CHAPTER 1

INTRODUCTION

1.1 PREVIOUS EXPLORATION

The west coast of Africa is currently the focus of intensive exploration by the petroleum industry, with producing oil fields in Nigeria, São Tome and Principe, Gabon (Teisserenc & Villemin, 1990) and most recently Angola (Burwood, 1997 & 1999), as well as the gas fields of Namibia (Marot, 1990). Although highly prospective, no producing wells have to date been drilled off the west coast of South Africa.

The Petroleum Agency, SA (previously Southern Oil Exploration Corporation {SOEKOR}) have however drilled a number of exploration boreholes off the west and south-west coast of South Africa. These wells all intersected thick sequences of Cretaceous and Tertiary strata, documenting non-marine, marginal marine and open water conditions, all of which are prospective for source rock and reservoir potential. Most of the reports on these wells are however in-house and therefore only a limited scientific literature base exists with regards to the west coast offshore Cretaceous-Tertiary successions.

Previous palynological studies of Cretaceous and Tertiary aged sequences within the boundaries of South Africa are limited to onshore successions which focus on the Tertiary to younger periods, as well as isolated offshore Cretaceous sites (de Villiers, 1994; Oboh - Ikuenobe & de Villiers, 2003). This is due mostly to the lack of suitable sites yielding positive palynological results.

During 1988 and 1992 the Petroleum Agency, SA drilled two boreholes off the west coast of South Africa, which have since become available for palynological research. The information gained from the identification of the microfossils present in these two Offshore Sites contributes not only to the biostratigraphy of this part of the geologic column but also to reconstructions of the Cretaceous palaeoflora and palaeoenvironment.

1.2 LOCATION OF OFFSHORE SITES

These two Offshore Sites were drilled into the Cape Basin, located off the west coast of South Africa (Figure 1.1). The sites studied are known as Offshore Sites C-B1 and O-A1 and are located ca. 243 km from each other.

Offshore Site C-B1 was cored into the continental rise of the Cape Basin ca. 66 km due south of Cape Town. Continental rises are less pronounced slopes that follow the steeper escarpments of the continental slopes (Levin, 1990). The sea floor was penetrated 412 m below sea level and sea floor to final depth was 1502 m with drilling terminating 37 m into meta-quartzite (metamorphosed basement). In December 1988, Offshore Site C-B1's rig was moved off location thereby terminating exploration at this site. The total depth (sea depth and continental rise penetration) that Offshore Site C-B1 passed through reached 1914 m.

Offshore Site O-A1 was drilled into the abyssal plain of the Cape Basin, ca. 297 km north-west of Cape Town. Abyssal plains are vast flattish regions that extend seaward from the base of the continental slopes (Levin, 1990). A water depth of 744 m was passed through before sea floor was penetrated. Sea floor to final depth was 3654 m terminating into an amygdaloidal basalt and the total depth (sea depth and abyssal plain penetration) that Offshore Site O-A1 passed through reached 4398 m. Drilling was terminated at this site in February 1992.

There are two important points to remember with regards to Offshore Sites C-B1 and O-A1. The first is that these two Offshore Sites have differing positions with regards to the palaeoshoreline and this may mean that they preserved different facies architecture, representing differing depositional environments and secondly, the continental rise and abyssal plains are the current positions of Offshore Sites C-B1 and O-A1 and not the locations they accumulated under.

1.3 GEOLOGICAL BACKGROUND

Both Offshore Sites have been age-defined by the Petroleum Agency, SA. Many of these age ranges were determined by the microfossils (forams, diniflagellates, pollen grains & trilete spores) present in the offshore cores (McLachlan, 1998 & 1999 *pers. comm.*) and generally range

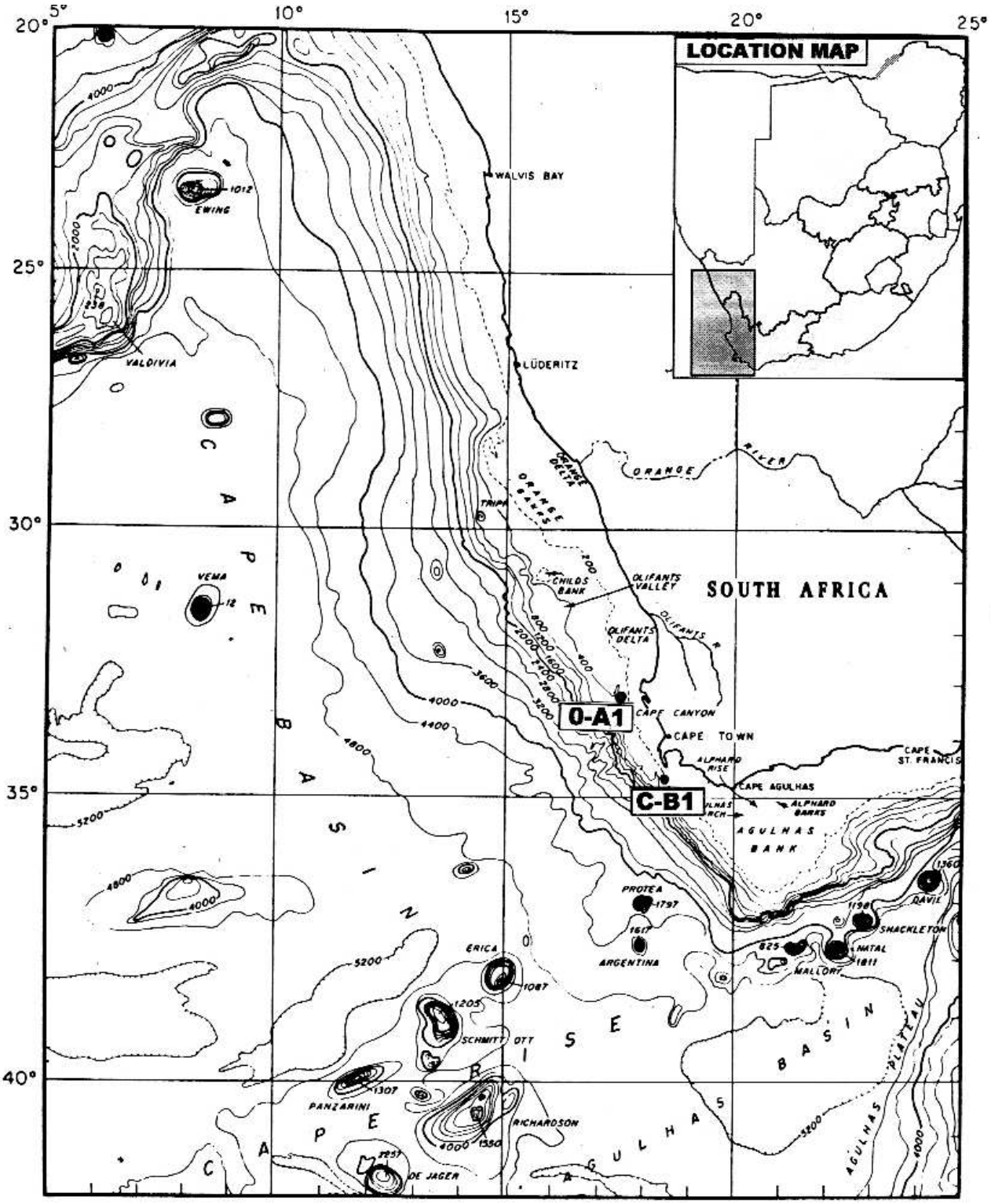

Figure 1.1. The area of study for Offshore Sites C-B1 and O-A1, including the bathymetry of the Cape Basin. Contours are at 400 m intervals with 200 m dashed intervals included. This figure has been modified from Simpson (1971), Uchupi (1971) and Connary (1972).

in age from the Early Cretaceous to the Late Tertiary periods. For this thesis, only eight stages of the Cretaceous Period namely the Barremian, Aptian, Albian, Cenomanian, Turonian, Coniacian, Santonian an Campanian have been studied and their proposed ages and general geological settings are presented in Table 1.1.

<table>
<tr><td rowspan="8">CRETACEOUS PERIOD</td><td rowspan="4">LATE CRETACEOUS PERIOD</td><td>Campanian Stage
83 Ma – 74 Ma</td><td rowspan="4">Middle drift (95 Ma – 80 Ma)</td></tr>
<tr><td>Santonian Stage
86. 4 Ma – 83 Ma</td></tr>
<tr><td>Coniacian Stage
88. 5 Ma – 86. 4 Ma</td></tr>
<tr><td>Turonian Stage
91 Ma – 88. 5 Ma</td></tr>
<tr><td rowspan="4">Cenomanian Stage
97 Ma – 91 Ma
(not present in Offshore Site O-A1)</td><td rowspan="4">Early drift (100 Ma – 95 Ma)
Late rift (106 Ma – 100 Ma)
Early rift: The Tristan Plume (133 Ma – 106 Ma)</td></tr>
<tr><td rowspan="3">EARLY CRETACEOUS PERIOD</td><td>Albian Stage
112 Ma – 97 Ma</td></tr>
<tr><td>Aptian Stage
124. 6 Ma – 112 Ma</td></tr>
<tr><td>Barremian Stage
131. 5 Ma – 124. 6 Ma</td></tr>
<tr><td>THE PRE-CRETACEOUS PERIOD</td><td>PRE-CRETACEOUS METAMORPHIC BASEMENT</td><td>Pre-Cretaceous</td><td>Pre-Rift: The Karoo Plume 188 Ma</td></tr>
</table>

Table 1.1. Age designations for both Offshore Sites C-B1 and O-A1. All Cretaceous ages from Burke *et al.,* 2003 and Gradstein *et al.,* 2004.

The Cape-Argentine Basin (Figure 1.2) was the main depo-centre for Cretaceous and Tertiary sediments in the south-east Atlantic Ocean and its formation was initiated during the continental separation between Africa and South America during the Early Cretaceous (Dingle & Hendey, 1984). The bulk of the sediments deposited into this basin are clastic in nature and are generally

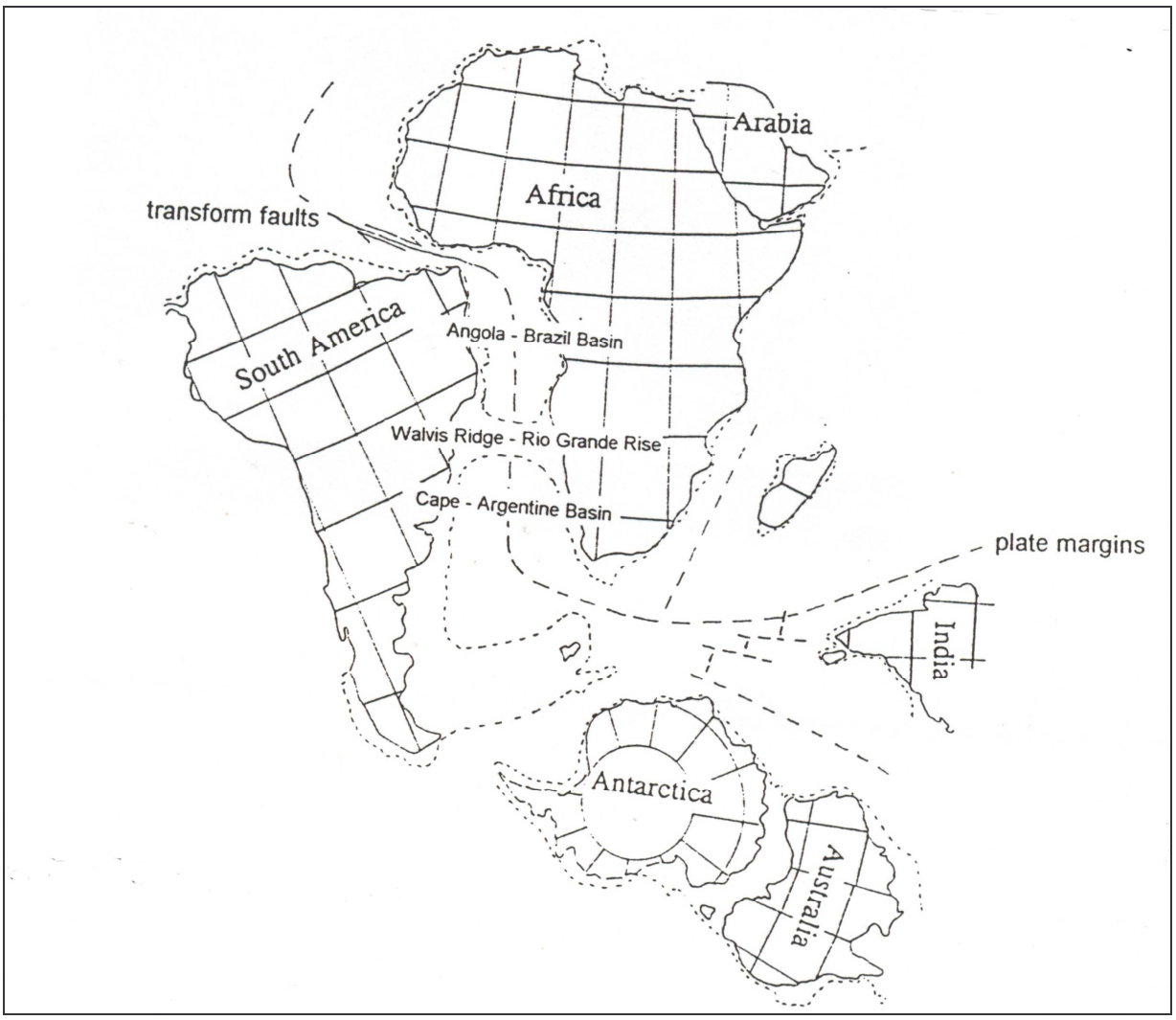

Figure 1.2. The restricted marine phase of the South Atlantic. Based on Briden *et al*., 1974 and Bolli *et al*., 1975.

assumed to have been derived from the adjacent continent mainly via the palaeo-Orange River (Emery *et al.,* 1975; Bolli *et al.,* 1978; Gerrard & Smith 1980; Dingle *et al.,* 1983; Dingle &

Hendey, 1984). Offshore Sites C-B1 and O-A1 were cored into the south-eastern region of the Cape - Argentine Basin (Figure 1.2) that is now more commonly referred to as the Cape Basin**.**

The geological history pertaining to the separation of South America from Africa and the formation of the Cape Basin may be subdivided into pre-rift, rift and drift phases as outlined below.

1.3.1 PRE-RIFT: THE KAROO PLUME (183 Ma – ca. 133 Ma)

The Karoo plume generated uplift on what is now the south-eastern coast of Africa ca. 183 million years ago (McKenzie & Weiss, 1975; England & Houseman, 1984, Burke *et al.,* 2003). This uplift took place at one end of a then active rift system stretching across Antarctica, and so pinned the continent of residual Gondwana (Burke *et al*., 2003). The plume however, failed to pin the motion of the whole of Pangea and evidence for this is that North America (Withjack *et al*., 1998) and Greater Antarctica (a large continent consisting of India, Antarctica, Madagascar, the Seychelles, Australia and Greater New Zealand) both left Africa abruptly between 180 Ma and 160 Ma, immediately after the Karoo volcanics erupted at 183 Ma (Burke *et al*., 2003). An extensive intracontinental rift-system network was initiated within Africa, South America and Arabia between 180 Ma and 133 Ma when the Tristan plume impinged into the crust. A t around 133 Ma residual Gondwana became mobile and resulted in South America and South Africa decoupling (Burke *et al*., 2003).

1.3.2 EARLY RIFT: THE TRISTAN PLUME (ca. 133 Ma – 106 Ma)

The early phase of rifting in the South Atlantic began during the Valanginian Stage ca. 133 Ma ago due to the impingement of the Tristan plume, which marked the beginning of early rift with the break-up of Africa from South America and continued through to the middle part of the Albian Stage ca. 106 Ma (Rabinowitz & La Brecque, 1979; Burke *et al*., 2003).

True ocean floor began to form at the end of the Barremian Stage (126 Ma) (Dietz & Holden, 1970; Smith *et al*., 1973; Austin & Uchupi, 1982) and once a spreading centre formed over the Tristan plume, true continental separation can be assumed to have occurred (Pitman *et al*., 1993; Burke *et al*., 2003). This continental separation resulted in the formation of a narrow oceanic

basin.

During this early phase of ocean floor formation, the Walvis thermal centre had become active (Bolli *et al.,* 1975). It's early history is that of a shallow ridge, possibly capped with islands formed virtually on top of the Mid-Atlantic Ridge by some combination of extensional and transform faulting (Bolli *et al*., 1975). Later this thermal centre developed into the Rio Grande Rise and the Walvis Ridge, both of which were carried generally north-westerly and north-easterly, respectively, by the moving plate (Dietz & Holden, 1970). Their presence provides evidence of the lateral movement of Africa and South America, since the Walvis thermal centre was activated during the Aptian Stage (ca. 121 Ma), and subsidence of the eastern segment of the Walvis Ridge occurred during the Albian Stage (ca. 110 Ma) (Ladd *et al*., 1973; Pastoret & Goslin, 1974; Goslin & Sibuet, 1975).

This Walvis Ridge / Rio Grande Rise effectively divided the narrow oceanic basin into two enclosed basins between South America and southern Africa (Bolli *et al*., 1975), the Anglo-Brazil Basin in the north and the Cape-Argentine Basin in the south (Figure. 1.2). Over time the Cape-Argentine Basin widened in an east-west direction and became subdivided into individual basins by the mid-Atlantic ridge.

In the southern South Atlantic (Cape-Argentine Basin) during the Late Aptian Stage, the Falkland Plateau, which extended eastwards from the southern tip of South America, had not yet cleared the Agulhas Bank. This created another shallow-water barrier that did not permit bottom water circulation into the southern South Atlantic (Cape-Argentine Basin), where anoxic conditions prevailed until the early part of the Albian Stage (Reyment & Dingle, 1987).

Therefore, at the start of the Valanginian Stage (133 Ma) only a narrow seaway separated Africa from South America but by the end of the Late Barremian Stage (ca. 126 Ma) the magnetic anomaly M-12 that dates the onset of continental drift was registered (Larson & Ladd, 1973; Burke *et al*., 2003).

1.3.3 LATE RIFT: 106 Ma - 100 Ma

During the Albian Stage significant oceanographic modifications occurred in the South Atlantic (Reyment & Dingle, 1987). During the Aptian to Albian stages the South Atlantic was a narrow, elongated ocean consisting of a number of basins that were between 3 – 4 km in depth, and separated from each other by ridges rising close to, or even above, sea level (Thierde, 1977). The anoxic benthic conditions that prevailed during the Aptian, terminated in the Early Albian (Dingle *et al.,* 1983) as a result of deep water circulation into the South Atlantic through gaps in the progressively separating Falkland-Agulhas Bank.

1.3.4 EARLY DRIFT: 100 Ma – 95 Ma

As it takes time after separation to develop a competant marine connection, Francis & Frakes (1993) estimated that from the Late Albian to middle part of the Cenomanian Stage (ca. 100 Ma to 95 Ma), Africa and South America were effectively separated for migration except for a few specialised species.

1.3.5 MIDDLE DRIFT: 95 Ma - 80 Ma

By the late part of the Santonian Stage (ca. 80 Ma), the South Atlantic Ocean had widened to about twice its former size (Thierde & van Andel, 1977) and the effective separation of South America from Africa had grown to a width exceeding 2000 km (Douglas *et al.,* 1987).

1.4 IDEALISED STRATIGRAPHIC COLUMNS FOR OFFSHORE SITES C-B1 AND O-A1

Both Offshore Sites C-B1 and O-A1 contain a package of sedimentary rock that spans a period of time that extends from the Early Cretaceous to the Late Cretaceous and early Tertiary (Figure 1.3). The Cenomanian Stage of the Cretaceous Period does not occur in Offshore Site O-A1 possibly due to the Turonian regressive episode (Haq *et al*., 1987), which were accompanied by erosion and tilting of earlier sediments (Dingle & Scruton, 1974). This affected the west coast continental shelf and resulted in the limited preservation of Cenomanian strata (Dingle & Scruton, 1974) in some areas. This package of sedimentary rock reflects the onset of the rift and drift sequences.

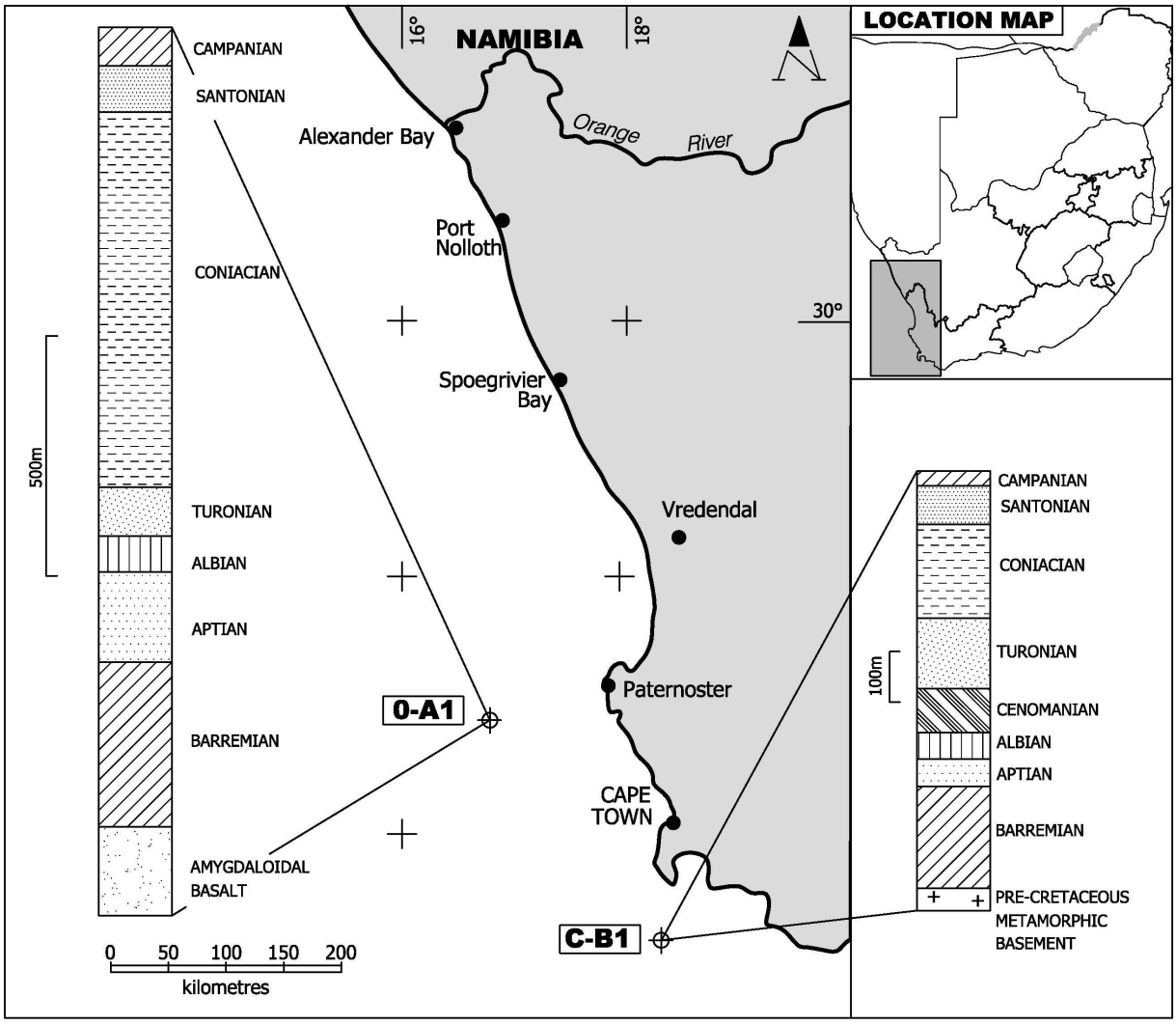

Figure 1.3. Idealised stratigraphic sequences for Offshore Sites C-B1 and O-A1. The above sequences includes only the Cretaceous Period.

Idealized stratigraphic columns for each site as well as a general legend describing the symbols used in each idealized stratigraphic column (Figure 1.4) are described and figured below. All stratigraphic columns have been modified from Petroleum Agency, SA Research. The initial interpretation of the cores from Offshore Site C-B1 was done by M.G. New and R.D.P Noble. H. Labuschagne conducted the initial interpretation of Offshore Site O-A1's cores.

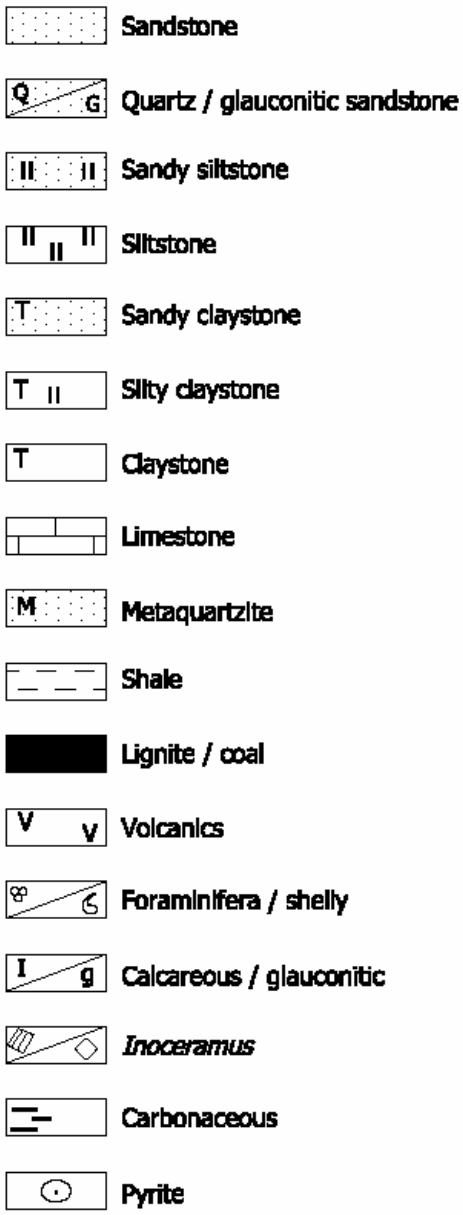

Figure 1. 4. A general legend describing the symbols used in each idealized stratigraphic sequence that follows.

1.4.1 PRE-CRETACEOUS METAMORPHIC BASEMENT OF OFFSHORE SITE C-B1

Thirty seven metres of metamorphic basement were intersected during drilling between 1914 m – 1877 m. This basement rock consists of grey-black to green-black metaquartzite (Figure 1.5).

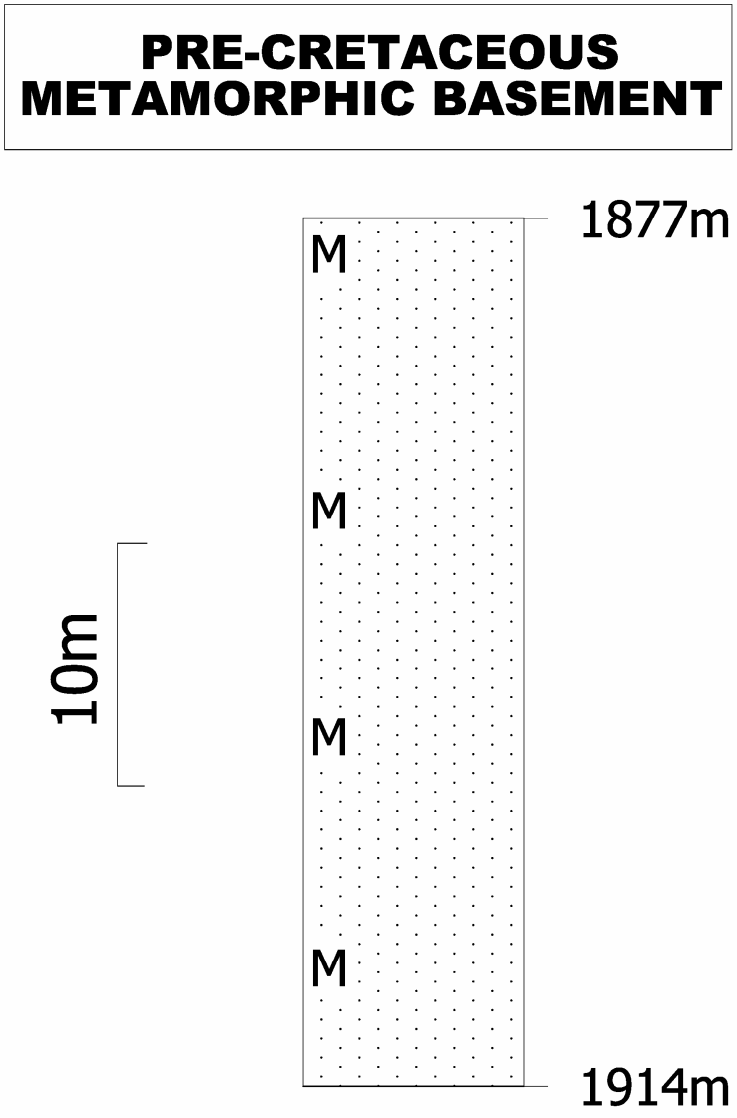

Figure 1. 5. Idealised stratigraphic sequence for the pre-Cretaceous metamorphic basement of Offshore Site C-B1.

1.4.2 THE BARREMIAN STAGE (1876 m – 1661 m) OF OFFSHORE SITE C-B1

The pre-Cretaceous metaquartzite is followed by a 216 m thick sedimentary package consisting of the following (Figure 1.6):

1877 m - 1857 m

The bottom 20 m of the Barremian Stage that follows the basement rock consists of alternating layers of siltstone and claystone. The siltstone layers gradually change colour from olive-grey to light grey due to iron staining.

1857 m - 1807 m

A 50 m succession follows and initially consists mainly of sandstone with minor claystone interbeds however this grades into a thick claystone layer capped by sandstone over the last 10 m of this unit. The claystone layers consist of clean claystone with no inclusions, however the sandstone layers are interbedded with lenses of mudrock and contain calcaeous and glauconitic inclusions.

1807 m - 1780.5 m

The claystone and sandstone succession grades back into 26.5 m of alternating of siltstone and claystone.

1780.5 m - 1721 m

A 59.5 m thick sandstone interval follows and includes shale interbeds located in the bottom 15 m and three claystone layers, one situated at the base (claystone with mudstone inclusions) and two at the top of the sequence respectively. Lignite fragments are found at intervals throughout the sandstone beds.

1721 m - 1692 m

This interval consists of 29 m of olive-grey claystone with fine-grained sandstone laminations and lenses that grade into silstone in places.

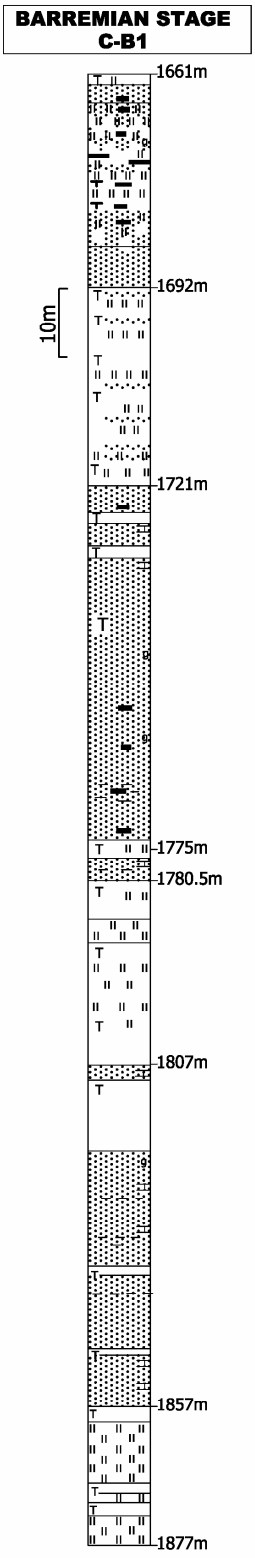

Figure 1. 6. Idealised stratigraphic sequence for the Barremian Stage of Offshore Site C-B1.

1692 m- 1661 m

The bottom-most 5.5 m of sandstone grade into sandstone with claystone and siltstone interbeds and stringers. Fragments of lignite, and glauconitic inclusions also occur throughout.

1.4.3 THE APTIAN STAGE (1661 m – 1600 m) OF OFFSHORE SITE C-B1

The Barremian Stage is followed by a 61 m thick sedimentary sequence consisting of the following (Figure 1.7):

1661 m - 1655 m

At the base of this sequence, a 6 m thick sandy glauconitic siltstone package includes carbonaceous / lignite fragments.

1655 m – 1646.5 m

The following 14 m consists of a 4 m thick sandstone package (1655 m – 1651 m) that is followed by a 3 m thick dark brown-grey siltstone (1651 m - 1648 m) with carbonaceous / lignite fragments and passes back into a 1.5 m thick sandstone layer (1648 m - 1646.5 m).

1646.5 m – 1641 m

Siltstone alternates with sandstone throughout a 5.5 m interval. The siltstone is dark brown-grey in colour and include lignite / carbonaceous fragments.

1641 m - 1620 m

A 21 m thick sandstone interval occurs that is light grey to brown-grey in colour. Calcareous inclusions are concentrated either above or below the glauconite inclusions. Lignite / carbonaceous fragments are abundant throughout.

1620 m - 1606.5 m

The next 13.5 m consists of claystone with sandstone and siltstone stringers.

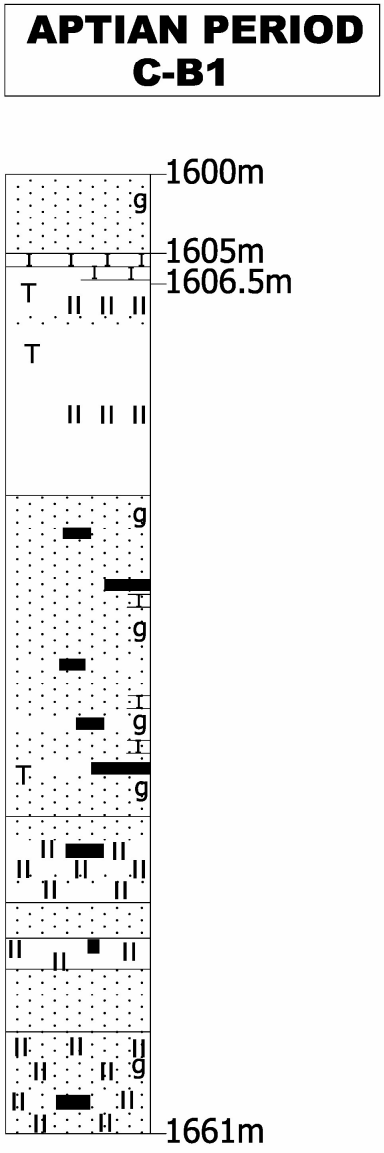

Figure1. 7. Idealised stratigraphic sequence for the Aptian Stage of Offshore Site C-B1.

1606.5 m – 1605 m

This claystone interval is capped by a 1.5 m thick limestone layer.

1605 m – 1600 m

The last 5 m consists of dark green glauconitic sandstone.

1.4.4 THE ALBIAN STAGE (1600 m - 1540 m) OF OFFSHORE SITE C-B1

The Aptian Stage was followed by a 60 m thick sedimentary unit consisting of the following (Figure 1.8):

1600 m – 1588 m

Glauconitic sandstone grades into claystone with glauconitic sandstone stringers over a 12 m interval. This layer is dark green to light grey in colour, medium to coarse-grained, and the grains are well-rounded and well-sorted.

1588 m - 1540 m

A 48 m thick claystone interval follows. Glauconitic sandstone stringers continue to occur throughout, and are brown-grey in colour and very fine to fine-grained. Thin limestone stringers form isolated inclusions higher up in the sequence at 1547 m and 1544.5 m respectively.

1.4.5 THE CENOMANIAN STAGE (1540 m - 1450 m) OF OFFSHORE SITE C-B1

The Albian Stage is followed by a 90 m thick sedimentary package consisting of the following (see Figure 1.9):

1540 m – 1450 m

A 90 m thick claystone sequence with glauconitic sandstone lenses occurring throughout can be found between 1540 m – 1450 m. These lenses are dark green-grey in colour, generally fine to medium grained, well sorted and angular to rounded in shape. Pyrite occurs at 1482 m and limestone stringers that range in colour from brown-yellow to light grey occur at intervals throughout the sequence.

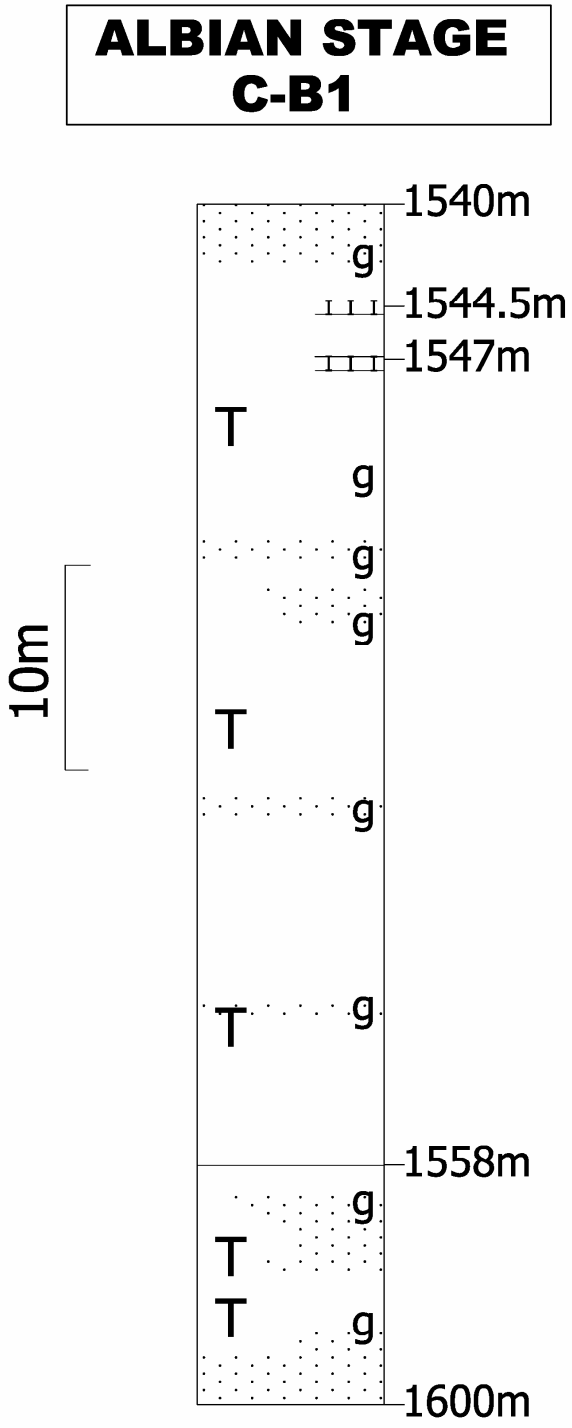

Figure 1. 8. Idealised stratigraphic sequence for the Albian Stage of Offshore Site C-B1.

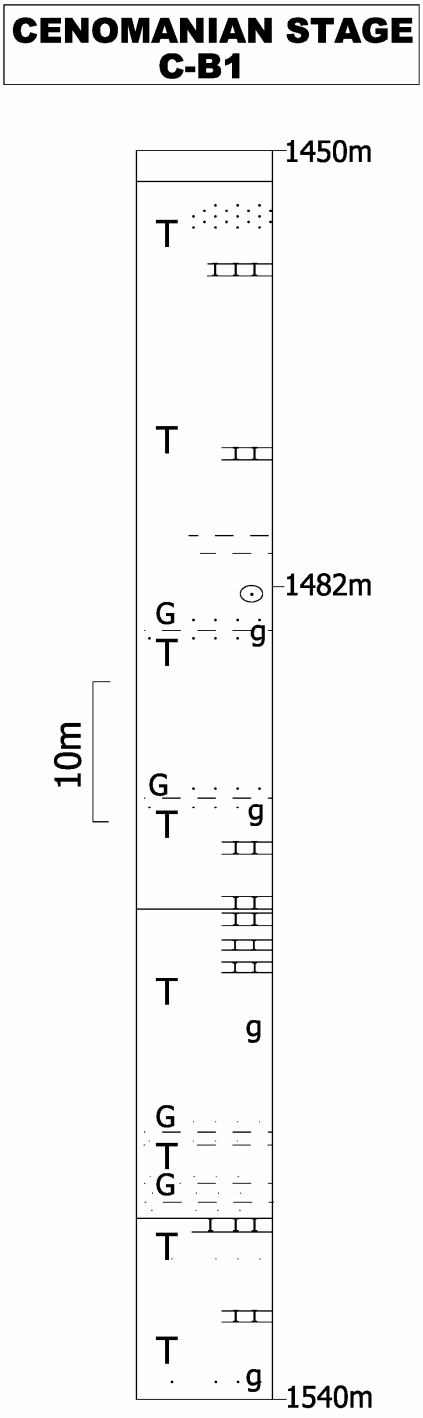

Figure 1. 9. Idealised stratigraphic sequence for the Cenomanian Stage of Offshore Site C-B1.

1.4.6 THE TURONIAN STAGE (1450 m - 1310 m) OF OFFSHORE SITE C-B1

The Cenomanian Stage is followed by a 90 m thick sedimentary sequence consisting of the following (Figure 1.10):

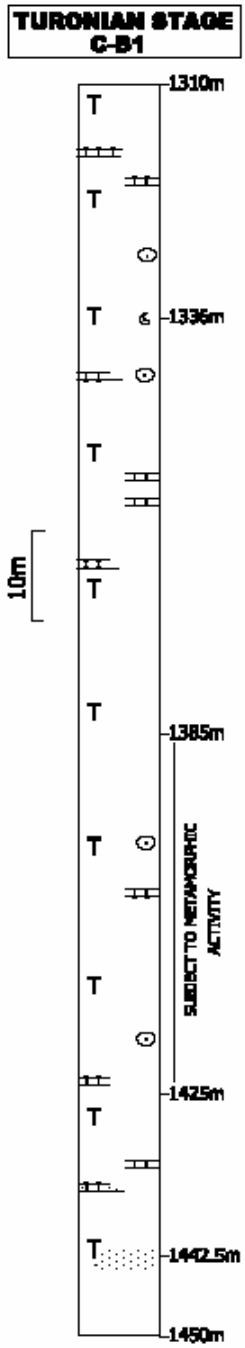

Figure 1. 10. Idealised stratigraphic sequence for the Turonian Stage of Offshore Site C-B1.

1450 m – 1310 m

The strata assigned to the Turonian Stage consist of a 140 m thick claystone package. Limestone stringers occur throughout this sequence and are brown-yellow to light grey in colour. Sandstone lenses occur at the bottom of this unit i.e. at 1442.5 m. A shelly assemblage can be found at 1336 m, and pyrite is found at regular intervals between 1425 m and 1332 m

1.4.7 THE CONIACIAN STAGE (1310 m - 1110 m) OF OFFSHORE SITE C-B1

The Turonian Stage was followed by a 200 m thick sedimentary package consisting of the following (Figure 1.11):

1310 m – 1207 m

The bottom half of this sequence consists of a 103 m thick claystone package. Limestone stringers occur throughout and are yellow-grey in colour. Sandstone lenses occur at 1278 m, 1266.5 m and 1262 m respectively. Pyrite can be found at regular intervals between 1310 m and 1207 m. **Inoceramus* and calcareous fragments occur between 1300 m and 1276 m.

1305 m – 1267 m

Subject to metamorphic overprint.

1240 m – 1204 m

Subject to metamorphic overprint.

1207 m – 1205.5 m

A 1.5 m thick glauconitic sandstone layer occurs between 1207 m – 1205.5 m. It is dark green-grey in colour, fine to very fine-grained with well-sorted grains which are rounded in shape.

1205.5 m – 1110 m

The top half of this sequence consists of a 95.5 m thick claystone unit that ranges from dark green-grey to olive-grey in colour. This is also a fossiliferous interval with shelly inclusions, **Inoceramus* fragments and calcareous inclusions occurring throughout. Pyrite, glauconite and limestone stringers also occur throughout.

*_Inoceramus_ are unidentifiable bone fragments of animal origin. Their presence is significant because these bone fragments have accumulated and been preserved in a marine environment.

1.4.8 THE SANTONIAN STAGE (1110 m - 1030 m) OF OFFSHORE SITE C-B1

The Coniacian Stage was followed by an 80 m thick sedimentary package consisting of the following (Figure 1.12):

1110 m – 1030 m

The Santonian Stage consists of an 80 m thick claystone package that ranges from dark green-grey to olive-grey in colour. This interval is extremely fossiliferous with shelly and calcareous inclusions and *Inoceramus* fragments occurring with high frequency throughout. Two limestone stringer occurs at 1091 m and 1052.5 m respectively. Sandstone stringers occur at intervals between 1090 m and 1060 m. Glauconite is mostly found in association with the sandstone stringers.

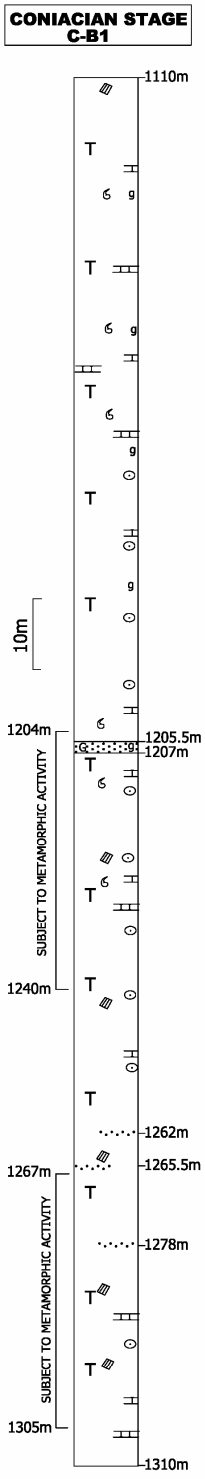

Figure 1.11. Idealised stratigraphic sequence for the Coniacian Stage of Offshore Site C-B1.

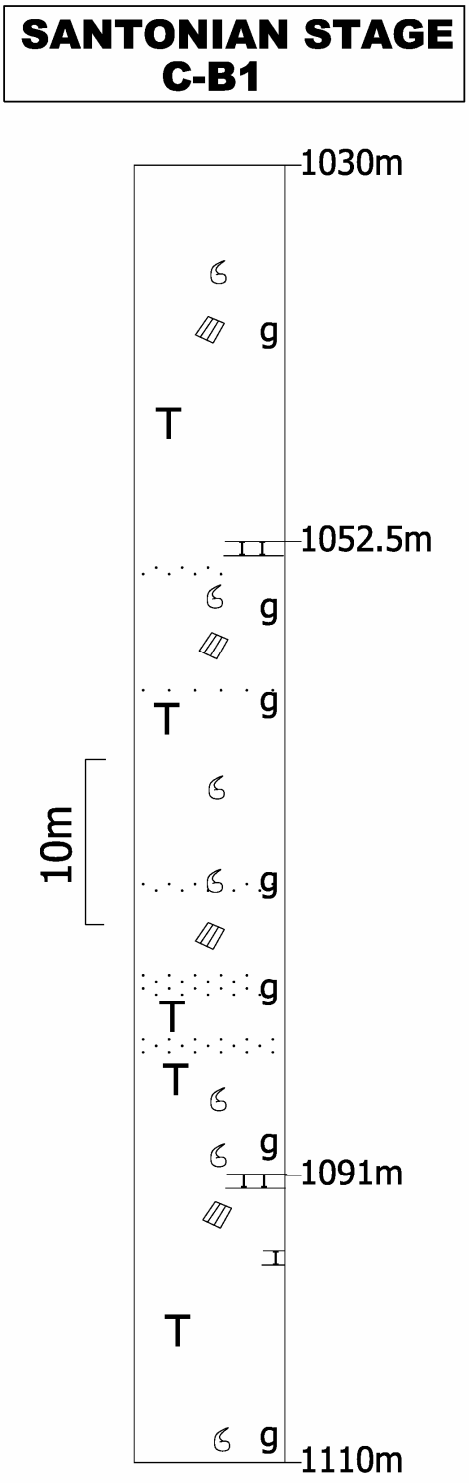

Figure 1.12. Idealised stratigraphic sequence for the Santonian Stage of Offshore Site C-B1.

1.4.9 THE CAMPANIAN STAGE (1030 m - 1000 m) OF OFFSHORE SITE C-B1

The Santonian Stage was followed by a 30 m thick sedimentary package consisting of the following (Figure 1.13):

1030 m – 1000 m

The Campanian Stage consists of a 30 m interval of dark grey-green to olive-green claystone. The last appearance of *Inoceramus* occurs at 1023 m. Glauconitic and shelly inclusions occur throughout. A single limestone stringer occurs at 1008 m and is olive-grey in colour.

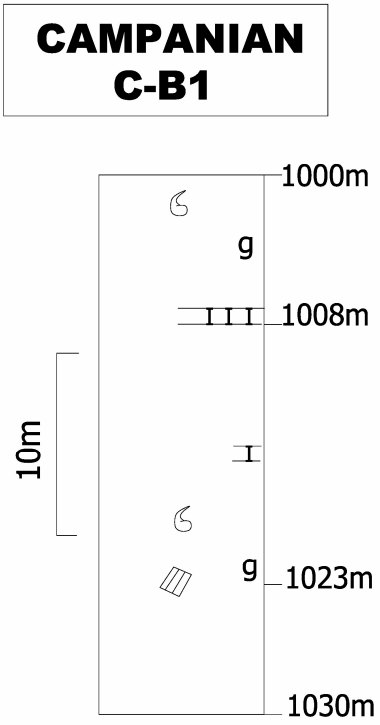

Figure1.13. Idealised stratigraphic sequence for the Campanian Stage of Offshore Site C-B1.

1.4.10 PRE-CRETACEOUS METAMORPHIC BASEMENT (4398 m - 4216 m) OF

OFFSHORE SITE O-A1

An 182 m thick basalt with rare sandstone interbeds was intersected at the base of this Offshore Site (Figure 1.14). The basalt is a dark red to dark green-grey in colour and is generally fine to medium grained. Dark green mineral quartz occurs within the basalt. Sandstone interbeds occur twice within the sequence at 4320 m and at 4270 m and are light grey in colour.

1.4.11 THE BARREMIAN STAGE (4216 m – 3879 m) OF OFFSHORE SITE O-A1

Basement rock was followed by a 337 m thick sedimentary package consisting of the following (Figure 1.15):

4216 m – 4185 m

A 31 m thick sandstone interval occurs at the base of this sequence, is medium light grey in colour, fine-grained and non-calcareous.

4185 m – 4181 m

Four metres of claystone directly overlays the sandstone interval.

4181 m – 4179 m

A 2 m thick limestone interval caps the claystone and grades from light to dark brown in colour.

4179m - 3879m

The limestone interval is followed by a 300 m thick interbedded sandstone and claystone package with two rare limestone stringers. The sandstone is light to medium grey in colour and grades from being calcareous at the base into a non-calcareous interval in the middle and then grades back into calcareous sandstone at the top. Claystone changes from dark brown-grey in colour at the base to dark black-grey in colour towards the top of this sequence. Lignite / carbonaceous fragment occurs between 4106 m – 4105 m and represent carbonized plant roots. Limestone stringers occur at 3984.5 m and 3974.5 m respectively and are dark brown in colour.

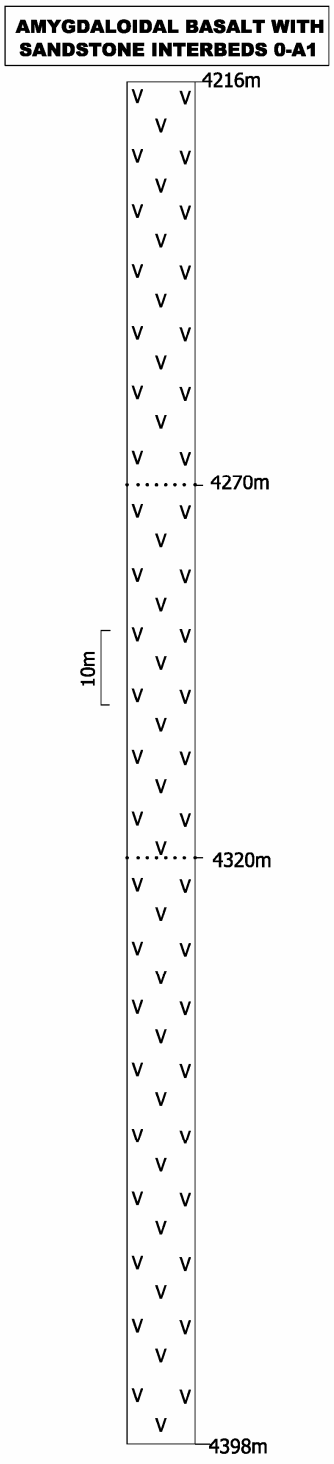

Figure 1. 14. Idealised stratigraphic sequence for the pre-Cretaceous basement of Offshore Site O- A1.

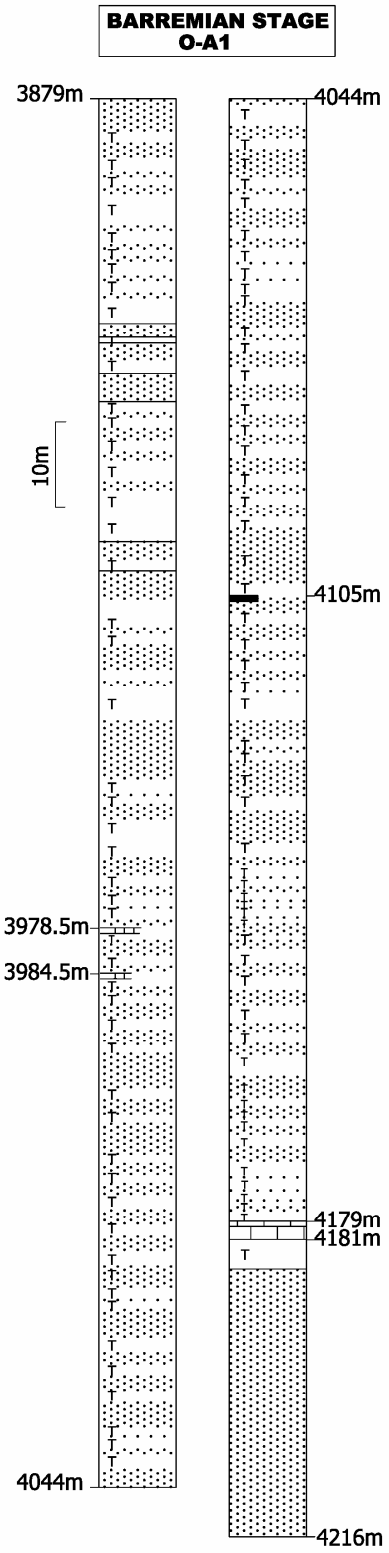

Figure 1.15. Idealised stratigraphic sequence for the Barremian Stage of Offshore Site O-A1.

1.4.12 THE APTIAN STAGE (3879 m - 3676 m) OF OFFSHORE SITE O-A1

The Barremian Stage was followed by a 203 m thick sedimentary package consisting of the following (Figure 1.16):

3879 m – 3793 m

The bottom half of the Aptian Stage includes an 86 m interbedded interval made up of sandstone and to a lesser extent claystone with rare limestone stringers. The sandstone is light to medium grey in colour and the claystone grades from dark brown-grey at the base to dark black-grey towards the top and is carbonate-rich throughout. Limestone stringers occur at intervals throughout and are dark brown in colour.

3793 m - 3791.5 m

A 1.5 m thick dark brown limestone layer caps the above claystone and sandstone interval.

3793 m – 3755.5 m

This interval appears to have been affected by metamorphic overprint. This event was noted by Petroleum Agency, SA geologists and is supported by a virtually barren palynological interval, however the type of metamorphic event (thermal, contact or regional) is not known.

3791.5m – 3676 m

A 115.5 m thick claystone package follows with sandstone stringers occurring towards the top of this interval. The claystone is light to dark grey in colour and is non-calcareous where dark grey and calcareous where light grey in colour. The sandstone is light grey in colour and very fine grained. Limestone stringers occur at intervals throughout.

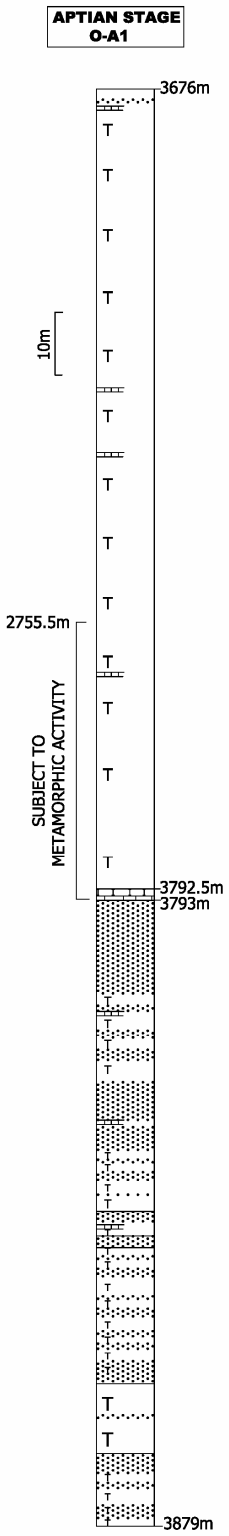

Figure 1. 16. Idealised stratigraphic sequence for the Aptian Stage of Offshore Site O-A1.

1.4.13 THE ALBIAN STAGE (3676 m - 3606 m) OF OFFSHORE SITE O-A1

The Aptian Stage was followed by a 70 m thick sedimentary sequence consisting of the following (Figure 1.17):

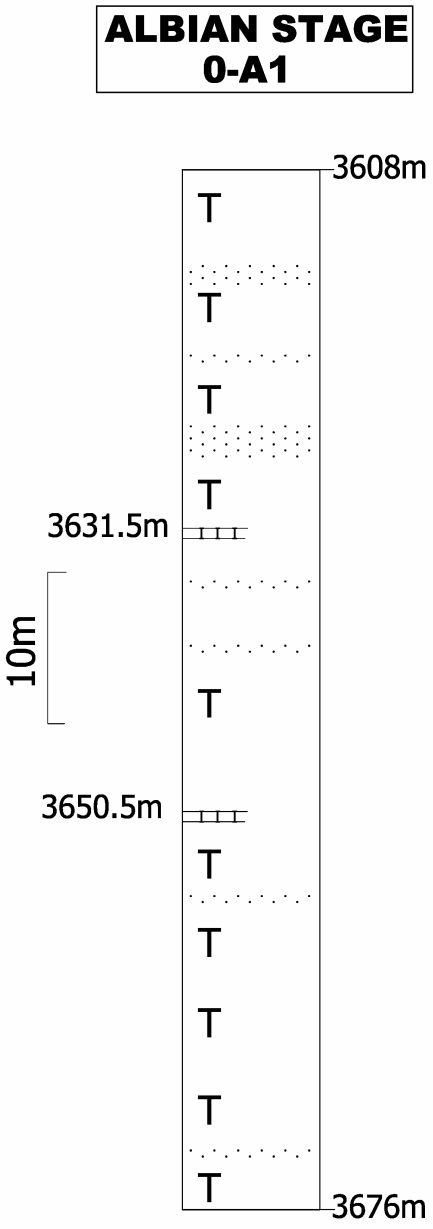

Figure 1.17. Idealised stratigraphic sequence for the Albian Stage of Offshore Site O-A1.

3676 m - 3606 m

A 70 m thick claystone interval occurs with sandstone and limestone stringers. The claystone is dark grey in colour and is non-calcareous in content. The sandstone is light grey in colour. Limestone stringers occur at 3650.5 m and 3631.5 m respectively. The limestone stringers are yellow-brown to dark brown in colour and carbonaceous-rich.

1.4.14 THE CENOMANIAN STAGE OF OFFSHORE SITE O-A1

The Cenomanian Stage is not present in the borehole core from this Offshore Site

1.4.15 THE TURONIAN STAGE (3606 m - 3507 m) OF OFFSHORE SITE O-A1

The Albian Stage was followed by a 99 m thick sedimentary package consisting of the following (Figure 1.18):

3606 m - 3507 m

This interval consists of a sedimentary package comprising a 99 m thick claystone interval with minor sandstone and occasional limestone stringers. The claystone is medium to dark grey in colour, carbonaceous but non-calcareous. The sandstone stringers are a light grey colour, very fine-grained and occur throughout this interval. Limestone stringers occur throughout the sequence and are yellow-brown to dark brown in colour and carbonaceous-rich in places

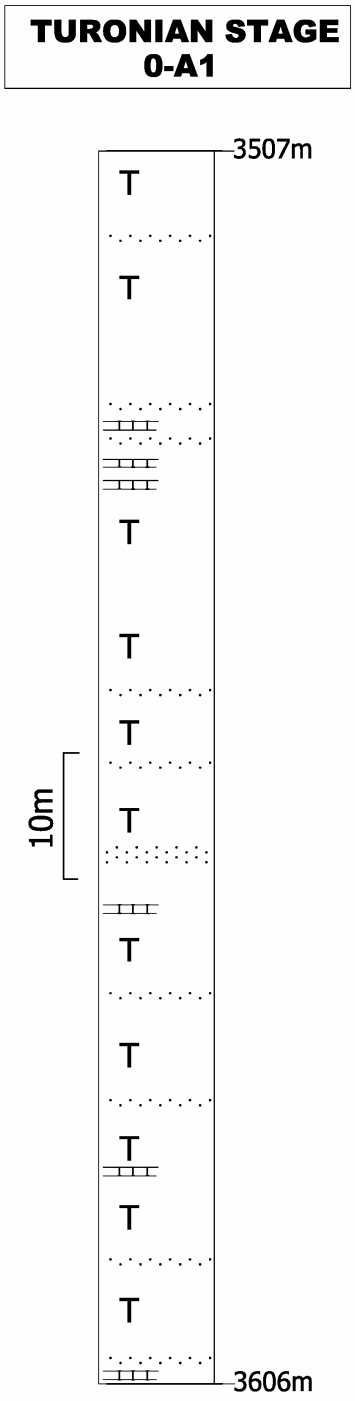

Figure 1. 18. Idealised stratigraphic sequence for the Turonian Stage of Offshore Site O-A1.

1.4.16 THE CONIACIAN STAGE (3507 m - 2721 m) OF OFFSHORE SITE O-A1

The Turonian Stage was followed by a 786 m thick sedimentary package consisting of the following (Figure 1.19):

3507 m – 3274 m

This 235 m thick claystone sequence begins with a single sandstone stringer at 3507 m. The claystone is medium to dark grey in colour, carbonaceous-rich but non-calcareous. The sandstone stringer is light grey in colour and very fine-grained. Limestone stringers occur throughout the sequence and are yellow-brown to dark brown in colour and carbonaceous-rich in places. Minor siltstone stringers are located towards the top of this sequence.

3274 m – 3273 m

A 1 m thick limestone layer caps the claystone interval.

3273 m – 2721 m

The limestone layer is followed by a 552 m thick claystone package that grades in colour from dark grey at the base to light grey towards the top of this package. Limestone and siltstone stringers and interbeds are common throughout. *Inoceramus* fragments occur at 2860 m.

1.4.17 THE SANTONIAN STAGE (2721 m - 2686 m) OF OFFSHORE SITE O-A1

The Coniacian Stage was followed by a 93 m thick sedimentary package consisting of the following (see Figure 1.20):

2721 m - 2686 m

The Santonian Stage consists almost exclusively of a 93 m thick package of claystone. The only other lithologies that occur are located at the base of this sequence and include two limestone stringers at 2217 m and 2210 m respectively. A siltstone stringer occurs directly above the bottom-most limestone stringer at 2216 m.

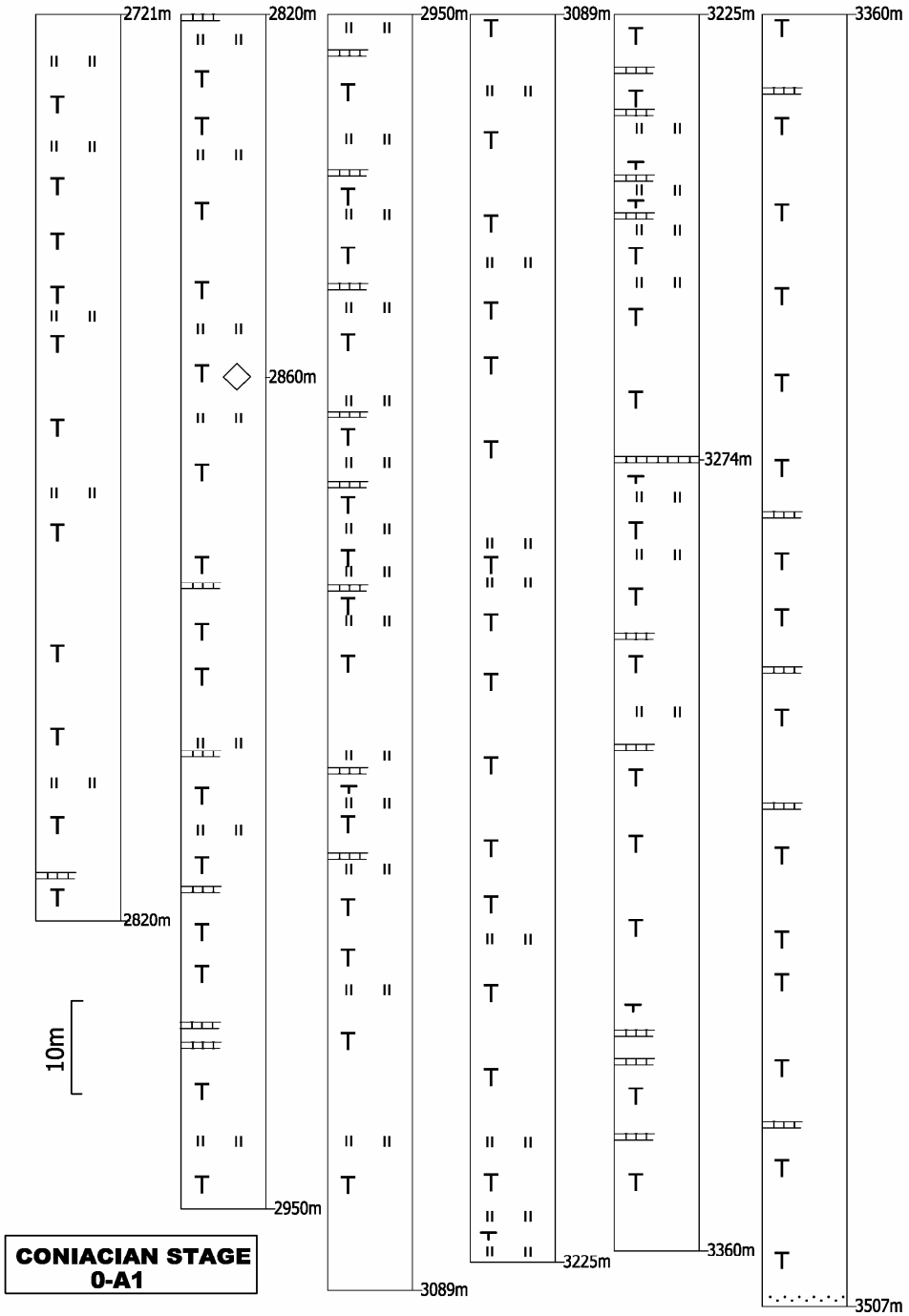

Figure 1.19. Idealised stratigraphic sequence for the Coniacian Stage of Offshore Site O-A1.

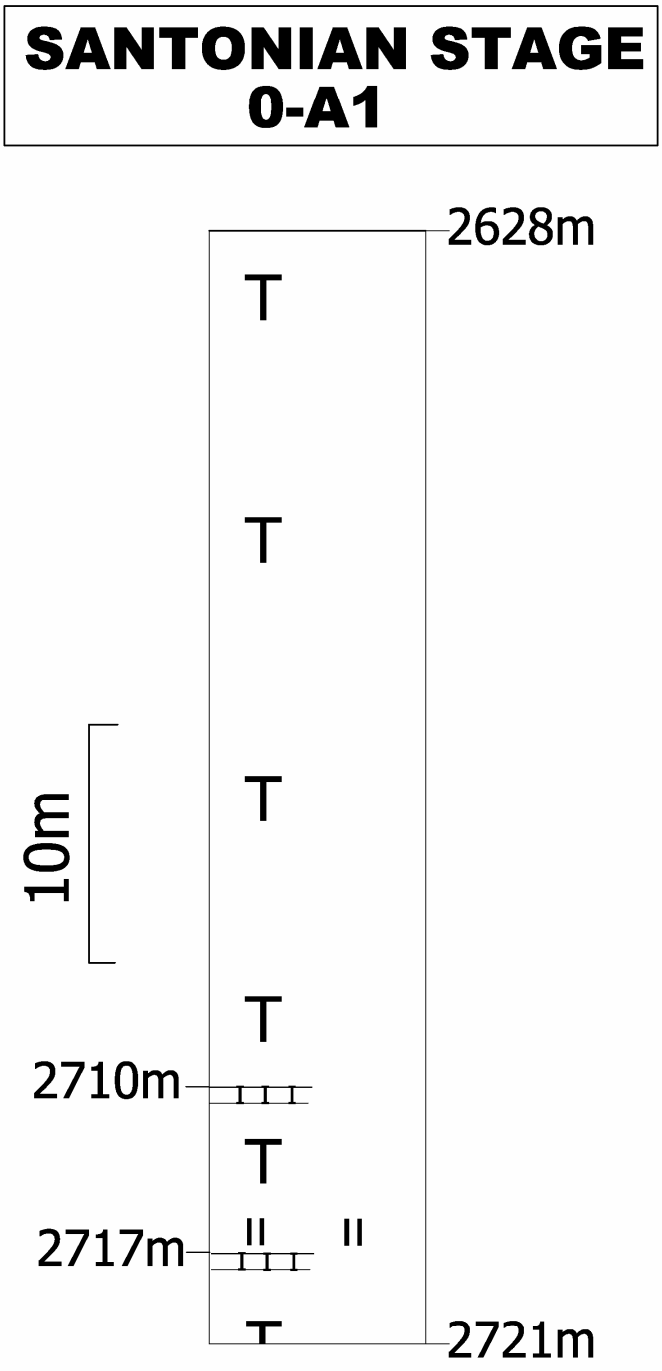

Figure 1.20. Idealised stratigraphic sequence for the Santonian Stage of Offshore Site O-A1.

1.4.18 THE CAMPANIAN STAGE (2686 m - 2550 m) OF OFFSHORE SITE O-A1

The Santonian Stage was followed by a 78 m thick sedimentary package consisting of the following (Figure 1.21):

2686 m - 2550 m

This stage consists entirely of a 78 m thick claystone interval with no interbeds, inclusions or stringers of any kind.

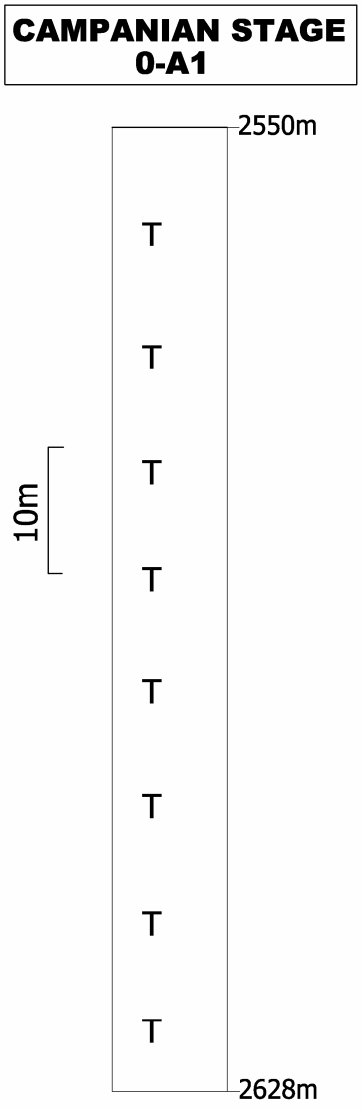

Figure 1.21. Idealised stratigraphic sequence for the Campanian Stage of Offshore Site O-A1.

1.5 PALAEOFLORAS

The following section outlines the trends in palaeobotany for the Cretaceous Period and provides a background to the type of vegetation expected for the west coast of South Africa during the Cretaceous.

Most of the approximately 470 million year history of terrestrial vegetation was dominated by the presence of bryophytes and pteridophytes (ferns, mosses, lycopods etc.) and of gymnosperms (conifers, cycads etc.) (Lupia *et al*., 1999). Angiosperms were a relatively recent evolutionary phenomenon and became important in the terrestrial vegetation only during the last 100 million years or so (Lidgard & Crane, 1989 & 1990; Crane & Lidgard, 1989 & 1990; Vakhrameev, 1991; Crane *et al*.,1995; Lupia *et al*., 1999).

The Early Cretaceous palaeofloras had worldwide similarities with the exception of a few regional differences that were probably dependent on sea and land distribution during the Early Cretaceous. By the Late Cretaceous, the first divergence of microfloras between Africa and South America had occurred. Microfloral assemblages from the Deep Sea Drilling Project of Site 361 in the Cape Basin (McLachlan & Pieterse, 1978; Figure 1.1) indicate that during the Late Cretaceous a mixed warm-temperature forest existed, with an under canopy rich in ferns, shrubs and mosses.

1.5.1 BRYOPHYTES

Bryophyta consist of mosses (Musci), liverworts (Hepaticeae) and hornworts (Anthocerotae) that are organizationally intermediate between green algae and green vascular plants (Playford & Dettmann, 1996). They commonly produce trilete spores (Traverse, 1988) that are homosporous i.e. producing only one kind of spore (Playford & Dettmann, 1996). These are primitive members of the plant community and have remained widespread till recent times.

1.5.2 PTERIDOPHYTES

A pteridophte is a seedless vascular plant. Leptosporangiate ferns that produced trilete and monolete spores thrived and diversified during the Cretaceous until the evolution of angiosperms, after which they showed a gradual decline in diversity (Spicer & Thomas, 1986).

1.5.3 GYMNOSPERMS

Jarzen & Nichols (1996) defined gymnosperms as any plants that produce seeds and also produce pollen, and this separates them from ferns and mosses that produce spores. The pteridosperms or seed ferns were one of the major groups of gymnosperms, and the first seed plants that evolved from spore-producing non-seed plants (Jarzen & Nichols, 1996).

A complete array of morphologies exhibited by gymnosperms had appeared by the Jurassic Period. Distinctive Jurassic gymnospermous pollen includes monosaccate conifer grains (*Zonalapollenites*); bisaccates produced by pteridosperms and conifers; trisaccates of podocarpaceous affinity; the circumpolles group (*Classopollis*); monosulcates (*Cycadopites*); polyplicates (*Ephidripites*); and a variety of inaperturate types including *Balmeiopsis* and the unique discoidal monoporate pollen *Exessipollenites*, which may be of taxodiaceous affinity (Traverse, 1988; Jarzen & Nichols, 1996). By the Late Cretaceous, however the distinctive monolete, trilete, saccates and striate saccates of the Triassic, Jurassic and Early Cretaceous periods had disappeared (Jarzen & Nichols, 1996).

Lidgard & Crane (1990) presented data showing that Cretaceous gymnosperm pollen is notably less diverse morphologically than that of preceding geological periods. Both plant megafosills and pollen showed a gradual decline in the diversity of conifers during the Cretaceous. The pollen record of gymnosperms other than that of conifers during this period shows little change however by the Tertiary Period, gymnospern pollen had become increasingly modern, due in part to the loss of the Cretaceous taxa, and in part to the appearance of modern extant taxa (Jarzen & Nichols, 1996).

1.5.4 ANGIOSPERMS

The transition from the Jurassic to Early Cretaceous flora, in which global vegetation was dominated by cycads, conifers, bennettitales and true ferns to a vegetation dominated by angiosperms occurred during the Late Cretaceous / Tertiary periods (Gotham & Remy, 1957). The history of the Earth's vegetation during the rise of angiosperms has been divided into four phases (Upchurch & Wolfe, 1987 and other researchers). However, only the first three phases

will be discussed here:

- Valanginian to Hauterivian stages.
- Aptian to the early part of the Cenomanian stages.
- Middle part of the Cenomanian to the Maastrichtian stages.

1.5.4.1 VALANGINIAN TO HAUTERIVIAN STAGE

Angiosperm plants appear to have emerged fully differentiated during the Early Cretaceous (Stebbins, 1974; Mildenhall, 1980; Taylor, 1981). The first unequivocal evidence of angiosperms (small, smooth, tricolpate grains) in the fossil record, provided by isolated pollen grains is from Valanginian and Hauterivian strata of Israel and Europe (Hughes & McDougal, 1987; Trevisan, 1988; Hughes, 1994; Brenner, 1996).

1.5.4.2 APTIAN TO THE EARLY PART OF THE CENOMANIAN STAGE

During the Early Cretaceous (Aptian to Early Albian stages) angiosperms were an unimportant element of the regional vegetation (Upchurch & Wolfe, 1987). Early angiosperms were probably weedy, rapidly reproducing colonizers of recently disturbed habitats (Doyle & Hickey, 1976; Takhtajan, 1976; Taylor & Hickey, 1996). Competition may have taken the form of a race for space as angiosperms with rapid life cycles perhaps invaded faster than pteridophytes, and were able to hold it by incumbency against subsequent invasion (Jackson, 1988; Rosenzweig & McCord, 1991). At this stage their relative abundance was 1 % or less in the regional palynofloras and they were a sporadic element in megafloras from stream-margin facies (Hickey & Doyle, 1977).

During the middle to Late Albian Stage angiosperms had a relative abundance of ca. 20 % in regional palynofloras, but could dominate local palynological and megafossil assemblages (Hickey & Doyle, 1977). Physiognomic diversity from the middle to Late Albian foliage is greater than for the Aptian to Early Albian angiosperms with all new foliar physiognomic types having features characteristic of extant early successional plants (Givinsh, 1979).
By the Early Cenomanian Stage (Late Cretaceous) angiosperm leaf assemblages were much more diverse than Early Cretaceous assemblages and showed higher species diversity and higher relative abundances (Upchurch & Wolfe, 1987).

In summary Upchurch & Wolfe (1987) found that the Aptian to Early Cenomanian Stages comprised the early diversification and initial rise to dominance of the angiosperms.

1.5.4.3 MIDDLE OF THE CENOMANIAN STAGE TO THE MAASTRICHTIAN STAGE

The middle part of the Cenomanian to Late Maastrichtian Stages comprised a relatively stable period in angiosperm history. Leaf size was still small at lower and middle palaeolatitudes and forests had poorly developed stratification, apparently resulting from low precipitation (Upchurch & Wolfe, 1987). During this time angiosperms became the most abundant element in regional palynofloras from low and middle palaeolatitudes (Upchurch & Wolfe, 1987).

Today angiosperms comprise most of extant terrestrial plant diversity, which is ca. 230 000 species as opposed to 40 000 species of all other groups of land plants (Mabberley, 1993; Taylor & Taylor, 1993).

1.6 PREVIOUS WORK

" Microfossils in the conventional sense, pollen and spores, are undoubtedly present in many Mesozoic strata, but have hardly been studied and analyzed on a basis comparable to those of Late Palaeozoic and Tertiary sequences. Here then is an almost virgin field for further palaeobotanical research, which is bound to yield unexpected results, for the greatest changes in floras occurred in the Mesozoic during the ascent and subsequent decline of the major gymnospermous groups and the sudden appearance of the angiosperms." (Dr Theodore Just, 1951).

There is no doubt that since Just (1951) made this statement, research into this field of study has begun, unfortunately it had not been with the academic force of enthusiasm he hoped for. Although studied in some detail by oil companies the microfossil record in southern Africa dating from the Jurassic to the Cretaceous periods is academically limited. The only palynological research from this time period and region is considered in the following literature review:

Kirchheimer (1934) researched Late Cretaceous material from the Arnot kimberlite pipe in Namaqualand and found that there was a wealth of plant fossils and microflora present. He discovered angiosperm and conifer pollen types that did not resemble the present day vegetation of the area.

Martin (1960) worked on sedimentary deposits from the Gamtoos River Basin. This basin is adjacent to Scott's Algoa Basin sedimentary deposits and both researchers found their palynomorphs to be of similar age i.e. Early Cretaceous in age.

Scott (1971; 1976) worked on cores from the Algoa Basin for his M.Sc. (1971)dissertation and other research (1976). He found that *Classopollis* was the dominant pollen genus in his miospore assemblage, while *Araucariacites, Tsugaepollenites* and *Cycadopites* were common. On comparing the microfossils of the Algoa Basin with those of other parts of the world, he could not prove or disprove that they belonged to the Valanginian, but concluded that the sporomorphs were similar to those of the Early Cretaceous of other parts of the world.

Harris (1977) recorded palynomorphs comprising terrestrially derived pollen and spores as well as a marine component of dinoflagellate cysts and acritachs from DSDP Sites 327, 328 and 330 located on the Falkland Plateau. He compared these sites to DSDP 249 that was drilled into the Mozambique Ridge east of Durban, and discovered that there was a very strong biofacies and biostratigraphic similarity with the Early Cretaceous sedimentary sequence sampled at DSDP Sites 327 and 330. This similarity between these sites reinforced other scientific research that these three sites were in the same region in the Indian Ocean during the Early Cretaceous. Harris also found that the relationships between the floras from DSDP Sites 327, 328 and 330 were strongly austral. The marine component showed a marked similarity with those of Western Australia and the Indian Ocean implying a proto Southern Atlantic circulation linked with that of the Indian Ocean.

As part of a palynological investigation, McLachlan & Pieterse (1978) studied a core drilled at DSDP Site 361, ca. 82 km west southwest of Cape Town. A nearly continuous sequence of

sedimentary rock was intersected ranging in age from the Aptian to the Eocene Stages. They found a profound difference between the Early and the Late Cretaceous floras in that spore diversity was low during the Early Cretaceous with no sample yielding more than 30 species, while the Late Cretaceous samples were much richer with a maximum of 82 species per sample. The low diversity could reflect either a harsh climate with possibly low rainfall and cold conditions, or a supply of spores and pollen from a restricted area or plant community. The higher diversities indicated a less harsh, warmer or wetter climate and a source of spores and pollen from a much wider area including more diverse plant communities. *Classopollis* pollen along with mono and bisaccates declined sharply during the Late Cretaceous after dominating the Early Cretaceous scene. Trisaccates became more important during the Late Cretaceous Period. Many of the trilete fern spores in the Early Cretaceous of DSDP Site 361 have also been recorded from Australia (Dettmann, 1981) but the species on which the Australian zonation is based are lacking. Angiosperms appeared very suddenly during the Cenomanian and in great abundance with monocolpates appearing earlier than tricolpates. *Northofagus*, a tricolpate used in zoning the Late Cretaceous of Australia was not found (McLachlan & Pieterse,1978).

Morgan (1978) undertook a study on the palynology of DSDP Site 364 in the Angola Basin. He found that the average pollen-spore diversity was about 30 species and that this finding suggested a stable and homogenous plant community, possibly living under harsh conditions. The taxonomic composition was dominated by ephedroid, cycadophyte, angiosperm and *Classopollis* pollen, suggesting a humid and possibly hot and semi-arid climate. These features and the presence of certain exotic spores suggests an affinity with the tropical Northern Gondwana Province / African-South American microfloral belt of Herngreen (1975), which occupies a band approximately 15 degrees of latitude both sides of the palaeo-equator, rather than the temperate
Southern Gondwana Province. This site is considered to be Albian to Senonian in age.

Scholtz (1985) continued earlier studies on the sedimentary rocks from the Arnot kimberlite pipe in Namaqualand and found an assemblage of spores, conifer and angiosperm pollen that he compared and contrasted with assemblages from Australia and the tropics of Africa. This assemblage of palynomorphs was found as part of the infill of the Crater Lake, which came into

existence after the emplacement of the Arnot Pipe in the Late Cretaceous.

Benson (1990) examined the palynofacies characteristics and assessed the source rock potential of the Early Cretaceous northern Orange Basin (Kudu 9A-2 and 9A -3). He found a sequence of five palynofacies types characterized by diagnostic palynomaceral assemblages, which defined five depositional environments within that portion of the Orange Basin. Dinoflagellates were found to be abundant and well preserved while the pollen *Classopollis* composed most of the microflora present.

Oboh-Ikuenobe & de Villiers (2003) studied the composition and distribution of phytoclasts, palynodebris and palynomorphs in the sedimentary samples taken from the western continental shelf of Namibia and South Africa. They found the age distribution of the palynomorphs included the Late Cretaceous to Late Pliocene periods. AOM, wood and black debris (palynodebris) was visually and statistically significant. The stratigraphic trend found that black debris was situated in the oldest sediments and that theses trends were controlled by provenance, diagenetic setting and age.

Since 1990 limited research has been undertaken or published on Cretaceous palynomorphs from South African on- or offshore basins.