BMR Journal of Australian Geology & Geophysics, 12, 119–144

Application of sequence stratigraphic concepts to Middle Cambrian phosphogenesis, Georgina Basin, Australia

P.N. Southgate[1] & J.H. Shergold[1]

The stratigraphic and spatial distributions of phosphatic and organic-matter rich Middle Cambrian sediments of the Georgina Basin are outlined in terms of sequence stratigraphic concepts. This approach has permitted an integrated analysis of Middle Cambrian depositional patterns and their time constraints. It has also provided insights into aspects of the basin's structure, the timing of subsidence of its primary components, and frequency of relative sea level fluctuations. Middle to early Late Cambrian sediments of the Georgina Basin are interpreted to occur in two stratigraphic sequences. In each sequence phosphorites, phosphatic limestones and organic-matter rich shales comprise a suite of repeating lithofacies restricted to retrogradational parasequence sets of the transgressive systems tract. The position of facies within each transgressive systems tract depends on relative sea level, palaeogeography and palaeotectonics. In sequence 1 (early Middle Cambrian), phosphogenesis is related to gradual transgression of a continent with irregular palaeotopography. Sequence 1a is interpreted to be of local significance, related to early subsidence of the Mt Isa Block during the late Ordian to early Templetonian. A rapid fall in relative sea level terminated sediment accumulation in sequence 1 and led to the development of a subaerial exposure surface. Sediments of the transgressive systems tract in stratigraphic sequence 2 are of late Templetonian to early Undillan age. Deposition in sequence 2 ceased in the Mindyallan. Rocks of the transgressive systems tract occur in three retrogradational parasequence sets. Recognition of sequence boundaries has helped clarify lateral biofacies, leading to improved reconstructions of the palaeogeographic distribution of the phosphorites and organic-matter rich shales.

Introduction

In this paper we explore the application of sequence stratigraphic concepts to explain Middle Cambrian phosphogenetic events in the Georgina Basin, northwestern Queensland and east central Northern Territory (Figs 1, 2). In so doing, we reassess the correlation of lithostratigraphic units throughout the basin, re-evaluate the currently available biochronology (Figs 3, 4), suggest revised palaeogeographic models, and conclude with palaeotectonic observations on the structure of the basin.

The Georgina Basin is a broad intracratonic depression covering some 325 000 km^2 of central northern Australia (Fig. 1). The eastern and northern margins abut Proterozoic rocks of the Mt Isa Block and Lawn Hill Platforms, while to the south and west the basin sequence is bounded by Proterozoic rocks of the Tennant Creek and Arunta Blocks. Rather than defining a palaeogeographic margin, the present outline is an erosional remnant of a much larger early Palaeozoic sedimentary province that once covered much of central and northern Australia.

Subsidence in the Georgina Basin followed a Late Proterozoic phase of crustal extension, now represented by volcanics of the Antrim Plateau Basalts and their correlatives (Lindsay & others, 1987). Although sediments of Early Cambrian age are found in the south (Walter & others, 1979), it was not until the Middle Cambrian that marine depositional environments prevailed throughout the basin (Shergold & Druce, 1980). A suite of anomalous chemical sediments locally rich in phosphate, organically-derived carbon, and noble metals was deposited during this Middle Cambrian transgression (Shergold, 1985; Donnelly & others, 1988). Eighteen phosphate deposits have been recognised in this transgressive sequence. The associated organic-matter rich shale facies has a total organic content (TOC) of 1–16%.

[1] Onshore Sedimentary & Petroleum Geology Program, Bureau of Mineral Resources, Geology & Geophysics, GPO Box 378, Canberra ACT 2601

Whitehouse (1936) and Öpik (1956, 1960, 1961 & 1979) provided the initial stratigraphic subdivision of the basin. It was based on biostratigraphic concepts, and resulted in a multitude of stratigraphic units which frequently lacked a clearly defined lithostratigraphic identity. De Keyser (1973) clearly demonstrated difficulties in the biostratigraphic classification, but a lack of detailed sedimentological information resulted in similar difficulties with his lithosome-based subdivisions. As a result, phosphate deposits of the Georgina Basin were until 1983 regarded as uniformly Templetonian in age, and placed in the Beetle Creek Formation (Russell, 1967; de Keyser & Cook, 1973). However, there is a laterally persistent erosion surface on top of the Thorntonia Limestone, and it has correlatable lithofacies associated with the Beetle Creek Formation in the type areas of these formations (Southgate, 1983, 1986a,b,c, 1988; Fig. 3). This raises doubts about the contemporaneity of phosphogenesis. An integrated sedimentological and palaeontological study of selected Middle Cambrian sediments investigated the implications of this disconformity to models of phosphogenesis. Although detailed biostratigraphic, lithostratigraphic and petrographic studies showed phosphorites of three different ages in a mosaic of repeating lithofacies and biofacies (Shergold & Southgate, 1988; Shergold & others, 1989), poor regional outcrop and the lack of data suitable for seismic stratigraphic interpretation prevented the use of this work in a regional model. However, using the predictive model of sequence stratigraphy (e.g. Van Wagoner & others, 1988; Sarg, 1988), data from geographically isolated areas have been integrated into a depositional model with implications for basin architecture and subsidence history.

Sequence stratigraphic concepts

Lack of outcrop continuity and the complexities of facies patterns often inhibit the regional correlation of units in sedimentary basins. Even though facies models constitute a predictive tool for interpreting facies patterns, they do not provide integrated models for basin development. Furthermore, difficulties arising from possible faunal element facies control, lack of fauna in some facies, and the possibility that faunal resolution is

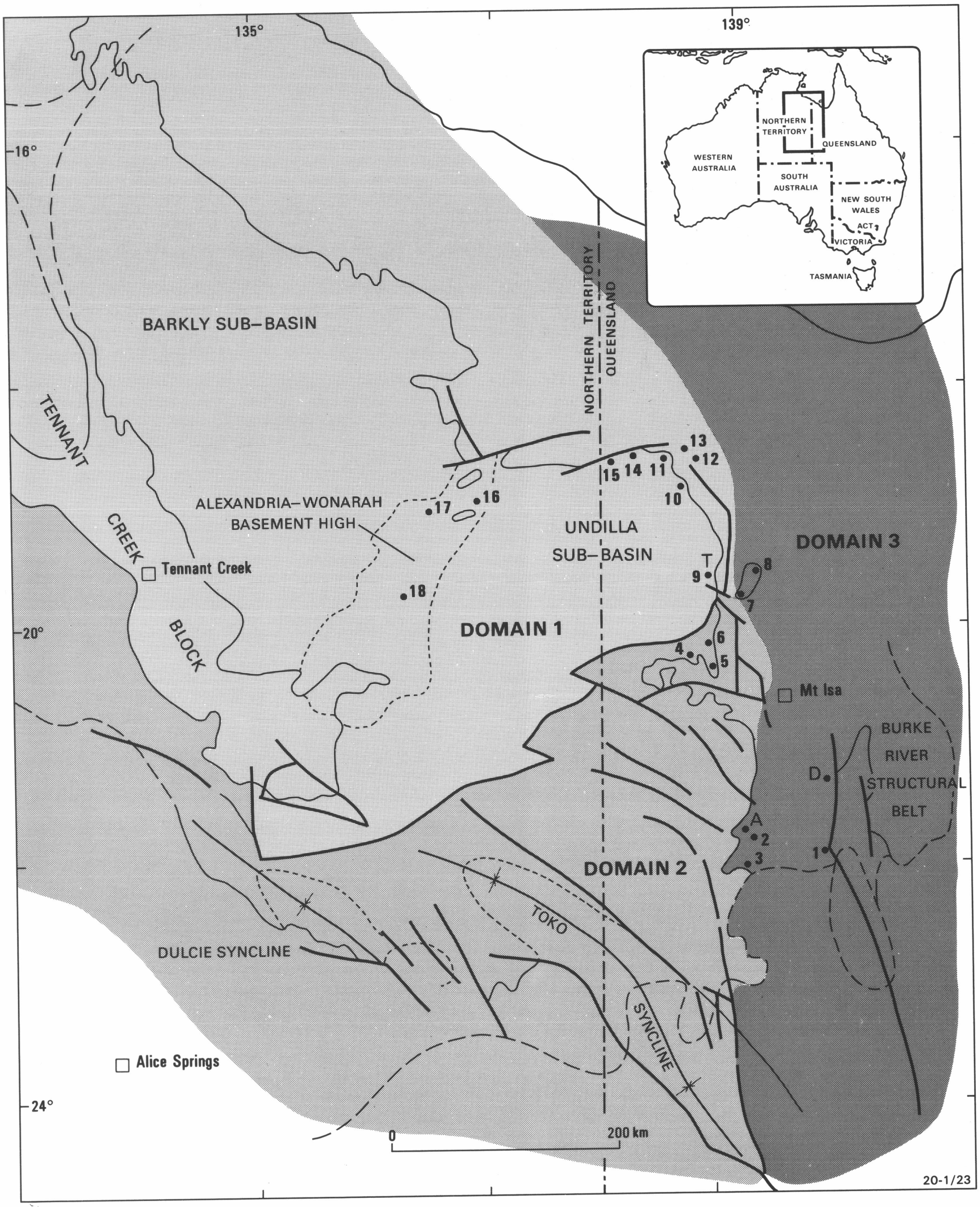


Figure 1. Principal structural features of the Georgina Basin, location of the respective domains, and geographic distribution of the phosphate deposits.
Numbered phosphate deposits: 1 Phosphate Hill, 2 Ardmore, 3 Quita Creek, 4 Lily Creek, 5 Sherrin Creek, 6 Yelvertoft, 7 Lady Annie, 8 Lady Jane, 9 D Tree, 10 Riversleigh, 11 Babbling Brook Hill, 12 Phantom Hills (Lawn Hill), 13 Mount Jennifer, 14 Mount O'Connor, 15 Highland Plains, 16 Alexandria, 17 Alroy, 18 Wonarah.

not at an appropriate scale to recognise genetically-related sedimentary units, have always hampered the correlation of sedimentary rocks on a regional scale.

Sequence stratigraphic interpretation of seismic data provides a predictive framework for combining lithostratigraphic and biostratigraphic data into regional models for basin development. In sequence stratigraphy, a complex sedimentary package is divided into chronostratigraphically-constrained, genetically-related strata, bounded either by surfaces of erosion or non-deposition, or by their correlative conformities (Van Wagoner & others, 1988). The fundamental unit of sequence stratigraphy is the sequence, a unit bounded by unconformities and their correlative conformities and containing systems tracts which are defined by the parasequences they contain (Van Wagoner & others, 1988). Although sequence stratigraphic studies have typically been based on seismic data, the model derived from sequence stratigraphy can also be a predictive tool where such data are unavailable. Sequence boundaries in seismic sections are normally recognised by stratal terminations. Such terminations are used to recognise unconformities in the field. However, disconformities and their correlative surfaces of non-deposition are often more difficult to recognise, both in seismic sections and in the field. Faunal breaks can be used to identify sequence boundaries of greater magnitude than the faunal resolution. Discontinuities in facies may indicate a sequence boundary, a change in systems tract, or

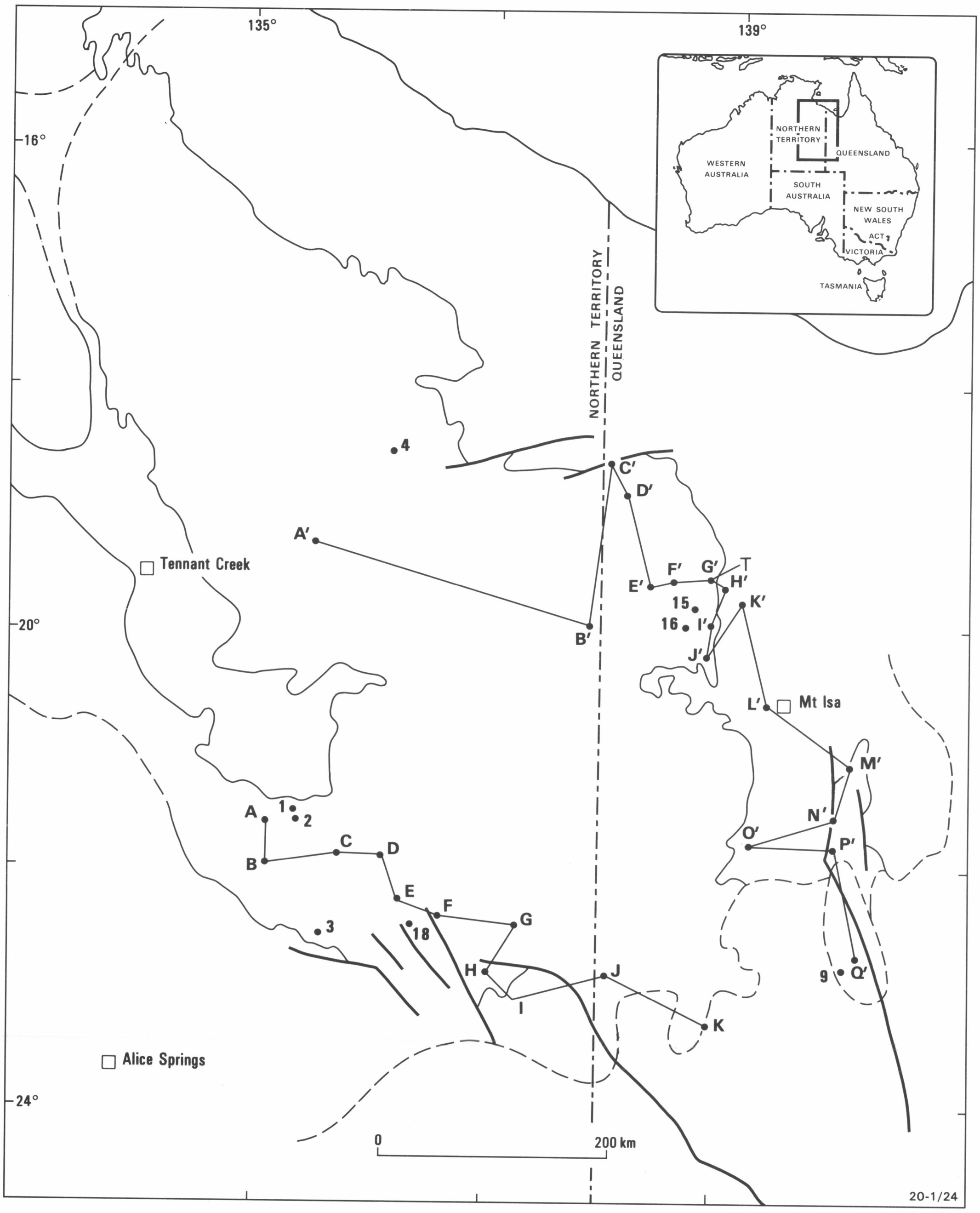


Figure 2. Distribution of stratigraphic and oil exploration wells, areas of principal outcrop, transects, and geographic localities used in the study.

A′	Frewena No. 1
B′	BMR Cattle Creek No. 1
C′	Highland Plains
D′	Lawn Hill
E′	Totts Creek
F′	Morstone No. 1
G′	Thorntonia West
H′	Thorntonia East
I′	D Tree
J′	Yelvertoft
K′	Lady Annie
L′	May Downs
M′	Roaring Bore
N′,	Monastery Creek
O′	Ardmore
P′	BMR Duchess No. 18
Q′	Black Mountain No. 1

A	NTGS Elkedra No. 7
B	NTGS Elkedra No. 6
C	NTGS Elkedra No. 3
D	BMR Sandover No. 13
E	NTGS Huckitta No. 1
F	Lucy Creek No. 1
G	BMR Cockroach No. 1
H	BMR Tobermory No. 14
I	BMR Hay River No. 11
J	Netting Fence No. 1
K	GSQ Mt Whelan No. 1

1	Ammaroo No. 1
2	Ammaroo No. 2
3	Huckitta No. 1
4	Brunette Downs No. 1
10	The Brothers No. 1
14	Marduroo No. 1
15	Elizabeth Springs No. 1
16	Canary No. 1
18	Beantree No. 1

Numbers: Data points or localities.
Letters: Transects.

a parasequence set. In each of these cases the facies are a response to, and a record of, changes in relative sea level. This contrasts with sedimentation within a parasequence, where changes in relative sea level are gradational and facies patterns predictable. Similar relationships also occur in those parts of a systems tract where the magnitude of relative sea level fluctuation is minor compared with the absolute water depth.

Domains

To simplify description of the Middle Cambrian sedimentary package, the sediments are grouped into geophysically defined and geographically and sedimentologically delineated areas, hereafter referred to as domains (Fig. 1). This terminology follows the work of Tucker & others (1979), who distinguished three structural domains within basement to the Georgina Basin. Regional differences in the sedimentary sequences recognised in the present study occur between these domains, suggesting that basement structures controlled subsidence patterns during the early stages of basin formation. The recrystallised dolostones of Domain 1 form a thin veneer of Middle, and possibly Upper, Cambrian sediment deposited in predominantly shallow shelf and peritidal environments (Shergold & Druce, 1980) on a stable carbonate platform undergoing comparatively little subsidence. In Domain 2, linear doublets of lows and highs, trending east–southeast but swinging more southerly farther east, characterise the gravity pattern (Fig. 1). The principal faults in this domain, and the associated Toko and Dulcie Synclines, parallel the gravity trends and contain some of the thickest Cambro-Ordovician sequences known in the basin. Domain 3 is defined by linear southerly to south–southeasterly trending gravity highs and lows. Its western margin is a major geophysical feature which in outcrop corresponds with the edge of the Mt Isa Block. Cambro-Ordovician sediments in Domain 3 occur in the Burke River Structural Belt, a graben-like structure parallel to the principal structural trends of the domain.

Biochronological framework

To make the present synthesis in the absence of seismic stratigraphy, great reliance has been placed on biostratigraphy to identify and correlate sequences and parasequence sets (Figs 3–6). In places, as the accompanying palaeogeographic reconstructions show, the information is inadequate and we have extrapolated observations from better known areas. These are the areas that have permitted the development of a Middle Cambrian biostratigraphy which is more complete and more intensively investigated than any other area in Australia. They have yielded the characteristic faunal assemblages which Öpik (1968a,b, 1979) used to define his Ordian, Templetonian, Floran, Undillan and Boomerangian Cambrian Stages. Original definitions made use of trilobite assemblages, particularly those of agnostoid trilobites, which evolved rapidly and had a wide geographic distribution (Öpik, 1979). Descriptions of these Middle Cambrian stages and evaluation of their concepts, including the need for revision, have been published elsewhere (Shergold, 1989). The Ordian and Templetonian Stages are particularly problematical and difficult to maintain in their original concepts (Shergold, 1989). When current basic taxonomic revisions (Laurie, 1988, 1989) are completed on materials originally used for definition by Whitehouse (1936, 1939) and Öpik (1961, 1970a,b, 1975, 1979), more refinement will be possible at this level. Here we foreshadow potential change by uniting the Ordian with the early Templetonian Stage, and the late Templetonian with the Floran. This has been brought about partly by the perceived contemporaneity of the Thorntonia Limestone and Beetle Creek Formation alluded to above, and the need to distinguish the latter (*sensu stricto*) from similar rocks in the Burke River Structural Belt and Huckitta–Elkedra regions.

In consequence the faunas of the Ordian Stage, characterised by biofacies based on *Redlichia chinensis*, must be regarded as coeval with the *Xystridura templetonensis* biofacies which characterises the Beetle Creek Formation (*sensu stricto*). The latter may then be discriminated from the *Xystridura*-bearing strata which additionally contain agnostoid trilobites of the *Triplagnostus gibbus* Zone occurring later elsewhere. Previously Shergold (1989) had considered that the *Xystridura*-bearing sequences of the Barkly Tableland and Elkedra area in the southwest Georgina Basin, for instance (which Öpik (1979) assigned to the *Peronopsis longinqua* Zone), could be a third contemporaneous Ordian/early Templetonian biofacies. Material recently determined from the NTGS Elkedra No. 3 borehole suggests that the *Peronopsis longinqua* Zone is more probably of late Templetonian age, perhaps equivalent to the early *Triplagnostus gibbus* Zone. Equally possible is the correlation of the *P. longinqua* Zone with an interval characterised by *Pentagnostus praecurrens* which predates and overlaps the range of *Triplagnostus gibbus* in the Great Basin (USA) and Scandinavia. Since *T. gibbus* is a long-ranging species and continues on into the overlying *Acidusus atavus* Zone, the existence of an independent zone of *T. gibbus* may be called into question. No continuously fossiliferous core is available to assist in the solution of such biostratigraphic problems. Nevertheless, as a result of current biostratigraphic revisions, it is possible to date the occurrence of phosphate deposits in all three geophysical domains, and in association with each of the stratigraphic sequences identified here. The faunas upon which these dates are based are listed in Appendices 1–3.

Sequence stratigraphy

Based on sequence stratigraphic concepts and predictable geometric relationships between facies, Middle Cambrian sediments of the Georgina Basin may be subdivided into two stratigraphic sequences (Figs 3 and 4; Table 1). Both sequences are of basin-wide extent and are subdivided into transgressive and highstand systems tracts. Sequence No. 1a is restricted to parts of Domain 3, and extends to the major geophysical feature that defines the western margin of this domain. In order to synthesise the facies information, the data are described in terms of the two transects shown in Figs 2, 5 and 6.

Stratigraphic sequence 1

Terrigenous clastic rocks, peritidal and shelf carbonate rocks, phosphorites and phosphatic carbonate rocks, and restricted basinal sediments occur in this stratigraphic sequence (Figs 5–7; Table 1). In the southern and central parts of the basin (transect 2, Domain 2), where outcrop is poor, biostratigraphic and lithostratigraphic data are from stratigraphic and oil

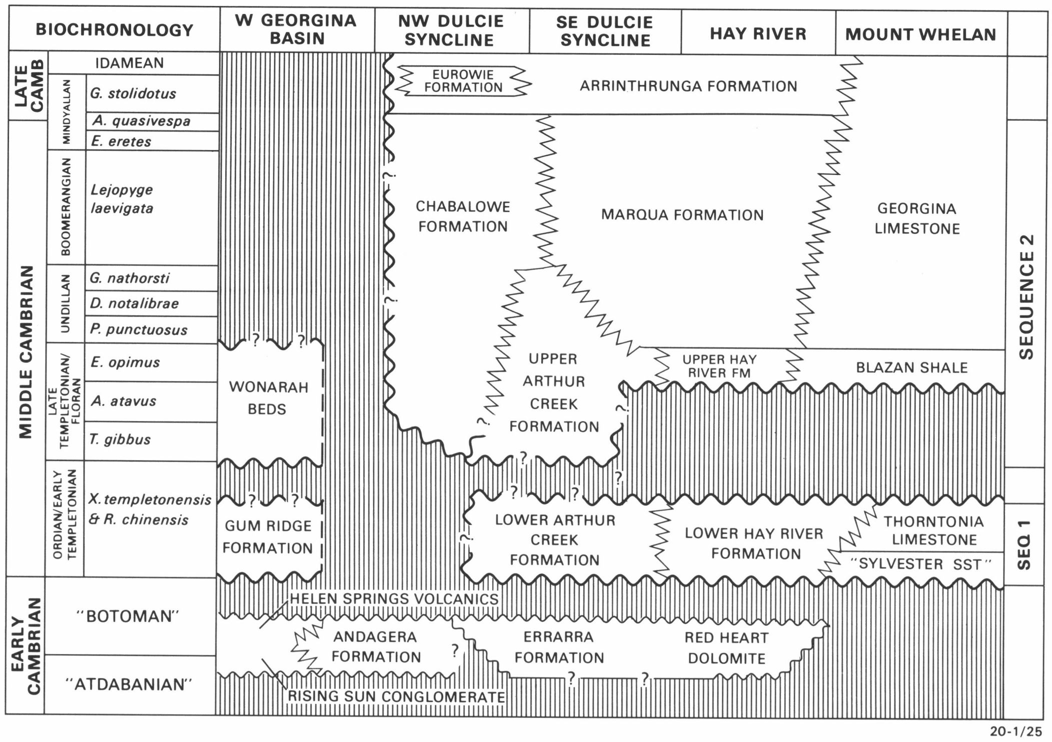


Figure 3. Sequence stratigraphic distribution of formations, northern transect.

exploration wells (Fig. 2). The best outcrop is in the northeast of the basin (transect 1, Figs 5, 7).

Sedimentation in sequence 1 commenced with gradual onlap of the palaeocontinent during the earliest Middle Cambrian (Ordian). It is not possible to estimate average sediment thickness because faulting (southern margin) and post-Tertiary erosion (northeastern margin) have removed parts of the sequence. Furthermore, the absence of sediments of appropriate age in some parts of the basin suggests that initial topographic relief on the palaeocontinent exceeded the rise in relative sea level. The thickest sections, 120–150 m, are in the northeastern parts of the basin in Domain 1. Along the northern transect (Fig. 5) sequence 1 sediments onlap in a southerly direction toward the May Downs area (Fig. 2 L′), where they terminate in shoreline facies. Along the remaining part of transect 1 and along transect 2, onlap occurs in a northerly direction, with shoreline facies developed in the northern parts of the Burke River Structural Belt and in the far southwest (Figs 5, 6). We interpret early subsidence of parts of the Mt Isa Block in Domain 3 as the cause of changed depositional patterns in stratigraphic sequence 1 (Fig. 7). This led to the accumulation of sediments in stratigraphic sequence 1a, a tectonically induced sequence, of local significance and major economic importance. A subaerial exposure surface, which indicates a major lowering in relative sea level, terminates deposition in stratigraphic sequences 1 and 1a (Fig. 8).

Lowstand systems tract. Terrigenous clastic sediments occur at the base of sequence 1 (Figs 5, 6; Table 1). Along the northern transect, poorly sorted conglomerate, sandstone, siltstone and shale beds of local provenance form thin, laterally discontinuous scree deposits and fluvial sequences which partly fill depressions in the irregular basement (Howard & Cooney, 1976; Rogers & Keevers, 1976). Over most of the Burke River Structural Belt, a soil profile caps red siltstone of the Mt Birnie Beds (de Keyser, 1968). The soil profile has a sharp upper contact with marine carbonate rocks of the Thorntonia Limestone. Along the southern transect, red to green terrigenous siltstone, mudstone, minor sandstone and marl rocks underlie sediments of the transgressive systems tract and have conformable contacts with them.

Transgressive systems tract — northern transect. Between Highland Plains (Fig. 2 C′) and May Downs Station (Fig 2 L′), phosphorite, phosphatic limestone and limestone were deposited during gradual onlap of an irregular basement. Rocks of the transgressive systems tract accumulated in peritidal, embayed and littoral environments (de Keyser & Cook, 1973) as shallowing upward cycles. Descriptions of these facies are given in de Keyser (1969) and Southgate (1986a,b, 1988). The six small phosphate deposits between Highland Plains and Riversleigh (Fig 2 D′; de Keyser & Cook, 1973) occur in this transgressive systems tract (Fig. 8).

Highstand systems tract — northern transect. Non-phosphatic dolostone overlies cyclic phosphatic sediment of the transgressive systems tract (Figs 5, 7, 8). In the northern parts of the transect, medium to thick peloid packstone and wackestone beds accumulated in deeper water platform environments. Later, as water depths decreased, peloid, ooid and oncolitic grainstone, packstone and wackestone and laminoid fenestral packstone accumulated in shallow submergent and emergent environments as progradational shallowing-upward cycles (Southgate, 1988). A shoreline for the lower parts of the highstand systems tract probably formed around a topographic high in the May Downs

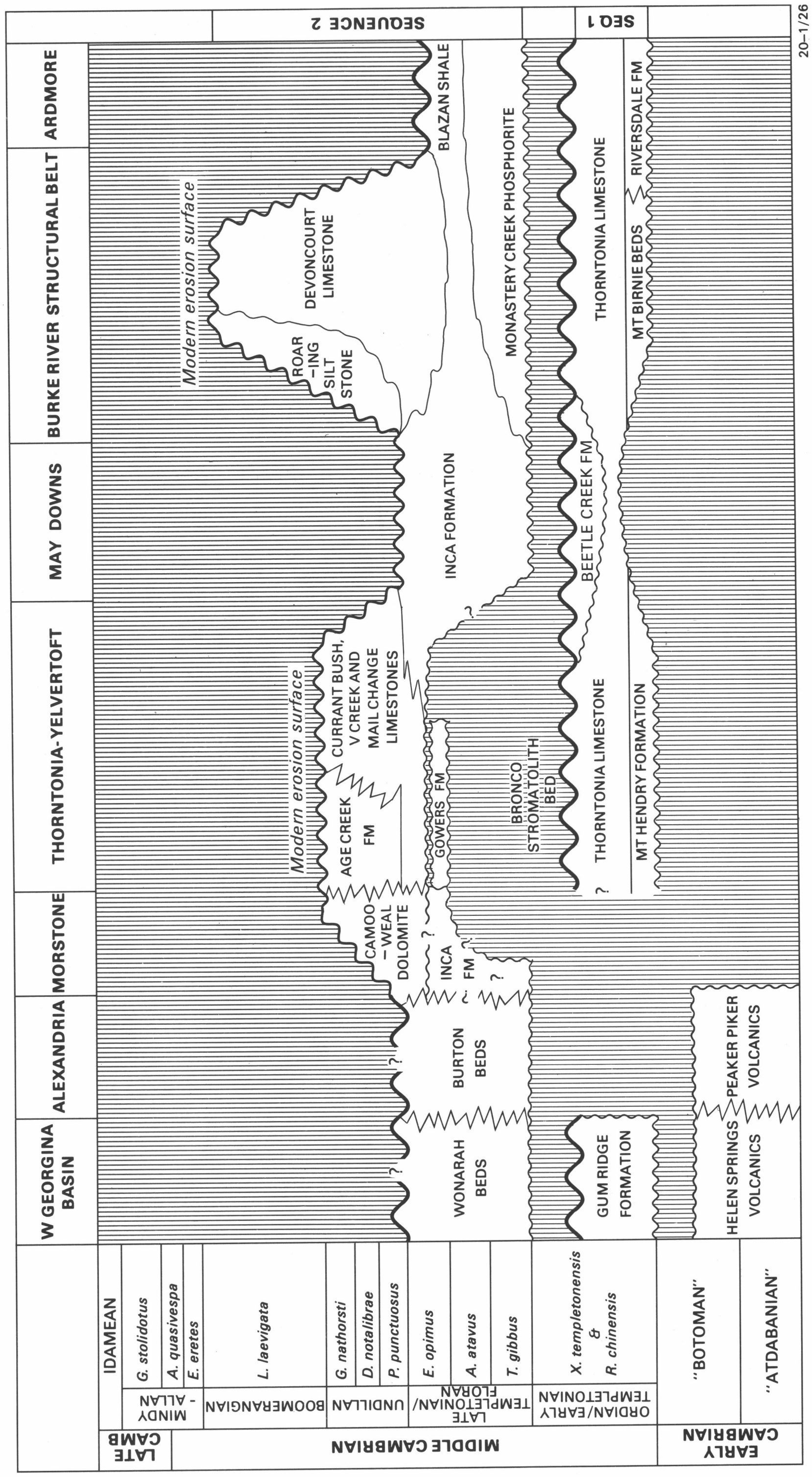


Figure 4. Sequence stratigraphic distribution of formations, southern transect.

area (Fig. 7). Here a 2–8 m thick interval of stromatolitic dolostone and chert of peritidal origin onlaps basement. This shoreline facies prograded in a northerly direction toward Yelvertoft (Fig. 2 J′).

Whereas the northern parts of the transect contain predominantly shallow water facies that onlap in a southerly direction, facies belts in the southern parts of the transect contain deeper water sediments that onlap in a northerly direction (Figs 5, 7). In the Burke River Structural Belt, the contact between the Thorntonia Limestone and coastal plain clastics of the Mt Birnie Beds is generally sharp and erosional. Retrogradational transgressive cycles are thin and poorly developed, suggesting that a rapid rise in relative sea level took place. This contrasts with the northern parts of the transect, where some 40–90 m of sediment is attributed to a keep-up transgressive systems tract (see Sarg, 1988). Such

Table 1. Distribution of Middle Cambrian formations in the Georgina Basin with respect to their stratigraphic sequence, depositional environment and domain.

Environments	*Domain 1*	*Domain 2*	*Domain 3*
Sequence 1			
Coastal plain clastics and carbonates	Mt Hendry Formation	Riversdale Formation, Sylvester Sandstone, Lower Arthur Creek Formation	Mt Birnie Beds
Peritidal carbonates	Thorntonia Limestone	Lower Arthur Creek Formation	Thorntonia Limestone and Ardmore Chert Mbr. Thorntonia Limestone
Platform carbonates	Thorntonia Limestone	Thorntonia Limestone, Lower Arthur Creek Formation	Thorntonia Limestone
Peritidal phosphorites and phosphatic limestones	Border Waterhole Formation, Thorntonia Limestone	—	? Black Mountain No. 1
Shelf phosphorites and phosphatic limestones	Border Waterhole Formation, Thorntonia Limestone	—	? Black Mountain No. 1
Black recrystallised dolostones	—	—	Thorntonia Limestone
Organic matter rich shales with a planktonic and benthonic fauna	Border Waterhole Formation	Lower Hay River Formation	? Black Mountain No. 1
Organic matter rich shales with a planktonic fauna	—	Lower Hay River Formation	? Black Mountain No. 1
Sequence 1a			
Coastal plain clastics and carbonates	—	—	Bronco Stromatolith Bed
Peritidal phosphorites and phosphatic limestones	Thorntonia Limestone & Beetle Creek Formation	—	Thorntonia Limestone and Beetle Creek Formation
Shelf phosphorites and phosphatic limestones	Thorntonia Limestone and Beetle Creek Formation	—	Thorntonia Limestone and Beetle Creek Formation
Organic matter rich shales with a planktonic and benthonic fauna	—	—	Siltstone Member Beetle Creek Formation
Organic matter rich shales with a planktonic fauna	—	—	Siltstone Member Beetle Creek Formation
Sequence 2			
Coastal plain clastics and carbonates	Bronco Stromatolith Bed	Upper Chabalowe Formation	—
Peritidal carbonates	Camooweal Dolomite	Hagen Member Chabalowe Formation	—
Platform carbonates	Camooweal Dolomite	Chabalowe Formation	—
Platform edge grainstones	Age Creek Formation	Steamboat Sandstone	—
Ramp carbonates	Currant Bush, V Creek and Mail Change Limestones	Georgina Limestones, Marqua Formation and Upper Hay River Formation	Devoncourt Limestone
Peritidal phosphorites and phosphatic limestones	Gowers Formation	Upper Arthur Creek Formation	Thorntonia Limestone and Monastery Creek Formation
Shelf phosphorites and phosphatic limestones	—	Upper Arthur Creek Formation	Monastery Creek Formation
Organic matter rich shales with a planktonic and benthonic fauna	—	Upper Arthur Creek Formation	Siltstone Member Monastery Creek Formation
Organic matter rich shale with a planktonic fauna	Inca Formation	Upper Arthur Creek Formation	Inca Formation, Blazan Shale, Roaring Siltstone

differences in sedimentation patterns suggest that sediment accumulation rates and/or subsidence rates varied across the basin.

Black recrystallised dolostone of the highstand systems tract (Thorntonia Limestone) accumulated in quiet-water environments, possibly below wave-base (Nordlund & Southgate, 1988). Slump folds infer deposition on an inclined or unstable substrate possibly affected by penecontemporaneous faulting. The lack of trace and shelly fossils infers restricted conditions of sedimentation. At Rogers Ridge (Fig. 2 P′), silicified fragments of the trilobite *Redlichia* sp., hyolithids and brachiopods are found in the uppermost 2 m of the black recrystallised dolostone (Fig. 5). This sparse shelly fauna heralds the rapid shallowing event that resulted in the deposition of an 8 m thick peritidal sequence of laminoid fenestral dolostone, peloid ooid grainstone, stromatolite and evaporite as the terminal sediments of this stratigraphic sequence. In the Burke River Structural Belts the peritidal dolostone sequence has a sharp lower contact with the recrystallised dolostone unit, suggesting that a rapid fall in relative sea level caused the deeper water facies to be succeeded by peritidal and emergent environments without a gradual change in corresponding facies (Fig. 8). A similar facies succession occurs in the Ardmore Outlier (Fig. 2 O′), where recrystallised black dolostone is succeeded by chert that contains the trilobite *Redlichia chinensis*, stromatolites and pseudomorphs of halite crystals which grew in brine pools on subaerially exposed flats (Southgate, 1982). North of Rogers Ridge, the Thorntonia Limestone is replaced by an interval of chert rubble interpreted by de Keyser (1968) as a Middle Cambrian regolith derived by dissolution and silicification of a precursor limestone.

Transgressive and highstand systems tracts — southern transect. Along the southern transect, sediments onlap in a northwesterly direction (Fig. 6). The deepest water and most restricted conditions of sedimentation occur in the Toko Syncline (Fig. 1). Here organic-matter rich shale and weakly phosphatic micritic dolostone of the Lower Hay River Formation form a condensed sequence (Fig. 8). The organic-matter rich shale, with TOC content of up to 16% in the Inca Formation and 6% in the Hay River Formation, accumulated in an oxygen minimum zone beneath an anoxic watercolumn (Donnelly & others, 1988). The associated laminated and concretionary phosphatic mudstone, in which phosphatic hardgrounds and skeletal debris occur, was deposited in

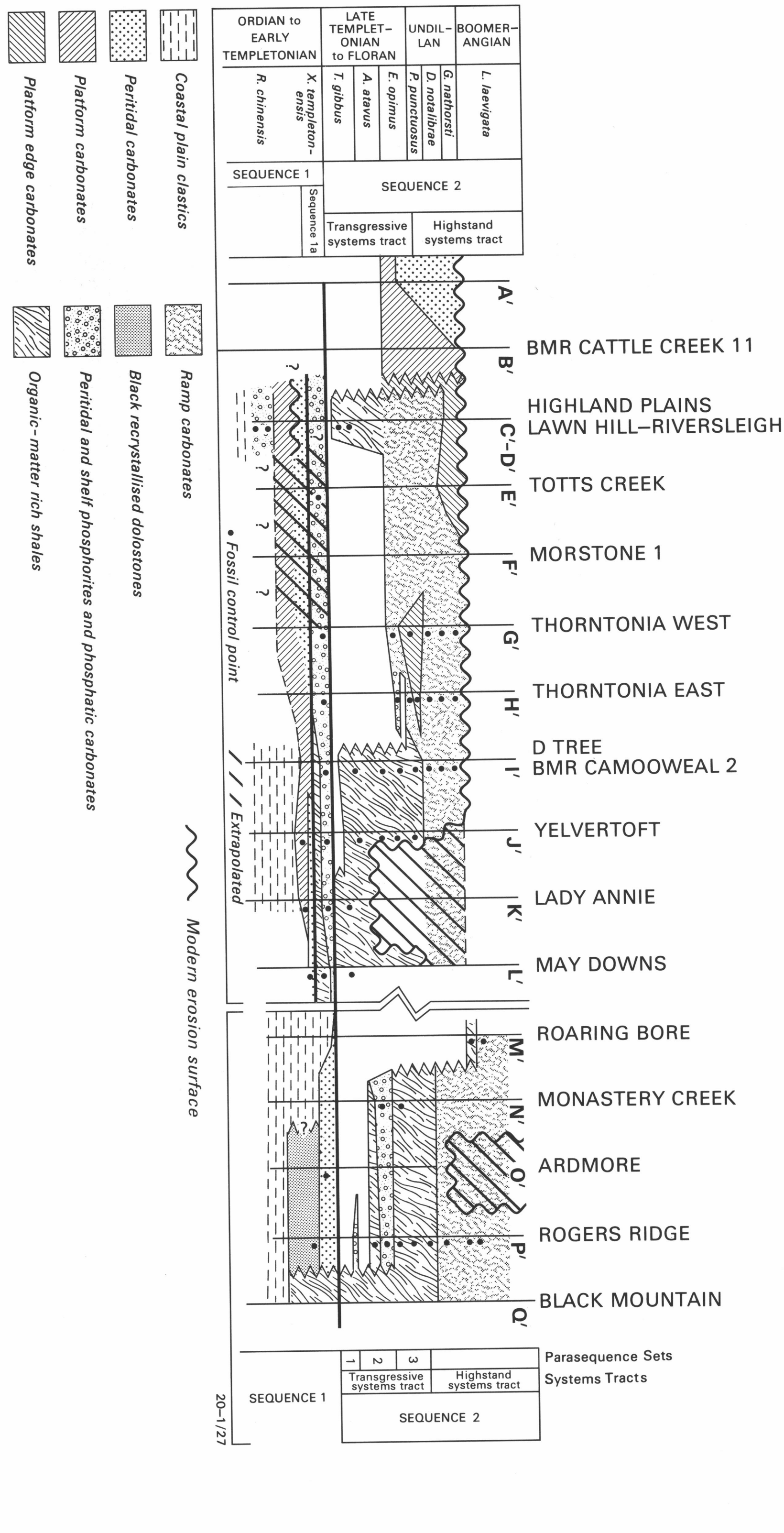


Figure 5. Sequence stratigraphic distribution of principal lithologies and interpreted depositional environments, northern transect. Cross-section plotted against time.

environments of fluctuating oxygen concentrations close to the upper boundary of the oxygen minimum zone (Donnelly & others, 1988). In BMR Hay River No. 11A (Fig. 2 I), dysaerobic phosphatic mudstone occurs in two retrogradational cycles at the base of the sequence, suggesting that transgression was rapid in this part of the basin and that euxinic conditions suitable for the deposition of organic-matter rich sediment were quickly established.

Because the sequence in Hay River No. 11A is incomplete, and a fault separates organic-matter rich shale in

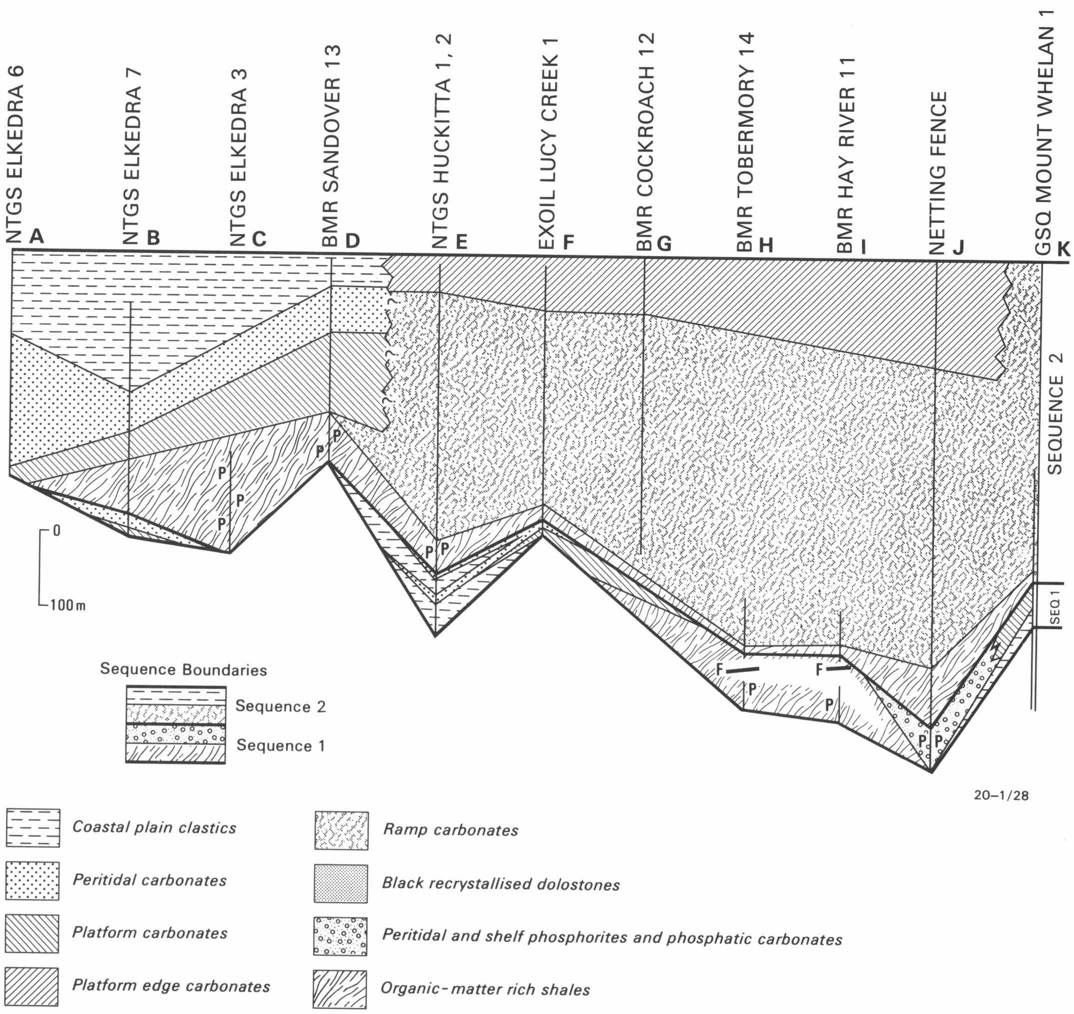


Figure 6. Sequence stratigraphic distribution of principal lithologies and interpreted depositional environments, southern transect. Cross-section plotted against sediment thickness.

this hole from similar rocks at the base of BMR Hay River No. 11, it is not possible to determine an accurate thickness for the organic-matter rich shale (Fig. 6). The presence of shale beneath 0.5 m of weathered, brown and grey laminated mudstone marking the top of this stratigraphic sequence indicates that a rapid fall in relative sea level terminated deposition (Fig. 8). Alternatively, any overlying peritidal facies indicative of shallowing may have been removed by erosion, but the absence of such sediments in outcrop makes this unlikely.

Rocks of stratigraphic sequence 1 age are poorly represented in the southwestern parts of the basin. Although their absence may be partly due to poor outcrop, it is likely that rocks of this age were only sporadically deposited in this part of the basin. Where palaeontological control exists (e.g. NTGS Elkedra No. 3; Figs 2 C, 6) organic-matter rich shale of sequence 2 age disconformably overlies archaeocyathan-bearing dolostone of Early Cambrian age. Elsewhere an interval of terrestrial clastic sediment and/or peritidal dolostone and limestone separates Lower Cambrian dolostone from sequence 2 organic-matter rich shale. As this intervening sequence has both upper and lower disconformable contacts it is assigned to sequence 1. Thus a shoreline for sequence 1 probably occurs in the vicinity of NTGS Huckitta No. 1 (Fig. 2 E), where a 60 m thick sequence of terrestrial clastics with thin interbeds of fenestral and stromatolitic dolostone occurs. Slightly deeper water conditions existed in the Dulcie Syncline in the vicinity of NTGS Elkedra No. 7 (Fig. 2 A), where peritidal fenestral dolostone and grainstone rather than terrestrial clastics sediments are found.

Summary

By associating facies patterns in sequence 1 with the principal structural elements in which they occur, the following conclusions can be drawn:

1. The most restricted and deepest water conditions of sedimentation in sequence 1 occur in the Toko Syncline, which suggests that this area underwent rapid subsidence in the early Middle Cambrian. Such a conclusion is consistent with the thin retrogradational cycles found at the base of the transgressive systems tract in this area, and the

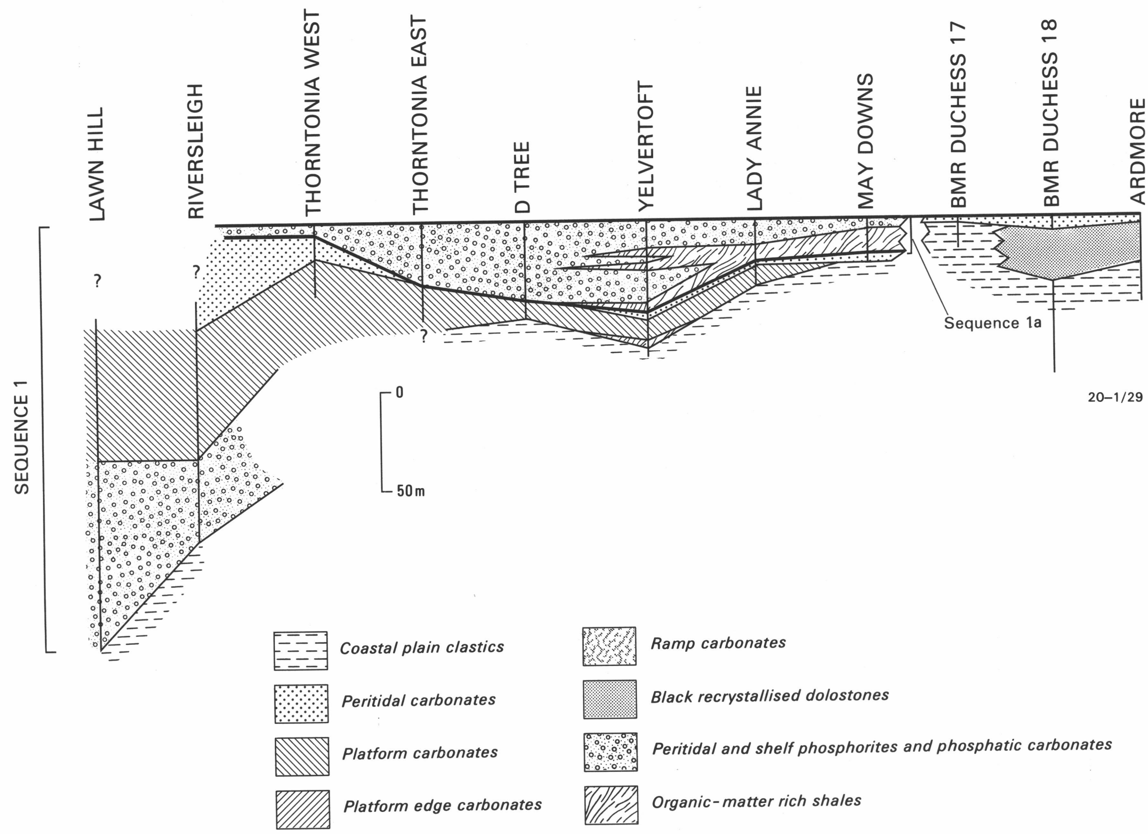


Figure 7. Sequence stratigraphic distribution of principal lithologies and interpreted depositional environments for the Lawn Hill–Thorntonia–May Downs region showing relationships between sequences 1 and 1a.
Note that sequence 1a forms a thin veneer of onlapping phosphatic sediment in the Thorntonia West region.

shallower water platform and peritidal facies found in GSQ Mount Whelan No. 1 (Fig. 2 K) and Exoil Lucy Creek No. 1 (Fig. 2 F) boreholes on the eastern and western flanks of this structure, respectively.

2. Rapid subsidence may also have taken place in the Burke River Structural Belt, permitting deposition of the recrystallised black dolostone, which also lacks a well developed transgressive systems tract at its base.
3. This scenario contrasts with that in Domain 1. In the northeast of the basin subsidence was much slower, permitting the development of a keep-up transgressive systems tract and the formation of several minor phosphate deposits.
4. In the southwest of the basin, sequence 1 sediments are best developed in the Dulcie Syncline. Elsewhere, this interval is represented by either an erosion surface, or terrestrial redbed sedimentation with minor marine incursions leading to the deposition of peritidal dolostone.
5. A rapid fall in relative sea level terminated sedimentation in sequence 1.

Tectonically enhanced stratigraphic sequence 1a

Sediments in sequence 1a form a parasequence set interpreted as accumulating in response to early subsidence of the Mt Isa block during the late Ordian/early Templetonian. Organic-matter rich shale and phosphorite of sequence 1a attains a maximum thickness of approximately 50 m, and onlaps platform and peritidal facies attributed to the previously described highstand (Figs 5, 7, 9b). Onlap is interpreted to have taken place in a northwesterly direction, thus reversing the shallowing trend previously described from sequence 1. The D Tree, Lady Annie and Yelvertoft phosphate deposits (Fig. 2 I′, K′, J′) belong in this stratigraphic sequence.

Northern transect — May Downs to Thorntonia West. Phosphatic limestone and phosphorite deposition in sequence 1a coincided with a return to some of the facies patterns and faunal elements previously attributed to the transgressive systems tract of sequence 1. The deepest water and most restricted conditions occurred in the May Downs area, where organic-matter rich shale and siltstone, containing whole and fragmented trilobites referred to *Xystridura* spp. (Appendix 2) accumulated in dysaerobic to anaerobic environments. To the north, at Yelvertoft, Lady Annie and D Tree, organic-matter rich shale interfingers with phosphatic, siliceous and calcareous rocks and phosphorites deposited in shallow water aerobic environments (Howard & Cooney, 1976; Cook & Elgueta, 1986). At Yelvertoft (Fig. 7), the phosphatic rocks occur in three shallowing upward

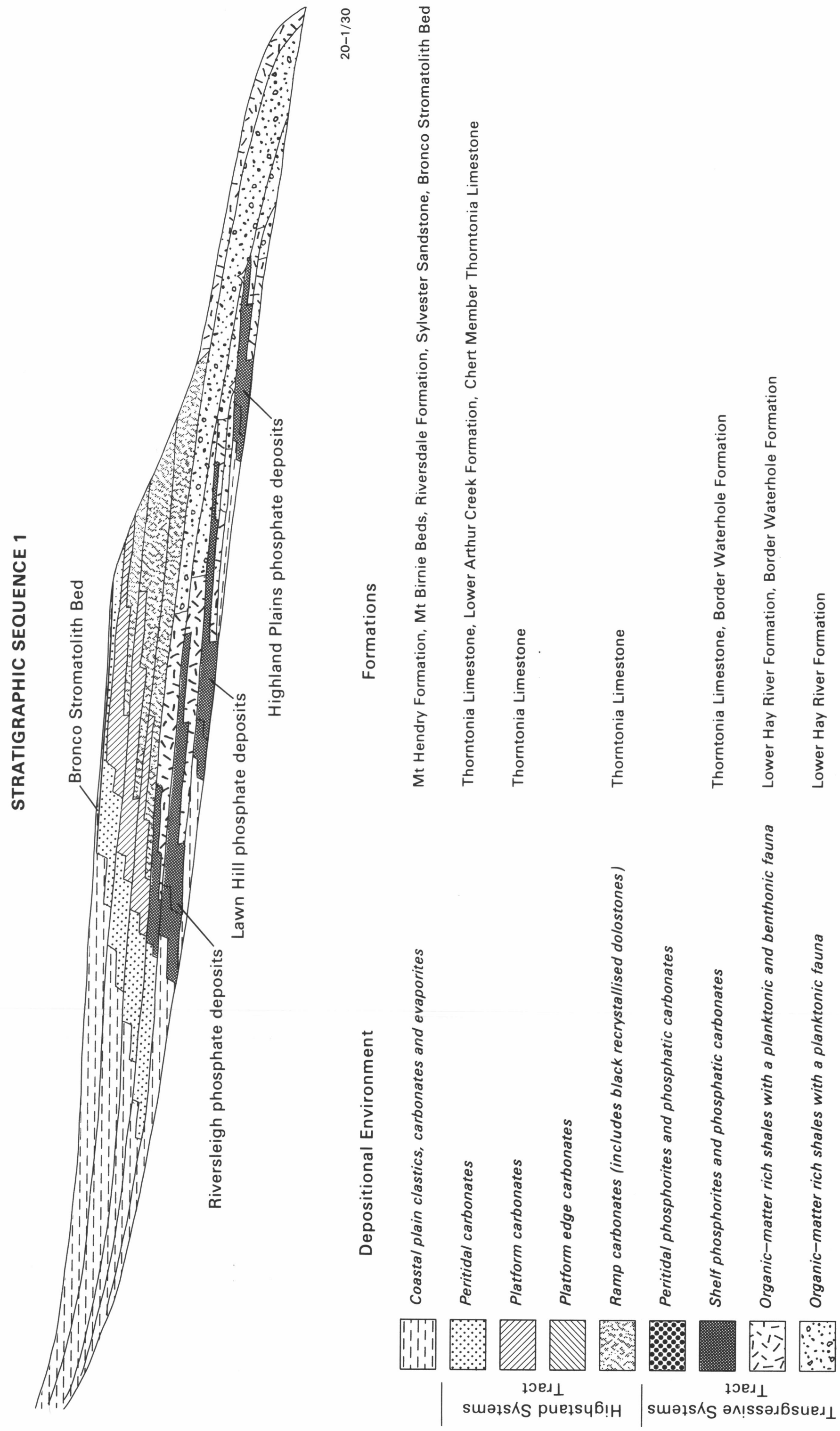


Figure 8. Sequence stratigraphic cross-section showing the relative positions of formations and their constituent facies in stratigraphic sequence 1 (after Van Wagoner & others, 1988).

cycles. Organic-matter rich shale and phosphatic mudstone dominate the lower parts of each cycle. Cycles culminate in the deposition of phosphatic grainstone, coquinite and phosphorite. Howard & Cooney (1976) recognised three organic-matter rich shale–phosphorite sequences in the D Tree deposit, and Cook & Elgueta (1986) described similar sediments in the Lady Annie deposit. In the uppermost parts of the D Tree deposit phoscrete crusts, laminoid fenestral phosphorite and desiccated mudstone phosphorite collectively indicate emergent conditions representing the cessation of sedimentation in this sequence. Between Thorntonia Station and Thorntonia West (Fig. 2 G), phosphatic coquinite forms a thin veneer of sediment onlapping emergent laminoid fenestral dolostone of the previously described highstand. Phoscrete crusts, vertically stacked coquinite and stromatolites indicating deposition in an algal marsh (Southgate, 1988) demonstrate emergent conditions associated with the boundary that terminates this sequence.

Summary

The changes in sediment mineralogy and facies patterns between non-phosphatic sediments of the highstand systems tract in sequence 1 and the overlying phosphatic sediments of sequence 1a are interpreted as related to subsidence of the Mt Isa block and the creation of a new seaway, through which nutrient-rich oceanic waters entered the May Downs–Yelvertoft–D Tree–Lady Annie areas (Figs 9, 12). Before this switch in facies patterns the sea shallowed in a southeasterly direction toward May Downs. At May Downs, the change from shoreline aerobic conditions to deeper water dysaerobic environments suitable for the accumulation of organic-matter rich shale indicates rapid subsidence and an accompanying change in current circulation patterns. At Yelvertoft, D Tree and Lady Annie, peloidal phosphorite and the associated phosphatic sediment accumulated in shallow, nutrient-rich, oxygenated waters. The change from non-phosphatic calcareous peritidal facies in the older *Redlichia*-bearing sequence to the phosphatic and skeletal-rich facies of the younger sequence provides evidence for a dramatic increase in the nutrient content of the flooding waters.

Stratigraphic sequence 2

Sediments of stratigraphic sequence 2 accumulated in terrestrial, shoreline, peritidal, platform, platform edge, ramp and basinal environments. The relative rise in sea level responsible for sequence 2 inundated the continent and resulted in the deepest water conditions attained in the Georgina Basin (Figs 6, 7, 12). The transgressive systems tract is considered in terms of the three parasequence sets thus far recognised. Each parasequence set comprises a repeating mosaic of lithofacies related to onlap during one or more of the three stepped rises in relative sea level. Rocks of parasequence set 1 contain agnostoid trilobites of late Templetonian age close to the overlap of the *Pentagnostus praecurrens* and *Triplagnostus gibbus* Zones (Appendix 3). Parasequence set 2 contains agnostoid and polymeroid trilobites which give an age at the overlap of the *Triplagnostus gibbus* and *Acidusus atavus* Zones within the late Templetonian/early Floran passage. Agnostoid trilobites in parasequence set 3 are of Floran age.

Transgressive systems tract

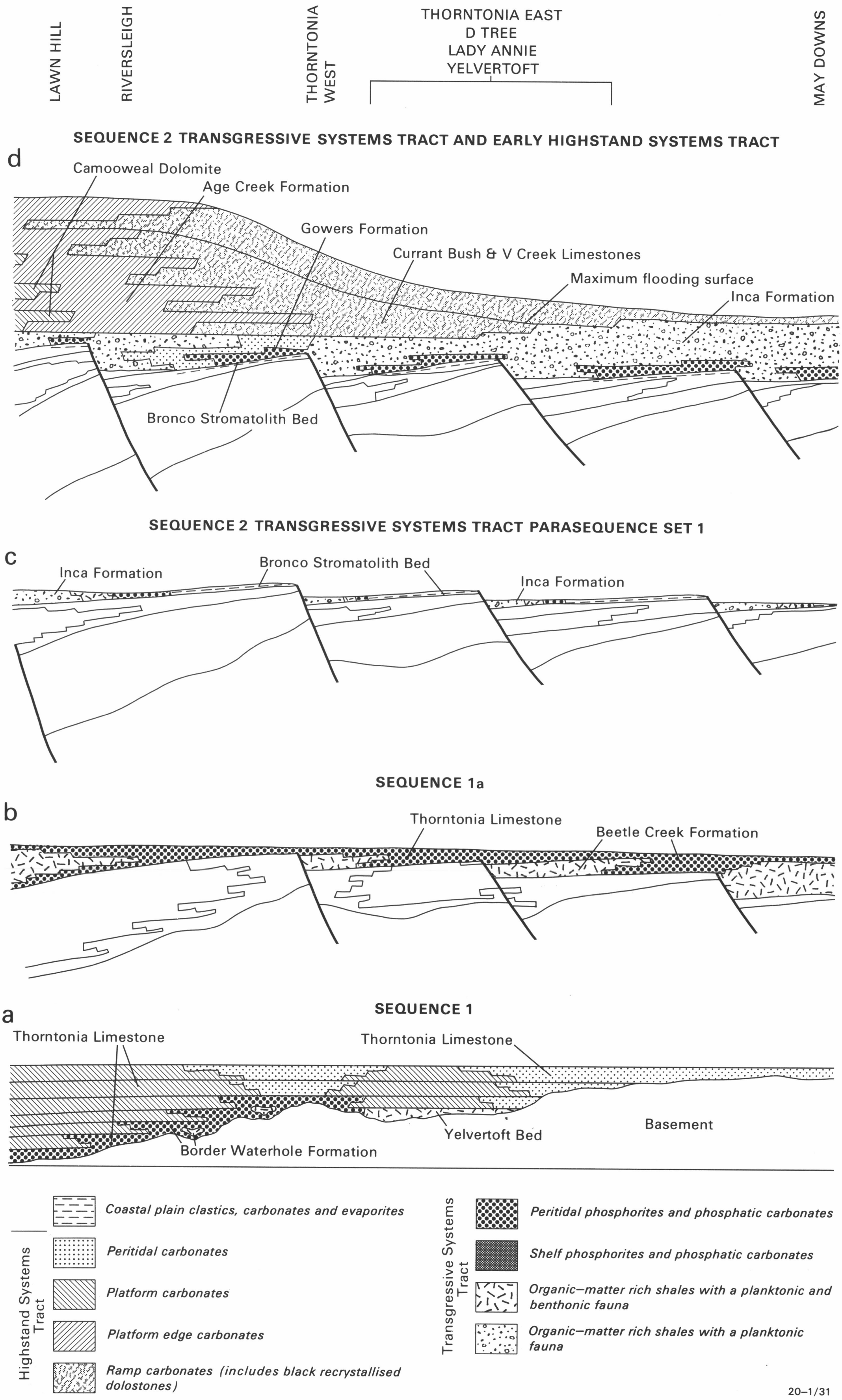
Northern Transect — Highland Plains to May Downs. Subsidence of the Mt Isa block controlled sedimentation in this area. In consequence, facies variations occur on the eastern and western sides of the prominent geophysical feature forming the western boundary of Domain 3. Organic-matter rich shale belonging to parasequence sets 1, 2 and 3 occurs in Domain 3 on the eastern side of this structure (Fig. 5). To the west, in Domain 1, rocks belonging to parasequence sets 1 and 2 are replaced by the Bronco Stromatolith Bed (Figs 5, 9, 10).

At Lady Annie and May Downs, laminated organic-matter rich shale of the Inca Formation overlies phosphorite, phosphatic carbonate rock and shale of sequence 1a age. Shale in the Beetle Creek Formation (sequence 1a) contains elements of a benthonic and planktonic trilobite fauna which indicate dysaerobic conditions. The overlying organic-matter rich shale of the Inca Formation only contains planktonic agnostoid trilobites, suggesting anaerobic bottom conditions. In the May Downs area, a limonitic horizon separates sequence 1a sediments from organic-matter rich shale of sequence 2. At Lady Annie, a chert-mudstone facies separates sequence 1a phosphorite from sequence 2 organic-matter rich shale (Cook & Elgueta, 1986). The mudstone facies has a blanket-like geometry that lacks both interfingering and gradational relationships with the underlying phosphorite, yet contains lithological and faunal elements which suggest it is associated with them.

The limonitic horizon at May Downs is interpreted as the transgressive sediment bypass surface at the base of sequence 2. The chert–mudstone facies at Lady Annie is interpreted as a transgressive interval at the base of the Inca Formation. At Lady Annie and May Downs, the lack of a subaerial exposure surface at the sequence boundary separating sequence 1a from sequence 2 (coupled with the trend from shallow water phosphatic sediments and phosphorites of sequence 1a to restricted deeper water organic-matter rich shale of sequence 2) suggests that in these areas a relative rise in sea level terminated the shallowing trends present in the upper parts of sequence 1a. Although outcrop on the eastern side of West Thornton Creek (Fig. 2 G′) is generally poor, the sequence in this area is similar to that at Lady Annie, and once again a subaerial exposure surface on top of sequence 1a is missing. Thus sedimentation across the boundary between stratigraphic sequences 1a and 2 was continuous in this part of Domain 3, and the sequence boundary is represented by a correlative conformable surface. However, on the western side of West Thornton Creek a different sedimentary record is found.

Between Yelvertoft and Thorntonia West, sediments belonging to parasequence sets 1 and 2 are represented by the Bronco Stromatolith Bed, a 1–30 cm thick stratigraphic interval representing minor deposition and erosion on a subaerial exposure surface (Southgate, 1986c, fig. 10). In this part of the basin, transgression commenced in parasequence set 3 time and resulted in onlap of a palaeogeographic high (Figs 5, 12). Near Thorntonia Station, phosphatic limestone and dolostone

Figure 9. Schematic development of stratigraphic sequences 1 and 2 in the northeastern parts of the basin between Lawn Hill and May Downs.
a. Stratigraphic sequence 1. Gradual inundation of the palaeocontinent. Phosphate deposits occur where retrogradational cycles of the transgressive systems tract impinge upon the irregular basement palaeotopography.
b. Stratigraphic sequence 1a. Subsidence of the Mt Isa Block (shown schematically as several half grabens) results in the deposition of organic-matter rich shales and their associated phosphorites.
c. Stratigraphic sequence 2. Continued subsidence during a period of fall in relative sea level results in the deposition of organic-matter rich shale and the development of a subaerial disconformity surface.
d. A gradual rise in relative sea level completely floods the Mt Isa block. This structural area (Domain 3) forms a carbonate ramp to a stable platform area to the west (Domain 1). Cross-bedded grainstone of the Age Creek Formation was deposited at the edge of the ramp.


LAWN HILL
RIVERSLEIGH
THORNTONIA WEST
THORNTONIA EAST
D TREE
LADY ANNIE
YELVERTOFT
MAY DOWNS
SEQUENCE 2 TRANSGRESSIVE SYSTEMS TRACT AND EARLY HIGHSTAND SYSTEMS TRACT
d
Camooweal Dolomite
Age Creek Formation
Gowers Formation
Currant Bush & V Creek Limestones
Maximum flooding surface
Inca Formation
Bronco Stromatolith Bed
SEQUENCE 2 TRANSGRESSIVE SYSTEMS TRACT PARASEQUENCE SET 1
c
Inca Formation
Bronco Stromatolith Bed
Inca Formation
SEQUENCE 1a
b
Thorntonia Limestone
Beetle Creek Formation
a
SEQUENCE 1
Thorntonia Limestone
Thorntonia Limestone
Yelvertoft Bed
Basement
Border Waterhole Formation
Highstand Systems Tract
Coastal plain clastics, carbonates and evaporites
Peritidal carbonates
Platform carbonates
Platform edge carbonates
Ramp carbonates (includes black recrystallised dolostones)
Transgressive Systems Tract
Peritidal phosphorites and phosphatic carbonates
Shelf phosphorites and phosphatic carbonates
Organic–matter rich shales with a planktonic and benthonic fauna
Organic–matter rich shales with a planktonic fauna
20–1/31

of the Gowers Formation forms a 0.1–15 m thick parasequence set that onlaps the Bronco Stromatolith Bed (Southgate, 1986c, fig. 9). A subaerial exposure surface caps the Gowers Formation and separates this phosphatic parasequence set from the overlying Currant Bush Limestone. Continued transgression drowned the northeastern parts of the basin and led to the deposition of (1) organic-matter rich shale–chert retrogradational cycles with caps of concretionary, glauconitic and phosphatic limestone, and (2) interbedded ribboned limestone and organic-matter rich shale. Slump folds in the organic-matter rich shale, and intervals of intraclast breccia up to 4 m thick, that are traceable over distances of 5–6 km, provide evidence for sediment deposition on an inclined seafloor and/or possible synsedimentary faulting during deposition of parasequence sets 2 and 3.

Northern transect — Roaring Bore to Black Mountain. The three parasequence sets recognised in the Burke River Structural Belt onlap in a northerly direction (Fig. 5). In consequence, all three parasequence sets are found in the southern parts of the transect (Black Mountain, Fig. 2 Q′, and Rogers Ridge, Fig. 2 P′) but only two parasequence sets occur at Monastery Creek (Fig. 2 N′) and Ardmore (Fig. 2 O′), and one at Roaring Bore (Fig. 2 M′).

Onlap during parasequence set 1 time deposited shoreline facies in the Rogers Ridge area (Figs 5, 10). Here, a 12 m thick interval of cyclic phosphatic limestone of peritidal origin rests disconformably on the Thorntonia Limestone (Nordlund & Southgate, 1988). These rocks are correlated with the Siltstone Member of the Monastery Creek Formation[2] which outcrops in the southern parts of the Duchess phosphate deposit and in turn correlates with the organic-matter rich shale intersected in Black Mountain 1. Thus the thin phosphatic interval at Rogers Ridge represents a shoreline facies for a sea that deepened to the south (Fig. 12).

Rocks of the Monastery Creek Formation and its accompanying Siltstone Member, which comprise the phosphate deposits in the Duchess and Ardmore areas, belong to parasequence set 2. North of Rogers Ridge and at Ardmore, rocks of parasequence set 2 overlie the sequence boundary (subaerial exposure surface) that caps sequence 1; to the south these rocks overlie phosphatic limestone and organic-matter rich shale belonging to parasequence set 1 (Figs 5, 11). At Rogers Ridge, phosphatic and glauconitic hardgrounds attest to sediment starvation on the transgressive surface of parasequence set 2 (Fig. 10). After the transgression, four facies belts were established. Intraclastic, bioclastic and siliceous phosphorite accumulated on structural highs and their attendant slopes; phosphorite of the micritic calcareous facies accumulated in sub-basins or structural lows (Russell & Trueman, 1971). In deeper water settings, or in areas of restricted circulation, organic-matter rich shale of the Siltstone Member was deposited in predominantly dysaerobic environments. Organic-matter rich shale devoid of a benthonic fauna, but containing elements of a planktonic fauna, accumulated in deeper and more restricted anaerobic environments.

Parasequence set 2 has both conformable and disconformable relationships with onlapping organic-matter rich shale of parasequence set 3 (Rogers & Crase, 1980; Soudry & Southgate, 1989). Soudry & Southgate (1989) interpreted mudstone phosphorites and their associated vadose miniprofiles in the uppermost unit of the Monastery Creek Formation as forming on subaerially exposed coastal flats during vadose diagenesis. In the phosphate pits, at the Duchess deposit, the contact with the Inca Formation is gradational. Packstone and wackestone phosphorite initially interbed with, but are rapidly succeeded by, finely laminated non-phosphatic shale. In the Rogers Ridge area, five retrogradational transgressive cycles form a gradational sequence, some 8 m thick, at the base of parasequence set 3 (Fig. 10). In each cycle, thin beds of black chert and siliceous mudstone with graded phosphatic laminae overlie the basal erosion surface and pass upwards into phosphatic and glauconitic, grain-supported limestone concretions. Thin crusts of mudstone phosphorite coat the eroded upper surfaces of some concretions (Fig. 10). In the uppermost retrogradational cycle (50 cm thick) organic-matter rich shale of the Inca Formation overlies the concretions.

The concretions are interpreted as sediment-starvation surfaces (marine flooding surfaces of Van Wagoner & others, 1988). They formed on the seafloor during times of sediment starvation and cementation, and underwent penecontemporaneous erosion and phosphate encrustation. Following each transgressive pulse, anoxic conditions prevailed on the seafloor and fine-grained siliceous sediments were deposited. Subsequent shallowing and minor progradation of the nearby shelf sediments resulted in the accumulation of granular phosphatic sediments in the upper parts of each retrogradational cycle.

Southern transect. In the southern parts of the basin, poor outcrop makes the regional correlation of rock units difficult. However, parasequence sets 2 and 3 are recognised in parts of the Dulcie Syncline, and parasequence set 3 occurs in the Toko Syncline (Figs 6, 12). Near the Dulcie Syncline, at the westernmost end of the transect, rocks of parasequence sets 2 and 3 onlap in a northwesterly direction. The oldest sediments are found in Elkedra No. 3 (Fig. 2 C) and Huckitta No. 1 (Fig. 2 E), where sedimentation started with the accumulation of lithoclastic and intraclastic grainstone in two retrogradational transgressive cycles (Fig. 10). In Huckitta No. 1 the grainstone is glauconitic and phosphatic. Following the initial transgression, organic-matter rich shale and interbedded phosphatic mudstone of parasequence sets 2 and 3 (anaerobic facies of Stidolph & others, 1988) accumulated in anaerobic and dysaerobic basinal environments. Phosphatic hardgrounds in the organic-matter rich shale and mudstone probably formed during times of sediment starvation when the sea floor was locally cemented by phosphate. Similar sediments are found to the northwest in Elkedra No. 7a (Fig. 2 A), but poor faunal resolution in this area and the lack of retrogradational cycles suggest that this interval of organic-matter rich shale belongs to parasequence set 3. Further to the north, in Elkedra No. 6 (Fig. 2 B), organic-matter rich shale is absent (Fig. 6). Here, carbonate rocks interpreted as deposited in shallow water platform environments overlie Proterozoic basement. These rocks pass rapidly upwards into carbonate rocks and sulphate evaporites of peritidal and sabkha facies, here interpreted as deposited in the overlying highstand systems tract. This suggests that inundation of Proterozoic basement in the northern parts of the Dulcie Syncline coincided with the maximum flooding surface (Fig. 11).

---

[2] Formerly referred to in the literature as the Beetle Creek Formation (e.g. Russell, 1967; Russell & Trueman, 1971).

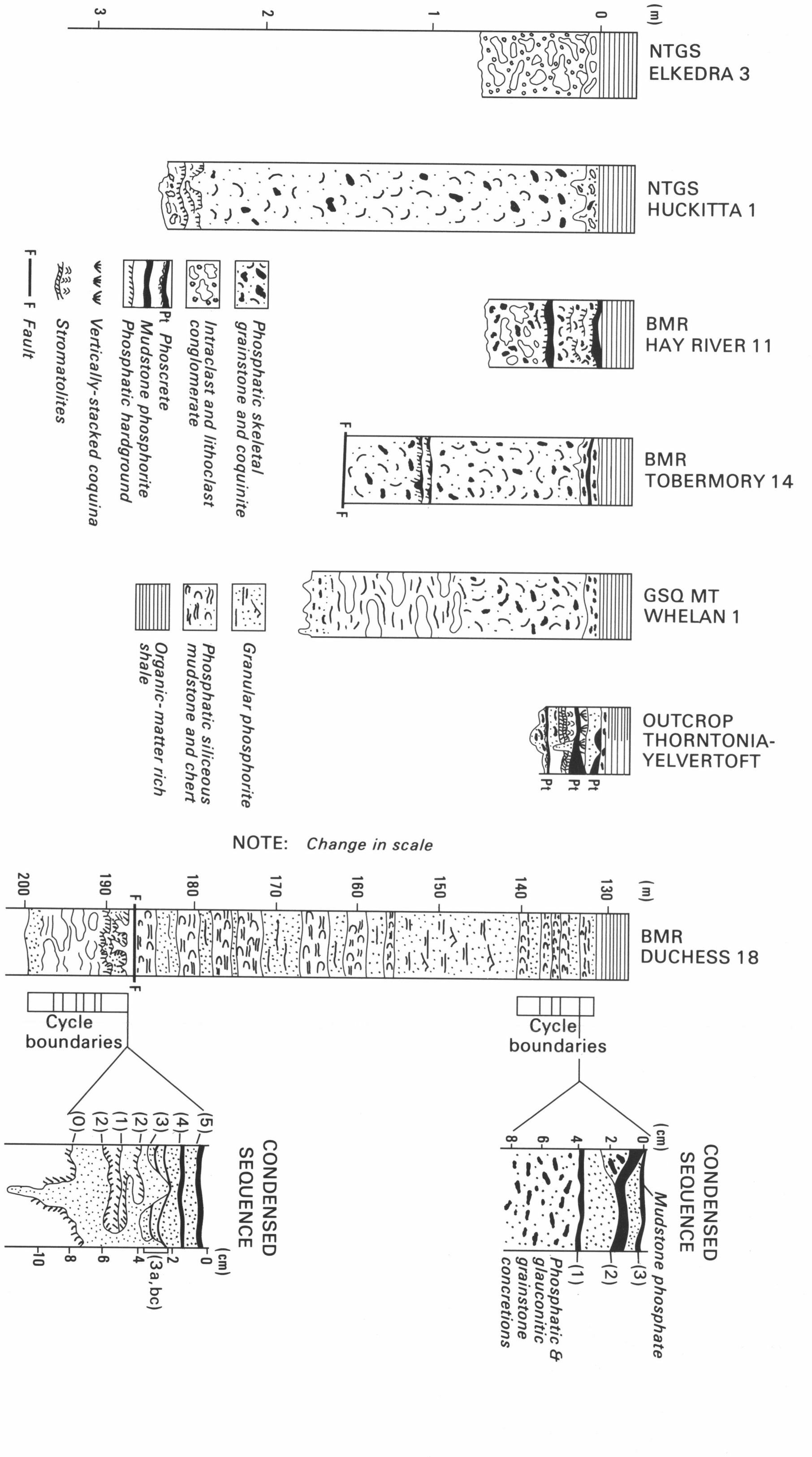


Figure 10. Distribution of phosphatic coquinite, skeletal grainstone and intraclastic conglomerate in drill core and outcrop for the first couple of retrogradational parasequences at the bottom of sequence 2.

The column shown for Duchess No. 18 depicts the three parasequence sets recognised in this hole. The interval from 187.73 m to 199.52 m shows a typical parasequence in parasequence set 1; the boundaries of individual cycles are shown on the right hand side. Parasequence set 2 (140.72–187.73 m) commences with the development of a condensed interval with a complex array of sediment bypass surfaces (right hand side). In the drill core, most of the organic-matter rich shale (dysaerobic depositional environments) that normally occurs beneath a deposit is missing due to faulting; it outcrops elsewhere on Rogers Ridge. Parasequence set 3 (140.72 m and upwards) consists of 5 retrogradational transgressive cycles between 140.72 m and 132.50 m. Above this, organic-matter rich shale of the Inca Formation passes gradationally upwards into Devoncourt Limestone.

East of the Dulcie Syncline, organic-matter rich shale in BMR Sandover No. 13 (Fig. 2 D) and Exoil Lucy Creek No. 1 (Fig. 2 F) is correlated with the previously described sediments (Fig. 6). Further east, in the Toko Syncline, sediment deposition in sequence 2 began in parasequence set 3 time, with the accumulation of reworked lag deposits and coquinite in thin retrogradational transgressive cycles (Fig. 10). This phase of rapid transgression deposited organic-matter rich shale of the Inca Formation and Blazan Shale, which correlates with similar facies to the west.

Summary

Three faunal assemblages occur in the regionally extensive blanket of organic-matter rich shale that characterises the transgressive systems tract of sequence 2 (Figs 4, 6, 11). As each assemblage coincides with a period of rapid onlap, followed by aggradation and progradation, the faunal assemblages are used to define the three parasequence sets. Similar facies patterns characterise each parasequence set. Reworked lag deposits, often phosphatic and coquinitic, and phosphate-encrusted sediment starvation surfaces occur at the base of each parasequence set (Fig. 10). In deeper water settings, these sediments are rapidly succeeded by anaerobic or dysaerobic organic-matter rich shale and siltstone (Fig. 11). Phosphatic limestone and phosphorite was initially deposited in laterally equivalent, shallower water environments. Later, as shallowing took place, these sediments prograded over the organic-matter rich shale facies. The initial flooding surface occurs in the basal lag. Subsidiary flooding surfaces occur in the organic-matter rich shale facies, the associated, spicular and concretionary limestone facies or the laterally equivalent phosphorite facies. The phosphatic rocks accumulated as aggradational and progradational parasequences in the upper parts of the parasequence set. Phosphate sedimentation ceased when the next rise in relative sea level resulted in the deposition of organic-matter rich shale.

Highstand systems tract

Although phosphate deposition is restricted to the transgressive systems tract, rocks of the highstand systems tract in sequence 2 are included in this study, to place the phosphatic interval in its stratigraphic context and to illustrate the dramatic changes that take place in Cambrian palaeogeography at this time (Figs 5, 6, 11, 12). Rocks of the highstand systems tract were deposited over the entire basin. The maximum flooding surface, which defines its lower boundary, is interpreted to occur within the organic-matter rich shale facies. The upper boundary coincides with the base of the Arrinthrunga Formation and its correlative formations (Fig. 4). Along the northern and southern transects, shallow water platform facies are found in the north and west in Domain 1; deeper water ramp and basinal facies occur in the south and east in Domains 2 and 3.

Northern Transect — Frewena to May Downs. Sediments of the highstand systems tract were deposited on a shallow water platform and a drowned ramp (Figs 5, 11, 12). De Keyser & Cook (1973) interpreted the Camooweal Dolomite as a large carbonate platform or shoal dominated by shallow water and supratidal hypersaline environments. The Age Creek Formation, a thick to thinly bedded grainstone unit present in foresets that dip to the southeast at 5–30° (Randal & Brown, 1962), is interpreted as defining the eastern margin of this platform. To the east, rocks of the Age Creek Formation interfinger with, and eventually pass into, nodular, ribbon and parted limestone and dolomitic limestone of the Currant Bush, V Creek and Mail Change Limestones (terminology after James & Stevens, 1986). These cherty mud-supported rocks contain articulated trilobites (which indicate an open marine fauna) and thin beds of skeletal debris. Burrows are common, and some lithified beds are punctured by *Trypanites* sp. borings to form hardgrounds. Thin beds of flat pebble conglomerate and intraclast breccia are interbedded with the mud-supported rocks, which lack features indicating subaerial exposure. Collectively, these features suggest deposition in comparatively deep water in a ramp setting.

Stratigraphic drilling in the Totts Creek area (Fig. 2 E′), close to the boundary of Domains 1 and 2 on the northern transect, intersected carbonate rocks which show a transition from ribbon and parted limestone at the base (Currant Bush, V Creek and Mail Change Limestones), through cross-bedded grainstone (Age Creek Formation) into recrystallised dolostone (Camooweal Dolomite). Such a transition is interpreted as a catch-up carbonate system (Sarg, 1988). Initial sediment aggradation took place in comparatively deep water below fair weather wave base (cf. Read, 1985) on a drowned ramp inclined in a southeasterly direction (Figs 11, 12). Water depths increased towards the present Mt Isa Block. Cross-bedded grainstones of the Age Creek Formation defined the edge of the platform and separated mud-supported carbonate rocks deposited in a ramp setting in Domain 3, from platform dolostone of the Camooweal Dolomite in Domain 1. Post-Cambrian erosion has removed the upper parts of this systems tract.

Northern Transect — Roaring Bore to Black Mountain. With the exception of the Burke River Structural Belt and its northern extension, the Landsborough Trough, post-Cambrian uplift of the Mt Isa Block and subsequent erosion has removed sediments of the highstand systems tract deposited north of present latitude 22°S. In the Burke River Structural Belt, laminated and concretionary limestone of the highstand systems tract (Devoncourt Limestone) was deposited in deep water outer-ramp environments. In parts of the Burke River Structural Belt there is evidence for synsedimentary tectonism at this time. At Rogers Ridge, organic-matter rich shale and phosphorite of the transgressive systems tract has an early to late Floran age. These same sediments have conformable and gradational contacts with rhythmically laminated and concretionary limestone of the highstand systems tract (Devoncourt Limestone). However, some 50 km north, at Roaring Bore (Fig. 2 M′), a hiatus spanning the Templetonian, Floran and Undillan stages of the Middle Cambrian separates dolostones of sequence 1 from organic-matter rich shale of the transgressive systems tract of sequence 2. Such a marked hiatus in an area of deep water sedimentation suggests that tectonic subsidence partly controlled relative sea level in this part of the basin.

Southern Transect. In the northwestern parts of this transect, organic-matter rich shale of the transgressive systems tract passes both vertically and laterally into carbonate rocks deposited in shelf and peritidal environments (Fig. 6). Thinning of this sequence in a westerly direction suggests progressive onlap over a basement high (Fig. 12). Sediment progradation, initially as a

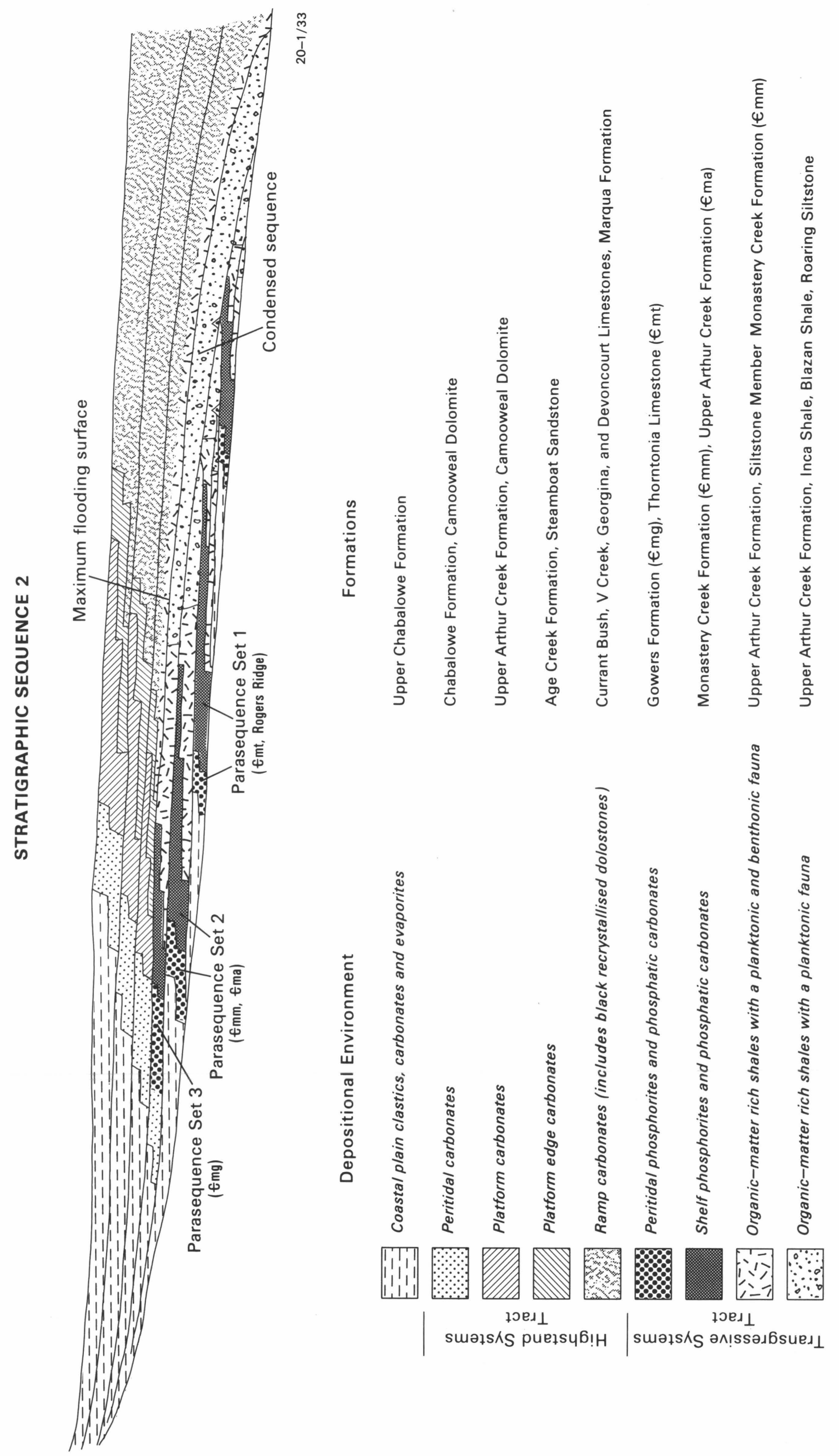


Figure 11. Modified sequence stratigraphic cross-section, showing the relative positions of formations and their constituent facies in stratigraphic sequence 2.
After Van Wagoner & others, 1988.

probable barrier-bar and lagoon system associated with the basement high, and later from other shoaling areas, eventually produced supratidal conditions and the accumulation of sulphate evaporite minerals in sabkha settings (Hagen Member of the Chabalowe Formation, Stidolph & others, 1988). As progradation continued, cross-laminated sandstone and desiccated, thinly bedded siltstone and mudstone accumulated in marginal marine playas and ephemeral streams of the coastal plain facies belt, landward of the previously described sabkhas. Periodic marine incursions promoted a return to lagoonal and sabkha environments. In Elkedra No.

7 (Fig. 2 A), these stromatolitic interbeds become progressively less frequent in the upper parts of the Chabalowe Formation.

Between Exoil Lucy Creek No. 1 (Fig. 2 F) and GSQ Mt Whelan No. 1 (Figs 2 K, 6) organic-matter rich shale of the transgressive systems tract grades into nodular, ribbon, parted and rhythmically laminated carbonate rocks of the highstand systems tract (Upper Hay River Formation, Georgina Limestone and Marqua Beds), and cross-stratified quartzitic carbonate rocks and sandstone of the Marqua Beds and Steamboat Sandstone. In this part of the basin, rocks of the highstand systems tract

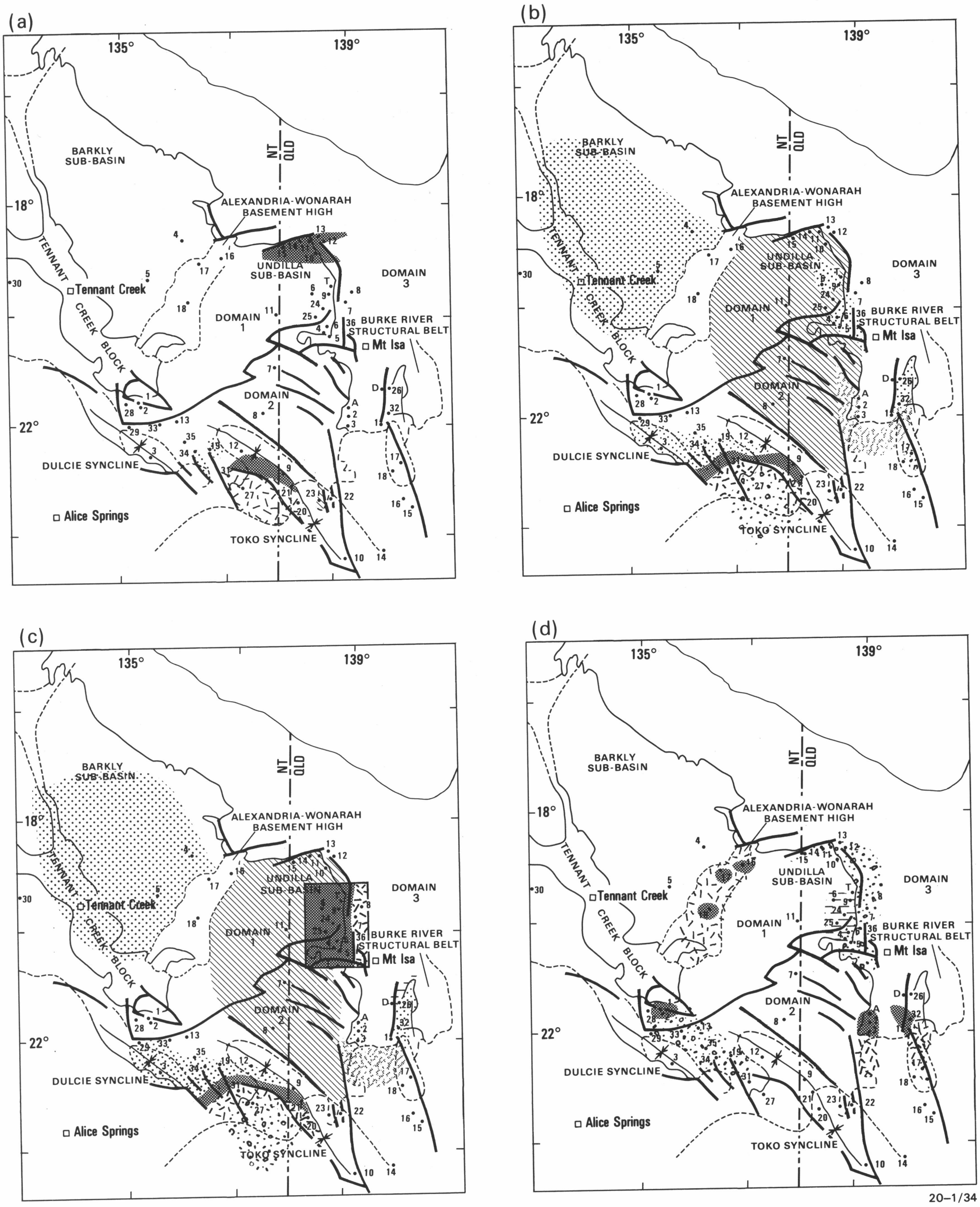


Figure 12. Palaeogeographic maps for stratigraphic sequences 1 and 2 structural elements and domains have been used to constrain boundaries on the maps.
Sequence 1a is shown as an inset in 12c, to emphasise the local tectonically induced aspect of this sequence and place it in its regional context.
a. Sequence 1, early transgressive systems tract. Initial onlap took place from the north in the Highland Plains to Riversleigh region to form the phosphate deposits. Transgression also occurred in the Toko Syncline region.
b. Sequence 1, highstand systems tract. Continued gradual onlap produced a mosaic of lithofacies in the early Middle Cambrian. Organic-matter rich shale accumulated in possible structural compartments in the southern parts of the basin.
c. Sequence 2. Rapid subsidence of the Mt Isa Block led to local tectonically enhanced onlap and the deposition of phosphatic sediments and their associated source rocks.
d. Sequence 2, parasequence set 2. Following a regional lowering in relative sea level, organic-matter rich source rocks and associated phosphorites were deposited in a number of structurally defined compartments.

thicken in a southerly direction. In PAP Netting Fence No. 1 (Fig. 2 J), they attain a maximum thickness of 600 m (Fig. 6). A BMR seismic survey of the Toko Syncline identified a 400 m thick southeasterly prograding sequence referred to the Marqua Beds and Steamboat Sandstone (Harrison, 1979). The gradual passage from fine-grained micritic and silty carbonate sediments deposited on a drowned platform or ramp, to shallower water and coarser grained sandy limestone and sandstone of the prograding sequence infers initial sediment aggradation in relatively deep water, followed by rapid progradation in shallower water (Figs 11, 12). Harrison (1979) interpreted the prograding sequence as indicating high sediment supply, slow basin subsidence

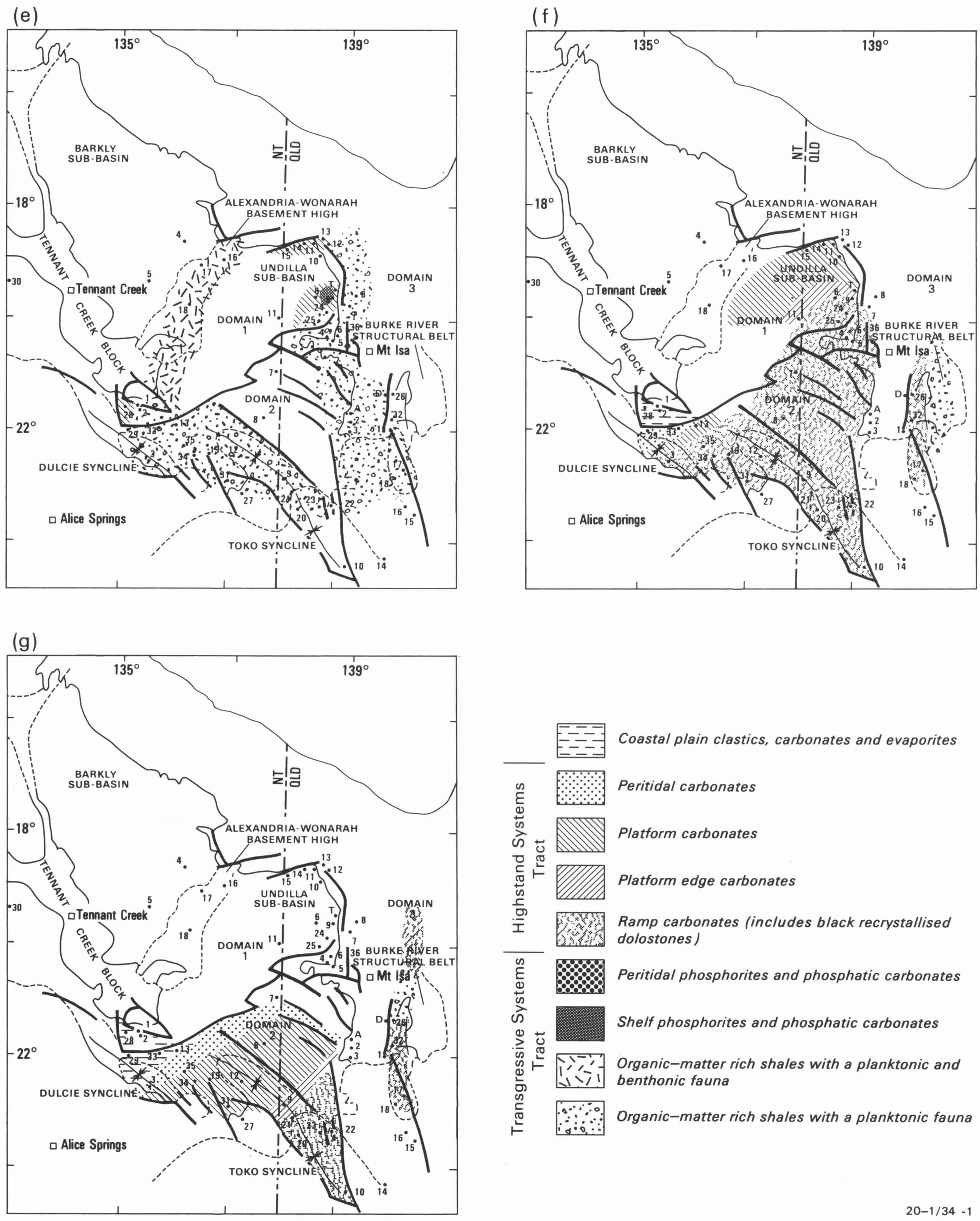


Figure 12 (continued)

e. Sequence 2, parasequence set 3. Continued onlap led to further deposition of organic-matter rich shale and associated phosphorite in structurally defined compartments. Clear water carbonate deposition commenced in structurally stable platform settings. Phosphatic limestone of the Gowers Formation was deposited during onlap of a structural high in the vicinity of Thorntonia Station.

f. Early highstand systems tract. A stable platform area developed in Domain 1. Deeper water carbonates accumulated on a southeasterly dipping ramp.

g. Sediment accumulation and a possible relative lowering in relative sea level resulted in gradual regression in a southeasterly direction. Mixed carbonates and siliciclastics formed a southeasterly dipping and prograding sequence in the region of the Toko Syncline.

and a stillstand of sea level. Such conditions are compatible with sedimentation in a highstand systems tract.

Thus, on the southern transect, water depths gradually increased from west to east (Figs 11, 12). In the west, peritidal carbonate sediments accumulated in shoal and sabkha environments on a carbonate platform, and a shoreline probably existed to the west of Elkedra No. 6 (Fig. 2 B). Gradual sediment accumulation during the highstand systems tract led to progradation of this shoreline in an easterly direction toward BMR Sandover No. 13 (Fig. 2 D; correlations in Stidolph & others, 1988). To the east, deeper water micritic and silty limestone accumulated on a southeasterly dipping drowned ramp (Figs 11, 12). The platform–ramp transition probably lay along the southern boundary of Domain 1. Quartz grains in the Marqua Beds and Steamboat Sandstone were probably derived from emergent basement in this domain.

The upper sequence boundary with the Arrinthrunga Formation and its correlatives changes in character from west to east. This reflects the change from terrestrial environments in the west to progressively deeper water platform and ramp settings in the east. In the west, peloid grainstones of the Arrinthrunga Formation (Kennard, 1981) onlap emergent coastal plain and peritidal sediments of the Chabalowe Formation. Further east, a gradational contact up to several metres thick occurs between peloid grainstones of the Arrinthrunga Formation and submergent platform carbonates and siliciclastics of the Arthur Creek and Marqua Formations (Kennard, 1981). In the far east, the Arrinthrunga Formation correlates with the outer ramp, nodular and rhythmically laminated carbonate rocks of the Georgina, Devoncourt and Selwyn Range Limestones.

Implications for phosphogenesis and organic-matter rich shale deposition

Riggs (1979) classified sedimentary phosphorites into two broad categories, (1) phosphate deposits of economic significance which form during periods of abnormal sedimentation, and (2) phosphatic occurrences associated with unconformities or surfaces of sediment bypass and non-deposition. Analysis of the distribution of economic phosphate deposits (Cook & McElhinny, 1979) supported the ideas of Riggs (1979), indicating that economic phosphate deposits have an episodic distribution, with peaks in the Late Proterozoic–Middle Cambrian, Ordovician, Permian, Jurassic, Late Cretaceous to Eocene and Miocene. With the advent of sequence stratigraphy (Van Wagoner & others, 1988), the regional importance of phosphatic hardgrounds associated with surfaces of sediment bypass, as indicators of condensed sections, and surfaces of maximum flooding, became apparent (Loutit & others, 1988).

The position of major economic phosphate deposits within the stratigraphic sequence model proposed by the EXXON group remained unclear. Sedimentological studies of economic phosphate deposits of Proterozoic and Cambrian age (Cook & Shergold, 1986), those of Late Cretaceous to Eocene age (Slansky, 1980; Soudry, 1987) and the Miocene deposits of Florida (Riggs, 1979) all indicate deposition in shallow submergent and, at times, emergent environments. Such shallow water environments appear incompatible with the deeper water continental margin settings considered as the depositional sites for phosphatic condensed sequences (Loutit & others, 1988). Yet the mineral and facies assemblages in both environmental settings are similar. Like phosphatic rocks in condensed sequences (Loutit & others, 1988), economic phosphate deposits are usually associated with the authigenic mineral glauconite and organic-matter rich sediments with anomalously high concentrations of noble metals (e.g. Shergold, 1985).

Sequence stratigraphic analysis of Middle Cambrian sediments in the Georgina Basin may provide an answer to some of these questions. In stratigraphic sequence 1, phosphate deposits in the Highland Plains to Riversleigh region are related to gradual onlap of the palaeocontinent (Figs 8, 9, 12). In sequence 1a, phosphate deposits in the Thorntonia, D Tree, Yelvertoft and Lady Annie areas occur in the transgressive systems tract and are related to early subsidence of the Mt Isa block and the creation of a new seaway deepening in a southeasterly direction (Figs 8, 9, 12). Phosphate deposits and occurrences in the Burke River Structural Belt, Ardmore, the southwestern parts of the basin and Thorntonia, found in stratigraphic sequence 2, are related to gradual onlap of the palaeocontinent during a second major rise in relative sea level (Figs 11, 12). The confinement of phosphate deposits and occurrences to retrogradational parasequence sets of the transgressive systems tract provides a link with the condensed sequences of Loutit & others (1988). Whereas condensed sequences occur in deep water environments with slow sedimentation rates, phosphate deposits in the Georgina Basin formed in shallow water environments in areas of more rapid sedimentation. Facies analysis of the phosphatic suite of sediments indicates that they were deposited in a range of environments varying from shallow shelf and emergent (economic phosphate deposits) to outer shelf and possibly basinal (condensed sequences).

In stratigraphic sequence 1, phosphatic sediments in the Highland Plains to Riversleigh region accumulated in a variety of semi-emergent to submergent peritidal environments (Southgate, 1988). At the same time, the organic-matter rich shale facies, with its interbedded glauconitic and phosphatic wackestone laminae and associated phosphatic hardgrounds (condensed sequence), formed in deeper water restricted environments in the Tobermory and Hay River areas (Figs 8, 12). Similar relationships occur in sequence 1a, where semi-emergent to shallow submergent phosphorites of the Lady Annie, D Tree and Yelvertoft deposits overlie and pass laterally into organic-matter rich shale of the Beetle Creek Formation (Fig. 9). The shale contains a rich fauna of benthonic and planktonic organisms. This suggests that, in proximal shallower water conditions, oxygen concentrations in the bottom waters fluctuated, permitting periodic colonisation by a benthonic fauna, subsequently killed by increasing anoxia. In sequence 2, the facies mosaic is once again repeated (Figs 11, 12). Continued transgression here eventually led to complete drowning of the continent, and the formation of depositional environments unsuitable for economic phosphate deposition.

Examination of the three parasequence sets in sequence 2 shows how this process takes place. During parasequence set 1 time, phosphatic limestone rocks at

Rogers Ridge accumulated in semi-emergent and shallow submergent environments, while organic-matter rich shale accumulated in deeper water environments to the south (Figs 11, 12). The next phase of onlap resulted in the deposition of parasequence set 2. At Rogers Ridge, these sediments overlie the transgressive surface, a 5 cm thick condensed interval of phosphatic and glauconitic wackestone and packstone cemented by phosphate to form phosphatic hardgrounds and crusts. Siliceous, organic-matter rich shale with interbedded packstone and mudstone phosphorite and a benthonic and planktonic trilobite fauna accumulated above the transgressive surface. The maximum flooding surface for this parasequence set probably lies within the siliceous shale beds, which grade both vertically and laterally into phosphatic grain-supported and mud-supported rocks forming the deposits.

These sediments accumulated in a variety of semi-emergent to submergent environments. The deposition of mud-supported and grain-supported phosphorite in the Burke River Structural Belt and at Ardmore coincided with accumulation of deeper water organic-matter rich shale and phosphorite, with interlaminated phosphatic hardgrounds, in the Huckitta and Elkedra areas in the southwest of the basin. At Rogers Ridge, the next phase of onlap resulted in five cycles, each capped by concretions of phosphatic and glauconitic spicular wackestone and packstone. Some of these concretions have eroded upper surfaces and associated phosphate crusts, thus inferring that each of these cycles is capped by a sediment starvation surface, and that the boundary between parasequence sets 2 and 3 is a condensed interval.

In the Rogers Ridge area, the transgression responsible for parasequence set 3 resulted in the termination of phosphate deposition and the accumulation of an organic-matter rich shale facies with a planktonic fauna (Figs 5, 11, 12). Elsewhere, phosphatic sediments of the Gowers Formation were deposited on a palaeohigh to the south of Thorntonia Station, while in the southwest and south of the basin the organic-matter rich shale facies, in which planktonic faunal elements are found but benthonic faunal components are lacking, accumulated above sediments of parasequence 1 or the transgressive surface.

As transgression continued, and water depths increased, anaerobic conditions responsible for the preservation of organic-matter rich shale were replaced by dysaerobic and aerobic bottom waters. Rhythmically laminated, nodular, ribbon and parted limestone was deposited there (Figs 11, 12). This sequence of events is probably related to changes in productivity and preservation potential of the organic matter. As water depths increased, the residence time for planktonic organic matter in the oxygenated portion of the water column also increased. This resulted in elevated levels of organic matter degradation before it reached the sea floor, a decline in bottom water anoxia, and eventually an oxic watercolumn. As onlap took place, oceanic circulation patterns would have changed, enabling cold, nutrient-rich waters to upwell on to the former continent.

The most vigorous upwelling and highest productivity probably coincided with the initial phases of transgression, resulting in the accumulation of organic-matter rich shale and phosphorite in shallow water embayed environments. Dysaerobic, and periodically aerobic, conditions permitted the development of a benthonic fauna in the near-shore shale facies, possibly as upwelling events increased in intensity and later decayed. Subsequent onlap led to deeper water and permanently anaerobic bottom waters in which organic-matter rich shale devoid of a benthonic fauna accumulated. Later, as water depth increased, circulation patterns stabilised, upwelling declined and productivity decreased. This resulted in a decline in organic material available for preservation on the seafloor, and as a consequence a return to more oxygenated bottom waters.

The sequence of events outlined above, although doubtless simplified, explains the consistent facies patterns observed in the transgressive systems tracts. Phosphorite, and its associated organic-matter rich shale facies that contains a benthonic fauna, accumulated in shallow water embayed and locally restricted environments subject to rapid fluctuations in oxygen concentrations, probably caused by variations in the intensity of upwelling events. With continuing onlap and increased water depth, the zone of vigorous upwelling moved shoreward, permitting the establishment of an oxygen minimum zone in the region of former phosphorite sedimentation. This in turn resulted in the accumulation of organic-matter rich shale devoid of a benthonic fauna. Subsequent onlap led to increased water depths, less vigorous upwelling and a gradual return to aerobic bottom water conditions in which deeper water ramp carbonate of the highstand systems tract accumulated.

Riggs (1979, 1984) has proposed an integrated model to explain the genesis of economic phosphate deposits of Neogene age in Florida and North Carolina. Although these deposits are much younger than the Cambrian sediments discussed here, many aspects of phosphate deposition in the southeastern USA are similar to those of the Georgina Basin. Riggs (1984) relates phosphate deposition to eustatic changes in relative sea level during the Neogene. Specifically, phosphate deposits of the southeastern USA accumulated during times of transgression when the Gulf Stream and its associated nutrient-rich waters moved on to the continental shelf, permitting the formation of shallow water environments suitable for phosphate deposition. Periods of maximum sea level rise coincide with the deposition of carbonate sediments and correspond with a cessation in phosphorite deposition. Riggs (1984) related Miocene phosphogenesis of the southeastern USA to the interplay of a variety of factors, including glacial eustatic sea level oscillations, bathymetric configuration, changes in the dynamics of the Gulf Stream and climate.

Although it is not possible to reconstruct Middle Cambrian palaeo-oceanographic conditions in the same detail, there are many similarities between the two suites of phosphatic sediments. In both cases phosphate deposits occurred during periods of major transgression, and phosphate deposition was greatest on the flanks of palaeobathymetric highs. Spatial positioning of phosphate deposits in sequence 1 was controlled by the interaction between relative sea level rise and palaeotopography (Southgate, 1988). Russell & Trueman (1971) interpreted similar relationships for the Duchess deposits and phosphatic limestone in the Gowers Formation also occurs on a palaeotopographic high.

Cyclical processes in deposition are recognised in Middle Cambrian and Neogene deposits, although a hierarchical system has not been established for the Cambrian cycles. In the Georgina Basin deposits, the transgressive systems tract in sequence 2 is divided into 3 parasequence sets. In sequence 1, onlap of phosphatic facies attributed to the highstand systems tract resulted in the inclusion of sequence 1a, a parasequence set, in the upper parts of sequence 1.

Each of these parasequence sets has its own transgressive surface, followed by several thin retrogradational cycles and an interval of organic-matter rich shale accumulation. The uppermost part of the parasequence set is then characterised by the aggradational and progradational accumulation of packstone and grainstone phosphorite. This suggests that each parasequence set may represent a lower order sequence. If this scenario is correct, the two sequences discussed here may be at the supercycle scale (Haq & others, 1988), and the parasequence sets may be comparable to the third order cycles of Haq & others (1988). This problem will be resolved when there is consensus on the age of the base of the Cambrian (e.g. Conway Morris, 1988) and additional sequence stratigraphic studies are undertaken in central Australia.

Conclusions

1. Phosphate deposits and occurrences of Middle Cambrian age in the Georgina Basin occur in two stratigraphic sequences. In each sequence they are restricted to the upper, progradational parts of retrogradational parasequence sets of the transgressive systems tract.
2. Phosphate deposits in sequence 1 are restricted to the northeast of the basin, between Highland Plains and Riversleigh. These deposits are related to gradual transgression of an irregular palaeotopography by a sea that deepened to the north.
3. Phosphate deposits in tectonically enhanced sequence 1a are restricted to the northeast of the basin between Thorntonia and Yelvertoft. These deposits accumulated in response to the synsedimentary subsidence of the Mt Isa block, creating a seaway that deepened to the southeast.
4. Phosphate deposits in sequence 2 are found in the Burke River Structural Belt, Ardmore Outlier, Huckitta–Elkedra region, along the Alexandria–Wonarah Basement High and near Thorntonia Station. These deposits are related to a stepped rise in relative sea level that completely inundated and drowned the palaeocontinent.
5. Carbonate rocks are the principal lithological component of the highstand systems tract in both stratigraphic sequences.
6. In the highstand systems tract of sequence 2, carbonate rocks, evaporites and mixed siliciclastics accumulated in coastal plain, platform and ramp depositional environments.
7. Organic-matter rich shale is best developed in the transgressive systems tract. Shale with benthonic and planktonic faunal components accumulated in dysaerobic environments close to the upper boundary of the oxygen minimum zone. These shale facies usually underlie phosphate facies of the same parasequence or parasequence set. Organic-matter rich shale with planktonic faunal components, but lacking benthos, accumulated in anaerobic bottom waters within the oxygen minimum zone. These sediments usually overlie phosphorites and as such occur in the next parasequence or parasequence set.
8. Difficulties in correlating sequences between structural domains, and across major structural features within domains, suggest that sedimentary facies are controlled by structural compartments. Lack of facies continuity is most pronounced in sediments of the transgressive systems tract, where phosphorites and organic-matter rich shales are the principal sediments.

Acknowledgements

Many people have provided assistance during the course of this work. Discussions with John Kennard and John Laurie helped us evolve some of the ideas presented here. The manuscript was improved by the constructive criticisms of Colin Gatehouse and David Feary. The assistance and support provided by Peter Cook and Malcolm Walter throughout the project are gratefully acknowledged.

References

Conway Morris, S., 1988 — Radiometric dating of the Precambrian–Cambrian boundary in the Avalon Zone. *In* Landing, E., Narbonne, G.M. & Myrow, P. (editors), Proceedings, Trace fossils, small shelly fossils and the Precambrian–Cambrian boundary, 1987, Memorial University. *New York State Geological Survey, Bulletin* 463, 53–58.

Cook, P.J. & Elgueta, S.A., 1986 — Proterozoic and Cambrian phosphorites - deposits: Lady Annie, Queensland, Australia. *In* Cook, P.J. & Shergold, J.H. (editors), Phosphate deposits of the world. 1: Proterozoic and Cambrian phosphorites. *Cambridge University Press, Cambridge*, 132–148.

Cook, P.J. & McElhinny, M.W., 1979 — A re-evaluation of the spatial and temporal distribution of sedimentary phosphate deposits in the light of plate tectonics. *Economic Geology*, 74, 315–330.

Cook, P.J. & Shergold, J.H., 1986 — Proterozoic and Cambrian phosphorites — nature and origin. *In* Cook, P.J. & Shergold, J.H. (editors), Phosphate deposits of the world. 1: Proterozoic and Cambrian phosphorites. *Cambridge University Press, Cambridge*, 369–386.

de Keyser, F., 1968 — The Cambrian of the Burke River outlier. *Bureau of Mineral Resources, Australia, Record* 1968/67.

de Keyser, F., 1969 — The phosphate-bearing Cambrian formations in the Lawn Hill and Lady Annie districts, northwestern Queensland. *Bureau of Mineral Resources, Australia, Record* 1969/147.

de Keyser, F., 1973 — A review of the Middle Cambrian stratigraphy in the Queensland portion of the Georgina Basin. *Bureau of Mineral Resources, Australia, Bulletin* 139, 13–27.

de Keyser, F. & Cook, P.J., 1973 — Geology of the Middle Cambrian phosphorites and associated sediments in northwestern Queensland. *Bureau of Mineral Resources, Australia, Bulletin* 138, 79 pp.

Donnelly, T.H., Shergold, J.H. & Southgate, P.N., 1988 — Anomalous geochemical signals from phosphatic Middle Cambrian rocks in the southern Georgina Basin, Australia. *Sedimentology*, 35, 549–570.

Fleming, P.J.G., 1971 — *In* Hill, D., Playford, G. & Woods J.T. (editors), Cambrian fossils of Queensland. *Queensland Palaeontographical Society, Brisbane*, 32 pp., 15 pl.

Fleming, P.J.G., 1973 — Bradoriids from the *Xystridura* Zone of the Georgina Basin, Queensland. *Geological Survey of Queensland, Publication* 356, *Palaeontological Papers*, 31, 9 pp.

Freeman, M.J., 1986 — Huckitta SF53-11, 1:250 000 Geological Map Series Explanatory Notes. *Northern Territory Geological Survey, Darwin*, 58 pp.

Green, P.M. & Balfe, P.E., 1980 — Stratigraphic drilling report — GSQ Mt Whelan 1 and 2. *Queensland Government Mining Journal*, 81 (941), 162–178.

Haq, B.U., Hardenbol, J. & Vail, P.R., 1988 — Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. *In* Wilgus, C.K. & others (editors), Sea-level changes : an integrated approach. *Society of Economic Paleontologists and Mineralogists, Special Publication* 42, 71–108.

Harrison, P.L., 1979 — Recent seismic studies upgrade the petroleum prospects of the Toko Syncline, Georgina Basin. *The APEA Journal*, 19 (1), 30–42.

Henderson, R.A. & McKinnon, D.I., 1981 — New Cambrian inarticulate Brachiopoda from Australasia, and the age of the Tasman Formation. *Alcheringa*, 5(3), 289–310.

Henderson, R.A. & Shergold, J.H., 1971 — *Cyclocystoides* from early Middle Cambrian rocks of northwestern Queensland, Australia. *Palaeontology*, 14(4), 704–710, pl. 138.

Howard, P.E. & Cooney, A., 1976 — D Tree phosphate deposit, Georgina Basin, Queensland. *In* Knight, C.L. (editor), Economic geology of Australia and Papua New Guinea. 4. Industrial minerals and rocks. *Australasian Institute of Mining and Metallurgy, Melbourne, Monograph* 8, 273–278.

James, N.P & Stevens, R.K., 1986 — Stratigraphy and correlation of the Cambro-Ordovician Cow Head Group Western Newfoundland. *Geological Survey of Canada, Bulletin* 366, 143 pp.

Jell, P.A., 1970 — *Pagetia ocellata*, a new Cambrian trilobite from northwestern Queensland. *Memoirs of the Queensland Museum*, 15, 303–313, pl. 23–24.

Jell, P.A., 1975 — Australian Middle Cambrian eodiscoids with a review of the Superfamily. *Palaeontographica* [A] 150, 97 pp.

Jell, P.A., Burrett, C.F. & Banks, M.R., 1985 — Cambrian and Ordovician echinoderms from eastern Australia. *Alcheringa*, 9, 183–208.

Jones, P.J. & McKenzie, K.G., 1980 — Queensland Middle Cambrian Bradoriida (Crustacea): new taxa, palaeobiogeography, and biological affinities. *Alcheringa*, 4(3), 203–225.

Kennard, J.M., 1981 — The Arrinthrunga Formation — Upper Cambrian epeiric carbonates in the Georgina Basin, central Australia. *Bureau of Mineral Resources, Australia, Bulletin* 211, 61 pp.

Laurie, J.R., 1988 — Revision of some Australian Ptychagnostinae (Agnostida, Cambrian). *Alcheringa*, 12, 169–205.

Laurie, J.R., 1989 — Revision of species of *Goniagnostus* Howell and *Lejopyge* Corda from Australia (Agnostida, Cambrian). *Alcheringa*, 13, 175–191.

Lindsay, J.F., Korsch, R.J. & Wilford, J.R., 1987 — Timing the breakup of a Proterozoic supercontinent: evidence from Australian intracratonic basins. *Geology*, 15, 1061–1064.

Loutit, T.S., Hardenbol, J., Vail, P.R. & Baum, G.R., 1988 — Condensed sections: the key to age determination and correlation of continental margin sequences. *In* Wilgus, C.K. & others (editors), Sea-level changes: an integrated approach. *Society of Economic Palaeontologists and Mineralogists, Special Publication*, 42, 183–213.

Nordlund, U. & Southgate, P.N., 1988 — Depositional environments and importance of the early Middle Cambrian sequence at Rogers Ridge, Georgina Basin, W. Queensland. *Acta Universitatis Upsaliensis, Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science*, 170(6), 19 pp.

Öpik, A.A., 1956 — Cambrian geology of Queensland. *20th Session International Geological Congress, Mexico*, 2, 1–24.

Öpik, A.A., 1960 — Cambrian and Ordovician geology (of Queensland). *Geological Society of Australia, Journal*, 7, 89–109.

Öpik, A.A., 1961 — Geology and palaeontology of the headwaters of the Burke River, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* 53, 249 pp., 24 pl.

Öpik, A.A., 1968a — The Ordian Stage of the Cambrian and its Australian Metadoxididae. *Bureau of Mineral Resources, Australia, Bulletin* 92, 133–170, pl. 19–20.

Öpik, A.A., 1968b — Ordian (Cambrian) Crustacea Bradoriida of Australia. *Bureau of Mineral Resources, Australia, Bulletin* 103, 37 pp., 4 pl.

Öpik, A.A., 1970a — Nepeiid trilobites of the Middle Cambrian of northern Australia. *Bureau of Mineral Resources, Australia, Bulletin* 113, 48 pp., 17 pl.

Öpik, A.A., 1970b — *Redlichia* of the Ordian (Cambrian) of northern Australia. *Bureau of Mineral Resources, Australia, Bulletin* 114, 66 pp., 14 pl.

Öpik, A.A., 1975 — Templetonian and Ordian xystridurid trilobites of Australia. *Bureau of Mineral Resources, Australia, Bulletin* 121, 84 pp., 32 pl.

Öpik, A.A., 1979 — Middle Cambrian agnostids: systematics and biostratigraphy. *Bureau of Mineral Resources, Australia, Bulletin* 172 (2 vols), 188 pp., 67 pl.

Öpik, A.A., 1982 — Dolichometopid trilobites of Queensland, Northern Territory and New South Wales. *Bureau of Mineral Resources, Australia, Bulletin* 175, 85 pp., 32 pl.

Öpik, A.A., Carter, E.K. & Noakes, L.C., 1961 — Mt Isa — 1:250 000 Geological Series Explanatory Notes, Sheet F/54-1. *Bureau of Mineral Resources, Australia*, 20 pp.

Randal, M.A. & Brown, G.A., 1962 — Additional notes on the geology of the Camooweal 4-mile sheet area. *Bureau of Mineral Resources, Australia, Record* 1962/49.

Read, J.F., 1985 — Carbonate platform facies models. *American Association of Petroleum Geologists, Bulletin* 69, 1–21.

Riggs, S.R., 1979 — Phosphorite sedimentation in Florida — a model phosphogenetic system. *Economic Geology*, 74, 285–314.

Riggs, S.R., 1984 — Paleoceanographic model of Neogene phosphorite deposition, US Atlantic continental margin. *Science*, 233 (4632), 123–131.

Rogers, J.K. & Crase, N.J., 1980 — The Phosphate Hill rock phosphate deposit, northwest Queensland, Australia — an outline of geological development. *In* Sheldon, R.P. & Burnett, W.C. (editors), Fertilizer mineral potential in Asia and the Pacific. Proceedings of the Fertilizer Raw Materials Resources Workshop, August 20–24, 1979, Honolulu, Hawaii. *East-West Resource Systems Institute, Honolulu*, 307–328.

Rogers, J.K. & Keevers, R.E., 1976 — Lady Annie — Lady Jane phosphate deposits, Georgina Basin, Queensland. *In* Knight, C.L. (editor), Economic geology of Australia and Papua New Guinea. 4. Industrial minerals and rocks. *Australasian Institute of Mining and Metallurgy, Melbourne, Monograph* 8, 251–265.

Runnegar, B.N. & Jell, P.A., 1976 — Australian Middle Cambrian molluscs and their bearing on early molluscan evolution. *Alcheringa*, 1(2), 109–138.

Russell, R.T., 1967 — Discovery of a major phosphate deposit in northwest Queensland. *Queensland Government Mining Journal*, 68, 153–157.

Russell, R.T. & Trueman, N.A., 1971 — The geology of the Duchess phosphate deposits, northwest Queensland, Australia. *Economic Geology*, 66, 1186–1214.

Sarg, J.F., 1989 — Carbonate sequence stratigraphy. *In* Wilgus, C.K. & others (editors), Sea-level changes: an integrated approach. *Society of Economic Paleontologists and Mineralogists, Special Publication* 42, 155–181.

Schmitt, M. & Southgate, P.N., 1982 — A phosphatic stromatolite, *Ilicta* cf. *composita* Sidorov, from the Middle Cambrian of northern Australia. *Alcheringa*, 6, 175–183.

Shergold, J.H., 1968 — Appendix: Cambrian Palaeontology. *In* de Keyser, F., The Cambrian of the Burke River outlier. *Bureau of Mineral Resources, Australia, Record* 1968/67.

Shergold, J.H., 1969 — Oryctocephalidae (Trilobita: Middle Cambrian) of Australia. *Bureau of Mineral Resources, Australia, Bulletin* 104, 66 pp., 12 pl.

Shergold, J.H., 1985 — Notes to accompany the Hay River-Mount Whelan Special 1:250 000 Geological Sheet, southern Georgina Basin. *Bureau of Mineral Resources, Australia, Report* 251, 47 pp.

Shergold, J.H., 1989 — Australian Phanerozoic timescales. 1, Cambrian. *Bureau of Mineral Resources, Australia, Record* 1989/31.

Shergold, J.H. & Brasier, M.D., 1986 — Proterozoic and Cambrian phosphorites — specialist studies: biochronology of Proterozoic and Cambrian phosphorites. *In* Cook, P.J. & Shergold, J.H. (editors), Phosphate deposits of the world. 1. Proterozoic and Cambrian phosphorites. *Cambridge University Press, Cambridge*, 295–326.

Shergold, J.H. & Druce, E.C., 1980 — Upper Proterozoic and Lower Palaeozoic rocks of the Georgina Basin. *In* Henderson, R.A. & Stephenson, P.J. (editors), The geology and geophysics of northeastern Australia. *Geological Society of Australia, Queensland Division, Brisbane*, 149–174.

Shergold, J.H. & Laurie, J.R., 1986 — Appendix 5: Palaeontological determinations from selected formations and field localities. *In* Shergold, J.H. & Southgate, P.N. (editors), Middle Cambrian phosphatic and calcareous lithofacies along the eastern margin of the Georgina Basin, Western Queensland. Australasian Sedimentologists Group, Field Guide Series 2. *Geological Society of Australia, Sydney*, 88–89.

Shergold, J.H. & Southgate, P.N. (editors), 1986 — Middle Cambrian phosphatic and calcareous lithofacies along the eastern margin of the Georgina Basin, western Queensland. Australasian Sedimentologists Group, Field Guide Series 2. *Geological Society of Australia, Sydney*, 89 pp.

Shergold, J.H. & Southgate, P.N., 1988 — Timing and distribution of Middle Cambrian phosphogenetic events in the Georgina Basin Australia. *In* A decade of phosphorite research and development. *11th International Field Workshop and Symposium, IGCP Project 156, Extended Abstracts*, 27–28.

Shergold, J.H., Southgate, P.N. & Cook, P.J., 1988 — Middle Cambrian phosphogenic system in Australia. BMR Research Symposium 88, Extended Abstracts. *Bureau of Mineral Resources, Australia, Record* 1988/42, 78–81.

Shergold, J.H., Southgate, P.N. & Cook, P.J., 1989 — New facts on old phosphates: Middle Cambrian, Georgina Basin. *BMR Research Newsletter, 10*, 14–15.

Slansky, M., 1980 — Géologie des phosphates sedimentaires. *Mémoire du BRGM*, 114, 92 pp.

Soudry, D., 1987 — Ultra-fine structures and genesis of the Campanian Negev high-grade phosphorites (southern Israel). *Sedimentology*, 34, 641–660.

Soudry, D. & Southgate, P.N., 1989 — Ultrastructure of a Middle Cambrian primary nonpelletal phosphorite and its early transformation into phosphate vadoids: Georgina Basin, Australia. *Journal of Sedimentary Petrology*, 59 (1), 53–64.

Southgate, P.N., 1982 — Cambrian skeletal halite crystals and experimental analogues. *Sedimentology*, 29, 391–407.

Southgate, P.N., 1983 — Middle Cambrian phosphatic and calcareous depositional environments, Undilla region of the Georgina Basin, Australia. *Ph.D. thesis, Australian National University, Canberra.*

Southgate, P.N., 1986a — Cambrian phoscrete profiles, coated grains, and microbial processes in phosphogenesis: Georgina Basin, Australia. *Journal of Sedimentary Petrology*, 56(3), 429–441.

Southgate, P.N., 1986b — Proterozoic and Cambrian phosphorites - specialist studies: Middle Cambrian phosphatic hardgrounds, phoscrete profiles and stromatolites and their implications for phosphogenesis. *In* Cook, P.J. & Shergold, J.H. (editors), Phosphate deposits of the World. 1. Proterozoic and Cambrian phosphorites. *Cambridge University Press, Cambridge,* 327–351.

Southgate, P.N., 1986c — The Gowers Formation and Bronco Stromatolith Bed, two new stratigraphic units in the Undilla portion of the Georgina Basin. *Queensland Government Mining Journal, October,* 407–411.

Southgate, P.N., 1988 — A model for the development of phosphatic and calcareous lithofacies in the Middle Cambrian Thorntonia Limestone, northeast Georgina Basin, Australia. *Australian Journal of Earth Sciences,* 35, 111–130.

Southgate, P.N., Laurie, J.R., Shergold, J.H. & Armstrong, K.J., 1988 — Stratigraphic drilling in the Georgina Basin, Burke River Structural Belt, August 1986–January 1987. *Bureau of Mineral Resources, Australia, Record* 1988/1.

Southgate, P.N. & Shergold, J.H., 1988 — Sequence stratigraphy and repeating facies mosaics in Middle Cambrian sediments of the Georgina Basin. *In* A decade of phosphate research and development. *11th International Field Workshop and Symposium, IGCP Project 156, Extended Abstracts*, 31–32.

Stidolph, P.A., Bagas, L., Donnellan, N., Walley, A.M., Morris, D.G. & Simons, B., 1988 — Elkedra SF53-7, 1:250 000 Geological Map Series Explanatory Notes. *Northern Territory Geological Survey, Darwin*, 54 pp.

Tucker, D.H., Wyatt, B.W., Druce, E.C., Mathur, S.P. & Harrison, P.L., 1979 — The upper crustal geology of the Georgina Basin region. *BMR Journal of Australian Geology & Geophysics*, 4, 209–226.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. & Hardenbol, J., 1988 — An overview of the fundamentals of sequence stratigraphy and key definitions. *In* Wilgus, C.K. & others (editors), Sea-level changes: an integrated approach. *Society of Economic Paleontologists and Mineralogists, Special Publication* 42, 40–45.

Walter, M.R., Shergold, J.H., Muir, M.D. & Kruse, P.D., 1979 — Early Cambrian and latest Proterozoic stratigraphy, Desert Syncline, southern Georgina Basin. *Journal of the Geological Society of Australia*, 26, 305–312.

Whitehouse, F.W., 1936 — The Cambrian faunas of northeastern Australia. Part 1 — Stratigraphic outline. Part 2 — Trilobita (Miomera). *Memoirs of the Queensland Museum*, 11(1), 59–112, pl. 8–10.

Whitehouse, F.W., 1939 — The Cambrian faunas of northeastern Australia. Part 3 — The polymerid trilobites (with supplement No. 1). *Memoirs of the Queensland Museum*, 11(3), 179–282, pl. 19–25.

Whitehouse, F.W., 1941 — The Cambrian faunas of northeastern Australia. Part 4 — Early Cambrian echinoderms similar to the larval stages of Recent forms. *Memoirs of the Queensland Museum*, 12(1), 1–28, pl. 1–4.

Appendix 1. Faunas of stratigraphic sequence 1.

1. Thorntonia Limestone

Shelf and peritidal sediments of the Thorntonia Limestone (*sensu stricto*) north and west of Riversleigh belonging to the transgressive and highstand systems tract.

Trilobita *Pagetia* cf. *oepiki* Jell, *Redlichia* sp. cf. *idonea* Whitehouse, *Xystridura* (*Xystridura*) sp. cf. *templetonensis* (Chapman).

Brachiopoda Undetermined acrotretid and oboloid inarticulate brachiopods.

Mollusca Undetermined hyolithids; *Latouchella* sp., *Pelagiella* sp. cf. *deltoides* Runnegar & Jell, *Protowenella* sp. cf. *flemingi* Runnegar & Jell.

Bradoriida Undetermined bradoriid.

Alga *Ilicta* sp. cf. *composita* Sidorov, *Girvanella* sp.

Miscellanea *Chancelloria* sp., sponge spicules

Age Ordian (*sensu* Öpik 1968a, 1979), Ordian/early Templetonian (herein), *Redlichia chinensis* biofacies.

References de Keyser (1969), Jell (1975), Schmitt & Southgate (1982), Shergold & Southgate (1986), Southgate (1983, 1988).

2. Yelvertoft Bed

Shelf and peritidal sediments assigned to the Yelvertoft Bed (*sensu stricto* at May Downs, *sensu lato* elsewhere), belonging to the transgressive systems tract, laterally equivalent to Thorntonia Limestone north and west of Riversleigh.

Trilobita *Onaraspis*? sp., *Pagetia* sp., *Redlichia chinensis* Walcott, *R. creta* Öpik, *R. idonea* Whitehouse, *R. lepta* Öpik, *R. micrograpta* Öpik, *R. myalis* Öpik, *R. venulosa* (Whitehouse), *R. versabunda* Öpik, *R. vertumnia* Öpik, *Xystridura (Xystridura) yaringensis* Öpik.

Brachiopoda Undetermined inarticulate brachiopods.

Mollusca Undetermined hyolithids, *Biconulites* sp. cf. *hardmani* Etheridge.

Echinodermata *Edriodiscus primotica* (Henderson & Shergold).

Bradoriida *Bradoria cornulata* Öpik, *B. curvifrons* Öpik, *B.* sp. cf. *curvifrons* Öpik, *B. petalina* Öpik, *Comptaluta calcarata*

Öpik, *C. profunda* Öpik, *Indota otica* Öpik, *Ophiosema spicatum* Öpik, *Tropidiana cirrata* Öpik.
Alga *Girvanella* sp.
Age Ordian (*sensu* Öpik, 1968a, 1979), Ordian/early Templetonian (herein), *Redlichia chinensis* biofacies.
References Henderson & Shergold (1971), Jell & others (1985), Öpik, (1968a,b, 1970a,b, 1975, 1979), Öpik & others (1961).

Appendix 2: Faunas of stratigraphic sequence 1a.

1. Thorntonia Limestone
Encrinitic, coquinitic 'upper' Thorntonia Limestone sediments of the transgressive systems tract between Thorntonia and Yelvertoft and part of the Bronco Stromatolith Bed, laterally equivalent to Beetle Creek Formation (*sensu stricto*) at May Downs.
Trilobita *Kootenia* sp., *Pagetia howardi* Jell, *P. macrommatia* Jell, Ptychopariida genera et spp. undetermined, *Peronopsis* sp., *Xystridura (Xystridura) hamosa* Öpik, *X. (X.) templetonensis* (Chapman), *X. (X.)* sp.
Brachiopoda Acrotretid and oboloid inarticulate brachiopods.
Molluscs Undetermined hyolithids, *Biconulites* sp.; *Helcionopsis* sp., *Latouchella* sp. cf. *accordionata* Runnegar & Jell, *Mellopegma georginensis* Runnegar & Jell, *Pelagiella* sp. cf. *deltoides* Runnegar & Jell, *Protowenella* sp. cf. *flemingi* Runnegar & Jell, *Yochelcionella* sp. cf. *ostentata* Runnegar & Jell, *Yochelcionella* sp.
Bradoriida *Zepaera* sp.
Alga Undetermined stromatolites.
Miscellanea *Chancelloria* sp., sponge spicules.
Echinodermata *Cymbionites craticula* Whitehouse, *Peridionites navicula* Whitehouse.
Age Early Templetonian (*sensu* Öpik, 1968a, 1979), Ordian/early Templetonian (herein), *Xystridura templetonensis* biofacies.
References de Keyser (1969), Jell (1975), Runnegar & Jell (1976), Öpik (1968a, 1973a,b, 1975, 1979), Shergold & Southgate (1986), Southgate (1983, 1986a, 1988), Whitehouse (1939, 1941).

2. Beetle Creek Formation
Beetle Creek Formation (*sensu stricto*) at its type area in the May Downs inlier and neighbourhood, representing the condensed sequence in the transgressive systems tract.
Trilobita *Chancia vicenalis* Whitehouse, *Chienaspis peregrina* (Whitehouse), *Deiradonyx* sp. aff. *collabrevis* Öpik, *Dinesus ida* Etheridge, *Elrathina* sp., *Kootenia modica* (Whitehouse), *Lyriaspis sigillum* Whitehouse, *Pagetia polygnota* Jell, *P. polymorpha* Jell, *Peronopsis* sp. cf. *P. normata* Whitehouse, *Sestrostega testa* Öpik, *Xystridura* (*Xystridura*) *dunstani* (Chapman), *X.* (*X.*) *milesi* (Chapman), *X.* (*X.*) *saintsmithi* (Chapman), *X.* (*X.*) *templetonensis* (Chapman).
Brachiopoda Undetermined species of *Acrotreta*, *Lingulella* and *Paterina*.
Mollusca *Biconulites* sp.
Age Early Templetonian (*sensu* Öpik 1968a, 1979), Ordian/early Templetonian (herein), *Xystridura templetonensis* biofacies.
References Jell (1975), Öpik (1968a, 1975, 1979, 1982), Öpik & others (1961), Shergold (1969), Whitehouse (1939).

Appendix 3: Faunas of stratigraphic sequence 2.

Transgressive systems tract parasequence set 1.
1. Thorntonia Limestone.
Cyclic, phosphatic, peritidal carbonates assigned to the Thorntonia Limestone (Unit 3), representing parasequence set 1 of the transgressive systems tract at Rogers Ridge, Burke River Structural Belt. Equivalent to black shales in Phillips Sunray Black Mountain No. 1 and Inca Formation at May Downs, Lady Annie and Thorntonia.
Trilobita Oryctocephalid undetermined, *Pagetia ocellata* Jell, *Peronopsis* sp. ex gr. *fallax* (Linnarsson), agnostoid aff. *Pentagnostus*? sp., ptychoparioid undetermined, *Xystridura (Xystridura)* sp.
Brachiopoda Undetermined acrotretid brachiopods.
Mollusca Undetermined hyolithids; *Helcionopsis*? sp., *Latouchella*? sp., *Pelagiella* sp. aff. *corinthiana* Runnegar & Jell, *Protowenella* sp. cf. *flemingi* Runnegar & Jell, *Tannuella*? sp.
Bradoriida Undetermined comptalutid bradoriid.
Annelida Undetermined annelid.
Echinodermata Echinodermal debris.
Problematica
Miscellanea *Chancelloria* sp., sponge spicules.
Age Late Templetonian (*sensu* Öpik, 1968a, 1979), late Templetonian/early Floran (herein), possibly *Pentagnostus praecurrens* Zone but more probably the *Triplagnostus gibbus* Zone lacking the index species.
References Nordlund & Southgate (1988).

Transgressive systems tract parasequence set 2.
2. Monastery Creek Formation
Parasequence set 2 contains the Monastery Creek Formation of the Burke River Structural Belt. This is equivalent to the 'Simpson Creek Phosphorite' plus underlying coquinite at Ardmore (D41). This set is laterally equivalent to and overlain by black shales.
Trilobita *Acidusus* sp. cf. *atavus* (Tullberg), *Oryctocephalites* sp. cf. *gelasinus* Shergold, *Oryctocephalus* sp., *Pagetia ocellata* Jell, *Pentagnostus* sp. cf. *praecurrens* (Westergård), *Peronopsis* spp., ptychoparioids undetermined, *Thoracocare* sp., *Triplagnostus* sp. cf. ex gr. *gibbus* (Linnarsson), *Xystridura* (*Xystridura*) *carteri* Öpik, *X.* (*X.*) sp. cf. *milesi* (Chapman).
Brachiopoda Species of the inarticulate brachiopods *Acrothele*, acrotretids, *Amictocracens*, *Linnarssonia* and oboloids.
Mollusca Undetermined hyolithids; *Helcionopsis* sp., *Latouchella* sp. cf. *accordionata* Runnegar & Jell, *Mellopegma* sp. cf. *georginensis* Runnegar & Jell, *Pelagiella deltoides* Runnegar & Jell, *Protowenella* sp. cf. *flemingi* Runnegar & Jell.
Bradoriida *Flemingopsis duo* Jones & McKenzie, *Hesslandona* sp., *Indota formosa* Fleming, *Monasterium dorium* Fleming, *M. oepiki* Fleming, *Ovaluta* sp., *Phaseolella dubia* Jones & McKenzie, *P. sestina* (Fleming), *P. sipa* (Fleming), *Svealuta* sp., *Zepaera rete* Fleming.
Annelida, Hyolithelminthida, Conodontophorida Undetermined.
Problematica Aff. *Microdictyon* sp., cf. *Utahphospha* sp., undetermined problematica, *Wiwaxia* sp.
Echinodermata Echinodermal debris.
Miscellanea *Chancelloria* sp., acanthose pentact sponge spicules, lithistid tetrad spicules, *Arborella* sp.
Age Late Templetonian (*sensu* Öpik 1968a, 1979), late Templetonian/early Floran (herein), at overlap of *Triplagnostus gibbus* and *Acidusus atavus* Zones.
References Fleming (1971, 1973), Jell (1970, 1975), Jones & McKenzie (1980), Öpik (1968a,b, 1975, 1979), Shergold & Brasier (1986), Shergold & Laurie (1986), Shergold & Southgate (1986), Southgate & others (1988).

3. Inca Formation
Parasequence set 2 also contains black shales laterally equivalent to the Monastery Creek Phosphorite Formation which have been referred either to the 'Lower Siltstone Member of the Beetle Creek Formation' in the Burke River Structural Belt, or to the Inca Formation at Lady Annie, May Downs, Yelvertoft and D Tree.
Trilobita *Acidusus* sp. cf. *atavus* (Tullberg), *Barklyella expansa* Shergold, *Elrathina* sp., *Galahetes fulcrosus* Öpik, *Lyriaspis* sp., *Oryctocephalites* sp. cf. *gelasinus* Shergold, *Pagetia* spp., *Peronopsis* sp., *Sandoveria* sp., *Triplagnostus* sp. cf. *gibbus* (Linnarsson), *Xystridura* (*X.*) *carteri* Öpik, *X.* (*X.*) *dunstani* (Chapman).
Brachiopoda Undetermined acrotretid and oboloid inarticulate brachiopods.
Bradoriida *Bradoria* sp., *Indota formosa* Fleming.
Mollusca Undetermined hyolithids.
Miscellanea Sponge spicules.
Age Late Templetonian (*sensu* Öpik, 1968a,b, 1979), late Templetonian/early Floran (herein), commencing at the overlap of the *Triplagnostus gibbus* and *Acidusus atavus* Zones as documented here, but ranging into the late Floran *Euagnostus opimus* Zone in the Thorntonia–D Tree area, and early Undillan *Ptychagnostus punctuosus* Zone in the Burke River Structural Belt (for faunal lists see Shergold & Laurie, 1986).
References Jell (1975), Fleming (1973), Öpik (1970a,b, 1979,

1982), Shergold (1968, 1969), Shergold & Laurie (1986), Shergold & Southgate (1986).

Transgressive systems tract parasequence set 3.
4. Concretionary interval
In the Burke River area a condensed interval represented by carbonate concretions, locally mantled by crusts of mudstone phosphate, is found at the base of the Inca Formation. It contains a largely reworked fauna from the Monastery Creek Formation.
Trilobita *Pagetia* sp., *Peronopsis* sp., *Xystridura* (*Xystridura*) sp.
Brachiopoda *Acrothele* sp., *Amictocrasens* sp., undetermined acrotretid and oboloid inarticulate brachiopods.
Bradoriida *Indota formosa* Fleming, *Monasterium dorium* Fleming, *Monasterium* sp. undet., *Phaseolella dubia* Jones & McKenzie, *P. sestina* (Fleming), *P. sipa* (Fleming), *Zepaera rete* Fleming.
Annelida Undetermined.
Conodophorida Undetermined.
Mollusca Undetermined hyoliths; *Latouchella* sp. cf. *accordionata* Runnegar & Jell, *Pelagiella* sp. cf. *deltoides* Runnegar & Jell, *Protowenella* sp. cf. *flemingi* Runnegar & Jell.
Echinodermata Echinodermal debris.
Miscellanea *Chancelloria* sp., sponge spicules.
Age Late Templetonian/early Floran overlap.
Reference Southgate & others (1988).

5. Gowers Formation
In the vicinity of Thorntonia Station this parasequence set is represented by the phosphatic Gowers Formation and overlying carbonate concretions of the Currant Bush Limestone. Contemporary black shales are included in the Inca Formation.
Trilobita *Baltagnostus*? sp., *Doryagnostus*? *deltoides* Robison, *Euagnostus cretus* Öpik, *E. opimus* Whitehouse, *Fuchouia* sp., *Goniagnostus* (*Criotypus*) *lemniscatus* Öpik, *Itydeois* sp., *Onymagnostus hybridus* Brögger, *O. semiermis* Öpik, *Opsidiscus microspinus* Jell, *Pagetia thorntonensis* Jell, *Peronopsis* sp. cf. *quadrata* (Tullberg), *Pseudoperonopsis ancisa* Öpik, *P. perplexa* Robison, *Ptychagnostus affinis* (Brögger), *Ptychopariida* undetermined, *Rhodotypiscus nasonis* Öpik, *Triplagnostus* (*Triplagnostus*) *gibbus* (Linnarsson), *Zeteagnostus scarifatus* Öpik.
Brachiopoda Undetermined species of the inarticulate genera *Acrothele*, *Lingulella*, *Linnarssonia*, *Protorthis*?, *Prototreta*, *Treptotreta*.
Mollusca Undetermined hyolithids; *Eotebenna pontifex* Runnegar & Jell, helcionellid undetermined, '*Latouchella*' sp., *Mellopegma georginensis* Runnegar & Jell, *Myona queenslandica* Runnegar & Jell, *Pelagiella corinthiana* Runnegar & Jell, *P. deltoides* Runnegar & Jell, *Protowenella flemingi* Runnegar & Jell, *Tannuella* sp., *Yochelcionella* sp.
Bradoriida *Oepikaluta dissuta* Jones & McKenzie.
Conodontophorida Undetermined.
Miscellanea *Chancelloria* sp., sponge spicules.
Age Late Floran, late *Euagnostus opimus* Zone (*sensu* Öpik, 1979).
References Henderson & McKinnon (1981), Jell (1975), Jones & McKenzie (1980), Laurie (1988), Öpik (1979, 1982), Shergold & Laurie (1986), Shergold & Southgate (1986), Southgate (1983, 1986c).