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The Gondwanan Carboniferous-Permian Boundary Revisited: New Data from Australia and Argentina

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Abstract

The identification and correlation of the Carboniferous-Permian (Gzhelian-Asselian) boundary within the sedimentary sequences of Gondwana has always been a topic of debate. Type latest Carboniferous and earliest Permian marine sequences are characterised by warm tropical faunas and come from the Uralian Region of Russia and Kazakhstan. Faunas include conodonts and fusulinid foraminiferids which are prime tools for correlation. Such faunal groups are absent from most Gondwanan sequences where reliance for correlations must be placed primarily on brachiopods, bivalve molluscs and palynology. The Western Australian marine sequences, with their contained ammonoids, provide a pivotal link for the dating and correlating of Early Permian Gondwanan sequences with those of the type regions and their palynostratigraphical record is essential for trans-Australian correlations and correlations elsewhere throughout Gondwanaland.

New data from the fully cored DM Tangorin DDH1 bore hole, drilled in the Cranky Corner Basin, New South Wales, Australia, reveals a sequence of descending faunal zones. The stratigraphically highest zone with *Eurydesma cordatum*, encompasses the Late Sakmarian (Sterlitamakian). The middle zone with *Tomiopsis elongata*, *Sulciplica crassa* and *Trigonotreta tangorini* straddles the Sterlitamakian-Tastubian boundary, with the palynomorphs *Pseudoreticulatispora pseudoreticulata* high in the zone and *Granulatisporites confluens* low in the zone. An impoverished fauna with *Trigonotreta* sp. nov., low in the *Granulatisporites confluens* Zone, is probably of latest Asselian or Tastubian age.

Significant new data from Argentina has revealed marine faunas from below the occurrence of *Granulatisporites confluens*. These are considered to be of Asselian age. Outcrops of the Tupe Formation, with a marine fauna, at La Herradura Creek in the western Paganzo Basin, San Juan Province, are best regarded as being of mid to late Asselian age. The Tupe Fauna has been recognised as the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone. Previously, this fauna was considered to be of Late Carboniferous or Stephanian age. Three faunal associations are known from the Río del Peñón Formation, Río Blanco Basin, La Rioja Province. The middle assemblage with *Tivertonia, Costatumulus, Kochiproductus* and *Trigonotreta*, appears to correlate well with the Tupe Formation fauna. The lower assemblage, with *Streptorhynchus, Etherilosia, Costatumulus, Trigonotreta* and a punctate spiriferid, as well as indeterminate productids, is probably of Early Asselian age. The youngest assemblage includes a species of *Rhynchopora* that is close to *Rhynchopora australasica* from the latest Asselian-early Tastubian of Western Australia.

The marine biostratigraphical data from Argentina has enabled a much greater understanding of the earliest Permian marine faunas to be achieved - a story that is apparently absent from the other cold and cool temperate regions of Gondwana.

Key words: Gzhelian, Asselian, Gondwana, Australia, Argentina.

Introduction

The recognition of the Carboniferous-Permian boundary for the Gondwanan supercontinent has been a matter of debate for many years. During the late nineteenth century and well into the twentieth century the term Permo-Carboniferous was widely applied to sequences close to the presumed boundary. The marked provincialism globally of late Palaeozoic faunas and floras is the prime reason for difficulties of global correlation and boundary recognition. With refinement of the boundary in the southern Urals and more recent work in the Gondwanan region, the boundary, in the latter region, has been more tightly constrained. This report draws on new data from the eastern Australian Permian faunal and palynological records and recently described and revised faunal and palynological data from the Pre-Cordilleran basins of Argentina. Argentina appears to offer the one and only region of Gondwanaland where a complete marine sequence of zones may straddle the Carboniferous-Permian boundary.

The Carboniferous-Permian Boundary

The base of the Asselian Stage (the earliest stage of the Permian System) has been biostratigraphically defined by key conodont and fusulinid species. The first appearance of the conodont *Streptognathodus isolatus* and the fusulinid *Sphaeroschwagerina aktjubensis* (= *vulgaris*) as well as a suite of distinctive ammonoid genera (*Boesites, Daixites, Glaphyrites, Artinskia, Svetlanoceras, Prostacheoceras* and *Prothalassoceras*) indicate the boundary (e.g., see Davydov et al., 1997; Mei et al., 1999; Bogoslovskaya et al., 1995, Lucas et al., 2001). The global stratotype section and point for the base of the Asselian (and hence the Permian) has been established in western Kazakhstan (Davydov et al. 1998).

The oldest Gondwanan Permian marine sequences totally lack species of conodonts and fusulinid foraminiferans and the critical ammonoid species are also lacking. The Western Australian sequences possess the most complete, although sporadic, occurrences of Permian ammonoids for global correlations (see summaries by Archbold, 1998a, 1999) although recognition of pre-Tastubian (pre-Sakmarian) species has not been possible in Australia. Possible Asselian *Glaphyrites* occurs in southern Africa and South America (see Archbold 2001) but such occurrences require modern analysis. These Gondwanan absences have resulted in much discussion in the past as to the recognition of the base of the Permian in Gondwanaland between zonal schemes based on palynomorphs and marine faunas (cf. Balme, 1980; Archbold, 1982). Furthermore, significant errors of correlation of eastern Australian provincial marine faunal zones has further hampered the resolution of eastern Australian and Gondwanan correlations (e.g., cf. discussions in Waterhouse, 1987, 1989 and Briggs 1998).

Considerable advances in Gondwanan biostratigraphical schemes and global correlations have been achieved in the last ten years, particularly for the Australian region, although questions remain to be answered. Comprehensive marine faunal zonation schemes have been proposed for Western Australia (Archbold, 1993, 1998a, 1998b) and eastern Australia (Briggs, 1998) using brachiopods primarily, but also other groups of fossils. Palynological schemes have also been revised and studied in detail for Western Australia (Backhouse, 1993, 1998; Mory and Backhouse 1997; Apak and Backhouse, 1999; Eyles et al. 2002) and eastern Australia (Jones and Truswell, 1992; Price 1997). Integrated studies of marine faunas and palynological data from subsurface sections have been undertaken (Foster and Waterhouse, 1988; Archbold, 1995; Archbold and Hogeboom, 2000). A comprehensive summary of many aspects of Australian, Gondwanan and global correlations has been published (Foster and Archbold, 2001) and earliest Permian sequences have also been reviewed in detail (Archbold, 2001). Further pertinent data from eastern Australia (the Cranky Corner Basin) and Argentina (the Pre-Cordilleran basins) is presented herein in order to further clarify the Carboniferous-Permian boundary and the recognition of Asselian faunal zones within Gondwana.

The Australian Data - Cranky Corner Basin

A fully cored bore hole (DM Tangorin DDH1) was drilled at the Great Greta Colliery in the Cranky Corner Basin (Fig. 1, Table 1) near Branxton, New South Wales, between February and April 1995. Full details of the bore hole, the geology of the Cranky Corner Basin and the history of work in the basin are provided in Facer and Foster (2003) and are not repeated herein. Drilling commenced in the Greta Coal Measures and continued down through the Permian marine Dalwood Group and terminated in the Carboniferous Mount Durham Tuff at a depth of 506 m. The Dalwood Group, in descending order, consists of 45.26 m of the Billy Brook Formation, 50.64 m of the Cranky Corner Sandstone, 130.31 m of the Beckers Formation and 82.05m of the Tamby Creek Formation. The Billy Brook Formation consists of sandstones and siltstones with a 7.23 m pebble/granule conglomerate at its base indicating prodelta and shelf environments of deposition. The Cranky Corner Sandstone consists of richly fossiliferous grey-green, very fine to medium sandstone with minor siltstone reflecting lower to upper shoreface environments. The Beckers Formation is silt rich with fine sandstone and reflects shoreface and shelf environments. The Tamby Creek Formation, with thick basal conglomerates is dominated by volcanic detritus and ash fall deposits of lateritic composition indicating deposition close to active volcanism.

McClung (1975, 1980) summarized much of the earlier work about the biostratigraphy of the Dalwood Group in the Cranky Corner Basin prior to the drilling of the DM Tangorin DDH1. He concluded that 'as yet microfloras are of limited value' (McClung, 1980, p. 362.)

This summary reviews the biostratigraphical data from marine faunas and palynology as provided in the studies by Archbold (2003) and Balme and Foster (2003). Much of the key data is included in table 1 and selected marine faunal elements are illustrated in figure 2. Inferred ages are provided in tables 1 and 2.

Early Permian (late Asselian? - Sakmarian, perhaps extending into the earliest Artinskian = Aktastinian) marine invertebrate faunas from DM Tangorin DDH1 are assigned to three assemblages. In descending stratigraphical order they are, firstly the *Eurydesma cordatum* and *Keeneia platyschismoides* Zone of the upper Cranky Corner Sandstone of Sterlitamakian age, perhaps extending into the Aktastinian. This zone occurs above the first appearance datum (FAD) of *Microbaculispora trisina* and hence occurs in the palynological Zone APP22. Beneath the *Eurydesma cordatum* marine zone, in the lower Cranky Corner Sandstone and the upper Beckers Formation is the zone of *Tomiopsis elongata* and *Trigonotreta tangorini* of early Sterlitamakian age possibly straddling the Tastubian-Sterlitamakian boundary and associated with the palynological zone AAP21 above the FAD of *Pseudoreticulatispora pseudoreticulata*. Below the FAD of *Granulatisporites confluens* (APP122) in the bore core, is a poorly known zone of *Trigonotreta* sp., a species characterised by fine and relatively simple costae. This

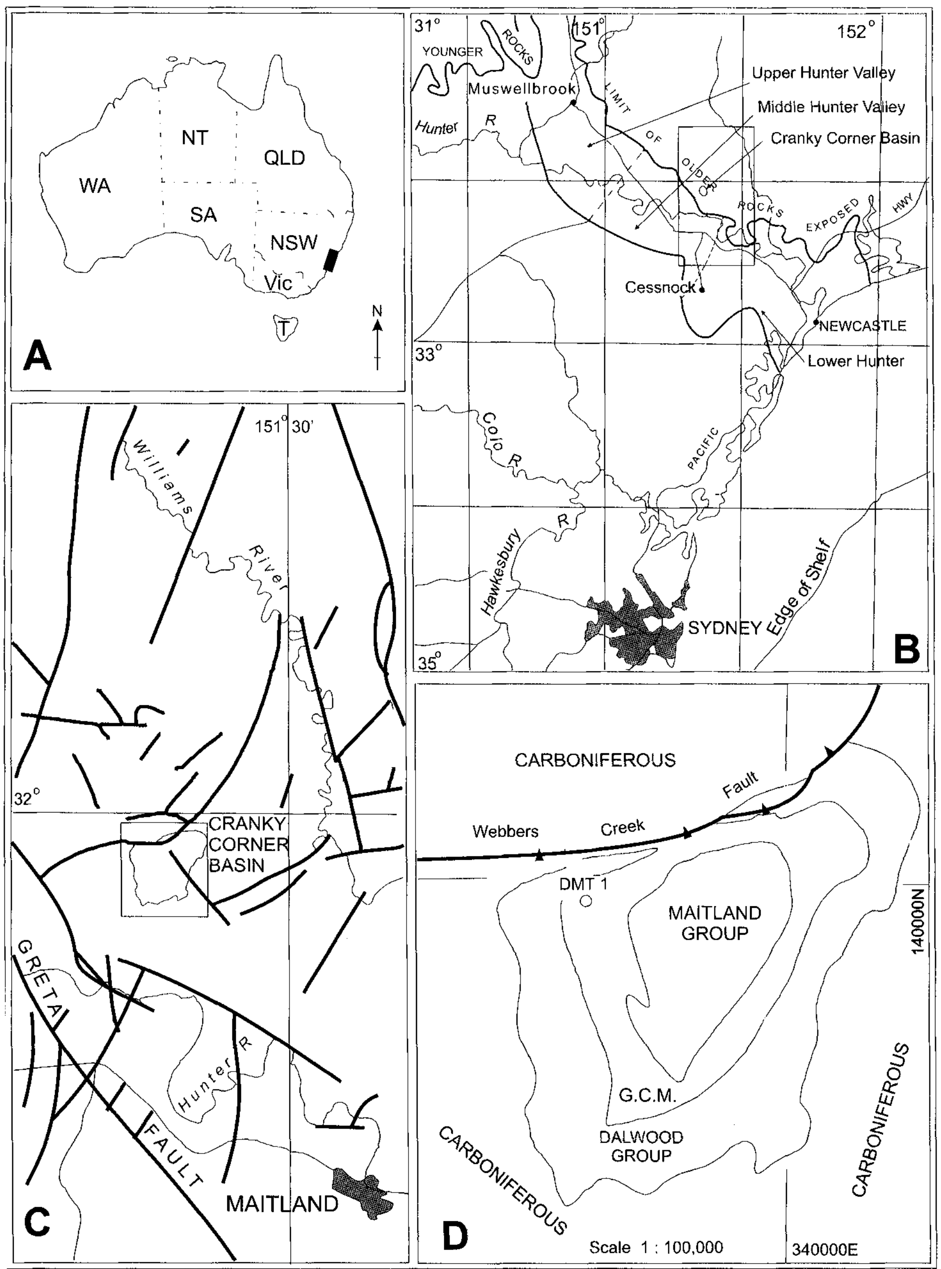
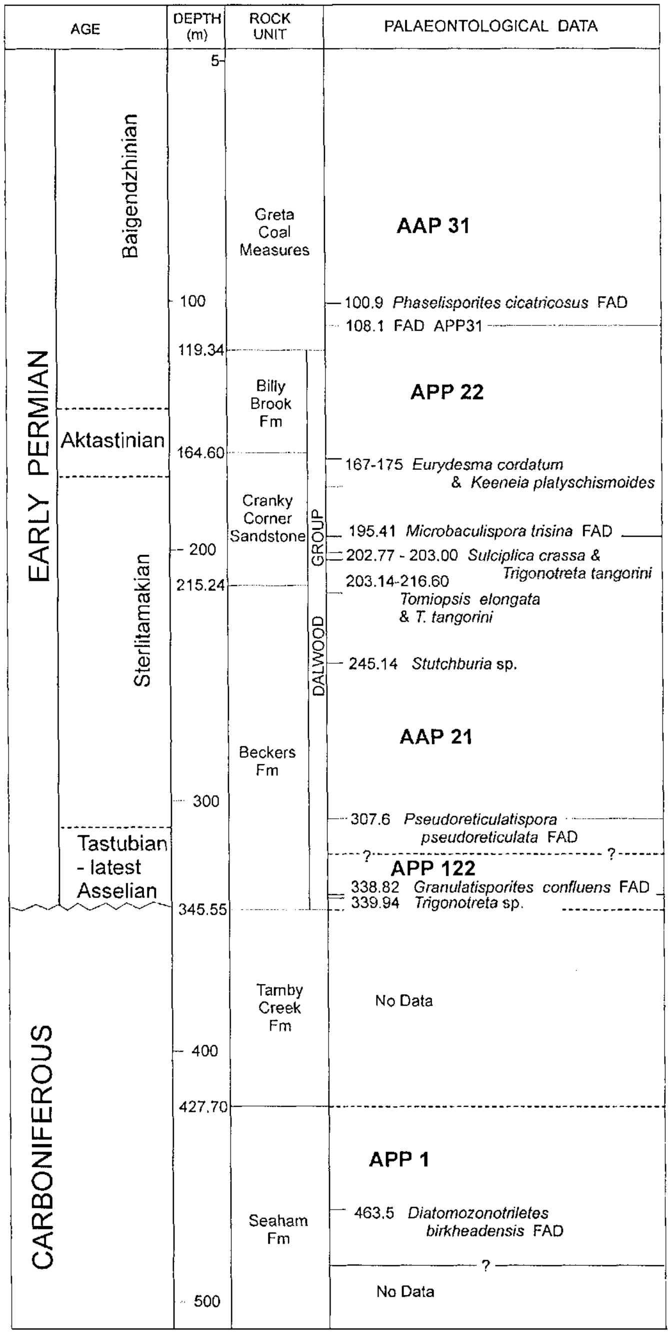


Fig. 1. Location diagrams for Cranky Corner Basin and DM Tangorin 1 drill hole.

Table 1. Estimated ages of key palaeontological events recorded from DM Tangorin 1.



species is apparently late Asselian or earliest Tastubian in age in view of its stratigraphical position. Complete faunal lists for each zone from the core material are provided in table 3.

Although it is often assumed that macrofossils are absent from thick intervals in basin sequences (Eyles et al., 2002 p. 315), richly fossiliferous sequences with abundant macro and micro fossils can provide a refined control over age determinations. The well constrained faunal and palynological data from the western Australian Carnarvon Basin subsurface sections (Archbold and Hogeboom, 2000) and the revised early Permian interpretations of the Carnarvon Basin stratigraphy described by Mory and Backhouse (1997) have been utilised to refine the Tangorin data in table 1 and the subsequent age assignments.

The Cranky Corner biostratigraphical data significantly reinforces the importance of integrated zonal schemes using a range of palaeontological data. The data examined revealed a major stratigraphical break in the Cranky Corner Basin sequence with the critical Carboniferous-Permian boundary and a substantial Asselian sequence missing. Asselian marine faunas are largely missing from the Gondwanaland supercontinent and the palynological record is seldom preserved (Jones and Truswell, 1992). The inferred global ages and correlations of the Gondwanan palynological zonal schemes are highly dependent on ages assigned to marine faunas (Archbold, 1982, 1995, 1999; Foster and Waterhouse, 1988; Mory and Backhouse, 1997; Jones and Truswell, 1992).

The Tangorin data has reinforced one somewhat surprising conclusion. The Allandale Formation fauna of the Hunter Valley region of the northern Sydney Basin (a correlative of the Cranky Corner Sandstone in this study) has traditionally been correlated with Tastubian faunas of Western Australia (Dickins, 1957, 1968; Runnegar, 1969; Archbold, 1982; Archbold et al., 1993) but palynological data would suggest that a Sterlitamakian correlation may be preferable as in Archbold (2001). The problem is one of faunal similarity (i.e., if the faunas are correlated, the key palynological species occur earlier in eastern Australia than western Australia) or palynological similarity (in which case the faunas appeared, or continued, later in eastern Australia than western Australia).

The Argentinian Data – the Pre-Cordilleran Basins

In view of the apparent absence of Carboniferous-Permian marine boundary faunas and significant Asselian marine faunas in Australia, India, Antarctica, southern Africa and the peripheral Gondwanan terranes, it is to South America that one must turn to in the hope of defining the period boundary for Gondwanaland.

Recent and ongoing work in the Pre-Cordilleran basins of Argentina (Fig. 3) has continued to document the extensive Late Palaeozoic sequences in the basins (Archangelsky, 1987, 1996). Palynological zones are well developed for these sequences (Vergel and Fasolo, 1999; Cesari and Gutierrez, 2000) and correlation with sequences elsewhere in Gondwanaland can be achieved

(Cesari and Gutierrez, 2000, p. 130). We would consider that the *Granulatisporites confluens* Zone of Western Australia (and widespread throughout Gondwana) is predominantly of early Sakmarian age (i.e., Tastubian, possibly extending down into the late Asselian) as indicated by a series of Australian studies (Foster and Waterhouse, 1988; Archbold, 1995; Archbold and Hogeboom, 2000) and reviews (Archbold 1999, 2001; Foster and Archbold, 2001). This would place the Gondwanan Carboniferous-Permian boundary lower than the base of the *G. confluens* Zone which, in turn, has implications for the age of marine faunas below the zone in Argentina and their correlatives.

Sequences in the Argentine pre-Cordilleran basins are tectonically and structurally complex, with faulting, but the sections from the Paganzo and Río Blanco Basins utilised in the present study are not faulted and hence act as reliable conformable reference sections.

Paganzo Basin

The brachiopod fauna and the full details of the stratigraphical section of the Tupe Formation in the Western sector of the Paganzo Basin ('Guandacol embayment') has been recently redescribed and reviewed (Cisterna at al., 2002a; Archbold and Simanauskas, 2001). The fauna includes *Streptorhynchus inaequiornatus, Tivertonia jachalensis, Kochiproductus* sp., *Costatumulus* sp., *Coronalosia argentinensis, Tupelosia paganzoensis, Trigonotreta pericoensis, Septosyringothyris* sp. aff. *S. jaguelensis* and *Crurithyris?* sp. The overall aspect of the fauna is Permian in character with some forms showing an ancestral morphology to well known Sakmarian Gondwanan species (as discussed for *Trigonotreta* by Cisterna et al., 2002b). We argue for an Asselian age for this *Tivertonia jachalensis-Streptorhynchus inaequiornatus* fauna which previous authors have referred to the Late Carboniferous (Sabattini et al., 1990; Gonzalez, 1997) and to the Stephanian (Tabaoda 1997) or Kasimovian (Kelly et al., 2001).

The Tupe fauna occurs some 90 metres above the top of the palynological zone and macroflora of the *Nothorhacopteris, Botrychiopsis, Ginkophylum* (NBG) Phytozone, traditionally regarded as extending into the Late Carboniferous (Archangelsky, 1996; Vergel and Fasolo, 1999). Some 20 metres above the Tupe fauna is a palynological assemblage of the *Granulatisporites confluens* Zone, indicating a Tastubian (or no older than latest Asselian) age. These palynological data points are therefore also consistent with a mid to late Asselian age for the fauna.

Río Blanco Basin

The section of the Río del Peñón Formation in the Rincon Blanco Syncline, Río Blanco Basin, has been considered to be a para-stratotype for the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone (Sabattini et al., 1990). Brachiopod faunas and details of the stratigraphical section of the Río del Peñón Formation have been described by Cisterna and Simanauskas (2000). Three faunas were recognised by the authors. The lowest fauna occurs in black shales immediately above beds with the NBG Phytozone (arguably at this locality of latest Carboniferous age - see Cisterna and Simanauskas, 2000, p. 132). This lowest fauna includes *Streptorhynchus* sp., *Etherilosia* sp., (= *Dyschrestia* sp. of Cisterna and Simanauskas, 2000), *Costatumulus* sp. A, a somewhat finely costate species of *Trigonotreta*, a punctate spiriferinid and *Orbiculoidea* sp. This fauna requires further study but is of Permian aspect and is regarded as being early Asselian in age because of its stratigraphical position below a fauna

Table 2. Proposed ages and correlations for the Cranky Corner Basin sequence and those of Argentinian Pre-Cordilleran basins.

	STAGE Substage/Horizon	CRANKY CORNER BASIN	EAST AUSTRALIAN PALYNOLOGY	PAGANZO BASIN		RIO BLANCO BASIN		
EARLY PERMIAN	Sterlitamakian	Cranky Corner Sandstone	APP22 *M. trisina*	Patquia Formation				Rio Del Penon Fm.
EARLY PERMIAN		Cranky Corner Sandstone	APP21 *Pseudoreticulatispora pseudoreticulata*	Patquia Formation				Rio Del Penon Fm.
EARLY PERMIAN	SAKMARIAN Tastubian	Beckers Formation	APP122 *Granulatisporites confluens*	? ? *Granulatisporites confluens*	Tupe Formation		?	Rio Del Penon Fm.
EARLY PERMIAN	Shikhan	Beckers Formation	APP122 *Granulatisporites confluens*	*Granulatisporites confluens*	Tupe Formation	3	*Rhynchopora* sp.	Rio Del Penon Fm.
EARLY PERMIAN	ASSELIAN Uskalyk			*Tivertonia-Streptorhynchus* Zone	Tupe Formation	2	*Tivertonia - Trigonotreta*	Rio Del Penon Fm.
EARLY PERMIAN	Sjuren				Tupe Formation	1	*Trigonotreta - Etherilosia*	Rio Del Penon Fm.

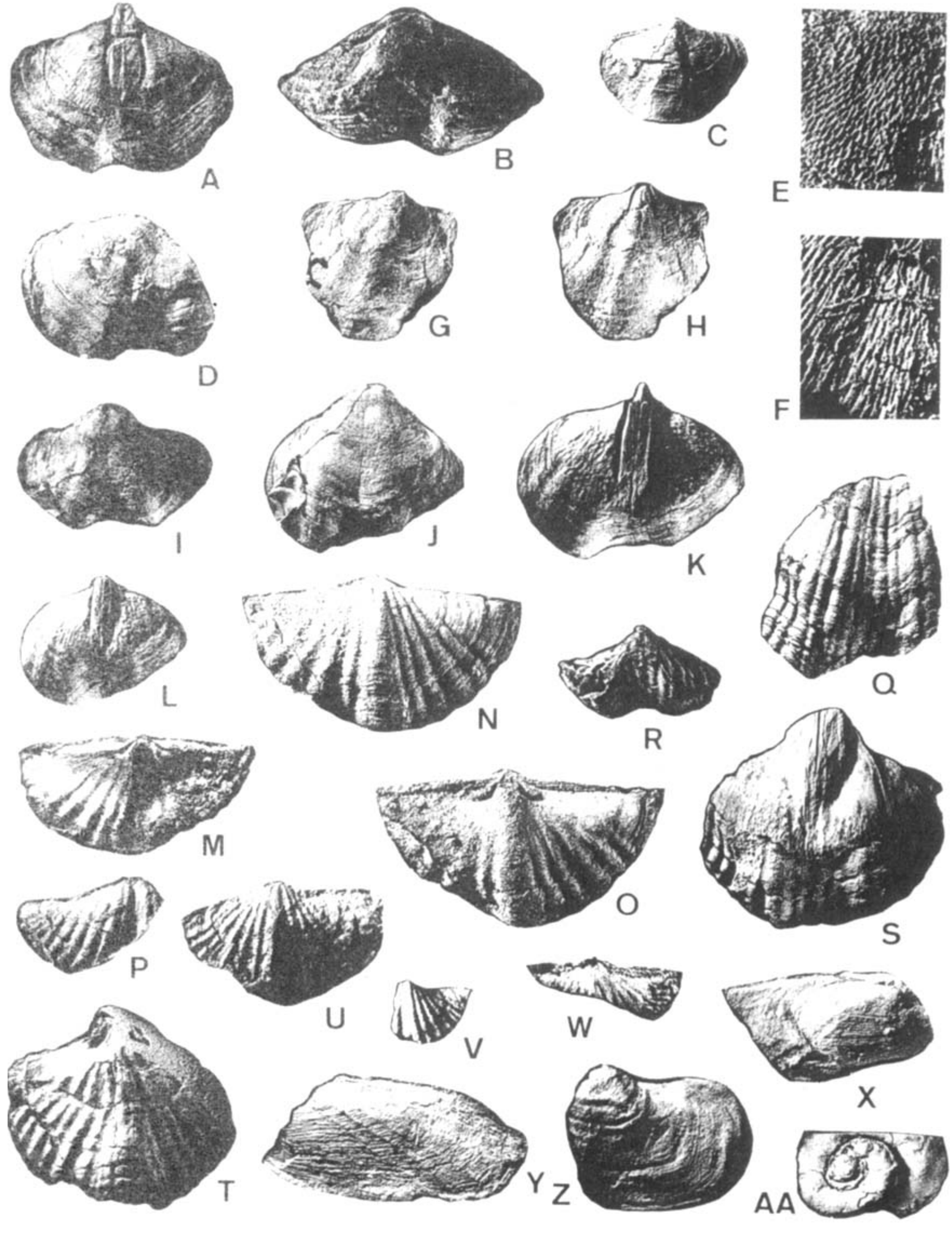


Fig. 2. (A-L) *Tomiopsis elongata* (McClung and Armstrong, 1975). (A-F) CPC35324, internal mould of shell in ventral and anterior views, x 1.5 and 1.6, latex cast of dorsal exterior, x 0.8, latex cast of ventral exterior, x 1.3 and micro-ornament, x 5.5. (G-H) CPC 35325, latex cast of dorsal valve exterior and dorsal valve internal mould, x 1.7. (I-L) CPC 35326, latex cast of ventral valve exterior in posterior and ventral views, x 1, internal mould of ventral valve in ventral views, x 1.1 and 0.8. (M-P) *Sulciplica crassa* Clarke 1990. (M-O) CPC 35341, latex cast of dorsal interior, x 0.8, latex cast of dorsal exterior, x 1.2, dorsal internal mould, x 1.2. (P) CPC 35342, latex cast of ventral exterior, x 0.8. (Q-V) *Trigonotreta tangorini* Archbold 2003. (Q-T) CPC 35327, holotype, latex cast of portion of ventral valve exterior, x 1.3, interior mould of shell in anterior, ventral and dorsal views, x 0.8 and 1.3. (U) CPC 35331, dorsal valve, x 1.2. (V) CPC 35330, latex cast of ventral exterior, x 0.8. (W) *Trigonotreta* sp. nov., CPC 35332, incomplete dorsal valve internal mould, x 0.8. (X-Y) *Stutchburia* sp. cf *S. variabilis* Dickins, 1957. (X) CPC 35334, right valve, x 1.3. (Y) CPC 35333, latex cast of left valve exterior, x 0.8. (Z) *Myonia* sp., CPC 35336, left valve, x 0.8. (AA). *Keeneia ocula* (Sowerby, 1838), CPC 35337, internal mould of juvenile shell, x 1.6. All specimens from Beckers Formation except for M-P, X and Z from Cranky Corner Sandstone.

that is correlatable with the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* fauna of the Paganzo Basin.

About 250m above the lowest fauna, the middle fauna occurs and is characterised by *Tivertonia jachalensis, Kochiproductus riojanus, Costatumulus* sp. B, *Trigonotreta riojanensis* and *Orbiculoidea* sp. This fauna is considered to be a correlative of the *Tivertonia jachalensis Streptorhynchus inaequiornatus* fauna and hence is considered to be of middle Asselian age, possibly extending into the late Asselian. It is of note that *Costatumulus* sp. B is closely comparable in terms of costae and rugae to the *Cancrinella* sp. of Kelly et al. (2001) from near Mount King, Alexander Island, Antarctic Peninsula, which is probably of comparable age. A study of the numerous *Costatumulus* species of Argentina, including *Costatumulus amosi* described by Taboada (1998), would be well worthwhile given the rapid evolutionary changes of species of linoproductidines.

Close to the top of the sequence of the middle member of the Río del Peñón Formation, the third fauna occurs, which consists of *Neochonetes pegnonensis, Costatumulus* sp. C, *Rhynchopora* sp. and *Septosyringothyris jaguelensis*. The *Rhynchopora* sp. is very close morphologically to *R. australasica* Archbold (1995) from the latest Asselian or earliest Tastubian of Western Australia, a species that occurs low in the *Granulatisporites confluens* Zone. *Rhynchopora* is a brachiopod genus that has a distinctive distribution in late Asselian and Tastubian Gondwanan faunas (Angiolini, 1995; Archbold et al., 1996; Archbold, 2001).

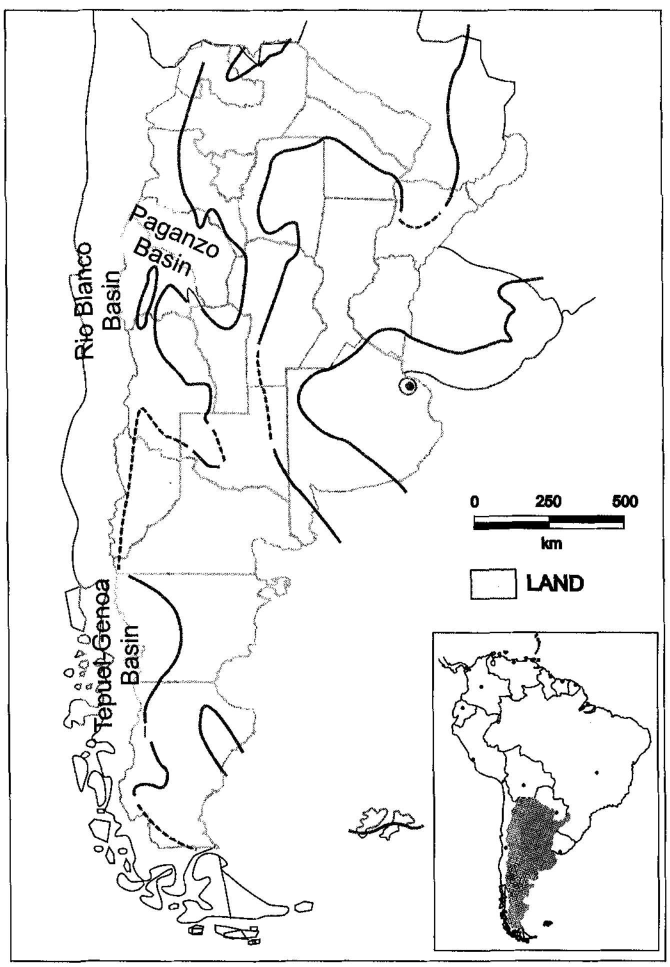


Fig. 3. Pre-Cordilleran basins of Argentina.

The Río Blanco Basin appears to have the most complete Asselian marine record of Argentina and Gondwanaland. Suggested correlations of the Pre-Cordilleran basins with the Cranky Corner Basin of eastern Australia are provided in table 2. Additions to this record appear to occur in the El Paso Formation of the Calingasta Uspallata Basin where a fauna of latest Carboniferous age may straddle the Carboniferous-Permian boundary (Simanauskas and Cisterna, 2001).

Conclusions

The study of the Early Permian brachiopod faunas of Gondwana sequences highlights the need for ongoing work in order to correctly identify the earliest Permian marine faunas and the Carboniferous-Permian boundary in Argentina and hence Gondwanaland. Substantial gaps in the stratigraphical and marine palaeontological record occur throughout most other regions of Gondwanaland. Integrated studies of marine faunas with the palynological record are required to firstly date that record and secondly to strengthen Gondwanan wide correlations. Ages for the Gondwanan record and particularly that of Argentina must be based on regions with clear stratigraphy, reference to places such as Western Australia with a somewhat more complete ammonoid record and peripheral Gondwanan regions (those with 'transitional' faunas that link faunal provinces in the peri-Gondwanan regions).

Table 3. Faunal zones of the Early Permian of the Cranky Corner Basin.

FAUNAL ASSEMBLAGE	SPECIES PRESENT
3. *Eurydesma cordatum - Keeneia platyschismoides* Zone	*Pyramus laevis* *Eurydesma cordatum* *Myonia sp.* *Stutchburia sp. cf S. variablis* *Megadesmus? sp.* *Keeneia platyschismoides* *Sulciplica crassa* *Trigonotreta tangorini*
2. *Tomiopsis elongata* Zone	*Pyramus? sp.* *Stutchburia sp. cf S. variablis* *Keeneia ocula* *Tomiopsis elongata* *Trigonotreta tangorini* *Hyolithes sp.* *Paraconularia sp.*
1. *Trigonotreta* sp. Zone	*Trigonotreta sp.*

The conclusions of the present authors are that the Pre-Cordilleran basins of Argentina possess the best known, most complete sequence of earliest Permian faunas for Gondwanaland and hence these basins are the preferred region to establish a regional stratotype in Gondwana for recognising the marine Gondwanan Carboniferous-Permian boundary.

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