finds in the Beaufort Group. If the distribution of fossil localities were found to be highly localised or biased to specific regions, this would impact negatively on the accuracy and significance of any distribution or biodiversity study. A gap and neighbourhood analysis was undertaken to determine if any bias did exist in the

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museum records and whether the data should be subjected to any further interpretation.

A Gap analysis is a model method to determine whether the spatial distribution of specimens is similar across the entire study area. To do this Arcview 3.2 and its spatial analysis extension was used to create a distance surface. The distance was calculated between the locations of all the specimen points. A contrast stretch was applied to the resultant surface to improve the visualisation of the surface (Netterberg *et al.,* 2004). The surface was derived for an area larger than the extent of the Beaufort Group, and then masked to the extent of the sampling to remove edge effects.

Figure 2.1 indicates the sampling distribution of fossils in the Beaufort Group. A lack of sampling could be because of the absence of an outcrop, the fact that nobody has as yet prospected there, or because of a scarcity of fossils and is indicated by shades of blue. Blue shading indicates a substantial distance between fossil collecting sites. On the other hand, a red – orange spatial pattern indicates a relative closeness of fossil sites to each other. An ideal spatial pattern would be the exclusive presence of red shading indicating that successive fossil locality sites are closely situated to each other across the entire study area. The overwhelming dominance of orange – red (Figure 2.1) indicates that the majority of fossil localities are in close proximity to each other with an *even* distribution of fossil sites for the Beaufort Group. This indicates a lack of sampling bias to particular areas and implies that the sampling of the Karoo fossil fauna as

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represented by the fossils in the collections will provide an accurate interpretation of the reality of faunal distribution patterns and ecological representation for the Beaufort Group.

Once the equality of the distribution of fossil finds across the Beaufort Group was established, Neighbourhood analysis technique was applied to determine where the highest density of specimens was located (Figure 2.2). The Neighbourhood Statistic which was used on the point feature class was the *sum* of all the points, with a circle neighbourhood with an 8km radius (Netterberg *et al.,* 2004). This was used to provide an indication of the number of specimens from a given location. The resultant surface was classified as Natural Breaks, to improve the visual representation of the analysis (Netterberg *et al.,* 2004).

The incidence of dark red shading represents those localities which have the highest density of specimens (Figure 2.2). The obvious horizontal line of red/orange dots in Figure 2.2 could highlight a collecting bias caused by the superior exposures of fossil bearing strata in the Sneeuberg and Neuweveld mountain ranges along the so-called "Great Escarpment". The strata most exposed in the escarpment belong to the *Tropidostoma, Cistecephalus* and *Dicynodon* Assemblage Zones. These assemblage zones have probably been over collected through the years thus accounting for the horizontal trend of high density fossil localities in Figure 2.2.

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Most fossil sites however, yield an average of 1- 60 specimens (as indicated by yellow shading). This result links up with and affirms the interpretation of fairness in spatial distribution within the Beaufort Group by revealing an average distribution in the abundance of fossil finds. The clear case however of "overcollecting" of well exposed strata compared to "undercollecting" in more poorly exposed intervals needs to be taken into account when a re-assessment of biodieversity patterns and faunal geospatial distribution is compiled after completion of Phase 2 of the GIS-initiative (Chapter 6).

The resultant findings of Figures 2.1 & 2.2 provided the 'green light' to confidently analyse the faunal assemblage of the Beaufort Group and the biodiversity patterns.

2.1.2.2 Viability assessment

Once the lack of bias in the collecting activities for the Beaufort Group was established, and before spatially mapping the palaeontological data from the Beaufort Group, it first had to be established if such a task was achievable. An entry level investigation of the degree of quantifiable content of a representative dataset was undertaken. The database of the BPI was selected as the sample dataset, both for reasons of convenience and also because it represents a broad spectrum of data fields and diversity. The results reveal that the majority of data is viable and could be used for spatial mapping purposes (Table 2.3). Viability was

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defined as those records having both a taxonomic identification as well as attached locality information.

2.1.2.3 Division of Beaufort Group data

A breakdown into three categories, of all recorded specimens in the Beaufort Group, is provided in Figure 2.3. This subdivision into degrees of locality resolution is necessary as a summary of the overall locality resolution quality of the Beaufort Group and is an exercise in quantifying the degree of compliance with digital information requirements. The subdivision also graphically depicts which portions of the amalgamated Beaufort Group dataset were used in addressing the various aims of this study.

Fifty-one percent of the museum records from the Beaufort Group have locality information, but no assemblage zone information. Forty-four percent of specimens have assemblage zone information and five percent of specimens have no locality or assemblage zone information. Although not all data of the amalgamated dataset of the Beaufort Group was utilised for each study, depending on the data requirements of the various studies addressed, ultimately all data was utilised at some point.

More than 56% of the fossil database does not have accompanying biozone provenance data, with the result that only 44% of the collections could be assigned to specific biozones (Figure 2.4). The *Eodicynodon* Assemblage Zone

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has 82 specimens listed with Assemblage Zone information. With 82 counts for the 9144 specimens listed with Assemblage Zone information, this particular biozone comprises one percent of the data used in the biodiversity, taxon assignment and biodiversity trend analyses.

The *Tapinocephalus* Assemblage Zone has 323 specimens listed with assemblage zone information. This comprises two percent of the Beaufort Group Database, but with 323 counts for the 9144 specimens listed with assemblage zone information; this biozone comprises four percent of the data used in the studies mentioned above.

The *Pristerognathus* Assemblage Zone has 34 specimens listed with assemblage zone information. With 34 counts for the 9144 specimens listed with assemblage zone information, this zone comprises 0.4% of the data used for these same studies.

Specimens with accompanying assemblage zone information for the *Tropidostoma*, *Cistecephalus* and *Dicynodon* Assemblage Zones occupy 4%, 15% and 3% of the total data for the Beaufort Group respectively. This translates to these biozones occupying 10%, 34% and 7% of assemblage zone data respectively.

The *Lystrosaurus* and *Cynognathus* Assemblage Zones occupy 13% and 4% respectively of the total data (with and without assemblage zone information).

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This translates, relative to records with assemblage zone information to 30% and 9% respectively. Five percent of records with accompanying assemblage zone information are relegated to the various transitional zones (Figure 2.4).

Almost thirty percent (29.3%) of recorded specimens for the Beaufort Group are indeterminate. Such a significant portion of the overall database required further analysis and subdivision. The reason for such an investigation was to deduce possible areas of investigation that may make use of such data. Although indeterminate records were not included for biodiversity and biodiversity trend analysis, they were utilised as part of the comparison of contributing museum content and numbers (Figure 2.5).

The 10800 records with locality information (Figure 2.3) were subdivided into those classified to genus level (this subdivision comprised 43% of the 10800 total, with 9023 specimens) and those that were indeterminate (comprising eight percent of the 10800 total, with 1777 indeterminate specimens accompanied with locality information).

Of the 9144 specimens with assemblage zone information (44% of the total Beaufort Group), 25% (5193) of these are classified to genus level and the remaining 19% (3951) are unidentified. Of the 1024 specimens with no locality or Assemblage Zone information (comprising five percent of the total), only three percent (607) are classified to genus level and the remaining two percent (417 specimens) are indeterminate (Figure 2.3). The values depicted in this table reveal

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the extent of information which cannot be utilised in the biodiversity study across assemblage zones. Future identification of currently unidentified specimens could change the biodiversity patterns determined for this dissertation.

The indeterminate specimens (3951) with assemblage zone information were subdivided further. Indeterminate specimen subdivision is portrayed as follows:

(a) 417 indeterminate specimens (Figure 2.5) with no locality or assemblage zone information. This grouping could only be utilised in the museum specimen count analysis, museum comparative study and Beaufort Group specimen count analysis.

(b) 1777 specimens (Figure 2.5) with locality information only.

(c) The remaining 3951 indeterminate specimens with attached assemblage zone information were subdivided into their relative alliance to the eight assemblage zones of the Beaufort Group.

The *Eodicynodon* Assemblage Zone has 31 indeterminate specimens, the *Tapinocephalus* Assemblage Zone has 140 indeterminate specimens (one percent of the total Beaufort Group population), the *Pristerognathus* Assemblage Zone lists five indeterminate specimens, the *Tropoidostoma* Assemblage Zone lists 549 indeterminate specimens (three percent of the total Beaufort Group population), the *Cistecephalus* Assemblage Zone lists 2109 indeterminate specimens (ten percent of the total Beaufort Group population), making it the assemblage zone with the greatest amount of indeterminate specimens, the *Dicynodon* Assemblage Zone lists 368 indeterminate specimens (two percent of the total Beaufort Group

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population), the *Lystrosaurus* Assemblage Zone lists 172 indeterminate specimens (one percent of the total Beaufort Group population) and the *Cynognathus* Assemblage Zone lists 259 indeterminate specimens (one percent of the total Beaufort Group population). The remaining 318 indeterminate specimens that have assemblage zone information are relegated to the various transitional zones (Figure 2.7).

Almost eighty percent (70.7 %) of all palaeontological records for the Beaufort Group have been identified to some extent. 5193 specimens (Figure 2.5) are classified to genus level with accompanying assemblage zone data.

Figure 2.7 depicts the further subdivision of identified records coupled with assemblage zone data. The *Eodicynodon* Assemblage Zone lists 51 specimens belonging to various genera. The *Tapinocephalus* Assemblage Zone lists 183 specimens belonging to various genera (this comprises one percent of the total Beaufort Group vertebrate fossils), the *Pristerognathus* Assemblage Zone lists 34 specimens belonging to various genera, the *Tropidostoma* Assemblage Zone lists 361 specimens classified to various genera (this comprises two percent of the total Beaufort Group vertebrate fossils), the *Cistecephalus* Assemblage Zone lists 1037 specimens classified to various genera (this comprises five percent of the total Beaufort Group vertebrate fossils), the *Dicynodon* Assemblage Zone lists 268 specimens belonging to various genera (this comprises one percent of the total Beaufort Group vertebrate fossils), the *Lystrosaurus* Assemblage Zone lists 2559 specimens classified to various genera (this comprises 12% of the total Beaufort

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Group vertebrate fossils), the highest count of classified specimens in the Beaufort Group and the *Cynognathus* Assemblage Zone lists 562 specimens belonging to various genera (this comprises three percent of the total Beaufort Group vertebrate fossils). The remaining 143 specimens classified to genus level are catalogued as being from various transition zones (Figure 2.7). A complete account of which genera are represented in each Assemblage Zone is displayed in Table 4.2. Figure 3.8 displays the quantity of specimens to specific genera.

2.2 Methods

2.2.1 Mapping palaeontological specimens

In order to understand the biodiversity of the fauna of the Beaufort Group, it has been necessary to capture the information from all these collections onto a single GIS system. This section details the processes involved in establishing a pilot GIS database system for fossils of the Beaufort Group. This section is long-winded, but in order to assist future researchers to overcome the problems encountered in setting up or adding to the GIS system the steps which were followed are explained in detail.

The broad-spectrum processes involved in presenting data within a spatial system can be divided into three stages, each of which was subdivided into successive tasks (Table 2.4):

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Stage 1: Acquisition and Processing of Raw Data

Stage 2: Establishing a GIS Management System

Stage 3: Reconciliation

2.2.1.1 Establishing a GIS management system

In order to perform tasks two, four and five of Stage 1, as well as tasks one - four of Stage 2 (Table 2.4), further refinement of the work breakdown structure was required to present the Beaufort Group data within a spatial system. The more detailed processes involved in spatially mapping the vertebrate fossils of the Beaufort Group are broadly subdivided into two phases:

Phase 1: Accessing and processing of data

Phase 2: Development of spatial model

The adopted methodology and execution of tasks one – eleven of Phase 1 and tasks one and two of Phase 2 are explained in the proceeding pages of this section (Table 2.5).

Firstly, a preliminary cleaning of the data had to be done (Tasks 3, 7, 8, 9 10 and 11 of Table 2.5), followed by the selection of data fields applicable for the project objectives. Data fields in each collection were investigated for use and then either retained or rejected. A summary of which datafieds were deleted from each museum is displayed in Table 2.6. The reasons for deleting certain columns of data are: firstly do away with those fields that had no bearing on the aim of the

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GIS-project (which was to digitally record specimens to their specific localities); and secondly to establish a similarity or a standardisation across all contributing museums. Thereafter, map layers applicable to the objectives of the GIS-project were selected. To get to the point where data was represented on a spatial map, two approaches were adopted. The first approach involved the selection of those records that qualified for automatic insertion into the system. The second approach involved those records that could only be entered onto the system manually.

2.2.1.1.1 Automated data entry procedure

The purpose of this component of the project was to select for those records that could be entered into the system automatically. This is easily realised for records which have GPS locality co-ordinates. However, as the majority of records have only a farm name for the locality a spatial database had to be created to allow records to automatically be inserted to specific localities referenced as farm centroids (Appendix D). The obvious disadvantage of using farm centoids as a spatial reference for fossils is that the accuracy and degree of resolution is diminished. Placing all fossils from a particular farm in the gravitational centre of that farm introduces possible errors, as certain farms cover more than one biozone. Chapter 6 offers suggestions as to how such challenges may be overcome. In order to get to the point for data to be inserted automatically certain tasks had to be completed (Table 2.7).

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Various map layers are necessary as backdrop data to interpret the distribution patterns of fossil taxa. Satellite imagery of the area comprising the Beaufort Group was selected as one of several backdrop map layers. Landsat 7 ETM+ data was provided by the Satellite Application Centre (SAC). The original plan was to use Landsat 7 data as backdrop data for the maps, as the imagery highlights topography and geological structures. However, this is far too detailed when portraying the full geographical extent of the Beaufort Group. The full range of satellite imagery is available on the system but due to cluttering of the map it was decided that the imagery would be utilised only on request.

Because most of the specimens recorded in older collections lack geographic co-ordinates for their place of discovery, the most accurate locality information in most of the databases is simply a farm (without a farm number) and district name. In order to present this locality information onto the GIS System, farm locality data was received in .FEA format from the Surveyor General (SG). These data for each of the necessary provinces (Northern Cape; Western Cape; Eastern Cape; Free State and Kwa-Zulu Natal) was converted into shape file format, using a converter provided by the office of the Surveyor General of South Africa. Alphanumeric data was exported as a point file and thus it was necessary to join this data to the polygon data. This was done using a spatial join (Appendix D) (Netterberg *et al.,* 2004). The cadastre received from the Surveyor General contained farm boundaries and their farm numbers, but very few farm names which posed a major problem for the project. Localities for most of the specimens were given only as locality names, which were assumed to correspond to the farm

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names. As such, the farm names were essential for the geocoding (Appendix D) of the localities and thus the specimens.

The Surveyor General data utilises only farm numbers, as these remain constant while the farm names change frequently. This then required an alternative solution as very few farm numbers are provided in the data of the museum collections.

To solve this, another data source containing a higher proportion of farm names was used, namely the Environmental Potenital Atlas (ENPAT 2004) farm cadastre data. The ENPAT data series contains cadastral data including the majority of farm names and their number. As a result it was decided to use this data as the new spatial layer to identify the localities. For each farm, centroids were automatically generated, which are the centres of gravity for polygons (ie: for farm boundaries). These were used to geocode the specimens by linking the specimen locality names to the farm names (Netterberg *et al.,* 2004). The farm centroid layer contains farm names and co-ordinate pairs for allocation to the specimen records. Additional backdrop map layers include the Surveyor General data for magisterial districts and provinces. This data was used to further identify the localities, as farm names are not unique across the country. Digitised geological maps covering the extent of the Beaufort Group were included as additional backdrop data.

The BPI Palaeontology collection database was selected to be used as a test case because of the high resolution of farm locality and map sheet data. Selecting a test

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case dataset was to ascertain whether the automated entry of palaeontological records was a feasible option. The Initial Working databases of the BPI collection (Chapter 3: Folder 4) were used as test-material data to measure the degree of automatic selection of unique farm names. The results would determine the number of localities able to be correctly identified automatically. Some problems were encountered, as some fields had additional characters such as commas, which meant that both records were returned as unique when in fact these are both the same locality. There are approximately 600 unique localities for the BPI collection. These unique localities were split into those with co-ordinates and those without. The process for locating the location of these two groups of localities was different.

Those localities with grid co-ordinates were extracted and all co-ordinate data converted to decimal degrees and imported into ArcGIS as an event theme and subsequently converted to a shape file (Appendix D) (Netterberg *et al.,* 2004). Each specimen is located as a point in the spatial data file (Netterberg *et al.,* 2004). These have not been aggregated to link all the specimens to one locality point in a many to one relationship as was done with those records linked to a specific farm centroid. The rapid rate and accuracy of insertion that results when using spatial location data (grid co-ordinates), proves that this method would be most useful to the field of palaeontology (Netterberg *et al.,* 2004).

Those localities without co-ordinates had to be identified by districts, farm names and map sheet indices. As an initial test, the unique map sheets (which were

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singly entered) were selected for the Northern Cape Province. Those farms which lie either partly or completely within these map sheets were selected (Netterberg, *et al.,* 2004). The farm names were compared visually, to determine as to how to link the two datasets. A simple join with farm names as key fields was not possible as these are not unique. The Surveyor General data has farm numbers in addition to certain farm names, whereas the BPI collection data for example, only has a farm name or a description of a specific locality.

As a test run to determine how to automate the linkage of the locality name provided by the BPI data to the farm records listed in the Surveyor General data, the localities in the district of Beaufort West were selected (Netterberg *et al.,* 2004). There are 12 distinct localities in the Beaufort West District (Figure 2.8). According to the alphanumeric data all these localities fall on the same map sheet except for the Winterberg (Gryskop) locality. Of the 12 localities only seven were able to be matched to the spatial data (Netterberg *et al.,* 2004). Of these seven, only two localities fall on the correct map sheet. The outcome of this specific test run suggested that it would be very difficult to automate the linking process.

Another test was run to determine if 'selection by map sheet' could be used as a method to link the alphanumeric data to the spatial data. Map sheet 3123DD was selected. All the alphanumeric records of the BPI collection, which are located on this map sheet, were selected (Netterberg *et al.,* 2004). This query returned 41 records. These records where then queried such that only the distinct localities would be returned. This query resulted in 38 distinct localities. Since the locality

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name is supposed to correspond to the farm name, it follows then that there should be 38 farms, which intersect with this map sheet. A query was performed to select all the farms, which lie wholly or partly on this map sheet. The query resulted in 16 farms (Netterberg *et al.,* 2004). This is less than half the number of distinct localities. If there is more than one locality on a farm, which is named differently, then these numbers cannot correspond. As the method of using locality names, farm names and farm centroids, was not very effective because in the majority of instances neither the locality names nor the farm names matched the government farm names as contained in the farm centroid attribute table or the ENPAT cadastral data, an alternative linkage solution needed to be created (Netterberg *et al.,* 2004).

The South African Museum database, which contains both locality names (popularly used by the various land owners) and formal government farm names, was used as the linkage mechanism. For each collection a query for distinct records of specimens was run. The results from this query where input into a second query where the centroids with their government farm names were linked to the specimens with their locality names via the joining table derived from the South African Museum data (Netterberg *et al.,* 2004). The results from these queries were imported into the GIS and merged to form one data file for the whole of the Beaufort Group: (*ALL_centroids_allfields_v3.shp*).

Of the 16 941 specimens in the six collections (Transvaal Museum data was inserted entirely manually), selected as records that have the potential to be

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automatically inserted, 8512 (50%) were located by centroid. These figures are based on the number of unique records, which paint a rather more positive picture than the actual matches due to the discrepancies in the data. Unfortunately, this method returned a low match. Running these aforementioned tests designed to automatically insert the palaeontological databases, showed inconclusively that the standard of the metadata (Appendix D) was not at a level condusive to such an objective. The only solution was for the remaining data to be manually inserted into the existing digital-palaeo system. By combining both automating procedure and manual entry procedure the intention of adding as much of the collective data in as short a time as possible could be achieved.

A geodatabase (Appendix D) was created for the project. The purpose of the geodatabase was to collectively house the spatial data of the farm boundaries, administrative boundaries, district boundaries, magisterial boundaries and local authorities' databases (Netterberg *et al.,* 2004).

Since farm names are not unique and can be repeated for several districts, the map sheet index was used in addition to the farm names and districts as identifiers for the location of the farm localities. As an index shape file of the 1:50 000 map sheet series does not exist, a map sheet index shape file was created by digitising the sheets (Netterberg *et al.,* 2004). The corners of these sheets are accurate to 3 decimal places. The lines were snapped (Appendix D) to a point file generated by a spreadsheet of point locations. These were labelled semi automatically by creating a point file with labels and joining the two files spatially (Netterberg *et*

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al., 2004). This was randomly checked for errors until none were found. This file was also added to the geodatabase (Netterberg *et al.,* 2004).

The automatic insertion of records yielded a poor rate of success. Of the 19 718 specimens selected for possible automatic insertion (Chapter 3: Folder 6), only 8512 were able to be inserted automatically. When these values are compared against the total number of records (20 968 – Table 2.1) that required import into the GIS, it is apparent that the success rate is very low, yielding only a 43.2% success rate (Table 2.8).

The success rate percentage is calculated against the number of specimens that required insertion into the GIS. Those records that could have been automatically inserted as they fulfilled the automating criteria (in that they possessed a farm name, district and map number or a GPS co-ordinate) are recorded in the tables of the Automated Input Databases (Chapter 3: Folder 6). The number of specimens listed is substantially less than the overall total of collected specimens as these values were obtained as possibilities for automated entry only.

A spatial database, containing those specimens which could be located by centroid, was created by linking their locality names (referenced from the museum collections) to farm names (sourced from both the SG and ENPAT databases). Instead of locating each locality and linking the relevant specimens to the locality, each specimen which could be located, was allocated a location (co-ordinate pair)

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by farm centroid (Netterberg *et al.,* 2004). Various files, including a number of different shape files, were created and are described in Table 3.13 and Table 3.14.

From this database, three separate project files were created:

(1) The first project was created for illustrating (mapping) the entire Beaufort Group. This shows the distribution of all specimens with locality data (both by centroid and co-ordinate pair) from six collections (Transvaal Museum data was imported manually) on a background of geology, plottable to A0 size.

(2) The second project was created for illustrating (mapping) the whole study area and shows the distribution of all specimens with locality data by centroid only, from the six collections on a background of geology (Netterberg, *et al.,* 2004). This is plottable to an A0 map with the specimens classified per assemblage zone as defined in Rubidge *et al.,* (1995).

(3) The third project was created to show the representation of fossil specimens recorded from each biozone of the Beaufort Group. In addition, a separate map was created for those records for which no assemblage zone data has been allocated. This project file has been optimised for plotting A4 size maps per specific assemblage zone (Netterberg *et al.,* 2004).

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The objective behind the establishment of the three project files is to allow for future corrections, alterations and additions to be performed on the spatial database as necessary, either at a localised scale, or for the full extent of the Beaufort Group. The complete contents of the project files are available on Paleo CD's 1-3. All manually entered specimens were added to the spatial map (both centroid and co-ordinate pair) of the above-mentioned first project file.

2.2.1.1.2 Manual data entry procedure

Data tables containing specimens that had failed to insert automatically were established for each museum (Manual Input Databases, Folder 5 of CD1). These data tables were established by selecting the records that had not been plotted on the spatial map, when compared against the original automatic insertion spreadsheets (CD1: Folder 6). These 'left-over' records were obtained by comparing the GIS attribute tables for each museum (Palaeo CD3) with the automatic insertion spreadsheets (CD1: Folder 6). The attribute tables (Palaeo CD3) for each museum provide a record of which fossil specimens were automatically plotted on the spatial map.

Thereafter, a further comparison for each museum was run between these newly created databases against their respective raw databases. What this amounted to was a sum of recorded specimens comprised of 'failure to automate' data with 'unautomatable' data. This sum approximates the total number of specimens collected per museum. This sum is less than the totals given per raw database due

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to the decisions taken earlier (2.1.1: Analysis of original data) to eliminate certain records (Table 2.2). Table 2.9 provides a summary of the degree of success in manually plotting fossil records. The success rate percentage is calculated against the number of specimens that required insertion into the GIS. Discussion of these results is covered in Chapter 3.

Manual entry databases for each museum were created on Excel and imported into the spatial map under separate map layers (a map layer for each museum collection). Each fossil entry from the Manual Entry Databases (Folder 5: CD1) was then systematically added in point format to the spatial map. Manual entry procedure involved a 'select by attributes' query and edit function. This investigative procedure was done in two stages. Initially a selection for district was queried for a specific fossil in a specific database, using the magisterial district map layer. The second selection was queried for farm name using the eccad, nccad, wccad, fscad, or the kzncad map layers.

These map layers collectively comprise the farm name and number as well as farm boundary databases obtained from the Surveyor General. 'nccad' (Northern Cape Province computer aided design), for example refers to the entire farm boundary and farm number data for the Northern Cape Province. (wc = Western Cape Province; fs = Free State Province and kzn = KwaZulu Natal Province). If the selected farm name fell inconclusively within the highlighted district of the active map layer, the investigated specimen was added to that farm randomly in point form and its details manually verified on the relevant attribute table. Where

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a farm name was found that did not spatially link to its supposed corresponding district, it was opted to retain the district information resolution only. This means that those specimens whose farm names could not be found or whose locality information did not match the listed district remained spatially bound to district resolution level only. A summary of totals of specimens manually inserted to farm name, co-ordinate as well as district resolution is provided in Table 2.10.

Problems encountered during the insertion process, such as: farm name and district linkage inconsistencies, failure to locate certain listed farm names in museum databases, together with vagueness in locality description are detailed in Chapter 6.

2.2.1.1.3 Collation of Beaufort Group data

The third phase of the mapping procedure involved collating the point data of the seven collections into one map layer, on completion of the plotting of the automated and manually inserted data onto a spatial map (Palaeo CD3). The list of shape files (Appendix D) requiring amalgamation are summarised in column 1 and 2 of Table 2.11. Such amalgamation is necessary to decrease the complexity of any future queries. The datasets under column 1: Manually Entered Data and column 2: Automated and Co-ordinate Entry Data (Table 2.11) represent the palaeontological specimens from the seven collections. This data was captured either by co-ordinate entry, allocation to farm centroids or manual entry. These

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datasets needed to be combined into one comprehensive dataset for future analytical purposes.

The original intention was to simply append all the datasets onto a single existing dataset. Because of the differing alphanumeric table structures and schemes of the contributing museums, this was not directly possible. Accordingly the alphanumeric table structures of the various data files where manipulated to conform to the structure shown in Table 2.12 (Netterberg *et al.,* 2004). The shape files, which ultimately needed to be combined, were manipulated in turn to conform to the structure shown in Table 2.12. Any duplicate records were removed manually from the shape files. The process was repeated for all the necessary files. This process is illustrated in Figure 2.9 (Netterberg *et al.,* 2004).

The append module in ArcGIS 9 was then used to append (Appendix D) all the files. Shape files that had a multipoint geometry type, rather than a point geometry type were converted to a point geometry type, and then appended (Netterberg *et al.,* 2004). The files that were appended are listed in Table 2.13. The result was the single point shape file: *Palaeo_Specimens.shp*.

The *Palaeo_Specimens.shp* dataset contains approximately 30 000 points and indicates where fossil vertebrates from the Beaufort Group were discovered in the field (Palaeo CD3). This dataset (*Palaeo_Specimens.shp*) will be subjected to further refinement and correction and, on completion of the digitisation and

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spatial mapping of the Beaufort Group initiative, will be the dataset on which future trend and pattern analysis will be performed.

For this dissertation, the pilot phase of the Beaufort Group GIS-initiative was completed. Much metadata has been collected for recorded fossils from the seven large collections of vertebrate fossils (listed in Chapter 1), but particularly for specimens collected long ago, the quality of the metadata is not compliant with the requirements for a reliable GIS study. As such the system has inherent inconsistencies and errors. Certain specimens were listed more than once, despite the selection of distinct records. This is because of capture errors and lack of standardisation in the original data. In a number of the spreadsheets, the unique identifier of the specimen was not unique which made removing redundant data that much more difficult. Although substantial data cleaning and alterations were performed (Section 2.2.2.2), there are still numerous flaws in the data set. However, the recognition that this project be viewed as a pilot project, allows for the inclusion of these inconsistencies and flaws, with the intention that they be corrected during successive phases of the GIS mapping initiative. Chapter 6 discusses future strategies to eliminate these inaccuracies which will result in a database that is calculatable, consistent and standardised.

Although the GIS-based digitised record of Beaufort Group fauna will be used extensively for future palaeontological research, for the objectives of this dissertation (an investigation of the biodiversity of the Beaufort Group) it was decided to make use of the original datasets provided by the contributing

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museums. Section 2.2.2 describes the processes involved in manipulating and synthesising these raw databases in order to address the aims set out for this project (see Chapter 1).

2.2.2 Standardisation and correction of Beaufort Group data

In utilising the datasets of the seven contributing museum collections, to fulfil the objectives of this dissertation, the principal philosophy adopted was to *assume* that the information contained in the various databases was *correct*. Challenges encountered with the datasets of the seven contributing museum collections involve:

(1) Outdated taxonomy (i.e. records not updated to current accepted taxonomic assignment).
(2) Incorrectly identified fossils.
(3) Incorrect assemblage zone assignment.
(4) Vague locality description.

Because of the very large number of records which are spread between the seven contributing collections, it was considered beyond the scope of the project to check and verify each entry from each museum. However, because of the accessibility of the BPI Palaeontology collection, the classification in the Amphibian and dicynodont categories were updated, verified and recorded in the synthesised records of the Bernard Price Institute.

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Updating and verifying these records involved the physical examination of fossils from the BPI collection with the assistance of appropriate palaeontological specialists. Furthermore, in an attempt to lessen the margin of error, when ultimately interpreting biodiversity and biodiversity patterns within the Beaufort Group, all listed species and genera from the contributing museums were assessed and taxonomically updated (where possible) (CD1: Folder 2). All updated records are catalogued in the standardisation spreadsheets discussed in section 2.2.2.2 of this chapter. The approach of thereafter *assuming* the records to be *correct* was then implemented.

Certain errors (e.g. locality, assemblage zone and taxonomic assignation) are obvious. These records are listed in the synthesised data. The decision to leave flawed records in the synthesised datasets is in keeping with the methodology of assuming accuracy (see Appendix F). This is because subtle errors in locality, assemblage zone and taxonomic assignation may not have been detected and are therefore inherent in the system. The elimination of obvious errors, by way of their minority, would not then significantly increase the reliability of the datasets as there is no measure of the degree of accuracy of the remaining records. The only way to measure accuracy and increase the reliability of the datasets, so that it is in accordance with the standards of digitised data for GIS purposes, is for each record to be checked and verified by palaeontologists specialising in specific tetrapod groups, at each museum. These updated records can then be collated for use in the next phase of the GIS–initiative.

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An analysis of the faunal content of each museum collection is presented in Chapter 3. Before the faunal content of each museum could be analysed, the dataset from each museum underwent extensive examination and alteration (Section: 2.2.2), culminating in Final Specimen Count Lists for each museum (Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31; and Table 2.34). From these spreadsheets, tables and figures depicting the total diversity of the Beaufort Group was created (such as Figure 3.8, Figure 4.3, Table 4.2 & Table 4.12), as a result of the fusion of individual museum collection databases. Appendix F highlights flaws in these datasets that became apparent after the completion of the standardisation and 'clean-up' procedures described in Section 2.2.2. The contents of Appendix F will be used as part of the data-cleaning component in Phase 1 of the GIS-initiative (Chapter 6) and will fast track the update of the contributing museum collections.

Appendix F lists where a specific flaw can be found. It must be noted that only the cumulative figure or table is listed, but the error runs *throughout* the system, and is detectable in all synthesised data. Therefore the error listed in Table 4.11, for *Placerias,* for example, will be in all tables from all museums and all figures mentioning that record. Genera such as *Daptocephalus, Parotosuchus, Scapanodon* and *Whaitsia* have remained in the system, although their specimen numbers have decreased. *Daptocephalus* was only updated to *Dicynodon* if a specific record listed the species (e.g. *Daptocephalus leoniceps*) (Refer to CD1: Folder 2: Species List). The descision to convert to another genus, such as *Daptocephalus* to *Dicynodon*, without species data could not be substantiated.

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Parotosuchus was only updated to *Xenothosuchus* for the same reasons mentioned for *Daptocephalus.* The same reasoning applies to the conversion of *Scapanodon* to *Titanosuchus* and *Whaitsia* to *Theriognathus*. It must be noted that there were a large number of conversions to *Diictodon* because the relevant *Dicynodon* species were listed (e.g. *Dicynodon pseudojouberti* updated to *Diictodon* – see CD1: Folder 2: Species List (all 7 databases)). After substantial data cleaning, the discussed approach of assuming correctness was implemented (Section 2.2.2).

An objective of Phase 1 of the GIS – initiative is to abandon the categorisation of records to assigned assemblage zones of the Beaufort Group. Once all records from each contributing museum collection have been assigned a geo-reference (Chapter 6), the process of re-defining and refining the assemblage zones of the Beaufort Group will commence. Making use of diagnostic genera to define a specific assemblage zone, the boundaries of that biozone will be drawn around grid-referenced locality data.

The majority of locality data used for this thesis had written or textual locality references (Chapter 6). The use of textual references to locate the exact locality of specimens is problematic (Chapter 6). Because not all textual references to locality have been geo-referenced, in alignment with stringent GIS standards, it was decided to utilise the assemblage zone assignation of each collection, in order to interpret biodiversity trends for the purpose of this thesis. It was reasoned that regardless of the disadvantages, the portion of records with assemblage zone data would be capable of presenting biodiversity trends across and within the

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assemblage zones of the Beaufort Group. The next stage of work (after this thesis) would involve the use of all available records for the Beaufort Group to create a denser picture of biodiversity. The analysis provided in Chapter 4, however, would not be in vain, as the systems created to interpret biodiversity are already in place (the work of this thesis). Phase 1 would involve making full use of the created templates and tools, but will provide a fuller and more refined picture.

The disadvantage in having opted to make use of existing assemblage zone assignation lies in acknowledging that potentially museum collections may have, in certain instances:

(1) Incorrectly assigned an assemblage zone to a certain record.
(2) Outdated biostratigraphic subdivisions of the Beaufort Group may have been used.

The two challenges listed above, were handled in the following:

(1) If a record was incorrectly assigned to an assemblage zone, it was listed in Appendix F. Appendix F serves as a high priority list when embarking on Phase 1 of the GIS – initiative.
(2) If a record was incorrectly assigned to an assemblage zone, although displayed in figures and tables, it was not utilised in analyses such as the calculation of ecological ratios for assemblage zones.
(3) This thesis makes use of the currently accepted biozonation of the Beaufort Group (Rubidge, B.S. (Ed.). 1995(b)). Museum collections that still retain (in small degrees) outdated biozonation schemes in

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their assignment of records to assemblage zones have been updated. Any updated information was catalogued in the standardistaion procedures performed on all museum collections. The method adopted was to alter any record (if any) referring to one or more of the following outdated assemblage zones:

a. Any reference to the *Pristerognathus/Diictodon* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Pristerognathus* Assemblage Zone.
b. Any reference to the *Tropidostoma microtrema/Endothiodon* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Tropidostoma* Assemblage Zone.
c. Any reference to the *Aulacephalodon baini/Cistecephalus* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Cistecephalus* Assemblage Zone.
d. Any reference to the *Dicynodon lacerticeps/-Whaitsia* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Dicynodon* Assemblage Zone.
e. Any reference to the *Daptocephalus* Zone (Kitching, 1970, 1977) was updated to the *Dicynodon* Assemblage Zone.
f. Any reference to the *Dinocephalian* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Tapinocephalus* Assemblage Zone.

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g. Any reference to the *Lystrosaurus-Thrinaxodon* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Lystrosaurus* Assemblage Zone.
h. Any reference to the *Kannemeyeria-Diademodon* Assemblage Zone (Keyser & Smith, 1979; Keyser, 1979, SACS, 1980) was updated to the *Cynognathus* Assemblage Zone.
i. No museum collection had applied the earlier biozonation schemes of Broom (1906) and Watson (1914).

The conversion methodology to the updated assemblage zone scheme discussed above could not be applied to museum collections assigning records to the *Cistecephalus* and *Tapinocephalus* Assemblage Zones. This is because what is referred to as belonging to the *Cistecephalus* Assemblage Zone could be a reference to the outdated biozonation of Kitching (1970; 1977) that did not recognise the existence of a *Tropidostoma* Assemblage Zone. In addition, in many instances, a reference to an upper or lower *Cistecephalus* Zone is not assigned. If there was assignation to an upper or lower *Cistecephalus* Zone, the conversion to *Dicynodon* and *Cistecephalus* Assemblage Zones could be deduced respectively. The same reasoning applies to the *Tapinocephalus* Zone (Kitching, 1970; 1977) where the existence of a *Pristerognathus* Assemblage Zone was not recognised. Again if there was assignation to an upper or lower *Tapinocephalus* Zone, the conversion to the *Pristerognathus* and *Tapinocephalus* Assemblage Zones could be deduced respectively.

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Museum collections retaining the biozonation scheme of Kitching, 1970; 1977, specifically for his *Cistecephalus* and *Tapinocephalus* zones, introduce the possibility of an erroneous interpretation of biodiversity for these biozones. What this means is that genera that have reference to being present in the *Cistecephalus* Assemblage Zone (Kitching, 1970; 1977), have the potential to be assigned to the *Tropidostoma* Assemblage Zone, if the current biozonation scheme was applied. The problem that arises is how to deduce whether an assignation to the *Cistecephalus* Assemblage Zone is based on outdated or current biozonation? The same problem arises for assignation to the *Tapinocephalus* Assemblage Zone.

The solution to this challenge was to identify the diagnostic genera of these problematic assemblage zones. The *Cistecephalus* Assemblage Zone is characterised by the presence of *Cistecephalus, Oudenodon* and *Aulacephalodon.* Additional genera found in this biozone and not the *Tropidostoma* Assemblage Zone are *Dinanomodon* and *Platycyclops.* The *Tropidostoma* Assemblage Zone is characterised by the association of *Tropidostoma* and *Endothiodon* and the absence of scylacosaurid Therocephalians. The *Tapinocephalus* Assemblage Zone is characterised by the presence of *Tapinocephalus, Emydops* and *Robertia* when compared to the *Pristerognathus* Assemblage Zone which is characterised by the absence of dinocephalians and the presence of *Endothiodon.*

Making use of genera that characterise the *Tropidostoma* and *Cistecephalus* Assemblage Zones, the following records were filtered:

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Tropidostoma: (1) 3 specimens from the BPI recorded for the *Cistecephalus* Assemblage Zone.

(2) 1 specimen from the SAM recorded for the *Cistecephalus* Assemblage Zone.

(3) 3 specimens from the NM are recorded for the *Cistecephalus/Dicynodon* Transition Zone.

The above specimens should be recorded in the *Tropidostoma* Assemblage Zone.

Oudenodon: (1) 1 specimen from the BPI recorded for the *Tropidostoma* Assemblage Zone.

(2) 54 specimens from the SAM recorded for the *Tropidostoma* Assemblage Zone.

The above specimens should be recorded in the *Cistecephalus* Assemblage Zone.

All records of *Dinanomodon* and *Platcyclops* are correctly assigned to the *Cistecephalus* Assemblage Zone. Two specimens of *Aulacephalodon* (BPI) are assigned to the *Tropidostoma/Cistecephalus* Transition Zone and seven specimens of *Oudenodon* are recorded from the *Tropidostoma/Cistecephalus* Transition Zone. Specimens assigned to these transition zones are not considered as being incorrectly assigned. In addition, there are no records of scylacosaurid Therocephalians assigned to the *Tropidostoma* Assemblage Zone.

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There are five specimens incorrectly assigned to the *Cistecephalus* Assemblage Zone that should be from the *Tropidostoma* Assemblage Zone. This means 0.16% (five out of 3146 specimens (Table 4.12)) is erroneous for this biozone. In turn the 55 specimens from the *Tropidostoma* Assemblage Zone that should be from the *Cistecephalus* Assemblage Zone, means that this biozone is lacking 1.7% of its data.

There are 55 specimens incorrectly assigned to the *Tropidostoma* Assemblage Zone that should be from the *Cistecephalus* Assemblage Zone. This means that 6% (55 out of 910 specimens (Table 4.12)) is erroneous for this biozone. In turn the five specimens from the *Cistecephalus* Assemblage Zone that should be from the *Tropidostoma* Assemblage Zone, means that this biozone is lacking 0.5% of its data.

Making use of genera that characterise an assemblage zone, it was found that *no records* had been incorrectly assigned to either the *Tapinocephalus* or *Pristerognathus* Assemblage Zones:

Tapinocephalus: No records are assigned to the *Pristerognathus* Assemblage Zone.

Emydops: No records are assigned to the *Pristerognathus* Assemblage Zone.

Robertia: No records are assigned to the *Pristerognathus* Assemblage Zone.

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Dinocephalia: No records are assigned to the *Pristerognathus* Assemblage Zone.

Endothiodon: No records are assigned to the *Tapinocephalus* Assemblage Zone.

The calculated loss of data for the problematic biozones discussed above was considered small enough to continue with the adopted approach of utilising assigned assemblage zones in order to interpret the biodiversity across and within the assemblage zones of the Beaufort Group. Those genera that have been incorrectly assigned to an assemblage zone are listed in Appendix F. These genera are retained in the current system, but will be corrected during Phase 1 of the GIS – initiative.

Fossils of the Beaufort Group were relegated to their relative taxa, termed "Taxon Assignment" (Chapter 4: Section 4.2). A Taxon Assignment refers to an 'umbrella group' to which a fossil belongs. There are 13 taxon assignments for the Beaufort Group: Amphibia; Archosauromorpha; Eosuchia, Biarmosuchia; Cynodontia; Diapsida; Dicynodontia; Dinocephalia; Fish; Gorgonopsia; Parareptilia; Pelycosauria and Therocephalia. Diapsida was subdivided into Archosauromorpha, Eosuchia and indeterminate Diapsida for this study. The grouping of Diapsida is still retained to accommodate five errant specimens from the National Museum that were neither archosauromorph nor Eosuchian. These diapsids are found in the *Dicynodon* and *Lystrosaurus* Assemblage Zones. In addition there is a final grouping of 13 fossils with unknown taxon assignment.

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In order to understand the biodiversity of the fauna of the Beaufort Group, it has been necessary to capture the information from all these collections onto a single amalgamated system (see section 2.2.2.2) that is adaptable to alteration and correction.

2.2.2.1 Synthesised data

2.2.2.1.1 Biodiversity lists for contributing museum collections

The spreadsheets from this subsection (2.2.2.1.1) are saved to CD1: Folder 8, due to the large volume of information contained in the lists. The spreadsheets are labelled A.1; B.1; C.1; N.1; R.1; S.1 and T.1. List A1 refers to the first (1) stage of the standardisation process performed on the Albany Museum (A), B1 refers to the first (1) stage of the standardisation process performed on the original BPI (B) database, etc. Excel worksheets A.1; B.1; C.1; N.1; R.1; S.1 and T.1 are collectively referred to as the Biodiversity lists for contributing museum collections. These worksheets (established per museum collection), collectively house all data pertaining to the recorded specimens of the Beaufort Group, taken directly from their original sources (i.e. 'Raw' Databases). The first stage of the standardising and 'cleaning' process can be seen in column 3 of each worksheet (Refer to CD1: Folder 8). Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

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Original assemblage zone information is listed, as well as deduced assemblage zone information. In all cases the evidence for deducing a specific assemblage zone for a particular fossil specimen is included. An example of such a deduction is from the Albany Museum (A1): Acc no: 324, *Arctognathus* - *Cynognathus* Assemblage Zone (see Folder 3: Albany Museum Raw data). Such meticulous note-taking is a necessary task in data-cleaning and standardising procedure, as it provides a safe-guard as well as evidence to account for any alterations to the databases. Any correction or alteration can only be instigated after proper procedure and continuity of procedure is adherred to throughout the process. If the system of standardisation and 'clean-up' methodology decided upon, is adherred to throughout the process, and each database is subjected to the same procedure, this results in a high measure of confidence in the synthesised data that results. Section 2.2.2 details the methodology adopted in the standardisation and initial 'clean-up' of data from the Beaufort Group. Refer to Appendix C for a summary of and directory for the spreadsheets of this subsection.

2.2.2.1.2 Specimen count lists for contributing museum collections

Specimen count lists for contributing museum collections were extrapolated from the Biodiversity lists for contributing museum collections (2.2.2.1.1). These spreadsheets (Table 2.14; Table 2.17; Table 2.20; Table 2.23; Table 2.26; Table 2.29 and Table 2.32), collectively referred to as Specimen count lists for contributing museum collections, were subjected to further refinement and are a more streamlined version of Section 2.2.2.1.1.

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The main objective of this set of data was to correct any spelling errors from the original datasets of each museum. See Section 2.2.2.2 for full description of this methodology. An additional 'balancing' application is evident in these datasets to guard against potential data loss that may occur during the various data cleaning procedures. This balancing system was applied to all synthesised data for this dissertation: The sum total of values assigned in the assemblage zone column for a specific fossil equals the total number of recorded specimens for that specific genus. A random example of this 'balancing' methodology is provided by the Albany Museum (Table 2.14). Focusing on the genus *Dicynodon* (Table 2.14), the museum has sixty seven specimens recorded for this genus. The assemblage zone information relating to this genus (and hence its distribution) is six specimens recorded for the *Cistecephalus* Assemblage Zone, one specimen recorded in the *Cistecephalus/Dicynodon* Transition Zone. Fifty specimens, although not recorded to a specific assemblage zone, have adequate locality information to assign to a biozone at a later time (v) and the remaining 10 have no locality information (x). The sum of the values assigned to the Assemblage Zone column is sixty seven, which is the sum of the specimens recorded for this genus. Each recorded specimen in the Beaufort Group database was subjected and verified to this balance. (Refer to Appendix C for a summary of and directory for the spreadsheets of this subsection).

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2.2.2.1.3 Original – to – Updated specimen count lists for contributing museum collections

The spreadsheets (Table 2.15; Table 2.18; Table 2.21; Table 2.24; Table 2.27; Table 2.30 and Table 2.33) highlight the changes which transpired during the updating process to correct taxonomic classification (to genus level). All listed species and genera from the contributing museums were assessed and taxonomically updated (where possible). CD1: Folder 2: File: Species List (All 7 Databases) provides a list of all specimens recorded in the Beaufort Group from the seven contributing museums. This spreadsheet includes the original classification as well as any necessary taxonomic updates. If a classification update is listed, it is accompanied by a referenced source accounting for such a change. Again, it must be noted that, at no point in this 'clean-up' procedure, was any data lost because of the application of the 'balance-sheet' system: when a particular genus was absorbed into another genus, for example, the accompanying assemblage zone and specimen count data was added to the new genus. To explain this balancing methodology, refer to Table 2.15. The genus *Cynognathus* for example, originally listed 10 recorded specimens for the Albany Museum. Their respective assemblage zone distribution is listed in Column 1 of Table 2.15. The genus *Gomphognathus,* for example, listed in Column 2 of Table Table 2.15 was updated to *Cynognathus.* This change is observed in Column 4 of Table 2.15, where the elimination of the genus and the subsequent specification of its movement is checked and accounted for at both *Gomphognathus* and its addition

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to *Cynognathus.* Coupled with the alteration is the resultant change in Assemblage Zone (Updated) as well as Specimen Count (Updated) data. The precise methodology, performed on all specimens, is detailed in section 2.2.2.2. (Refer to Appendix C for a summary of and directory for the spreadsheets of this subsection).

2.2.2.1.4 Updated specimen count lists for contributing museum collections

The Updated specimen count lists for contributing museum collections represent the final product in the streamlining and 'cleaning' process, undergone by each museum in the previous three cleaning processes (described in Sections 2.2.2.1.1 – 2.2.2.1.3). Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31 and Table 2.34 are the final product for each museum, on which subsequent graphs were based. Utilising these spreadsheets (Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31 and Table 2.34) the amalgamated collection of Beaufort Group data was established. Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31 and Table 2.34, provide a listing of genera (updated) for each museum, as well as the number of specimens recorded for each genus including their respective assemblage zone data. The precise methodology, performed on all specimens, is detailed in section 2.2.2.2. (Refer to Appendix C for a summary of and directory for the spreadsheets of this subsection).

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2.2.2.1.5 Beaufort Group Super-Collection

A single standardised collection of all fossil finds in the Beaufort Group did not exist prior to this research project. Data from the aforementioned seven collections were fused to form a synthesised Beaufort Group database. The resultant spreadsheet displaying this fusion of databases can be seen in Table 2.35. Table 2.35 was the template from which subsequent research tools (such as Tables 4.12; 3.39 & 3.40) were created. The creation of these amalgamated spreadsheets was necessary to not only address the aims proposed in this thesis, but also to create useful tools for future research and queries. The amalgamation of all recorded specimens from each museum onto various user-friendly databases, collectively form part of the Beaufort Group Super–Collection.

Valuable and accessible research tools that provide immediate data on any recorded specimen have been created. The spreadsheets extrapolated from Table 2.35 are structured to include not only specimen numbers, but precisely where each specimen is housed as well as its recorded locality information. The research tools extrapolated from the establishment of this Super-Collection are described below. The precise methodology for the creation of each spreadsheet is detailed in Section 2.2.2.2. Refer to Appendix C for a summary of and directory for the spreadsheets and figures pertaining to the Beaufort Group Super-Collection.

Table 3.39 displays the fusion of updated data from all seven contributing museums. This spreadsheet summarises the diversity of genera in the Beaufort

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Group, with specific reference to where records of particular genera are housed, as well as the numbers of specimens and their respective assemblage zone data recorded for each genus.

Table 3.40 is a specimen count organogram of all recorded specimens of the Beaufort Group and was created to display 'count-cells' in each museum collection. The use of these 'count-cells' is a useful tool for quick access to which genera (and how many) are housed in which museum.

Table 4.12 is a useful tool providing a summary of the biodiversity within the Beaufort Group. Each genus recorded for the Beaufort Group is coupled to locality information, displayed in such a way that at a glance, its specific distribution within biozone(s) can be viewed. In addition, a summary is listed of the number of specimens within a specific genus, without biozone data, but with reliable locality information (v) and those specimens without any locality information (x).

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2.2.2.2 Methodology and standardisation procedure for synthesised data

The methodology and standardisation procedures described below address Technical Aim 2 (first page of this chapter). Standardisation and 'clean-up' procedures are observed in the following Excel® spreadsheets:

(1) Biodiversity lists for contributing museum collections (CD1: Lists A1; B1; C1; N1; R1; S1 and T1).

(2) Specimen count lists for contributing museum collections (Table 2.14; Table 2.17; Table 2.20; Table 2.23; Table 2.26; Table 2.29 and Table 2.32).

(3) Original – to – Updated specimen count lists for contributing museum collections (Table 2.15; Table 2.18; Table 2.21; Table 2.24; Table 2.27; Table 2.30 and Table 2.33).

(4) Updated specimen count lists for contributing museum collections (Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31 and Table 2.34).

(5) Amalgamated list of updated specimen count lists from contributing museum collections (Table 3.39 and Table 3.40).

(6) Beaufort Group (Amalgamated data) – Table 2.35, Table 2.36, Table 4.12 and Table 4.13.

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2.2.2.2.1 Biodiversity lists for contributing museum collections

Biodiversity lists (CD1: A.1; B.1; C.1; N.1; R.1; S.1 and T.1) were extrapolated from the raw databases of each of the seven museum collections. The selection of data fields as well as the formatting of each datafield is generic across all museums. The data fields for spreadsheets A.1; B.1; C.1; N.1; R.1; S.1 and T.1, from left to right, include:

- Column 1: Specimens (Listed to generic level). Row contents are sorted alphabetically according to genera.
    - Note 1: Purple font denotes those specimens which require re-classification to currently accepted genera. e.g.: *Dicynodon sollasi* (to *Diictodon*)
    - Note 2: Spelling errors are highlighted in red, blue & green font. Example, *Hofmeyeria* (i.e.: the second 'e' was omitted) – spelling errors are rectified completely in the secondary lists.
- Intermediate columns: Locality Information – pertaining to specific locality information per specimen (in applicable instances, depending on the resolution and accuracy of locality information).
- Final column: Assemblage Zone – The contents of this column were either originally supplied or deduced from the comments/notes listed in the raw data.

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- Note.1: The majority of recorded specimens have reliable locality information. From this information, their recording to respective assemblage zones will be extrapolated at a later date. The groundwork for creating referencing lists of *Locality-to-AssemblageZone* and *GridMap-to-AssemblageZone* templates have been established, but surpass the scope of this project.
- Note.2: Seemingly incorrect assemblage zone information was compared with documentation in Biostratigraphy of the Beaufort Group (Karoo Supergroup) (Rubidge *et al.*, 1995): Table 1 & Figure 3. Outdated biostratigraphic subdivisions of the Beaufort Group are retained in certain instances in certain databases. Where this occurred, biostratigraphic subdivision was updated, as demonstrated in the examples below:

- *Cistecephalus(U)/Lystrosaurus(L)* is the equivalent of the *Dicynodon/Lystrosaurus* Transition Zone according to the biozone nomenclature of Watson (1914a,b).
- *Daptocephalus* Zone equated with the *Dicynodon* Assemblage Zone (Kitching, 1970 & 1977). Therefore *Cistecephalus/Daptocephalus* and *Daptocephalus/Lystrosaurus* Transition Zones have been equated to the *Cistecephalus/ Dicynodon* and *Dicynodon/Lystrosaurus* Transition Zones, respectively.
- A listing of *Endothiodon* Zone is equated to the *Tropidostoma* Assemblage Zone (Broom, 1906; Watson, 1914a,b). Therefore

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Endothiodon/Cistecephalus Transition Zone has been equated to the *Tropidostoma/Cistecephalus* Transition Zone.

- A single listing (Transvaal Museum) of *Upper Tapinocephalus* or *Lower Endothiodon*, has been equated to the *Pristerognathus/Tropidostoma* Transition Zone (Watson, 1914a,b).
- A single listing (Transvaal Museum) of *Tapinocephalus* or *Cistecephalus* appears in the work of Kitching (1970; 1977). This listing was not equated to a modern equivalent.
- A single listing (National Museum) of *Lystrosaurus* overlap - a *Moschorhinus* specimen from the *Dicynodon* Assemblage Zone (becoming extinct before the middle of the *Lystrosaurus* Assemblage Zone) was equated to the *Dicynodon/Lystrosaurus* Transition Zone.

Blank rows between the different Genera were inserted to reduce visual confusion. x was inserted to cells containing no information.

2.2.2.2.2 Specimen count lists for contributing museum collections

From the Biodiversity lists above, specimen count lists (Table 2.14; Table 2.17; Table 2.20; Table 2.23; Table 2.26; Table 2.29 and Table 2.32) were extrapolated for each of the museum collections. These lists are a streamlined version of the original Biodiversity lists (CD1: A1; B1; C1; N1; R1; S1 and T1). The selection of data fields as well as the formatting of each datafield is generic across all museums

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Datafield content from left to right for Table 2.14; Table 2.17; Table 2.20; Table 2.23; Table 2.26; Table 2.29 and Table 2.32 is:

- Column 1: Highlights spelling errors, with the corrected spelling directly next to it in the main Genera column. (See *Notes below - spelling)

- Column 2: Genera list, in alphabetical order, as occurs in Biodiversity lists (CD1: A1; B1; C1; N1; R1; S1 and T1).

- Column 3: Specimen count of each genus - the sum of which is provided in the light yellow bar at the bottom of this column.

- Column 4: Specimen count totals are divided into their associated assemblage zones. (See *Notes below - abbreviations).

***NOTES:**

- Spelling errors in Column 1:
  - ❖ Incorrect letter:
    - ❑ Original name highlighted in Red – with incorrect letter in Blue.
    - ❑ Single arrow '>' points to the correct spelling.
    - ❑ Corrected spelling in Green – with corrected letter in Black or omitted where necessary. This methodology is demonstrated in the example below:

      Aulocephalodon > *Aulacephalodon* or *Prorubridgea* > *Prorubidgea*

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- ❖ Omitted letter:
  - Original name highlighted in Red – with omitted letter in Green, with brackets.
  - Single arrow '>' points to the correct spelling.
  - Corrected spelling in Green – with corrected letter inserted in Green and underlined: This methodology is demonstrated in the example below:

    R(h)*achiocephalus* > *Rhachiocephalus*

  In instances where not *all* listed genera maintain a spelling error, error counts are listed first followed by the spelling corrections. Such an example would be: 2 x *Plat(y)cyclops* > *Platycyclops*.

- Spelling corrections in Column 2:

  The corrected Genus name is highlighted in Green (**bold)**, for example, ***Aulacephalodon***.

- Column 4: Assemblage zone abbreviations (Assemblage zones are sorted in alphabetical order):
  - ❖ Where the specimen count 1, its associated assemblage zone is listed (e.g. *Cistecephalus*).
  - ❖ Where there are multiple specimen counts from a single assemblage zone, the relevant assemblage zone is listed, followed by '=', with the numerical count (e.g. *Cistecephalus* = 5)
  - ❖ Where there are multiple specimen counts from two assemblage zones, the initial assemblage zone is subjected to the methodology above,

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followed by '+', with the subsequent assemblage zone. (e.g. *Cistecephalus* = 5 + *Dicynodon* = 3)

- Where there are multiple specimen counts from multiple assemblage zones, the zones are subjected to the methodology above, except for the abbreviation of names (e.g. Ciste=8 + Cynog=22 + Dicyn=1 + Lystro=4).
- Transition zones are subjected to the same standardisation procedures stated above. Transition zones are highlighted in Pink (e.g. *Cistecephalus/Dicynodon* or (Ciste=12 + Ciste/Dicyn=14 + Cynog=13 + Dicyn=4)
- Where assemblage zone information has not been included but locality information is provided, which may be used at a later date to verify suggested assemblage zone representation, a blue (upper case) '**V'** (denoting later verification) has been inserted. (e.g. V=1 or Ciste=4 + Tapino=31 + V=18)
- Where the assemblage zone information has not been included *and* no locality information is provided, a red (upper-case) '**X'** has been inserted. (e.g. X=1 or Ciste=8 + Priste=7 + Tropid=30 + V=20 + X =101).
- In certain instances, only geological formation listings were provided. For the purposes of this study these listings were deemed too vague (as they range over three or more assemblage zones). These formations are highlighted in blue (full or abbreviated) and are treated as 'V' variables.

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(e.g. V(Abrahamskraal)=1 or V(Adelaide=4) or V(Tarkastad)=5 or V:3+(Ab2)+(Ad.5)+(Tar.7)=14).

2.2.2.2.3 Original – to - Updated specimen count lists for contributing museum collections

The tables in this subsection specify the changes which transpired during the updating process in correcting genera, for each museum. In addition, they specify any alterations to the accompanying assemblage zone information.

A spreadsheet model comprised of seven data fields per museum displays, this update of information (Tables 2.15; 2.18; 2.21; 2.24; 2.27; 2.30 and 2.33). All original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes. Datafield contents include:

- Columns 1 – 3: Original specimen count columns (CD1: Folder 7. Example: Refer to Albany Museum: Specimen Count file: Column E: Specimen Count, to explain what is meant by 'original specimen count columns'). In addition the original assemblage zone data for each museum collection was utilised. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.

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- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.

- Columns 5 – 7: Upgraded version of Columns 1 – 3.

NOTES:

All changes to taxonomic assignation were initiated as a response to either:

(1) Incorrect/outdated taxonomic classification, or

(2) Broad/'umbrella group' taxonomic assignation. Such wide-scope classification were relegated to their relative indeterminate counts.

Thus, Specimen Counts were only shifted or altered, but not deleted. The original sum total Specimen Count = Updated sum total Specimen Count.

All incorrect and corrected variables in the main Genera & Numerical Count columns have been highlighted in **bold**.

All changes are either an addition or a subtraction, to or from one genus to another.

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2.2.2.2.3.1 Methodology for standardisation of spreadsheets

The procedure adopted in standardising Table 2.15; Table 2.18; Table 2.21; Table 2.24; Table 2.27; Table 2.30 and Table 2.33 was:

(1) Examine affected row/s to Columns 1 – 3 (Original Genera, Specimen Count and Assemblage Zones).

(2) Apply alterations in Column 4: Alterations Column.

(3) Display upgraded data in Columns 5 – 7 (Upgraded Genera, Specimen Count and assemblage zones).

2.2.2.2.3.2 Categories of changes enlisted

- **Transferral of specimens from one genus to another:**
  - Original specimens (moving *out*):
    - The genus, in Column 2 (Genera (original)), was highlighted in bold Lavender, with a strikethrough. This indicates that the genus will not appear in the final list. (e.g. ~~***Moschorhynchus***~~).
    - The accompanying count, in Column 3 (Specimen Count (original)), was highlighted in bold Lavender, but with no strikethrough. This is because, although the count does not appear directly opposite, it was added to the count of another genus and hence was not lost (e.g. ~~2~~).

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- The accompanying assemblage zones, in Column 1 (Assemblage Zones - given & deduced), is highlighted in Lavender, with a strikethrough. This is because the affected variable moved, along with its affected specimen, to the assemblage zone counts of the other involved genus. (e.g. ~~Cistecephalus=1 + X=1~~).

Columns 5 – 7 in affected rows are empty, as final changes have not been instituted at this point in the 'cleaning' procedure.

- Column 4: Updates & Alterations:

There are three categories of notes associated with genus alteration. Which category of alteration and therefore which 'cleaning' process was dependent on the status of the Genus being *added* to:

- Subtraction from original genus to a genus *not* included in the original list:
  - ✓ Subtraction: The *original* genus is in Lavender, followed by a *double-arrow* '>>', with the *updated* genus in Purple. (e.g. *Nythosaurus* >> *Thrinaxodon*).
  - ✓ Addition: The *accepted* ('new') specimen name is underlined, bold and in Purple, followed by 'from', with the *rejected* genus in Lavender. (e.g. ***Thrinaxodon*** from *Nythosaurus*).

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- Subtraction from original genus to a genus *included* in the original list:

  - ✓ Subtraction: The *original* genus is in Lavender, followed by a *single-arrow* '>' with a '+', followed by the moving specimen count (Green brackets), thereafter by a 'to:' and finally by the *updated* genus in Purple. (e.g. *Compsodon* > + (3) to: *Tropidostoma*).
  - ✓ Addition: The *existing* (and *accepted*) specimen name is in Black, with its *original* count in Green brackets with a '+'. This is followed by the *additional* (*to be rejected*) genus in Lavender, with its original count in Green brackets with a '='. Followed finally by the new count total in Green, bold and underlined. (e.g. *Tropidostoma*(1) + *Compsodon*(3) = **4**)

- Subtraction from original genus to a genus *not* included in the original list (More than one genus being subtracted from and added to the 'new' genus):

  - ✓ Subtraction: The *original* genus is in Lavender, followed by a *double-arrow* '>>' with a Purple '&' and Black '+'. This is followed by the moving count (in Green brackets) with a 'to:', followed finally by the *updated* and 'new' genus in Purple.

    (e.g. *Moschorhynchus* >> & + (2) to: *Theriognathus*).

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- ✓ Addition: The 'new' specimen's name is underlined, bold and in Purple, followed by 'from' with the additional (to be *rejected*) genera names in Lavender, with their counts in Green brackets and separated by '+' symbols. This is followed by '=' and finally by the count total in Purple, bold and underlined. (e.g. ***Theriognathus*** from *Moschorhynchus*(2) + *Notaelurops*(1) + *Notosollasia*(1) = **4**)

- Updated Specimens (moving *in*):

  - Column 5 (Genera (Updated)) and Column 6 (Specimen Count (Updated)):

    A specific Genus with its accompanying Specimen Count is processed in one of two ways:

    - ✓ Genus name is *not* in original list: The genus and its count are highlighted in bold Purple. This indicates that it is a 'new' addition to the list. (e.g. ***Theriognathus* |4**)
    - ✓ Genus name *is* included in original list: The genus is highlighted in bold Black in both the original and updated columns. Its count is in bold Red in the *original* Specimen Count column and in bold Green in the *updated* Specimen Count column. This process indicates a change occurring to the Specimen Count. (e.g. ***Tropidostoma* | 1 – *Tropidostoma* | 4**)

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- Column 7 (Assemblage Zones - updated):

  The contents of this column contain Assemblage Zone information, which accompanied the added counts. They are shown in the A-typical style – as seen in the Original specimen count lists.

Columns 1 – 3 in affected rows are empty, if the Genus has been *added* to the list, as final changes have not been instituted at this point in the 'cleaning' procedure.

❖ Fragmenting of specimens from one genus into two or more other genera:

There is only one instance of the above mentioned fragmentation, occurring in the Transvaal Museum. Table 2.17 shows such fragmentation. The example in Table 2.17: Example 1 (Fragmentation Methodology) is abridged. The complete process indicating movement into *Dicynodon* is illustrated later on.

This instance was subjected to the same process as those specimens that moved to an updated genus (i.e. Purple font denoting those specimens re-classified to currently accepted genera. e.g.: *Dicynodon sollasi* (to *Diictodon*). The variation in the process lay in the management of the 'Original Assemblage Zone' and 'Updates & Alterations' columns.

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- Original Assemblage Zone column (*Moving out – but fragmenting*):

  - Original information is displayed in red, underlined and placed in curly brackets. This is preceded by a red bullet. (e.g. • {V=1 + X=9})
  - Assemblage zone information accompanying the moving counts is highlighted in Lavender, with a strikethrough. This is because these variables will be moving, with the specimens, to the assemblage zone counts of other genera. This is preceded by a Black bullet. Separate moves are placed on separate lines (e.g. • ~~V=1 + X=8~~ • ~~X=1~~)

Columns 5 -7 in the affected row are empty as final changes have not been instituted at this point in the 'cleaning' procedure.

- Column 4: Updates & Alterations:

  The management of the affected notes in this column were subjected to the same process listed above, the only differences being the use of two or more bullets – depending on the extent of the fragmentation of the count.

  (e.g. *Daptocephalus* > + (9) to: *Dicynodon*

  Daptocephalus > + (1) to: Indet. DiCynodontia)

  Numbers (9) and (1) above, add up to the original *Daptocephalus* specimen count (9 + 1 = 10.)

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❖ Relocation of select specimens from one genus to another:

This occurs when a number of species retain their classification to a certain genus, but others require relocation to a different genus.

- Original specimens (*A number of specimens moving out*):
  - The genus name (Genera (original)) column was highlighted in bold Olive, with no strike-through (e.g. ***Aelurognathus***), as the particular genus in question remains in the final list. In the Updated Genera column, the affected genus was highlighted in bold Black. (e.g. ***Aelurognathus***).
  - The accompanying count (Specimen Count (original)) column was highlighted in bold Red. (e.g. **4**). The altered, remaining count (bold Green) appears in the Specimen Count (updated) column. Logically, the count will have decreased. (e.g. **2**).
- Original Assemblage Zone column (*A number of specimens moving out*):
  - The original affected information is preceded by a Red bullet then bracketed, underlined and highlighted in Red. (e.g. • {Cistecephalus=4}).
  - The affected assemblage zones which accompany the *moving* counts are preceded by a Black bullet, highlighted in Lavender, with a strikethrough. This is because they move, with the specimens, to the

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assemblage zone counts of the other genus. Separate moves are placed on separate lines.

(e.g. • ~~Cistecephalus=2~~)

- The remaining assemblage zone information (preceded by a Black bullet) is mirrored in the final Updated Assemblage Zone column.

(e.g. • Cistecephalus=2)

Columns 5 -7 in these affected rows are **not** empty as final changes have been instituted in the 'cleaning' process.

- Column 4: Updates & Alterations:

  - Partial-subtraction from original genus to a genus *not* included in the original list:
    - ✓ Subtraction: The original genus is in Black, with its count bracketed in Red, followed by '–' and the count being subtracted in bracketed Olive. Thereafter, '>>' and the 'new' updated genus in Purple. The final figure in bold, underlined Olive is '=' (to) the new genus count. (e.g. *Atherstonia*(11) – (2) >> *Amblypterus* = **9**).
    - ✓ Addition: Example: ***Amblypterus*** from *Atherstonia*.

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- Partial-subtraction from original genus to a genus included in the original list:
  - ✓ Subtraction: The original genus is in Black, with its count bracketed in Red, followed by '–' and the count being subtracted in bracketed Olive. Thereafter, a single-arrow '>'and a 'to:' followed by the updated genus in Purple. The final figure in bold, underlined Olive is '=' (to) the new Genus count. (e.g. *Aelurognathus*(4) – (2) > to: *Arctops* = **2**).
  - ✓ Addition: Example: *Arctops*(4) + *Aelurognathus*(2) = **6**.

- Partial-subtraction from original genus to a genus *not* included in the original list (where there is more than one genus being subtracted from to establish the 'new' genus):
  - ✓ Subtraction: The original genus is given in Black, with its count bracketed in Red, followed by '–' and the count being subtracted in Olive brackets. Thereafter, '>>', '&', and 'to:', followed by the updated genus in Purple. The final figure (bold, underlined Olive) is '=' (to) the 'new' genus count. (e.g. *Parotosuchus*(7) – (5) >> & to: *Xenotosuchus* = **2**).
  - ✓ Addition: Example: ***Xenotosuchus*** from *Capitosaurus*(1) + *Parotosuchus*(5) + *Rhytidosteus*(1) = **7**).

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- Updated Specimens (*moving in*):

The same processes listed in 'Updated Specimens (moving *in*) detailed in prior pages was adopted for this subsection.

❖ Complex movements of specimens, *in and out*, of various Genera:

Complex movements occur when a number of species of a particular genus, *remain* in that genus, while the remainder are *shifted* to another genus. In addition, this genus is *further added to* by specimens from other genera. Such instances are merely complex versions of the examples and processes described above. A single example from the Transvaal Museum is described below, to illustrate the complex movement process (Table 2.33).

- Original Specimens (*some moving out - & - some moving in*):

  - The genus (Genera (original) column) is highlighted in Light Blue (bold), with no strike-through, as it remains in the final list. (e.g. ***Dicynodon***).

    - ✓ The genus remains unchanged in the Updated Genera column.

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- The accompanying count (Specimen Count (original) column) is highlighted in bold Red. (e.g. **145**).
  - ✓ The *new* count (Specimen Count (Updated) column) is highlighted in bold Green. This count has either increased or decreased. (e.g. **43**)

- Original Assemblage Zone column (*only those moving out*):

Affected rows in this column were subjected to the same processes listed in 'Relocation of select specimens from one genus to another'. The difference in this instance is that the assemblage zone information in the Final Updated column will differ from the remaining assemblage zones, due to subsequent additions.

- Column 4: Updates & Alterations:

The contents of the affected rows in this column were subjected to the same processes illustrated in prior 'Column 4: Updates & Alterations' descriptions. Criteria controlling the nature of the various 'moves' are the same as previously explained and are therefore not expanded on again below.

- Partial-subtraction from original genus including additions to that genus (occurring in the same cell):
  - ✓ Original genus in Black (preceded by a Black bullet), with its count bracketed in Red. (e.g. *Dicynodon*(145)).

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- ✓ Subtraction: Lines were indented before bulleting, to indicate the trail of occurrences:
  - Original genus in Lavender (preceded by a Lavender bullet with a strike-through).
  - Followed by either (>>) / (>> & + (0) to:) / (> + (0) to:) – depending on the move type. Thereafter:
  - Updated genus in Purple.

  (e.g. · ~~*Dicynodon*~~ > + (105) to: *Diictodon*
  · ~~*Dicynodon*~~ > + (3) to: *Oudenodon*
  · ~~*Dicynodon*~~ >> & + (3) to: *Tropidostoma*).
- ✓ Addition: These lines were further indented before the bullets, to indicate the next step in the process:
  - Original genus in Black (preceded by a Purple bullet) is added to. (e.g. · *Dicynodon*(34) + *Daptocephalus*(9) = **43**).

2.2.2.2.4 Updated specimen count lists for contributing museum collections

The Updated specimen count lists (Tables 2.16; 2.19; 2.22; 2.25; 2.28; 2.31 and 2.34) are streamlined/'cleaned' versions of the last three updated columns in the third set of lists (Table 2.15; Table 2.18; Table 2.21; Table 2.24; Table 2.27;

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Table 2.30 and Table 2.33). An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Columns 1 – 3:

- Column 1: List of Updated Genera in alphabetical order.
- Column 2: Updated Specimen Count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3*:* Specimen count totals are subdivided into their associated Updated Assemblage Zones. (Note: Assemblage Zone Counts = Specimen Counts)

2.2.2.2.5 Beaufort Group Super-Collection

2.2.2.2.5.1 Table 3.39: Methodology

(1) The Updated lists of all seven contributing museums were imported into a single Excel® worksheet and stacked. The column (Grey) on the extreme left, acts as a guide to the specimen *contributions* of each museum (abbreviated).

(2) The list was ordered alphabetically: (i) according to genus, then
(ii) museum abbreviation.

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The Museum Abbreviation column is a useful tool to reference the data in each row to its *source*.

Note: (i) Blank rows were inserted between genera, to reduce visual confusion.

(ii) Other than the Museum Abbreviation column, the columns follow the same format as the Updated collection lists.

(iii) The lime coloured bar provides the specimen count total (20968).

2.2.2.2.5.2 Table 3.40: Methodology

The organogram is comprised of a system of 'count-cells' from the Museum Collection columns and Genus rows. A count-cell is defined as those cells containing *only* numerical values. These count-cells were included in a grid system. The final Beaufort Group specimen count list was created using rows of count-cells, from the seven museum collections, to obtain sums for each genus. This organogram is an effective visual tool because it depicts a simplified grid version of the sub-counts which comprise each of the final counts as well as the final totals.

The rows are governed by the Genera column on the right, which is the complete list of genera found in the Beaufort Group. For comparison and validation, the Specimen Counts column from Version 1 was added.

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- Columns 1 – 7: List of the contents of the seven contributing museums (alphabetical order).

- Column 8: Counts of each of the specimens in their respective rows. The count-cells were left empty (Grey) when the count for a certain Genus in a specific museum was (0).

- Column 9 (Green): Sum of the rows in the Column 1.

The final row of the organogram contains totals for each of the museums, including the final total.

2.2.2.2.5.3 Beaufort Group - Biodiversity lists: Methodology

2.2.2.2.5.3.1 Table 2.35: Beaufort Group: Specimen count and assemblage zone list

The amalgamated collections list was streamlined to form a final Beaufort Group specimen count list. The process involved removing duplicate genus names with their accompanying counts, merged to reach a final total for each genus. A similar process was then applied for assemblage zone information accompanying each count – reaching a final assemblage zone count list for genera.

The columns of the final streamlined list adhere to the same formatting template of the seven updated collection lists (Table 2.16; Table 2.19; Table 2.22; Table

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2.25; Table 2.28; Table 2.31 and Table 2.34). The row containing the specimen count total (Gold) signifies the completed product.

2.2.2.2.5.3.2 Beaufort Group: Assemblage zone grid (Table 4.12)

Table 4.12 contains specimen count information, assemblage zone listing, assemblage zone numerical grid and totals and was obtained by enhancing Table 2.35 to a systemised grid. This grid is a useful tool which makes it possible to quickly identify which specimens, of any particular genus, are found in which assemblage zone(s).

Blank rows were inserted between each of the genera and their respective counts (bold). Following the Assemblage Zone column, 19 'count-cell' columns were created. Each of these columns represents an assemblage, transition or unknown biozone. The data in these columns are a numerically sub-divided representation of the abbreviated text in the Assemblage Zone column. What this means is if the Assemblage Zone text column reads: Ciste=5 + Lystro=1 + V=13 + X=24, then the count, in the relative row, will be (5) in the '*Cistecephalus*' column, (1) in the '*Lystrosaurus*' column, (13) in the 'V' column and (24) in the 'X' column.

The choice of colour matches the scheme chosen for assemblage zones in Biostratigraphy of the Beaufort Group (Karoo Supergroup) (Rubidge *et al.,* 1995) - Figure 1. In addition 'V'=Blue; 'X'=Red with 'Transition Zones' in Pink. The columns include:

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- Columns 1 – 3:

  - "V" column: Counts with locality information *but no* assemblage zone information (i.e. these counts hold potentially verifiable assemblage zone information).

  - "X" column: Counts with *no* assemblage zone *or* locality information (i.e. associating assemblage zone information to these specimens seems unlikely at this point).

  - "V+X" column: A sum of the counts which have no assemblage zone information at this time and were of deemed non-viable for the purposes of the biodiversity study through time.

- Columns 4 - 20:

  - Columns 4-19: Tagged to eight assemblage zones with transition zones. Column 4 (*Eodicynodon* Assemblage Zone) → Column 19 (*Cynognathus* Assemblage Zone)

    - ✓ Note: The assemblage zone is abbreviated (Grey) in Blank cells.

  - Column 20: A sum of the counts which have assemblage zone information.

- Final row: Totals for each column, including a final total of viable assemblage zone Counts.

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2.2.2.2.5.3.3 Table 2.36: Beaufort Group – Indeterminate taxon assignment grid

Indeterminate (Indet.) taxon assignments in Table 4.12 were isolated into a sub-list (Table 2.36). This was done to separate their totals from the specimens of valid Genera. The format is identical to Table 4.12.

As mentioned earlier, the groundwork for creating referencing lists of Locality-to-AssemblageZone and GridMap-to-AssemblageZone have been created. This has led to the establishment of a partial Excel® template for standardisation procedure of raw-databases of museum collections. The standardisation and 'cleaning' of these raw-databases will create an efficient Primary System and will go a long way to ensure that the maximum potential of the data is realised. The Excel® lists, created for this study, comprise the Secondary System – onto which further updates may be added.

2.2.2.2.6 Beaufort Group Super-Collection: Graphs

2.2.2.2.6.1 Specimen count graphs for contributing museum collections: Figures 3.1 – 3.7

For each of the seven museum collections, custom histograms were created in Corel Draw®. The data required to create these graphs, was obtained from Excel®

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spreadsheets: Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31; and Table 2.34. In these graphs (Figures 3.1 – 3.7) the specimen counts of each updated genus are represented per museum. (Refer to Appendix A for further methodology applied for the creation of these graphs).

2.2.2.2.6.2 Diversity of genera and their relative abundances in the Beaufort Group: Figure 3.8

The data from the seven museum collection lists where combined into a final graph (Figure 3.8). Data from Excel® spreadsheet: Table 2.35 was used to create this graph, which visually represents the total specimen counts of every represented genus in the Beaufort Group. It was created in the same format as the specimen count graphs of the seven museum collections (Figures 3.1 – 3.7). Refer to Appendix A for further methodology applied for the creation of these graphs.

2.2.2.2.6.3 Figures 2.3 – 2.7: Analysis of Beaufort Group data

Five Excel Pie Charts (Figures 2.3 – 2.7) were created using data obtained from the totals and sub-totals found in Table 4.12 and Table 2.35. The choice of colour matches the scheme chosen to illustrate the Assemblage Zones in Biostratigraphy of the Beaufort Group (Karoo Supergroup) - Figure 1 (Rubidge *et al.,* 1995). In addition 'V'=Blue and 'X'=Red.

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2.2.2.2.6.4 Representation of genera within each assemblage zone of the Beaufort Group: Figure 4.3

A graph depicting the diversity and abundance of genera across time, through the relative representation of genera per biozone(s) within the Beaufort Group (Figure 4.3) was created using the specimen count and assemblage zone data extrapolated from Table 4.12. The choice of colour matches the scheme chosen to illustrate the eight Assemblage Zones in Biostratigraphy of the Beaufort Group (Karoo Supergroup) - Figure 1 (Rubidge *et al.*, 1995). In addition 'V'=Blue and 'X'=Red.

The count blocks, for each genus, were merged where necessary, enlarged (along the horizontal axis only) and then rounded off. The graph provides a visual representation of the existence and disappearance of genera during the Middle Permian to Middle Triassic of South Africa. (Refer to Appendix B for further methodology applied for the creation of this graph).

Collectively, all graphs created for this research project, form part of the Tertiary System and provide a visual synthesis of all fossil vertebrate data pertaining to the Beaufort Group. The Tertiary System is dependent on information generated by the aforementioned Secondary System.

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Chapter 3: Synthesis of Data

3.1 Synthesised data from museum collections

The synthesis of data involved the filtering and manipulation of raw data sources for the purpose of trend interpretation and faunal pattern analysis for the Beaufort Group of South Africa. A raw database is defined as the original database as received in varying formats from the contributing South African museum collections (Chapter 1).

The majority of the content of this chapter, that is all synthesised data manipulated from their respective original sources, is saved to compact disc because of the large volume of data (refer to CD1: Synthesis of Data to view the listed data tables). Synthesised data is subdivided into seven folders. In addition, the raw databases of the seven contributing museums are also available (CD1: Folder 3) for comparative purposes. (Refer to Table 3.1 for a directory of files saved to this folder). Below is a summary of the contents of CD1, which have been subdivided into eight folders:

Folder 1: Genera within Beaufort Group (Table 3.2: Directory of files on CD1, Folder 1). Generic representation in individual collections per biozone. Refer to Section 3.1.1.1 for an explanation of the contents of this folder.

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Folder 2: Species within Beaufort Group (Table 3.3: Directory of files on CD1, Folder 2). Species representation in individual collections per biozone. Refer to Section 3.1.1.2 for an explanation of the contents of this folder.

Folder 3: Raw Databases (Table 3.1: Directory of files on CD1, Folder 3.). Original databases as obtained from individual museum collections.

Folder 4: Initial Working Databases (Table 3.5: Directory of files per subfolder of Folder 4 (CD1). Refer to Section 3.1.1.3 for an explanation of the contents of this folder.

Folder 5: Manual Input Databases (Table 3.6 Directory of files on CD1, Folder 5). Refer to Section 3.1.1.4 for an explanation of the contents of this folder.

Folder 6: Automated Input Databases (Table 3.7: Directory of files on CD1, Folder 6). Refer to Section 3.1.1.5 for an explanation of the contents of this folder.

Folder 7: Specimen Count Databases (Table 3.11: Directory of files on CD1, Folder 7). Refer to Section 3.1.1.6 for an explanation of the contents of this folder.

Folder 8: Biodiversity databases (Table 3.12: Directory of files on CD1, Folder 8). Refer to Section 3.1.1.7 for an explanation of the contents of this folder.

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The subsections and referenced tables below serve as a guide, not only to the contents of CD1, but also to summarise the aim and intention of each category of synthesised information.

3.1.1 Folder content

The contents of Folders 1 – 8, represent the successive and advancing manipulation and analysis of the original data obtained from the seven contributing museums. The investigation of data from folders 1 through to 8 (apart from Folder 3: Raw Databases) was necessary to set the stage for the final fusion of data from all seven datasets onto a single dataset, referred to as the Beaufort Group Super-Collection. The Beaufort Group Super-Collection is the final product in the investigative, cleaning, filtering and manipulative processes (observed in varying degrees in Folders 1 through to 8). The Super-Collection database and its resultant research tools was utilised to address the aims of this project which are listed in Chapter 1.

3.1.1.1 Folder 1: Genera within Beaufort Group

The contents of this folder include a listing of those genera present in each of the seven contributing museum databases and are presented in Microsoft Excel® format. In addition a further subdivision of genera for certain museums has been created whereby a record of genera per biozone per museum is presented. This further

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subdivision was performed on the Bernard Price Institute Collection, South African Museum, Rubidge Collection and National Museum because the formatting of these raw datasets allowed for such a subdivision, as much assemblage zone information was included. The file: Genera List (All 7 Databases) is a compilation of the genera represented in all seven museum collections and provides a summary of the diversity of genera recorded for the Beaufort Group. This first phase of data exploration does not include the abundance of specimens recorded of each genus. The objective of this facet of data investigation was to provide a summary of vertebrate faunal records (to genus level) from the Beaufort Group to date. Refer to Table 3.2 for a directory of files saved to this folder.

3.1.1.2 Folder 2: Species within Beaufort Group

The contents of this folder include a listing of species present in each museum and are presented in Microsoft Excel format®. There is a further subdivision of species for certain museums whereby a listing of species per assemblage zone per museum was created. This further subdivision was performed on the Bernard Price Institute Collection, South African Museum, Rubidge Collection and National Museum because the formatting of these raw datasets allowed for such a subdivision as much assemblage zone information was included. The file, Species List (All 7 Databases), is an amalgamation of the species present in all seven museums. The species information was subjected to a taxonomic update and only after this was completed

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was the generic level used for further analysis (Refer to Species List (All 7 Databases) of this folder – see Table 3.3).

The decision was to make use of taxonomic information only to genus level because of the subjectivity and unreliability of taxonomic classification to species level. This entry level phase of data exploration does not include the abundance of specimens recorded for specific species. The objective of this facet of data investigation was to provide a summary of vertebrate faunal records (to species level) from the Beaufort Group to date, with the intention of using this data for the taxonomic updating of recorded specimens to genus level. Refer to Table 3.3 for a directory of files saved to this folder.

3.1.1.3 Folder 4: Initial working databases

This folder contains the first manipulation and filtering of data directly from the original source (Folders 1 and 2 are simple investigations into dataset content) and is written in Microsoft Excel® format. Folder 4 represents the primary manipulation of museum data, where raw data was segregated into groups and themes. This was necessary for standardisation purposes in preparation for GIS formatting and query procedure.

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The initial working databases are concerned with data content and aim to group relevant information thereby allowing for easier and more fluid access of information. Such theme clustering and grouping is apparent for example in the “Initial BPI” database where distinct files contain information on farm locality co-ordinates, species representation, taxon and farm locality information and taxon representation. This grouping is also present in the National Museum, Rubidge Collection and South African Museum databases. The original formatting of the Albany Museum, Council for Geoscience and the Transvaal Museum did not readily allow for such grouping.

The aim of ‘theming’ data was to create templates of specific information that can in time be easily altered, improved and added to. Refer to Table 3.4 for a directory of subfolders saved per museum collection and thereafter refer to Table 3.5 for a directory of files saved to the subfolders listed in Table 3.4.

3.1.1.4 Folder 5: Manual input databases

Data tables containing records which had failed or were unable to be to inserted automatically (i.e. those specimens from both the automated data tables and remaining raw data tables) were established for each museum. The manual data tables were firstly established from the GIS Attribute Tables by comparing the attribute table contents for each museum with the automated data tables (to view the Attribute Tables refer to Palaeo CD3). The differences between the GIS attribute tables and the

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automated data tables for each museum respectively, led to the creation of the manual data tables. In addition, a further comparison for each museum was run between these newly created manual databases against their respective raw databases. The difference between the manual data tables and the raw data tables was then added to the existing manual data tables. The contents of the manual data tables include the sum of specimens comprised of 'failure to automate' data from the Automated data tables with 'unautomatable' data from the Raw data tables. This sum can only approximate (depending on the quality of the original data) the total number of specimens collected per museum because:

Theoretical Specimen Total = Sum of all specimens from all museums regardless of quality of locality information or taxonomic listing.

Actual (Viable) Specimen Total = Sum of all specimens from all museums that qualified for use in GIS and biodiversity analysis (those that comply with accessible locality information and relevant taxonomic listing). From the above definitions it follows that:

Theoretical Specimen Total > Actual (Viable) Specimen Total and

Actual (Viable) Specimen Total = Automated Data Tables + Manual Entry Tables.

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The objective of this facet of data manipulation was to provide a review of faunal finds within the Beaufort Group that needed to be manually inserted into the established GIS. Refer to Table 3.6 for a directory of files saved to this folder.

3.1.1.5 Folder 6: Automated input databases

Folder 6 includes documentation of specifically selected records per museum that had the potential to be entered into the GIS automatically because of the accompanying resolution and accuracy of their described locality information or their possession of a co-ordinate pair signifying fossil locality. (Refer to Table 3.7 for a directory of files saved to this folder). The objective for establishing this set of data (the contents of Folder 6) was to provide the alphanumeric data needed to create a spatial database containing localities (per farm centroid) as well as a record of specimens that carried accurate geo-references (co-ordinates).

From the data contained in the various tables housed in Folder 6, a spatial database containing those specimens which could be located by centroid and co-ordinate pair was created. This was done by linking their locality names to registered farm names. Instead of locating each locality and linking the relevant specimens to the locality, each specimen, which could be located, was allocated a location (co-ordinate pair) by farm centroid (Netterberg *et al.,* 2004) (as discussed in Section 2.2.1.1.1 of Chapter 2). The success rate of automated data entry was discussed in Section 2.2.1.1.1 of

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Chapter 2. The overall success rate of using the filtered data in Folders 5 and 6, calculated entirely from the perspective of establishing a GIS for palaeontological specimens in the Beaufort Group, is summarised in Table 3.8. The success rate for automated data entry is calculated at 41% against the background of tetrapod fossils for the Beaufort Group (totalling 20 968 specimens). The manual entry success rate is calculated at 57% against the same total. The sum of the percentages of automatic and manual entry for the GIS is 98%. This means that less than 2% of the fossil vertebrate data that belongs to the Beaufort Group was not entered into the system.

The number of fossil vertebrate specimens which have been collected from the Beaufort Group, regardless of the resolution or quality of their accompanying locality information are summarised in Table 3.9. The concept of what 'belongs' and what 'does not belong' to the Beaufort Group was discussed in Chapter 2: Section 2.1.1. From these selected records (Table 3.9) further manipulation and analysis was performed in order to determine the biodiversity of the Beaufort Group.

3.1.1.6 Folder 7: Specimen count databases

The contents of Folder 7 are subdivided into three categories per museum (each category focuses on a specific aspect of biodiversity). In addition there are a further eighteen subdivisions of amalgamated data, headed under Beaufort Group data: Each

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of these eighteen categories focuses on a facet of biodiversity across the entire Beaufort Group.

Museum categories are:

(1) Specimen Count

(2) Summary Specimen Count

(3) Abundance Specimen Count

Beaufort Group categories are:

(1) Summary Specimen Count
(2) Abundance Specimen Count
(3) Taxon Assignment Subdivision
(4) Taxon Assignment Summary
(5) Gorgonopsian Representation
(6) Therocephalian Representation
(7) Biarmosuchian Representation
(8) Cynodont Representation
(9) Dicynodont Representation
(10) Amphibian Representation
(11) Archosauromorph Representation
(12) Dinocephalian Representation
(13) Diapsid Representation
(14) Fish Representation
(15) Parareptile Representation
(16) Pelycosaur Representation
(17) Unknown Taxon Representation
(18) Eosuchian Representation

Analyses of the results of the categories above are discussed in more detail in Chapter 4 and are graphically represented in Figure 4.1. Table 3.10 summarises the numbers of specimens recorded for each Taxon Assignment in the Beaufort Group. The Taxon Assignments for the Beaufort Group are listed from numbers 5 – 18 above. The

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greatest abundance of fossil finds occurs within Dicynodontia and the specimens in this Taxon Assignment comprise 76% of the total number of fossils found in the Beaufort Group. The second highest abundance falls within Parareptilia, which comprises 5% of the total number of fossils found.

The objectives for establishing the contents of Folder 7 were five-fold:

Objective 1: Provide a listing of specimen diversity per museum:

This inventory is coupled with taxonomic revision where necessary. The contents of this faunal register per museum, is found in all three of the above mentioned museum data categories.

Objective 2: Quantify faunal inventory:

Extrapolated from the faunal register compiled above, specimen numbers (classified to genus level), per genus per museum were calculated. These figures are instituted in all three categories of museum data. Category 2: Summary Specimen Count is a condensed version of category 1 (Specimen Count). The summary provides only the genus name with its coupled quantity. The 'undiluted' specimen count data, with its listing of each recorded organism was necessary as a precursor to the establishment of Folder 8 (the databases for the biodiversity analyses).

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Objective 3: Sort faunal inventory in decreasing order of abundance:

Extrapolated from the Summary Specimen Count spreadsheet, data was sorted in decreasing order of frequency. This means that the most abundantly found taxa are rated first, followed by genera present with ever increasing degrees of rarity.

Objective 4: Collate faunal inventories from each museum:

Faunal lists from each contributing museum were amalgamated onto a single spreadsheet labelled: *Beaufort Group – Summary Specimen Count (Folder 7). The contents of this file equate to the sum total of faunal diversity within the Beaufort Group of the Karoo Supergroup of South Africa. Coupled to this diversity inventory, are the physical numbers of recorded specimens per genus in the Beaufort Group. The contents of the Beaufort Group-Abundance Specimen Count file grade organisms in decreasing order of frequency.

Objective 5: Collate Beaufort Specimens to Taxon Assignment:

Extrapolated from the amalgamated Beaufort Group faunal diversity inventory (at*above), specimens were further partitioned into 13 subcategories, pertaining to therapsid alliance (i.e. Dinocephalia, Gorgonopsia, Therocephalia, Biarmosuchia, Cynodontia and Dicynodontia) and remaining Taxonomic Assignment (i.e. Fish, Parareptilia, Pelycosauria, Amphibia, Eosuchia and Archosauromorpha) (Table 3.10). To aid in the

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filtering for taxon assignment categorisation, the file: Beaufort Group-Taxon Assignment Subdivision was compiled. From this file, the above mentioned taxon assignment subcategories were filtered.

The contents of Folder 7 were created on Microsoft Excel®. All graphical presentations of data in this folder, portrayed as histograms are analysed in Chapter 4. Graphics were created on CorelDraw®. (Refer to Table 3.11 for a directory of files saved to this folder).

3.1.1.7 Folder 8: Biodiversity databases

The incentive for compiling the spreadsheets that are housed in the category of data labelled Biodiversity data was to create a dataset from which the biodiversity of the Beaufort Group could be analysed. The biodiversity analysis involved not only an assessment of the general diversity of organisms found within the Beaufort Group, but also their relative abundance as well as their presence or absence at different times during the time span covered by the rocks of the Beaufort Group. The presence or absence of specimens in one or more of the eight assemblage zones of the Beaufort Group, translates to their existence at varying time intervals. This is because the assemblage zones approximate time, with the oldest rocks found in the *Eodicynodon* Assemblage Zone and the youngest rocks of the Beaufort Group represented by the *Cynognathus* Assemblage Zone (as mentioned in Chapter 1). The spreadsheets in Folder 8 (refer to Table 3.12 for a directory of files saved to this folder) represent the

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first phase of data manipulation and synthesis, in order to achieve the final product (discussed in Chapter 2: Section 2.2.2.1.1). The objectives for compiling the spreadsheets in Folder 8 are two-fold:

Objective 1:

Demonstrate adopted standardisation procedure, paving the way for future collecting procedure and data capture.

Objective 2:

Provide an accurate account of the diversity of specimens from the Beaufort Group, from each contributing museum.

Chapter 2: Section: 2.2.2 describes all categories of synthesised data compiled for the Beaufort Group, apart from the contents of synthesised data in Folders 1 to 7. Appendix C provides a summary and directory of this synthesised data. Therefore Chapter 2: Section 2.2.2 and Chapter 3: Section 3.1 collectively describes all data synthesised for the Beaufort Group. These various categories of synthesised data, each tailored specifically to assist in analysis and interpretation, were utilised to address the specific aims of this research project.

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3.2 Synthesised data for GIS

The objectives of the foundation phase of the spatial mapping project are to:

(1) Incorporate onto a GIS all fossil finds from the Beaufort Group which have locality data.

(2) Execute preliminary data cleaning

The completion of the foundation phase has left aspects of the plotted data still in need of being suitably refined to a higher resolution and accuracy for locality. Certain records also need to be taxonomically verified. These aspects are beyond the scope of this study. The established GIS does not fully comply with the standards of bio-geospatial referencing methodology because of textual references for localities. The main objective of the final two phases (listed in Chapter 6) is to conform to these standards. Only by matching these standards, can the spatial database be 'user-friendly' and accurate. Appendix E shows the tiresome process that would be involved in selecting for the distribution of Dicynodontia using original museum collection datasets. The need to include all variations of 'Dicynodontia' is necessary to ensure a complete account of Dicynodontia distribution when data is not adequately cleaned. Cleaned data means zero variation of the key word during a search.

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The visual and methodological contents of the GIS study are saved to Palaeo CD's 1 - 4. Apart from the databases created in Microsoft Access® format, all remaining data was created on ArcGIS®.

3.2.1 Palaeo Compact Disc content

3.2.1.1 Palaeo CD1

All data saved to compact disc (CD1: Synthesis of Data, Palaeo CD1, Palaeo CD2, Palaeo CD3 and Palaeo CD4) are housed in Volume 3. Palaeo CD1 houses the following folders:

(1) Databases: Contains all the databases in Microsoft Access® format.

(2) Documents: Contains all project statistics.

(3) Expressions: Contains expressions for queries in ArcGIS® for the respective assemblage zones and mapsheet query.

(4) Shapes: Contains all the shape files for the project and a geodatabase.

3.2.1.2 Palaeo CD2

Palaeo CD2 contains the Folder: Alphnum. This folder contains alphanumberic data, ranging from the original data, to all stages of workings.

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3.2.1.3 Palaeo CD3

Palaeo CD 3 contains automated entries data. It represents the first stage of the GIS study, whereby specimens with co-ordinates and specimens with automatically locatable farm locality information from six of the seven contributing museums were plotted. The contents of Palaeo CD3 combine map layers and specimen location. The contents of Palaeo CD3 represent the wrapping up of the work in progress seen in Palaeo CD1 and Palaeo CD2. Palaeo CD3 houses the following folders:

(1) Alphanum*:* Contains all the alphanumeric data, ranging from the original data, to all stages of workings.

(2) Databases*:* Contains all the databases in Microsoft Access® format.

(3) Documents*:* Contains all project statistics.

(4) Expressions*:* Contains expressions for queries in ArcGIS® for the respective assemblage zones and the mapsheet query.

(5) Shapes*:* Contains all shape files for the project as well as a geodatabase.

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3.2.1.4 ArcGIS® Project Files for Palaeo CD 1 - 3

Directory: *D:\Palaeo_Project*

There are three project files for Palaeo CD 1 – 3:

(1) *AssemblageZones_A3.mxd:* A4 size template layout for each of the 8 Assemblage Zones of the Beaufort Group.

(2) *Overview_includ_coords_A0.mxd:* A0 size layout for all the specimens located either by farm centroid and co-ordinate pair.

(3) *Study Area_Overview_A0.mxd*: A0 size layout showing an overview of the study area.

Each project file was established to fulfil a different objective over the course of the GIS-initiative. Once all records have a corresponding grid reference (Phase 1 of the GIS-initiative) they will be assigned to their corresponding biozone (Phase 2 of the GIS-initiative). Project File 1 is a pre-prepared template that will allow for the automatic insertion of fossil records with their corresponding assemblage zone data to the appropriate assemblage zone template. Once all records from the Beaufort Group from all contributing South African museum collections have been correctly assigned to biozones, the boundaries of each biozone can be refined based on the geo-spatial distribution of diagnostic genera.

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Project File 2 was created to house all farm centroid and original grid-referenced data. This file can be viewed as an experimental file establishing optimum ways to automatically insert data.

Project File 3 was created to serve as a springboard on which all future work (Phase 1 and onwards) be carried out on. It is an overview of the entire project and includes not only centroid and grid-referenced records, but all records that were manually inserted onto the system. The content of Palaeo CD4, which is the culmination of the pilot phase of the GIS-initiative is an expansion of this project file.

3.2.1.5 Databases for Palaeo CD 1 - 3

Three databases have been created for Palaeo CD1 – 3:

(1) *Centroids_v2.mdb:* Contains all the centroids used in the project. Tables of centroids per province, tables of centroids per collection including all instances of specimens, tables of centroids per collection, with only one point per farm (ie distinct centroids by location).

(2) *Collections.mdb:* This database contains tables per collection with all the specimens both excluding the co-ordinates of the respective centroids as well as tables including the centroid co-ordinates; a table of all the centroids; and a table with all the specimens from all the collections. Table 3.13 is a summary of which databases comprise the *Collections.mdb.*

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(3) *GEO SURV. RAW DATA.mdb:* contains the raw data from the geological survey.

Each of the three databases listed above house different aspects of data. Database 1 contains only data pertaining to the farm centroid aspect of the pilot phase of the GIS-initiative. Farm centroids were used to spatially map fossil records that lacked a grid-reference, but had a textual referral to a farm locality.

Certain museum records collected in the last decade were coupled with a grid-reference. Database 2 was established to house both farm centroid and grid-referenced data from five museum collections (Table 3.13). Transvaal Museum records are not included as all records from this collection were manually inserted onto the spatial map. In addition, the records from the Council for Geoscience are not included because a separate database was created for these records.

A separate database was created for the Council for Geoscience because it was the only database (of the seven contributing museum collections) whose records were entirely grid-referenced. It was used as an experimental database to assess the speed and accuracy of purely grid-referenced data. The complete database was spatially mapped within 30 minutes. Such speed attests to the advantages of such a system and justifies why all fossil records from the Beaufort Group will be grid-referenced by the completion of the GIS-initiative.

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Table 3.14 provides a summary of the total number of shape files created for Palaeo CD1 – 3. The creation of these shape files was necessary to establish a spatial setting in which fossil specimens could be plotted within the confines of the area comprising the Beaufort Group of South Africa.

3.2.1.6 Palaeo CD4

The *Palaeo_Specimens.shp* dataset contains approximately 27 000 points and indicates where palaeontological specimens of the Beaufort Group have been found. This dataset is the final collation of all specimens found to date in the Beaufort Group of South Africa and which are housed in South African museum collections. It is the result of the fusion of seven contributing South African museums and represents the final synthesis of both automated and manually inserted data. Refer to Table 3.15 for a summary of which files, extrapolated from Palaeo CD3, were appended to bring about this final synthesis. It is with this dataset, after refinement, that future researchers can perform queries on distribution and analyse trends and patterns. Palaeo CD4 contains the final amalgamated product and represents the foundation phase of the long term project involving the digitised Mapping of Palaeontological Specimens of Karoo Fossils of South Africa.

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3.3 Contributing museums – A comparative analysis

The faunal content (specimen representation and numbers) of the contributing museum collections are examined in this section. This analysis not only links to the investigation in Chapter 4 on the biodiversity of the Beaufort Group, but is also necessary to highlight the relative strengths and limitations (from a biodiversity perspective), of each collection. These results may serve as a guide for each museum, channelling future actions and focuses.

If the faunal content of a particular museum is considered limited, this is largely due to the incidence of one (or both) of the following tendencies:

- That a collection houses an abundance of recorded specimens, but a narrow range of taxonomic diversity, and/or
- that a large percentage of those recorded specimens are unidentified.

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By comparison, the consideration that the faunal content of a particular museum has strengths is due to the incidence of one (or all) of the following tendencies:

- That a collection houses an abundance of recorded specimens, classified to a wide range of specimen diversity, and/or
- that only a small percentage of recorded specimens are unidentified, and/or
- that various datafield columns are sufficiently recorded, encompassing a large quantity of assemblage zone and/or locality information, or that the collection as a whole is recorded to a small margin of error with regard to spelling consistency and data entry standards, etc.

The descriptions above of the features which define the strength or limitation of any museum collection is a theoretical definition. It must be noted that the reality of the situation is that the content of the collections of museums is dependent on:

- Geographic position of the museum
- The research focus of the palaeontologists employed by the museum
- Diligence of the palaeontologists to pursue fieldwork

Because of these variables (mainly geographic position), the content of the collections will vary. The results of the analysis on the characteristics of each

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museum were extrapolated from Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31; and Table 2.34 and presented graphically (Figures 3.1 – 3.7).

3.3.1 Specimen totals in each collection

The total number of specimens within each of the collections is recorded in Table 3.16. This total includes both indeterminate specimens (Table 2.36) as well as specimens identified to genus level. Any record that had no taxonomic classification (e.g. 'Unknown' or 'Unidentified' or 'Indet.') or whose taxonomic classification was too broadly based (e.g. 'Parareptile' or 'Synapsid') was relegated to the category "Indeterminate Specimens".

Table 3.16 comprises three categories of values:

(1) Total number of recorded specimens.

(2) Number of specimens identified to genus level.

(3) Abundance of unidentified (referred to as 'indeterminate') specimens per museum collection.

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Drawing on the results of Table 3.16, contributing museums were graded in order of decreasing strength (Table 3.17), based on the dominance of:

(1) The higher the number of recorded specimens, the greater the relative strength of the museum for biodiversity studies, in comparison to a smaller collection with limited fossils.

(2) The higher the number of specimens identified to genus level, the greater the relative strength of the museum for biodiversity studies, in comparison with a collection with a large number of unidentified records. It is only with identified records that biodiversity trends and ecological representation can be interpreted.

(3) The lower the number of specimens not provided with a taxonomic classification, the greater the relative strength of the museum collection for biodiversity studies.

The South African Museum (5424) has the highest total of recorded Beaufort Group specimens; followed by the Council for Geoscience (5322); the Bernard Price Institute (4483); the National Museum (3171); the Transvaal Museum (1250); the Rubidge Collection (850) and finally the Albany Museum (468). (Tables 3.16 & 3.17)

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Of the recorded total of fossils from the Beaufort Group (20968) only 14823 have been identified to genus level (Table 3.16), a total of 70.69%. This portion of the overall data was viable for potential use in biodiversity studies. Each collection then has what is termed a 'true' specimen count which excludes unidentified records. The Council for Geoscience (5264) has the highest number of specimens classified to genus level (Table 3.16), followed by the South African Museum (3795); the National Museum (2184); the Bernard Price Institute (2013); the Transvaal Museum (802); the Albany Museum (424) and lastly, with the least amount of specimens classified to genus level, the Rubidge Collection (341) (Table 3.17).

The total amount of recorded specimens for the Beaufort Group of 20968 was determined regardless of the quality of accompanying information. 6145 of these records are unidentified (Table 2.36), a total of 29.30% (Table 3.16). The unidentified fossils within the collections can be viewed as a weakness, although the data has been made use of in broader studies (such as this comparative study), but is an obvious disadvantage in more refined biodiversity studies. The Albany Museum (44) has the smallest number of indeterminate specimens. For this reason, the Albany Museum had the greatest strength as concerns the overview of recorded specimens to genus level, followed by the Council for Geoscience (58); the Transvaal Museum (448); the Rubidge Collection (509); the National Museum (987); the South African Museum (1629) and the Bernard Price Institute (2470) with the greatest recording of indeterminate specimens (Tables 3.16, 3.17).

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3.3.2 Diversity of genera in each collection

3.3.2.1 Literature review

Currently recognised biodiversity for the Beaufort Group includes 158 genera – but much taxonomic revision remains to be undertaken in the curation of collections (Anderson, 1999). The trend over the past 30 years has been to lump taxa resulting in the synonymy of many previously described genera (e.g., dinocephalians – Boonstra, 1969, King, 1988; dicynodonts – Cluver & Hotton, 1981; Cluver & King, 1983; King & Rubidge, 1993; cynodonts – Hopson & Kitching, 1972; Gorgonopsians – Sigogneau, 1989; parareptiles – Gow, 1999, Modesto, 2000 and diapsids – Gow, 1975, Welman, 1993). 115 of the 158 genera (73%) only occur in a single biozone (Anderson, 1999). The stratigraphic ranges of three genera (*Rhinesuchus*, *Pristerodon* and *Diictodon*) span five biozones while a further three genera (*Emydops*, *Gorgonops* and *Ictidosuchoides*) span a total of four biozones (Anderson, 1999).

3.3.2.2 Current study

The biodiversity analysis for this thesis was dependent on the number of genera identified within each collection (Table 2.16; Table 2.19; Table 2.22; Table 2.25; Table 2.28; Table 2.31 and Table 2.34), followed by the total diversity of genera in the Beaufort Group (Figure 3.8 & Tables 3.39 & 3.40). Subsequent to revision of

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taxonomic data from the original datasets (Table 3.18), the South African Museum has the greatest diversity of genera (163), followed by the Bernard Price Institute (124), the National Museum (88), the Rubidge Collection (85), the Transvaal Museum (73), the Council for Geoscience (63) and the Albany Museum (56).

The total number of genera per museum was further subdivided into those genera that are *unique* to a specific collection (Table 3.19 & 3.20). By comparison with Table 2.35, the remaining genera *common* to all museums was extrapolated. The sum of unique genera and common genera (minus unidentified taxa) gives a total diversity of genera within the Beaufort Group. This result is outlined in the Table 3.20. The biodiversity of the Beaufort Group is graphically presented in Figure 3.8 (Refer to Appendix F, for a record of errors in this dataset).

This study reveals a biodiversity for the Beaufort Group to include 271 genera (Figure 3.8). The diversity calculated for this study is increased by 112 genera, when compared to the diversity of 158 genera calculated for the Beaufort Group in Anderson (1999). The 147 genera unique to specific collections (Table 3.20) may be found to be synonymous with genera common to the seven contributing museums after further investigation (Phases 1 and 2 of the GIS–initiative: Chapter 6). If this is found to be the case, the diversity of genera calculated for this study will decrease. 146 of 271 genera (54%) are confined to a single biozone. 33 genera span two biozones (12%). 20 genera span three biozones (7%). Four genera (*Aulacephalodon*,

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Cynosaurus, Cyonosaurus and *Ictidosuchops*) span four biozones. Eight genera (*Dicyndon, Emydops, Ictidosuchoides, Lystrosaurus, Moschorhinus, Pareiasaurus, Pristerodon* and *Rhachiocephalus)* span 5 biozones. *Rhinesuchus* spans 6 biozones, including 2 Indeterminate Taxon groups (Indet. Cynodontia and Indet. Parareptilia). Those genera (including indeterminate groups) that span seven or more biozones include: Indet. Amphibia, Indet. Fish, Indet. Gorgonopsia, Indet. Therocephalia, Indet. Dicynodontia, *Dicynodon, Diictodon* and *Oudenodon.*

The grouping of genera to previously established biozones (e.g. Kitching, 1977; Keyser & Smith, 1978; Rubidge, 1995) also includes the grouping to transitional zones. The concept of a 'Transition Zone' had to be incorporated into this dissertation, as records from some collections documented fossil finds 'in-between' assemblage zones (e.g. *Dicynodon/Lystrosaurus* Assemblage Zone). Such records were subsequently categorised to a transition zone for this study.

Of the 146 genera relegated to a single biozone, four of these had a transitional zone applicable to their stratigraphic distribution. Of the 33 genera relegated to two biozones, three of these had a transitional zone applicable to their stratigraphic distribution. Of the 20 genera relegated to three biozones, nine of these had a transitional zone applicable to their stratigraphic distribution. Of the four genera relegated to four biozones, three of these had a transitional zone applicable to their stratigraphic distribution. Of the eight genera relegated to five biozones, seven of

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these had a transitional zone(s) relevant to their stratigraphic distribution. The inclusion of one or more transitional zones also applies to those genera or indeterminate groups that are relegated to seven or more biozones. Refer to Table 4.2 to view the subdivision of genera and indeterminate groups to specific assemblage and transition zones.

3.4 Commentary on each collection (for comparative purposes)

In this section, the faunal content of each collection is examined separately. The examination of the faunal content of each museum acted as a precursor to both the examination of the biodiversity of the Beaufort Group as a whole, but more importantly as a guide for highlighting potential aspects of individual museum collections that may need to be improved upon – especially when viewed in the light of digital requirements for virtual museums and spatially mapped data. Refer to Figures 3.1 – 3.7 for a graphical depiction of the faunal content of each contributing museum collection. Each collection is successively evaluated under the following five categories:

1) Reclassification/Updated Classification: The outdated classifications of genera and species are discussed together with a breakdown analysis of indeterminate specimens. The method and application of reclassification was performed in order to update and standardise museum data to current

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classification. (Table 2.15; Table 2.18; Table 2.21; Table 2.24; Table 2.27; Table 2.30 and Table 2.33).

2) Specimen Representation: Number of specimens (updated) of a particular genus are analysed first, followed by a count of those genera which are unique to a collection (Table 3.20). Thereafter, an account of the most abundant genera and Indeterminate Specimens of a specific museum are listed.
3) Taxon Assignment: The prevalence of various taxonomic groups are analysed for each museum. Numbers of updated specimens within their respective taxon assignments is discussed.
4) Assemblage Zone Information: The quantity and quality of assemblage zone information provided from the Raw Datasets is analysed.
5) Locality information: General notes on quantity and quality are discussed per individual museum collection.

3.4.1 Albany Museum

1) Reclassification/Updated Classification: Relative to the other museum databases few classification updates were required (Refer to CD1:A1; Table 2.14; Table 2.15 and Table 2.16, for an overview of successive alterations made to the original Albany Museum database).

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2) Specimen Representation (Figure 3.1):

- Out of 468 specimens recorded for this museum collection, variously belonging to 56 genera (Table 3.18), 24 of these genera have only a single specimen representative.
- The Albany Museum has 11 genera not listed in the other seven collections. Specimens recorded to these unique genera amount to 23.
- This collection has the highest number of *Atherstonia(9)* and *Noteosuchus(3)* specimens.
- The most abundant genera in the collection are: *Procolophon* (130), *Dicynodon* (61), *Oudenodon* (61) and *Lystrosaurus* (34).
- There are 44 Indeterminate Specimens from the Albany Museum. These are predominantly dicynodonts (26) and fish (13).

3) Taxon Assignment: Recorded specimens of the Albany Museum have representation for 10 of the 13 taxon groups found in the Beaufort Group (Table 3.21).

4) Assemblage Zone information: The original Albany Museum database does not record a column for assemblage zone data. There was, however, much assemblage zone information scattered throughout the “Locality” and “Notes” columns. This information was pooled together to form an Assemblage Zone

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column. Assemblage zone information was deduced for 12.6% of the specimens (Table 3.22). The lack of resolution in the remaining locality information make the possibility for later verification to Assemblage Zone challenging for 80% of the specimens and a huge obstacle for 7.26% of the specimens. These challenges may be overcome by investigative expeditions to said localities (refer to Chapter 6). The *Eodicynodon, Pristerognathus* and *Dicynodon* Assemblage Zones are not represented in this collection, with the representation of a single Transition Zone (Table 3.23).

5) Locality information: The quality of locality information in the Raw-database is poor (this criticism is purely from a GIS requirement perspective). There are two locality information columns and the system within is in disarray. Most of the information is general – there are no map-sheet indices or co-ordinates. There are however copious notes which are useful.

3.4.2 Bernard Price Institute

1) Reclassification/Updated Classification: This collection required the highest number of classification updates of all the South African collection databases (CD1:B1; Table 2.17; Table 2.18 and Table 2.19 show the successive alterations made to the original database). A reason for this is the age and size of the collection.

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2) Specimen Representation (Figure 3.2):

- Out of 4483 specimens recorded for this museum collection, belonging to 124 genera (Table 3.18), 30 of these genera are represented by only one specimen.
- The Bernard Price Institute has 19 genera not listed in the other seven collections. Specimens recorded to these unique genera amount to 26.
- This collection has the highest numbers of the following 45 genera (or taxon assignment), most notably: Indet. Dicynodontia (1791), Indet. Amphibia (218), *Cistecephalus* (156), *Procolophon* (148), Indet. Cynodontia (82), *Diademodon* (72), *Thrinaxodon* (52), *Lydekkerina* (43), *Trirachodon* (30), *Theriognathus* (24), *Xenotosuchus* (21) and *Kestrosaurus* (20).
- The most abundant specimens in the collection are: *Lystrosaurus* (552), *Cistecephalus* (156), *Procolophon* (148), *Oudenodon* (140), *Diictodon* (96), *Diademodon* (72), *Dicynodon* (64), *Thrinaxodon* (52), *Lydekkerina* (43), *Kannemeyeria* (41), *Aulacephalodon* (37), *Cynognathus* (36), *Trirachodon* (30), *Pareiasaurus* (27), *Pristerodon* (27), *Emydops* (25), *Theriognathus* (24), *Xenotosuchus* (21) and *Kestrosaurus* (20).
- There are 2470 Indeterminate Specimens in the Bernard Price Institute collection. They are: dicynodonts (1791), Amphibians (218), gorgonopsians (111), therocephalians (104), cynodonts (82), fish (64), dinocephalians (50) and parareptiles (31).

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3) Taxon Assignment: Recorded specimens of the Bernard Price Institute collection have representation in 12 of the 13 taxon groups found in the Beaufort Group (Table 3.24), but this is only because the taxon Diapsida has been subdivided to accommodate five errant records from the National Museum (Table 3.39).

4) Assemblage Zone information: The assemblage zone information for the Bernard Price Institute is of high quality. For this reason it will be used in the advanced GIS project, as the template for further assemblage zone allocation standards. All 4483 specimens were provided with Assemblage Zone information, i.e.: there are no 'V' or 'X' Zones. All assemblage zones are represented, including two transition zones (Table 3.25).

5) Locality information: The provided locality information for the BPI was not made use of in the Biodiversity Study across Assemblage Zones (Chapter 4) as the provided assemblage zone information was adequate. The locality information in the original database is well documented and detailed with many map-sheet indices and to a lesser degree, co-ordinates (co-ordinates are recorded for fossils discovered in the last decade). The textual locality information will be used extensively in phases 1 and 2 of the advanced GIS – initiative (Chapter 6), where the intention is to provide all textual locality data with a GPS co-ordinate. The detailed locality descriptions from this collection will assist greatly in this endeavour.

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3.4.3 Council for Geoscience

1) Reclassification/Updated Classification: For standardisation purposes changes were made only to the system of indeterminate classification, (e.g.: Pisces to Indet. Fish). Refer to CD1:C1; Table 2.20; Table 2.21 and Table 2.22 for an overview of the few alterations made to the original database.

2) Specimen Representation (Figure 3.3):

- Out of 5322 specimens recorded for this collection, variously belonging to 63 genera (Table 3.18), 14 of these genera are represented by a single specimen.
- The Council for Geoscience has 5 genera unique to its collection (Table 3.20). The validity of these genera is questionable (Appendix F) and will be verified during phase 1 of the GIS-initiative. Specimens recorded to these unique genera amount to 56.
- This collection has the highest number of specimens (across all seven museums) of the following 10 genera: *Diictodon* (3482), *Dicynodon* (486), *Pristerodon* (167), *Tropidostoma* (103), *Gorgonops* (78), *Aulacephalodon* (48), *Pristerognathus* (48), *Rhachiocephalus* (43), *Endothiodon* (39) and *Ictidosuchoides* (20).
- The most abundant genera in the collection are: *Diictodon* (3482), *Dicynodon* (486), *Oudenodon* (245), *Lystrosaurus* (172), *Pristerodon* (167), *Tropidostoma* (103), *Gorgonops* (78), *Emydops* (63), *Cistecephalus* (49), *Aulacephalodon*

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(48), *Pristerognathus* (48), *Rhachiocephalus* (43), *Endothiodon* (39), *Dinocephalina* (33) (Appendix F) and *Ictidosuchoides* (20).

- There are 58 Indeterminate Specimens from the Council for Geoscience. They are mainly representatives of Gorgonopsia (29) and Amphibia (15).

3) Taxon Assignment: Recorded specimens from the Council for Geoscience have representation in 11 of the 13 taxon groups found in the Beaufort Group (Table 3.26).

4) Assemblage Zone and (5) Locality information: The database of the Council for Geoscience has no assemblage zone data. However, all 5322 specimens have excellent locality data with accompanying co-ordinate data. The locality data was therefore categorised as Potentially Viable Zones (V).

3.4.4 National Museum

1) Reclassification/Updated Classification: Numerous re-classifications were made to this collection. Refer to CD1:N1; Table 2.23; Table 2.24 and Table 2.25 for an overview of the successive alterations made to the original database.

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2) Specimen Representation (Figure 3.4):

- Out of 3171 specimens recorded for this collection, belonging to 88 genera (Table 3.18), 32 of these genera are represented by a single specimen.
- The National Museum has 12 genera unique (Table 3.20) to its collection. Specimens recorded to these unique genera amount to 16.
- This collection has the highest number of specimens (across all seven museums) of the following 6 genera: *Lystrosaurus* (1467), *Kannemeyeria* (108), *Eodicynodon* (47), *Daptocephalus* (12), *Galesaurus* (8) and *Whaitsia* (4).
- The most abundant genera in the collection are: *Lystrosaurus* (1467), *Kannemeyeria* (108), *Procolophon* (69), *Oudenodon* (66), *Eodicynodon* (47), *Cynognathus* (36), *Aulacephalodon* (31), *Cistecephalus* (30), *Lydekkerina* (29), *Semionotus* (29), *Trirachodon* (27), *Diictodon* (25), *Thrinaxodon* (24) and *Diademodon* (15).
- There are 987 Indeterminate Specimens from the National Museum. They are dicynodonts (748), amphibians (56), gorgonopsians (53), therocephalians (48), fish (27), dinocephalians (22) and cynodonts (21). The National Museum is the only collection with an Indet. Diapsida (5) assignment.

3) Taxon Assignment: Recorded specimens from the National Museum have representation in 12 of the 13 taxon groups found in the Beaufort Group (Table 3.27).

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4) Assemblage Zone information: Assemblage zone data for the National Museum is well documented (Table 3.28). Only 8.8% of specimens were not provided with accompanying assemblage zone information. The locality information is accurate, thereby allowing for the deduction of assemblage zone information established for another 5% of these specimens. All assemblage zones are represented, except for the *Tropidostoma* Assemblage Zone. Two transition zones have representation (Table 3.29).

5) Locality information: Locality information in the original database is well documented with many instances recorded to map-sheet indices and co-ordinates.

3.4.5 Rubidge Collection

1) Reclassification/Updated Classification: Relative to the other museums, there were many classification updates. Refer to spreadsheets: CD1:R1; Table 2.26; Table 2.27 and Table 2.28 for an overview of successive alterations made to the original database.

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2) Specimen Representation (Figure 3.5):

- Out of 850 specimens recorded for this collection, variously belonging to 85 genera (Table 3.18), 38 of these genera have only one specimen as representative.
- The Rubidge Collection has 27 genera unique to its collection (Table 3.20). Specimens recorded to these unique genera amount to 33.
- This collection has the highest number of the following 7 genera: *Platycyclops* (7), *Pelanomodon* (6), *Dinanomodon* (5), *Nanictosaurus* (3), *Cyniscops* (2), *Millerosaurus* (2) and *Nanoparia* (2).
- The most abundant genera in the collection are: *Cistecephalus* (42), *Lystrosaurus* (36), *Diictodon* (23) and *Dicynodon* (18).
- There are 509 Indeterminate Specimens from the Rubidge Collection. They are mostly dicynodonts (455) and gorgonopsians (29).

3) Taxon Assignment: Recorded specimens from the Rubidge Collection have representation in 9 of the 13 taxon groups found in the Beaufort Group (Table 3.30).

4) Assemblage Zone information: Assemblage zone data for the Rubidge Collection is very well documented (Table 3.31). Only 1% of the specimens were not provided with accompanying assemblage zone information. For this reason, this

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collection together with the BPI will be used in the advanced GIS project, as the template for further assemblage zone allocation standards. The *Eodicynodon* and *Pristerognathus* Assemblage Zones are not represented in this collection. A single transition zone has representation (Table 3.32).

5) Locality information: The locality information for the Rubidge Collection was not made use of in the Biodiversity Study across Assemblage Zones (Chapter 4) as the provided assemblage zone information was adequate. The additional locality information in the original database is not accompanied with map-sheet indices or co-ordinates. Most of the information is general and will be used for advanced investigative purposes (Phases 1 and 2 of the GIS – initiative).

3.4.6 South African Museum

1) Reclassification/Updated Classification: The collection was subjected to many classification updates. The reason for this would be the age and size of the collection. Refer to CD1:S1; Table 2.29; Table 2.30 and Table 2.31 for an overview of successive alterations made to the original database. This database has a vast array of detailed taxonomic data, identified (in most instances) to every taxonomic rank.

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2) Specimen Representation (Figure 3.6):

- Out of 5424 specimens recorded for this collection, variously belonging to 163 genera (Table 3.18), 55 of these genera have only one specimen as representative.
- The South African Museum has 58 genera not listed in the other seven collections (Table 3.20). Specimens recorded to these unique genera amount to 117.
- This collection has the highest number of the following 18 genera or Taxon Assignments: *Oudenodon* (253), Indet. Therocephalia (204), Indet. Gorgonopsia (119), *Emydops* (84), Indet. Parareptilia (84), Indet. Fish (74), *Bradysaurus* (64), *Titanosuchus* (55), *Tapinocephalus* (50), *Jonkeria* (43), *Anteosaurus* (37), *Euparkeria* (37), *Robertia* (35), *Struthiocephalus* (31), *Kingoria* (24), *Trirachodon* (24), *Kannemeyeria* (22) and *Cynognathus* (21).
- The most abundant genera in the collection are: *Diictodon* (1427), *Lystrosaurus* (416), *Oudenodon* (253), *Pristerodon* (153), *Dicynodon* (150), *Emydops* (84), *Procolophon* (76), *Cistecephalus* (66), *Pareiasaurus* (66), *Bradysaurus* (64), *Titanosuchus* (55), *Tapinocephalus* (50), *Jonkeria* (43), *Pristerognathus* (43), *Aulacephalodon* (40), *Anteosaurus* (37), *Euparkeria* (37), *Robertia* (35), *Struthiocephalus* (31), *Thrinaxodon* (30), *Diademodon* (29), *Moschops* (26), *Tropidostoma* (26), *Endothiodon* (24), *Kingoria* (24), *Trirachodon* (24), *Kannemeyeria* (22) and *Cynognathus* (21).

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- There are 1629 Indeterminate Specimens from the South African Museum. They are mostly dicynodonts (957), therocephalians (204), gorgonopsians (119), dinocephalians (94), parareptiles (84), fish (74), cynodonts (48) and amphibians (44).

3) Taxon Assignment: Recorded specimens from the South African Museum have representation in 12 of the 13 taxon groups found in the Beaufort Group (Table 3.33), but this is only because the taxon Diapsida has been subdivided to accommodate five errant records from the National Museum (Table 3.39).

4) Assemblage Zone information: The assemblage zone data for the South African Museum is poorly documented. Only 11.74% of specimens were provided with accompanying assemblage zone information (Table 3.34). Locality information is very well documented, to a high degree of resolution, allowing for the possibility of establishing assemblage zone information for another 84.27% of specimens. Due to vague Locality information in a few instances, the possibility for later verification to assemblage zones for 3.98% of specimens is not possible. All assemblage zones are represented, except for the *Eodicynodon* Assemblage Zone. A single transition zone has representation (Table 3.35).

5) Locality information: Locality information is very well documented (as mentioned above) and is comparable to the locality information quality and standards of the Council for Geoscience. The majority of specimens are recorded

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with accompanying map-sheet indices and co-ordinates (Chapter 6: Section 6.6.4).

3.4.7 Transvaal Museum

1) Reclassification/Updated Classification: Relative to the other museums, there were many classification updates. Refer to CD1:T1; Table 2.32; Table 2.33 and Table 2.34 for an overview of successive alterations made to the original database.

2) Specimen Representation (Figure 3.7):

- Out of 1250 specimens recorded for this collection, variously belonging to 73 genera (Table 3.18), 37 of these genera have a single specimen as representative.
- The Transvaal Museum has 15 genera not listed in the other seven collections (Table 3.20). Specimens recorded to these unique genera amount to 16.
- This collection has the highest number of the following 5 genera or Taxon Assignments: Indet. Dinocephalia (171), *Pareiasaurus* (83), *Palemydops* (3), *Uranocentrodon* (7), and *Scylacognathus* (3).
- The most abundant genera in the collection are: *Lystrosaurus* (371), *Diictodon* (108), *Pareiasaurus* (83), *Dicynodon* (43), *Oudenodon* (29), *Lydekkerina* (28), *Thrinaxodon* (20) and *Aulacephalodon* (15).

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- There are 448 Indeterminate Specimens from the Transvaal Museum. They are mostly dinocephalians (171), dicynodonts (148), amphibians (80) and gorgonopsians (31).

3) Taxon Assignment: Recorded specimens from the Transvaal Museum have representation in 11 of the 13 taxon groups found in the Beaufort Group (Table 3.36).

4) Assemblage Zone information: Assemblage zone data for the Transvaal Museum is poorly documented. Assignment to specific assemblage zones was able to be deduced from accompanying notes in a few instances. Only 18.32% of specimens were provided with accompanying assemblage zone information (Table 3.37). Vagueness in Locality information makes the possibility for later verification unfeasible for over 50% of specimens. All assemblage zones are represented, except for the *Eodicynodon* Assemblage Zone. Four transition zones have representation (Table 3.38).

5) Locality information: Locality information in the original database is poorly documented. The majority of the information is general, not standardised, with a low resolution level (there are datafields listed for Province/State, with an additional field for locality notes). In addition, there are no map-sheet indices or co-ordinates.

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Chapter 4: Discussion

4.1 Introduction

More than a billion biological specimens are preserved in museum collections around the world and are the foundation of our knowledge about past and present biological biodiversity. Researchers in biodiversity informatics are engaged in providing digital access to biodiversity data associated with specimens to create new research opportunities for ecological analysis, predictive modelling and synthesis (Beaman *et al.*, 2004). The trend in utilising digitised data was adopted for this thesis and applied to address issues relating to biodiversity of Permian and Triassic tetrapod faunas by using data related to fossils collected from rocks of the Beaufort Group.

In Chapter 3 the datasets from each of the museum collections were presented and analysed, and finally amalgamated to produce a complete digitised dataset of all the fossils which have been collected from the Beaufort Group. This is the first time that such a dataset has been compiled for mid-Permian – mid-Triassic continental vertebrate faunas, and provides an opportunity to address the aims of the project as set out in Chapter 1.

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4.2 Fossil vertebrate taxonomic diversity from the rocks of the Beaufort Group

Fossils of a large variety of vertebrate taxa have been recovered from the Beaufort Group and are housed in South African museum collections (Figure 4.1). The ratio of taxon categories relative to the entire Beaufort Group and relative to each other is summarised in Table 4.1. CD1: Folder 7 (Files: Beaufort Group – Taxon Assignment Summary and Beaufort Group – Taxon Assignment Subdivision), show an account of the synthesised data involving assignment to taxa. Figures 4.2.a & 4.2.b expand on the representation of taxa within the Beaufort Group and show representation of these taxa within each assemblage zone of the Beaufort Group.

Although the presence of particular taxon groups within certain assemblage zones is well documented (e.g. Rubidge, 1995; Kitching, 1977; Keyser & Smith, 1979), this is the first time a study has been undertaken that includes an amalgamation of all genera (from every South African museum collection) from the Beaufort Group, coupled with their relative abundance per genus (Table 4.2; Figures 4.2.a & 4.2.b). Figures 4.2.a & 4.2.b display the relative abundance of particular taxa per assemblage zone as well as showing their differing degrees of frequency across successive biozones and hence the stratigraphic longevity of each taxon group across the Beaufort Group. Relative abundance in this instance is defined as the total number of fossils collected in South Africa for a specific genus. In broad terms, fish are found in all the

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assemblage zones of the Beaufort Group, including the *Dicynodon/Lystrosaurus* Transition Zone. Amphibia have been collected from all assemblage zones, except the *Pristerognathus* Assemblage Zone (Table 4.2; Figures 4.2.a & 4.2.b). Rare finds of pelycosaurs are limited to the *Tapinocephalus* Assemblage Zone. Archosauromorpha are present in the *Lystrosaurus* and *Cynognathus* Assemblage Zones and a single unidentified specimen (from the BPI) erroneously recorded from the *Cistecephalus* Assemblage Zone (Appendix F). More specifically, Eosuchians are recorded from the *Tropidostoma, Cistecephalus, Dicynodon, Lystrosaurus* and *Cynognathus* Assemblage Zones.

Representatives of Biarmosuchia have been collected from the *Tapinocephalus* and *Cistecephalus* Assemblage Zones (Table 4.2; Figures 4.2.a & 4.2.b) and more recently in the *Tropidostoma* Assemblage Zone as well (Sidor *et al.,* 2004; Smith *et al.*, 2006). Although the presence of biarmosuchians is recorded from the *Dicynodon* Assemblage Zone (Rubidge, 1995(b)), there was no record of Biarmosuchia with assemblage zone data documented in this study (Table 4.2).

Dinocephalia are limited to the *Eodicynodon* and *Tapinocephalus* Assemblage Zones.

Following the dataset the presence of Gorgonopsia is documented for the *Eodicynodon, Tapinocephalus, Tropidostoma, Cistecephalus, Dicynodon, Lystrosaurus* and *Cynognathus* Assemblage Zones. The erroneous presence of gorgonopsians in the *Lystrosaurus* and *Cynognathus* Assemblage Zones will be

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corrected in Phase 1 of the GIS–initiative (Appendix F). In addition, their presence is recorded for in the *Tropidostoma/Cistecephalus, Cistecephalus/Dicynodon* and *Dicynodon/Lystrosaurus* Transition Zones.

Therocephalia display a vast stratigraphic range with recordings for all assemblage zones as well as for four transition zones (Table 4.2; Figures 4.2.a & 4.2.b).

Dicynodontia are found in abundance in every assemblage zone of the Beaufort Group, including the *Tropidostoma/Cistecephalus, Cistecephalus/Dicynodon* and *Dicynodon/Lystrosaurus* Transition Zones. Cynodontia have been collected from all biozones from the *Tropidostoma* Assemblage Zone upwards (Table 4.2; Figures 4.2.a & 4.2.b).

Parareptilia are found in the *Tapinocephalus, Tropidostoma, Cistecephalus, Dicynodon, Lystrosaurus* and *Cynognathus* Assemblage Zones. They also appear in the *Cistecephalus/Dicynodon* and *Dicynodon/Lystrosaurus* Transition Zones (Table 4.2; Figures 4.2.a & 4.2.b).

4.3 Diversity of tetrapod taxa within different biozones

This study has highlighted changing generic representation in successive biozones of the Beaufort Group. The diversity of genera presented includes only those specimens

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with quantifiable assemblage zone data (Figure 4.3; Tables 4.2 & 4.12). The main intention for establishing a graphic depiction of diversity across the Beaufort Group (Figure 4.3) is to analyse biodiversity changes. From Figure 4.3 and Table 4.12, exact numbers of specimens belonging to specific genera which have been found in the Beaufort Group are presented for the first time.

A by-product of Figure 4.3 is that flaws or anomalous occurrences of taxa outside of their currently accepted biozones, in the original datasets have been highlighted. The advantage of this, is that focus can be directed on correcting and eliminating these faults with the goal of ultimately establishing Beaufort Group records that are seamless and in alignment with the requirements of stringent digital data (Phases 1 and 2: GIS - initiative) (Chapter 6).

The intention of this section is to compare tetrapod diversity within each assemblage zone, as established from the fusion of the contributing museum collections which have assemblage zone data, with documented diversity (from literature) within each assemblage zone. The format is the same for each biozone except for the *Cynognathus* Assemblage Zone because of the recent three-fold subdivision of this biozone (Hancox *et al.,* 1995; Hancox, 1998; Neveling *et al.,* 2000): The first paragraph(s) of each biozone chronicle a literature review of the tetrapod taxa known from that biozone. The rest of the discussion is a synthesis of the taxa (in the order of Amphibia, Pelycosauria, Archosauromorpha, Eosuchia, Biarmosuchia, Dinocephalia,

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Gorgonopsia, Therocephalia, Dicynodontia, Cynodontia and Parareptilia) derived from the database and how it compares to what is recorded in the literature.

4.3.1 *Eodicynodon* Assemblage Zone

4.3.1.1 Literature review

A diverse fauna has been described from the *Eodicynodon* Assemblage Zone, comprising the basal anomodont *Patranomodon* (Rubidge & Hopson, 1990, 1996), the earliest dicynodonts *Eodicynodon* (Barry, 1974; Cluver & King, 1983; Rubidge, 1990b) and dinocephalians (Rubidge, 1991, 1994; Rubidge, 1995(b)) – including *Tapinocaninus* and the basal anteosaurid dinocephalian, *Australosyodon* (Rubidge, 1994). This carnivorous dinocephalian is more primitive than *Anteosaurus* and more closely resembles the most primitive anteosaurids of the Russian fauna (Rubidge, 1994). Other representatives from the *Eodicynodon* Assemblage Zone include the therocephalians *Alopecodon* and *Glanosuchus* (Rubidge *et al.,* 1983; Rubidge, 1995(b)) and unidentified gorgonopsians (Rubidge, 1988, 1995; Rubidge, 1995(b)). At this stage dicynodonts, gorgonopsians and therocephalians were already present in South Africa (Rubidge, 1995b) but had not yet appeared in Laurasian faunas (Battail, 2000).

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4.3.1.2 Current study

Amphibia

For this study, 8 unidentified amphibian specimens (all in the National Museum) (Tables 4.2 & 4.12; Figure 4.3) have been recorded.

Dinocephalia

Representatives of the earliest dinocephalians, include the presence of a single representative of the above mentioned genus *Australosyodon*, 3 specimens belonging to *Tapinocaninus* and a further 8 unidentified dinocephalians (Table 4.2; Figure 4.3).

Gorgonopsia

The presence of early gorgonopsians is documented for the *Eodicynodon* Assemblage Zone (Rubidge, 1988, 1995; Rubidge, 1995(b)) and is verified in this study by the presence of unidentified gorgonopsians (Table 4.2), although gorgonopsian genera are not accounted for (Figure 4.3). The recorded 268 (Table 4.2) gorgonopsians from the entire Beaufort Group with high resolution locality data but no assigned assemblage zone data will be analysed in Phase 2 of the GIS – initiative.

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Therocephalia

Therocephalians include a single specimen of *Alopecodon* (Table 4.12 shows the stratigraphic range of this genus as well as its abundance in successive assemblage zones) and a single specimen of *Glanosuchus* (although a total of 8 specimens are recorded for this genus, only one specimen is recorded from the *Eodicynodon* Assemblage Zone) (Table 4.12), as well as 4 unidentified therocephalians (Table 4.2).

Anomodontia

The presence of primitive anomodonts in Figure 4.3; Table 4.12 & Table 4.2 is represented by a single specimen of *Patranomodon.*

Dicynodontia

The earliest dicynodonts include 42 specimens of *Eodicynodon,* the earliest and most primitive member of the Dicynodontia (Rubidge, 1988, 1990; Rubidge *et al.,* 1994). The remaining 11 specimens of a total of 53 recorded specimens for this genus do not possess assemblage zone data. The exclusivity of *Eodicynodon* to the lowermost part of the Beaufort Group (Rubidge, 1988, 1990; Rubidge, *et al.,* 1994) concurs with this study. A further 7 unidentified dicynodonts are recorded for this biozone (Table 4.2). Another basal dicynodont from this zone is represented by the single occurrence of *Lanthanostegus. Lanthanostegus* is catalogued in Appendix F. This record, from the National Museum (Number: 3396 from Zwartrivier in Klipplaat) is erroneously recorded for this biozone and requires correction (Phase 1 of the GIS – initiative).

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4.3.2 *Tapinocephalus* Assemblage Zone

4.3.2.1 Literature review

The documented faunal diversity of the *Tapinocephalus* Assemblage Zone includes temnospondyl amphibians represented by a single genus, *Rhinesuchus.*

A wide diversity of anapsid and synapsid taxa has been described from the *Tapinocephalus* Assemblage Zone (Boonstra, 1969; Keyser, 1979; Keyser & Smith, 1979; Modesto *et al.*, 2001). The most basal synapsids from this biozone include the pelycosaurs *Elliotsmithia* and *Anningia* (see Appendix F) (Dilkes & Reisz, 1996).

Biarmosuchians are represented by *Hipposaurus*, *Pachydectes* and *Bullacephalus* (Rubidge & Kitching, 2003; Rubidge & Sidor, 2001, 2002; Rubidge, Sidor & Modesto, 2006).

The *Tapinocephalus* Assemblage Zone hosts numerous dinocephalians represented by: *Anteosaurus, Avenantia, Criocephalus, Delphinognathus, Jonkeria, Keratocephalus, Mormosaurus, Moschops, Paranteosaurus, Phocosaurus, Riebeeckosaurus, Struthiocephalus, Struthicephaloides, Struthionops, Styracocephalus, Tapinocephalus, Taurocephalus* and *Titanosuchus* (Rubidge, 1995(b)).

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Gorgonopsians are known only from South Africa during this biozone-equivalent time period and are represented by: *Aelurosaurus, Broomisaurus, Eoarctops, Galesuchus, Gorgonops* and *Scylacognathus* (Rubidge, 1995(b)).

Therocephalians are represented by: *Alopecodon, Blattoidealestes, Glanosuchus, Icticephalus, Lycosuchus, Pardosuchus, Pristerognathus* and *Scylacosaurus* (Rubidge, 1995(b); Van den Heever, 1994).

Also included in the *Tapinocephalus* Assemblage Zone fauna are anomodonts represented by a single genus *Galeops.* Present in South Africa, but not known from other countries are dicynodonts represented by: *Diictodon, Emydops, Pristerodon* and *Robertia* (Keyser & Smith, 1979; Rubidge, 1995(b)).

Parareptiles are represented by one identified specimen of the procolophonomorpha (Gow & Rubidge, 1997; Cisneros, 2006) and *Eunotosaurus* (Keyser & Smith 1979) which are not known from other countries. Additional parareptiles from this biozone include *Bradysaurus* and *Embrithosaurus* (Rubidge, 1995(b)).

4.3.2.2 Current study

Amphibia

This study has recognised the following genera from the *Tapinocephalus* Assemblage Zone: Temnospondyl amphibians are represented by a single genus, *Rhinesuchus*, with three representatives in this biozone with assemblage zone data. There are a

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further 27 specimens of *Rhinesuchus* with high resolution locality data (Table 4.2). After the completion of Phase 1 of the GIS-initiative, where all fossil records will be assigned both a grid-reference and an assemblage zone, certain of these 27 specimens will be found to be from the *Tapinocephalus* Assemblage Zone. The long stratigraphic range of rhinesuchids is shown in Figure 4.3, beginning in the *Tapinocephalus* Assemblage Zone and ending in the *Lystrosaurus* Assemblage Zone. This is not the case with *Uranocentrodon* as this genus falls conclusively within the Permian (*Dicynodon* Assemblage Zone) (Latimer *et al.*, 2002). There are four unidentified Amphibian fossils recorded for this biozone. It can be inferred that these unidentified fossils are representatives of *Rhinesuchus* as this genus is the only amphibian representative for this biozone.

Pelycosauria

In the Beaufort Group, pelycosaurs are exclusive to the *Tapinocephalus* Assemblage Zone and are represented by *Elliotsmithia* (2) and *Anningia* (1) (Table 4.2; Figure 4.3). According to Dilkes & Reisz (1996) *Anningia*, is a *nomen dubium*.

Biarmosuchia

Biarmosuchians are represented by two specimens of *Hipposaurus* with assemblage zone data catalogued to this biozone, out of a possible seven recorded for the Beaufort Group (Table 4.12). There are an additional three as yet unidentified biarmosuchians listed for the *Tapinocephalus* Assemblage Zone (Figure 4.3). Although *Bullacephalus* is recorded from the *Tapinocephalus* Assemblage Zone of

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the Beaufort Group (Rubidge & Kitching, 2003; Rubidge & Sidor, 2002) it is a late entry onto the database and is therefore not indicated on Figure 4.3; Table 4.2 or Table 4.12. According to Table 4.2, there are 4 specimens of Biarmosuchia of a total of 18 specimens collected for this taxon that possess high resolution locality data but require cataloguing to assemblage zone(s).

Dinocephalia

Dinocephalians are represented by ten recorded specimens of *Anteosaurus* which are documented as coming from the *Tapinocephalus* Assemblage Zone (of a total of 44 specimens) (Figure 4.3 & Table 4.12), *single* representatives of *Avenantia* (of a total of three specimens), *Eccasaurus* (of a total of two specimens), *Keratocephalus* (of a total of three specimens), *Delphinognathus* (of a total of four specimens) and all exclusive to this biozone. There are 46 specimens of *Jonkeria* recorded for the Beaufort Group, only five of these however, are listed with assemblage zone information, with an additional specimen recorded from the Abrahamskraal Formation (in this instance recording to the *Tapinocephalus* Assemblage Zone was inferred).

Moschops is represented by eight specimens with catalogued data to this biozone, of a total of 27 specimens collected for this genus. This genus appears to be exclusive to this biozone (Figure 4.3 & Table 4.12). All specimens of *Scapanodon* (3) were recorded from the *Tapinocephalus* Assemblage Zone (see Chapter 2: Section 2.2.2). The genus *Struthiocephalus* documents four specimens of a possible 34 with data

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indicating inclusion to this biozone; *Styracocephalus* (three specimens of a possible ten with data indicating inclusion to this biozone) and *Tapinocephalus,* a poorly represented 4 specimens of a richly documented 55 with data indicating inclusion to this biozone. Finally *Titanosuchus* is even more poorly represented by 3 specimens that were able to be catalogued to the *Tapinocephalus* Assemblage Zone out of a total of 59 specimens for the Beaufort Group. Furthermore, there are 52 unidentified dinocephalians recorded for this biozone. Additional tapinocephalid dinocephalians such as *Criocephalus, Mormosaurus, Phocosaurus, Riebeeckosaurus, Struthicephaloides, Struthionops,* and *Taurocephalus*, although documented in the collective datasets, do not have accompanying assemblage zone data, and were therefore not depicted on Figure 4.3 or recorded on Table 4.2.

Gorgonopsia

The documented diversity of gorgonopsians that is recorded (Rubidge, 2005; Rubidge, 1995(b)) for the *Tapinocephalus* Assemblage Zone is poorly represented (Figure 4.3). A single member of the genus *Arctops* is recorded for the *Tapinocephalus* Assemblage Zone. Representation of this genus is apparent in both the *Cistecephalus* and *Dicynodon* Assemblage Zones, with eight and one specimen(s) respectively (Table 4.12). Two and a half percent of the total unidentified gorgonopsian fossils are represented in the *Tapinocephalus* Assemblage Zone (9 out of a possible 374 unidentified fossils) (Table 4.2).

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Therocephalia

In this study, therocephalians are represented by two specimens of *Alopecodon,* (the stratigraphic range of this genus is presented in Figure 4.3, continuing from the *Eodicynodon* Assemblage Zone into the *Tapinocephalus* Assemblage Zone), a single specimen of *Cynariognathus* (of a total of six specimens), a single specimen of *Glanosuchus* continuing its representation from the previous biozone, single representation of *Hyaenasuchus* (Appendix F), *Trochosuchus* (Appendix F) and *Pardosuchus* (all exclusive to the *Tapinocephalus* Assemblage Zone), eleven specimens of *Pristerognathus* and a single individual of the genus *Scaloposaurus.* The 're-appearance' of *Scaloposaurus* is recorded from the *Dicynodon-Lystrosaurus* Transition Zone, with the final appearance of this genus in the *Lystrosaurus* Assemblage Zone (Figure 4.3; Table 4.12). There is no recorded assemblage zone information for this genus in the *Pristerognathus, Tropidostoma, Cistecephalus* or *Dicynodon* Assemblage Zones.

In addition, there are 27 unidentified therocephalians recorded for this biozone. Although the genera *Scylacosaurus* and *Lycosuchus* are documented for this biozone (Rubidge, 1995(b)), the only representatives of these genera (from the South African Museum) do not possess assemblage zone data. These specimens do however have high resolution locality data that will be assigned to their relative assemblage zones during Phase 1 of the GIS – initiative.

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Anomodontia

Anomodonts are represented by the following genera and are represented on Figure 4.3: Single individuals of *Galechirus* and *Galeops* which are exclusive to this biozone.

Dicynodontia

Dicynodonts display a wide diversity within the *Tapinocephalus* Assemblage Zone. The following dicynodont genera are represented on Figure 4.3 and Table 4.2: The erroneous recordings of a single individual of *Tropidostoma,* two representatives of *Oudenodon* and two representatives of *Dicynodon;* single representation of *Chelyondops* (exclusive to this biozone); *Diictodon* has 49 representatives in the *Tapinocephalus* Assemblage Zone. This genus has a large representation of 5166 specimens for the Beaufort Group (Table 4.2), with only 6% of these recorded with assemblage zone information.

Pristerodon is represented by four specimens in the *Tapinocephalus* Assemblage Zone. The majority (84%) of the specimens of this genus are not categorised with assemblage zone information, but those that have such data display the long stratigraphic range of *Pristerodon* in the Beaufort Group. Much of the information pertaining to dicynodonts is indeterminate. There are 4129 unidentified dicynodonts recorded for the Beaufort Group, with 39 of these assigned to the *Tapinocephalus* Assemblage Zone. The reduction in unidentified dicynodont numbers as more

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specimens are identified will in future alter the representation of dicynodont genera in the Beaufort Group.

Parareptilia

Parareptiles in the *Tapinocephalus* Assemblage Zone are represented by the following genera: a single specimen of the genus *Nochelesaurus. Bradysaurus,* with 16 specimens out of a possible listing of 79 specimens is exclusive to the *Tapinocephalus* Assemblage Zone. *Embrithosaurus,* also exclusive to the *Tapinocephalus* Assemblage Zone is represented by four specimens with assemblage zone data, out of a potential eleven specimens collected for the genus (Figure 4.3; Table 4.12). There are five specimens of *Eunotosaurus* with assemblage zone data of a potential 32 recorded fossil finds. The remaining 27 *Eunotosaurus* specimens have high resolution locality descriptions that will be assigned to the relative assemblage zone during Phase 1 of the GIS - initiative.

The recording of *Pareiasaurus* (22 individuals) listed from the *Tapinocephalus* Assemblage Zone is erroneous as Battail (2000) has shown that *Embrithosaurus schwartzi* and *Bradysaurus seeleyi* from South Africa are the earliest known pareisaurs. Lee (1997a) considers *Bradysaurus* (from the *Tapinocephalus* Assemblage Zone) the most basal pareiasaurid. The locality information pertaining to these 22 individuals (one from the Albany Museum, thirteen from the Bernard Price Institute and eight from the South African Museum) (Table 3.39), requires correction (Appendix F).

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There is a total of 126 unidentified parareptiles in the Beaufort Group. Three of these are from the *Tapinocephalus* Assemblage zone, with a further one, ten, two, nine and 57 from the *Tropidostoma, Cistecephalus, Dicynodon, Lystrosaurus* and *Cynognathus* Assemblage Zones respectively. According to Lee (1997a,b), pareiasaurs are restricted to the Permian. The findings of this study concur with this view.

Lee (1997a) in his review of Pareiasaurid taxa lists the genus *Pumiliopareia* as being valid in addition to the genera listed. There are no specimens of this genus present in South African collections.

4.3.3 *Pristerognathus* Assemblage Zone

4.3.3.1 Literature review

Documented faunal diversity from the *Pristerognathus* Assemblage Zone is characterised by a therapsid fauna of low diversity dominated by *Diictodon* in association with *Pristerognathus*. The faunal assemblage includes Amphibia (*Rhinesuchus*); Biarmosuchia (*Hipposaurus*); Gorgonopsia (*Gorgonops*); Therocephalia (*Ictidosuchoides, Pristerognathus*); Dicynodontia (*Diictodon, Endothiodon,* and *Pristerodon*) and Parareptilia (*Bradysaurus, Embrithosaurus, Eunotosaurus*) (Rubidge, 1995(b)). The *Pristerognathus* Assemblage Zone is a relatively new addition to the biozonation scheme for the Beaufort Group (Keyser &

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Smith, 1979) and the only three collections which have specimens recorded as coming from this biozone are in the Council for Geoscience, the Bernard Price Institute for Palaeontological Research and more recently the South African Museum. The remaining museum collections have not upgraded their databases to include this biozone, which accounts for the absence of certain taxa in the faunal account for this biozone below.

4.3.3.2 Current study

For this study, there are only 34 specimens with assemblage zone data recorded for the *Pristerognathus* Assemblage Zone (Table 4.12). This biozone has no recorded representatives of Amphibia, Biarmosuchia or Cynodontia with assemblage zone data. The absence of Eosuchia is in alignment with documentation that the earliest Eosuchian is recorded from the *Tropidostoma* Assemblage Zone (Smith & Evans, 1995), and the same applies to Archosauromorpha where the earliest representatives appear at the beginning of the Triassic with genera such as *Prolacerta* and *Proterosuchus* from the *Lystrosaurus* Assemblage Zone (Welman & Flemming, 1993).

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Gorgonopsia

Although gorgonopsians were the dominant terrestrial carnivores for much of the Late Permian (Kitching, 1995) and are documented from this biozone (Rubidge, 1995(b)) no gorgonopsians with assemblage zone data are recorded for this biozone.

Therocephalia

Therocephalians are represented by the following genera: *Ictidosuchoides* and *Pristerognathus.* The single individual of *Ictidosuchoides* and the two specimens of *Pristerognathus* are both from the South African Museum (Table 3.39). There is a single unidentified therocephalian in this biozone.

Dicynodontia

Dicynodonts are represented by *Diictodon* and *Pristerodon.* The 14 specimens of *Diiictodon* are from the Bernard Price Institute (2) and the South African Museum (12). The three individuals of *Pristerodon* are from the South African Museum (Table 3.39). *Oudenodon, Rhachiocephalus* and *Tropidostoma* are erroneously recorded as coming from this biozone (Appendix F). The seven specimens of *Oudenodon,* the single recordings for *Rhachiocephalus* and *Tropidostoma* are from the South African Museum (Table 3.39). In addition, there are three unidentified dicynodonts from the *Pristerognathus* Assemblage Zone.

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Parareptilia

There are no recorded parareptiles from the *Pristerognathus* Assemblage Zone (Table 4.12; Figure 4.3), although their earliest appearance is noted from the *Tapinocephalus* Assemblage Zone (Smith & Keyser, 1995). However, 519 of 995 records for Parareptilia (Table 4.2) have high resolution locality information that could in future be assigned to applicable assemblage zones. This implies that some of the 52% of data without assemblage zone assignment may well be assigned to the *Pristerognathus* Assemblage Zone in the future. The apparent absence of pareiasaurs from this biozone may support the hypothesis that they suffered a major extinction at the end of the *Tapinocephalus* Assemblage Zone (Lee, 1997a).

4.3.4 *Tropidostoma* and *Cistecephalus* Assemblage Zones

As the documented faunas of these two biozones are similar, apart from the range of *Tropidostoma,* which is restricted to the *Tropidostoma* Assemblage Zone (Smith & Keyser, 1995), the literature review combines these two biozones.

4.3.4.1 Literature review

The faunas of the *Tropidostoma* and *Cistecephalus* Assemblage Zones have been summarised by several authors (Keyser & Smith, 1979; Kitching, 1977; Smith & Keyser, 1995; Rubidge, 1995(b); Angielczyk *et al.,* 2006) and include representatives

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of Rhinesuchidae, the earliest capitosaurid family (Damiani & Rubidge, 2003) and the small captorhinid *Saurorictus australis,* from the *Tropidostoma* Assemblage Zone. This is the first captorhinid discovered in South Africa (Modesto & Smith, 2001). The faunal assemblages of these biozones include the first occurrence of *Youngina* (Smith & Evans, 1995). Additional faunal representatives include Burnetiamorpha (Sidor & Welman, 2003; Sidor *et al.,* 2004; Smith *et al.*, 2006).

Gorgonopsians are represented by: *Cyonosaurus, Lycaenops, Gorgonops* and *Prorubidgea* – known from the *Tropidostoma* and *Cistecephalus* Assemblage Zones and *Arctognathus, Clelandina, Dinogorgon* and *Rubidgea* known from the *Cistecephalus* Assemblage Zone. Therocephalians are represented by: *Ictidosucoides* and *Ictidosuchops*.

Dicynodonts are represented by: *Cistecephalus, Diictodon, Endothiodon, Pristerodon, Emydops, Tropidostoma, Rhachiocephalus* and *Aulacephalodon. Dinanomodon, Oudenodon* and *Platycyclops* are known from the *Cistecephalus* Assemblage Zone.

Parareptiles are represented by *Pareiasaurus* with *Owenetta* and *Anthodon* from the *Cistecephalus* Assemblage Zone.

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4.3.4.2 Current study for the *Tropidostoma* Assemblage Zone

Amphibia

Temnospondyl amphibians are represented by a single genus – *Rhinesuchus* (1). It is inferred that the three unidentified amphibians for this biozone belong to *Rhinesuchus*, as this is the only genus present in the Permian (Damiani & Rubidge, 2003).

Eosuchia

Eosuchians are represented by two specimens of *Youngina* (Table 4.12). This genus has a stratigraphic range extending from the *Tropidostoma* Assemblage Zone to the *Dicynodon* Assemblage Zone (Figure 4.3). *Youngina* is the only diapsid genus from the Permian Beaufort Group (Rubidge, 2005).

Captorhinida

The first captorhinid from South Africa (Modesto & Smith, 2001c), *Saurorictus* (Table 4.2), is recorded from *Tropidostoma* Assemblage Zone strata north of Beaufort West and is now housed in the South African Museum (Table 3.39).

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Biarmosuchia

The findings of this study reveal no representatives of Biarmosuchia for the *Tropidostoma* Assemblage Zone (Table 4.12; Figure 4.3), although the presence of *Paraburnetia* (SAM-PK-K10037) (Smith *et al.*, 2006) is documented for the *Tropidostoma-Cistecephalus* Transition Zone (Table 3.39).

Gorgonopsia

The documented diversity of gorgonopsians that is recorded for the *Tropidostoma* Assemblage Zone (Keyser & Smith, 1995) concurs with the findings of this study (Figure 4.3; Table 4.12). Gorgonopsian genera represented in the *Tropidostoma* Assemblage Zone include *Aelurognathus* (a single individual from the South African Museum), *Aelurosaurus* (a single individual from the Transvaal Museum) and *Scylacognathus* (three individuals from the Transvaal Museum) (Table 3.39). The validity of these three genera being assigned to this biozone will be verified during Phase 1 of the GIS-initiative (Appendix F). *Clelandina* (a single individual from the Rubidge Collection) is erroneously recorded as representative of this biozone (Appendix F) and its locality data requires verification. A valid genus for this biozone is *Gorgonops* (two individuals from the Bernard Price Institute). There are 13 unidentified Gorgonopsians recorded for this biozone (Table 4.12).

Prorubidgea, although documented for this biozone (Rubidge, 1995(b)), was not recorded in this study as from the *Tropidostoma* Assemblage Zone. A total of twelve

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specimens of *Prorubidgea* have been collected in the Beaufort Group, six of these are assigned to the *Cistecephalus* Assemblage Zone and two to the *Dicynodon* Assemblage Zone. The remaining four individuals have accurate locality information that will be assigned assemblage zone data during Phase 1 of the GIS - initiative. These remaining four could prove to belong to this biozone.

Therocephalia

Therocephalians are represented by 3 specimens of *Hofmeyeria,* which makes its first appearance in this biozone (Figure 4.3), single representatives of *Ictidosuchoides* (present in five biozones), *Ictidosuchus* (exclusive to this assemblage zone) (see Appendix F) and *Ictidosuchops* (Figure 4.3). There are two unidentified therocephalians in this biozone. Therocephalian representation comprises 1% of the taxonomic diversity of the *Tropidostoma* Assemblage Zone (eight records of 910) (Table 4.12).

Dicynodontia

Dicynodonts display a wide diversity within the *Tropidostoma* Assemblage Zone. The documented dicynodont fauna of this biozone (Keyser & Smith, 1979; Kitching, 1977; Smith & Keyser, 1995) concurs with the findings of this study (Table 4.12) and includes the following genera (Figure 4.3): *Cistecephalus* (2), *Diictodon* (176) (6% of *Diictodon* specimens are recorded with assemblage zone information with the densest recording of *Diictodon* occurring in the *Tropidostoma* Assemblage Zone, with 176 representatives), *Tropidostoma* (29), *Emydops* (15), *Emydopsis* (1) (Appendix F),

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Endothiodon (22), *Eumantellia* (1), *Palemydops* (1), *Pristerodon* (25), and *Rhachiocephalus* (1). *Dicynodon* (12) and *Oudenodon* (55) are erroneously recorded as coming from this biozone (Appendix F) and their locality data requires verification. There are 529 unidentified dicynodonts recorded for this assemblage zone (Table 4.2).

Cynodontia

The presence of cynodonts from the *Tropidostoma* Assemblage Zone is represented by *Charassognathus* (Botha *et al.*, 2007). Because this discovery has only recently been reported, the record of this fossil has not as yet been captured on the original dataset. Cynodonts are erroneously represented by a single specimen of the genus *Trirachodon* (SAM, Number: 55319) for this biozone. Of the 85 individuals representative of this genus, 65 (76%) are found in the *Cynognathus* Assemblage Zone (Table 4.7). The remaining 18% of *Trirachodon* specimens possess a high degree of locality accuracy that retains the capacity for assignment to assemblage zone data.

Parareptilia

Parareptiles in the *Tropidostoma* Assemblage Zone are represented by the genus *Pareiasaurus* (2) and there is also a single unidentified parareptile. Based on documentation that pareiasaurs are the representative parareptiles for this biozone (Rubidge, 2005), it is inferred that the unidentified specimen is a pareiasaur.

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4.3.4.3 Current study for the *Cistecephalus* Assemblage Zone

Amphibia

A false increase in amphibian taxonomic diversity is observed in the databases of specimens from the *Cistecephalus* Assemblage Zone. The databases erroneously indicate *Lydekkerina* (BPI, Numbers: 214, 216) and *Muchocephalus* (BPI, Number: 213) as coming from the *Cistecephalus* Assemblage Zone. Recent research documents *Rhinesuchus* as the only genus from the Permian (Damiani & Rubidge, 2003) validating the five *Rhinesuchus* specimens recorded in the database (Table 4.2). This biozone has the highest incidence (110) of unidentified amphibians. The total number of amphibian specimens in the Beaufort Group is 684 (Table 4.2). 413 (60%) of these are unidentified with 27% (110) from the *Cistecephalus* Assemblage Zone (Table 4.2). Following Damiani and Rubidge (2003), it is inferred that the unidentified amphibian specimens in this biozone belong to *Rhinesuchus.*

Eosuchia

Amongst the diapsids *Youngina* is the only genus recognised from the *Cistecephalus* Assemblage Zone and there are nine specimens recorded, plus one specimen of *Youngopsis* which has been synonomised with *Youngina* (Watson, 1957) (Appendix F). It can be inferred that the six unidentified eosuchians and one unidentified

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archosauromorph also belong to *Youngina*, increasing the abundance of this genus to 17 (Table 4.2).

Biarmosuchia

Biarmosuchians are known from the Middle and Late Permian (Hopson & Barghusen, 1986; Smith *et al.*, 2006). During *Cistecephalus* Assemblage Zone times biarmosuchians have the greatest diversity of taxa at any time and comprise the following four genera: *Hipposaurus* (2), *Lemurosaurus* (3) *Lycaenodon* (1) and *Rubidgina* (2) (Table 4.12).

Gorgonopsia

It appears that there was a significant flourishing of gorgonopsians during *Cistecephalus* Assemblage Zone times, where the generic diversity of Gorgonopsia reaches a peak (Table 4.2). According to this study, Gorgonopsia comprises the following 21 genera from the *Cistecephalus* Assemblage Zone: *Aelurognathus* (6) (Appendix F), *Aelurosaurus* (3) (Appendix F), *Aloposaurus* (2) (Appendix F), *Arctognathus* (2), *Arctops* (8), *Broomicephalus* (1), *Clelandina* (1), *Cynarioides* (1), *Cyniscops* (2), *Cyonosaurus* (17), *Dinogorgon* (6), *Galerhynchus* (1), *Gorgonops* (7), *Lycaenops* (9), *Prorubidgea* 6), *Rubidgea* (6), *Scylacognathus* (3) (Appendix F), *Scylacops* (2) (Appendix F), *Scymnognathus* (1), *Smilesaurus* (1) and *Sycosaurus* (3).

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In addition there are 125 unidentified gorgonopsians recorded from this biozone (Table 4.12; Table 4.2 & Figure 4.3).

Therocephalia

The diversification of therocephalians in the *Cistecephalus* Assemblage Zone is apparent from Table 4.2 and Table 4.12, which shows the following 14 genera for the *Cistecephalus* Assemblage Zone: *Alopecopsis (1)* (Appendix F), *Euchambersia (1), Hewettia (1), Hofmeyeria (3), Homodontosaurus (7), Ictidostoma (1), Ictidosuchoides* (1), *Ictidosuchops* (19), *Moschorhynchus* (3) (Appendix F), *Nanictocephalus* (1) (Appendix F), *Notosollasia* (3), *Proalopecopsis* (1) (Appendix F), *Tetracynodon* (2) and *Theriognathus* (30). In addition, there are 45 unidentified therocephalians in this biozone. *Akidnognathus* (1), *Moschorhinus* (3) *and Sesamodon* (1) (Table 4.2) are erroneously recorded as coming from this biozone (Appendix F). The locality data of these records requires verification.

Dicynodontia

A significant radiation of dicynodonts is apparent during *Cistecephalus* Assemblage Zone times, where the diversity of dicynodont genera reaches a peak (Table 4.2). Recorded dicynodonts from this biozone comprise the following 15 genera: *Aulacephalodon* (71), *Cistecephalus* (225), *Dicynodontoides* (3), *Diictodon* (56), *Dinanomodon* (3), *Emydops* (30), *Emydorhinus* (2) (Appendix F), *Endothiodon* (5), *Kingoria* (7), *Oudenodon* (212) (less than 46% of fossils belonging to *Oudenodon* are

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paired with assemblage zone information), *Palemydops* (1), *Pelanomodon* (6), *Platycyclops* (7), *Pristerodon* (25) and *Rhachiocephalus* (22) (Table 4.12; Table 4.2 & Figure 4.3). *Daptocephalus* (1) (see Chapter 2 for discussion), *Dicynodon* (71), *Lystrosaurus* (3), *Myosauroides* (1), *Tetragonias* (1) and *Tropidostoma* (4) are erroneously recorded as being present during *Cistecephalus* Assemblage Zone times (Appendix F). The locality data of these records requires verification. There are 1747 unidentified dicynodonts recorded for this biozone, making it the biozone with the highest recording (42%) of unidentified dicynodonts.

Cynodontia

Cynodonts are represented by *Cynosaurus* (4), *Scalopocynodon* (1) (Appendix F), *Silpholestes* (1) (Appendix F). *Nanictosuchus* (1), *Procynosuchus* (12), *Silpholestses* (1) and *Tritylodontoides* (1) are erroneously recorded as being present during *Cistecephalus* Assemblage Zone times (Appendix F) (Table 4.12). In addition, there are eight unidentified cynodonts recorded for this biozone.

Parareptilia

Parareptiles in this biozone are represented by *Anthodon* (4), *Nanomilleretta* (2) (Appendix F), *Nanoparia* (4), *Owenetta* (10), *Polycynodon* (1) (Appendix F), *Pareiasaurus* (21) and *Pareiasuchus* (3) (Table 4.12). *Milleretta* (10) and *Paliguana* (1) are erroneously recorded as being present during *Cistecephalus* Assemblage Zone times (Appendix F) (Table 4.12). In addition, there are ten unidentified parareptiles recorded for this biozone.

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4.3.5 *Dicynodon* Assemblage Zone

4.3.5.1 Literature review

Fossil tetrapod taxa recorded from the *Dicynodon* Assemblage Zone (Kitching, 1995; Smith, 1995; Smith & Ward, 2001; Rubidge, 1995(b)) include rhinesuchid amphibians (Smith & Keyser, 1995; Rubidge, 2005), eosuchians (*Saurosternon* and *Youngina*), biarmosuchians (*Burnetia, Lemurosaurus* and *Rubidgina)* (Rubidge & Sidor, 2002), gorgonopsians (*Broomicephalus, Clelandina, Cyonosaurus, Dinogorgon, Lycaenops, Leontocephalus, Prorubidgea, Rubidgea* and *Paragalerhinus*), therocephalians (*Akidnognathus, Cerdops, Homodontosaurus, Ictidosuchoides, Ictidosuchops, Lycideops, Moschorhinus, Nanictidops, Promoschorhynchus, Scaloporhinus, Scaloposuchus, Tetrcynodon* and *Theriognathus*) dicynodonts (*Aulacephalodon, Diictodon, Dicynodon, Dinanomodon, Emydops, Lystrosaurus, Oudenodon, Palemydops, Pelanomodon, Pristerodon* and *Propelanomodon*), cynodonts (*Cynosaurus, Nanictosaurus* and *Procynosuchus*) and parareptiles (*Anthodon, Milleretta, Millerosaurus, Owenetta, Pareiasaurus* and *Spondylolestes*) (Rubidge, 1995(b)).

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4.3.5.2 Current study

Amphibia

Two identified *Rhinesuchus* specimens with assemblage zone data from the *Dicynodon* Assemblage Zone are present in South African collections, as well as an additional three unidentified specimens. This study incorrectly affirms that *Rhinesuchus* is the only amphibian genus from the *Dicynodon* Assemblage Zone because although *Uranocentrodon* (National Museum: Table 3.39) is recorded as coming from the *Lystrosaurus* Assemblage Zone (Table 4.12), subsequent research has shown that this genus falls conclusively within the *Dicynodon* Assemblage Zone (Latimer *et al.*, 2002). The ten records of *Uranocentrodon* (Table 3.39) will be correctly assigned to the *Dicynodon* Assemblage Zone during Phase 1 of the GIS-initiative

Archosauromorpha

Three specimens of *Youngina* with assemblage zone data are recorded from the *Dicynodon* Assemblage Zone. The single recordings of *Youngoides* and *Youngopsis* add to this figure as they have been synonomised with *Youngina* (Watson, 1957) (Appendix F). Their synonymy with *Youngina* will be corrected during Phase 1 of the GIS-initiative. In addition one specimen of *Saurosternon* and three unidentified eosuchians are recorded from the *Dicynodon* Assemblage Zone.

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Biarmosuchia

No biarmosuchians from the *Dicynodon* Assemblage Zone are recorded in the database (Table 4.12, Table 4.2 & Figure 4.3). *Burnetia* is documented for the *Dicynodon* Assemblage Zone (Rubidge & Sidor, 2002), but as the only specimen is housed in the Natural History Museum in London (Rubidge & Sidor, 2002) it is not reflected in this database (Chapter 3: Folder 3).

Gorgonopsia

Gorgonopsians were the dominant terrestrial carnivores for much of the Late Permian (Kitching, 1995) and are represented by the following 13 genera (Table 4.2): *Aelurognathus* (2) (Appendix F), *Arctops* (1), *Broomisaurus* (1), *Cerdops* (1), *Cyniscops* (1), *Cyonosaurus* (6), *Dinogorgon* (1), *Galerhynchus* (1), *Leontocephalus* (1), *Lycaenops* (1), *Paragalerhinus* (1), *Prorubidgea* (2) and *Rubidgea* (1). Two specimens of *Gorgonops* are erroneously recorded for this biozone (Appendix F). Their locality data will be verified during Phase 1 of the GIS-initiative. In addition there are 24 unidentified gorgonopsian specimens recorded for this biozone (Table 4.2).

Therocephalia

Therocephalians in the *Dicynodon* Assemblage Zone are represented by the following twelve genera: *Ictidochampsa* (1) (Appendix F), *Ictidosuchoides* (2), *Ictidosuchops* (6), *Moschorhinus* (8), *Nanictidops* (1), *Notosollasia* (3), *Pelictosuchus* (1),

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Promoschorhynchus, *Scaloposuchus* (1), *Tetracynodon* (1), *Theriognathus* (7) and *Whaitsia* (3) (See Chapter 2 for discussion). In addition there are 13 unidentified therocephalians recorded for this biozone (Table 4.2; Table 4.12 & Figure 4.3).

Dicynodontia

The following 12 dicynodont genera have been recorded: *Aulacephalodon* (3), *Daptocephalus* (8) (see Chapter 2 for discussion), *Dicynodon* (43), *Dicynodontoides* (1), *Diictodon* (9), *Dinanomodon* (3), *Emydops* (1), *Kingoria* (3), *Oudenodon* (62), *Pelanomodon* (5), *Pristerodon* (2) and *Propelanomodon* (1), (Table 4.12; Table 4.2 & Figure 4.3). *Lystrosaurus* (12), *Platycyclops* (1), *Rhachiocephalus* (1) and *Tropidostoma* (1) are erroneously represented in this biozone (Appendix F) (Table 4.2). Their locality data will be verified during Phase 1 of the GIS-initiative.

There are 315 unidentified dicynodonts in the *Dicynodon* Assemblage Zone, translating to 8% of the unidentified dicynodont fossils of the Beaufort Group as coming from this biozone (Table 4.2). The recorded 12 dicynodont genera from the *Dicynodon* Assemblage Zone represent 29% of the total diversity of 41 dicynodont genera for the Beaufort Group. Furthermore, of the total of 837 *Dicynodon* specimens collected, 655 of these do not possess assemblage zone data. This calculates to a 78% loss of data for this genus for this study.

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Cynodontia

Four cynodont genera are recorded for this biozone: *Cynosaurus* (3), *Mygalesaurus* (1), *Nanictosaurus* (3) and *Procynosuchus* (12) as well as three unidentified cynodonts (Table 4.2). *Megalesuchus* (1) and *Thrinaxodon* (1) are erroneously recorded as being present during *Dicynodon* Assemblage Zone times (Appendix F). Their locality data will be verified during Phase 1 of the GIS-initiative.

Parareptilia

Parareptiles in the *Dicynodon* Assemblage Zone are represented by the following five genera: *Milleretta* (4), (Appendix F), *Millerosaurus* (2), *Owenetta* (2), *Pareiasaurus* (6) and *Spondylestes* (1). *Millerenoides* (1), *Millerettoides* (1) and *Millerettops* (1) are synonymous with *Milleretta.* Their synonymy with *Youngina* (Appendix F) will be corrected during Phase 1 of the GIS-initiative. In addition there are two unidentified parareptiles from the Rubidge Collection and National Museum (Table 3.39). The presence of single specimen of *Procolophon* from the Rubidge Collection (Table 3.39) is erroneous as all procolophonoid genera, apart from *Owenetta*, are Triassic in age (Gow & Rubidge, 1997; Cisneros, *pers comm.*). The locality descriptions for this specimen (Number: RC283) will be verified in Phase 1 of the GIS – initiative. Although *Anthodon* is documented as coming from both this biozone and the *Cistecephalus* Assemblage Zone (Rubidge, 1995), it is not accounted for from this biozone, but only from the *Cistecephalus* Assemblage Zone (Table 4.2). Five specimens, of a total of nine specimens lack specific assemblage zone data (Table

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4.2). Once the locality data of these five specimens have been allocated an assemblage zone (Phase 1 of the GIS-initiative) the presence of *Anthodon* from the *Dicynodon* Assemblage Zone will be accounted for in the research tools of this thesis.

4.3.6 *Lystrosaurus* Assemblage Zone

4.3.6.1 Literature review

The fossil fauna from the lower part of the *Lystrosaurus* Assemblage Zone has been summarised and detailed by various authors (Keyser & Smith, 1979; Kitching, 1977; Groenewald & Kitching, 1995; Neveling, 2002, 2004; Shishkin *et al.*, 1995; Shishkin *et al.*, 1996; Smith, 1995; Smith & Ward, 2001; Smith & Botha, 2005; Botha & Smith, 2006). Amphibians in the lower part of the *Lystrosaurus* Assemblage Zone are typically represented by lydekkerinid and lonchorhynchine amphibians which have a distribution over all of Pangaea (Damiani & Rubidge, 2003; Shishkin *et al.*, 1996; Rubidge, 2005). Archosaurs include the proterosuchids *Prolacerta* and *Proterosuchus* (Welman & Flemming, 1993). Eosuchians include *Noteosuchus.*

Dicynodonts are represented by *Lystrosaurus* in abundance and relatively few specimens of *Myosaurus.* Therocephalians are represented by: *Ericiolacerta*, *Moschorhinus*, *Oliviera*, *Regisaurus*, *Scaloposaurus*, *Tetracynodon* and *Zorillodontops.* Cynodont representatives include *Thrinaxodon*, *Progalesaurus*,

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Platycraniellus and *Galesaurus*, with parareptiles typically represented by *Procolophon*, *Paliguana* and *Owenetta* (Groenewald & Kitching, 1995; Smith & Botha, 2005).

The upper part of the *Lystrosaurus* Assemblage Zone, i.e. the uppermost part of the stratigraphic range of *Lystrosaurus* and the *Procolophon* "Abundance Zone", has produced a trematosaurid mandible (Neveling *et al.*, 1999; Damiani *et al.*, 2000a) which is very similar to *Trematosaurus*. This genus is known from the Upper Olenekian (Spathian) of Germany and *Parotosuchus* fauna of Russia (Damiani *et al.*, 2000a; Shishkin & Welman, 1994; Shishkin *et al.*, 1996; Shishkin & Rubidge, 2000). As *Trematosuchus* is recorded in both the *Lystrosaurus* and *Cynognathus* Assemblage Zones (see Table 4.2), this suggests that the *Lystrosaurus* Assemblage Zone extends into the base of the upper Olenekian (Neveling, 2002, 2004).

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4.3.6.2 Current study

Amphibia

An enormous radiation of amphibian taxa is apparent in the Triassic (Damiani & Rubidge, 2003; Shishkin, Rubidge & Kitching, 1996), revealing dramatic changes in the evolution of amphibian fauna during the Permo-Triassic turnover phase of the Gondwanan terrestrial biota (Shishkin & Rubidge, 2000). Such a radiation is verified in this study, where the diversity of amphibian taxa increases five-fold in the *Lystrosaurus* Assemblage Zone (Table 4.2). The amphibian fauna is dominated by *Lydekkerina* (81), with *Micropholis* having the next highest abundance (14) followed by *Pneumatostega* (2) and *Eolydekkerina* (1). *Broomistega*, a rhinesuchid representative from the Early Triassic of South Africa (Shishkin & Rubidge, 2000), is correctly recorded for in this study (Table 4.2) as being part of the faunal assemblage of the *Lystrosaurus* Assemblage Zone as *Broomistega* is the sole rhinesuchid representative for the Triassic (Shishkin & Rubidge, 2000). There are 45 unidentified amphibians recorded for this biozone (Table 4.2).

Trematosuchus (1) and *Xenotosuchus* (1) are erroneously recorded as being present during *Lystrosaurus* Assemblage Zone times (Appendix F). The locality data and/or taxonomic data of these genera will be corrected during Phase 1 of the GIS-initiative. The presence of *Kestrosaurus* (South African Museum, Number: SAM-PK-003452) is erroneous as *Kestrosaurus* is found in the lowermost Subzone A of the

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Cynognathus Assemblage Zone (Shishkin *et al.*, 2004). The locality description of this specimen will be updated to the *Cynognathus* Assemblage Zone during Phase 1 of the GIS – initiative. The record of *Rhinesuchus* and two *Uranocentrodon* specimens (National Museum) from the *Lystrosaurus* Assemblage Zone is erroneous (Table 4.2, Table 4.12 & Figure 4.3) as these genera fall conclusively within the Permian (Latimer *et al.*, 2002).

The genus *Rhytidosteus* (Specimen Number: SAM-PK-000636) is documented for in the South African Museum (Table 2.38) for this biozone, but because of speculation in the original database, that the specimen is 'most probably' *Parotosuchus africanus* (i.e. *Xenotosuchus*) the genus was then altered accordingly (see CD1: Folder 3: South African Museum). This alteration still makes this record incorrect as *Xenotosuchus* is part of the faunal assemblage of the *Cynognathus* Assemblage Zone (Appendix F).

Archosauromorpha

In the *Lystrosaurus* Assemblage Zones there is a marked increase in the number of diapsid taxa. The earliest archosaur from South Africa is *Proterosuchus* which first appears at the beginning of the Triassic (Welman & Flemming, 1993; Smith & Botha, 2005). *Elaphrosuchus* (Appendix F) is synonymous with *Proterosuchus* (Cruickshank, 1972), which means that two archosauromorph genera are recorded for the *Lystrosaurus* Assemblage Zone: *Prolacerta* and *Proterosuchus* (Table 4.2, Table 4.12 & Figure 4.3). It is assumed that the three unidentified archosauromorphs as well

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as the four unidentified diapsids may be identified to one of these two genera (Table 4.2).

Eosuchia

Eosuchians are represented by five specimens of *Noteosuchus,* which concurs with current documentation. In addition, there are two unidentified eosuchians which are assumed to be representatives of *Noteosuchus.*

Gorgonopsia

A single gorgonopsian genus, *Cyonosaurus,* and a single unidentified gorgonopsian are recorded for the *Lystrosaurus* Assemblage Zone. *Arctognathus* is recorded for the *Cynognathus* Assemblage Zone, in addition to two unidentified gorgonopsians (Table 4.2, Table 4.12 & Figure 4.3). The assemblage zone data pertaining to the single individual of *Cyonosaurus* from the Bernard Price Institute, *Arctognathus* (Albany Museum) and the unidentified gorgonopsians (Bernard Price Institute and National Museum) is incorrect (Table 3.39; Appendix F) as gorgonopsians became extinct at the end of the Permian (Kitching, 1995).

Therocephalia

Therocephalian representation for the *Lystrosaurus* Assemblage Zone includes the following seven genera: *Cerdosuchoides* (1), *Ericiolacerta* (1), *Moschorhinus* (16), *Olivieria* (=*Oliveriosuchus* [Kammerer & Sidor, 2002]) (1), *Regisaurus* (1), *Scaloposaurus* (11) and *Tetracynodon* (1). *Ictidosuchoides* (2) and *Ictidosuchops* (6)

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are erroneously recorded as being present during *Lystrosaurus* Assemblage Zone times (Appendix F; Table 4.2). There are 58 unidentified therocephalians recorded for this biozone (Table 4.2; Table 4.12 & Figure 4.3).

Dicynodontia

The most abundant dicynodont genus for the *Lystrosaurus* Assemblage Zone is *Lystrosaurus* with 2037 specimens recorded (Table 4.12). *Lystrosaurus* makes up 13% of the total abundance of dicynodonts for the Beaufort Group with 67% of *Lystrosaurus* recorded with assemblage zone data. The remaining 33% will be assigned to the *Lystrosaurus* Assemblage Zone during Phase 1 of the GIS – initiative. *Myosaurus* (6) and *Dicynodon* (6) are the only other possible dicynodonts from the *Lystrosaurus* Assemblage Zone. The taxonomic data and/or assemblage zone for the additional dicynodont genera: *Dinanomodon* (1), *Emydops* (1), *Oudenodon* (1), and *Prolystrosaurus* (1) recorded in this study (Table 4.2 & Figure 4.3) for this biozone are incorrect (Appendix F). In addition there are 26 unidentified dicynodonts recorded for this biozone (Table 4.2).

Cynodontia

Of the wide variety of Triassic cynodonts, *Galesaurus* and *Thrinaxodon* were the dominant Early Triassic (*Lystrosaurus* Assemblage Zone) genera (Rubidge & Sidor, 2001; Rubidge, 1995(b); Smith & Botha, 2005) (Tables 4.2 & 4.12). An additional cynodont genus recorded for the *Lystrosaurus* Assemblage Zone is *Platycraniellus.* *Cynosaurus* (1), *Glochinodontoides* (2) and *Nanictosaurus* (2) are erroneously

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recorded as being present during *Lystrosaurus* Assemblage Zone times. The assemblage zone data of these flawed records will be recitified during Phase 1 of the GIS-initiative. In addition there are 23 unidentified cynodonts recorded for this biozone (Table 4.2).

Parareptilia

Procolophonid genera recorded for this biozone include *Owenetta* (4), *Paliguana* (5) and *Procolophon* (218) (Table 4.12, Table 4.2 & Figure 4.3). In South Africa *Owenetta,* is known from the Late Permian *Cistecephalus* and *Dicynodon* and the Early Triassic *Lystrosaurus* Assemblage Zones (Kitching, 1995, Groenewald & Kitching, 1995, Smith & Keyser, 1995; Modesto, *et al.*, 2001b; Reisz & Scott, 2001). Ten individuals of *Owenetta* are recorded for the *Cistecephalus* Assemblage Zone, two for the *Dicynodon* Assemblage Zone and four specimens are from the Triassic *Lystrosaurus* Assemblage Zone (Table 4.2; Table 4.12 & Figure 4.3). There are nine unidentified parareptiles recorded as coming from this biozone.

4.3.7 *Cynognathus* Assemblage Zone

In the past decade a number of significant breakthroughs have been made in understanding the nature of biodiversity and biostratigraphy of the Beaufort Group. These breakthroughs include a more refined biostratigraphic subdivision for the uppermost Beaufort Group strata, and a better understanding of the biogeographic

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distribution of temnospondyl amphibians, archosauriforms and dicynodonts. The biostratigraphic subdivision of the *Cynognathus* Assemblage Zone, encompassing the boundary between the Early and Middle Triassic (Hancox *et al.*, 2001) has partitioned its faunal content into a three-fold subdivision: Subzones A, B and C (Hancox *et al.*, 2001) (see Chapter 1).

Subzone A of the *Cynognathus* Assemblage Zone

The lowermost subzone A of the *Cynognathus* Assemblage Zone is considered to be Olenekian in age (Shishkin *et al.*, 1995; Hancox, 1988, 2000). This is based on the combined presence of *Kestrosaurus* (Shishkin *et al.*, 2004), *Parotosuchus* (Damiani, 1999) (both accounted for in this study) and *Trematosaurus* (Shishkin & Welman, 1994) (not recorded for in South African museum collections). Abdala *et al.*, (2005) list cynodont representatives for subzone A as *Diademodon*, *Cynognathus* and *Trirachodon*. These genera are accounted for in this study, but not refined to the level of subzonation (Table 4.2). The dominance (in terms of numbers of individuals) of *Diademodon* (87) and *Cynognathus* (78) in subzone A is apparent when compared to the frequency of other cynodont genera (Tables 4.2 & 4.12). Furthermore, there are an additional 29 specimens of *Diademodon* and 31 specimens of *Cynognathus*, having high resolution locality data that will be assigned to this subzone during Phase 1 of the GIS – initiative.

In subzone A Parareptilia are represented by *Procolophon* (Table 4.2) which is accounted for in this study (Table 4.2). An additional component of subzone A is

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Paliguana (Hancox, 1998, 2000). There are no recordings in the database of this genus being present during *Cynognathus* Assemblage Zone times. Once the erroneous recording of *Paliguana* from the Albany Museum (Number: 4133) for the *Cistecephalus* Assemblage Zone is corrected, it may prove to be a representative of Subzone A of the *Cynognathus* Assemblage Zone.

Subzone B of the *Cynognathus* Assemblage Zone

Subzone B of the *Cynognathus* Assemblage Zone is based on the combined presence of the amphibians, *Xenotosuchus* (accounted for in Table 4.2) and *Batrachosuchus* (Hancox *et al.*, 1995; Shishkin *et al.*, 1995), accounted for in Table 4.2 together with the archosauromorph *Erythrosuchus* (accounted for in Table 4.2) (Hancox *et al.*, 1995; Shishkin *et al.*, 1995). In Olenekian rocks of the Beaufort, a new archosauromorph, very similar to the genus *Garjainia* known from the Yarenskian horizon of Russia has been discovered (Hancox & Rubidge, 1997) and appears to be phylogenetically between *Proterosuchus* and *Erythrosuchus* from the slightly younger Anisian rocks of the *Cynognathus* B Assemblage Zone (Hancox *et al.*, 1995; Hancox, 2000). The 20 specimens of *Garjainia* are taken to refer to this discovery for this study.

Representative groups further include additional amphibians such as *Trematosuchus* - accounted for in Table 4.2, archosauromorphs (*Palacrodon* - accounted for in Table 4.2, *Howesia* - accounted for in Table 4.2, *Mesosuchus* - accounted for in Table 4.2, and *Euparkeria* - accounted for in Table 4.2), therocephalians (*Bauria* - accounted for

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in Table 4.2 and *Melinodon* – not recorded in the original museum collections), dicynodonts (*Kannemeyeria* and *Kombuisia* - accounted for in Table 4.2), and parareptiles (*Thelegnathus* - accounted for in Table 4.2 and *Myocephalus* – lacking assemblage zone classification).

Cynodont representatives from subzone B are *Cynognathus* (accounted for in Table 4.2), *Diademodon* (accounted for in Table 4.2) and *Trirachodon* (accounted for in Table 4.2). Hopson and Kitching (2001) recently described *Lumkuia fuzzi* from the *Cynognathus* Assemblage Zone, as the oldest probainognathid and the first member of the family from South Africa – a clade previously known only from the Middle and Upper Triassic of Argentina (Martinez *et al.*, 1996) (Table 4.12, Table 4.2 & Figure 4.3).

Subzone C of the *Cynognathus* Assemblage Zone

A new tetrapod fauna, previously unknown from South Africa, has been recognised recently from the uppermost Beaufort Group (Hancox, 1998; Hancox & Rubidge, 1994, 1996, 1997). This assemblage, informally known as the *Cynognathus* subzone C, is based on the presence of the amphibians *Microposaurus* and *Paracyclotosaurus* (Hancox *et al.*, 2000b), both accounted for in Table 4.2. The single specimen of *Paracyclotosuchus* is taken to be *Paracyclotosaurus* for this study (Appendix F).

Dicynodonts in this subzone are represented by *Angonisaurus*, *Shansiodon* (accounted for in Table 4.2) and the possible presence of *Dolichuranus* (not recorded

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in the Raw Datasets) (Hancox, 1998). Cynodonts are represented by *Cricodon* (not recorded in the original museum collection datasets) (Abdala *et al.*, 2005).

The gorgonopsian genus *Arctognathus,* the therocephalian genera *Aelurosuchus* and *Sesamodontoides,* the dicynodont genera *Diictodon* and *Placerias* as well as the cynodont genera *Procynosuchus* and *Sysphinctostoma* are erroneously recorded as being present during *Cynognathus* Assemblage Zone times (Table 4.2; Appendix F). The assemblage zone data of these records will be corrected during Phase 1 of the GIS-initiative.

Finally, the 93 unidentified amphibians, 11 unidentified archosauromorphs, 76 unidentified cynodonts, 11 unidentified dicynodonts, 57 unidentified parareptiles and 3 unidentified therocephalians recorded for the *Cynognathus* Assemblage Zone are unable to be relegated to an appropriate subzone.

4.4 Ecological representation per assemblage zone

Tetrapod generic biodiversity in the different biozones of the Beaufort Group has been presented, but in order to holistically interpret the total biodiversity it is necessary to include the relative abundance of these genera to eliminate treating rare and common genera equally. Furthermore, it is necessary to determine which genera

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are most common in a community, as dominant genera are major players in defining the organisation of a community (Krebs, 1994).

Because the depositional history of the Beaufort Group covers an extended period from the Middle Permian to Middle Triassic, a period of at least 35 million years (Anderson, 1999), it affords a unique opportunity to study changes in ecological representation over this period. In addition, the division of the Beaufort Group into "time slices" by means of the biozonation scheme (Kitching, 1977; Keyser & Smith, 1979; Rubidge, 1995) has enabled the determination of ecological representation of vertebrates for each time slice (biozone).

This study is the first which is able to address the number of individuals of any taxonomic group which have been collected from all museum collections in South Africa, thus making it possible to study the total ecological representation of terrestrial vertebrates in Gondwana from the Middle Permian to the Middle Triassic.

In order to achieve this it was necessary to categorise the various taxa into their relative trophic levels (Krebs, 1994) and to calculate the relative percentage of representation of each trophic level for each biozone. Only those tetrapod records which have accompanying assemblage zone data recorded in the museum datasets are included in this analysis.

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The assignment of taxa to either a carnivorous, herbivorous or an omnivorous trophic level was assessed through collaboration with colleagues at the Bernard Price Institute, specialising in specific taxonomic groups: amphibians were assessed by Damiani with literature affirmation by Warren & Black (1985), Shishkin *et al.* (1996) and Schoch (1998); archosauromorphs, diapsids and eosuchians were assessed by both Yates and Vasconcelos with literature affirmation by Welman & Flemming, (1993) and Welman (1995); biarmosuchians, dinocephalians, therocephalians and pelycosaurs were assessed by Rubidge with literature affirmation by Van den Heever, (1994); Rubidge & Sidor (2001), Rubidge & van den Heever (1997), Rubidge *et al*. (1983), Rubidge (1994); gorgonopsians were assessed by Renaut with literature affirmation by Sigogneau-Russell (1989) and Maisch (2002); dicynodonts were assessed through literature affirmation by King (1988), Rubidge *et al.* (1994), Ruben (1986) and Renaut (2001); cynodonts were assessed by Abdala with literature affirmation by Neveling *et al.* (2001) and Kemp (1982) and parareptiles were assessed by both Cisneros and Yates with literature affirmation by Reisz & Laurin (1991), Modesto & Damiani (2000), Lee (1995, 1997a,b).

4.4.1 *Eodicynodon* Assemblage Zone

For the *Eodicynodon* Assemblage Zone the genera were categorised into the following trophic levels:

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Carnivore

No amphibians from this biozone have been identified to genus level (Table 4.3). Without knowledge of the genera present in this biozone, the generalised mode of a scavenger-like (carnivorous) feeding style has been applied to indeterminate amphibians. All gorgonopsian genera, including unidentified gorgonopsians (Table 4.3) were categorised as carnivores. All Permian therocephalian genera, including unidentified therocephalians (Table 4.3) were categorised as carnivores. Therocephalian genera for this biozone include *Alopecodon* and *Glanosuchus.* For dinocephalians, *Australosyodon* was assigned to a carnivorous trophic level

Herbivore

All anomodont genera, including unidentified dicynodonts (Table 4.3) were categorised as herbivores. Anomodont genera for this biozone include *Eodicynodon* and *Patranomodon.* For dinocephalians, *Tapinocaninus* was assigned to a herbivorous trophic level.

Dinocephalians occupied all three ecological feeding niches (carnivore, herbivore and omnivore) (Boonstra, 1969) so that it is not possible to apply a trophic level to unidentified dinocephalian specimens. Accordingly indeterminate dinocephalian specimens could not be calculated in the ecological representation ratios for this biozone. The dicynodont *Lanthanostegus* is erroneously recorded as coming from this

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biozone (Appendix F). Accordingly it was not calculated in the ecological representation ratios for this biozone.

Of the 70 specimens calculated from this biozone (Table 4.3), 53 are herbivorous and 17 are carnivorous, meaning that 76% of the faunal assemblage of the *Eodicynodon* Assemblage Zone was herbivorous and 24% carnivorous. The ratio of herbivores to carnivores for this biozone is 3:1 (Table 4.13).

4.4.2 *Tapinocephalus* Assemblage Zone

For the *Tapinocephalus* Assemblage Zone the genera were categorised into the following trophic levels:

Carnivore

Amphibians are represented by *Rhinesuchus* (Table 4.4). The generalised mode of a scavenger-like (carnivorous) feeding style has been applied to unidentified amphibians. For pelycosaurs *Elliotsmithia* was assigned to a carnivorous trophic level. All biarmosuchian genera, including unidentified biarmosuchians (Table 4.4) were categorised as carnivores. Biarmosuchians are represented by *Hipposaurus*. All gorgonopsian genera, including unidentified gorgonopsians (Table 4.4) were categorised as carnivores. Gorgonopsians are represented by *Arctops.* All Permian therocephalian genera, including unidentified therocephalians (Table 4.4) were

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categorised as carnivores. Therocephalian genera for this biozone include *Alopecodon, Cynariognathus, Glanosuchus, Hyaenasuchus, Pardosuchus, Pristerognathus, Scaloposaurus* and *Trochosuchus* (Appendix F). For dinocephalians, *Anteosaurus* was assigned to a carnivorous trophic level.

Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.4) were categorised as herbivores. Dicynodont genera for this biozone include *Chelydontops, Diictodon* and *Pristerodon.* The anomodonts *Galechirus* and *Galeops* were categorised as herbivores. For dinocephalians the following genera were assigned to a herbivorous trophic level: *Avenantia; Delphinognathus, Eccasaurus; Jonkeria; Keratocephalus; Moschops; Scapanodon; Struthiocephalus; Styracocephalus; Tapinocephalus;* and *Titanosuchus.* All parareptiles, including unidentified parareptiles were categorised as herbivores for this biozone. Parareptile genera for this biozone include *Bradysaurus*, *Embrithosaurus*, *Eunotosaurus* and *Nochelesaurus*.

Dinocephalians occupied all three ecological feeding niches (carnivore, herbivore and omnivore) (Boonstra, 1969) so that it is not possible to apply a trophic level to unidentified dinocephalian specimens. Accordingly indeterminate dinocephalian specimens could not be calculated in the ecological representation ratios for this biozone. *Dicynodon, Oudenodon, Pareiasaurus* and *Tropidostoma* were erroneously recorded as being present during *Tapinocephalus* Assemblage Zone times (Appendix

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F). An additional elimination from the ecological ratios below is the indeterminate trophic level for the single *Dinosuchus* specimen and *Anningia* (Table 4.4). Accordingly, these genera were not calculated in the ecological representation ratios for this biozone.

Of the 238 specimens calculated from this biozone (Table 4.4), 158 are herbivorous and 80 are carnivorous, meaning that 66% of the faunal assemblage of the *Eodicynodon* Assemblage Zone was herbivorous and 34% carnivorous. The ratio of herbivores to carnivores for this biozone is 2:1 (Table 4.13).

4.4.3 *Pristerognathus* Assemblage Zone

For the *Pristerognathus* Assemblage Zone the genera were categorised into the following trophic levels:

Carnivore

All Permian therocephalian genera, including unidentified therocephalians (Table 4.5) were categorised as carnivores. Therocephalian genera for this biozone include *Ictidosuchoides* and *Pristerognathus.*

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Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.5) were categorised as herbivores. Dicynodont genera for this biozone include *Diictodon* and *Pristerodon.*

Oudenodon, Rhachiocephalus and *Tropidostoma* were erroneously recorded as being present during *Pristerognathus* Assemblage Zone times (Appendix F; Table 4.5). Accordingly, these genera were not calculated in the ecological representation ratios for this biozone.

Of the 24 specimens calculated from this biozone (Table 4.5), 20 are herbivorous and 4 are carnivorous, meaning that 83% of the faunal assemblage of the *Pristerognathus* Assemblage Zone was herbivorous and 17% carnivorous. The ratio of herbivores to carnivores for this biozone is 5:1 (Table 4.13).

As mentioned earlier, the *Pristerognathus* Assemblage Zone is a relatively new addition to the biozonation scheme for the Beaufort Group (Keyser & Smith, 1977) and the only three of the museum collections document recordings from this biozone. Records stating alignment to the *Pristerognathus* Assemblage Zone comprises 0.16% of overall data – this makes the ratio of 5:1 (herbivores: carnivores) for this biozone a potentially doubtful result.

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4.4.4 *Tropidostoma* Assemblage Zone

For the *Tropidostoma* Assemblage Zone the genera were categorised into the following trophic levels:

Carnivore

Amphibians are represented by *Rhinesuchus* (Table 4.6). The generalised mode of a scavenger-like (carnivorous) feeding style has been applied to unidentified amphibians. For eosuchians *Youngina* was assigned to a carnivorous trophic level. All gorgonopsian genera, including unidentified gorgonopsians (Table 4.6) were categorised as carnivores. Gorgonopsians are represented by *Aelurognathus* (Appendix F), *Aelurosaurus* (Appendix F), *Gorgonops* and *Scylacognathus* (Appendix F). All Permian therocephalian genera, including unidentified therocephalians (Table 4.6) were categorised as carnivores. Therocephalian genera for this biozone include *Hofmeyeria*, *Ictidosuchoides*, *Ictidosuchops* and *Ictidosuchus.*

Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.4) were categorised as herbivores. Dicynodont genera for this biozone include *Cistecephalus; Diictodon; Emydops; Emydopsis* (Appendix F)*; Endothiodon; Eumantellia; Palemydops; Pristerodon; Rhachiocephalus* and *Tropidostoma,* which gives a total of

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802 dicynodont specimens for the *Tropidostoma* Assemblage Zone. All parareptiles, including unidentified parareptiles were categorised as herbivores for this biozone. Identified parareptiles are represented by *Pareiasaurus.* The captorhinid *Saurorictus* was assigned to a herbivorous trophic level (Table 4.6).

Clelandina, Dicynodon, Oudenodon and *Trirachodon* were erroneously recorded as being present during *Tropidostoma* Assemblage Zone times (Appendix F; Table 4.6). Accordingly, these genera were not calculated in the ecological representation ratios for this biozone.

Of the 840 specimens calculated from this biozone (Table 4.6), 806 are herbivorous and 34 are carnivorous, meaning that 96% of the faunal assemblage of the *Tropidostoma* Assemblage Zone was herbivorous and 4% carnivorous. The ratio of herbivores to carnivores for this biozone is 24:1 (Table 4.13). However as the *Tropidostoma* Assemblage Zone is a relatively new biozone, this ratio may not be accurate.

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4.4.5 *Cistecephalus* Assemblage Zone

For the *Cistecephalus* Assemblage Zone the genera were categorised into the following trophic levels:

Carnivore

Amphibians are represented by *Rhinesuchus* (Table 4.8). The generalised mode of a scavenger-like (carnivorous) feeding style has been applied to unidentified amphibians. For eosuchians, *Youngina* was assigned to a carnivorous trophic level. Because *Youngina* is the only representative from this biozone, is has been assumed that the six unidentified eosuchians are specimens of *Youngina*. All biarmosuchian genera (Table 4.8) were categorised as carnivores and are represented by *Lemurosaurus*. All gorgonopsian genera, including unidentified gorgonopsians (Table 4.8) were categorised as carnivores. Gorgonopsians are represented by *Aelurognathus; Aelurosaurus; Aloposaurus; Arctognathus; Arctops; Broomicephalus; Clelandina; Cynarioides; Cyniscops; Cyonosaurus; Dinogorgon; Galerhynchus; Gorgonops; Lycaenops; Prorubidgea; Rubidgea; Scylacognathus; Scylacops; Scymnognathus; Smilesaurus* and *Sycosaurus.*

All Permian therocephalian genera, including unidentified therocephalians (Table 4.8) were categorised as carnivores. Therocephalian genera for this biozone include *Alopecopsis; Euchambersia; Hofmeyeria; Homodontosaurus; Ictidostoma;*

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Ictidosuchoides; Ictidosuchops; Nanictocephalus; Proalopecopsis; Tetracynodon and *Theriognathus* (Table 4.8). Carnivorous parareptiles include *Owenetta* and *Polycynodon* (Appendix F).

Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.8) were categorised as herbivores. Dicynodont genera for this biozone include *Aulacephalodon, Cistecephalus, Dicynodontoides, Diictodon, Dinanomodon, Emydops, Emydorhinus* (Appendix F), *Endothiodon, Kingoria, Oudenodon, Palemydops, Pelanomodon, Platycyclops, Pristerodon* and *Rhachiocephalus.* The herbivorous assemblage of this biozone comprises 2422 valid dicynodont specimens. The majority are *Cistecephalus* (225 records) and *Oudenodon* (212 records). The number of specimens not yet classified to genus level, is 1747 (70% of the dicynodonts of this biozone). The parareptiles *Anthodon, Nanoparia, Pareiasaurus and Pareiasuchus* were assigned to a herbivorous trophic level (Table 4.8).

Various representatives of parareptiles, eosuchians, archosauromorphs and cynodonts occupied all three ecological feeding niches so it is not possible to apply a trophic level to unidentified specimens of these taxa. Accordingly these unidentified specimens could not be calculated in the ecological representation ratios for this biozone.

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The following genera are erroneously recorded as being present during *Cistecephalus* Assemblage Zone times (Appendix F; Table 4.8) and accordingly were not used in the calculation of ecological representation ratios for this biozone: amphibians: *Lydekkerina* and *Muchocephalus;* biarmosuchians: *Lycaenodon, Hipposaurus* and *Rubidgina;* therocephalians: *Akidonognathus, Hewittia, Moschorhinus, Moschorhynchus* and *Sesamodon;* dicynodonts: *Daptocephalus, Dicynodon, Lystrosaurus, Myosauroides, Tetrgonias* and *Tropidostoma;* cynodonts: *Cynosaurus, Nanictosuchus, Procynosuchus, Scalopocynodon, Silpholestes* and *Tritylodontoides* and parareptiles: *Milleretta, Nanomilleretta* and *Paligunana.*

Of the 2923 specimens calculated from this biozone (Table 4.8), 2454 are herbivorous and 469 are carnivorous, meaning that 84% of the faunal assemblage of the *Cistecephalus* Assemblage Zone was herbivorous and 16% carnivorous. The ratio of herbivores to carnivores for this biozone is 5:1 (Table 4.13).

4.4.6 *Dicynodon* Assemblage Zone

For the *Dicynodon* Assemblage Zone the genera were categorised into the following trophic levels:

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Carnivore

Amphibians are represented by *Rhinesuchus* (Table 4.9). The generalised mode of a scavenger-like (carnivorous) feeding style has been applied to unidentified amphibians. For eosuchians *Saurosternon, Youngina, Youngoides* (Appendix F) and *Youngopsis* (Appendix F) were assigned to a carnivorous trophic level (Table 4.9). All gorgonopsian genera, including unidentified gorgonopsians (Table 4.4) were categorised as carnivores. Gorgonopsians are represented by *Aelurognathus* (Appendix F), *Arctops, Broomisaurus, Cerdops, Cyniscops, Cyonosaurus, Dinogorgon, Galerhynchus, Leontocephalus, Lycaenops, Paragalerhinus, Prorubidgea and Rubidgea* (Table 4.9).

All Permian therocephalian genera, including unidentified therocephalians (Table 4.4) were categorised as carnivores. Therocephalian genera for this biozone include *Ictidochampsa, Ictidosuchoides, Ictidosuchops, Moschorhinus, Nanictidops, Notosollasia, Pelictosuchus, Promoschorhynchus, Scaloposuchus, Tetracynodon, Theriognathus* and *Whaitsia* (see Chapter 2). Therocephalians from this biozone are dominated in numbers by *Theriognathus* (7) and *Moschorhinus* (8) (Table 4.9). Carnivorous cynodonts are represented by *Procynosuchus*. Carnivorous (i.e insectivorous) parareptiles are represented by *Millerenoides* (Appendix F), *Milleretta*, *Millerettoides* (Appendix F), *Milleretops* (Appendix F), *Millerosaurus*, *Owenetta* and *Spondylestes* (Table 4.9).

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Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.9) were categorised as herbivores. Dicynodont genera for this biozone include *Aulacephalodon, Daptocephalus* (see Chapter 2), *Dicynodon, Dicynodontoides, Diictodon, Dinanomodon, Emydops, Kingoria, Oudenodon, Pelanomodon, Pristerodon and Propelanomodon.* Dicynodonts from this biozone are dominated by *Dicynodon* with 43 and *Oudenodon* with 62 specimens. Dicynodont specimens not yet classified to genus level, number 315 (67% of the dicynodonts of this biozone). The parareptile *Pareiasaurus* was assigned to a herbivorous trophic level.

Omnivore

The omnivores (insectivores and plant-eaters) recorded for this biozone are the eight cynodont specimens from the following genera: *Cynosaurus, Megalesaurus* (Appendix F), *Mygalesaurus* and *Nanictosaurus* (Table 4.9).

Various representatives of parareptiles, cynodonts, diapsids and eosuchians occupied all three ecological feeding niches (carnivore, herbivore and omnivore) so that it is not possible to apply a trophic level to any unidentified members of these taxa. Accordingly these records could not be calculated in the ecological representation ratios for this biozone.

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The following genera are erroneously recorded as being present during *Dicynodon* Assemblage Zone times (Appendix F; Table 4.9) and accordingly were not used in the calculation of ecological representation ratios for this biozone: gorgonopsians: *Gorgonops;* dicynodonts: *Lystrosaurus, Platycyclops, Rhachiocephalus* and *Tropidostoma;* cynodonts: *Thrinaxodon* and parareptiles: *Procolophon.*

Of the 598 specimens calculated from this biozone (Table 4.9), 462 are herbivorous, 128 are carnivorous and 8 are omnivorous, meaning that 77% of the faunal assemblage of the *Dicynodon* Assemblage Zone was herbivorous, 21% carnivorous and 2% omnivorous. The ratio of herbivores to carnivores to omnivores for this biozone is 40:10:1. The ratio of herbivores to carnivores (without considering the influence of omnivores for comparative purposes) is 4:1 (Table 4.13).

4.4.7 *Lystrosaurus* Assemblage Zone

For the *Lystrosaurus* Assemblage Zone the genera were categorised into the following trophic levels:

Carnivore

Carnivorous specimens from this biozone include unidentified amphibians as well as the following amphibian genera: *Broomistega*, *Eolydekkerina*, *Lydekkerina*, *Micropholis* and *Pneumatostega* (Table 4.10). For archosauromorphs *Elaphrosuchus*

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(Appendix F), *Prolacerta* and *Proterosuchus* were assigned to a carnivorous trophic level (Table 4.10). For eosuchians *Noteosuchus* was assigned to a carnivorous trophic level (Table 4.10).

Triassic carnivorous therocephalians are represented by the following genera (Table 4.10): *Cerdosuchoides, Ericiolacerta, Moschorhinus, Olivieria* (=*Oliveriosuchus* [Kammerer & Sidor, 2002]), *Regisaurus, Scaloposaurus* and *Tetracynodon*. All unidentified therocephalians were assigned to a carnivorous trophic level, as amongst these unidentified specimens there was no probability for potential representation of Triassic herbivorous bauriid therocephalians, as these are from the *Cynognathus* Assemblage Zone. Triassic carnivorous cynodonts are represented by the following genera: *Galesaurus, Platycraniellus* and *Thrinaxodon*. Carnivorous (insectivorous) parareptiles are represented by *Owenetta* and *Paliguana* (Table 4.10).

Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.10) were categorised as herbivores. Dicynodont genera for this biozone include *Dicynodon, Lystrosaurus* and *Myosaurus.* Dicynodonts total 2079 specimens with assemblage zone data. The value of 2079 for this biozone is dominated by *Lystrosaurus* (2037) which comprises 98% of the dicynodont count. The parareptile *Procolophon* was assigned to a herbivorous trophic level.

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Various representatives of archosauromorpha, eosuchians, diapsids, cynodonts and parareptiles occupied all three ecological feeding niches (carnivore, herbivore and omnivore) so that it is not possible to apply a trophic level to any unidentified members of these taxa. Accordingly these records could not be calculated in the ecological representation ratios for this biozone.

The following genera are erroneously recorded as being present during *Lystrosaurus* Assemblage Zone times (Appendix F; Table 4.10) and accordingly were not used in the calculation of ecological representation ratios for this biozone: amphibians: *Kestrosaurus, Rhinesuchus, Trematosuchus, Uranocentrodon* and *Xenotosuchus;* therocephalians: *Ictidosuchoides* and *Ictidosuchops:* dicynodonts: *Dinanomodon*, *Emydops, Prolystrosaurus* and *Oudenodon;* cynodonts: *Cynosaurus*, *Glochinodontoides, Nanictosaurus* and *Progalesaurus;* unidentified taxa: *Glochinodon* and *Micrictodon.*

The gorgonopsians recorded from the *Lystrosaurus* Assemblage Zone (Table 4.2; Table 4.10) - a single *Cyonosaurus* record (Number: 3895 from Oliviershoek Pass) and a single indeterminate gorgonopsian (Number: 4593 from Fairydale), both from the BPI (Table 3.39) are erroneous (Appendix F) as gorgonopsians became extinct at the end of the Permian (Kitching, 1995). The *Cyonosaurus* specimen however, was from the *Lystrosaurus* Assemblage Zone but according to Kitching *pers. comm*, it

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was reworked. These records have therefore been excluded in the ecological representation calculation for carnivores of this biozone.

Of the 2663 specimens calculated from this biozone (Table 4.10), 2293 are herbivorous and 370 are carnivorous, meaning that 86% of the faunal assemblage of the *Lystrosaurus* Assemblage Zone was herbivorous and 14% carnivorous. The ratio of herbivores to carnivores for this biozone is 6:1 (Table 4.13).

4.4.8 *Cynognathus* Assemblage Zone

For the *Cynognathus* Assemblage Zone the genera were categorised into the following trophic levels:

Carnivore

Carnivorous specimens from this biozone include unidentified amphibians as well as the following amphibian genera: *Batrachosuchus*, *Kestrosaurus*, *Microposaurus*, *Paracyclotosaurus* (Appendix F), *Paracyclotosuchus* (Appendix F), *Parotosuchus*, *Trematosuchus* and *Xenotosuchus* (Table 4.11). For archosauromorphs *Erythrosuchus*, *Euparkeria*, *Garjainia*, *Howesia* and *Mesosuchus* were assigned to a carnivorous trophic level (Table 4.11). For eosuchians *Palacrodon* was assigned to a carnivorous trophic level (Table 4.11). Carnivorous cynodonts are represented by the following genera (Table 3.11): *Cynognathus* and *Lumkuia*.

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Herbivore

All dicynodont genera, including unidentified dicynodonts (Table 4.11) were categorised as herbivores. Dicynodont genera for this biozone include *Angonisaurus*, *Kannemeyeria*, *Kombuisia* and *Shansiodon.* Herbivory is also assigned to the Therocephalian *Bauria,* the cynodont *Diademodon* as well as the parareptile genus *Thelegnathus.*

Omnivore

A single cynodont genus, *Trirachodon* (65 specimens with assemblage zone data) is assigned to the omnivorous trophic level (Table 4.11).

Various representatives of archosauromorphs, cyndonts and parareptiles occupied all three ecological feeding niches (carnivore, herbivore and omnivore) so that it is not possible to apply a trophic level to any unidentified members of these taxa. Accordingly these records could not be calculated in the ecological representation ratios for this biozone. Furthermore, the indeterminate specimen count for therocephalians was discarded in the calculation of ecological representation because there may be representatives of Triassic herbivorous bauriid therocephalians amongst indeterminate therocephalian specimens.

The following genera are erroneously recorded as being present during *Cynognathus* Assemblage Zone times (Appendix F; Table 4.11) and accordingly were not used in

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the calculation of ecological representation ratios for this biozone: therocephalians: *Aelurosuchus* and *Sesamodontoides:* dicynodonts: *Diictodon* and *Placerias* (National Museum: Number 3338 from Vanstadensrus)*;* cynodonts: *Procynosuchus* and *Sysphinctostoma* (Rubidge Collection, Number RC113: Holotype) and parareptiles: *Procolophon.*

The gorgonopsians recorded for the *Cynognathus* Assemblage Zone (Table 4.2; Table 4.11) - a single *Arctognathus* record (AM Number: 324 from Stewards Farm) and two indeterminate gorgonopsians (BPI Number: 5878 from Eden 96 and NM Number 1152 from Badskop), are erroneous (Appendix F). These records have therefore been excluded in the ecological representation calculation for carnivores of this biozone.

Of the 614 specimens calculated from this biozone (Table 4.11), 269 are herbivorous, 280 carnivorous and 65 omnivorous, meaning that 44% of the faunal assemblage of the *Cynognathus* Assemblage Zone was herbivorous, 45% carnivorous and 11% omnivorous. The ratio of herbivores to carnivores to omnivores for this biozone is approximately: 4:4:1 (Table 4.13). The ratio of herbivores to carnivores (without considering the influence of omnivores for comparative purposes) is 1:1 (Table 4.13).

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4.4.9 Ecological representation summary

The average domination by herbivores in terms of numbers of individuals in the ecological structure of Permo-Triassic tetrapods is 76% (this value calculated as the mean herbivore percentage across the eight assemblage zones). The average representation by carnivores in terms of numbers of individuals in the ecological structure of Permo-Triassic tetrapods is 22% and omnivores 2%. This approximates a 3:1 ratio of herbivores to carnivores for the Beaufort Group and a 38:11:1 ratio of herbivores to carnivores to omnivores for the Beaufort Group (Table 4.13). According to Martinez (1991) the ratio of three prey species for every predator species in food webs is viable. The ratio calculated for this study of three prey species for every predator makes sense in the increasingly arid environment of the Middle Permian to Middle Triassic (Smith *et al.*, 1993), where the lower energy requirements of the reptilian predators could support such a ratio (Plough, 1980). Their modest energy requirements allow amphibians and reptiles to exploit various adaptive zones such as ecological situations characterised by periodic shortages of food, water, or oxygen (Pough, 1980). Therefore the ratio of 3:1 seems to support the increasingly arid environment of the Middle Permian to Middle Triassic. Further argument supporting such an interpretation of the 3:1 predator:prey ratio is observed in the Cleveland-Lloyd Dinosaur Quarry, where drought appears to be most consistent with available data as an explanation for this ratio (Gates, 2004), as opposed to the more

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traditional interpretation that the quarry represents a “predator trap”. Additional support comes from modern drought analogues (Gates, 2004).

The ratio of 24:1 for herbivores to carnivores (Table 4.13) as observed from the *Tropidostoma* Assemblage Zone may be because this biozone is not recognised in all collections and has apparently not been properly sampled. 99% of the total herbivorous population for this assemblage zone is dominated by dicynodonts (802 records out of 806 herbivore numbers). Of the 802 dicynodonts 529 (66%) are unidentified dicynodonts. This means that 63% of the bulk of individuals comprising the herbivorous trophic level for this assemblage zone is made up of unidentified dicynodonts. The domination of dicynodonts for this assemblage zone is the reason for the non-viable ratio of 24:1 (herbivores to carnivores). This ratio is non-viable because the food consumption of a top herbivore was approximately eight times that of a top carnivore (Burness *et al.*, 2001). The characteristic aridity of the period would result in a decrease in herbivore numbers because of the resultant autotroph abundance decrease. The environment simply could not support such high numbers of reptilian herbivores because there is a decrease in the biomass density of resources with warming (Vasseur & McCann, 2005). This is a tentative assumption because the effects of energy on food web structure have been debated for at least 80 years (Arim *et al.*, 2007). Nevertheless, the empirical evidence is meager, especially from terrestrial ecosystems. Further, the increase in food chain length with available energy probably represents an aggregate attribute, driven to a large extent by predators with

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higher consumption rates, rather than being the result of compensatory responses among predators (Arim *et al.,* 2007).

The ratio of 1:1 for herbivores to carnivores (Table 4.13) as observed for the *Cynognathus* Assemblage Zone is not in keeping with the constancy of ratios where herbivores outweigh carnivores in previous biozones. Such a ratio may be because of a collecting bias in favour of carnivores as no natural system could support such a ratio. Before *Cynognathus* Assemblage Zone times, the average percentage of herbivores from a particular assemblage zone was 76%. The representation of herbivores collected from the *Cynognathus* Assemblage Zone drops by almost half to 44%. It does appear that selective collecting activities occurred in the *Cynognathus* Assemblage Zone. This is shown by the very low number of unidentified dicynodonts (eleven) collected from this biozone (Table 4.2).

The general pattern that emerges regarding the ratio of herbivores to carnivores (apart from the *Tropidostoma* and *Cynognathus* Assemblage Zones mentioned above) is an overall increase in prey numbers from the *Eodicynodon* to the *Lystrosaurus* Assemblage Zone when compared to the consistency of predators (Table 4.13: Ratio Column). According to Rosenzweig & MacArthur (1963), differing equilibrium states will produce different feeding ratios: for example many predators will cause prey to decline; few predators will result in an increase in prey; many predators and much prey with excessive predation will drive prey numbers down. Therefore, two scenarios of disequilibrium in feeding ratios exist: prey increase or prey decrease.

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It appears that prey numbers were relatively low during *Eodicynodon* and *Tapinocephalus* Assemblage Zones times, signifying a disequilibrium state of prey decrease, while in the *Pristerognathus, Cistecephalus, Dicynodon* and *Lystrosaurus* Assemblage Zones a disequilibrium state of prey increase is observed. The existence of two scenarios of disequilibrium in feeding ratios is a response to an environmental cue and the regularity of one of these two scenarios existing during Permo-Triassic times suggests that they have been produced in conformity with a set of basic principles rather than as accidents of history (Spiller & Schoener, 1988). Disequilibrium states are the response of consumer-resource systems to increasing mean temperature (warming) (Vasseur & McCann, 2005). In addition, there is a decrease in the biomass density of resources with warming (Vasseur & McCann, 2005). These predictions are in line with many current observations and experiments (Vasseur & McCann, 2005).

Polis (1991) argues that actual community food webs are extraordinarily more complex than those webs catalogued by theorists, stating that most catalogued webs are oversimplified caricatures of actual communities. Complexity arises from the large number of interactive species, the frequency of omnivory, age structure, looping, the lack of compartmentalisation, and the complexity of the soil faunas. Consequently, the practice of abstracting empirical regularities (such as predator:prey ratios) from such catalogues (such as the Beaufort Group Database) yields an inaccurate and artifactual view of trophic interactions within communities (Polis,

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1991). That cataloged webs depict so few species, absurdly low ratios of predators on prey and prey eaten by predators (as observed for this study), so few links, so little omnivory, a veritable absence of looping, and such a high proportion of top predators strongly reveal that they poorly represent real biological communities (Polis, 1991). This is the main disadvantage of directly interpreting fossil abundance ratios and inferring that they reflect the ancient ecosystem. For now, the results shown here act as a guide because of the "trial-run" nature of this thesis. Once Phase 2 of the GIS-initiative has been implemented, only then would fleshing out the results make sense by introducing for example, the "Signor Lipps" compensation for rarity in the original ecosystem as well as the problem of "ghost taxa" complicating the observed extinction/survival ratios.

4.5 Biodiversity Trends

As pointed out in Section 4.4 because of the uniquely comprehensive record of Permian-Triassic terrestrial tetrapod biodiversity preserved in the rocks of the Beaufort Group, it is possible to study trends in biodiversity across this extended time period.

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4.5.1 Trends in generic diversity within and across assemblage zones

Establishing the extent of survival into a successive biozone and degree of extinction of genera within biozones was calculated from the percentage of terminated genera within a specific biozone and the degree of survivorship calculated from the remaining genera that have record of continuation into successive biozones. Because of the limitations of the database as regards accuracy of sampling, it is currently impossible to provide exact stratigraphic ranges of all genera. However, the biostratigraphic scheme makes it possible to assess generic biodiverisity across biozones and to determine the degree of biodiversity change/modification across successive biozones (Tables 4.14 – 4.20).

Analysis of the fossil distribution alone shows the percentage of genera that became extinct by the close of the *Eodicynodon* Assemblage Zone was 57%, and the survival rate into successive zone(s) was 43%. The percentage of genera that became extinct by the close of the *Tapinocephalus* Assemblage Zone was 74%, and the survival rate into successive zone(s) was 26%. The percentage of genera that became extinct by the close of the *Pristerognathus* Assemblage Zone was 8%, and the survival rate into successive zone(s) was 92%. The percentage of genera that became extinct by the close of the *Tropidostoma* Assemblage Zone was 12%, and the survival rate into successive zone(s) was 88%. The percentage of genera that became extinct by the close of the *Cistecephalus* Assemblage Zone was 45%, and the survival rate into

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successive zone(s) was 55%. The percentage of genera that became extinct by the close of the *Dicynodon* Assemblage Zone was 64%, and the survival rate into successive zone(s) was 36%. The percentage of genera that became extinct by the close of the *Lystrosaurus* Assemblage Zone was 82%, and the survival rate into the *Cynognathus* Assemblage Zone was 18%. (Refer to Tables 4.14 – 4.20 respectively; Figure 4.5). The focus in literature on the exclusivity of an extinction event at the Permo-Triassic boundary is diluted when viewed in the light of other drastic faunal turnover patterns in certain of the remaining assemblage zones.

The results above show that the assemblage zone with the highest degree of extinction of genera was the *Lystrosaurus* Assemblage Zone (Table 4.20). In the light of the end-Permian mass extinction event (Stanley & Yang, 1994; Smith & Botha, 2005; Erwin, 2006) this may be interpreted as a Permo-Triassic recovery fauna that only temporarily flourished in the altered environment at the onset of the Triassic – only to be replaced with an emerging 30 genera during *Cynognathus* (sub zone B) Assemblage Zone times, once conditions had stabilised (Table 4.20).

The *Tapinocephalus* Assemblage Zone yielded an extinction of 74% of the diversity of fauna (Table 4.15). This result quantifies the hypothesis of an extinction event during *Tapinocephalus* zone times where all four families of Dinocephalia disappeared, reflecting more than normal background extinction (Anderson, 1999).

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The low extinction rates in the successive *Pristerognathus* (8%) and *Tropidostoma* (12%) assemblage zones, suggest hiatus periods signifying episodes of stability (Tables 4.16; 4.17). After the extinction event, where 74% of genera disappeared by the close of the *Tapinocephalus* Assemblage Zone (Table 4.15), two genera: *Ictidisuchoides* and *Rhachiocephalus* emerge after the *Tapinocephalus* Assemblage Zone extinction event from the *Pristerognathus* Assemblage Zone (Table 4.16). This means that 17% of the faunal assemblage of this biozone is comprised of emergent fauna.

The high incidence of extinction in the *Eodicynodon* Assemblage Zone (57%) is most probably an artefact because of the smallness of the sample size. The low abundance and diversity of the biozone may have yielded a distorted result (Table 4.14).

The 45% extinction rate calculated by the close of the *Cistecephalus* Assemblage Zone signifies the onset of a gradual pattern of faunal diversity decline, up to the end of the *Lystrosaurus* Assemblage Zone (Figure 4.4: Green line). Such a pattern can be interpreted as evidence for lessening the proposed suddenness of the Permo-Triassic crisis on land (Smith & Ward, 2001).

The *Dicynodon* and *Lystrosaurus* Assemblage Zones register a net loss in generic diversity by the termination of each of these biozones, when compared to the *Tapinocephalus, Pristerognathus, Tropidostoma* and *Cistecephalus* Assemblage Zones which register a net gain in generic diversity by the termination of each of

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these biozones (Figure 4.4: Green line). Figure 4.4 shows the decline of generic diversity, with ever-increasing loss, after the close of the *Cistecephalus* Assemblage Zone. The general pattern that emerges is that there is an increase in overall generic diversity until some time during the *Dicynodon* Assemblage Zone (Figure 4.4: Red line). In this biozone, the diversity of genera is reduced by 64% (22 surviving genera from 61), with the diversity continuing then to decrease in subsequent biozones. By comparison, the faunal content of the *Tropidostoma* Assemblage Zone shows a 48% increase in diversity, adding to the original diversity of 13 genera (12 genera appear sometime during *Tropidostoma* Assemblage Zone times) and only a 12% faunal loss by the end of the biozone (Table 4.17; Figure 4.4). (Refer to p.119 of Volume II for an explanation of the methodology used to draw Figure 4.4). The results described here only provide a summary of net gains, losses or stability within the assemblage zones of the Beaufort Group.

The 22 genera that survived from the *Tropidostoma* Assemblage Zone (Table 4.17) into the *Cistecephalus* Assemblage Zone experienced seemingly favourable environmental circumstances as the period of time embodied by the *Cistecephalus* Assemblage Zone appears to be characterised by a period of generic radiation, shown by the increase in generic diversity. 43 valid genera (Appendix F) emerged sometime during *Cistecephalus* Assemblage Zone times (Table 4.18). This translates to 64% of the faunal assemblage comprised of emerged genera. Under half (45%) of the total generic diversity of this biozone became extinct sometime within the period of time

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embodied by the *Cistecephalus* Assemblage Zone, with over half (55%) managing to cross over in to the *Dicynodon* Assemblage Zone.

Comparing the newly emerging fauna of the *Cistecephalus* and *Dicynodon* assemblage zones, it was calculated, by comparing emerging ratios, that the *Cistecephalus* Assemblage Zone experienced a 64% emergence of new genera (Table 4.18), whereas the fauna of the *Dicynodon* Assemblage Zone, subjected to increasing arid depositional conditions (Smith, 1990; Smith *et al.*, 1993) experienced half the expansion of generic diversity, with only 31% of newly emerged fauna recorded before the end of the Permian (Table 4.19). This interpretation of the Beaufort Group environment is consistent with data on the global aridification of Pangaea during the earliest Triassic (Shishkin & Ochev, 1993; Shishkin, 1997).

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Chapter 5: Conclusion

5.1 Conclusion

This study has resulted in the establishment, for the first time, of a single standardised GIS database incorporating all vertebrate fossils from the rocks of the Beaufort Group. As the Karoo geological succession preserves the most complete record of Middle Permian to Middle Triassic continental tetrapod biodiversity a study of this nature is of great importance for an understanding of Karoo biodiversity changes and for basin modeling.

In setting up the foundations of the digitised GIS database (this thesis) incorporating all the fossil vertebrate data from the rocks of the Beaufort Group, numerous problems had to be overcome. These problems are highlighted in Chapter 6 and relate largely to the standardisation, screening and streamlining of data from different museum collection catalogues. In addition a methodology was developed in order to make the GIS database a useful analytical tool, and led to the development of a single database of fossil vertebrate fauna from the rocks of the Beaufort Group (referred to throughout the thesis as the “Beaufort Group database”).

Establishment of the Beaufort Group database has resulted in the creation of research aids which can be utilised to answer questions relating to Permo-Triassic continental

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vertebrate biodiversity. The resulting databases manifest generic diversity in the Beaufort Group, with specific reference to the housing of particular genera, including numbers of specimens of each genus and their respective locality and/or assemblage zone data. This unique dataset provides a record of fossil vertebrate continental biodiversity from the Middle Permian to the Middle Triassic, and shows accurate numbers of specimens of the various taxa which have been collected.

The study revealed that 29 968 fossils have been collected, comprising 271 distinct identifications recognised from this database. In addition this study has determined the number of individuals collected of each genus and the relative numbers of each genus.

The database manifests which genera occur in different biozones and the numbers of individuals of each genus in successive biozones. Because of limitations imposed by the nature of data recording in collection catalogues, it is not possible (from this database) to determine accurate stratigraphic ranges of taxa. However this study has highlighted biodiversity changes across successive biozones, and so it has been possible to calculate the extent of extinction of taxa within successive time slices. This has allowed for the determination of trends in biodiversity changes through time.

An overall increase of genera is noted from the base of the succession until the end of the *Cistecephalus* Assemblage Zone, where after there is a decline in generic diversity. The *Cistecephalus* Assemblage Zone is characterised by a period of

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radiation of numbers of genera. In comparison, the *Dicynodon* Assemblage Zone, subjected to increasingly arid depositional conditions (Smith & Botha, 2005), has less than half the number of genera recorded for the *Cistecephalus* Assemblage Zone. A diverse Permo-Triassic extinction recovery fauna is present in the *Lystrosaurus* Assemblage Zone and is almost completely (80%) replaced by an emergent fauna in *Cynognathus* Assemblage Zone times.

The assignation of trophic levels to each genus has allowed for the determination of relative numbers of individuals from different trophic levels for each vertebrate biozone. The ratio of herbivores appears to increase through time such that for the *Eodicynodon* Assemblage Zone this ratio is 3:1 while that for the *Lystrosaurus* Assemblage Zone is 6:1. An anomalous situation is present in the *Cynognathus* Assemblage Zone, the youngest biozone, where the ratio is 1:1 and is probably the result of collecting bias for carnivores. A ratio of between 3:1 and 6:1, which is a relatively low prey-predator ratio, is indicative of an arid environment when dealing with the lower energy requirements of non-homeothermic animals (Martinez, 1991).

An important product of this database is that it is now possible for researchers to identify museums which curate the largest sample of any particular taxon and will thus facilitate future research. In addition it has highlighted problems in the fossil record and where future collecting should be undertaken.

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Chapter 6: The Way Forward

6.1 Introduction

The original intention of this project was to combine all the South African databases of vertebrate fossils from the Beaufort Group onto a geographical information system which could be utilised to address issues relating to Permo-Triassic continental tetrapod biodiversity. In the process of setting up this expanded GIS database system it became apparent that the course of action is not simply a matter of combining all the databases and coming up with answers. This is largely because of a lack of consistency of data in the different collections, as has been highlighted in Chapter 2, but also because, for most of the records, precise GPS co-ordinates of localities of fossils are not recorded, and only a farm locality is given. This involved a great amount additional work in order to make the data useable for future projects. These projects are beyond the scope of this thesis, but are discussed here to encourage and facilitate further research using this database resource, as well as to identify opportunities.

This chapter addresses the following issues, some of which have been partially addressed in Chapter 2:

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(1) Highlighting gaps and pitfalls that became evident when fulfilling the requirements of the foundation phase of the mapping project.

(2) Challenges encountered during the mapping process.

(3) Proposing future modes of action, to improve alignment with the criteria established for digital geospatial data.

(4) Suggestions for improving the current success rate of digitising fossil localities

6.2 Development of a Beaufort Group spatial map

The *foundation/pilot phase* of the GIS project is completed, and can be viewed on GIS CD'S 1 – 4. The description of the methodology and processes involved in completing the *foundation* phase is set out in Chapter 2. Consequent stages of this GIS-project, which fall outside the scope of this thesis, will involve the further development and refinement of the Spatial Map of Beaufort Group fossil specimens. The additional refinement will result in a reliable product that may be used as an analytical and research tool. What needs to be done to realise this goal, can be addressed in two phases:

- Phase 1: Advanced development of Spatial Model.
- Phase 2: Biological interpretation of the Beaufort Group.

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Phase 1 will involve the complete conversion of alphanumeric data to spatial data. The adopted procedure involved in converting textual locality information to quantitative geospatial co-ordinates is discussed. This phase will also include the development of key genera distribution models, the development of genus abundance models as well as the development of a spatial distribution model of Beaufort Group fauna that will refine the delineation of assemblage zones, as a result of the biogeographic distribution of key generic distribution.

Phase 2 will address the following issues:

(1) Analysis of geo-spatial distribution and faunal distribution models.

(2) Analysis and interpretation of faunal spatial trends.

(3) Faunal biodiversity changes through time.

(4) Geo-spatial distribution trends in faunal biodiversity patterns. For example are taxa that are present in a particular biozone in the south of the basin the same in the north of the basin. The results could assist in understanding the pattern of basin infill and highlight the changes in community structure across the basin – i.e. biofacies.

(5) Biodiversity patterns and ecological representation of the Beaufort Group faunal assemblage.

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6.3 Using GIS technology as a tool to solve academic and curational queries

The completed spatial map will allow for any query to be performed relating to geo-spatial distribution, which may assist in understanding the pattern of basin infill as well as significant biodiversity patterns. Because of the lack of reliable lithological markers as well as datable volcanic rocks, index fossils have been used as markers to develop basin development models (Catuneanu *et al.*, 1998; Rubidge, 1995; Hancox, 1998; Neveling, 2002). Now that the database of Karoo fossils is available on a GIS system, the biogeographic distribution patterns of index taxa should be determined and used to see if they correspond with proposed basin development models. One method of testing these proposed models may be by comparing the faunal distribution patterns of faunas in different parts of the Beaufort Basin, in order to appraise depositional and environmental differences during Beaufort Basin development. In order to adequately perform this query it is necessary to evaluate faunal distribution patterns.

The challenge with the current contributing museums' datasets is that they contain locality information pertaining to historical (and now non-existing) provincial information (such as 'Orange Free State' and 'Cape Province'). To compare the currently demarcated Western, Eastern and Northern Cape with the currently demarcated Free State and KwaZulu Natal, the total Beaufort Group distribution

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needs to be split by these regions. The currently demarcated three Cape provinces may be used in combination to produce an area which is comparable to the historical Cape Province. These queries can be performed by way of a spatial containment query ("select by location"). Highlighting such aspects of faunal distribution patterns could have important consequences for future basin development models of the Karoo Basin.

Queries on the distribution of key genera can be selected. After the distribution queries are performed the selected specimens can be converted to layer files and analysed for significant trends. An example of such a query could be a comparison of dinocephalian and dicynodont distribution. This query can assess the validity of the hypothesis that initially dinocephalians outnumber dicynodonts in the Middle Permian at the beginning of the *Tapinocephalus* Assemblage Zone deposition (Boonstra, 1969) and then the reverse occurring in the upper part of the biozone.

6.4 Action pathway

The digital acquisition, integration and application of biological collections data are increasingly viewed as fundamental to biodiversity research (Beaman, *et al.,* 2004). The way forward for the digitised spatial map of the Beaufort Group of the Karoo Basin is to create easier access to researchers, where currently, access to collections is limited by their distributed nature on museum shelves (Beaman, *et al.*, 2004).

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Digitising the Beaufort Group Fossil databases has been an enormous task and much of the finer points of this task still lie ahead in order to make this GIS database of use to researchers.

Of the various classes of information linked to biological specimens, geospatial co-ordinates used for mapping species location and distribution are the most crucial in establishing a workable and reliable spatial system (Beaman *et al.*, 2004). Access to geospatially referenced data from fossils provides a quantitative basis for biodiversity analyses over time and predictive niche modelling for determining sampling densities of various sites.

Providing locality co-ordinates (geospatial references) has proven a significant challenge for this project. Few records have GPS co-ordinates. One museum has tried to address this by allocating GPS co-ordinates after referring to old field notes and maps of the collectors. This exercise has only added to the problem as many of the grid co-ordinates which were issued bear no resemblance to reality.

While all the raw data from the seven contributing museums was provided in digital format, it is clear that they were manual records that had been digitised, rather than digital data that had been used extensively in computerised analysis. This project highlights the drawback encountered when having to apply human interpretation verses the required, structured inflexible logic of the computer. This project also highlights the value of establishing how to, from now on, structure data so that it is

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suited to GIS application. The migration of paper records to useful electronic records cannot simply be carried out verbatim. The data needs to be restructured such that it facilitates analysis through electronic means - the way forward for palaeontological research.

The majority of the recorded specimens of the contributing museums are associated with a georeference, but this is in most instances a worded description of the localities from where they were discovered. Furthermore, locality information in the various datasets is not standardised, but because it has a degree of similarity within and across the collections, the task of converting textual references to geospatial co-ordinates is made less complicated. Similarities notwithstanding, there remain a number of interesting challenges. A few examples of textual locality statements illustrating these challenges are shown in Table 6.1.

Because most of the locality information in the museum databases is in textual form, the greatest task that lies ahead is the converting of the worded locality descriptions to geospatial references of space. The task of deriving space from place will be accomplished using a combination of paper maps, desktop GIS tools, GoogleEarth® and GPS plotting (this will involve physically finding textual localities).

Given the scope of both the specimen locality data and the necessity for this data to be available in a readily usable form, efficiency and accuracy are of prime importance in this task of geospatial referencing. Individual institutions housing palaeo-

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collections typically lack the resources or informatics expertise to meet the challenges of georeferencing alone (Beaman *et al.,* 2004). Designing a collaborative geospatial referencing methodology using the combined expertise of all palaeontologists in South Africa will yield an accurate and reliable spatial map.

With the foundation phase of the project completed, the following four tasks need to be undertaken:

- **Task 1: Data cleaning:**

  All alphanumeric data needs to be cleaned accurately (Refer to Appendix F). Spelling errors need to be corrected, and the content needs to be standardised to allow computerised queries to be performed. Locality names require verification and the correct localities together with the corresponding farm names and numbers, districts and provinces need to be allocated. Farm names with their corresponding farm numbers need to be aligned with the deeds office farm names and the Surveyor General's farm numbers.

- **Task 2: Plotting localities by GPS:**

  The use of farm centroids to signify specific fossil localities is not accurate, especially as there may be more than one assemblage zone present on a farm, yielding specimens of differing ages. Forcing such localities into a single point at

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the gravitational centre of the farm naturally introduces error and inaccuracy into the data. However, considering the nature of locality information for existing records, the centroid method remains the best option for the foundation phase of the GIS – initiative. In future locality data needs to be captured accurately by GPS, GoogleEarth® or other such methods. This data needs to be standardised and allocated a key with the locality names, farm names and farm numbers. Once this is done the specimen data can be linked to the localities to create a comprehensive spatial database.

- **Task 3: Creating Digital Terrain:**

The creation of digital terrain (3-dimensional mapping) is an objective to be achieved on completion of this project. This will involve the application of Voxel (3-dimensional pixel) analysis. The use of Voxel technology is necessary as terrain in the Beaufort Group is irregular and cannot therefore be described with a simple mathematical formula - it requires a high degree of detail to appear realistic. In the same way as pixels are appropriate for storing data that can be broken up into small squares, 'voxels' are appropriate for storing data that can be broken up into small rectangular blocks and provide a 3-dimensional area or height map.

While a height map provides information on altitude, an additional detail that is necessary is colour. The colour map will be crafted from the retained (Chapter 2)

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satellite imagery of the Beaufort Group terrain. This satellite imagery is really then a huge texture map that will be used to paint the landscape.

- **Task 4: Updating and Verifying Taxonomic Data:**

An important aspect to consider improving the reliability of the current datasets is the accurate assigning of taxonomic data as this is crucial when ultimately interpreting results. The updating and verification of both assemblage zone as well as taxonomic classification can be accomplished through the collaborative work of palaeontologists, each selected for their proficiency with specific groups of animals and/or geological expertise. Specimens in collections need to be checked and identified using current taxonomic criteria (diagnoses), particularly the National Museum, Transvaal Museum and Albany Museum collections.

6.5 Conclusion

The application of GIS technologies will have significant impact as it could open further avenues of GIS-based research in palaeontology (Netterberg *et al.*, 2004). However, rather than to simply release all the acquired spatial information into cyberspace, a more controlled approach may be necessary as a precaution against unlawful fossil hunting practices for example. A better approach would be a structured and tiered degree of access to the digitised palaeo-spatial data. The amount

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of available information would be directly proportional to the research requirement, or the commercial reason for access. Providing digital access to the Karoo collection is enabled by two critical technologies:

(1) The digital capture of specimen collection data, and

(2) the ongoing development of a cyberinfrastructure that links the digital collection to an accessible and distributed environment.

A great deal of progress has been made recently on developing the infrastructure to provide digital access to data (Beaman, *et al.,* 2004). Models for community solutions for distributed data access are evident in numerous projects such as the Global Biodiversity Information Facility (GBIF, 2002), the Biological Collection Access Service for Europe (BioCase, 2003), and the European Natural History Specimen Information Network (ENHSIN, 2000), which are establishing distributed Internet-based information systems for accessing, integrating and conducting predictive biotic modelling on specimen-based biodiversity data (Beaman, *et al.,* 2004).

As a pilot project for palaeontology in South Africa, this project has raised and re-enforced many issues in both palaeontology and GIS technology. This project has placed palaeontology in line with the future trend of establishing and making extensive use of virtual museums. The foundation phase of the project has provided a model to set up a digital database which is useful for research and curational requirements.

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TETRAPOD BIODIVERSITY THROUGH THE PERMO-TRIASSIC BEAUFORT GROUP (KAROO SUPERGROUP) OF SOUTH AFRICA.

Volume II

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A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2007.

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Abbreviations

AM	Albany Museum, Grahamstown, South Africa
BG	Beaufort Group, Karoo Supergroup of South Africa
BPI	Bernard Price Institute for Palaeontological Research, University of the Witwatersrand, Johannesburg, South Africa
CGS	Council for Geoscience, Tshwane, South Africa
CSIR	Council for Scientific and Industrial Research, Tshwane, South Africa
ENPAT	Environmental Potentital Atlas
GIS	Geographic Information System
NM	National Museum, Bloemfontein, South Africa
RC	Rubidge Collection, Graaff-Reinett, South Africa
SAC	Satellite Application Centre, division of CSIR, Hartebeeshoek, South Africa
SAM	South African Museum, Cape Town, South Africa
SG	Surveyor General
TM	Transvaal Museum, Tshwane, South Africa

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List of Appendices

Appendix A: Visual notes on specimen count graphs Page 3

Appendix B: Visual notes on assemblage zone graph Page 5

Appendix C: Summary of synthesised data Page 7

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Appendix F: Recorded errors in museum collection databases Page 27

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Appendix C: Summary of synthesised data

Appendix C summarises all data (graphs, tables and figures) that has been synthesised, fused, reworked and/or altered to varying degrees from the original database sources for utilisation in this thesis. The original databases (see CD1: Folder 3) are the seven contributing South African museum fossil records from the Beaufort Group, Karoo Supergroup of South Africa

Section 1: Excel spreadsheets

1.1 Synthesis of contributing museums

(1) Biodiversity lists for contributing museum collections. (Overleaf).

This data is presented on spreadsheets on the Microsoft® Programme Excel® which are on the accompanying CD: CD1: Synthesis of Data: Folder 8. The contents of Folder 8 are shown overleaf.

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Footer	Header	Name and Directory of the 7 Excel files on CD1
List A.1	ALBANY MUSEUM Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **1AlbanyMuseum_1_database_CD.xls**
List B.1	BERNARD PRICE INSTITUTE Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **2BernardPriceInstitute_1_database_CD.xls**
List C.1	COUNCIL FOR GEOSCIENCE Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **3Council-for-Geoscience_1_database_CD.xls**
List N.1	NATIONAL MUSEUM Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **4NationalMuseum_1_database_CD.xls**
List R.1	RUBIDGE COLLECTION Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **5RubidgeCollection_1_database_CD.xls**
List S.1	SOUTH AFRICAN MUSEUM Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **6SouthAfricanMuseum_1_database_CD.xls**
List T.1	TRANSVAAL MUSEUM Biodiversity list of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **7TransvaalMuseum_1_database_CD.xls**

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(2) Specimen count lists for contributing museum collections

Refer to Sections 2.2.2.1.2 and 2.2.2.2.2 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Table 2.14	ALBANY_MUSEUM Specimen Count (original)	Vol. 2 Chap. 2
Table 2.17	BERNARD_PRICE_INSTITUTE Specimen Count (original)	Vol. 2 Chap. 2
Table 2.20	COUNCIL_FOR_GEOSCIENCE Specimen Count (original)	Vol. 2 Chap. 2
Table 2.23	NATIONAL_MUSEUM Specimen Count (original)	Vol. 2 Chap. 2
Table 2.26	RUBIDGE_COLLECTION Specimen Count (original)	Vol. 2 Chap. 2
Table 2.29	SOUTH_AFRICAN_MUSEUM Specimen Count (original)	Vol. 2 Chap. 2
Table 2.32	TRANSVAAL_MUSEUM Specimen Count (original)	Vol. 2 Chap. 2

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(3) Original – to – Updated specimen count lists for contributing museum collections

Refer to Sections 2.2.2.1.3 and 2.2.2.2.3 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Table 2.15	ALBANY MUSEUM Specimen Count (original – to – updated)	Vol.2 Chap. 2
Table 2.18	BERNARD PRICE INSTITUTE Specimen Count (original – to – updated)	Vol.2 Chap. 2
Table 2.21	COUNCIL FOR GEOSCIENCE Specimen Count (original – to – updated)	Vol.2 Chap. 2
Table 2.24	NATIONAL MUSEUM Specimen Count (original – to – updated)	Vol.2 Chap. 2
Table 2.27	RUBIDGE COLLECTION Specimen Count (original – to – updated)	Vol.2 Chap. 2
Table 2.30	SOUTH AFRICAN MUSEUM Specimen Count (original – to – updated)	Vol.2 Chap. 2
Table 2.33	TRANSVAAL MUSEUM Specimen Count (original – to – updated)	Vol.2 Chap. 2

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(4) Updated specimen count lists for contributing museum collections

Refer to Sections 2.2.2.1.4 and 2.2.2.2.4 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Table 2.16	ALBANY MUSEUM Specimen Count (updated)	Vol.2 Chap. 2
Table 2.19	BERNARD PRICE INSTITUTE Specimen Count (updated)	Vol.2 Chap. 2
Table 2.22	COUNCIL FOR GEOSCIENCE Specimen Count (updated)	Vol.2 Chap. 2
Table 2.25	NATIONAL MUSEUM Specimen Count (updated)	Vol.2 Chap. 2
Table 2.28	RUBIDGE COLLECTION Specimen Count (updated)	Vol.2 Chap. 2
Table 2.31	SOUTH AFRICAN MUSEUM Specimen Count (updated)	Vol.2 Chap. 2
Table 2.34	TRANSVAAL MUSEUM Specimen Count (updated)	Vol.2 Chap. 2

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1.1 Amalgamation of Beaufort Group data (Super-collection)

Refer to Section 2.2.2.1.5 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

(1) Amalgamated list of updated specimen counts from contributing museums (Super-collection)

Table 3.39	**Amalgamated specimen count list**	Vol. 2 Chap. 3
Table 3.40	**Amalgamated specimen count organogram**	Vol. 2 Chap. 3

(2) Beaufort Group - Biodiversity lists (Super-collection)

Table 2.35	**Beaufort Group: Final specimen count and assemblage zone list**	Vol. 2 Chap. 2
Table 4.12	**Beaufort Group: Assemblage zone grid**	Vol. 2 Chap. 4
Table 2.36	**Beaufort Group: Indeterminate taxon grid**	Vol. 2 Chap. 2
Table 4.2	**Biodiversity analysis of the Beaufort Group**	Vol. 2 Chap. 4

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Section 2: Corel® & Excel® graphs

(1) Specimen count graphs for museum collections

Refer to Section 2.2.2.2.6.1 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Figure 3.1: Albany Museum: Specimen count graph	Vol. 2 Chap. 3
Figure 3.2: Bernard Price Institute: Specimen count graph	Vol. 2 Chap. 3
Figure 3.3: Council for Geoscience: Specimen count graph	Vol. 2 Chap. 3
Figure 3.4: National Museum: Specimen count graph	Vol. 2 Chap. 3
Figure 3.5: Rubidge Collection: Specimen count graph	Vol. 2 Chap. 3
Figure 3.6: South African Museum: Specimen count graph	Vol. 2 Chap. 3
Figure 3.7: Transvaal Museum: Specimen count graph	Vol. 2 Chap. 3

(2) Beaufort Group – Specimen count graph (Super-collection)

Refer to Section 2.2.2.2.6.2 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Figure 3.8: Beaufort Group - Specimen count graph	Vol. 2 Chap. 3

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(3) Beaufort Group – Pie charts (Super-collection)

Refer to Section 2.2.2.2.6.3 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Figure 2.3	**Analysis of Beaufort Group data**	**Vol. 2:** Chap. 2
Figure 2.4	**Analysis of Beaufort Group data**	**Vol. 2:** Chap. 2
Figure 2.5	**Analysis of Beaufort Group data**	**Vol. 2:** Chap. 2
Figure 2.6	**Analysis of Beaufort Group data**	**Vol. 2:** Chap. 2
Figure 2.7	**Analysis of Beaufort Group data**	**Vol. 2:** Chap. 2
Figure 4.1	**Relative numbers of fossils of designated taxa which have been recovered from the rocks of the Beaufort Group**	**Vol. 2:** Chap. 4
Figure 4.6	**Extinction vs. survival percentages within each assemblage zone of the Beaufort Group**	**Vol. 2:** Chap. 4

(4) Biodiversity analysis within and across the assemblage zones of the Beaufort Group (Super-collection)

Refer to Section 2.2.2.2.6.4 of Chapter 2 (Volume I) for an explanation of the methodology and objectives for creating this set of data.

Figure 4.3:	**Representation of genera within each assemblage zone of the Beaufort Group**	**Vol.2** Chap. 4

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(5) Relative numbers of fossils of designated taxa represented within and across the assemblage zones of the Beaufort Group (Super-collection)

Figure 4.2.a:	**Representation of taxa within each assemblage zone of the Beaufort Group (Numerical blocks)**	Volume 2: Chapter 4
Figure 4.2.b	**Representation of taxa within each assemblage zone of the Beaufort Group (Organic version)**	Volume 2: Chapter 4

(6) Biodiversity trends within the Beaufort Group (Super-Collection)

Figure 4.4	**Biodiversity trends within and across assemblage zones of the Beaufort Group**	Vol. 2 Chapter 4

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Appendix D: Glossary of GIS terminology

Append: ArcCatalog and ArcToolbox each contain tools to import spatial data shapefiles and CAD feature classes into a geodatabase. They also contain tools for importing nonspatial data from INFO and dBASE tables. Tables and shapefiles can also be imported in other ways. However, it is recommended that these tools are used to import data into a geodatabase for the following reason:

When a shapefile or CAD feature class is imported using an ArcCatalog or ArcToolbox tool, a geodatabase feature class is created to store the features. This feature class stores both the geometry and attributes from the input data. The feature class is automatically registered with the geodatabase system tables so that it can participate in relationships and geometric networks and have validation rules etc. Similarly, when a table is imported, a table is created in the geodatabase and automatically registered with the geodatabase system tables. Coverages, shapefiles, and CAD feature classes are imported into ESRI simple feature classes. INFO and dBASE tables are imported into ESRI simple row tables.

Attribute: 1. A piece of information describing a map feature. The attributes of a census tract, for example, might include its area, population, and average per capita income.

2. A characteristic of a geographic feature described by numbers, characters, images, and CAD drawings, typically stored in tabular format and linked to the feature by a user-assigned identifier. For example, the attributes of a well might include depth and gallons per minute.

3. A column in a table

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Attribute table: A DBMS or other tabular file containing rows and columns. In ArcInfo, attribute tables are associated with a class of geographic features (for example, wells or roads). Each row represents a geographic feature. Each column represents one attribute of a feature.

CAD dataset: A feature dataset representation of a CAD drawing. A CAD feature dataset is composed of feature classes representing all the points, lines, polygons, or annotation in the CAD drawing. For example, a CAD drawing may contain two line layers representing roads and parcel boundaries, respectively. The CAD dataset's line feature class represents all features in both the road and parcel boundary layers. A CAD dataset can contain wld files to put CAD drawings and data in geographic units rather than page units

Centroid: A farm centoid is the calculated gravitational centre of a polygon (farm boundaries are polygons). This is calculated using the ArcMap field calculator which automatically sets a field value for a single record or even all records.

Co-ordinate: A set of numbers that designate location in a given reference system, such as x,y in a planar coordinate system or x,y,z in a three-dimensional coordinate system. Coordinate pairs represent a location on the earth's surface relative to other locations.

Co-ordinate system: 1. A reference system used to measure horizontal and vertical distances on a planimetric map. A coordinate system is usually defined by a map projection, a spheroid of reference, a datum, one or more standard parallels, a central meridian, and possible shifts in the x- and y-directions to locate x,y positions of point, line, and area features.

2. In ArcInfo, a system with units and characteristics defined by a map projection, a common coordinate system is used to spatially register geographic data for a given area.

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3. A reference system consisting of a set of points, lines, and/or surfaces, and set of rules used to define the positions of points in space either in two or three dimensions.

Feature:

1. An object class in a geodatabase that has a field of type geometry. Features are stored in feature classes.

2. A representation of a real-world object.

3. A point, line, or polygon in a coverage, shapefile, or geodatabase feature class.

Field: A column in a table. Each field contains the values for a single attribute.

File: A set of related information that a computer can access by a unique name (for example, a text file, a data file, a DLG file). Files are the logical units managed on disk by the computer's operating system. Files may be stored on tapes or disks.

File type: Files that are not geographic data sources can appear in ArcCatalog if they have been added to the file types list. A file type consists of a description of the file's format (such as "Text Document"), the file extension associated with this type of file (such as ".txt"), and the icon used to represent these files.

Geocoding: The process of creating geometric representations for locations (such as point features) from descriptions of locations (such as addresses).

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Geodatabase: An object-oriented geographic database that provides services for managing geographic data. These services include validation rules, relationships, and topological associations. A geodatabase contains feature datasets and is hosted inside of a relational database management system

Geoprocessing: GIS operations such as geographic feature overlay, coverage selection and analysis, topology processing, and data conversion

GPS: Global positioning system. A system of satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on earth by calculating the time difference for signals from different satellites to reach the receiver.

Key attributes: To join two tables together, each table must have a column containing the same values. For example, a country feature with a "Name" attribute can be joined to the appropriate record in a table of demographic data that has a "Country_Name" column.

Metadata: 1. Information about GIS data describing a collection of data. Metadata for geographical data may include the source of the data, its creation date and format, its projection, scale, resolution, and accuracy, and its reliability with regard to some standard. ArcCatalog stores metadata in XML (extensible markup language), so the same metadata can be viewed in many different ways using different style sheets.

2. Metadata consists of properties and documentation. Properties are derived from the data source, while documentation is entered by a person. By default, ArcCatalog automatically creates and updates metadata, which is stored as well-formed XML data in a file alongside the data or within a geodatabase. Metadata for a folder can also consist of a well-formed HTML file describing its contents.

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Polygon: A two-dimensional feature representing an area such as a farm boundary or district or county.

Shape: The characteristic appearance or visible form of a geographic object. Geographic objects can be represented on a map using one of three basic shapes: points, lines, or polygons.

Shapefile: A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.

Snapping: The process of moving a feature to coincide exactly with the coordinates of another feature within a specified snapping distance or tolerance

Spatial analysis:

1. The study of the locations and shapes of geographic features and the relationships between them.

2. The process of modeling, examining, and interpreting model results. Spatial analysis is useful for evaluating suitability and capability, for estimating and predicting, and for interpreting and understanding. There are four traditional types of spatial analysis: topological overlay and contiguity analysis; surface analysis; linear analysis; and raster analysis

Spatial join: A type of spatial analysis in which the attributes of features in two different layers are joined together based on the relative locations of the features.

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Spatial modelling: Analytical procedures applied with a GIS. Three categories of spatial modeling functions can be applied to geographic features within a GIS:

- Geometric models (calculating the Euclidean distance between features, generating buffers, calculating areas and perimeters)
- Coincidence models (topological overlay)
- Adjacency models (pathfinding, redistricting, and allocation)

All three model categories support operations on spatial data, including points, lines, polygons and grids. Functions are organised in a sequence of steps to derive the desired information for analysis.

Spatial overlay: The process of superimposing layers of geographic data that occupy the same space in order to study the relationship between them.

Query: A question or request used for selecting features. A query often appears in the form of a statement or logical expression. In ArcMap, a query contains a field, an operator, and a value.

Raster: Represents any data source that uses a grid structure to store geographic information.

Vector: A co-ordinate-based data structure commonly used to represent linear geographic features. Each linear feature is represented as an ordered list of vertices. Traditional vector data structures include double-digitized polygons and arc–node models. Shapefiles are examples of vectors.

Vector model: A representation of the world using points, lines, and polygons. Vector models are useful for representing and storing discrete features such as farm boundaries.

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Appendix E: 'Uncleaned' dicynodont selection

Selecting all Dicynodontia from the *Palaeo_specimens* shape file (stored on Palaeo CD4) would involve selecting for all *variations* of 'dicynodont' from the seven contributing museum collections.

This would involve selecting where:

"Current_Ta" = 'DICYNODON' OR
"Current_Ta" = 'DICYNODON?' OR
"Current_Ta" = 'DICYNODONEMA' OR
"Current_Ta" = 'DICYNODONT' OR
"Current_Ta" = 'DICYNODONTOIDES' OR
"Current_Ta" = 'Dicynodon ("juvenile")' OR
"Current_Ta" = 'Dicynodon = An' OR
"Current_Ta" = 'Dicynodon ?leontocephalus' OR
"Current_Ta" = 'Dicynodon acutiro' OR
"Current_Ta" = 'Dicynodon aetorhamophus' OR
"Current_Ta" = 'Dicynodon allani' OR
"Current_Ta" = 'Dicynodon annae' OR
"Current_Ta" = 'Dicynodon antjiesfonteinensis (sp. nov.)' OR
"Current_Ta" = 'Dicynodon antjiesfonteinensis' OR
"Current_Ta" = 'Dicynodon benjamini' OR
"Current_Ta" = 'Dicynodon bolorhinus' OR
"Current_Ta" = 'Dicynodon brachyrhynchus' OR
"Current_Ta" = 'Dicynodon broilii (sp. nov.)' OR
"Current_Ta" = 'Dicynodon broilii' OR

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"Current_Ta" = 'Dicynodon cadlei' OR
"Current_Ta" = 'Dicynodon calverleyi' OR
"Current_Ta" = 'Dicynodon cf. grimbeeki' OR
"Current_Ta" = 'Dicynodon clarencei' OR
"Current_Ta" = 'Dicynodon curvatus’ OR
"Current_Ta" = 'Dicynodon daptocephaloides sp. nov.' OR
"Current_Ta" = 'Dicynodon duvenhagei' OR
"Current_Ta" = 'Dicynodon galecephalus' OR
"Current_Ta" = 'Dicynodon glaucops' OR
"Current_Ta" = 'Dicynodon grahami' OR
"Current_Ta" = 'Dicynodon grimbee' OR
"Current_Ta" = 'Dicynodon grimbeecki' OR
"Current_Ta" = 'Dicynodon grimbeek' OR
"Current_Ta" = 'Dicynodon grimbeeki' OR
"Current_Ta" = 'Dicynodon howardi' OR
"Current_Ta" = 'Dicynodon ingens' OR
"Current_Ta" = 'Dicynodon jouberti' OR
"Current_Ta" = 'Dicynodon kolbei' OR
"Current_Ta" = 'Dicynodon lacerticeps' OR
"Current_Ta" = 'Dicynodon leontocephalus' OR
"Current_Ta" = 'Dicynodon lissops' OR
"Current_Ta" = 'Dicynodon maccabei' OR
"Current_Ta" = 'Dicynodon macrodon' OR
"Current_Ta" = 'Dicynodon mustoi' OR
"Current_Ta" = 'Dicynodon nanus' OR
"Current_Ta" = 'Dicynodon psittacops' OR
"Current_Ta" = 'Dicynodon richardi' OR
"Current_Ta" = 'Dicynodon robustus' OR
"Current_Ta" = 'Dicynodon rubidgei' OR
"Current_Ta" = 'Dicynodon scheepersi' OR

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"Current_Ta" = 'Dicynodon schroederi (sp. nov.)' OR
"Current_Ta" = 'Dicynodon schroederi' OR
"Current_Ta" = 'Dicynodon sidneyi' OR
"Current_Ta" = 'Dicynodon sollasi' OR
"Current_Ta" = 'Dicynodon sp' OR
"Current_Ta" = 'Dicynodon sp. ?' OR
"Current_Ta" = 'Dicynodon sp.' OR
"Current_Ta" = 'Dicynodon swierstrai' OR
"Current_Ta" = 'Dicynodon trigonocephalus' OR
"Current_Ta" = 'Dicynodon validus' OR
"Current_Ta" = 'Dicynodon vanderhorsti ("female")' OR
"Current_Ta" = 'Dicynodon vanderhorsti (sp. nov.)' OR
"Current_Ta" = 'Dicynodon vanderhorsti' OR
"Current_Ta" = 'Dicynodon wellwoo' OR
"Current_Ta" = 'Dicynodon wellwoodensis' OR
"Current_Ta" = 'Dicynodon' OR
"Current_Ta" = 'Dicynodon?' OR
"Current_Ta" = 'Dicynodont vanderhorsti' OR
"Current_Ta" = 'Dicynodont' OR
"Current_Ta" = 'Dicynodontia' OR
"Current_Ta" = 'Indedt Dicynodont' OR
"Current_Ta" = 'Indent Dicynodont' OR
"Current_Ta" = 'Indert. Dicynodont' OR
"Current_Ta" = 'Indert. Dicynodont' OR
"Current_Ta" = 'Indet . Dicynodont' OR
"Current_Ta" = 'Iudet Dicynodon' OR
"Current_Ta" = 'Indet Dicynodont' OR
"Current_Ta" = 'Indet. ?dicynodont' OR
"Current_Ta" = 'Indet. Dicynodon' OR
"Current_Ta" = 'Indet. Dicynodont' OR

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"Current_Ta" = 'Indet. Dicynodont' OR
"Current_Ta" = 'Indet. Dicynodontia' OR
"Current_Ta" = 'Indet. Dicynodontidae' OR
"Current_Ta" = 'Iadet.Dicynodont' OR
"Current_Ta" = 'Inet. Dicynodont' OR
"Current_Ta" = 'Inted. Dicynodont' OR
"Taxon_Assi" = 'Dicynnodontia' OR
"Taxon_Assi" = 'Dicynodentia' OR
"Taxon_Assi" = 'Dicynodntia' OR
"Taxon_Assi" = 'Dicynodon lacerticeps' OR
"Taxon_Assi" = 'Dicynodon' OR
"Taxon_Assi" = 'Dicynodont' OR
"Taxon_Assi" = 'DicynodontIa' OR
"Taxon_Assi" = 'Dicynodontia (Aulacephalodontinae)' OR
"Taxon_Assi" = 'Dicynodontia (Aulacocephalodontidae)' OR
"Taxon_Assi" = 'Dicynodontia (Cistecephalidae)' OR
"Taxon_Assi" = 'Dicynodontia (Dicynodontidae)' OR
"Taxon_Assi" = 'Dicynodontia(Dicynodontoidea) ' OR
"Taxon_Assi" = 'Dicynodontia(Diictodontidae) ' OR
"Taxon_Assi" = 'Dicynodontia(Dinanomodon) ' OR
"Taxon_Assi" = 'Dicynodontia(Emydopidae) ' OR
"Taxon_Assi" = 'Dicynodontia(Emydopinae) ' OR
"Taxon_Assi" = 'Dicynodontia (Endothiodontidae)' OR
"Taxon_Assi" = 'Dicynodontia (Galeopsidae)' OR
"Taxon_Assi" = 'Dicynodontia (Kannemeyeriidae)' OR
"Taxon_Assi" = 'Dicynodontia (Kannemeyriinae)' OR
"Taxon_Assi" = 'Dicynodontia (Kingoriidae)' OR
"Taxon_Assi" = 'Dicynodontia (Lystrosauridae)' OR
"Taxon_Assi" = 'Dicynodontia (Myosaurinae)' OR
"Taxon_Assi" = 'Dicynodontia (Oudenodontidae)' OR

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"Taxon_Assi" = 'Dicynodontia (Oudenodontinae)' OR

"Taxon_Assi" = 'Dicynodontia (Pelanomodontinae)' OR

"Taxon_Assi" = 'Dicynodontia (Pristerodontidae)' OR

"Taxon_Assi" = 'Dicynodontia (Pristerodontidae/Diictodon' OR

"Taxon_Assi" = 'Dicynodontia (Pristerodontidae/Diictodonti' OR

"Taxon_Assi" = 'Dicynodontia (Rhachiocephalinae)' OR

"Taxon_Assi" = 'Dicynodontia (Robertidae)' OR

"Taxon_Assi" = 'Dicynodontia (Robertiidae)' OR

"Taxon_Assi" = 'Dicynodontia (Tropidostominae)' OR

"Taxon_Assi" = 'Dicynodontia' OR

"Taxon_Assi" = 'Dicynodontia, Amphibia' OR

"Taxon_Assi" = 'Dicynodontia?' OR

"Taxon_Assi" = 'Dicynodontiia' OR

"Taxon_Assi" = 'Dicynodontis'

"Taxon_Assi" = 'Dicynodontoa'

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APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Aelurognathus - valid genus?	Figure 3.8	Verify and alter
Aelurosaurus - valid genus?	Figure 3.8	Verify and alter
Aelurosuchus - valid genus?	Figure 3.8	Verify and alter
Aelurosuchus not present in *Cynognathus* AZ	Table 4.11	Alter assemblage zone data
Akidnognathus from *Dicynodon* not *Cistecephalus* AZ	Table 4.8	Verify and alter
Alopecopsis – valid genus?	Table 4.8	Verify and alter
Aloposaurus – valid genus?	Table 4.8	Verify and alter
Anningia regarded as *nomen dubium*	Table 4.4	Annotate
Arctognathus not from *Cynognathus* AZ	Table 4.2	Alter assemblage zone data
Aulacephalodon should not extend into *Dicynodon* AZ	Figure 4.3	Verify locality Data
Chasmatosaurus synonymous with *Proterosuchus*	Table 4.10	Verify and alter
Clelandina not from *Tropidostoma* AZ, but *Cistecephalus* AZ?	Figure 4.6	Verify locality Data
Cynodontina - valid genus?	Figure 3.8	Verify and alter

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Cynosaurus not from *Cistecephalus* Assemblage Zone	Table 4.8	Update assemblage zone data
Cynosaurus not from *Lystrosaurus* Assemblage Zone	Table 4.10	Update assemblage zone data
Cyonosaurus not from *Lystrosaurus* AZ	Table 4.11	Alter assemblage zone data
Daptocephalus not from *Cistecephalus* AZ	Table 4.8	Verify locality Data
Diaelurodon - valid genus?	Figure 3.8	Verify and alter
Dicellopygae - valid genus?	Figure 3.8	Verify and alter
Dicynodon not from *Cistecephalus* AZ	Table 4.8	Verify locality Data
Dicynodon not from *Tapinocephalus* AZ	Table 4.4	Correct to *Diictodon*
Dicynodon not from the *Tropidostoma* Assemblage Zone?	Table 4.6	Verify locality Data
Diictodon not from *Cynognathus* AZ	Figure 4.8	Verify locality Data
Dinonomodon not from *Lystrosaurus* AZ	Table 4.10	Alter assemblage zone/ taxonomic data
Eccasaurus = incertae sedis	Table 4.4	Alter
Elaphrosuchus = Proterosuchus	Table 4.10	Alter

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Emydops not from *Lystrosaurus* AZ	Table 4.10	Alter assemblage zone/ taxonomic data
Emydopsis – valid genus?	Table 4.6	Verify and alter
Emydorhinus – valid genus? (Synonymous with *Emydops?*)	Table 4.8	Verify and alter
Ericiolaienta = *Ericiolacerta*	Table 4.10	Alter
Galechirus, *Galeops* = Anomodontia	Table 4.3	Alter
Garjainia – from S.A?	Figure 3.8	Verify and alter
Glochinodon – valid genus?	Figure 4.10	Verify and alter
Glochinodontoides – valid genus?	Table 4.2	Update taxonomic data
Gorgonops not from *Dicynodon* Assemblage Zone	Table 4.9	Verify and alter
Gorgonopsia not from Triassic rocks	Table 4.10	Update taxonomic data
Haughtoniscus - valid genus?	Figure 3.8	Verify and alter
Hewittia from *Dicynodon* Assemblage Zone	Table 4.8	Update assemblage zone data
Hipposaurus is exclusive to *Tapinocephalus* AZ	Table 4.4	Verify locality Data

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Hipposaurus not present in *Cistecephalus* AZ	Figure 4.6	Verify locality & Taxonomic Data
Ictidochampsa – valid genus?	Table 4.9	Verify and alter
Ictidosaurus - valid genus?	Figure 3.8	Verify and alter
Ictidostoma - valid genus?	Figure 3.8	Verify and alter
Ictidosuchoides not from *Lystrosaurus* Assemblage Zone	Table 4.10	Verify and alter
Ictidosuchops not from *Lystrosaurus* Assemblage Zone	Table 4.10	Verify and alter
Ictidosuchus – valid genus?	Table 4.6	Verify and alter
Indet. Archosauromorpha not present in *Cistecephalus* AZ	Table 4.2	Verify and alter
Indet. Pelycosauria?	Figure 3.8	Verify and alter
Kestrosaurus from *Cynognathus* Assemblage Zone	Table 4.2	Update assemblage zone data
Koalemasaurus - valid genus?	Figure 3.8	Verify and alter
Lanthanostegysus - valid genus?	Figure 3.8	Verify and alter
Lanthanostegysus in *Tapinocephalus* AZ, not *Eodicynodon* AZ	Table 4.3	Verify locality Data

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Lycaenodon not from *Cistecephalus* Assemblage Zone	Table 4.8	Verify locality Data
Lydekkerina should not be present in the Permian	Table 4.2	Verify locality Data
Lystrosaurus not from the *Cistecephalus* Assemblage Zone	Table 4.8	Verify locality Data
Lystrosaurus not from the *Dicynodon* Assemblage Zone	Table 4.9	Verify locality Data
Machaeracanthus - valid genus?	Figure 3.8	Verify and alter
Maraisaurus - valid genus?	Figure 3.8	Verify and alter
Megalesuchus - valid genus? Synonymous with *Mygalesaurus*?	Table 4.9	Verify and alter
Mentzichthys not present in Beaufort Group (Witteberg)	Figure 3.8	Verify locality Data
Micrictodon - valid genus?	Figure 3.8	Verify and alter
Microposaurus - valid genus?	Figure 3.8	Verify and alter
Milleretta not from *Cistecephalus* Assemblage Zone	Table 4.8	Verify and alter
Millerenoides - valid genus? = *Milleretta?*	Figure 3.8	Verify and alter
Millerettoides - valid genus? = *Milleretta?*	Figure 3.8	Verify and alter

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Millerettops - valid genus? = *Milleretta?*	Figure 3.8	Verify and alter
Moschorhinus not from *Cistecephalus* Assemblage Zone	Table 4.8	Verify and alter
Moschorhynchus – valid genus?	Table 4.8	Verify and alter
Muchoscephalus = *Muchocephalus*	Figure 3.8	Confirm & Alter
Muchocephalus should not be present in the Permian	Table 4.2	Verify locality Data
Myosauroides – valid genus?	Table 4.8	Verify and alter
Nanictidops – valid genus?	Table 4.2	Verify and alter
Nanictocephalus – valid genus?	Table 4.8	Verify and alter
Nanictosaurus not from *Lystrosaurus* Assemblage Zone	Table 4.10	Verify and alter
Nanictosuchus not from *Cistecephalus* Assemblage Zone	Table 4.8	Verify and alter
Nanomilleretta - valid genus? (Synonymous with *Milleretta?*)	Figure 3.8	Verify and alter
Notaelurodon - valid genus?	Figure 3.8	Verify and alter
Noteosuchus should be in *Lystrosaurus* AZ	Table 4.8	Verify locality Data

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Oudenodon not present in *Lystrosaurus* AZ	Table 4.10	Alter assemblage zone/ taxonomic data
Oudenodon should not be in *Tropidostoma* AZ or below	Figure 4.3	Alter assemblage zone/ taxonomic data
Oudenodon should not be in *Trop/Cist* TZ but in *Cistecephalus* AZ	Figure 4.3	Alter assemblage zone/ taxonomic data
Oxygnathus - valid genus?	Figure 3.8	Verify and alter
Paliguana not from the *Cistecephalus* A.Z	Table 4.2	Alter assemblage zone/ taxonomic data
Paliguana not from the *Lystrosaurus* A.Z	Table 4.2	Alter assemblage zone/ taxonomic data
Paracyclotosuchus – taken to be *Paracyclotosaurus* for subzone C	Table 4.11	Verify and alter
Paracyclotosuchus not from S.A? Zambia? As above.	Figure 3.8	Verify locality Data
Paragalerhinus – valid genus?	Figure 4.7	Verify and alter
Pareiasaurus not present in *Tapinocephalus* AZ	Figure 4.6	Verify locality & Taxonomic Data
Pelictosuchus - valid genus?	Figure 3.8	Verify and alter
Pholidophorus - valid genus?	Figure 3.8	Verify and alter
Placerias not from S.A	Table 4.11	Alter

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Platycyclops not from *Dicynodon* Assemblage Zone	Table 4.9	Confirm and Alter
Plesiosaurus not from Karoo Basin - Algoa Basin	Figure 3.8	Confirm and Alter
Polycynodon - valid genus?	Figure 3.8	Verify and alter
Pristerognathoides - valid genus?	Figure 3.8	Verify and alter
Pristerosaurus - valid genus?	Figure 3.8	Verify and alter
Proalopecopsis – valid genus?	Table 4.8	Verify and alter
Proburnetia = Paraburnetia	Figure 3.8	Alter
Procolophon should be *Lystrosaurus* AZ	Table 4.9	Update assemblage zone data
Procolophon should not be in *Dicynodon* AZ?	Figure 4.3	Verify locality Data
Procolophon should not be in *Cynognathus* AZ	Table 4.11	Verify locality Data
Procynosuchus not present in *Cynognathus* AZ	Table 4.11	Update assemblage zone data
Procynosuchus should not be in *Cistecephalus* AZ?	Figure 4.3	Verify locality Data
Progalesaurus – valid genus?	Table 4.10	Verify and alter

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Prolystrosaurus not present in *Lystrosaurus* AZ	Table 4.10	Alter assemblage zone/ taxonomic data
Ptomalestes should be in *Tapinocephalus* AZ?	Figure 4.3	Verify locality Data
Regisaurus not from *Cynognathus* Assemblage Zone	Table 4.11	Alter assemblage zone data
Rhachiocephalus not from *Pristerognathus* Assemblage Zone?	Table 4.5	Verify locality Data
Rhachiocephalus not from *Dicynodon* Assemblage Zone?	Table 4.9	Verify locality Data
Rhinesuchus from the Permian	Table 4.10	Update assemblage zone data
Rhytidosteus from the *Cynognathus* Assemblage Zone	Table 4.2	Update assemblage zone data
Riebeeckosaurus should be in *Tapinocephalus* AZ?	Figure 4.3	Verify locality Data
Robertia should be in *Tapinocephalus* AZ?	Figure 4.3	Verify locality Data
Rubidgina not from *Cistecephalus* Assemblage Zone	Table 4.9	Verify locality Data
Saurorictus – valid assemblage zone data?	Table 4.6	Verify locality Data
Scalopocynodon - invalid genus	Figure 3.8	Update and alter
Scalopocynodon not from *Cistecephalus* Assemblage Zone	Table 4.8	Update assemblage zone data

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Scaloporhinus - valid genus?	Figure 3.8	Verify and alter
Scaloposuchus - valid genus?	Figure 3.8	Verify and alter
Scapanodon = Jonkeria	Table 4.4	Confirm & Alter
Scylacognathus - valid genus?	Figure 3.8	Verify and alter
Scylacops - valid genus?	Figure 3.8	Verify and alter
Sesamodon not present in *Cistecephalus* AZ	Figure 4.9	Verify locality Data
Sesamodontoides – valid genus?	Table 4.11	Verify and alter
Silpholestes – valid genus? & valid locality?	Table 4.8	Verify and alter
Should be no gorgonopsia in Triassic	Table 4.11	Verify locality Data
Struthiocephaloides - valid genus?	Figure 3.8	Verify and alter
Struthiocephaloides should be in *Tapinocephalus* AZ?	Figure 4.3	Verify locality Data
Struthionops - valid genus?	Figure 3.8	Verify and alter
Sysphinctostoma - valid genus?	Figure 3.8	Verify and alter

APPENDIX F: RECORDED ERRORS IN MUSEUM COLLECTION DATABASES		
ERROR	**WHERE?**	**SOLUTION**
Tetragonias not present in *Cistecephalus* AZ	Table 4.8	Verify locality Data
Theriognathus not present in *Cistecephalus* AZ?	Table 4.8	Confirm &Verify locality Data
Therioides - valid genus?	Figure 3.8	Verify and alter
Therocephalina - valid genus?	Figure 3.8	Verify and alter
Trematosuchus should be *Cynognathus* Assemblage Zone	Table 4.2	Update assemblage zone data
Thrinaxodon should be *Lystrosaurus* AZ	Table 4.9	
Thrinaxodon should not be in *Dicynodon* AZ	Figure 4.3	Confirm & Verify locality Data
Trirachodon not from the *Tropidostoma* AZ	Table 4.7	Alter assemblage zone data
Tritylodontoides not present in Beaufort Group (Elliot Formation)	Figure 3.8	Verify locality Data
Trochorhinus - valid genus?	Figure 3.8	Verify and alter
Trochosaurus - valid genus?	Figure 3.8	Verify and alter
Trochosuchus - valid genus?	Figure 3.8	Verify and alter
Tropidostoma from *Cistecephalus* Assemblage Zone	Table 3.39	Update assemblage zonation

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ERROR	**WHERE?**	**SOLUTION**
Unidentified gorgonopsians – not from Triassic	Table 4.2	Alter assemblage zone data
Uranocentrodon = Rhinesuchus	Figure 3.8	Confirm & alter
Uranocentrodon from *Dicynodon* Assemblage Zone	Table 4.10	Update assemblage zone data
Xenotosuchus in *Cynognathus* Assemblage Zone	Table 4.2	Update assemblage zone data
Youngoides – valid genus? Synonymous with *Youngina?*	Table 4.9	Verify and alter
Youngopsis = Youngina Synonymous with *Youngina?*	Figure 3.8	Confirm & alter

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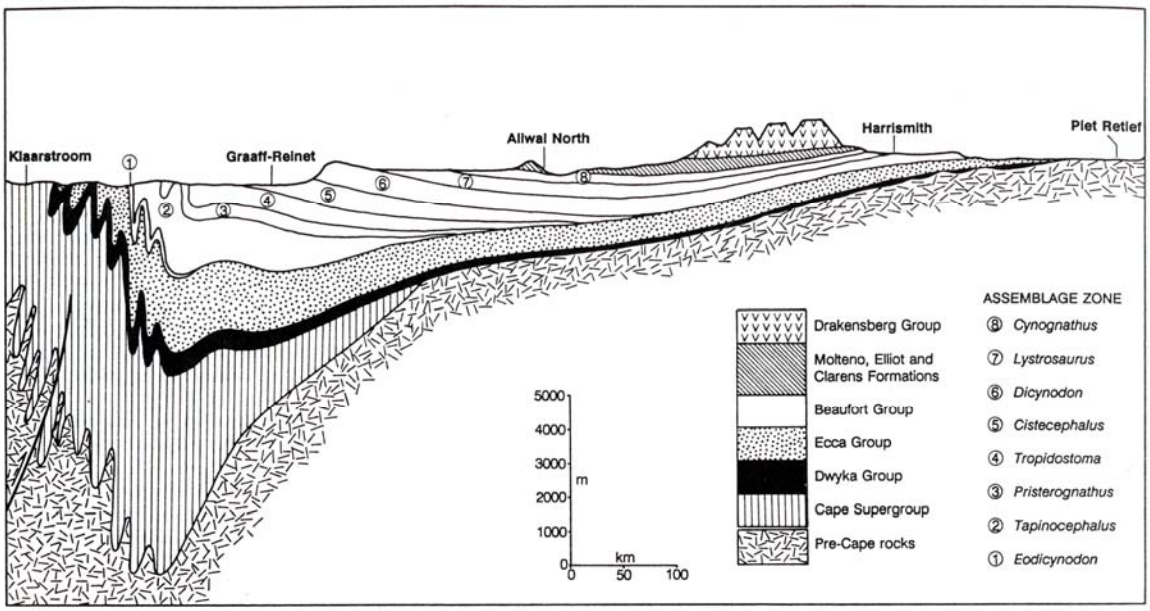
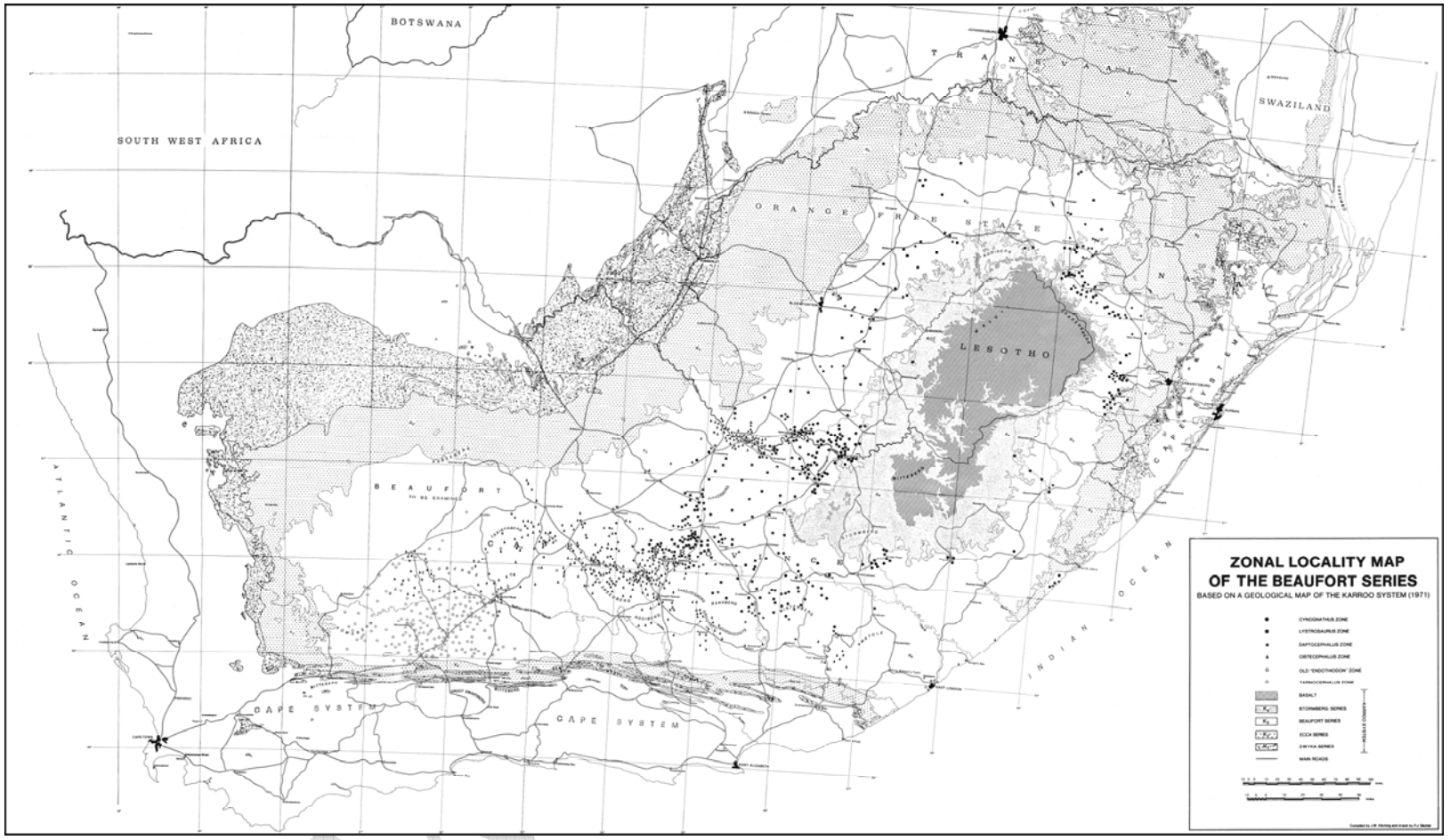


Figure 1.1: Cross section of Karoo Basin: showing the vertical relationship of vertebrate biozones of the Beaufort Group (Rubidge, B.S. (Ed.). 1995(b)).



Figure 1.2: Pin map of fossil locations prepared by James Kitching at the Bernard Price Institute for Palaeontology.



<u>Figure 1.3</u>: Zonal locality map of the Beaufort Group, prepared by James Kitching, showing the distribution of the Karoo vertebrate fauna.

Table 2.1: Workable data after initial elimination from original records. The original datasets from the seven contributing museum collections (Column 1) provide a *theoretical potential* of 26 837 (Column 2). The *theoretical potential* of 26837 is the sum of the original, unaltered records of each contributing museum. Certain records were eliminated (see Table 2.2). After data elimination, the *actual potential of analysable vertebrate specimens* in the Beaufort Group amounted to 20968 (Column 3). This table shows the number of records per museum collection remaining after elimination and these values expressed as a percentage (column 4) of which records can be utilised when compared to the original records.

DATABASE	TOTAL RECORDS	RECORD (AFTER INITIAL ELIMINATION)	% *POTENTIAL* VIABLE DATA
Albany Museum	588	468	79.59
Bernard Price Institute	4780	4483	93.79
Council for Geoscience	7579	5322	70.22
National Museum	3520	3171	90.09
Rubidge Collection	854	850	99.53
South African Museum	6797	5424	79.80
Transvaal Museum	2719	1250	45.97
	THEORETICAL TOTAL	**POTENTIALLY USABLE TOTAL**	**% *POTENTIAL* VIABLE TOTAL**
	26837	**20968**	**78.13**

Table 2.2: Elimination of non-viable data. After investigation of the contents of each museum collection, criteria for the elimination of certain records were established. Each data field per museum was analysed for data not applicable to, or useable for, the investigation of the biodiversity of the Beaufort Group. This table shows those records per museum collection requiring elimination. Bold font in column 2, refers to a specific datafield within a collection. Motivation for the elimination of records includes the removal of data pertaining to fossils not from the Beaufort Group, specimens which are non-vertebrate or taxonomically unidentified records.

Collection Name	Data Eliminated (Spreadsheet Rows)
Rubidge Collection	**Locality**: Unlisted farm locality & district information; Keetmashoop; Lady Frere. **Taxon**: *Mesosaurus*; *Sysphinctostoma*
BPI Collection	**Biozone**: Equivalent of L. *Cistecephalus* Z. **Geology**: ?Stormberg; Equivalent of Beaufort. **District/Country**: Ficksburg (FS); Namaqualand (NC); Fouriesberg (FS); Clocolan (FS); Ceres (WC); Worcester (WC); Calvinia (NC); Prieska (NC); Marquard; Lady Brand; Lady Grey; Zambia. **Genus**: *Tritylodon*; Amniota; Dinosauria; Plants; Taxon Indet.; Squamata? ?Diapsida; Reptilia; Indet.; Tetrapoda; Trace Fossil; Worm Burrows; Indet. Amniote; Indet. Dinosaur; Indet. Reptile; Indet. Tetrapod Burrow Cast; Unidentified Bone in Lag. **Locality**: Unlisted Locality Information; Locality Unknown; Various Localities.
National Museum Collection	**Taxon**: Unidentified Taxon & Current Identification; *Aetonyx*; Saurischia; Dinosauria; *Anchisaurus*; *Baroqueosuchus*; ?; Basutodon (Large Thecodont); *Bothriolepis*; Invertebrata; Conchostracans; *Elpistostege*; *Euskelosaurus*; *Roccosaurus*; *Fabrosaurus*; Footprints (*Bradysaurus*?); Unlisted Information; *Gryponyx*; *Herrerasaurus*; *Holopthychius*; Hout; Footprint (Ichnitis); *Massospondylus*; *Melanosaurus*; *Mesosaurus*; Orthosuchus; Mollusca (Palecypoda); *Pedeticosaurus*; Plant; Rauisuchid; Reptile; *Riojasaurus* (Prosaurosushia); Sauischia; *Scaumenacia*; *Sysphinctostoma*; *Thecodontosaurus*; *Tritylodon*; Unidentified; Unknown; Various; Worms; Dinosauria; Invertebrata; Lacertilia; Ornithischia. **Country/Locality**: Unlisted district/farm; Unlisted province; Quebec (Canada); Barkley East; Bethlehem; Clarens; Golden Gate; Clocolan; Elliot; Essex (England); Ficksburg; Fouriesburg; Gumtree; Herschel; Hopetown; Jamestown; Lady Frere; Ladybrand; Leribe; Marquard; Mafeteng; Maseru; Rosendal; Slabberts; Zastron; Wes Duitsland (Holzmaden). **Geology**: Non-applicable Assemblage Zone; Elliot; Clarens; Molteno; Ecca; Stormberg;

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	Waterford; Whitehill. Zone: *Euskelosaurus*; *Massospondylus*; *Trityledon* Acme Zone
South African Museum Collection	**Geology/Age/Assemblage Zone**: Ecca; Stormberg; Dwyka; Witteberg; Carboniferous; Bokkeveld; Devonian; Late Jurassic; Early Cretaceous; Cretaceous; Eocene; Middle Pennsylvanian; Upper Dwyka; Sakemena; Adolphspoort; Blue Lias; Carbondale; Elliot; Great Oolite; Green River Shale; Greensand; Irati; Kirkwood; Kupferschiefer; Lower Chalk; Lower Elliot; Lower Greensand; Lower Sakemena; Rio Bonito; Serra Alba; Whitehill; Early Triassic; Earliest Triassic; Early Carboniferous; Early Devonian; Early Jurassic; Early Permian; Jurassic; Kimmeridgian; Late Cretaceous; Late Jurassic/Early Cretaceous; Late Triassic; Lower Devonian; Lower Permian; Middle Devonian; Oligocene; Euskelosaurus; Reptile Beds. **Country**: Scotland; USA; Tanzania; Madagascar; Zambia; Namaqualand; Angola; Australia; Brazil; England; France; Germany; Great Britain; Ireland; Lebanon; Lesotho; Malawi; Mozambique; Namibia; North America; Wales; Zimbabwe; Unlisted locality (district/farm). **Province**: Caithness; Cambridge; Dumfries; Illinois; Mocamedes; New South Wales; Parana. District: Barkley East; Boputhatswana; Calvinia; Britstown; Ceres; Clocolan; Carnarvon; Dorset; Elliot; Fouriesburg; Hay; Herbert; Herschel; Hopetown; Kirkwood; Jansenville; Lady Grey; Ladybrand; Luangwa; Maclear; Mafeteng; Messina; Mokerong; Not Known; Outshoorn; Port Elizabeth; Port Shepstone; Prieska; Swellendam; Ranohira; Quacha's Nek; Quthing; Sebungwe; Uitenhage; Underberg; Utrecht; Will County; Williston; Wodehouse; Worcester. **Genus**: Beetle; Mammal; Osteolepis; Acanthodes; Acanthodian; Acanthopterygid; *Acrodus*; *Adroichthys*; *Aestuarichthys*; *Aetonyx*; *Astrodon*; Camarasauridae; *Opisthias*; *Pleurocoelus*; *Algoasaurus*; *Alopias*; *Anaethalion*; Anchisaurid; *Anoxypristis*; Anura; Arthrodire; *Asteracanthus*. **Class/Subclass**: Aves; Insect; Insecta; Mammalia; Placodermi; Vertebrata incertae sedis; Holocephali; Lepospondyli; Neornithes; Prototheria; Testundinata; Theria; Insectifora; Antiarchi; Anura; Arthrodira; Batoidea; Chelonia; Crocodylia; Cyprinodontiformes; Ellimmichthyformes; Elopiformes; Gadiformes; Galeomorpha; Ichthyopterygia; Lepisosteiformes; Mesosauria; Ornithischia; Sauropodamorpha; Lebias; Diplomystus; Elopoidei; Dastilbe; Anaethalion; Palaeomolva; Lamna; Carcharodon; Squalicorax; Isurus; Alopias; Heterodontus; Campylodon; Communis; Leptolepiformes;

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	Pachycormiformes; Paleospondyliformes; Pelecaniformes; Perciformes; Salmoniformes; Saurischia; Triconodonta
Council for Geoscience Collection	**Genus**: Indet.(No identification listed); Anura; Anomodontia; Lower Jaw; Nodules; Padda; Stromatolite; Therapsida; Theriodont; Vertebrata; Indet. Anomodontida. **Locality**: Unlisted locality information
Albany Museum Collection	Plants, Unlisted Acc. No., **Geology**: Buntsandstein, Lower Triassic; Elgin Sandstone; Gravel Banks; Cave Sandstone; Red Beds; Elliot Formation; Dwyka; Kirkwood Formation; Uitenhage Group (Kirkwood Formation); Upper Dwyka Shales; Shale. **Country and Locality**: England (Shale); Lyas (Switzerland). **District**: Barkley East; Scotland; Farm Rietfontein; Barkley Pass; Lyme Regis, England; Bolotive; Bunter Landstein, Switzerland; Farm Glencoe (Barkley East); Ibid.; Kirkwood Cliffs, Sunday's River; Lady Frere, Glen Gray; Mafeteng District, Lesotho; Moirosi's Mount, Lesotho; N. Luangwa Valley, N. Malawi; Near Alice; Penhoek, Stormberg; Riechen, Switzerland; Skietnek, Kirkwood Village; Thaba-Chau (Tsueu, Chu, Cho); Unknown. **Taxon**: Unknown; Small Reptile; Unidentified; Massopondylus; Chelonia; Unidentified; Sauropod Dinosaur; Dinosaur Prosauropod; Anomodont; Fossil Wood – Podocarpus; Dinosaur-like Styracosaurus; Hortalotarsus; Large Prosauropod? *Euskelosaurus*; *Mesosaurus*; Saurischia – Prosauropod Dinosaur; Saurischia (perhaps Plateosaurus); Saurischia (Dinosaur); Saurischia (Euskelosaurus); Small Reptile; Thecodontia – Pseudosuchian; Therapsid; Therapsid – Unidentified; Theropod – Nqebasaurus; Unidentifed; Unidentified Small Reptile; Unidentified Small Dinosaur; Unknown; Unlisted Taxon Information
Transvaal Museum Collection	**Genus**: Unidentified; Undescribed Anomodont; Bivalve Shells; Boks 140; *Aristosaurus*; *Eozostrodon*; Fossil Bone with Matrix; Fossil Reptile; *Gangomopteris* (a plant); *Gigantoscelus*; Large Anomodont; Large Mammal; Massopondylus; Reptile; Small Anomodont; Therapsid?; Theriodontia?; Theropoda; Unident.; Unlisted Genera. **Biozone**: Cave Sandstone; Red Beds; Rhaetic (Late Triassic). Locality: Tunnels; "Tunnels" Donga; Senekal; Jame's Donga; Provenance Unknown; St. Fort (Setsoanastad) Bethelehem District; Witjies Hoek; Milius Donga; Unlisted locality information; Letjiesbosch; Klipbank; Karoo Site; Arcadia Donga; Commander Jone's House; Apparently East of Fossil Valley; "Diamond Diggings". **Province**: Unlisted locality information. **Country**: Unlisted locality information; England

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Table 2.3: Summary of viability study (BPI as testcase). An investigation of the degree of quantifiable content of a representative dataset, after initial elimination (Table 2.2), was undertaken to establish whether the task of spatially mapping the palaeontological data from the Beaufort Group was achievable. The database of the BPI was selected as the sample dataset, both for reasons of convenience and also because it represents a broad spectrum of datafields and diversity. The results reveal that the majority of data is viable and could be used for spatial mapping purposes. Column 4 shows the percentages of viable data per data field that may be potentially usable for GIS purposes. Viability was defined as those records having both a taxonomic identification as well as attached locality information.

***Tropidostoma* A.Z.**	**Recorded Data (Total)**	**Viable Data (Total)**	**% Viable Data**
Taxon Assignment	681	652	95,7
Current Identification	681	92	13,5
Locality Name	681	681	100
Province	681	681	100
Country/State	681	681	100
District	681	681	100
Mapsheet	681	681	100
Geology: Group	681	681	100
Geology: Zone	681	681	100

***Eodicynodon* A.Z.**	**Recorded Data (Total)**	**Viable Data (Total)**	**% Viable Data**
Taxon Assignment	6	6	100
Current Identification	6	1	16,6
Locality Name	6	6	100
Province	6	6	100
Country/State	6	6	100
District	6	6	100
Mapsheet	6	6	100
Geology: Group	6	6	100
Geology: Zone	6	6	100

***Pristerognathus - Diictodon* A.Z.**	**Recorded Data (Total)**	**Viable Data (Total)**	**% Viable Data**
Taxon Assignment	4	4	100
Current Identification	4	1	25,0
Locality Name	4	3	75,0
Province	4	4	100
Country/State	4	4	100
District	4	4	100
Mapsheet	4	4	100
Geology: Group	4	4	100
Geology: Zone	4	4	100

Dicynodon - Daptocephalus A.Z.	Recorded Data (Total)	Viable Data (Total)	% Viable Data
Taxon Assignment	133	127	95,4
Current Identification	133	38	28,5
Locality Name	133	132	99,2
Province	133	133	100
Country/State	133	133	100
District	133	132	99,2
Mapsheet	133	132	99,2
Geology: Group	133	133	100
Geology: Zone	133	132	99,2

Cistecephalus A.Z.	Recorded Data (Total)	Viable Data (Total)	% Viable Data
Taxon Assignment	2287	2133	93,2
Current Identification	2287	593	25,9
Locality Name	2287	2256	98,6
Province	2287	2286	99,9
Country/State	2287	2286	99,9
District	2287	2285	99,9
Mapsheet	2287	2285	99,9
Geology: Group	2287	2286	99,9
Geology: Zone	2287	2286	99,9

Lystrosaurus A.Z.	Recorded Data (Total)	Viable Data (Total)	% Viable Data
Taxon Assignment	1120	1026	91,6
Current Identification	1120	841	75,0
Locality Name	1120	1114	99,4
Province	1120	1119	99,9
Country/State	1120	1120	100
District	1120	1118	99,8
Mapsheet	1120	1118	99,8
Geology: Group	1120	1120	100
Geology: Zone	1120	1119	99,9

Cynognathus A.Z.	Recorded Data (Total)	Viable Data (Total)	% Viable Data
Taxon Assignment	536	507	94,5
Current Identification	536	285	53,1
Locality Name	536	494	92,1
Province	536	494	92,1
Country/State	536	536	100
District	536	495	92,3
Mapsheet	536	495	92,3
Geology: Group	536	496	92,5
Geology: Zone	536	496	92,5

Tapinocephalus A.Z.	Recorded Data (Total)	Viable Data (Total)	% Viable Data
Taxon Assignment	214	207	96,7
Current Identification	214	83	38,7
Locality Name	214	214	100
Province	214	214	100
Country/State	214	214	100
District	214	214	100
Mapsheet	214	214	100
Geology: Group	214	214	100
Geology: Zone	214	214	100

Table 2.4: Summary of processes for presenting data within a spatial system. (Overleaf). This table summarises the processes involved in establishing a pilot GIS Database System for fossils of the Beaufort Group, Karoo Supergroup of South Africa. The broad-spectrum processes involved in presenting data within a spatial system are divided into three stages, listed under processes. Each stage was subdivided into successive tasks. Stage 1 is comprised of five tasks; Stage 2, four tasks and Stage 3, three tasks. Tasks 1 and 3 of Stage 1 are detailed in Sections 2.1.1 and 2.1.2. Execution and methodology of tasks 2, 4 and 5 of Stage 1, as well as tasks 1 – 4 of Stage 2 are explained in Section 2.2.1.1. Tasks 1 and 3 of Stage 3 are described in Chapter 6 and Task 2 of Stage 3 is detailed in Section 2.2.2.2 and Chapter 6.

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Table 2.4: Summary of processes for presenting data within a spatial system.

TASK ORDER	PROCESSES		
	STAGE 1: Acquisition and Processing of Raw Data	**STAGE 2: Establishing a GIS Management System**	**STAGE 3: Reconciliation**
1	Review and assimilation of raw databases	Selection of map layers	Challenges encountered during the mapping process
2	Creation of applicable Data Fields	Conversion of data	Future possible modes of action, as well as standardising criteria to adopt concerning data capture and data capture methods
3	Criteria established for the elimination of non-viable data and subsequent deletion	Establishing an alternative base data.	Suggestions for improving the current success rate of digitising fossil localities
4	Division into Automated and Manual Entry databases	Establishing a Geodatabase.	[redacted]
5	Creation of a map sheet shape file	[redacted]	[redacted]

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Table 2.5: Summary of specific processes for presenting digitised Karoo Data. (Overleaf). In order to perform tasks 2, 4 and 5 of Stage 1 and tasks 1 – 4 of Stage 2 (Table 2.4), further refinement of the work breakdown structure was required to present the Beaufort Group data within a spatial system. These detailed processes involved in spatially mapping the vertebrate fossils of the Beaufort Group are broadly subdivided into the listed two phases. Firstly, a viability study (task 1 of Phase 1) was undertaken to assess whether Beaufort Group data was able to be presented on a spatial map, then preliminary cleaning of the data had to be performed (tasks 3, 7, 8, 9 10 and 11 of Phase 1). Thereafter datafields in each collection were investigated for use and either retained or rejected (tasks 2 and 4 of Phase 1). A summary of which datafieds were deleted from each museum collection is displayed in Table 2.7. Map layers applicable to the objectives of the GIS-project were selected (task 2 of Phase 2) and all alphanumeric data automatically converted to spatial data using ArcGIS® (task 1 of Phase 2). To get to the point where data was represented on a spatial map, two approaches were adopted. The first approach involved the selection of those records that qualified for automatic insertion into the system (task 5 of Phase 1). The second approach involved those records that could only be entered onto the system manually (task 6 of Phase 1).

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Table 2.5: Summary of specific processes for presenting digitised Karoo data

TASK ORDER	PHASES	
	PHASE 1: ACCESSING AND PROCESSING OF DATA	**PHASE 2: DEVELOPMENT OF SPATIAL MODEL**
1	Initial test case using the recorded fauna of the BPI database	Converting alphanumeric data to spatial data
2	Selection of datafields applicable for project objectives	Acquisition and application of selected map layers
3	Preliminary data cleaning	[redacted]
4	Establishment of criteria list allowing for automatic validation	
5	Selection of data that would allow for automatic insertion into GIS	
6	Establishment of manual insertion faunal data	
7	Establishment of genera and species lists	
8	Acceptance or reclassification of taxonomical classification	
9	Establishment of final genera/species list for BPI database	
10	Assignment of fossil locality data to each specimen	
11	Repetition of 2 – 10 for remaining six databases (BPI as template)	

Wits ETD

Table 2.6: Elimination of datafields from raw databases. Specific datafields for each museum collection were deleted to eliminate data that had no bearing on the aim of the GIS-project (which was to digitally record specimens to their specific localities) and to establish standardisation across all contributing museums.

Collection Name	Datafields Eliminated (Spreadsheet Columns)
Rubidge Collection	Status, Loc., Description, Describer/Identifier, Collector, Date
National Museum	Code, Status, Description, Date, Collector, LocDesc, Identifier, Field Number., Field Book., Page, Sequence, Prep deg, Preparation, Adhesive, Preparator, Storage, Loans, Merker vir Print
South African Museum	Store Location (Row, cupboard, shelf), Safe, Complete Skeleton, Elements: Cranial, Elements: No. of Skulls, Elements: Lower Jaw, Elements: Post Cranial, Identifier, Identification Date, Type-Status, Identifier & Date of Type, Cast, Fate, References, Collector/Donor, Date Collected, Field Notes, Field Number, Plotted, Supergroup, Subgroup, Unit/Bed, Range Zone, Age, Attributes, Preparation, Preparation Type, Preparator, Filler/Consolidant, Preparation Remarks, Loan To, Loan Number, Length of Loan, Date Loaned, Due Date, Specimen Kept, Other Number, Length of Skull, General Comments, Epoch, Acme Zone, Era
Council for Geoscience	Loc_Uncert, Field-3, Collar, Site Description, Project Number, Project Name, Finder, Date_Found, Finder_Institution, Fossil_Description, Identified_By, Author, Litho_Rank, Bed, Member, Lithology, Text_Qual, Litho_Name, Rank, Sample_Repos_Inst, Sample_repos_loc, Sample_depth_From, Sample_depth_To, Uncertain, Sample_Repos_No., Georeference, Eff_Public_Date, Organ, Preserv_Status, Preparator, Collected By, Colour 1, Colour 2, Colour Distribution, Uq_Sageolit No., Ap.Job, Ap.Strip, Ap. No., Publication Title, Par_Rank, Common Name, Country, Sequence, Uncertain.
Albany Museum	Extra, Old No., Collector, Date, Remarks, Description, In Coll
Transvaal Museum	Code, Dist_Park, DD, MM, YYYY, Collector, Gridref, Lat, Long, Skeletal Part, Storage, Photo, Notes, Publication, Loan No.
BPI Collection	Description, 1st Collector, Collection Date, General Remarks/Notes

WITS ETD

Table 2.7: Methodology for automating spatial data. (Overleaf). The purpose of this component of the GIS project to spatially map the fossils of the Beaufort Group was to select for those records that could be entered into the system automatically. The scheme was to create a spatial database that allowed records to automatically be inserted to specific localities referenced as farm centroids. The majority of data for the Beaufort Group has farm localities referenced as its highest resolution for locality; therefore this approach was the only feasible option allowing for the establishment of the foundation of a spatial database for karoo fossils. In order to get to the point were data was able to be inserted automatically, certain tasks, listed in successive order from left to right, for 6 Phases of implementation were executed. Section 2.2.1.1.1 discusses the methodology involved allowing for the successful completion of these tasks.

Wits ETD

Table 2.7: Methodology for automating spatial data.

PHASE		TASK(S)			
1	**Obtain necessary data**	1.Landsat imagery	2.Geology (1:250 000)	3. Farms and farm boundaries	4. Fossil records
2	**Transform Spatial data**	1. Data exploration	2. Check projections of spatial data for accuracy and relevance		
3	**Sort alphanumeric data**	1. Sort records per farm and per assemblage zone			
4	**Digitise vertebrate fossil specimen localities**	1. Digitise localities per farm using ArcGIS®	2. Align ID keys with alphanumeric database		
5	**Link alphanumeric database**	1. Link alphanumeric database to spatial database (Compound Key			
6	**Output**	1. Spatial database of vertebrate fossil localities			

Table 2.8: Automated Entry success rate. This table summarises the success rate of the automated entry procedure.The success rate percentage per museum collection (Column 4) is calculated against the number of specimens that required insertion into the GIS (Column 3). Of the 19 718 specimens selected for possible automatic insertion, 8512 were able to be inserted automatically. When these values are compared against the total number of records (20 968) that required import into the GIS (Table 2.1), it is apparent that the success rate for automated data entry is very low.

Museum	Automated entry total	Records requiring insertion	Insertion success rate (% Inserted)
AM	27	468	5.8
BPI	795	4483	17.7
CGS	4005	5322	75.2
NM	364	3171	11.5
RC	209	850	24.6
SAM	3112	5424	57.4
Totals	**8512**	**19718**	**43.2**

Wits ETD

Table 2.9: Manual Entry success rate. Data tables containing specimens that had failed to insert automatically were established for each museum (CD1: Folder 5). Thereafter, a comparison was run between these data tables and their respective original databases, culminating in data showing records still requiring insertion into the GIS (Column 3 below). This table provides a summary of the degree of success of manually plotting the records in Column 3 into the GIS, per museum collection. The success rate percentage is calculated against the number of specimens that required insertion into the GIS. The resultant number of records (Column 3), per museum collection, is the sum of recorded specimens that failed to automate together with 'unautomatable' data. This sum is less than the totals given per original database due to the elimination of certain records (Table 2.2).

Museum	Manually inserted records	Records requiring insertion (Automated records subtracted)	Success Rate (%)
South African Museum	2125	3685	**58**
Bernard Price Institute	3909	3985	**98**
Rubidge Collection	645	645	**100**
Albany Museum	451	561	**80**
National Museum	2920	3156	**93**
Council for Geoscience	1557	3574	**44**
Transvaal Museum	343	1250	**13**

Table 2.10: Manually inserted specimen summary. This table provides a breakdown of the degree of locality resolution for manually inserted records. Manual entry success was categorised into 4 levels of entry (listed below). The optimum degree of resolution is coding to grif-reference, followed by coding to the provided locality (textual reference). The least optimum are those records coded to district level. The process of geo-referencing textual locality data in Phase 1 of the GIS – initiative, will eradicate such low resolution locality entries. In addition, the percentage of records that failed to be coded per museum collection is listed.

Museum	Manual Insertion Total	MANUAL ENTRY SUCCESS			
		% to provided locality	% not coded	% to district	% coded to Long/Lat
BPI	3909	85	15	N/A	N/A
SAM	2125	N/A	0.5	19.5	80
AM (FISH)	35	N/A	14	86	N/A
AM (TETRAPODS)	416	36.5	27	36.5	N/A
CGS	1557	N/A	N/A	N/A	100
NM	2920	39.5	0.5	60	N/A
RC	645	30	2.5	67.5	N/A

Table 2.11: List of shape files. The datasets under column 1: Manually Entered Data and column 2: Automated and Co-ordinate Entry Data represent the sum of palaeontological specimens from the seven museum collections. This data was captured onto the GIS, either by co-ordinate entry, allocation to farm centroids or manual entry. These datasets needed to be combined into one comprehensive dataset for future analytical purposes and is necessary to decrease the complexity of any future queries. This involved collating the point data of the seven museum collections into one map layer. Columns 3 – 5 are the additional shape files housed on the Geographical Information System as aids for analysis and interpretation.

SHAPE FILES				
MANUALLY ENTERED DATA	**AUTOMATED & CO-ORDINATE ENTRY DATA**	**ASSEMBLAGE ZONES**	**PROVINCIAL CENTROIDS**	**BASE DATA**
ALBANY FISH_point.shp	AM_centroids _allfieids.shp	Ass_Z_*Cistecephalus*. shp	KZN_centroids_v1.shp	Geology_1m.shp
ALBANY REPTILES_point.shp	BPI_centroids _allfieids_v2.shp	Ass_Z_*Cynognathus*. shp;	WC_centroids_v1.shp	Mapsheets_50000.shp
COUNCIL FOR GEOSCIENCE_point.shp	GS_centroids_ allfieids_v2.shp	Ass_Z_*Dicynodon*. shp	EC_centroids_v1.shp	sa.shp
FINAL1_point.shp	NM_centroids_ allfieids.shp	Ass_Z_*Eodicynodon*. shp	FS_centroids_v1.shp	
NATIONAL MUSEUM_point.shp	RC_centroids_ allfieids_v2.shp	Ass_Z_*Lystrosaurus*. shp	NC_centroids_v1.shp	
RUBIDGE_point.shp	SAM_centroids_ allfieids_v3.shp	Ass_Z_*Pristerognathus*. shp		
SAM 1 (MANUAL INPUT DATA)_point.shp	BPI_Coll.shp	Ass_Z_*Tapinocephalus*. shp		
SAM 1_point.shp	Geo_surv_ Coll.shp	Ass_Z_*Tropidostoma*. shp		
TRANSVAAL MUSEUM_point_shp	ALL_centroids_ allfield_ v3.shp	Ass_Z_Unknown. shp		

Table 2.12: Alphanumeric table structure (Netterberg *et al,* 2004). The original intention, when collating the point data of the seven museum collections into one map layer, was to append all datasets (see Table 2.13) onto a single existing dataset. Due to the differing alphanumeric table structures and schemes of the contributing museum collections, this was not directly possible. Accordingly, the alphanumeric table structures of the various data files for the museum collections, where manipulated to conform to the structure shown in the table below. The shape files (Table 2.11), which needed to be combined, were manipulated in turn to conform to the structure shown in this table and required that the field names only be 10 characters long (Netterberg *et al,* 2004). Any duplicate records were removed manually from the shape files. This process was repeated for all necessary files and is illustrated in Figure 2.9.

FIELD NAME	DATA TYPE
Id	Short Integer (6)
Specimen_I	Text (50)
Current_Tax	Text (50)
Taxon_Assi	Text (50)
Biozone	Text (50)
Province	Text (50)
District	Text (50)
Locality_N	Text (50)
Mapsheet	Text (6)
Old_ID	Text (10)
Census_Dis	Text (50)
Farm_Name	Text (50)
Co_ord_X	Double (8,7)
Co_ord_Y	Double (8,7)

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Table 2.13: Appended files. Once the shape files (Columns 1 & 2 of Table 2.11), which needed to be combined onto a single map layer, were manipulated to conform to the structure shown in Table 2.12, the append module in ArcGIS 9® was then used to append all necessary files. The appended files are listed below. Shape files that had a multipoint geometry type, rather than a point geometry type were converted to a point geometry type, and then appended (Netterberg, *et al*, 2004). The result was the single point shape file: *Palaeo_Specimens.shp*.

APPENDED FILES		
Point.shp files	**Allfields.shp files**	**Coll.shp files**
ALBANY FISH_point.shp	AM_centroids_allfieids.shp	BPI_Coll.shp
ALBANY REPTILES_point.shp	BPI_centroids_allfieids_v2.shp	Geo_surv_Coll.shp
COUNCIL FOR GEOSCIENCE_point.shp	GS_centroids_allfieids_v2.shp	
FINAL1_point.shp	NM_centroids_allfieids.shp	
NATIONAL MUSEUM_point.shp	RC_centroids_allfieids_v2.shp	
RUBIDGE_point.shp	SAM_centroids_allfieids_v3.shp	
SAM 1 (MANUAL INPUT DATA)_point.shp		

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<u>Table 2.14</u>: Albany Museum: Specimen count (Original). (Overleaf).

List A1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the Albany Museum (A), This spreadsheet houses all data pertaining to the recorded specimens of the Albany Museum, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the Albany Museum was extrapolated from spreadsheet A1. This spreadsheet (Table 2.14) was subjected to further refinement and is a streamlined version of A1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum. An additional 'balancing' application is evident in these datasets to guard against potential data loss that may occur during the various data cleaning procedures. This balancing system was applied to all synthesised data for this dissertation: The sum total of values assigned in the assemblage zone column for a specific fossil equals the total number of recorded specimens for that specific genus, for this and all subsequent tables.

Datafield content from left to right for Table 2.14 is:

- <u>Column 1</u>: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- <u>Column 2</u>: Genera list, in alphabetical order, as occurs in (CD1: A1).

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- Column 3: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- Column 4*:* Specimen count totals are divided into their associated assemblage zones.

Wits ETD

Table 2.15: Albany Museum: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

If a classification update is listed, it is accompanied by a referenced source accounting for such a change. To explain this balancing methodology, refer to *Cynognathus* for example (Table 2.15), originally listing 10 recorded specimens for the Albany Museum. Their respective assemblage zone distribution is listed in Column 1. The genus *Gomphognathus,* for example, listed in Column 2 was updated to *Cynognathus.* This change is observed in Column 4, where the elimination of the genus and the subsequent specification of its movement is checked and accounted for at both *Gomphognathus* and its addition to *Cynognathus.* Coupled with the alteration is the resultant change in the Assemblage Zone (Updated) as well as Specimen Count (Updated) columns.

Datafield content from left to right for Table 2.15 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.

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- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with ‘navigating’ the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.16: Albany Museum: Specimen count (Updated). (Overleaf). This table is the final product for the Albany Museum after the implementation of standardisation procedures. Subsequent graphs for the Albany Museum are based on this spreadsheet. Table 2.16 provides a listing of genera (updated) for the Albany Museum, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.16 is a streamlined/'cleaned' version of the final three updated columns in Table 2.15. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.16 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated specimen count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3: Specimen count totals are subdivided into their associated updated assemblage zones.

WitsETD

Table 2.17: Bernard Price Institute: Specimen count (Original). (Overleaf). List B1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the Bernard Price Institute for Palaeontological Research (B). This spreadsheet houses all data pertaining to the recorded specimens of the Bernard Price Institute for Palaeontological Research, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the Bernard Price Institute for Palaeontological Research was extrapolated from spreadsheet B1. This spreadsheet (Table 2.17) was subjected to further refinement and is a streamlined version of B1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum.

Datafield content from left to right for Table 2.17 is:

- Column 1: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- Column 2: Genera list, in alphabetical order, as occurs in (CD1: B1).
- Column 3: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- Column 4*:* Specimen count totals are divided into their associated assemblage zones.

WitsETD

Table 2.18: Bernard Price Institute: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. If a classification update is listed, it is accompanied by a referenced source accounting for such a change. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

Datafield content from left to right for Table 2.18 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.
- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.19: Bernard Price Institute: Specimen count (Updated). (Overleaf). This table is the final product for the Bernard Price Institute for Palaeontological Research after the implementation of standardisation procedures. Subsequent graphs for the Bernard Price Institute for Palaeontological Research are based on this spreadsheet. Table 2.19 provides a listing of genera (updated) for the Bernard Price Institute for Palaeontological Research, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.19 is a streamlined/'cleaned' version of the final three updated columns in Table 2.18. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.19 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated specimen count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3*:* Specimen count totals are subdivided into their associated updated assemblage zones.

Wits ETD

Table 2.20: Council for Geoscience: Specimen count (Original). (Overleaf). List C1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the Council for Geoscience (C). This spreadsheet houses all data pertaining to the recorded specimens of the Council for Geoscience, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the Council for Geoscience was extrapolated from spreadsheet C1. This spreadsheet (Table 2.20) was subjected to further refinement and is a streamlined version of C1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum.

Datafield content from left to right for Table 2.20 is:

- Column 1: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- Column 2: Genera list, in alphabetical order, as occurs in (CD1: C1).
- Column 3: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- Column 4: Specimen count totals are divided into their associated assemblage zones.

Wits ETD

Table 2.21: Council for Geoscience: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

Datafield content from left to right for Table 2.21 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.
- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.22: Council for Geoscience: Specimen count (Updated). (Overleaf). This table is the final product for the Council for Geoscience after the implementation of standardisation procedures. Subsequent graphs for the Council for Geoscience are based on this spreadsheet. Table 2.22 provides a listing of genera (updated) for the Council for Geoscience, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.22 is a streamlined/'cleaned' version of the final three updated columns in Table 2.21. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.22 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated specimen count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3: Specimen count totals are subdivided into their associated updated assemblage zones.

Wits ETD

<u>Table 2.23</u>: National Museum: Specimen count (Original). (Overleaf). List N1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the National Museum (N). This spreadsheet houses all data pertaining to the recorded specimens of the National Museum, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the National Museum was extrapolated from spreadsheet N1. This spreadsheet (Table 2.23) was subjected to further refinement and is a streamlined version of N1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum.

Datafield content from left to right for Table 2.23 is:

- <u>Column 1</u>: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- <u>Column 2</u>: Genera list, in alphabetical order, as occurs in (CD1: N1).
- <u>Column 3</u>: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- <u>Column 4</u>*:* Specimen count totals are divided into their associated assemblage zones.

Wits ETD

Table 2.24: National Museum: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

Datafield content from left to right for Table 2.24 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.
- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.25: National Museum: Specimen count (Updated). (Overleaf). This table is the final product for the National Museum after the implementation of standardisation procedures. Subsequent graphs for the National Museum are based on this spreadsheet. Table 2.25 provides a listing of genera (updated) for the National Museum, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.25 is a streamlined/'cleaned' version of the final three updated columns in Table 2.24. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.25 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated specimen count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3: Specimen count totals are subdivided into their associated updated assemblage zones.

Wits ETD

<u>Tables 2.26</u>: Rubidge Collection: Specimen count (Original). (Overleaf). List R1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the Rubidge Collection (R). This spreadsheet houses all data pertaining to the recorded specimens of the Rubidge Collection, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the Rubidge Collection was extrapolated from spreadsheet R1. This spreadsheet (Table 2.26) was subjected to further refinement and is a streamlined version of R1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum.

Datafield content from left to right for Table 2.26 is:

- <u>Column 1</u>: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- <u>Column 2</u>: Genera list, in alphabetical order, as occurs in (CD1: A1).
- <u>Column 3</u>: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- <u>Column 4</u>: Specimen count totals are divided into their associated assemblage zones.

Wits ETD

Table 2.27: Rubidge Collection: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

Datafield content from left to right for Table 2.27 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.
- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.28: Rubidge Collection: Specimen count (Updated). (Overleaf). This table is the final product for the Rubidge Collection after the implementation of standardisation procedures. Subsequent graphs for the Rubidge Collection are based on this spreadsheet. Table 2.28 provides a listing of genera (updated) for the Rubidge Collection, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.28 is a streamlined/'cleaned' version of the final three updated columns in Table 2.27. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.28 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated specimen count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3: Specimen count totals are subdivided into their associated updated assemblage zones.

Wits ETD

Table 2.29: South African Museum: Specimen count (Original). (Overleaf). List S1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the South African Museum (S). This spreadsheet houses all data pertaining to the recorded specimens of the South African Museum, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the South African Museum was extrapolated from spreadsheet S1. This spreadsheet (Table 2.29) was subjected to further refinement and is a streamlined version of S1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum.

Datafield content from left to right for Table 2.29 is:

- Column 1: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- Column 2: Genera list, in alphabetical order, as occurs in (CD1: S1).
- Column 3: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- Column 4: Specimen count totals are divided into their associated assemblage zones.

Wits ETD

Table 2.30: South African Museum: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

Datafield content from left to right for Table 2.30 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.
- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.31: South African Museum (Updated). (Overleaf). This table is the final product for the South African Museum after the implementation of standardisation procedures. Subsequent graphs for the South African Museum are based on this spreadsheet. Table 2.31 provides a listing of genera (updated) for the South African Museum, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.31 is a streamlined/'cleaned' version of the final three updated columns in Table 2.30. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.31 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated Specimen Count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3: Specimen count totals are subdivided into their associated updated assemblage zones.

Wits ETD

<u>Table 2.32</u>: Transvaal Museum: Specimen count (Original). (Overleaf). List T1 (CD1: Folder 8) refers to the first (1) stage of the standardisation process performed on the Transvaal Museum (T). This spreadsheet houses all data pertaining to the recorded specimens of the Transvaal Museum, taken directly from its original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of this spreadsheet. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

A specimen count list for the Transvaal Museum was extrapolated from spreadsheet N1. This spreadsheet (Table 2.32) was subjected to further refinement and is a streamlined version of N1. The main objective of this set of data was to correct any spelling errors from the original datasets of each museum.

Datafield content from left to right for Table 2.32 is:

- <u>Column 1</u>: Highlights spelling errors, with the corrected spelling directly next to it in the Genera Column.
- <u>Column 2</u>: Genera list, in alphabetical order, as occurs in (CD1: T1).
- <u>Column 3</u>: Specimen count of each genus - the sum of which is provided in the yellow bar at the bottom of this column.
- <u>Column 4</u>*:* Specimen count totals are divided into their associated assemblage zones.

Wits ETD

Table 2.33: Transvaal Museum: Specimen count (Original-to-Updated). (Overleaf). This table shows the changes which transpired during the updating process to correct taxonomic classification (to genus level). This spreadsheet includes the original classification as well as any necessary taxonomic updates. In addition, they specify any alterations to accompanying assemblage zone information. A spreadsheet model comprised of seven datafields, displays this update of information.

Datafield content from left to right for Table 2.33 is:

- Columns 1 – 3: Original Specimen Count Column (CD1: Folder 7), with the original assemblage zone datafield. This datafield was shifted to the left of the original genera column. The narrow, grey, column was inserted for increased visual clarity.
- Column 4: Notes specifying what changes were made. These notes were necessary as an aid to assist with 'navigating' the changes. The flanking on either side by narrow, black columns was inserted for increased visual clarity.
- Columns 5 – 7: Upgraded version of Columns 1 – 3.

In this table all original information is positioned left, with corrected information positioned right. Accompanying notes are positioned between these extremes.

Wits ETD

Table 2.34: Transvaal Museum: Specimen count (Updated). (Overleaf). This table is the final product for the Transvaal Museum after the implementation of standardisation procedures. Subsequent graphs for the Transvaal Museum are based on this spreadsheet. Table 2.34 provides a listing of genera (updated) for the Transvaal Museum, as well as the number of specimens recorded for each genus including their respective assemblage zone data.

Table 2.34 is a streamlined/'cleaned' version of the final three updated columns in Table 2.33. An aspect of the 'cleaning' process involved eliminating blank rows and standardising font colour and weight.

Datafield content from left to right for Table 2.34 is:

- Column 1: List of updated genera in alphabetical order.
- Column 2: Updated Specimen Count of each genus. The sum total is given in the yellow bar at the bottom of this column.
- Column 3: Specimen count totals are subdivided into their associated updated assemblage zones.

Wits ETD

Table 2.35: Beaufort Group: Final specimen count and assemblage zone list. Data from the seven museum collections were fused to form a synthesised Beaufort Group database showing the faunal biodiversity and abundance of the group. Table 2.35 represents this fusion of databases. This table was extrapolated from Tables 3.39 & 3.40 (Amalgamated Collections List). The process involved filtering for duplicate genus names with their accompanying counts and merging them to reach a final number of specimens for each genus. A similar process was then applied for assemblage zone information accompanying each count – reaching a final assemblage zone count list for genera.

The columns of this table adhere to the same formatting template of the seven updated collection lists (Tables 2.16; 2.19; 2.22; 2.25; 2.28; 2.31 and 2.34). The row containing the specimen count total (Gold) signifies the final product after fusion.

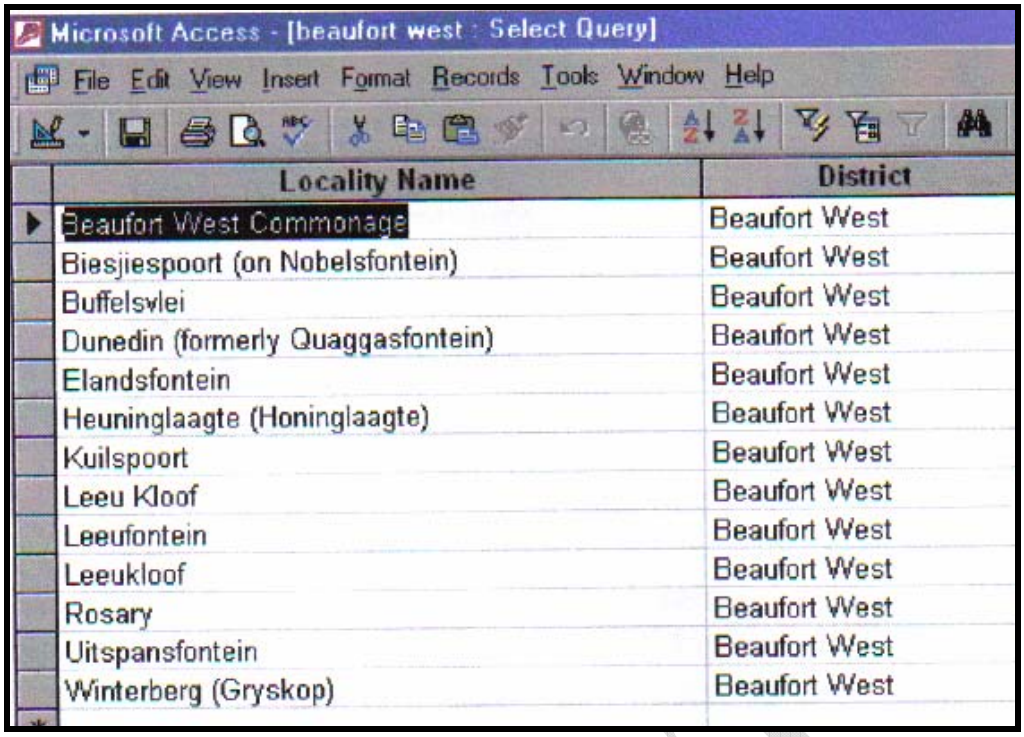
Wits ETD

<u>Figure 2.1</u>: Distance from localities (Specimen points) (Netterberg *et al*, 2004). (Overleaf). Map showing distribution of Beaufort Group fossil localities. A lack of sampling is indicated by shades of blue and indicates a substantial distance between fossil collecting sites. A red – orange spatial pattern indicates a relative closeness of fossil sites to each other. The dominance of orange – red indicates that the majority of fossil localities are in close proximity to each other with an even distribution of fossil sites for the Beaufort Group, indicating a lack of sampling bias to particular areas.

Wits ETD

Figure 2.2: Neighbourhood Analysis – Sum of specimens (Netterberg *et al,* 2004). (Overleaf). Map shows where the highest density of specimens is located. The incidence of dark red shading represents those localities with the highest density of specimens. The majority of fossil sites yield an average of 1- 60 specimens (as indicated by yellow shading). The results indicate an even density of specimen finds, indicating an average distribution in the abundance of fossil finds.

Wits ETD



Locality Name	District
Beaufort West Commonage	Beaufort West
Biesjiespoort (on Nobelsfontein)	Beaufort West
Buffelsvlei	Beaufort West
Dunedin (formerly Quaggasfontein)	Beaufort West
Elandsfontein	Beaufort West
Heuninglaagte (Honinglaagte)	Beaufort West
Kuilspoort	Beaufort West
Leeu Kloof	Beaufort West
Leeufontein	Beaufort West
Leeukloof	Beaufort West
Rosary	Beaufort West
Uitspansfontein	Beaufort West
Winterberg (Gryskop)	Beaufort West

Figure 2.8: Unique localities in the Beaufort West District (Netterberg *et al*, 2004).

As a test run to determine how to automate the linkage of locality name to farm records listed in the Surveyor General data, the localities in the district of Beaufort West for the BPI were selected. There are 13 localities in the Beaufort West District; however the "Leeu Kloof"entries, one written as "Leeukloof" and the other as "Leeu Kloof" are the same locality, making 12 distinct localities in the Beaufort West District. According to the alphanumberic data all these localities fall on the same map sheet (3222BC) except for the Winterberg (Gryskop) locality (3223AD). Of the 12 localities only 7 were able to be matched to the spatial data. Of these 7 only 2 localities fall on the correct map sheet. The outcome of this specific test run suggested that it would be very difficult to automate the linking process.

Wits ETD

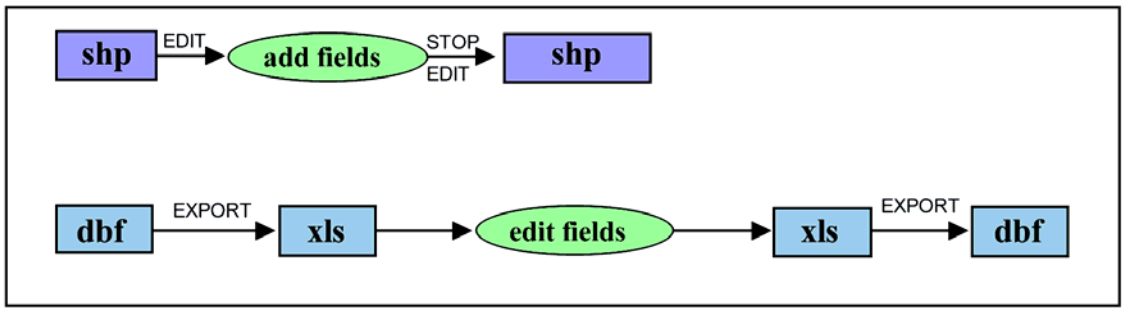


Figure 2.9: **Field manipulation** (Netterberg *et al*, 2004). The point data of the seven museum collections needed to be collated onto a single map layer. The list of shape files requiring collation is listed in column 1 and 2 of Table 2.11. The alphanumeric table structures and shape (shp) files of the various data files for each museum collection where manipulated to conform to the structure shown in Table 2.12, in order to bring about collation. Any duplicate records were removed manually from the shape files. The process, bringing about conformity of shape files and tables is illustrated in this figure and was repeated for all necessary files.

Wits ETD

Table 3.1: Directory of files on CD1, Folder 3. These files contain the raw databases, before manipulation of the seven contributing museum collections.

FOLDER 3
RAW DATABASES
CONTENTS
Raw Albany Museum
Raw BPI Collection
Raw Council for Geoscience
Raw National Museum
Raw Rubidge Collection
Raw South African Museum
Raw Transvaal Museum

Table 3.2: Directory of files on CD1, Folder 1. Each file contains a list of the fossil genera from the Beaufort Group collected per museum collection (**bold**) and in turn according to assemblage zone, for certain museum collections whose original formatting allowed for this. An amalgamated summary of genera from the Beaufort Group is found in file: Genera List (All 7 databases).

FOLDER 1		
GENERA WITHIN BEAUFORT GROUP		
CONTENTS		
(BPI) *Cistecephalus* Z – List of Genera	(NM) *Lystrosaurus* Z – List of Genera	(SAM) *Tapinocephalus* Z – List of Genera
(BPI) *Cynognathus* Z – List of Genera	(NM) *Pristerognathus* Z – List of Genera	(SAM) *Tropidostoma* Z – List of Genera
(BPI) *Dicynodon-Daptocephalus* Z – List of Genera	(NM) *Tapinocephalus* Z – List of Genera	(SAM) Unknown Z – List of Genera
(BPI) *Eodicynodon* Z – List of Genera	(NM) Unknown Z – List of Genera	**ALBANY MUSEUM LIST OF GENERA**
(BPI) *Lystrosaurus* Z – List of Genera	(RC) *Cistecephalus* Z – List of Genera	**BPI LIST OF GENERA**
(BPI) *Pristerognathus-Diictodon* Z – List of Genera	(RC) *Dicynodon* Z – List of Genera	**COUNCIL FOR GEOSCIENCE LIST OF GENERA**
(BPI) *Tapinocephalus* Z – List of Genera	(RC) *Endothiodon* Z – List of Genera	**NATIONAL MUSEUM LIST OF GENERA**
(BPI) *Tropidostoma-Endothiodon* Z – List of Genera	(RC) *Lystrosaurus* Z – List of Genera	**RUBIDGE COLLECTION LIST OF GENERA**
(NM) *Cistecephalus* Z – List of Genera	(SAM) *Cistecephalus* Z – List of Genera	**SOUTH AFRICAN MUSEUM LIST OF GENERA**
(NM) *Cynognathus* Z – List of Genera	(SAM) *Cynognathus* Z – List of Genera	**TRANSVAAL MUSEUM LIST OF GENERA**
(NM) *Daptocephalus* Z – List of Genera	(SAM) *Dicynodon* Z – List of Genera	**GENERA LIST (ALL 7 DATABASES)**
(NM)Dicynodon Z – List of Genera	(SAM)Lystrosaurus Z – List of Genera	
(NM)Eodicynodon Z – List of Genera	(SAM)Pristerognathus Z – List of Genera	

Wits E

Table 3.3: Directory of files on CD1, Folder 2. Each file contains a list of the fossil species from the Beaufort Group collected per museum collection (**bold**) and in turn according to assemblage zone, for certain museum collections whose original formatting allowed for this. An amalgamated summary of species from the Beaufort Group is found in file: Species List (All 7 databases).

FOLDER 2		
SPECIES WITHIN BEAUFORT GROUP		
CONTENTS		
(BPI) *Cistecephalus* Z – Species List	(NM) *Lystrosaurus* Z – Species List	(SAM) *Tropidostoma* Z – Species List
(BPI) *Cynognathus* Z – Species List	(NM) *Tapinocephalus* Z – Species List	(SAM) Unknown Z – Species List
(BPI) *Cistecephalus* Z – Species List	(NM) Unknown Z – Species List	**ALBANY MUSEUM LIST OF SPECIES**
(BPI) *Cynognathus* Z – Species List	(RC) *Cistecephalus* Z – Species List	**BPI LIST OF SPECIES**
(BPI) *Dicynodon-Daptocephalus* Z – Species List	(RC) *Dicynodon* Z – Species List	**COUNCIL FOR GEOSCIENCE LIST OF SPECIES**
(BPI) *Eodicynodon* Z – Species List	(RC) *Endothiodon* Z – Species List	**NATIONAL MUSEUM LIST OF SPECIES**
(BPI) *Lystrosaurus* Z – Species List	(RC) *Lystrosaurus* Z – Species List	**RUBIDGE COLLECTION LIST OF SPECIES**
(BPI) *Tapinocephalus* Z – Species List	(SAM) *Cistecephalus* Z – Species List	**SOUTH AFRICAN MUSEUM LIST OF SPECIES**
(BPI) *Tropidostoma-Endothiodon* Z – Species List	(SAM) *Cynognathus* Z – Species List	**TRANSVAAL MUSEUM LIST OF SPECIES**
(NM) *Cistecephalus* Z – Species List	(SAM) *Dicynodon* Z – Species List	**SPECIES LIST (ALL 7 DATABASES)**
(NM) *Cynognathus* Z – Species List	(SAM) *Lystrosaurus* Z – Species List	
(NM) *Daptocephalus* Z – Species List	(SAM) *Pristerognathus* Z – Species List	
(NM) *Eodicynodon* Z – Species List	(SAM) *Tapinocephalus* Z – Species List	

Table 3.4: Directory of subfolders for Folder 4 (CD1). This folder contains the first manipulation and filtering of data from the original respective museum sources, whereas Folders 1 and 2 are investigations into dataset content. This table is a directory of subfolders saved per museum collection and Table 3.5, a directory of files saved to each subfolder. The contents of Folder 4 (Table 3.5) show the segregation of original (raw) data into groups and themes. Such groupings are necessary for standardisation purposes in preparation for GIS formatting and query procedure.

FOLDER 4	
INITIAL WORKING DATABASES	
SUBFOLDERS	
Albany Museum – Initial	South African Museum - Initial
BPI Collection - Initial	Rubidge Collection - Initial
Council for Geoscience - Initial	Transvaal Museum - Initial
National Museum - Initial	

WITS

Table 3.5: Directory of files per subfolder of Folder 4 (CD1). This set of 'Initial Working' databases groups' relevant information, allowing for easier access to information. The aim of 'theming' data was to create templates of specific information that can in time be improved and added to. Such theme clustering is apparent in the Initial BPI database (Column 2) for example, where separate files contain information on farm locality co-ordinates, species representation, taxon and farm locality information and taxon representation. This grouping of data was also performed on the National Museum, Rubidge Collection and South African Museum databases. The original formatting of the Albany Museum, Council for Geoscience and the Transvaal Museum did not allow for such grouping, as such these databases were not segregated to the themes described above.

FOLDER 4 SUBFOLDER CONTENTS MUSEUM/COLLECTION (INITIAL DATABASE)						
ALBANY	BPI	CGS	NATIONAL	RUBIDGE	SOUTH AFRICAN	TRANSVAAL
Albany Museum-fish	Cisteceph Z – Farm locality co-ords	CGS Database	(NM)Cistecephalus Z – Farm locality co-ords	(RC)Cistecephalus Z – Farm locality co-ords	(SAM)Cistecephalus Z – Farm locality co-ords	Transvaal Museum Database
Albany Museum-tetrapods	Cisteceph Z – Species representation		(NM)Cistecephalus Z – Species representation	(RC)Cistecephalus Z – Species representation	(SAM)Cistecephalus Z – Species representation	
	Cisteceph Z – Taxon & Farm locality		(NM)Cistecephalus Z – Taxon & Farm locality	(RC)Cistecephalus Z – Taxon & Farm locality	(SAM)Cistecephalus Z – Taxon & Farm locality	
	Cisteceph Z – Taxon representation		(NM)Cistecephalus Z – Taxon representation	(RC)Cistecephalus Z – Taxon representation	(SAM)Cistecephalus Z – Taxon representation	
	Cynognathus Z – Farm locality co-ords		(NM)Cynognathus Z – Farm locality co-ords	(RC)Cynognathus Z – Non-locatable specimens	(SAM)Cynognathus Z – Farm locality co-ords	
	Cynognathus Z – Species representation		(NM)Cynognathus Z – Species representation	(RC)Dicynodon – Farm locality co-ords	(SAM)Cynognathus Z – Species representation	
	Cynognathus Z – Taxon & Farm locality		(NM)Cynognathus Z – Taxon & Farm locality	(RC)Dicynodon Z – Species representation	(SAM)Cynognathus Z – Taxon & Farm locality	
	Cynognathus Z – Taxon representation		(NM)Cynognathus Z – Taxon representation	(RC)Dicynodon Z – Taxon & Farm locality	(SAM)Cynognathus Z – Taxon representation	
	Dicyno-Daptoceph Z – Farm locality co-ords		(NM)Daptocephalus Z – Farm locality co-ords	(RC)Dicynodon Z – Taxon representation	(SAM)Dicynodon – Farm locality co-ords	
	Dicyno-Daptoceph Z – Species representation		(NM)Daptocephalus Z – Species representation	(RC)Endothiodon – Farm locality co-ords	(SAM)Dicynodon Z – Species representation	

FOLDER 4
SUBFOLDER CONTENTS
MUSEUM/COLLECTION (INITIAL DATABASE)

ALBANY	BPI	CGS	NATIONAL	RUBIDGE	SOUTH AFRICAN	TRANSVAAL
	Dicyno-Daptoceph Z – Taxon & Farm locality		(NM)Daptocephalus Z – Taxon & Farm locality	(RC)Endothiodon Z – Species representation	(SAM)Dicynodon Z – Taxon & Farm locality	
	Dicyno-Daptoceph Z – Taxon representation		(NM)Daptocephalus Z – Taxon representation	(RC)Endothiodon Z – Taxon & Farm locality	(SAM)Dicynodon Z – Taxon representation	
	Eodicynodon – Farm locality co-ords		(NM)Dicynodon – Farm locality co-ords	(RC)Endothiodon Z – Taxon representation	(SAM)Lystrosaurus Z – Farm locality co-ords	
	Eodicynodon Z – Species representation		(NM)Dicynodon Z – Species representation	(RC)Lystrosaurus Z – Farm locality co-ords	(SAM)Lystrosaurus Z – Species representation	
	Eodicynodon Z – Taxon & Farm locality		(NM)Dicynodon Z – Taxon & Farm locality	(RC)Lystrosaurus Z – Species representation	(SAM)Lystrosaurus Z – Taxon & Farm locality	
	Eodicynodon Z – Taxon representation		(NM)Dicynodon Z – Taxon representation	(RC)Lystrosaurus Z – Taxon & Farm locality	(SAM)Lystrosaurus Z – Taxon representation	
	Lystrosaurus Z – Farm locality co-ords		(NM)Eodicynodon – Farm locality co-ords	(RC)Lystrosaurus Z – Taxon representation	(SAM)Pristerognathus Z – Farm locality co-ords	
	Lystrosaurus Z – Species representation		(NM)Eodicynodon Z – Species representation		(SAM)Pristerognathus Z – Species representation	
	Lystrosaurus Z – Taxon & Farm locality		(NM)Eodicynodon Z – Taxon & Farm locality		(SAM)Pristerognathus Z – Taxon & Farm locality	
	Lystrosaurus Z – Taxon representation		(NM)Eodicynodon Z – Taxon representation		(SAM)Pristerognathus Z – Taxon representation	
	Pristerognathus-Diictodon Z – Farm locality co-ords		(NM)Lystrosaurus Z – Farm locality co-ords		(SAM)Tapinocephalus Z – Farm locality co-ords	
	Pristerognathus-Diictodon Z – Species representation		(NM)Lystrosaurus Z – Species representation		(SAM)Tapinocephalus Z – Species representation	
	Pristerognathus-Diictodon Z – Taxon & Farm locality		(NM)Lystrosaurus Z – Taxon & Farm locality		(SAM)Tapinocephalus Z – Taxon & Farm locality	
	Pristerognathus-Diictodon Z – Taxon representation		(NM)Lystrosaurus Z – Taxon representation		(SAM)Tapinocephalus Z – Taxon representation	
	Tapinocephalus Z – Farm locality co-ords		(NM)Pristerognathus Z – Farm locality co-ords		(SAM)Tropidostoma Z – Farm locality co-ords	
	Tapinocephalus Z – Species representation		(NM)Pristerognathus Z – Species representation		(SAM)Tropidostoma Z – Species representation	
	Tapinocephalus Z – Taxon & Farm locality		(NM)Pristerognathus Z – Taxon & Farm locality		(SAM)Tropidostoma Z – Taxon & Farm locality	
	Tapinocephalus Z – Taxon representation		(NM)Pristerognathus Z – Taxon representation		(SAM)Tropidostoma Z – Taxon representation	
	Tropidostoma-Endothiodon Z – Farm locality co-ords		(NM)Tapinocephalus Z – Farm locality co-ords		(SAM)Unknown Z – Farm locality co-ords	
	Tropidostoma-Endothiodon Z		(NM)Tapinocephalus Z –		(SAM)Unknown Z – Species	

FOLDER 4 SUBFOLDER CONTENTS MUSEUM/COLLECTION (INITIAL DATABASE)						
ALBANY	BPI – Species representation	CGS	NATIONAL Species representation	RUBIDGE	SOUTH AFRICAN representation	TRANSVAAL
	Tropidostoma-Endothiodon Z – Taxon & Farm locality		(NM)Tapinocephalus Z – Taxon & Farm locality		(SAM)Unknown Z – Taxon & Farm locality	
	Tropidostoma-Endothiodon Z – Taxon representation		(NM)Tapinocephalus Z – Taxon representation		(SAM)Unknown Z – Taxon representation	
			(NM)Unknown Z – Farm locality co-ords			
			(NM)Unknown Z – Species representation			
			(NM)Unknown Z – Taxon & Farm locality			
			(NM)Unknown Z – Taxon representation			

Wits B

Table 3.6: Directory of files on CD1, Folder 5. The contents within this directory list those records which failed or were unable to be too fed automatically into the spatial map. The contents of the manual data tables established per museum collection, include the sum of 'failure to automate' data taken from the automated data tables (Table 3.7) with 'unautomatable' data from the original data tables. This established a list of records within the Beaufort Group that required manual insertion into the established GIS.

FOLDER 5	
MANUAL INPUT SPREADSHEETS	
CONTENTS	
ALBANY MUSEUM MANUAL INPUT (FISH)	BPI COLLECTION (MANUAL INPUT DATA)-NCAPE
ALBANY MUSEUM MANUAL INPUT (TETRAPODS)	BPI COLLECTION (MANUAL INPUT DATA)-WCAPE
BPI COLLECTION (MANUAL INPUT DATA – NO CO-ORDINATES)	COUNCIL FOR GEOSCIENCE (MANUAL INPUT DATA)
BPI COLLECTION (MANUAL INPUT DATA)	NATIONAL MUSEUM (MANUAL INPUT DATA)
BPI COLLECTION (MANUAL INPUT DATA)-ECAPE	RUBIDGE COLLECTION (MANUAL INPUT DATA)
BPI COLLECTION (MANUAL INPUT DATA)-FREE STATE	SOUTH AFRICAN MUSEUM (MANUAL INPUT DATA)
BPI COLLECTION (MANUAL INPUT DATA)-KWAZULU NTL	TRANSVAAL MUSEUM (MANUAL & AUTOMATIC INPUT)

WITS ETD

Table 3.7: Directory of files on CD1, Folder 6. Files comprising Folder 6 list specifically selected records per museum collection that had the potential to be entered into the GIS automatically because of their accompanying resolution and accuracy of described locality information or their having of a co-ordinate pair signifying fossil locality. These records were sourced from the original museum datasets. The objective for establishing this set of data (the contents of Folder 6) was to provide the alphanumeric data needed to create a spatial database containing localities (per farm centroid) as well as a record of specimens that carried accurate geo-references (co-ordinates).

FOLDER 6	
AUTOMATED INPUT SPREADSHEETS	
CONTENTS	
AM AUTOMATED DATA	RC AUTOMATED DATA
BPI AUTOMATED DATA	SAM AUTOMATED DATA
CGS AUTOMATED DATA	TRANSVAAL MUSEUM DATABASE AUTO & MANUAL DATA
NM AUTOMATED DATA	

Wits ETD

Table 3.8: Quantity Matrix. The number of records that were manually inserted per museum is shown in column 4 (MI). The number of records that were automatically inserted per museum is shown in column 3 (AI). The success rate for automated data entry is 41% (the AI total divided with the total number of tetrapod fossils (Column 7) for the Beaufort Group requiring import to the GIS). The manual entry success rate is 57% (using the MI total). From column 6 (RD – TI), the National Museum requires 6.7% of its records imported to the GIS, the Albany Museum requires 18.7% of its records imported to the GIS, the BPI requires 1.6% of its records imported to the GIS, the Transvaal Museum requires 87.3% of its records imported to the GIS, the Council for Geoscience requires 26.6% of its records imported to the GIS and the South African Museum requires 22.9% of its records imported to the GIS. The mean percentage of records still requiring import into the GIS is 23.4%, with 76.6% of records for the Beaufort Group plotted on the spatial database. The records that still require import onto the spatial map are those records that have vague or no locality and/or taxonomic detail. These records require further investigation and clarification. Only then would it be possible to enter them onto the spatial map.

MUSEUM	RD	AI	MI	AI + MI = TI	RD - TI	SPECIMEN COUNT
NM	3520	364	2920	3284	236	3171
AM	588	27	451	478	110	468
BPI	4780	795	3909	4704	76	4483
TVL	2719	N/A	343	343	2376	1250
CGS	7579	4005	1557	5562	2017	5322
RC	854	209	645	854	0	850
SAM	6797	3112	2125	5237	1560	5424
TOTAL	26837	8512	11950	20462	6375	20968

KEY TO TABLE

RD = Raw Data Total
AI = Automatic Input Total
MI = Manual Input Total
TI = Total Input to GIS

Table 3.9: Museum specimen count. The numbers of fossil vertebrate specimens which have been collected from the rocks of the Beaufort Group, regardless of the resolution or quality of their accompanying locality information are shown in this table. From these selected records (column 2) further manipulation and analysis was performed to determine the biodiversity of the Beaufort Group. These records were used to address the aims of this thesis. The various manipulations of these records culminated in the synthesised data summarised in Appendix C. The Beaufort Group specimen count total (b) is the result of the fusion of the museum collections listed below (see Table 2.35 & Figure 3.8). The Beaufort Group specimen count (c) is the number of fossil vertebrate specimens which have been collected from the rocks of the Beaufort Group. Some of these records have been subjected to an update of classification to genus level (for these records refer to Tables 2.15; 2.18; 2.21; 2.24; 2.27; 2.30 and 2.33). The three totals (a, b & c) are equal, signifying that no data was lost in the fusion and updating processes.

MUSEUM	SPECIMEN COUNT
Transvaal Museum specimen count	1250
Albany Museum specimen count	468
Bernard Price Collection specimen count	4483
Council for Geoscience specimen count	5322
Rubidge Collection specimen count	850
National Museum specimen count	3171
South African Museum specimen count	5424
(a) TOTAL (Sum of specimens from individual museums)	**20968**
(b) Beaufort Group Specimen Count	**20968**
(c) Beaufort Group Specimen Count (Classification Upgrade)	**20968**

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Table 3.10: Number of specimens recorded per taxon assignment. There are 13 taxon assignments recorded for the Beaufort Group, including an additional grouping for 13 specimens of unknown taxon assignment. Diapsida was subdivided into Archosauromorpha, Eosuchia and Indeterminate Diapsida for this study. The grouping of Diapsida is retained to accommodate 6 errant specimens from the National Museum that were neither archosauromorph nor eosuchian. These diapsids were collected from the *Dicynodon* and *Lystrosaurus* Assemblage Zones.

TAXON	TOTAL
AMPHIBIA	684
ARCHOSAUROMORPHA	169
BIARMOSUCHIA	18
CYNODONTIA	717
DIAPSIDA	6
DICYNODONTIA	15844
DINOCEPHALIA	676
EOSUCHIA	50
FISH	351
GORGONOPSIA	631
PARAREPTILIA	995
PELYCOSAURIA	4
THEROCEPHALIA	810
UNKNOWN TAXON	13
TOTAL	**20968**

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Table 3.11: Directory of files on CD1, Folder 7. The contents of Folder 7 are subdivided into three categories per museum collection. Each category focuses on a specific aspect of biodiversity. In addition there are a further eighteen subdivisions of amalgamated data, headed under Beaufort Group data: Each of these eighteen categories focuses on a facet of biodiversity across the entire Beaufort Group (see 3.1.1.6, vol. 1).

FOLDER 7	
SPECIMEN COUNT DATABASES	
MUSEUM CONTENT	
ALBANY MUSEUM-ABUNDANCE SPECIMEN COUNT	RUBIDGE COLLECTION-ABUNDANCE SPECIMEN COUNT
ALBANY MUSEUM-SPECIMEN COUNT	RUBIDGE COLLECTION-SPECIMEN COUNT
ALBANY MUSEUM-SUMMARY SPECIMEN COUNT	RUBIDGE COLLECTION-SUMMARY SPECIMEN COUNT
BPI-ABUNDANCE SPECIMEN COUNT	SOUTH AFRICAN MUSEUM-ABUNDANCE SPECIMEN COUNT
BPI-SPECIMEN COUNT	SOUTH AFRICAN MUSEUM-SPECIMEN COUNT
BPI-SUMMARY SPECIMEN COUNT	SOUTH AFRICAN MUSEUM-SUMMARY SPECIMEN COUNT
COUNCIL FOR GEOSCIENCE-ABUNDANCE SPECIMEN COUNT	TRANSVAAL MUSEUM-ABUNDANCE SPECIMEN COUNT
COUNCIL FOR GEOSCIENCE-SPECIMEN COUNT	TRANSVAAL MUSEUM-SPECIMEN COUNT
COUNCIL FOR GEOSCIENCE-SUMMARY SPECIMEN COUNT	TRANSVAAL MUSEUM-SUMMARY SPECIMEN COUNT
NATIONAL MUSEUM-ABUNDANCE SPECIMEN COUNT	[redacted]
NATIONAL MUSEUM-SPECIMEN COUNT	
NATIONAL MUSEUM-SUMMARY SPECIMEN COUNT	
BEAUFORT GROUP CONTENT	
ARCHOSAUROMORPH REPRESENTATION	BIARMOSUCHIAN REPRESENTATION
CYNODONT REPRESENTATION	DICYNODONT REPRESENTATION
GORGONOPSIAN REPRESENTATION	AMPHIBIAN REPRESENTATION
UNKNOWN TAXON REPRESENTATION	DIAPSID REPRESENTATION
DINOCEPHALIAN REPRESENTATION	EOSUCHIAN REPRESENTATION
FISH REPRESENTATION	**BEAUFORT GROUP - TAXON ASSIGNMENT SUMMARY**
PELYCOSAUR REPRESENTATION	**BEAUFORT GROUP-TAXON ASSIGNMENT SUBDIVISION**
THEROCEPHALIAN REPRESENTATION	**BEAUFORT GROUP-ABUNDANCE SPECIMEN COUNT**
PARAREPTILE REPRESENTATION	**BEAUFORT GROUP-SUMMARY SPECIMEN COUNT**

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Table 3.12: Directory of files on CD1, Folder 8. Lists A1, B1, C1, N1, R1, S1 and T1 contain all data pertaining to the first stage of the standardisation process performed on the contributing museum collections. These spreadsheets house all data pertaining to the recorded specimens of each museum collection taken directly from their corresponding original database. The first stage of the standardising and 'cleaning' process can be seen in column 3 of the spreadsheets. Here the original taxonomic classification of each recorded specimen in each museum is listed. Where necessary, notes on spelling errors and taxonomic updates *to be* made, are cited.

Footer	Header	Name & Directory of Excel files on CD1
List A.1	ALBANY MUSEUM Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **1AlbanyMuseum_1_database_CD.xls**
List B.1	BERNARD PRICE INSTITUTE Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **2BernardPriceInstitute_1_database_CD.xls**
List C.1	COUNCIL FOR GEOSCIENCE Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **3Council-for-Geoscience_1_database_CD.xls**
List N.1	NATIONAL MUSEUM Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **4NationalMuseum_1_database_CD.xls**
List R.1	RUBIDGE COLLECTION Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **5RubidgeCollection_1_database_CD.xls**
List S.1	SOUTH AFRICAN MUSEUM Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **6SouthAfricanMuseum_1_database_CD.xls**
List T.1	TRANSVAAL MUSEUM Biodiversity Study of specimens found in the Beaufort Group	FOLDER_8_BIODIVERSITY_STUDY_DATABASES / **7TransvaalMuseum_1_database_CD.xls**

Table 3.13: File descriptions for automated entry procedure (Databases). A spatial database containing specimens which could be located by centroid is saved to Palaeo CD1 – 3. Various databases and shape files were established to create this spatial database. These files are listed in Tables 3.13 (databases) & 3.14 (shape files). Three databases were created for the centroid facet of the foundation phase of the GIS – initiative:

(1) *Centroids_v2.mdb*: Contains all the centroids used in the project. This includes tables of centroids per province, tables of centroids per collection (including all instances of specimens) and tables of centroids per collection, with only one point per farm (ie distinct centroids by location).

(2) *GEO SURV. RAW DATA.mdb*

(3) *Collections.mdb.* Table 3.13 is a summary of which databases comprise the *Collections.mdb.* The contents of this database contain tables per museum collection, showing all specimens without co-ordinates of the respective centroids as well data including the centroid co-ordinates; a table of all centroids; and a table with all specimens from all collections.

Data from the Council for Geoscience is not listed in this table as all data pertaining to the Council for Geoscience is housed in the *GEO SURV. RAW DATA.mdb*. Data from the Transvaal Museum is not listed on this table as all records pertaining to the Beaufort Group of the Transvaal Museum were manually inserted into the spatial database (see Table 3.8).

DATABASE	DESCRIPTION
BPI_Collection.mdb **National Museum.mdb** **Rubidge collection.mdb** **South African Museum Collection.mdb** **Albany Museum.mdb**	Each database (mbd) contains the data of the specified collection. This is the data imported from the original excel spreadsheets as separate tables. They contain queries for aggregating the data, into single tables, a table of all centroids, including a query to match farm names.

Table 3.14: File descriptions for automated entry procedure (Shape Files). This table is a summary of the total number of shape files created for Palaeo CD1 – 3. The creation of these shape files was necessary to establish a spatial setting in which fossil specimens could be plotted within the confines of the area comprising the Beaufort Group of South Africa.

SHAPE FILE	DESCRIPTION
Ass_Z_Cistecephalus.shp **Ass_Z_Cynognathus.shp** **Ass_Z_Dicynodon.shp** **Ass_Z_Eodicynodon.shp** **Ass_Z_Lystrosaurus.shp** **Ass_Z_Pristerognathus.shp** **Ass_Z_Tapinocephalus.shp** **Ass_Z_Tropidostoma.shp** **Ass_Z_Unknown.shp**	This series of shape files contains the farm centroids of all farms. This series of shape files also listed the associated assemblage zone of each record. There is a point (located at the farm centroid) on the spatial map for each specimen along with all the alphanumeric data associated with it.
AM_centroids_allfields.shp **BPI_centroids_allfields_v2.shp** **GS_centroids_allfields_v2.shp** **NM_centroids_allfields.shp** **RC_centroids_allfields_v2.shp** **SAM_centroids_allfields_v3.shp**	This series of shape files contains the farm centroids of all the farms with specimens, which appear in the relative collection. There is a point (located at the farm centroid) for each specimen in the specific collection, along with all the alphanumeric data associated with it.
ALL_centroids_allfields_v3.shp	This shape file contains the farm centroids of all the farms with specimens from all the collections. There is a point (located at the farm centroid) for each specimen, along with all the alphanumeric data associated with it.
BPI_Coll.shp **Geo_surv_Coll.shp**	These shape files contain those specimens of the BPI collection and CGS collection, located by co-ordinate pairs, along with the relative alphanumeric data.
EC_centroids_v1.shp **FS_centroids_v1.shp** **KZN_centroids_v1.shp** **NC_centroids_v1.shp** **WC_centroids_v1.shp**	These shape files contain the farm centroids for each province. Centroids are calculated in ArcGIS and are the gravitational centre of the respective farm.
eccad.shp **fscad.shp** **kncad.shp** **nccad.shp** **wccad.shp**	These shape files contain the farm cadastre for the respective provinces. Data scource : ENPAT
Mapsheets_50000.shp	Representation of the grid of 1:50 000 mapsheets.
sa.shp	Contains the provincial and national boundaries of South Africa.

Table 3.15: List of files fused to establish a final synthesis of Beaufort Group specimen records. The *Palaeo_Specimens.shp* dataset contains approximately 27 000 points and indicates where palaeontological specimens of the Beaufort Group have been found. This dataset is a collation of all specimens found to date in the Beaufort Group of South Africa. It is the result of the fusion of databases of seven contributing South African museums and represents the final synthesis of both automated and manually inserted data. This table summaries which files, extrapolated from Palaeo CD3, were appended to bring about this final synthesis. The 'point' shape files (column 1) represents all records that were manually inserted to the spatial database and the 'centroid_allfields' shape files (column 2) represent all data that was automatically inserted to the spatial map. It is with this dataset (*Palaeo_Specimens.shp*), after refinement, on which future trend and pattern analysis will be performed. Palaeo CD4 contains the final amalgamated product and represents the foundation phase of the long term project involving the digitised Mapping of Palaeontological Specimens of Karoo Fossils of South Africa.

LIST OF APPENDED FILES	
ALBANY FISH_point.shp	BPI_centroids_allfieids_v2.shp
ALBANY REPTILES_point.shp	GS_centroids_allfieids_v2.shp
COUNCIL FOR GEOSCIENCE_point.shp	NM_centroids_allfieids.shp
RUBIDGE_point.shp	RC_centroids_allfieids_v2.shp
NATIONAL MUSEUM_point.shp	SAM_centroids_allfieids_v3.shp
SAM 1 (MANUAL INPUT DATA)_point.shp	BPI_Coll.shp and Geo_surv_Coll.shp
AM_centroids_allfieids.shp	FINAL1_point.shp
RESULTANT FILE	
Palaeo_Specimens.shp	

Table 3.16: Total numbers of specimens per collection, showing subdivision into which of these records have been identified to genus level and which have not (per museum collection).

Museum collection	Total number of specimens	Unidentified specimens	Total number of identified specimens
Albany Museum	468	44	424
Bernard Price Institute	4483	2470	2013
Council for Geoscience	5322	58	5264
National Museum	3171	987	2184
Rubidge Collection	850	509	341
South African Museum	5424	1629	3795
Transvaal Museum	1250	448	802
TOTALS	**20968**	**6145**	**14823**

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Table 3.17: Decreasing order of strength based on sum total, genera and indeterminate specimen totals. Drawing on the results of Table 3.16, contributing museums were graded in order of decreasing strength, based on the following criteria: (1) The higher the number of recorded specimens, the greater the relative strength of the museum collection, in comparison to a smaller collection with limited fossils. (2) The higher the number of specimens identified to genus level, the greater the relative strength of the museum collection, in comparison to a collection with a large number of unclassified records. (3) Conversely, the lower the number of unidentified specimens, the greater the relative strength of the museum.

Museum collection	Specimen count
South African Museum	**5424**
Council for Geoscience	**5322**
Bernard Price Institute	**4483**
National Museum	**3171**
Transvaal Museum	**1250**
Rubidge Collection	**850**
Albany Museum	**468**

Museum collection	Unidentified specimens
Albany Museum	**44**
Council for Geoscience	**58**
Transvaal Museum	**448**
Rubidge Collection	**509**
National Museum	**987**
South African Museum	**1629**
Bernard Price Institute	**2470**

Museum collection	Identified specimens
Council for Geoscience	**5264**
South African Museum	**3795**
National Museum	**2184**
Bernard Price Institute	**2013**
Transvaal Museum	**802**
Albany Museum	**424**
Rubidge Collection	**341**

Table 3.18: Diversity of genera within each collection. This table lists the diversity of genera within each collection, in order of decreasing diversity.

Museum collection	Diversity of genera
South African Museum	163
Bernard Price Institute	124
National Museum	88
Rubidge Collection	85
Transvaal Museum	73
Council for Geoscience	63
Albany Museum	56

Table 3.19: Number of genera unique to specific South African museum collections.

Museum collection	Number of genera unique to each museum collection
Albany Museum	11
Bernard Price Institute	19
Council For Geoscience	5
National Museum	12
Rubidge Collection	27
South African Museum	58
Transvaal Museum	15
Total number of genera unique to each museum	**147**

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Table 3.20: List of genera which are unique to specific South African Museum collections. The values on the right hand column of each museum collection indicate the number of specimens recorded for a specific genus.

Albany Museum	
Adroichthys	1
Alopecopsis	1
Alopecorhinus	1
Amblypterus	2
Cynosuchus	1
Hewittia	1
Lycosaurus	1
Mentzichthys	1
Palaeoniscus	12
Sclerosaurus	1
Tigrisuchus	1
Unique Genera = 11	

Bernard Price Institute	
Akidnognathus	1
Aloposaurus	2
Angonisaurus	3
Broomistega	1
Cynarioides	1
Eolydekkerina	1
Euchambersia	1
Ictidostoma	1
Lumkuia	1
Moschorhynchus	3
Muchoscephalus	1
Nanomilleretta	2
Paracyclotosaurus	2
Proalopecopsis	1
Propelanomodon	1
Regisaurus	1
Scalopocynodon	1
Shansiodon	1
Tetragonias	1
Unique Genera = 19	

Rubidge Collection	
Broomicephalus	1
Cerdops	1
Clelandina	3
Elaphrosuchus	1
Galerhynchus	2
Ictidochampsa	1
Leontocephalus	1
Lycaenodon	1
Megalesuchus	1
Millerenoides	1
Millerettoides	1
Millerettops	1
Mygalesaurus	1
Myosauroides	1
Nanictidops	1
Nanictocephalus	1
Nanictosuchus	1
Notosollasia	3
Paragalerhinus	1
Pelictosuchus	1
Polycynodon	1
Scaloposuchus	1
Sesamodontoides	1
Smilesaurus	2
Spondylestes	1
Sysphinctostoma	1
Youngoides	1
Unique Genera = 27	

South African Museum	
Acanthotoposaurus	1
Aelurosuchus	1
Akkedops	1
Alopecideops	1
Arnognathus	1
Avenantia	3
Caruichthys	1
Chasmatosaurus	3
Chelydontops	2
Coelacanthus	4
Cosmolepis	9
Criocephalus	4
Cyclotosaurus	1
Eccasaurus	2
Elonichthys	1
Embrithosaurus	11
Galechirus	2
Gorgonognathus	1
Haughtoniscus	1
Heleosaurus	1
Howesia	3
Hyaenasuchus	1
Hydropessum	1
Ictidosaurus	1
Keratocephalus	3
Koalemasaurus	1
Koupia	1
Lycosuchus	1
Machaeracanthus	1
Maraisaurus	1
Meidiichthys	1
Mesosuchus	9
Mormosaurus	2
Myocephalus	1
Nochelesaurus	4
Oxygnathus	1

UNDER PEER REVIEW

Table 3.20: List of genera which are unique to specific South African Museum collections. (Continued). The values on the right hand column of each museum collection indicate the number of specimens recorded for a specific genus.

Council For Geoscience	
Cynodontina	14
Dinocephalina	33
Herpetogale	1
Scalenodon	3
Therocephalina	5
Unique Genera = 5	

National Museum	
Australosyodon	1
Ericiolaienta	1
Lanthanostegysus	2
Namaichthys	2
Olivieria	1
Paracyclotosuchus	1
Patranomodon	1
Placerias	1
Plesiosaurus	1
Sesamodon	1
Tapinocaninus	3
Tritylodontoides	1
Unique Genera = 12	

Transvaal Museum	
Emydorhinus	2
Eumantellia	1
Glochinodon	1
Hyenosaurus	1
Micrictodon	1
Newtonella	1
Notaelurodon	1
Platycraniellus	1
Silpholestes	1
Trochorhinus	1
Unique Genera = 15	

SUMMARY	
Sum of genera unique to each museum collection	147
Sum of genera common to each museum collection	136
Unidentified taxa (Not included in total below)	12
Number of genera in Beaufort Group	**271**

South African Museum (continued)	
Palaeoniscum	4
Pardosuchus	1
Phocosaurus	5
Pholidophorus	1
Pristerognathoides	1
Pristerosaurus	1
Proburnetia	1
Progalesaurus	1
Ptomalestes	2
Riebeeckosaurus	1
Saurorictus	1
Scaloporhinus	1
Scapanodon	3
Scylacosaurus	1
Scymnognathus	2
Struthiocephaloides	2
Struthionops	1
Therioides	1
Trochosaurus	1
Trochosuchus	1
Zinnosaurus	1
Zorillodontops	1
Unique Genera = 58	

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Table 3.21: Albany Museum: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	0
ARCHOSAUROMORPHA	6
BIARMOSUCHIA	0
CYNODONTIA	21
DIAPSIDA	0
DICYNODONTIA	220
DINOCEPHALIA	7
EOSUCHIA	4
FISH	49
GORGONOPSIA	6
PARAREPTILIA	145
PELYCOSAURIA	1
THEROCEPHALIA	7
UNKNOWN TAXON	**2**

Tables 3.22; 3.28; 3.31; 3.34 & 3.37: Categorisation of locality data. Locality data provided by each museum collection was sorted into one of three categories:

(1) **Potentially Viable ("V"): Records with locality information but no assemblage zone information.** These records have a high degree of textual and/or grid-referenced locality data, to which a relevant assemblage zone will be assigned on completion of phase 1 of the GIS – initiative (Chapter 6).

(2) **Non-Viable ("X"): Records with no assemblage zone or locality data.** Geo-referencing these records are not possible and are therefore of no use for spatial mapping purposes.

(3) **Assemblage Zones: Records with accompanying assemblage zone data.** Phases 1 and 2 of the GIS – initiative (Chapter 6) will not utilise assemblage zone data. An objective of phase 1 is to geo-reference all locality data (i.e. "V" data and assemblage zone data that possess additional locality data). Once all locality data has been geo-referenced the subsequent assignment of this data to assemblage zones will be based on the faunal assemblages of localities. The geo-spatial trends of the fauna of the Beaufort Group will then define the boundaries of the biozones and will not rely on any pre-labelling to assemblage zones (as in the current databases). For this study, because geo-referencing has not yet been completed, current assemblage zone data had to be made use of. For the purposes of this study, it was assumed that assignment to assemblage zones was correct.

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Tables 3.22: Albany Museum: Categorisation of locality data. See page 196 for an explanation of locality data categories.

LOCALITY DATA CATEGORIES	NUMBER OF RECORDS
Potentially Viable ('V') Zones	375
Non-Viable ('X') Zones	34
Assemblage Zones	59

Table 3.23: Albany Museum: Number of records assigned to specific assemblage zones. The number of records cited below refers *only* to those records that possess assigned assemblage zone data as extracted from the original datasets. Records possessing "X" and "V" locality data (see table above) are not accounted for in this table. Where an interpretation of biodiversity required the use of assemblage zone assignment, it was only these records listed below (and for each museum collection) that were made use of. The colours selected for each assemblage zone remain constant throughout the thesis. The use of these colours is apparent in all spreadsheets and graphs pertaining to biodiversity across and within assemblage zones (Chapter 4).

ASSEMBLAGE ZONES	NUMBER OF RECORDS
Eodicynodon	**0**
Tapinocephalus	**2**
Pristerognathus	**0**
Tropidostoma	**1**
Cistecephalus	**28**
Dicynodon	**0**
Lystrosaurus	**10**
Cynognathus	**12**
Cistecephalus/Dicynodon Transition Zone	**6**

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Table 3.24: Bernard Price Institute: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	340
ARCHOSAUROMORPHA	65
BIARMOSUCHIA	7
CYNODONTIA	303
DIAPSIDA	0
DICYNODONTIA	2985
DINOCEPHALIA	65
EOSUCHIA	15
FISH	74
GORGONOPSIA	173
PARAREPTILIA	254
PELYCOSAURIA	1
THEROCEPHALIA	201
UNKNOWN TAXON	0

Table 3.25: Bernard Price Institute: Number of records assigned to specific assemblage zones. The number of records cited below refers only to those records that possess assigned assemblage zone data as extracted from the original datasets. Records possessing "X" and "V" locality data are not accounted for in this table. Where an interpretation of biodiversity required the use of assemblage zone assignment, it was only these records listed below (and for each museum) that were made use of.

ASSEMBLAGE ZONES	NUMBER OF RECORDS
Eodicynodon	**5**
Tapinocephalus	**206**
Pristerognathus	**4**
Tropidostoma	**602**
Cistecephalus	**2006**
Dicynodon	**120**
Lystrosaurus	**936**
Cynognathus	**473**
Tropidostoma/Cistecephalus Transition Zone	**52**
Dicynodon/Lystrosaurus Transition Zone	**79**

Table 3.26: Council for Geoscience: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	27
ARCHOSAUROMORPHA	7
BIARMOSUCHIA	1
CYNODONTIA	37
DIAPSIDA	0
DICYNODONTIA	4929
DINOCEPHALIA	34
EOSUCHIA	0
FISH	9
GORGONOPSIA	138
PARAREPTILIA	39
PELYCOSAURIA	1
THEROCEPHALIA	97
UNKNOWN TAXON	3

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Table 3.27: National Museum: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	97
ARCHOSAUROMORPHA	14
BIARMOSUCHIA	3
CYNODONTIA	134
DIAPSIDA	5
DICYNODONTIA	2578
DINOCEPHALIA	27
EOSUCHIA	0
FISH	68
GORGONOPSIA	58
PARAREPTILIA	90
PELYCOSAURIA	0
THEROCEPHALIA	96
UNKNOWN TAXON	1

Table 3.28: National Museum: Categorisation of locality data. See page 196 for an explanation of locality data categories.

LOCALITY DATA CATEGORIES	NUMBER OF RECORDS
Potentially Viable ('V') Zones	164
Non-Viable ('X') Zones	112
Assemblage zones	2895

Table 3.29: National Museum: Number of records assigned to specific assemblage zones. The number of records cited below refers only to those records that possess assigned assemblage zone data as extracted from the original datasets. Records possessing "X" and "V" locality data (see table above) are not accounted for in this table. Where an interpretation of biodiversity required the use of assemblage zone assignment, it was only these records listed below (and for each museum) that were made use of.

ASSEMBLAGE ZONES	NUMBER OF RECORDS
Eodicynodon	**77**
Tapinocephalus	**39**
Pristerognathus	**2**
Tropidostoma	
Cistecephalus	**311**
Dicynodon	**292**
Lystrosaurus	**1618**
Cynognathus	**241**
Cistecephalus/Dicynodon Transition Zone	**307**
Dicynodon/Lystrosaurus Transition Zone	**8**

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Table 3.30: Rubidge Collection: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	6
ARCHOSAUROMORPHA	2
BIARMOSUCHIA	2
CYNODONTIA	21
DIAPSIDA	0
DICYNODONTIA	649
DINOCEPHALIA	0
EOSUCHIA	14
FISH	0
GORGONOPSIA	69
PARAREPTILIA	39
PELYCOSAURIA	0
THEROCEPHALIA	48
UNKNOWN TAXON	0

Table 3.31: Rubidge Collection: Categorisation of locality data. See page 196 for an explanation of locality data categories.

LOCALITY DATA CATEGORIES	NUMBER OF RECORDS
Potentially Viable ('V') Zones	6
Non-Viable ('X') Zones	3
Assemblage Zones	841

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Table 3.32: Rubidge Collection: Number of records assigned to specific assemblage zones. The number of records cited below refers only to those records that possess assigned assemblage zone data. Records possessing "X" and "V" locality data (see previous table) are not accounted for in this table. Where an interpretation of biodiversity required the use of assemblage zone assignment, it was only these records listed below (and for each museum) that were made use of.

ASSEMBLAGE ZONES	
Eodicynodon	**0**
Tapinocephalus	**2**
Pristerognathus	
Tropidostoma	**2**
Cistecephalus	**608**
Dicynodon	**169**
Lystrosaurus	**55**
Cynognathus	**2**
Tropidostoma/Cistecephalus Transition Zone	**3**

Table 3.33: South African Museum: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	95
ARCHOSAUROMORPHA	74
BIARMOSUCHIA	5
CYNODONTIA	168
DIAPSIDA	1
DICYNODONTIA	3733
DINOCEPHALIA	369
EOSUCHIA	10
FISH	148
GORGONOPSIA	146
PARAREPTILIA	337
PELYCOSAURIA	0
THEROCEPHALIA	338
UNKNOWN TAXON	0

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Table 3.34: South African Museum: Categorisation of locality data. See page 196 for an explanation of locality data categories.

LOCALITY DATA CATEGORIES	NUMBER OF RECORDS
Potentially Viable ('V') Zones	4571
Non-Viable ('X') Zones	216
Assemblage Zones	637

Table 3.35: South African Museum: Number of records assigned to specific assemblage zones. The number of records cited below refers only to those records that possess assigned assemblage zone data. Records possessing "X" and "V" locality data (see table above) are not accounted for in this table. Where an interpretation of biodiversity required the use of assemblage zone assignment, it was only these records listed below (and for each museum) that were made use of.

ASSEMBLAGE ZONES	NUMBER OF RECORDS
Eodicynodon	**0**
Tapinocephalus	**68**
Pristerognathus	**28**
Tropidostoma	**198**
Cistecephalus	**163**
Dicynodon	**55**
Lystrosaurus	**31**
Cynognathus	**92**
Tropidostoma/Cistecephalus Transition Zone	**2**

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Table 3.36: Transvaal Museum: Extent of representation in each taxon assignment for the Beaufort Group. The 14 taxon assignment categories, including the category for unknown taxon assignment are listed alphabetically (column 1). Column 2 shows the total number of records within the collection, documented for a specific taxon assignment for the Beaufort Group, Karoo Supergroup of South Africa.

TAXON ASSIGNMENT	TOTAL
AMPHIBIA	119
ARCHOSAUROMORPHA	1
BIARMOSUCHIA	0
CYNODONTIA	33
DIAPSIDA	0
DICYNODONTIA	750
DINOCEPHALIA	174
EOSUCHIA	7
FISH	3
GORGONOPSIA	41
PARAREPTILIA	91
PELYCOSAURIA	1
THEROCEPHALIA	23
UNKNOWN TAXON	7

Table 3.37: Transvaal Museum: Categorisation of locality data. See page 196 for an explanation of locality data categories.

LOCALITY DATA CATEGORIES	NUMBER OF RECORDS
Potentially Viable ('V') Zones	362
Non-Viable ('X') Zones	659
Assemblage Zones	229

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Table 3.38: Transvaal Museum: Number of records assigned to specific assemblage zones. The number of records cited below refers only to those records that possess assigned assemblage zone data as extracted from the original datasets. Records possessing "X" and "V" locality data (see Table 3.37) are not accounted for in this table. Where an interpretation of biodiversity required the use of assemblage zone assignment, it was only these records listed below (and for each museum) that were made use of. The colours selected for each assemblage zone remain constant throughout the thesis. The use of these colours is apparent in all spreadsheets and graphs pertaining to biodiversity across and within assemblage zones (Chapter 4).

ASSEMBLAGE ZONES	NUMBER OF FOSSILS
Eodicynodon	**0**
Tapinocephalus	**6**
Pristerognathus	
Tropidostoma	**107**
Cistecephalus	**23**
Dicynodon	**2**
Lystrosaurus	**86**
Cynognathus	**1**
Pristerognathus/Tropidostoma Transition Zone	**1**
Tropidostoma/Cistecephalus Transition Zone	**1**
Cistecephalus/Dicynodon Transition Zone	**1**
Dicynodon/Lystrosaurus Transition Zone	**1**

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Table 3.39: Amalgamated specimen count list. (Overleaf). Amalgamated specimen count lists (Tables 3.39 & 3.40) may be used as tools to verify which genera (and in what quantity) are housed in a particular museum. Table 3.39 displays the fusion of updated data from all seven contributing museum collections. This table summarises the diversity of genera in the Beaufort Group, with specific reference to where records of particular genera are housed, as well as the numbers of specimens and their respective assemblage zone data recorded for each genus. Column 1 (Collection) shows which museums house which genera. This column is a useful tool to reference the data in each row to its original source. Column 2 (Genera) is ordered alphabetically, firstly according to genus, then according to museum abbreviation.

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Table 3.40: Amalgamated specimen count organogram. (Overleaf). This table is a specimen count organogram of all recorded genera of the Beaufort Group The organogram is comprised of 'count-cells' portrayed in a grid system. A 'count-cell' contains only the numerical abundance of specific genera. This table is an effective visual tool because it allows for quick access to which genera (and how many) are housed in which museum.

The rows are governed by Column 10 (Genus), which is the complete list of genera found in the Beaufort Group. As a check, to ensure no data loss, Column 9 (Spec Count) from Table 3.39 was added. Columns 1 – 7 list the generic content of the seven contributing museum collections in alphabetical order. The count-cells are shaded grey when a genus is absent in a museum collection. Column 8 shows the total abundance of each genus. The final row of this table contains record totals for each museum collection as well as the final fused total of recordings for the Beaufort Group.

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<u>Figure 3.1</u>: Albany Museum (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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<u>Figure 3.2</u>: Bernard Price Institute (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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Figure 3.3: Council for Geoscience (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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Figure 3.4: National Museum (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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<u>Figure 3.5</u>: Rubidge Collection (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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<u>Figure 3.6</u>: South African Museum (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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<u>Figure 3.7</u>: Transvaal Museum (Count of specimens in collection). (Overleaf). In this graph, each updated genus and its associated abundance is represented. The X-axis shows the updated genera (and abundance count), in alphabetical order, within the museum collection and the Y-axis shows the extent of the abundance associated with each genus (Specimen count). The counts (abundance) are recorded as a clustered column. The histogram columns are 50 pixels wide and extend upwards to the ratio of 1 specimen = 15 pixels. Refer to Appendix A for an explanation of the key applied to this graph.

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<u>Figure 3.8</u>: Diversity of genera and their relative abundances in the Beaufort Group. (Overleaf). This figure visually represents the abundance of every represented genus in the Beaufort Group. It was created in the same format as the specimen count graphs for each museum collection (see captions of Figures 3.1 – 3.7). Data from the seven museum collection lists (Tables 2.16; 2.19; 2.22; 2.25; 2.28; 2.31 & 2.34) were combined to form Table 2.35, which is an amalgamation of all records for the Beaufort Group. Refer to Appendix A for an explanation of the key applied to this graph.

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Table 4.1: Degree of representation per taxon assignment within the Beaufort Group.

TAXON ASSIGNMENT	RATIO (% occupying entire Beaufort Group)
Amphibia	3.26
Archosauromorpha	0.81
Biarmosuchia	0.09
Cynodontia	3.42
Diapsida	0.03
Dicynodontia	75.56
Dinocephalia	3.22
Eosuchia	0.24
Fish	1.67
Gorgonopsia	3.01
Parareptilia	4.75
Pelycosauria	0.02
Therocephalia	3.86
Indet. Taxon	0.06

Table 4.2: Biodiversity analysis of the Beaufort Group. (Overleaf). A record of genera represented in each assemblage zone of the Beaufort Group is displayed in this table. This table lists genera recorded for the Beaufort Group (Column 2) with their associated taxon assignment (Column 1), the total number of specimens (Column 3) (regardless of locality resolution data) and assignment to relevant assemblage zone(s) (Columns 6 – 20). The record of assignment to assemblage zones involves only those specimens with recorded assemblage zone data. Column 4 ("V") refers to those records with a high resolution of locality data, but without assignment to assemblage zones and Column 5 ("X") refers to those records with a low grade or no locality data. The last column serves as a check column, sourced from the original datasets where the locality data values listed equal the number of specimens per genus assigned to assemblage zones and/or "V" and/or "X" columns on the left hand side.

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Tables 4.3 – 4.11 (excluding Table 4.7): These tables focus on the representation of genera, listed alphabetically, in specific assemblage zones of the Beaufort Group (Column 2) and categorises them into their relative trophic levels (Carnivore, Herbivore or Omnivore) (Column 1). The objective of this categorisation is to ascertain the percentage of carnivores to herbivores, carnivores to omnivores and herbivores to omnivores within each biozone of the Beaufort Group. Calculation of these percentages establishes the ecological representation of tetrapods within each biozone of the Beaufort Group. Only those tetrapod records which have accompanying assemblage zone data recorded in the museum datasets are included for calculation to establish ecological representation. The total number of specimens recorded for any genus (Column 3) is shown as a yardstick of what potentially has been excluded from the analysis. Grey shading indicates that the application of a trophic level is not possible and therefore records within the 'grey zone' could not be used in the calculation of ecological representation ratios for that particular biozone.

Table 4.3: Ecological representation in the *Eodicynodon* Assemblage Zone. Grey shading was applied to unidentified dinocephalians because dinocephalians as a group occupied all three ecological feeding niches (trophic levels). Without knowing the dinocephalian genus and hence the appropriate feeding niche, applying a trophic level to indeterminate dinocephalian specimens is not possible. These records were not used in the calculation of ecological representation ratios for this biozone.

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*EODICYNODON* A.Z
CARNIVORE	*Alopecodon*	4	1
CARNIVORE	*Australosyodon*	1	1
HERBIVORE	*Eodicynodon*	53	42
CARNIVORE	*Glanosuchus*	8	1
CARNIVORE	Indet. Amphibia	413	8
HERBIVORE	Indet. Dicynodontia	4129	7
INDETERMINATE	Indet. Dinocephalia	337	8
CARNIVORE	Indet. Gorgonopsia	374	2
CARNIVORE	Indet. Therocephalia	374	4
ERRONEOUS	*Lanthanostegysus*	2	1
HERBIVORE	*Patranomodon*	1	1
HERBIVORE	*Tapinocaninus*	3	3

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Table 4.4: Ecological representation in the *Tapinocephalus* Assemblage Zone.

TROPHIC LEVEL	GENUS	TOTALSPECIMEN. COUNT	*TAPINOCEPHALUS* A.Z
CARNIVORE	*Alopecodon*	4	2
NOMEN DUBIUM	*Anningia*	1	1
CARNIVORE	*Anteosaurus*	44	10
CARNIVORE	*Arctops*	12	1
HERBIVORE	*Avenantia*	3	1
HERBIVORE	*Bradysaurus*	79	16
HERBIVORE	*Chelydontops*	2	1
CARNIVORE	*Cynariognathus*	6	1
HERBIVORE	*Delphinognathus*	4	1
ERRONEOUS	*Dicynodon*	837	2
HERBIVORE	*Diictodon*	5166	49
INDETERMINATE	*Dinosuchus*	1	1
HERBIVORE	*Eccasaurus*	2	1
CARNIVORE	*Elliotsmithia*	2	2
HERBIVORE	*Embrithosaurus*	11	4
HERBIVORE	*Eunotosaurus*	32	5
HERBIVORE	*Galechirus*	2	1
HERBIVORE	*Galeops*	3	1
CARNIVORE	*Glanosuchus*	8	1
CARNIVORE	*Hipposaurus*	7	2
CARNIVORE	*Hyaenasuchus*	1	1
CARNIVORE	Indet. Amphibia	413	4
CARNIVORE	Indet. Biarmosuchia	4	3
HERBIVORE	Indet. Dicynodontia	4129	39
INDETERMINATE	Indet. Dinocephalia	337	52
CARNIVORE	Indet. Gorgonopsia	374	9
HERBIVORE	Indet. Parareptilia	126	3
CARNIVORE	Indet. Therocephalia	374	27
HERBIVORE	*Jonkeria*	47	5
HERBIVORE	*Keratocephalus*	3	1
HERBIVORE	*Moschops*	27	8
HERBIVORE	*Nochelesaurus*	4	1
ERRONEOUS	*Oudenodon*	808	2
CARNIVORE	*Pardosuchus*	1	1
ERRONEOUS	*Pareiasaurus*	210	22
HERBIVORE	*Pristerodon*	364	4
CARNIVORE	*Pristerognathus*	104	11
CARNIVORE	*Rhinesuchus*	42	3
CARNIVORE	*Scaloposaurus*	28	1
HERBIVORE: Appendix F	*Scapanodon*	3	3
HERBIVORE	*Struthiocephalus*	34	4
HERBIVORE	*Styracocephalus*	10	3
HERBIVORE	*Tapinocephalus*	55	4
HERBIVORE	*Titanosuchus*	59	3
CARNIVORE: Appendix F	*Trochosuchus*	1	1
ERRONEOUS	*Tropidostoma*	144	1

Table 4.5: Ecological representation in the *Pristerognathus* Assemblage Zone.

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*PRISTEROGNATHUS* A.Z
HERBIVORE	*Diictodon*	5166	14
CARNIVORE	*Ictidosuchoides*	38	1
HERBIVORE	Indet. Dicynodontia	4129	3
CARNIVORE	Indet. Therocephalia	374	1
ERRONEOUS	*Oudenodon*	808	7
HERBIVORE	*Pristerodon*	364	3
CARNIVORE	*Pristerognathus*	104	2
ERRONEOUS	*Rhachiocephalus*	78	1
ERRONEOUS	*Tropidostoma*	144	1

Table 4.6: Ecological representation in the *Tropidostoma* Assemblage Zone.

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*TROPIDOSTOMA* A.Z
CARNIVORE: Appendix F	*Aelurognathus*	10	1
CARNIVORE: Appendix F	*Aelurosaurus*	5	1
HERBIVORE	*Cistecephalus*	357	2
ERRONEOUS	*Clelandina*	3	1
ERRONEOUS	*Dicynodon*	837	12
HERBIVORE	*Diictodon*	5166	176
HERBIVORE	*Emydops*	196	15
HERBIVORE: Appendix F	*Emydopsis*	1	1
HERBIVORE	*Endothiodon*	90	22
HERBIVORE	*Eumantellia*	1	1
CARNIVORE	*Gorgonops*	91	2
CARNIVORE	*Hofmeyeria*	6	3
CARNIVORE	*Ictidosuchoides*	38	1
CARNIVORE	*Ictidosuchops*	35	1
CARNIVORE: Appendix F	*Ictidosuchus*	4	1
CARNIVORE	Indet. Amphibia	413	3
HERBIVORE	Indet. Dicynodontia	4129	529
CARNIVORE	Indet. Gorgonopsia	374	13
HERBIVORE	Indet. Parareptilia	126	1
CARNIVORE	Indet. Therocephalia	374	2
ERRONEOUS	*Oudenodon*	808	55
HERBIVORE	*Palemydops*	5	1
HERBIVORE	*Pareiasaurus*	210	2
HERBIVORE	*Pristerodon*	364	25
HERBIVORE	*Rhachiocephalus*	78	1
CARNIVORE	*Rhinesuchus*	42	1
HERBIVORE	*Saurorictus*	1	1
CARNIVORE: Appendix F	*Scylacognathus*	6	3
ERRONEOUS	*Trirachodon*	86	1
HERBIVORE	*Tropidostoma*	144	29
CARNIVORE	*Youngina*	19	2

Table 4.7: Recorded quantity and location of *Trirachodon*. 7.5 % of data that could potentially be utilised to determine the ecological representation within the *Tropidostoma* Assemblage Zone is false. This percentage pertains (amongst other genera: Table 4.6) to the erroneous presence of the cynodont *Trirachodon* (Table 4.7: (SAM): South African Museum) as this omnivorous genus is is not from this biozone (Appendix F). This table summaries the resolution of locality information and assemblage zone assignment for all recorded specimens of *Trirachodon* for the Beaufort Group. In Column 4, "V" refers to those records with a high resolution of locality data, but without assignment to assemblage zones and "X" refers to those records with a low grade of or no locality data. The total number of *Trirachodon* specimens per museum collection in Column 3 (Abundance) is equal to the distribution of *Trirachodon* according to categories of locality data. For example, the Albany Museum records three specimens of *Trirachodon.* Of these specimens, one is assigned to the *Cynognathus* Assemblage Zone and the remaining two retain a high resolution of locality data ("V") that will be assigned to an appropriate assemblage zone after completion of Phase 1 of the GIS – initiative (see Chapter 6).

MUSEUM	GENUS	ABUNDANCE	ASSEMBLAGE ZONE
Alba	*Trirachodon*	3	*Cynognathus*=1 + V=2
BPI	*Trirachodon*	30	*Cynognathus*=30
CGS	*Trirachodon*	1	V=1
NatM	*Trirachodon*	27	*Cynognathus*=27
SAM	*Trirachodon*	24	*Cynog*=7 + *Tropid*=1 + V=14 + X=2
TvlM	*Trirachodon*	1	X=1

Table 4.8: Ecological representation in the *Cistecephalus* Assemblage Zone

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*CISTECEPHALUS* A.Z
CARNIVORE: Appendix F	*Aelurognathus*	10	6
CARNIVORE: Appendix F	*Aelurosaurus*	5	3
ERRONEOUS	*Akidnognathus*	1	1
CARNIVORE: Appendix F	*Alopecopsis*	1	1
CARNIVORE: Appendix F	*Aloposaurus*	2	2
HERBIVORE	*Anthodon*	9	4
CARNIVORE	*Arctognathus*	4	2
CARNIVORE	*Arctops*	12	8
HERBIVORE	*Aulacephalodon*	185	71
CARNIVORE	*Broomicephalus*	1	1
HERBIVORE	*Cistecephalus*	357	225
CARNIVORE	*Clelandina*	3	1
CARNIVORE	*Cynarioides*	1	1
CARNIVORE	*Cyniscops*	3	2
ERRONEOUS	*Cynosaurus*	12	4
CARNIVORE	*Cyonosaurus*	31	17
ERRONEOUS	*Daptocephalus*	23	1
ERRONEOUS	*Dicynodon*	837	71
HERBIVORE	*Dicynodontoides*	21	3
HERBIVORE	*Diictodon*	5166	56
HERBIVORE	*Dinanomodon*	10	3
CARNIVORE	*Dinogorgon*	9	6
HERBIVORE	*Emydops*	196	30
HERBIVORE: Appendix F	*Emydorhinus*	2	2
HERBIVORE	*Endothiodon*	90	5
CARNIVORE	*Euchambersia*	1	1
CARNIVORE	*Galerhynchus*	2	1
CARNIVORE	*Gorgonops*	91	7
CARNIVORE	*Hewittia*	1	1
ERRONEOUS	*Hipposaurus*	7	2
CARNIVORE	*Hofmeyeria*	6	3
CARNIVORE	*Homodontosaurus*	7	7
CARNIVORE	*Ictidostoma*	1	1
CARNIVORE	*Ictidosuchoides*	38	1
CARNIVORE	*Ictidosuchops*	35	19
CARNIVORE	Indet. Amphibia	413	110
INDETERMINATE	Indet. Archosauromorpha	19	1
INDETERMINATE	Indet. Cynodontia	162	8
HERBIVORE	Indet. Dicynodontia	4129	1747
CARNIVORE	Indet. Eosuchia	13	6
CARNIVORE	Indet. Gorgonopsia	374	125
INDETERMINATE	Indet. Parareptilia	126	10
CARNIVORE	Indet. Therocephalia	374	45
HERBIVORE	*Kingoria*	30	7
CARNIVORE	*Lemurosaurus*	3	3
ERRONEOUS	*Lycaenodon*	1	1
CARNIVORE	*Lycaenops*	28	9

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TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*CISTECEPHALUS* A.Z
ERRONEOUS	*Lydekkerina*	113	2
ERRONEOUS	*Lystrosaurus*	3048	3
ERRONEOUS	*Milleretta*	16	10
ERRONEOUS	*Moschorhinus*	42	3
ERRONEOUS	*Moschorhynchus*	3	3
ERRONEOUS	*Muchocephalus*	1	1
ERRONEOUS	*Myosauroides*	1	1
CARNIVORE: Appendix F	*Nanictocephalus*	1	1
ERRONEOUS	*Nanomilleretta*	2	2
ERRONEOUS	*Nanictosuchus*	1	1
HERBIVORE	*Nanoparia*	4	4
HERBIVORE	*Oudenodon*	808	212
CARNIVORE	*Owenetta*	24	10
HERBIVORE	*Palemydops*	5	1
ERRONEOUS	*Paliguana*	6	1
HERBIVORE	*Pareiasaurus*	210	21
HERBIVORE	*Pareiasuchus*	6	3
HERBIVORE	*Pelanomodon*	14	6
HERBIVORE	*Platycyclops*	11	7
CARNIVORE: Appendix F	*Polycynodon*	1	1
HERBIVORE	*Pristerodon*	364	25
CARNIVORE: Appendix F	*Proalopecopsis*	1	1
ERRONEOUS	*Procynosuchus*	34	12
CARNIVORE	*Prorubidgea*	12	6
HERBIVORE	*Rhachiocephalus*	78	22
CARNIVORE	*Rhinesuchus*	42	5
CARNIVORE	*Rubidgea*	15	6
ERRONEOUS	*Rubidgina*	2	2
ERRONEOUS	*Scalopocynodon*	1	1
CARNIVORE: Appendix F	*Scylacognathus*	6	3
CARNIVORE: Appendix F	*Scylacops*	3	2
CARNIVORE	*Scymnognathus*	2	1
ERRONEOUS	*Sesamodon*	1	1
CARNIVORE	*Smilesaurus*	2	1
CARNIVORE	*Sycosaurus*	4	3
ERRONEOUS	*Silpholestes*	1	1
CARNIVORE	*Tetracynodon*	4	2
ERRONEOUS	*Tetragonias*	1	1
CARNIVORE	*Theriognathus*	44	30
ERRONEOUS	*Tritylodontoides*	1	1
ERRONEOUS	*Tropidostoma*	144	4
CARNIVORE	*Youngina*	19	9
CARNIVORE: Appendix F	*Youngopsis*	2	1

Table 4.9: Ecological representation in the *Dicynodon* Assemblage Zone

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*DICYNODON* A.Z
CARNIVORE	*Aelurognathus*	10	2
CARNIVORE	*Arctops*	12	1
HERBIVORE	*Aulacephalodon*	185	3
CARNIVORE	*Broomisaurus*	2	1
CARNIVORE	*Cerdops*	1	1
CARNIVORE	*Cyniscops*	3	1
OMNIVORE	*Cynosaurus*	12	3
CARNIVORE	*Cyonosaurus*	31	6
HERBIVORE	*Daptocephalus*	23	8
HERBIVORE	*Dicynodon*	837	43
HERBIVORE	*Dicynodontoides*	21	1
HERBIVORE	*Diictodon*	5166	9
HERBIVORE	*Dinanomodon*	10	3
CARNIVORE	*Dinogorgon*	9	1
HERBIVORE	*Emydops*	196	1
CARNIVORE	*Galerhynchus*	2	1
ERRONEOUS	*Gorgonops*	91	2
CARNIVORE	*Ictidochampsa*	1	1
CARNIVORE	*Ictidosuchoides*	38	2
CARNIVORE	*Ictidosuchops*	35	6
CARNIVORE	Indet. Amphibia	413	3
INDETERMINATE	Indet. Cynodontia	162	3
INDETERMINATE	Indet. Diapsida	5	1
HERBIVORE	Indet. Dicynodontia	4129	315
INDETERMINATE	Indet. Eosuchia	13	3
CARNIVORE	Indet. Gorgonopsia	374	24
INDETERMINATE	Indet. Parareptilia	126	2
CARNIVORE	Indet. Therocephalia	374	13
HERBIVORE	*Kingoria*	30	3
CARNIVORE	*Leontocephalus*	1	1
CARNIVORE	*Lycaenops*	28	1
ERRONEOUS	*Lystrosaurus*	3048	12
ERRONEOUS	*Megalesuchus*	1	1
CARNIVORE	*Millerenoides*	1	1
CARNIVORE	*Milleretta*	16	4
CARNIVORE	*Millerettoides*	1	1
CARNIVORE	*Millerettops*	1	1
CARNIVORE	*Millerosaurus*	3	2
CARNIVORE	*Moschorhinus*	42	8

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*DICYNODON* A.Z
OMNIVORE	*Mygalesaurus*	1	1
CARNIVORE	*Nanictidops*	1	1
OMNIVORE	*Nanictosaurus*	5	3
CARNIVORE	*Notosollasia*	3	3
HERBIVORE	*Oudenodon*	808	62
CARNIVORE	*Owenetta*	24	2
CARNIVORE	*Paragalerhinus*	1	1
HERBIVORE	*Pareiasaurus*	210	6
HERBIVORE	*Pelanomodon*	14	5
CARNIVORE	*Pelictosuchus*	1	1
ERRONEOUS	*Platycyclops*	11	1
HERBIVORE	*Pristerodon*	364	2
ERRONEOUS	*Procolophon*	447	1
CARNIVORE	*Procynosuchus*	34	12
CARNIVORE	*Promoschorhynchus*	4	2
HERBIVORE	*Propelanomodon*	1	1
CARNIVORE	*Prorubidgea*	12	2
ERRONEOUS	*Rhachiocephalus*	78	1
CARNIVORE	*Rhinesuchus*	42	2
CARNIVORE	*Rubidgea*	15	1
CARNIVORE	*Saurosternon*	3	1
CARNIVORE	*Scaloposuchus*	1	1
CARNIVORE	*Spondylestes*	1	1
CARNIVORE	*Tetracynodon*	4	1
CARNIVORE	*Theriognathus*	44	7
ERRONEOUS	*Thrinaxodon*	138	1
ERRONEOUS	*Tropidostoma*	144	1
CARNIVORE	*Whaitsia*	9	3
CARNIVORE	*Youngina*	19	3
CARNIVORE	*Youngoides*	1	1
CARNIVORE	*Youngopsis*	2	1

Table 4.10: Ecological representation in the *Lystrosaurus* Assemblage Zone.

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*LYSTROSAURUS* A.Z
CARNIVORE	*Broomistega*	1	1
CARNIVORE	*Cerdosuchoides*	1	1
ERRONEOUS	*Cynosaurus*	12	1
ERRONEOUS	*Cyonosaurus*	31	1
HERBIVORE	*Dicynodon*	837	6
ERRONEOUS	*Dinanomodon*	10	1
CARNIVORE	*Elaphrosuchus*: Appendix F	1	1
ERRONEOUS	*Emydops*	196	1
CARNIVORE	*Eolydekkerina*	1	1
CARNIVORE	*Ericiolaienta*: Appendix F	1	1
CARNIVORE	*Galesaurus*	21	16
ERRONEOUS	*Glochinodon*	1	1
ERRONEOUS	*Glochinodontoides*	2	2
ERRONEOUS	*Ictidosuchoides*	38	2
ERRONEOUS	*Ictidosuchops*	35	6
CARNIVORE	Indet. Amphibia	413	45
INDETERMINATE	Indet. Archosauromorpha	19	3
INDETERMINATE	Indet. Cynodontia	162	23
INDETERMINATE	Indet. Diapsida	5	4
HERBIVORE	Indet. Dicynodontia	4129	26
INDETERMINATE	Indet. Eosuchia	13	2
ERRONEOUS	Indet. Gorgonopsia	374	1
INDETERMINATE	Indet. Parareptilia	126	9
CARNIVORE	Indet. Therocephalia	374	58
ERRONEOUS	*Kestrosaurus*	21	1
CARNIVORE	*Lydekkerina*	113	81
HERBIVORE	*Lystrosaurus*	3048	2037
INDETERMINATE	*Micrictodon*	1	1
CARNIVORE	*Micropholis*	16	14
CARNIVORE	*Moschorhinus*	42	16
HERBIVORE	*Myosaurus*	9	6
ERRONEOUS	*Nanictosaurus*	5	2
CARNIVORE	*Noteosuchus*	5	5
CARNIVORE	*Olivieria*	1	1
ERRONEOUS	*Oudenodon*	808	1
CARNIVORE	*Owenetta*	24	4
CARNIVORE	*Paliguana*	6	5
CARNIVORE	*Platycraniellus*	1	1

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*LYSTROSAURUS* A.Z
CARNIVORE	*Pneumatostega*	2	2
HERBIVORE	*Procolophon*	447	218
ERRONEOUS	*Progalesaurus*	1	1
CARNIVORE	*Prolacerta*	11	10
ERRONEOUS	*Prolystrosaurus*	2	1
CARNIVORE	*Proterosuchus*	19	13
CARNIVORE	*Regisaurus*	1	1
ERRONEOUS	*Rhinesuchus*	42	1
CARNIVORE	*Scaloposaurus*	28	11
CARNIVORE	*Tetracynodon*	4	1
CARNIVORE	*Thrinaxodon*	138	81
ERRONEOUS	*Trematosuchus*	4	1
ERRONEOUS	*Uranocentrodon*	10	2
ERRONEOUS	*Xenotosuchus*	28	1

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Table 4.11: Ecological representation in the *Cynognathus* Assemblage Zone.

TROPHIC LEVEL	GENUS	TOTAL SPECIMEN COUNT	*CYNOGNATHUS* A.Z
ERRONEOUS	*Aelurosuchus*	1	1
HERBIVORE	*Angonisaurus*	3	3
ERRONEOUS	*Arctognathus*	4	1
CARNIVORE	*Batrachosuchus*	15	15
HERBIVORE	*Bauria*	17	14
CARNIVORE	*Cynognathus*	109	78
HERBIVORE	*Diademodon*	120	87
ERRONEOUS	*Diictodon*	5166	1
CARNIVORE	*Erythrosuchus*	44	22
CARNIVORE	*Euparkeria*	40	7
CARNIVORE	*Garjainia*	20	20
CARNIVORE	*Howesia*	3	3
CARNIVORE	Indet. Amphibia	413	93
INDETERMINATE	Indet. Archosauromorpha	19	11
INDETERMINATE	Indet. Cynodontia	162	76
HERBIVORE	Indet. Dicynodontia	4129	11
ERRONEOUS	Indet. Gorgonopsia	374	2
INDETERMINATE	Indet. Parareptilia	126	57
INDETERMINATE	Indet. Therocephalia	374	3
HERBIVORE	*Kannemeyeria*	186	146
CARNIVORE	*Kestrosaurus*	21	20
HERBIVORE	*Kombuisia*	2	2
CARNIVORE	*Lumkuia*	1	1
CARNIVORE	*Mesosuchus*	9	1
CARNIVORE	*Microposaurus*	3	2
CARNIVORE	*Palacrodon*	5	4
CARNIVORE	*Paracyclotosaurus*	2	2
CARNIVORE	*Paracyclotosuchus*	1	1
CARNIVORE	*Parotosuchus*	9	8
ERRONEOUS	*Placerias*	1	1
ERRONEOUS	*Procolophon*	447	6
ERRONEOUS	*Procynosuchus*	34	1
ERRONEOUS	*Sesamodontoides*	1	1
HERBIVORE	*Shansiodon*	1	1
ERRONEOUS	*Sysphinctostoma*	1	1
HERBIVORE	*Thelegnathus*	7	5
CARNIVORE	*Trematosuchus*	4	1
OMNIVORE	*Trirachodon*	86	65
CARNIVORE	*Xenotosuchus*	28	22

Table 4.12: Beaufort Group: assemblage zone grid. (Overleaf). This table contains generic abundance data, locality data categorisation and assemblage zone faunal content depicted on an assemblage zone numerical grid. (Table 2.35 was enhanced to create this systemised grid). This grid is a useful tool which makes it possible to quickly identify which genera are found in which assemblage zone(s). Blank rows were inserted between each genus (Column 1) and their respective abundance counts (Column 2) to increase visual clarity. Following Column 3 (Assemblage Zone/Locality data) are 19 'count-cell' columns. Each of these columns represents an assemblage zone, transition zone, or a locality quality categorisation ("V" or "X"). The data in these columns are a numerical representation of the abbreviated text in Column 3. This means that if text in Column 3 reads: Ciste=5 + Lystro=1 + V=13 + X=24, then the count, in the relative row, will be (5) in the *Cistecephalus* Assemblage Zone (Cist) column, (1) in the *Lystrosaurus* Assemblage Zone (Lyst) column, (13) in the 'V' column (where "V" records have a high resolution of locality data but no assignation to assemblage zones) and (24) in the 'X' column (where "X" records possess little or no locality data). The objective of this table is to depict the diversity of genera across the eight assemblage zones of the Beaufort Group and hence show biodiversity changes over time. On completion of Phase 1 of the GIS – initiative, once all locality data has been geo-referenced and then assigned to an appropriate assemblage zone, this table will be updated so that the total abundance of recorded genera will approximate the total number of records assigned to assemblage zone(s). What this means is that "V" data will ultimately not exist as it will be incorporated into appropriate assemblage zones. The "X" data is redundant and will be removed from the system as these records cannot be spatially mapped.

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Table 4.13: Summary of ecological representation within each assemblage zone of the Beaufort Group.

ASSEMBLAGE ZONE	HERBIVORE	CARNIVORE	OMNIVORE	RATIO	RATIO
	Percentage	Percentage	Percentage	Herb:Carn	Herb:Carn:Omn
Eodicynodon	76	24	N/A	3:1	N/A
Tapinocephalus	66	34	N/A	2:1	N/A
Pristerognathus	83	17	N/A	5:1	N/A
Tropidostoma	96	4	N/A	24:1	N/A
Cistecephalus	84	16	N/A	5:1	N/A
Dicynodon	77	21	2	4:1	40:10:1
Lystrosaurus	86	14	N/A	6:1	N/A
Cynognathus	44	45	11	1:1	4:4:1
MEAN RESULTS	**76**	**22**	**2**	**3:1**	**38:11:1**

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Tables 4.14 – 4.20: Show the faunal assemblage of each biozone of the Beaufort Group and highlights the termination by the end of or the continuation beyond the biozone of each genus. Tables 4.14 – 4.20 were extrapolated from Table 4.2. Each of these tables displays two categories of data:

(1) Genera sorted by their termination by the end of a specific assemblage zone
(2) Genera that continued beyond the assemblage zone in question

No indeterminate genera were included in this analysis. The tables operate in succession and begin with a recording of those genera that did not survive past the *Eodicynodon* Assemblage Zone, followed by a recording of those genera that did survive past the biozone (Table 4.14). This system is repeated through the successive biozones through to those genera (Table 4.20) that survived into (or originated in) the *Lystrosaurus* Assemblage Zone, and either ceased or continued past the biozone. An extinction and survival table was not established for the *Cynognathus* Assemblage Zone as data verifying which genera became extinct by the end of this biozone and which genera persisted out of the Beaufort Group falls beyond the scope of this study. Instead, a *Cynognathus* Assemblage Zone summary was created that includes data pertaining only to the Beaufort Group (bottom of Table 4.20).

The criteria for the selection and sorting of genera involved only selecting for those specimens, classified to genus level with assemblage zone data. This means that Tables 4.14 – 4.20 display a quarter (Figure 2.3) of potential data recorded for the Beaufort Group. V' and 'X' data is maintained throughout to show the potential loss of data in each table.

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<u>Figure 4.2.a</u>: Number of individuals of designated taxa within each assemblage zone of the Beaufort Group. (Overleaf). Figures 4.2.a & 4.2.b show the number of fossils found per taxon assignment. These graphs display the relative abundance of taxa per assemblage zone as well as showing their differing degrees of frequency across successive biozones and hence the stratigraphic longevity of each taxon group across the Beaufort Group. The X-axis lists the 13 taxa of the Beaufort Group with an additional listing of specimens with unknown taxon assignment. The number of specimens within each taxon is shown in brackets. The graph has been designed for A3-landscape format at a ratio of 1 specimen = 1 pixel. The colours of the numerical blocks adhere to the same colour-code as the specimen count graphs (see page 2 of Appendix A). The Y-axis is segregated into assemblage zones, transition zones with the 'V' and 'X' sections above this.

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<u>Figure 4.2.b</u>: Number of individuals of designated taxa within each assemblage zone of the Beaufort Group (Organic version). (Overleaf). In this figure the numerical blocks of Figure 4.2.a, were merged and rounded off to create an organic feel to the presence of taxa within assemblage zones across time.

Wits ETD

<u>Figure 4.3</u>: Number of specimens of each genus within each assemblage zone of the Beaufort Group. (Overleaf). This figure is a graphic depiction of the contents of Table 4.12 and shows the representation of genera according to biozone. The width of columns reflects the number of individual specimens collected within each genus. The X-axis alphabetically lists the faunal content of the Beaufort Group, recorded to genus level. The number of individual specimens collected within each genus is shown in brackets after the genus name. The graph is designed for A4-landscape format at a ratio of 1 specimen = 1 pixel. The numerical blocks adhere to the same colour-coding of the specimen count graphs (Appendix A). Refer to Appendix B for further explanation on the methodology adopted for this graph. The Y-axis is segregated into assemblage zones, transition zones with 'V' and 'X' sections above this. The numerical blocks for each genus, were merged where necessary, enlarged along the horizontal axis and rounded off to create an organic feel to the extension of genera across biozones. These 'organic blocks' are grey and placed behind their relative numerical colour blocks. The objective of this graph is to visually display the stratigraphic range of genera during the Middle Permian to Middle Triassic of South Africa. Because of the constraints of the database, representation within a biozone does not reflect stratigraphic range of the genus within the biozone.

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<u>Figure 4.4</u>: Generic biodiversity trends within and across assemblage zones of the Beaufort Group. (Overleaf). This figure shows fluctuations in generic diversity within and across assemblage zones. These fluctuations are calculated firstly on the basis of the faunal content within a specific biozone (including genera that persisted from the previous biozone) and secondly on which genera survived across into the successive biozone. The Y-axis is calibrated to show the number of genera. The green line shows a net gain or loss of diversity within a specific assemblage zone. Taking the unequal thicknesses (Anderson, 1999) of the assemblage zones into account, the relative widths of the assemblage zones on the x-axis are not sized uniformly. Their relative widths are sized according to the ratio derived from Figure 3 of SACS (Rubidge, B.S. (Ed.). 1995(b)). It must be noted that the discussion of biodiversity trends based on this figure provides the broadest of trend overviews as more refined occurences of peaks, troughs, and extinctions of genera within a specific biozone are unknown and may have happened at the onset, later, gradually or protracted in the time period encompassing a specific biozone. Because of this gap in the resolution of data any speculation on the mode of an extinction event has not been attempted in this study.

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New explanation for new figFigure 4.5: Biodiversity trends within assemblage zones of the Beaufort Group with emphasis on the pace of change. (Overleaf). As a way to interpret faunal stability or changing faunal compositon within a specific assemblage zone, the angle at the apex of each assemblage zone was drawn as an indicator of stability or flucuation. The number and alteration of genera within a biozone was used as the indicator of faunal fluctuation. Again, for the purposes of this study, the ratio of relative thicknesses of assemblage zones (shown on the X-axis) was applied in this figure and assumed to be correct (Rubidge, B.S. (Ed.). 1995(b)). If data emerges that provides evidence for a change in thickness, the results discussed below may alter, but the reasoning and application still applies.

This figure (extrapolated from Figure 4.4) operated within the parameters of the following criteria that affected the resultant angles:

(1) The number of entry genera into an assemblage zone (i.e. those genera that crossed over from the previous biozone).
(2) Faunal assemblage within the biozone (presented genera).
(3) Exit ('survivor') genera (i.e. those genera crossing into the next biozone).
(4) Thickness of the biozone.

The total number of genera within a biozone is the sum of entry and presented genera. The number of genera is calibrated on the Y-axis. Circles which span the width and are centred on the apex of the genera counts of each biozone (from Figure 4.4), were drawn to encase the angles created by changes in generic diversity. Angles could not be cut for the *Eodicynodon* and *Cynognathus* Assemblage Zones as these biozones lack a summit (because of no entry and exit level data, respectively). For the purposes of relative comparison, the 'apex angles' were re-sized to equal diameter. The resultant pattern reveals that the smaller the angle at the apex, the greater the suddeness and severity of biodiversity change and the wider the angle at the apex, the more stable the faunal composition within a specific assemblage zone. The arrow lines drawn across the established biozone angles (see bottom of this figure) show either a net increase (green) or net decrease (red) in diversity by the end of a specific biozone.

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Table 6.1: Challenges posed by textual geo-referencing.

EXAMPLE OF TEXTUAL GEO-REFERENCE (RANDOM SELECTION)	CHALLENGE POSED
Matjiesfontein Bronkhorstspruit	**Same locality name for more than one locality**
Ndanyana Hill on Hartebeespruit	**Topological nesting**
Tiparery (?Tipperary) Ndanayane? (Ndanyana) Hill	**Complex grammar**
0.25 miles NW of Mnweni River Hantam Mts, Toren, 12 miles W of Calvinia	**Linear feature measurement**
On the road between Masite and Kolo	**Linear ambiguity**
"Various sites in Bamboeshoek Valley" "Possibly from Kiesbeen behind Platberg" "Between the road and the Sundays River" "Foothills of Lootsberg Pass"	**Vague Localities**
Transvaal, Wiepe	**Change of political borders over time**
'Fossil Bend' near Harrismith Newcastle Admiralty Estate Group	**Historical and 'in-house' placename**

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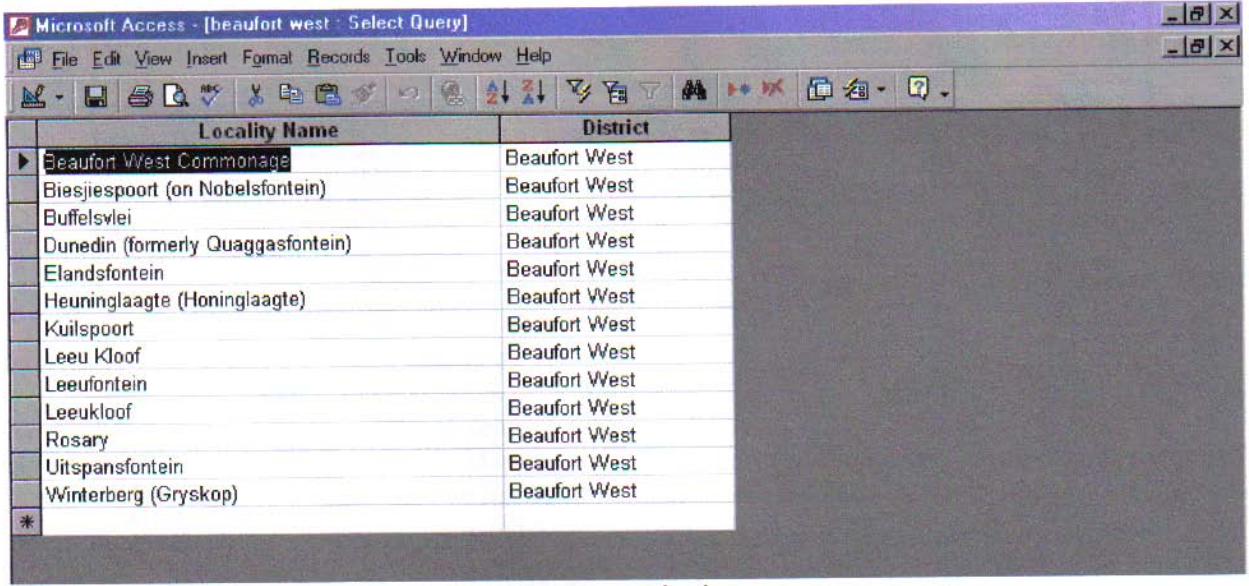


Locality Name	District
Beaufort West Commonage	Beaufort West
Biesjiespoort (on Nobelsfontein)	Beaufort West
Buffelsvlei	Beaufort West
Dunedin (formerly Quaggasfontein)	Beaufort West
Elandsfontein	Beaufort West
Heuninglaagte (Honinglaagte)	Beaufort West
Kuilspoort	Beaufort West
Leeu Kloof	Beaufort West
Leeufontein	Beaufort West
Leeukloof	Beaufort West
Rosary	Beaufort West
Uitspansfontein	Beaufort West
Winterberg (Gryskop)	Beaufort West

Figure 1: Unique localities in the Beaufort West District.

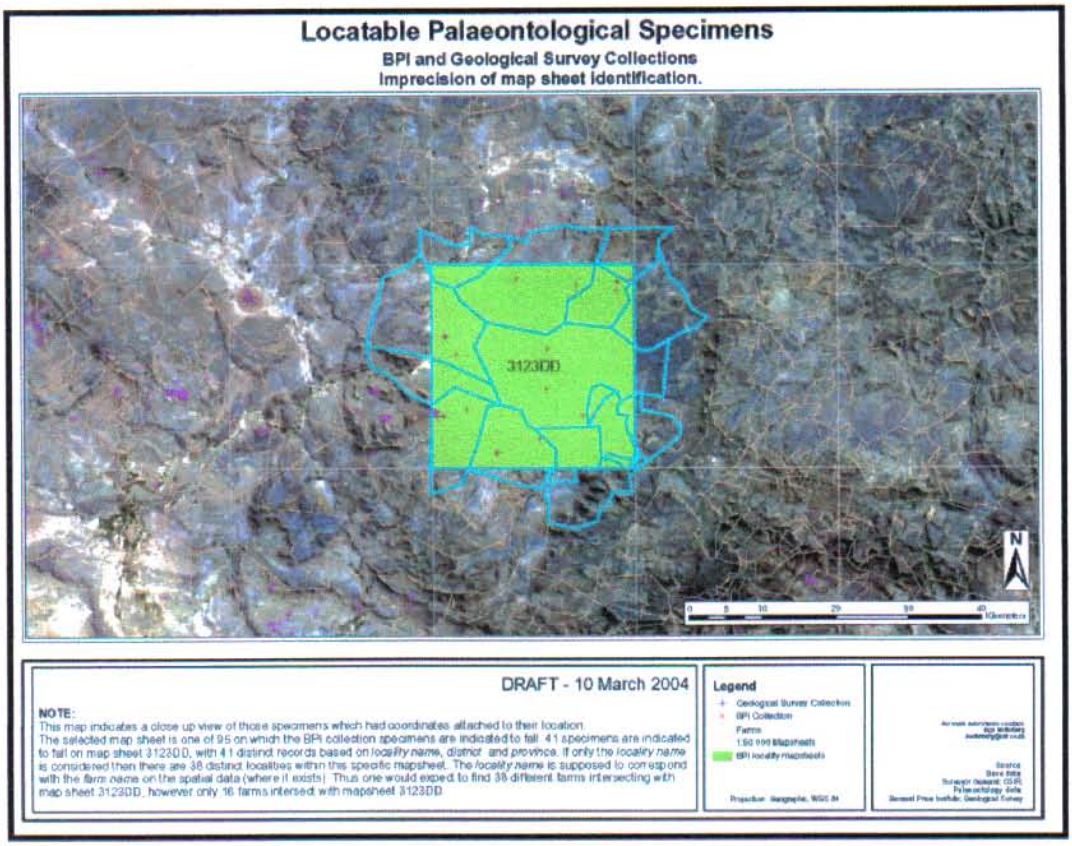
Microsoft Access - [mapsheet 3123DD : Select Query]

File Edit View Insert Format Records Tools Window Help

locality_ID	Locality Name	District	Province	Mapsheet
BPI_L_0158	Bakensklip	Murraysburg	ECAPE	3123DD
BPI_L_0409	Bakensklip	Murraysburg	NCAPE	3123DD
BPI_L_0410	Murraysburg Commonage	Murraysburg	NCAPE	3123DD
BPI_L_0501	?Ringsfontein	Murraysburg	WCAPE	3123DD
BPI_L_0502	Aasvoelkrans	Murraysburg	WCAPE	3123DD
BPI_L_0503	Aasvogelskrans	Murraysburg	WCAPE	3123DD
BPI_L_0504	Aasvogelskrans (alias 'Kapoksplaas')	Murraysburg	WCAPE	3123DD
BPI_L_0506	Angora	Murraysburg	WCAPE	3123DD
BPI_L_0507	Badsfontein	Murraysburg	WCAPE	3123DD
BPI_L_0508	Bakensklip	Murraysburg	WCAPE	3123DD
BPI_L_0509	Beeldhouersfontein	Murraysburg	WCAPE	3123DD
BPI_L_0510	Blaauwpoort	Murraysburg	WCAPE	3123DD
BPI_L_0511	Bloupoort	Murraysburg	WCAPE	3123DD
BPI_L_0512	Brandkraal	Murraysburg	WCAPE	3123DD
BPI_L_0513	Brookfield (formerly named 'Engelsmanskraal')	Murraysburg	WCAPE	3123DD
BPI_L_0514	Coetzeeskraal	Murraysburg	WCAPE	3123DD
BPI_L_0515	Driehoeksfontein	Murraysburg	WCAPE	3123DD
BPI_L_0516	Flip Hill	Murraysburg	WCAPE	3123DD
BPI_L_0517	Groot Driefontein	Murraysburg	WCAPE	3123DD
BPI_L_0518	Grootplaas	Murraysburg	WCAPE	3123DD
BPI_L_0519	Hoeksplaas	Murraysburg	WCAPE	3123DD
BPI_L_0521	Kirkvors (part of Bloupoort, also = De Hoop)	Murraysburg	WCAPE	3123DD
BPI_L_0522	Klipgat, alias Rusoord	Murraysburg	WCAPE	3123DD
BPI_L_0523	Kraaifontein	Murraysburg	WCAPE	3123DD
BPI_L_0524	Leeufontein	Murraysburg	WCAPE	3123DD

Record: 1 of 41

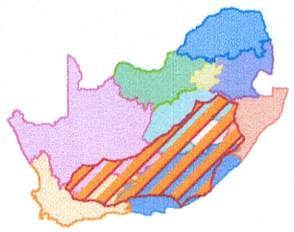
Figure 3: Selection of specimens by map sheet.



Map 3: Locatable Palaeontological Specimens: BPI and Geological Survey Collections: imprecision of map sheet identification

N

South Africa



NORTHERN CAPE

FREE STATE

KWAZULU-
NATAL

EASTERN CAPE

WESTERN CAPE

Kilometers
0 25 50 100 150 200

Sum of Specimens

- 1 - 60
- 61 - 160
- 161 - 298
- 299 - 491
- 492 - 749
- 750 - 1096
- 1097 - 1571
- 1572 - 2220
- 2221 - 2782

ZONAL LOCALITY MAP OF THE BEAUFORT SERIES

BASED ON A GEOLOGICAL MAP OF THE KARROO SYSTEM (1971)

- CYNOGNATHUS ZONE
- LYSTROSAURUS ZONE
- DAPTOCEPHALUS ZONE
- CISTECEPHALUS ZONE
- OLD "ENDOTHIODON" ZONE
- TAPINOCEPHALUS ZONE
- BASALT
- K_4 STORMBERG SERIES
- K_3 BEAUFORT SERIES
- K_2 ECCA SERIES
- K_1 DWYKA SERIES

KARROO SYSTEM

MAIN ROADS

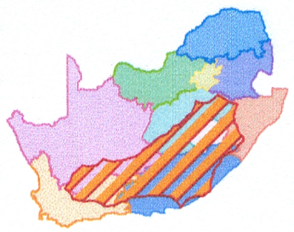
10 5 0 10 20 30 40 50 60 70 80 90 100 kms.

10 5 0 10 20 30 40 50 miles

Compiled by J.W. Kitching and drawn by P.J. Stickler

N

South Africa



NORTHERN CAPE

FREE STATE

KWAZU
NATA

WESTERN CAPE

EASTERN CAPE

Kilometers

0 20 40 80 120 160

Specimen localites

Distance

High

Low

<u>Figure 2.1</u>: Distance from localities (Specimen points) (Netterberg *et al*, 2004). Map showing distribution of Beaufort Group fossil localities. A lack of sampling is indicated by shades of blue and indicates a substantial distance between fossil collecting sites. A red – orange spatial pattern indicates a relative closeness of fossil sites to each other. The dominance of orange – red indicates that the majority of fossil localities are in close proximity to each other with an even distribution of fossil sites for the Beaufort Group, indicating a lack of sampling bias to particular areas.

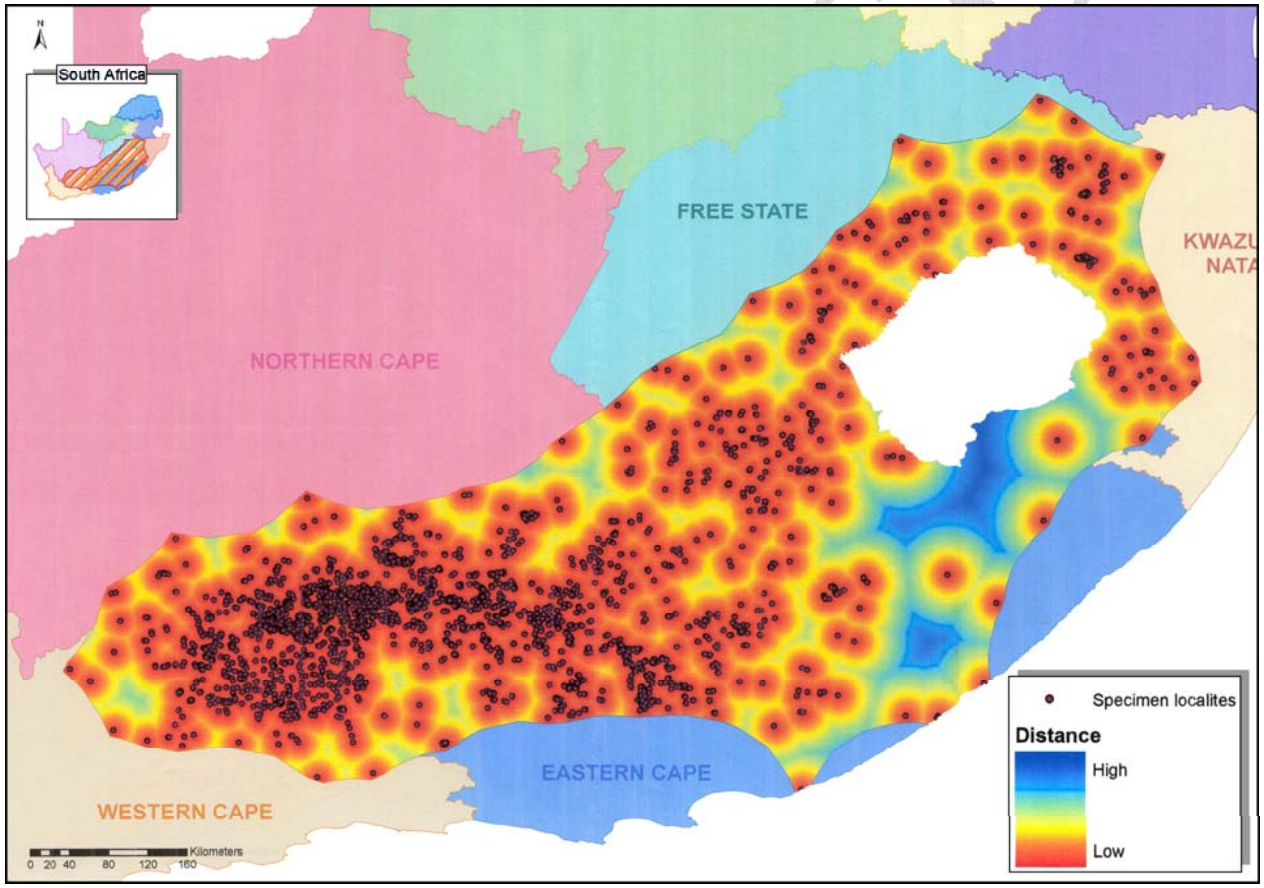
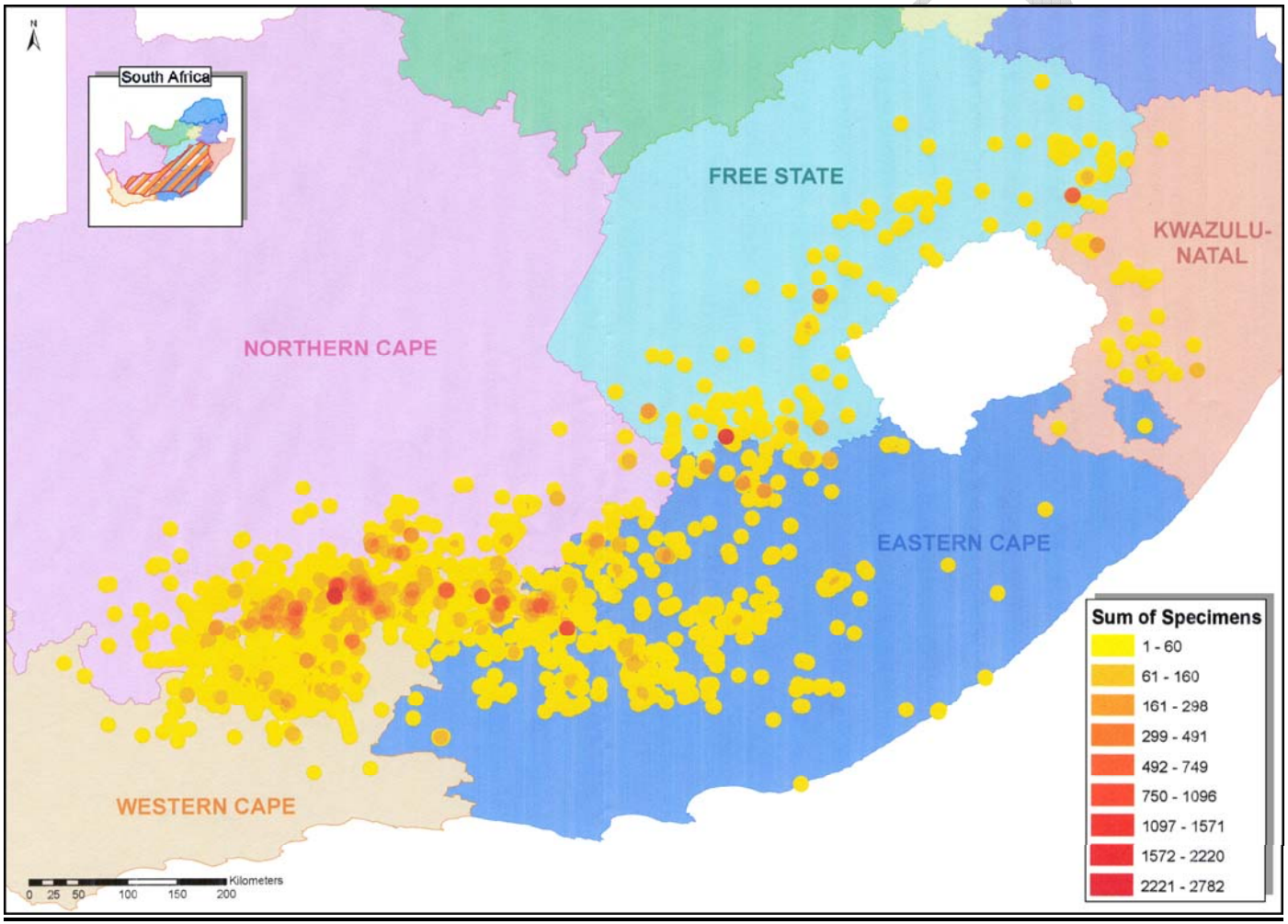


Figure 2.2: Neighbourhood Analysis – Sum of specimens



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