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THE BIOSTRATIGRAPHY OF THE PERMIAN AND TRIASSIC

Part 2 (Charts 23–35)–A Preliminary Review of the Distribution of Permian and Triassic Strata in Time and Space

by

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CONTENTS

* Charts sent out under separate cover.

1. INTRODUCTORY NOTE

The charts presented here (i.e. charts 23–35) are intended to form part of a series with those (i.e. charts 1–22) compiled by H. M. Anderson and J. M. Anderson as a supplement to Palaeontologia Africana, Volume 13, 1970 (see bibliography). Charts 1–22 were presented under the title "A preliminary review of the biostratigraphy of the uppermost Permian, Triassic and lowermost Jurassic of Gondwanaland". Further charts are to follow and will be numbered from 36 onwards.

The overall series of charts will henceforth be entitled—"The biostratigraphy of the Permian and Triassic". Charts 1–22 form *Part 1* of the series; charts 23–35 form *Part 2*. Parts 3, 4, 5 etc. will deal in turn with particular aspects of the flora and fauna. The tetrapod vertebrates, insects and macroflora will most likely be studied first.

The work completed to date was carried out under the auspices of Southern Oil Exploration Corporation (SOEKOR) and the University of the Witwatersrand. J. M. Anderson was employed from January 1971 to the present at the Bernard Institute for Palaeontology, Witwatersrand University, as a research officer, with the help of a substantial grant from SOEKOR and from April 1970 to March 1973 as a geologist/palynologist on the permanent SOEKOR staff. H. M. Anderson has been employed as a junior research officer from January 1971 to the present at the Bernard Price Institute for Palaeontology, Witwatersrand University.

2. THE AIM OF THE OVERALL PROJECT

The aim is to discover the evolving story of life and landscape during the 90 odd million years of the Permian and Triassic, and to appreciate the interdependence of the patterns of evolution of the plants, animals, climate and landscape.

In order to attain this understanding it is intended to compile—

(i) Separate phylogenetic charts (all to the same scale—½ cm equals 1 million years) for each major plant and animal group (e.g. the macroflora, microflora, tetrapod vertebrates, insects, ammonites).
(ii) A series of fairly detailed palaeogeographic maps, each representing a single "Standard Stage" or "Substage" of the Permian and Triassic.

2.1. Compilation of Initial Data on Major Plant and Animal Groups

There follows a brief account of the envisaged approach to compiling the initial data (prior to drawing up the palaeogeographic maps and phylogenetic charts) for each particular plant or animal group. Each group will be dealt with in the same manner. Imagine, therefore, that the following account applies, say, to the tetrapod vertebrates.

(i) A correlation chart (drawn to the same scale as the eventual phylogenetic chart) including all known productive horizons—formations, members, zones etc., will be compiled (see chart 5 in Anderson and Anderson, 1970).
(ii) A series of geological maps (as in chart 26) covering each productive area will be drawn up to indicate, as far as is possible, each known collecting locality. The position of these areas will be indicated on a reduced simplified world map of the Permian and Triassic (see chart 26).
(iii) A brief account of the general productivity (considering both quantity and quality of material) of the formation, member or zone, will be given. This falls into two parts:
   (a) The estimated potential productivity of the unit;
   (b) The comprehensiveness of the collections presently available.
(iv) For each productive unit a comprehensive, fully classified list of the available material (down to species where possible) will be given. (See charts 1 to 4 of Anderson and Anderson, 1970.) The list will be arranged in phylogenetic order according to the most recent, most reliable systematics available. Each species, genus (or larger taxa where necessary) will be commented on as regards—
   (a) The vintage and reliability of the taxonomy available;
   (b) The number of specimens available. In cases where the material is common, the relative abundance will be given;
   (c) The number of localities from which the material is known;
   (d) The state of preservation of the material.
(v) A brief but comprehensive account of the known flora and fauna of the unit will be given.
(vi) For each productive unit a brief geological account will be given, e.g. isopach map, facies map, current directions etc.
(vii) For each productive unit a brief palaeogeographic assessment will be made.

2.2. The Phylogenetic Charts

These charts will be drawn up more or less as was chart 5 in Anderson and Anderson (1970).

The degree to which the phylogenetic chart will reflect the true picture will depend on several factors—

(i) The accuracy of the correlation chart incorporating each productive horizon (formation etc.) (see section 5 of text for elaboration on the approach taken in the compilation of a correlation chart).

(ii) The state of the systematics and taxonomy available.
(iii) The comprehensiveness of the collections available from each productive horizon (formation etc.).
(iv) The degree to which a theoretically fully comprehensive collection from a productive horizon (formation etc.) actually reflects the true composition of the flora or fauna existing in the area at the time.
(v) The degree to which a full set of comprehensive collections from each existing productive horizon (formation etc.) of the same age throughout the world would reflect the true composition of the flora and fauna of the world at the time.

The reliability of the correlations, systematics and the comprehensiveness of the collections will vary greatly from horizon to horizon. These factors must be clearly recognized when compiling or studying any phylogenetic chart. Certain portions of any such chart will necessarily be based on very shaky correlations, rudimentary systematics and inadequate collections, whilst others will be based on excellent data. The charts will need to be updated at fairly regular intervals.

In studying the phylogenetic charts it will also be very important to have a realistic awareness of points (iv) and (v) above. Very briefly it may be stated, however, that the apparent lack of diversity of plant and animal life during the Permian and Triassic (see Anderson and Anderson, 1970) and the often marked similarity between assemblages of the same age from widely separated areas in the world suggest that the phylogenetic charts could eventually present a fairly reliable reflection of the true story.

3. THE PURPOSE OF THE PRESENT SET OF CHARTS

It is necessary to review the presently available data ragarding the distribution of Permian and Triassic strata in time and space. It is the aim in the present text and set of charts to attempt this.

The world map (chart 23), showing the known distribution of Permian and Triassic strata, is considered a desirable prerequisite to an understanding of the palaeogeography of the time. The general relationship between the various depositional areas—the geosynclinal troughs, the shelf seas, the intra-cratonic basins, the restricted valley deposits—become simpler to comprehend.

The distribution of known productive localities for any particular animal or plant group for the time-span being considered can be plotted (as in chart 26 for example—"Maps showing the known distribution of Dzhulfian, Changhsingian and Griesbachian ammonoid faunas") in relation to known Permian and Triassic strata.

The remaining charts (24—35) are all directed towards an attempt to compile meaningful, time-oriented correlation charts of the Permian and Triassic strata. Rigorous definition and international usage of "Standard Reference Stages", "Substages" and "Ammonite Zones"; the application of absolute age data and the consideration of rates and continuity of deposition and compaction of sediments are all considered vital in an attempt to compile a correlation chart which is to be used as a base for subsequent phylogenetic studies. See section 5 for further comment on the application of these aspects, dwelt on in charts 24 to 34, to the compilation of chart 35 (Correlation of World Permian strata).

It will be noted that most attention is paid to the "Reference Stages" and correlation of Permian strata and far less to the Triassic. Tozer (1967 and 1971) (see bibliography) has dealt at length with the proposal of "Standard Reference Stages", "Substages" and "Ammonite Zones", based on strata in Western and Arctic Canada, for the Triassic System. His proposals are accepted in this paper with further discussion offered only with regard to the lowest Triassic Stage, i.e. Griesbachian. No extensive correlation chart of Triassic strata is given here. However, study of charts 5 and 21 of Anderson and Anderson (1970) and charts 29 and 31 of this paper partially fills this need.

4. NOTES ON THE PERMIAN SYSTEM: "STANDARD REFERENCE STAGES", "SUBSTAGES" AND "AMMONITE ZONES"; LOWER AND UPPER BOUNDARIES

4.1. Brief historical sketch of the development of the present concept of the Permian System and its stages in the type area, i.e. The southern Urals and Russian platform

Dunbar *et al.* (1960, p. 1765–6) wrote "The Permian rocks on which the system was founded occupy a vast structural basin west of the Ural Mountains, measuring about 700 miles from west to east and 1 000 miles from north to south. This region is divisible into two major structural elements, the Russian platform and the Uralian geosyncline. Over the broad platform the Carboniferous and Permian strata are nearly horizontal and of moderate thickness, but as they pass eastwards into the geosyncline the Permian rocks thicken greatly and undergo rapid facies changes. It was here, along the western border of the Ural Mountains that the Permian System was established".

Murchison visited this region during the summer of 1840 and 1841 and proposed and defined the Permian System in 1841 and 1845. The original Permian System, as conceived by Murchison, comprised only the rocks now included in the Kungurian, Kazanian, and Tatarian Stages.

In 1874 Karpinsky proposed and defined the Artinskian Stage. In a monograph on the ammonites of this stage Karpinsky, in 1889, proposed that the stage should be included in the Permian. This suggestion gained almost immediate recognition. "Thus the base of the Permian was lowered in its type region to the base of the Artinskian".

"In the original statement in which Karpinsky proposed the Artinskian Stage and described its type section, he referred to a basal calcareous unit in the Orenburg region as the Sakmarian limestone, named for exposures along the Sakmara River".

"In a comprehensive restudy of this region Ruzhentsev (1936) proposed to subdivide the original Artinskian into two stages, restricting the name Artinskian to the upper and using the name Sakmarian for the lower . . .".

In 1937 Ruzhentsev referred to the basal Sakmarian as the Assel horizon. In 1950 these beds were elevated to the rank of a "Substage" of the Sakmarian Stage and in 1951 Ruzhentsev proposed that the Asselian should be recognised as a stage (see Ruzhentsev, 1954, p. 1).

4.2. **The "Standard Reference Stages" and "Substages" of the Permian System** (See Charts 24, 29 and 31.)

Unlike the Carboniferous, Triassic and Jurassic Systems, where the succession of "Standard Reference Stages" occurs in each case in a more or less coherent area (see Chart 31), the Permian presents a difficult case. The type area for the Permian along the western flank of the Urals does not provide an unbroken sequence of marine ammonite-bearing strata throughout the Permian. Only the Lower Permian "Reference Stages" are based on the southern Urals sequence. The Upper Permian "Reference Stages" have to be sought elsewhere.

The sequence of "Standard Reference Stages" used in this paper (see Charts 24, 29 and 31) is built up from three different areas—

(i) The Asselian, Sakmarian and Artinskian Stages (with five substages) of the Lower Permian—typified by strata in the southern Urals (USSR).

(ii) The Guadalupian Stage (with four substages—Roadian, Wordian, Capitanian and Amarassian) comprising the lower half of the Upper Permian—typified by strata in western Texas and northern Mexico.

(iii) The Dzhulfian and Changhsingian Stages of the upper half of the Upper Permian—typified by strata in the Trans-Caucasus (USSR) and northern Iran.

4.2.1. *The Asselian, Sakmarian and Artinskian Stages of the Lower Permian—typified by strata in the southern Urals (USSR).* (See Charts 24 and 25 for details.)

In contrast, particularly to the upper half of the Upper Permian, a fair degree of unanimity exists regarding the useage of "Standard Reference Stages" of the Lower Permian. The well exposed highly fossiliferous marine strata of the southern Urals clearly present the most useful "Standard Reference" sequence for this period. Of this fact, few authors in the last decade or so would throw any doubt. Some difference of opinion does exist however as to the stage breakdown of the sequence. These differences are made clear in the following summary of "Standard Stage" preferences indicated in a number of significant papers dating from 1961.

(i) *Glenister and Furnish* (1961, p. 678–684, t. 2) in a paper on "The Permian ammonoids of Australia", recognised three stages—the Asselian, Sakmarian and Artinskian, typified by strata in the southern Urals. In the Artinskian they recognised two substages—the Aktastinian and Baigendzhinian.

(ii) *Nassichuk, Furnish and Glenister* (1965, p. 2–4, t.1) in a paper on "The Permian Ammonoids of Arctic Canada", recognised the same three stages—the Asselian, Sakmarian and Artinskian, typified by strata in the southern Urals. However, in this paper three substages were recognised in the Artinskian—the Aktastinian, Baigendzhinian and a third unnamed substage typified by the Basal Word Limestone of the Glass Mountains, western Texas. This third substage they include in the Artinskian of the Lower Permian, rather than the Guadalupian of the Upper Permian, since they regarded its ammonite and brachiopod faunas as more closely related to the former. They write—"In these two groups of fossils there are such strong relationships with those found in the underlying Leonard Formation [the U.S.A. equivalent of the Artinskian] that this stratigraphic unit should logically be regarded as uppermost Lower Permian rather than basal Guadalupian as commonly assigned. Under our definition this time boundary corresponds to the extinction in two of the most characteristic Lower Permian ammonoid elements: the Perrinitidae and Metalegoceratidae".

(iii) *Ruzhentsev and Sarýcheva* (1965, p. 88–90, t. 13) in a paper on "The development and change of marine organisms at the Palaeozoic-Mesozoic boundary" wrote "there is good agreement about the subdivision of the Lower Permian section. Recent data, summed up by Glenister and Furnish (1961), indicate that the Lower Permian deposits can and should be divided into three stages, Asselian, Sakmarian and Artinskian". They wrote further as regards the necessity for international recognition and usage of a sequence of "Standard Reference Stages" for the Permian . . . "further study of the Permian deposits of the globe is only possible if we accept a unified scale".

(iv) *Smith* (1964, p. 211–214) in his chapter "The Permian Period" in "The Phanerozoic Time-scale" writes—"For the purpose of erecting a Permian time-scale the standard section adopted is that of the type-area of the Russian platform and southern Urals". He recognised three stages within the Lower Permian—the Sakmarian, Artinskian and Kungurian.

(v) *Chao* (1965, correlation table) in a paper on "The Permian ammonoid—bearing formations of south China", referred to the Russian platform and southern Urals as the "Standard Reference". He recognised three stages within the Lower Permian—the Sakmarian, Artinskian and Kungurian.

(vi) *McKee et al.* (1967) in their comprehensive correlation chart of the Permian strata of the United States referred to the Russian platform and southern Urals as the "Standard Reference". They recognised three stages within the Lower Permian—the Sakmarian, Artinskian and Kungurian.

(vii) *Dickins* (1969) in his comprehensive correlation chart of the Permian strata of Australia referred to the Russian platform and southern Urals as the "Standard Reference". He recognised three stages within the Lower Permian—the Sakmarian, Artinskian and Kungurian.

Comments and résumé of "Reference Stages" used in this paper.

(a) All the authors listed above recognise the southern Urals as the "Standard Reference Section" for the Lower Permian.

(b) Glenister and Furnish (1961) and Ruzhentsev and Sarýcheva (1965) recognise three "Standard Reference Stages" within the Lower Permian—the Asselian, Sakmarian and Artinskian.

(c) Nassichuk, Furnish and Glenister (1965) recognised the same three "Standard Stages" but refer an additional substage (typified by the Basal Word Limestone of the Glass Mountains, western Texas) to the uppermost Artinskian. In the present paper this substage is referred to the base of the Guadalupian Stage (see notes on Guadalupian Stage below).

(d) Smith (1964), Chao (1965), McKee *et al.* (1967) and Dickins (1969) all recognise the Sakmarian, Artinskian and Kungurian as the "Standard Reference Stages" of the Lower Permian.

(e) The present paper follows Glenister and Furnish (1961) and Ruzhentsev and Sarýcheva (1965) in referring to the Asselian, Sakmarian and Artinskian Stages as "Standard" for the Lower Permian. No particular reason is known why the authors in note (d) dismiss the Asselian. The Kungurian by virtue of its very limited marine fauna is of little use as a basic reference.

4.2.2. *The Guadalupian Stage (with four substages—Roadian, Wordian, Capitanian and Amarassian) comprising the lower half of the Upper Permian—typified by strata in western Texas and northern Mexico.* (See Chart 24 for details.)

The lower half of the Upper Permian is well represented by marine ammonite-bearing strata in western Texas and northern Mexico. Excellent highly fossiliferous strata (with ammonites) covering this period are exposed in three areas—the Guadalupe Mountains at the northern end of the Delaware Basin in western Texas; the Glass Mountains at the southern end of the same basin; and in Val de Las Delicias, Coahuila Province, northern Mexico. Prior to 1965 only two stages, the Wordian and Capitanian, were recognised in these strata. Since then:

(i) *Nassichuk, Furnish and Glenister* (1965, p. 2–4, t. 1) suggested that an additional stage, comprising the basal limestone of the Word Formation, should probably be recognised. No formal name was proposed. They suggested that the included ammonite fauna was more similar to that in the upper Leonardian Series than that in the lower Guadalupian Series, and that the stage should therefore be regarded as uppermost Lower Permian rather than lowermost Upper Permian. They note that "... there is little ammonoid evidence for detailed correlation of the American sections with those of the late Artinskian in the Urals, although certain species in the upper Leonard Formation appear to be younger phylogenetically".

(ii) *Spinosa, Furnish and Glenister* (1970, p. 730–31) recognised a distinctive fauna in the uppermost part of the Guadalupian Series as developed in Val de Las Delicias, Coahuila Province, northern Mexico. They note that "Collectively, this fauna is similar to that designated as the Amarassi 'faunal element' [which] ... represents the youngest Permian on Timor". They refer to these uppermost Guadalupian strata as Amarassian. They do not actually define the Amarassian as a distinct stage or substage of the Guadalupian.

(iii) *Furnish and Glenister* (1970, p. 154–155, t.1) list a chronological sequence of "Reference Stages" for the upper part of the Permian in which they include the Roadian (represented by the basal limestone of the Word Formation and its faunas) and the Amarassian (represented by the faunas mentioned above from Coahuila and Timor). This appears to be the first occasion on which the Roadian and Amarassian have been introduced as stages. Although they do not officially define them, they mention that "Furnish and Glenister are preparing a manuscript to elaborate on the names ...".

Comments and résumé of "Reference Stage and Substages" used in this paper.

(a) In the present paper I have recognised the Guadalupian Stage (typified by strata in the western Texas/northern Mexico region) as being divisible into four substages—Roadian, Wordian, Capitanian and Amarassian.

(b) The term Amarassian (based on strata in

Timor) is used here, purely provisionally, as a means of referring to the uppermost substage recognised, but as yet unnamed, in the Guadalupian of the western Texas/ northern Mexico region. It would be preferable for all four substages to be defined and named in this region. In Charts 24, 29 and 35 I have bracketed Amarassian to indicate that its use is a provisional convenience.

(c) The evidence, although not particularly clear, suggests that time gaps (included as two million years on Charts 24, 29 and 35) occur between the top of the Artinskian and the base of the Roadian, and between the top of the Amarassian and the base of the Dzhulfian.

4.2.3. *The Dzhulfian and Changhsingian Stages of the upper half of the Upper Permian—typified by strata in the Trans-Causasus (USSR) and northern Iran—(See Charts 24 and 27 for details.)*

A great diversity of opinion persists in the most recent literature in regard to the recognition of "Standard Reference Stages" for the post-Guadalupian Permian. This is clearly a reflection of the incomplete nature of the information presently available.

The following are the most relevant conclusions arrived at by a series of authors from 1961 to 1972 and I will conclude with my own assessment of what appear to be the most useful available "Standard Reference Stages" for the period in question.

(i) *Glenister and Furnish* (1961, p. 684, t. 2), according to Spinosa *et al.* (1970, p. 730), formally defined the Dzhulfian Stage as a ". . . post-Guadalupian standard for the uppermost Permian". The Dzhulfian Stage (based on the Trans-Caucasus) was taken to represent the whole of post-Guadalupian Permian. The stage as proposed by Glenister and Furnish presumably coincides with the ammonite-bearing upper three beds of the Dzhulfian Stage as defined in detail by Ruzhentsev and Sarýcheva (1965) (see below). The Chhidru beds of the Salt Range, the Kuling Shales of the Himalayas, the Wuchiaping Formation of southern China, the Ankitokazo fauna of Madagascar, the Foldvik Creek Formation of east central Greenland, were all considered equivalents of the Dzhulfian Stage of the Trans-Caucasus, with *Cyclolobus*, although rare, taken as "the best index fossil".

(ii) *Ruzhentsev and Sarycheva* (1965, t. 14 and p. 18–20), regarded the Dzhulfian Stage as occupying the whole period between the upper limit of the Guadalupian and the end of the Permian. They defined the stage in detail with reference to the type-section at Dorasham 2, Dzhul'fa Gorge, in the Trans-Caucasus (see Chart 26). They divided the stage into a series of five beds, the lower two being characterised particularly by fusulinids and brachiopods respectively with no known ammonites; the upper three bearing numerous ammonite specimens.

(iii) *Chao* (1965, p. 1825 and correlation charts) suggested that the *Tompophiceras–Paratirolites* sequence of beds which succeed the Dzhulfian Stage in the Trans-Caucasus (Ruzhentsev and Sarýcheva (1965, p. 20–21) had placed these beds in the lowermost Triassic) should be included in the uppermost Permian and correlated them with the Changhsing Formation of south China on ammonite evidence. Chao referred to the Kazanian and Tatarian as his "Standard Reference Stages"; the Changhsing Formation of south China and the *Tompophiceras–Paratirolites* beds of the Trans-Caucasus he equated with the Tatarian; the Wuchiaping Formation of south China, the Chhidruan Stage of the Salt Range and the Dzhulfian Stage of the Trans-Caucasus he equated with the Kazanian.

(iv) *Furnish* (1966) recognised two Permian stages above the Guadalupian, i.e. the Chhidruan followed by the Dzhulfian with the Chhidruan divided into two substages, the Godthaabian and the Jabian. He writes (p. 266)—"On a somewhat informal basis, the term 'Neopermian' is employed for that segment of geologic time in which the genus *Cyclolobus* is known to have existed. The Chidruan Stage, typified by Salt Range strata is the primary reference, but the genus has been reported to occur in the next younger Dzhulfian Stage. Godthaabian Substage (early Chidruan) is defined on the basis of an evolutionary step in the genus *Cyclolobus*. Jabian Substage is then applied to the late Chidruan in the type area. Only the term Godthaabian is new in a time-rock sense; it is derived from Godthaab (Good Hope) Gulf near the East Greenland *Cyclolobus* localities."

His Chidruan (Chhidruan) Stage was represented apparently by the upper three (ammonite-bearing) beds of the Dzhulfian stage as defined by Ruzhentsev and Sarýcheva 1965 (see above). Furnish did not have this Russian work available to him at the time of writing.

(v) *Stepanov et al.* (1969, fig. 6) and *Taraz* (1969, text and figs.), following Ruzhentsev and Sarýcheva (1965), considered the *Tompophiceras–Paratirolites* beds to be lowermost Triassic and had the Dzhulfian Stage occupying the whole period between the end of the Guadalupian and the end of the Permian.

(vi) *Tozer* (1969, t. 2 and p. 349–350) followed Chao (1965) in including the *Tompophiceras–Paratirolites* beds of the Trans-Caucasus in uppermost Permian. He writes that it is apparent ". . . that there is no satisfactorily defined stratigraphical term, based on a marine sequence, to accommodate the youngest Permian rocks . . . For the time being, it is probably best to follow Chao (1965, p. 1824), and Waterhouse (1967) who use the term Tatarian, despite the fact that the typical Tatarian based almost entirely on red continental deposits, does not constitute a satisfactory standard stage".

(vii) *Furnish and Glenister* (1970, p. 154–155, t. 1) write—"There is little unanimity of opinion regarding Permian stage names, particularly in the upper portion of the system . . . New data within the last few years suggest relationships for the post-Guadalupe sequence not visualized previously (Furnish, 1966)." They recognised three stages between the top of the Guadalupian and the end of the Permian, i.e. the Araksian (typified by strata in the Trans-Caucasus), followed by the Chhidruan (typified by strata in the Salt Range) and the Changhsingian (typified by strata in south China). They include the three stages in the Dzhulfian Series. The Araksian and Changhsingian Stages were introduced for the first time, but were not formally defined; this was deferred for a manuscript presently in preparation by them.

The Araksian stage they write—" . . . is thought to be largely synonymous with Godthaabian (Furnish, 1966) from East Greenland, but it is introduced because it now has the advantage of a diverse fauna in sequence". The Araksian Stage is presumably intended to correspond with (and to replace) the Dzhulfian Stage of the Trans-Caucasus as defined by Rezhentsev and Sarýcheva (1965).

The Chhidruan Stage I assume is still intended (as in Furnish, 1966) to be typified by the whole of the Chhidru Formation of the Salt Range.

The Changhsingian Stage is presumably intended (as in Furnish, 1966) to be typified by the Changhsing Formation as presented in Chao (1965), and to be equivalent to the *Tompophiceras–Paratirolites* beds of the Trans-Caucasus as defined by Ruzhentsev and Sarýcheva (1965).

(viii) *Tozer* (1971, p. 453–454) offered a number of critical comments on the Araksian, Chhidruan and Changhsingian sequence of stages as proposed by Furnish and Glenister (1970), but made no attempt to present an alternative scheme. He feels that the "Standard Reference Stages" for the post-Guadalupian Permian should, as far as is possible, be typified by strata comprising a single section and suggests the well known Trans-Caucasus for this purpose. He writes— "Having Araksian and the Changhsingian equivalent defined in the same section would also focus attention on a major problem— The position of the Chhidruan stage in relation to Araksian [i.e. Dzhulfian] and Changhsingian. Furnish and Glenister place the Chhidruan between the other two, because Chhidruan cyclolobids are believed to be more advanced than Araksian. But this begs another question: how is the Chhidruan represented at Dzhulfa (in the Trans-Caucasus)? By an unconformity or non sequence? Furnish and Glenister do not provide the answer, but in the context of proposing a sequence of three stages to cover latest Permian time, as they have done, should not this question have been considered? "

(ix) *Waterhouse* (1972, p. 159) also offered critical comment on the Araksian, Chhidruan and Changhsingian sequence of stages proposed by Furnish and Glenister (1970). He writes—"If one plots several sequences in which Capitan and/or Chhidru faunas are known—such as those in the Glass Mountains, Guadalupe Mountains, Coahuila—Mexico, Kolyma River in eastern Siberia, Japan (several areas), China (several areas), eastern and western Australia, New Zealand, Armenia, Iran, Salt Range, and Cambodia—he will be immediately struck by the fact that not a single section shows both the Capitanian and Chhidruan stages. If one is present, the other is absent; nowhere do they occur together. The reason is obvious—they are one and the same stage. Each has a characteristic ammonoid genus, *Timorites* and *Cyclolobus*. These two genera inhabited different geographic realms of the same age . . . They were contemporaneous."

He notes also that the Chhidruan and Dzhulfian (Araksian) seem to be "mutually exclusive", but then continues to write: "In not one sequence does the Chhidruan fauna follow a Djulfian fauna, including the name or type areas of Djulfa, Chhidru-Salt Range, and Changhsing! By contrast, the rival interpretation can point to several successions, firmly correlated by various faunal and stratigraphic data, in which the Chhidruan fauna is followed by the lower Djulfian Fauna, (e.g. Waterhouse, 1969)".

Comments and résumé of "Reference Stages" used in this paper.

(a) *The time relationship between the Araksian (Dzhulfian) and Chhidruan Stages as proposed by Furnish and Glenister (1970)*

(N.B.) Under this heading I shall refer to the Dzhulfian Stage—as defined by Ruzhentsev and Sarýcheva (1965)—rather than the Araksian Stage, since the two appear to be synonymous, and the Dzhulfian has priority).

It is interesting to follow the evolution of thought concerning this question in the three papers—Glenister and Furnish (1961); Furnish (1966); and Furnish and Glenister (1970). In the first paper the faunas of the two stages

TABLE 1. THE KNOWN DISTRIBUTION OF THE GENUS CYCLOLOBUS (Excluding *C. persulcatus*)

		C. oldhami	*C. walkeri*	*C. teicherti*
Known *Cyclolobus* material of the Chhidruan Stage (typified by the Chhidru Formation of the Salt Range).	Salt Range	7 specimens	6 specimens	1 specimen
	Spiti area of Himalayas	2 specimens	30 specimens	–
	E. Kumaon of Himalayas	1 specimen	2 specimens	–
	Madagascar	–	> 150 specimens	–
		C. kullingi		
Known *Cyclolobus* material of the Dzhulfian Stage (typified by strata in the Trans-Caucasus (USSR) and northern Iran	Trans-Caucasus (USSR)	1 specimen		
	N. Iran	1 specimen		
	C. Iran	1 specimen		
	E. C. Greenland	several specimens		

were considered to be of the same age, in the second the Chhidruan fauna was considered to be the older, and in the third the Dzhulfian fauna was considered to be the older.

Furnish and Glenister (1970) write—"To a large degree, an understanding of age relationships in the Upper Permian is based upon ammonoid faunas. A phylogenetic sequence of cyclolobids constitutes the primary reference, although there are a number of other less diagnostic families ranging through this portion of the system".

The above table presents the known distribution of the species within the genus *Cyclolobus*. (nb. *C. persulcatus*, which occurs in the Amarassian Stage of Timor, and is the most primitive known species within the genus, is not included.) The arrangement of species is according to Furnish and Glenister (1970), and constitutes the latest revision of the genus. See Chart 27 for further details.

C. kullingi is regarded by Furnish and Glenister (1970) as more primitive than *C. oldhami* and *C. walkeri*. *C. teicherti* (known from only one specimen) is considered by them to be closely related to *C. kullingi* and even more so to *C. persulcatus*, the Amarassian form from Timor.

Of the 19 other ammonite genera (see table on Chart 27) known from the eight areas listed above as representing the Dzhulfian and Chhidruan Stages, only two, *Stacheoceras* and *Medlicottia* are common to both stages. Very few specimens of these two genera are available and I am aware of no detail suggesting whether or not the Dzhulfian Stage representatives are indicative of an earlier stage in development than those from the Chhidruan Stage.

Of the remaining genera, *Popanoceras, Episageceras, Xenodiscus* and *Xenaspis* occur exclusively in the Chhidruan; whilst *Pseudogastrioceras* and 10 genera of the family Araxoceratidae occur exclusively in the Dzhulfian. Those genera exclusive to the Chhidruan are all known from Guadalupian or pre-Guadalupian strata.

The differing peculiarities of generic distribution between the Dzhulfian and Chhidruan Stages appear to be far more indicative of ecological rather than age differences. The differences exhibited by the included *Cyclolobus* species do not appear to provide concrete evidence that the Dzhulfian is older than the Chhidruan as tentatively suggested by Furnish and Glenister (1970). *C. kullingi*, even if shown to exhibit primitive characteristics, could easily represent a conservative offshoot from the main evolutionary line. It would appear that the associated invertebrate faunas of the two stages cannot be invoked to solve the problem.

Until such time as further information suggests evidence to the contrary, I prefer to regard the Dzhulfian and Chhidruan stages as contemporary, and since the Dzhulfian has priority, it is favoured in the present paper. Also, the latest Permian stage (see below) occurs in sequence with the Dzhulfian in its type area, but is not present in the Salt Range, the type area of the Chhidruan Stage.

(b) *The time relationship between the Dzhulfian and the underlying Amarassian.*

Spinosa *et al.* (1970), write—"A problem in relating the Dzhulfian to the underlying Guadalupian has involved failure to recognize the ancestry of the dominant Dzhulfian ammonoid [family], the Araxoceratidae . . . in older strata. This problem has been resolved with the discovery of an ancestral araxoceratid, *Eoaraxoceras ruzhencevi* Spinosa, Furnish and Glenister . . . in the uppermost Guadalupian (Amarassian) . . . beds of the Valle de Las Delicias, Coahuila, Mexico. Recognition of this Mexican occurrence appears to provide the link between the Paraceltitinae, which characterize the Guadalupian, and the advanced Dzhulfian araxoceratids". The Dzhulfian Stage of the Trans-Caucasus moreover contains, according to Spinosa *et al.*, representatives of other genera, e.g. *Pseudogastrioceras, Stacheoceras* and *Cyclolobus* which can all be related to ancestral forms in the Guadalupian of western Texas, northern Mexico and Timor.

Waterhouse (1972) (see earlier), on the other hand, considers the Chhidruan Stage (and apparently also the Dzhulfian Stage) to be equivalent to the "Capitanian Stage". In arriving at this assessment he had apparently not yet had the Spinosa *et al.* (1970) paper available to him.

In the "Standard Reference Stages" (see Charts 29 and 35) I have taken Spinosa *et al.* (1970) to be correct.

Moreover, as in the case between the top of the Changhsingian and the base of the Triassic, it seems most reasonable to presume that some time gap exists between the end of the Amarassian Stage (typified by strata in northern Mexico) and the base of the Dzhulfian Stage (typified by strata in the Trans-Caucasus). It is most unlikely that the one follows on immediately after the other.

(c) *The Changhsingian Stage.*

Following Chao (1965), Tozer (1969), Furnish and Glenister (1970), the *Tompophiceras–Paratirolites* beds of the Trans-Caucasus (and northern and central Iran) and the equivalent Changhsingian Stage of southern China are considered to be uppermost Permian, rather than lowermost Triassic. The *Tompophiceras–Paratirolites* beds overlie the type Dzhulfian Stage strata in the Trans-Caucasus and would constitute an obvious "Standard Reference" for the uppermost Permian stage, as suggested by Tozer (1971). However, no stage name has, as yet, been coined for this sequence of beds, and I have used for provisional convenience the term Changhsingian as the only partially suitable name available. In Charts 29 and 35 I have bracketed Changhsingian to indicate that its use is purely a matter of convenience.

(d) *The time relationship between the Changhsingian and the overlying Griesbachian (the lowest Triassic stage)*

(See notes on Chart 29 elaborating on this point).

(e) *Résumé of "Reference Stages" used in this paper.*

The Trans-Caucasus (USSR) and the closely adjacent northern Iran sections provide the most useful known post-Guadalupian Permian sequence for use as a "Standard Reference" for this period. The two stages recognised within this sequence of strata, i.e. the Dzhulfian followed by an unnamed stage equivalent to the Changhsingian Stage of South China, are taken to be the "Standard Stages". The unnamed stage is referred to in Charts 29 and 35 as (Changhsingian). In the text to the charts and in the general text the brackets are discarded.

Time gaps of unknown duration are considered, in this paper, to occur between the Dzhulfian and the underlying Amarassian and between the Changhsingian and the overlying Griesbachian. These time gaps are included in Charts 24, 29 and 35 as occupying two million and one million years respectively.

4.3. The "Standard Reference Ammonite Zones" of the Permian System

"The pre-eminence of ammonites as zonal marker fossils for local and world-wide correlations is undisputed. No other organisms enable the Upper Paleozoic and Mesozoic systems to be classified and correlated in anything like such detail. This usefulness is due to their rapidity of evolution, with wealth of forms changing rapidly up the stratal column, their wide distribution and comparative indifference to facies, and usually their ease of recognition, even in the field without the use of the microscope or laborious techniques".—Arkell (1957, p. L 124).

This view, apparently, does not ride entirely undisputed. Waterhouse (1972, p. 160) in conclusion to a discussion on the "Reference Stages" of the Middle to Upper Permian writes for instance " . . . it does not mean that ammonoids have to be abandoned as time indices for the Middle and Upper Permian, however. They are certainly as useful as Fusulinacea, and, where present, as accurate as brachiopods, and obviously just as open to misinterpretation". Ammonites first appear in the Lower Devonian and die out at the end of the Cretaceous. The diversity attained by them within the Devonian, Carboniferous and Permian is relatively limited (see Table 2). A marked increase in the number of genera is met with in the Triassic, Jurassic and Cretaceous. The number of recognisable "Ammonite Zones" per system is more or less directly proportional to the number of genera occurring. Miller *et al.* (1957, p. L 24) in the *Treatise on Invertebrate Paleontology* record only five "Ammonite Zones" in the Permian whereas Arkell (1957, p. L 125) in the same volume records 58 for the Jurassic. For the Permian therefore each zone occupied nine million years on average, whereas in the Jurassic each zone occupied only a little over one million years. The situation in which a nine million year resolution of 'Ammonite Zones' for the Permian is the best achievable does not augur well for meaningful world-wide correlation within this system. A lot has been written, however, on the ammonites of the Permian since 1957 and now 11 "Reference Stages" and/or "Substages" can be recognised. Ruzhentsev and Sarýcheva (1965) recognise seven "Ammonite Zones" within the upper two stages (see Chart 24). Zonal schemes have not been devised for the lower

TABLE 2. NUMBER of AMMONITE FAMILIES, GENERA + REFERENCE ZONES RECOGNIZED IN THE DEVONIAN to CRETACEOUS.

AGE IN MILLIONS of YEARS	GEOLOGICAL SYSTEM	APPROX. NUMBER of FAMILIES + GENERA	NUMBER OF REFERENCE AMMONITE ZONES	DURATION IN MILLIONS OF YEARS	REFERENCES
65–135	CRETACEOUS	47 fams. 530 gen.	36 zones	70	Arkell '57, p. L 128 (genera) Teichert '67, fig 20 (families)
135–210	JURASSIC	40 fams. 650 gen.	58 zones	75	Arkell '57, p. L 128 (genera) Teichert '67, fig 20 (families)
210–255	TRIASSIC	72 fams. 395 gen.	34 zones	45	Tozer '71
255–300	PERMIAN	16 fams. 70 gen.	(5 zones)	45	Miller et al '57; p. L 24, L 29-L 79 (genera) Chart 24 of this paper (families)
300–360	CARBONIFEROUS	15 fams. 70 gen.	11 zones	60	Miller et al '57; p. L 24, L 29-L 79.
360–395	DEVONIAN	19 fams. 80 gen.	8 zones	35	Miller et al '57; p. L 24, L 29-L 79.

nine stages (and/or substages) and considering the fairly low diversity of genera occurring, such zones would possibly not be more finely resolved than the stages.

4.4. The Carboniferous/Permian boundary

4.4.1. *Brief description of certain aspects of Carboniferous strata in the Northern Hemisphere (based on Francis and Woodland 1964, p. 221–226).*

(The notes presented here are intended to accompany Table 3, and are included for general reference in the discussion on the Carboniferous/Permian boundary.)

North-west Europe (Stephanian).

"The Stephanian Stage . . . is confined almost entirely to isolated intermontane 'limnic' basins which extend intermittently from central France to Czechoslovakia". Plant beds are abundant.

Russia (general Carboniferous).

"In the *Moscow basin* the Carboniferous rocks consist almost entirely of marine limestones and dolomites of shallow water facies. In the *Urals* the sequence is very varied: on the western slopes marine limestones predominate as in the Moscow basin, though the facies in general appears to be of deeper-water type; traced eastwards considerable parts of the limestone sequence are replaced by rapid interdigitation with marine clastic deposits, interbedded locally with much volcanic materials; coals occur only locally among the lower deposits".

In the *Donetz Basin* red beds of continental facies containing plant remains apparently predominate in the Carboniferous. Limestones containing marine faunas interdigitate with these red beds.

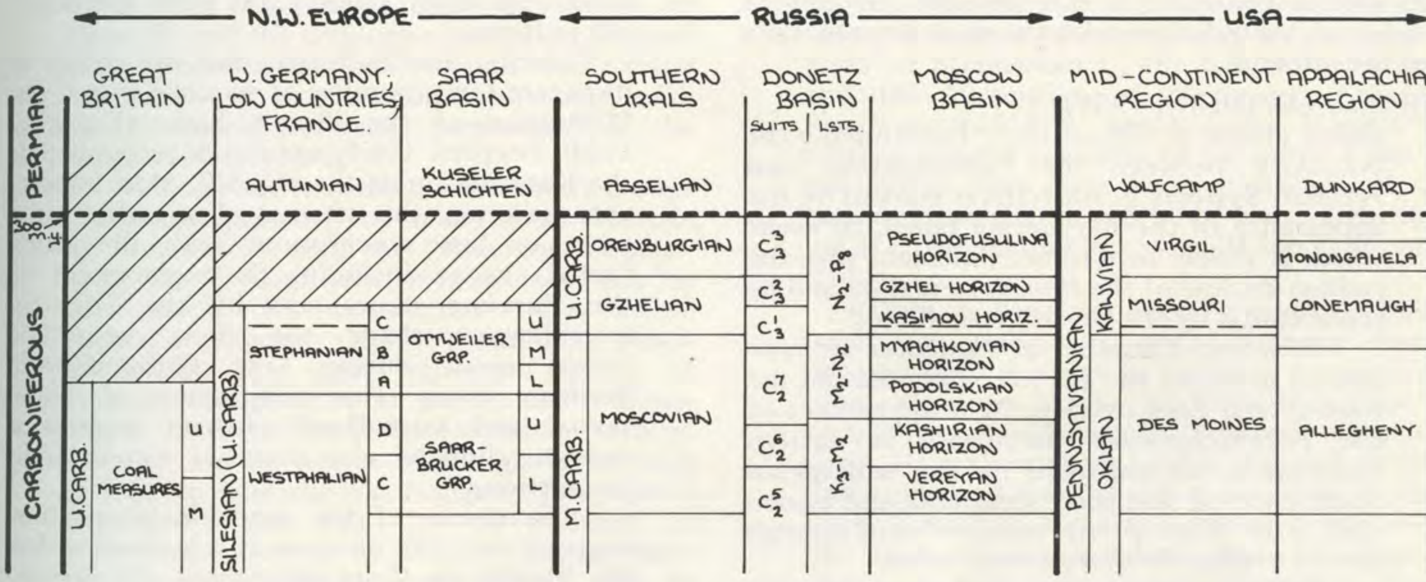
U.S.A. (Pennsylvanian).

In the *Appalachian* region the Pennsylvanian sequence is very similar to the U. Carboniferous in north-west Europe. "It is a cyclic coal-bearing non-marine sequence . . ." Correlations with Europe are based on the floras. In the *Mid-continent* region marine sequences occur in the Pennsylvanian. "Foraminifera are widespread in the marine limestones. In the beds above the Atoka in particular the fusulinid fauna is remarkably similar to that of Russia". Interdigitation of plant and marine facies allows correlation with the Appalachian section. See also notes by Helby (1969) quoted later in the section regarding the Permian/Carboniferous boundary as recognised in Australia.

4.4.2. *The Carboniferous/Permian boundary as recognised in the Northern Hemisphere continents.*

Smith (1964, p. 214–215) writes that the Carboniferous/Permian boundary is taken " . . . at the base of the zone of the fusuline, *Pseudoschwagerina (Schwagerina)* as originally proposed by Beede and Kniker (1924) and since adopted by the geological surveys of the USSR and the USA, by the Geological Society of America's Permian Subcommittee, by comparable Soviet committees (e.g. Stepanov *et al.,* 1962) and by leading authorities on the Permian from many countries. This horizon has been chosen because (a) in the view of most authors it marks the major break in marine faunas taken as a whole; (b) in many parts of the world it directly succeeds an unconformity or non-sequence and; (c) the faunal assemblage of the zone as a whole is so distinctive as to make it easily recognized. A minority view favoured by some Russian and most Chinese authors is that the base of the Permian should be taken at the top of

TABLE 3. THE UPPER HALF OF THE CARBONIFEROUS SYSTEM IN THE NORTHERN HEMISPHERE



Based on: Francis & Woodland (1964, T. 1)
Helby (1969, p 69–71)

Key: ---- The Carboniferous/Permian boundary as recognized by Francis & Woodland (1964, T. 1), & adhered to in this paper.

— — — The position of the Carboniferous/Permian boundary as recognized by Helby (1969, p 69–71).

the zone of *Pseudoschwagerina* because they consider that it is at this horizon that the major evolutionary break in fusulines occurs."

"Recognition of the Permian-Carboniferous transition in continental sequences is more difficult, but by widely accepted convention [recommended by the Congress for the Advancement of Studies of the Geology and Stratigraphy of the Carboniferous (at Heerlen, 1952)—see Helby, 1969, p. 70] it is taken at the base of the lowest beds containing the plant *Callipteris conferta* Brongniart."

"Since very few sequences contain interdigitations of typical marine and continental beds much controversy has centred on the time relationship between the respective index-fossils. Fomichev (1960), however, has shown that in the Donetz basin [where interdigitation of marine beds with fusulinids and continental beds with plants does occur (see Francis and Woodland, 1964, p. 223–224] *Callipteris conferta* appears much earlier than *Pseudoschwagerina*."

According to Francis and Woodland (1964, p. 223–224) this difference between the first appearance of *Callipteris conferta* and *Pseudoschwagerina* " . . . may be as much as 1 900 metres. This apparent difference may be due to accidents of collection or preservation, but there is no gainsaying the fact that there is almost insurmountable difficulty in correlating the continental facies of one area with the marine facies of another."

Ruzhentsev (1954, p. 4) writes—"The boundary between the Carboniferous and Permian according to the vertical distribution of the ammonoids, and also in terms of the other groups in the fauna, should be drawn between the Orenburg and Assel Stages [of the southern Urals] . . . No new data will be able to alter this conclusion, to which the majority of investigators have come—the conclusion that the Assel deposits belong to the Permian System . . . The ammonites of the Assel Stage are undoubtedly more closely related to those of the Sakmar Stage than to those of the Orenburg."

As far as I can ascertain (see Ruzhentsev, 1954, p. 1 and Dunbar *et al.,* 1960, p. 1766) the boundary between the Carboniferous and Permian, i.e. between the Orenburgian and Asselian Stages, as defined according to the ammonoids (see above and Chart 24) in the southern Urals is taken to coincide with the base of the Zone of *Pseudoschwagerina*. How exactly this is so I have no means of knowing from the literature available to me.

The definition of the "Standard Reference Stages and Substages" of the Permian is based on ammonites. Surely the Carboniferous/Permian boundary should be defined likewise and not on a different group of organisms, i.e. the fusulinids, as is presently the most internationally accepted custom. It is apparent that an exact definition of the boundary, based on the ammonite faunas of the southern Urals, should be instituted.

4.4.3. *The Carboniferous/Permian boundary as recognised in the Gondwana continents.*

Locating, with confidence, the correct position of the Carboniferous/Permian boundary in the Gondwana countries is not possible on present evidence. Australia provides the most hopeful data for the attempt.

(i) *Australia* (Helby, 1969).

Helby (1969, p. 70) writes: "Traditionally the boundary between the Carboniferous and Permian Systems in Australia is marked by the appearance of the *Eurydesma* fauna, an event which is widely held to be coincident with the sudden decline of the *Rhacopteris* flora and its replacement by the *Glossopteris* flora."

However, a number of sequences are now known in which the *Eurydesma* fauna and the *Rhacopteris* flora overlap. "The appearance of the *Potonieisporites* microflora in eastern Australia is accompanied by the widespread occurrence of glacigene sediments and associated with *Rhacopteris* remains" and appears also to overlap the *Eurydesma* fauna.

Helby suggests that the base of this microflora (hitherto regarded as the uppermost Carboniferous microflora in Australia) ". . . is the closest available approximation to and most convenient location for the top of the Carboniferous System in Australia."

Helby's discussion regarding the relationships between the most significant biological changes in Australia and Euramerica near the Carboniferous/Permian boundary runs as follows:

"If problems of terminology are to be avoided, the location of the Carboniferous/Permian boundary in Australia should be based on an adequate definition of both the top of the Carboniferous type section and the base of the Permian type section. In brief, the top of the Stephanian C—the uppermost division of the Stephanian in the St. Etienne and Saar Basins—defines the top of the Carboniferous System, and, consequently, the base of the Permian System, in Western Europe. To alleviate the considerable problems concerning delineation of this boundary, the Congress for the Advancement of Studies of the Geology and Stratigraphy of the Carboniferous (at Heerlen, 1952) recommended that the top of the Carboniferous be drawn below the lowest occurrence of the gymnosperm *Callipteris conferta* Sternberg."

"A distinct lithological change from coal measure to red beds can be seen in the central portions of the Stephanian C, accompanied by a marked floral change from a typical Stephanian flora to a flora with a distinct Autunian aspect (Cignoux, 1955, p. 200). In a study of the palynostratigraphy across the presently recognised Carboniferous/Permian boundary in the Pfalz Basin, a northern extension of the Saar Basin, Helby (1966) demonstrated the presence of a major microfloral change within the Breitenbach Formation (Stephanian C), characterised by the decline of dominant *Lycospora* and the rise to prominence of *Potonieisporites, Illinites* and other spermatophyte forms."

"Helby also indicated that this change is duplicated in a number of sections within the Missourian of the Illinois Basin (Kosanke, 1950; Peppers, 1964) and can be recognised in the Kassimovian of the U.S.S.R. More important, however, this change of microflora was more or less synchronous with the major faunal change—including the replacement of the *Fusulina* microfauna by the *Triticites* microfauna—perhaps the most important faunal event during Late Carboniferous/Permian times. This coincidence of major faunal and microfloral changes suggests a sudden climatic alteration of considerable proportions."

"Synthesis of the available information suggests that the changes at a horizon within the Stephanian C are expressions of a drastic, widespread change in the earth's climatic patterns. Numerous changes in the style of sedimentation at this particular horizon complement the theory. A similar pattern can be recognised in Australia, where the major floral event of the Upper Carboniferous/Permian sequence is represented by the sudden decline of the *Grandispora* microflora and its replacement by the *Potonieisporites* microflora, an event which appears to be intimately associated with the widespread development of glacigene sediments in eastern Australia. Of further interest is the appearance in abundance of *Potonieisporites* and other spermatophyte pollen, both in the Euramerican and Australian regions. It appears reasonable to suggest that the changes described above are virtually synchronous. Physical evidence supporting this hypothesis is provided by the apparent parallelism of this horizon with the line marking the base of the Kiaman Magnetic Interval."

Helby's suggestion that the base of the *Potonieisporites* microflora ". . . is the closest available approximation to and most convenient location for the top of the Carboniferous System in Australia. . ." means that he is advocating a fairly considerable downward displacement of the Carboniferous/Permian boundary in the various reference sections in Russia, Europe and U.S.A.

In view of the discussion held earlier in this section (4.4.2.) his suggestion would probably not be widely acceptable.

(ii) *Australia and remainder of Gondwanaland.* (This paper).

(N.B. References and detail regarding the microfloral data discussed below are given in Anderson, 1973, Ph.D Thesis in preparation).

Unlike the remainder of Gondwanaland, excellent marine invertebrate faunas occur commonly in Australian Permian strata. Ammonite faunas of Tastubian to Roadian age occur (the location of these are shown on Chart 35 and the fauna given on Chart 30) and these provide a reasonably sound basis for the correlation of strata, within this range, with the "Standard Reference Sequences" of the Northern Hemisphere.

None of the remaining invertebrate groups provide, at present, any really good evidence for correlations with the "Reference Sequences". The foraminifera, for instance, can be used safely for correlation only within Australia (Crespin, 1958). Fusulinids, stratigraphically the most important group of Permian foraminifera in the Northern Hemisphere, are unknown in the Australian Permian.

The marine faunas of the glacigene beds of Western Australia (i.e. Nangetty Fm., Lyons Grp. and Grant Fm.) are all included in invertebrate Zone A by Dickins (1969). Since the Holmwood Shale (Perth Basin) with its Tastubian age ammonoids is placed in the upper part of Zone A by Dickins (1969), we may presume the glacigene beds to be not much older (unless Zone A represents a longer time period than later zones). I have included the Holmwood Shale (in Chart 35) as upper Tastubian and the glacigene beds as lower Tastubian.

The microflora of the Nangetty Fm. (Perth Basin–Microbaculispora Assemblage Zone of Segroves, 1970) and the Grant Fm. (Canning Basin) appear to be equivalent. I am aware of no published work on the microflora of the Lyons Group (Carnarvon Basin). The Microbaculispora Assemblage is only subtly different from the Quadrisporites Assemblage (in the lower part of which occurs the Holmwood Shale), further evidence to suggest that no long time interval separates the glacigene beds from the Tastubian.

The Microbaculispora Assemblage Zone of Western Australia can be fairly confidently correlated with microfloral Stage 2 of eastern Australia, also associated with glacigene beds. It occurs in the Boonderoo beds of the Galilee Basin, the Merrimelia Fm. of the Cooper Basin and the glacigene beds of Victoria.

Thus there apparently occurred in Australia widespread deposition of glacigene deposits during the lower Tastubian. These deposits, and younger Permian deposits in areas where the glacigene beds do not occur, rest most frequently with unconformity on L. Carboniferous or older rocks. In certain areas in eastern Australia (e.g. the Joe Joe Fm. of the Galilee Basin and western Springsure Shelf; and the Seaham Fm. of the Lower Hunter Valley–Sydney Basin) glacigene beds, apparently of uppermost Carboniferous age were deposited. These constitute microfloral Stage 1 of Evans (1967), i.e. the *Potonieisporites* microflora discussed by Helby (1969) (see above). This microflora Helby takes to be the time equivalent of microfloras in the upper parts of Stephanian C, the Kasimov Horizon and the Missourian of north-west Europe, Russia and U.S.A. respectively. If this is correct and the correlations shown in Table 3 are correct, then these lower glacigene beds of eastern Australia would be of lower Gzhelian age (i.e. the second-last stage of the Carboniferous).

Thus in Australia there appears to have been two pulses of glacial activity (each occupying very probably less than a ½ million years–see notes on Dwyka Tillite in Section 5 of text), one occurring in the lower Gzhelian some 10 million years before the end of the Carboniferous and the other occurring in the lower Tastubian some five million years after the start of the Permian. The first pulse appears to have been of less widespread effect than the second.

Taking into consideration the remaining Gondwana countries (particularly those areas included in Chart 35), throughout there occur glacigene strata at the base of an essentially Permian/Triassic sequence. These strata rest for the greater part with strong angular unconformity on Precambrian strata or Basement Granite. For the remainder (i.e. the southern and south-eastern extremities of the Karroo Basin of South Africa; the Transantarctic Mountains; and the Parana Basin of South America) they apparently rest unconformably on beds of Devonian and earlier Palaeozoic age. (At places in the Southernmost Karroo Basin the lithological evidence suggests a break in sedimentation between the strata of the Witteberg beds of the Cape 'Supergroup' and the overlying Dwyka Tillite. The former is thought to be Devonian or possibly L. Carboniferous in age on uncertain palaeontological evidence (Anderson, 1973).

The microfloras of these glacigene beds are (considering those areas where they are fairly well known, e.g. northern Karroo Basin of South Africa; Middle Zambezi Valley of Rhodesia; Parana Basin of South America; India) essentially the same and can be matched with the Stage 2 microflora of eastern Australia and the Microbaculisporites Assemblage Zone of the Perth Basin of Western Australia, i.e. with the second pulse of glacial activity in Australia.

Present data thus seem to suggest that the bulk of the glacigene strata throughout Gondwanaland are of essentially the same age. The exceptions are the uppermost Carboniferous glacial period in eastern Australia (discussed previously) and the Carboniferous alpine glaciation of South America (discussed below).

Along the Andean Mountain belt of Bolivia and Argentina numerous scattered small outcrops (often connected in subsurface to form relatively small basins—see Chart 23) of Upper Palaeozoic strata display evidence of glacial activity. These areas are not included in the correlation chart (i.e. Chart 35).

Frakes and Crowell (1969, p. 1007, see also Figure 3), write—"Glacial activity is recorded in rocks of Early Middle and Late Carboniferous and Early Permian (?) age in Argentina and Bolivia . . . Direct evidence for glaciation in the . . . Andean basins consists of a single striated floor and common striated clasts in diamictites and associated strata. Many Andean diamictites are intercalated in sequences which contain marine invertebrate fossils and turbidites . . . Ice centers apparently developed in rugged highlands within the Andean orogenic belt. Alpine or piedmont glaciers, or both, flowed downward onto narrow shelves, and till then moved into the marine portions of the basins by mudflow and sliding. The continental portions of the basins lay generally eastward of the marine areas and a topographically mature terrane still farther east was affected only slightly by glaciation, presumably because it was distant from glacial centers and lay at a relatively low elevation."

The overall history of glaciation in the Carboniferous and Permian of Gondwanaland thus possibly reads as follows:

(a) Alpine and piedmont type glaciation occurred in the rugged highlands of the Andean orogenic belt (of Bolivia and Argentina) intermittently throughout the Carboniferous.
(b) A relatively minor pulse of glaciation (of less than 500 000 years duration, and of fairly restricted nature) affected several areas in eastern Australia some 10 million years before the close of the Carboniferous.
(c) A major period of glaciation, possibly reminiscent of the Pleistocene glacial epoch, lasting up to 500 000 years and affecting the whole of Gondwanaland occurred some five million years after the start of Permian.

The attempt to locate the Carboniferous/Permian boundary in Gondwanaland has clearly become an attempt to date the ubiquitous glacial deposits. The major proportion of these appear to fall within the Permian and to rest with distinct unconformity on Lower Carboniferous and older rocks.

4.5. The Permian/Triassic boundary

See notes on Chart 29 for discussion on the Permian/Triassic boundary. Nothing further is added here.

5. DISCUSSION ON THE PERMIAN CORRELATION CHART (Chart 35).

A good proportion of the information in Charts 24–34 is directed towards an attempt to compile a meaningful correlation table (Chart 35) representing the true time-relationships between Permian strata distributed throughout the world.

The following factors are considered vital to an attempt to compile a correlation chart to be used as a base for subsequent phylogenetic studies:

(i) The choice of "Standard Reference Stages", "Substages" and "Ammonite Zones" and the definition of the lower and upper boundaries of the Permian System. (See 5.1 below.)
(ii) The application of absolute age data. (See 5.2 below.)
(iii) The consideration of all available palaeontological and lithological data. (See 5.3 below.)
(iv) The consideration of rates and continuity of deposition, and of compaction of sediments. (See 5.4 below.)

5.1. The choice of "Standard Reference Stages", "Substages" and "Ammonite Zones" and the definition of the lower and upper boundaries of the Permian System

Considerable controversy exists in the literature as to what should constitute the "Standard Reference Stages", "Substages", and "Ammonite Zones"; and the lower and upper boundaries of the Permian System. I have thus been obliged to make my own judgements. (See Charts 24 to 30 and section 4 of text.)

The "Standard Reference Sequence" used is by no means ideal since it is necessary to compile it from three sections from three different areas, i.e. the Lower Permian from the southern Urals; the lower half of the Upper Permian from western Texas and northern Mexico; and the upper half of the Upper Permian from the Trans-Caucasus (USSR). The exact time relationships between these three sections are not clear, but there appear to exist time intervals between them. The duration of these intervals cannot, on present evidence, be confidently estimated, but since it is necessary to indicate them on the correlation chart, I have taken them to occupy two million years each. There appears likewise to be a break in time between the top of the Changhsingian Stage and the base of the Triassic. I have taken it to occupy one million years. There is, as far as I can gather, no evidence for a break between the lowermost Permian and uppermost Carboniferous as defined in the southern Urals.

Further questions exist: Did there not occur time breaks within each of the three sequences combined to form the "Standard Reference", and if so how long were they? What was the true relative time duration of each "Stage" and "Substage"? As I have drawn Chart 35, most of the "Substages", plus those "Stages" which have not been further subdivided, are each taken to occupy the same period of time, i.e. four million years. The Amarassian and Roadian "Substages" have each been taken to occupy two million years.

It must be accepted that the presently used foundation for world Permian correlations is shaky and subject to possible need for substantial alterations.

5.2. **The application of absolute age data** (See Charts 31–33).

The data presently available is very limited and is of use only in forming a rough provisional guide to the age of the start and finish of the Permian System and hence to its duration, i.e. ± 45 million years. No ages can be applied to any of the "Reference Stages" and certainly no direct use of absolute age data can be made in the correlation of Permian strata.

5.3. **The consideration of all available palaeontological and lithological data**

I have attempted to indicate on Chart 35, for each formation, member etc., the palaeontological content (other than the microfloras) on which the correlations are based. Microfloras have been used extensively, particular in the case of the Gondwana countries, in correlations, but because of the difficulty experienced in gathering comprehensive data (relating to which strata yield good assemblages, poor assemblages or no assemblages at all) I have not attempted to indicate such information. A similar problem exists in the case of marine deposits of the U.S.A. I have not been able to gather adequately comprehensive data as to which portions of which sections are marine (with or without ammonites), weakly marine or non-marine and have therefore indicated only certain of this information (see Chart 35 for notes).

New and improved palaeontological data will continually become available and will necessitate a continual need for revision of the correlation chart.

In the case of barren or palaeontologically unstudied strata correlation has to be attempted where possible on lithological characteristics alone. This is reasonable where the succession in adjacent or even widely separated basins is similar and where certain horizons in one or other of the basins are barren or unstudied.

5.4. **Rates and continuity of deposition; compaction of sediments**

These factors need to be seriously considered when compiling a time-oriented correlation chart. Unfortunately, at the present time, only rough conclusions can be drawn from our state of knowledge concerning recent and present rates of deposition, continuity in sedimentation and compaction of sediments (see Chart 34). A brief discussion follows, taking the strata of the Karroo Basin of South Africa as an example of the manner in which I have attempted to apply the available information (see map on Chart 35 for location of areas discussed and Anderson (1973) for derivation of information included in this section).

Upper Ecca (of the Welkom and Ladybrand —marked LA on chart 35/areas.

General Thickness: ± 250 m.

Sediment type and environment of deposition: The Upper Ecca sediments represent a single, apparently unbroken transgressive-regressive sequence from delta-front (sandy to clayey silts) to pro-delta (silty clays) and back to delta-front deposits. The pro-delta sediments occupy some 5/6 of the total sequence. The sediments fine steadily from the top and bottom to the middle of the succession. The Middle Ecca below and the Tapinocephalus Zone equivalent above represent the delta-plain and alluvial-plain facies of the same cycle. The Upper Ecca sediments of the area under discussion were deposited in a shallow shelf sea (apparently non-marine) deepening gradually to the south-east and in all likelihood never reaching more than 50–100 m in depth.

No time break, of any significance, in the succession from the Middle Ecca through the Upper Ecca into the Tapinocephalus Zone equivalent is suggested from a study of the included microfloral assemblages.

Possible maximum depth of burial in past: ± 2 000 m (N.B. this figure is a direct estimate of the thickness of strata that have possibly been removed by erosion and is not based on diagenetic evidence).

Porosity: 10–12% in Welkom area, steadily decreasing to 2–4% in Ladybrand area.

Original clay content: Unknown.

Present clay content: Mixed layer illite—montmorillonite, and kaolinite most abundant; chlorite and true illite generally less abundant; true montmorillonite very rare.

Calculations on duration of sedimentation:

The only rates of deposition figures available in the table on Chart 34 which can possibly be applied to the Upper Ecca are those of 7 and 5 cm/1 000 years for sandy and silty clays of the upper continental slope and silty clays of the lower continental slope, respectively, of the Gulf of Mexico. Just what Kukal (1971) is referring to as the upper and lower continental slopes and just how nearly applicable these situations are to the Upper Ecca I cannot be sure. It would be most desirable to have numerous figures available on recent and present delta-front and pro-delta deposition.

At a rate of 6 cm/1 000 years, 60 m would be deposited in one million years (assuming no compaction occurred, i.e. that the porosity remained what it was at the original sediment surface: ± 80%).

General compacted thickness of Upper Ecca: 250 m.

Average primary porosity: 7%.

Original porosity at sediment surface: 80%.

If we assume that the reduction to 7% porosity was a result purely of compaction, then the present sediment thickness is ± 1/5 what it would have been assuming no compaction had occurred. Thickness of Upper Ecca (assuming no compaction) would then be: 1 250 m (nb. it is not necessary to compensate for montmorillonite—see notes on compaction of shales and muds on Chart 34—since for any porosity under about 15% the sediment would be ± 1/5 thickness of the uncompacted sediment).

At a rate of 60 m/one million years, the duration of Upper Ecca sedimentation would be in the order of 21 million years.

On Chart 35 the period between the Middle Ecca and the Tapinocephalus Zone equivalent is 13½ million years. (The positions on the Chart of the Middle Ecca and Tapinocephalus Zones are based on general world-wide palaeontological correlations.)

I have concluded, on the above calculation and on palynological evidence that no hiatus of any time significance occurred during Middle Ecca to Tapinocephalus Zone equivalent sedimentation.

The theoretically calculated 21 million years does not coincide exactly with the possible maximum of 13½ million years available on Chart 35. It would be remarkable if it did, considering the provisional nature of the correlation chart and the urgent need for more data on recent and present rates of deposition.

Middle Ecca. (In those areas of the northern Karroo where it is preceded and succeeded by normal Lower and Upper Ecca deposits.)
Thickness: Variable from 15 to 300 m.
Sediment type and environment of deposition: Typical sandstones, siltstones, shales and coals of deltaic and alluvial-plain sequences.
Porosity of sandstones: ± 12% in Welkom area grading down to ± 6% in Ladybrand (LA) area.
Duration of Middle Ecca sedimentation: Sediments accumulate far more rapidly in delta-plains than in shallow shelf seas (see table on Chart 34). It would be impossible, on presently available information, to calculate very precisely the duration of Middle Ecca sedimentation, but assuming there had been no major breaks in sedimentation it would probably have been well within one million years. However, on palynological evidence at least one major break appears to be present. I have exaggerated the probable duration of the Middle Ecca on Chart 35 for the sake of clarity.

Lower Ecca (of the Ladybrand (LA) area, and elsewhere in the northern Karroo).

Lower Ecca sediments and their inferred environment of deposition are much the same as those of the Upper Ecca. Without repeating the above calculation, it is possible to conclude that the Lower Ecca in its normal development occupies the full period between the Dwyka Tillite and the Middle Ecca.

Dwyka Tillite (of the northern Karroo area).

If the Pleistocene glaciation can be taken as a guide, the Dwyka Tillite, consisting of a very variable thickness of tillites, varves, sandstones, siltstones etc. deposited on an irregular glacially eroded basement, was most likely deposited in under one million years. The Pleistocene glacial period according to synthesis of all the most recent data (Evans in PTS '71) endured for ± 400 000 years. I have included the Dwyka Tillite (and supposed equivalents throughout Gondwanaland) on chart 35 as occupying two million years, rather than the possibly more likely ½ million years, to avoid cramping.

The tetrapod-bearing zones of the Beaufort Series (whole of Karroo Basin considered).

I am aware of no figures on rates of deposition of recent or present sediments which may offer a guide to the duration of the various zones of the Beaufort Series.

However, a consideration of the vertebrate assemblage known from each successive zone suggests the occurrence of definite time-intervals between them (except perhaps between the Cistecephalus and Daptocephalus Zones). Considerable advances in the general evolutionary status of the overall assemblage of each successive zone are evident. On the other hand, no evidence of evolutionary change is evident within the scope of any particular zone. Since only 15—20 million years are available for accommodating four zones it would appear most likely that each was of relatively short duration.

In Chart 35 I have included each as occupying two million years. This very likely represents an over-exaggeration.

5.5. Explanation of the variable emphasis directed towards the treatment of the various countries in the Permian correlation chart

Particular emphasis has been placed on the attempt to correlate strata of Gondwanaland with strata in the Northern Hemisphere.

As regards the Northern Hemisphere, all those sections including the important marine strata (particularly ammonite-bearing strata) and vertebrate-bearing strata have been included.

As regard Gondwanaland, most attention has been paid to Australia and southern Africa. Fairly comprehensive coverage of these areas has been attempted. For India, Antarctica and South America only a single section has been given in each case—the most complete and representative for that country (continent).

The reason for the emphasis placed on Australia is that marine strata are far more common than in any other Gondwana region. Ammonite-bearing beds of Tastubian to Roadian age occur and it is these that provide the essential basis for the correlation of Gondwana strata with the Northern Hemisphere (see Chart 30).

Southern Africa has been emphasised for two reasons. Firstly, virtually all known tetrapod vertebrate-bearing beds of the upper 2/5 or so of the Gondwana Permian occur in this region (particularly in the Karroo Basin of South Africa). These provide some basis for correlation with the tetrapod zones of the Russian platform. Secondly, my particular field of specialization involves the elucidation of the Permian microfloral sequence in South Africa. It is via this microflora that correlation is achieved with Australia and hence indirectly with the Northern Hemisphere.

5.6. Concluding remarks on the Permian correlation chart

I have attempted to take into consideration all available information in the compilation of this chart. It must be appreciated, however, that any correlation chart can, at best, only be as good as the available information. A very great deal of data must still be forthcoming before any such chart can be confidently regarded as accurately reflecting the true sequence of events that occurred.

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9. NOTES ADDED AT PROOF STAGE

Note 1

TEICHERT, C. April 1973 (letter). The University of Kansas, Paleontological Institute, Department of Geology, Lawrence, Kansas 66044, U.S.A.

Teichert has brought to my attention four very recent papers (which are unfortunately not yet available to me) relevant to the discussion on the Permian-Triassic boundary. Three of these were presented at the Permian-Triassic conference in Calgary, Alberta, 1971, the proceedings of which have now been published as vol. 20, No. 4 (December, 1972) of the Bulletin of Canadian Petroleum Geology. Two of the three conference papers were by Kummel and Teichert on the Permian-Triassic boundary of East Greenland and in the Tethys area, and the third by Kummel on lower Scythian faunas. The fourth reference is a major work (250 pages and numerous plates) on the Permian-Triassic boundary in North-western Iran (Kuh-e-Ali Bashi), to be published later this year in the Bulletin of the Museum of Comparative Zoology, Harvard University. Teichert writes that it "... will be the first fully palaeontologically documented discussion of the section in that area. Among other things we show that the ammonoid zonation introduced by the Russians for the 'Changhsingian' interval is based in part on erroneously identified genera and has to be greatly modified."

Note 2 (see Charts 29 and 35)

The Zaluch Group of the Salt Range should be extended to include the Chhidru Formation.

Note 3 (see Charts 28 and 29)

KUMMEL, B. (1972). The Lower Triassic (Scythian) Ammonoid *Otoceras*. *Bull. Mus. comp. Zool. Harv.*, 143(6), 365–417.

(a) Kummel recognises only one species, with two subspecies, within the genus *Otoceras* i.e. *Otoceras woodwardi woodwardi* (restricted to the Himalayan region) and *Otoceras woodwardi boreale* (restricted to the Arctic region).

(b) Kummel finds the Griesbachian Stage (of the Sverdrup Basin) and its four-fold ammonoid zonation proposed by Tozer unacceptable as a standard for international correlation. Teichert (1973, letter) agrees with Kummel. The disparity of views currently held is a reflection of the incomplete state of the information available. Further material and taxonomic studies will undoubtedly smooth out the problems.

Note 4 (refer to Chart 35).

McLACHLAN, I. R. and ANDERSON, Ann (1973) (see bibliography). McLachlan, I. R. 1973 (pers. comm.). Bernard Price Institute for Palaeontological Research, Witwatersrand University, Johannesburg.

The marine strata indicated for the Kalahari Basin and the Warmbad Basin (both in South West Africa) should be shifted down and included in the uppermost part of the glacial Dwyka Tillite equivalents. A marine horizon of equivalent age occurs in the uppermost sections of the Dwyka Tillite over at least the Southern two-thirds of the South African Karroo Basin.

An unconformity is thought to occur between the Nossob Sandstone and the 'Eurydesma Beds' in the Kalahari Basin.

10. ERRATA Referring to Part 1. (i.e. Charts 1–22 and accompanying text).

Page 4 References.
Add "(See chart 8)" after "Balme (1968)"

Chart 1 (a) Third last paragraph, bottom right hand corner.
Add "(See chart 8)" after "Gyronitan zone".
(b) Last paragraph, bottom right hand corner.
Replace "Bed 3 of Madagascar" by "Bed 5 of Madagascar".
(c) See note (nb.) in Cistecephalus zone title block.
Replace "actually included there" by "indicated in the correlation section thereof".
(d) Cynognathus zone: See notes referring to Euparkeria capensis.
Replace "bipedal" by "semi-bipedal".
Replace "hybernation" by "aestivation".
(e) Cynognathus zone. Invertebrate fauna.
Replace "millipedes" by "millepedes".
(f) Lystrosaurus zone; See notes referring to Myosaurus gracilis.
Replace "mouse sized" by "rat sized".

Chart 2 Red Beds; See notes referring to Hypsilophodontidae.
Replace "Both forms are the order of 4 inches long" by "The skulls of both forms are the order of 4 inches in length".

Chart 3 South America; Ischichuca Fm.
Replace "Masetognathus" by "Massetognathus".

Chart 5 (a) Add "Germ (Rhaet)" in the list indicating the geographic and stratigraphic distribution of the Tritylodontidae.
(b) Stratigraphic columns. China.

Delete West and South; switch Yunnan with Shansi and Sinkiang at heads of columns.

Chart 9 5th paragraph of explanatory notes. Delete "at present" from first line.

Chart 20 (a) Madagascar; Sakamena Group; Bed 5. Add "(See chart 8)" after "Gyronitan zone".

(b) Southern Africa; Middle Zambesi Valley etc.; Palaeontology; Ripple Marked Flags. Delete "No descriptions . . . presented, but" in second sentence.

Add at end of second sentence "Descriptive work on the flora is confined to two very brief and poorly illustrated papers–i.e. Seward, A.C. 1921 (See Bibliography) and Walton, J. 1926; Additions to our knowledge of the fossil flora of the Somabula Beds, Southern Rhodesia. *Trans. geol. Soc. S. Afr.* 29: 137–140.

Chart 21 (a) See note (c) beneath key. Replace "both plants and invertebrates occur" by "both plants and vertebrates occur".

(b) Drakensberg lavas. Replace "dolerite feeders" by "Karroo dolerites (possible feeders)".