Evolving Depositional Environments in the Triassic of the South-West Bowen Basin, Queensland, Australia

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ABSTRACT

Sedimentation in the Bowen Basin during the Triassic occurred in a foreland setting between cratonic stable areas to the west and the active New England Orogen in the east. Sediment was accumulated in continental environments, which were predominantly fluvial, and much of the sediment was derived from the active orogen.

Typical exposures from each of the three major Triassic stratigraphic units (Rewan Group, Clematis Group and Moolayember Formation) were studied, to illustrate the variations in depositional style throughout the evolution of the basin.

The basal Triassic Rewan Group is dominated in the study area by poorly interconnected and sharply bounded channel sands of moderate width (tens of meters), with height to width ratios of individual channel bodies around 1:7. Sandbodies are separated by abundant chocolate brown to red mudrocks (siltstone and claystone) which shows evidence of soil formation and desiccation.

The overlying quartzose Clematis Group represent a re-organisation of drainage in the basin and was derived from the stable craton to the west during a time of relative tectonic quiescence. Much of the Clematis Group accumulated in large sandy braidplains and now forms a cliff-forming sheet sandstone. Thickness to width ratios estimated for Clematis deposits in the area range from 1:30 to 1:70. The uppermost part of the unit records a rapid change to lacustrine conditions associated with a major lacustrine flooding event affecting the southern Bowen Basin (Snake Creek Flooding).

Cuadernos de Geología Ibérica, núm. 21, pp. 171-201.
Servicio de Publicaciones. Universidad Complutense, Madrid, 1996.

The overlying Moolayember Formation comprises laminated and bioturbated mudrocks and interbedded fine grained quartz-lithic and micaceous sandstones with evidence of wave and combined flow activity, which accumulated in a large open circulation lake. A lowering of relative baselevel resulted in a period of progradation and infilling of the lake. Fluvial deposits post-dating the major progradation are dominated by moderate sized, sinuous streams with locally preserved scroll-bar and levee morphologies. Upper Moolayember streams studied here exhibited interpreted thickness to width ratios of 1:9.

Keywords: Triassic, Bowen Basin, Australia, architectural elements.

RESUMEN

La sedimentación triásica de la Cuenca de Bowen se llevo a cabo en un asentamiento de «antepais» entre una zona estable al oeste y el orógeno activo de Nueva Inglaterra en el este. Los sedimentos acumulados fueron básicamente de tipo continental, con dominio de ambientes fluviales que provenían del citado orógeno activo.

El presente estudio se ha llevado a cabo mediante el análisis de facies de afloramientos conocidos de cada una de las tres unidades triásicas más importantes (Grupo Rewan, Grupo Clematis y Fm. Moolayember), para mostrar las variaciones en el estilo deposicional a través de la evolución de la cuenca. Todos los afloramientos fueron elegidos de un área próxima al margen cratónico de la cuenca, donde la influencia de la tectónica local es mucho más reducida que en el lado este de la misma.

El triásico basal del Grupo Rewan se acumuló durante la etapa de subsidencia rápida de la historia de la cuenca y está dominada en el área de estudio por un sistema de canales de arena poco conectados entre si, de moderada anchura (decenas de metros) y con una relación profundidad / anchura de los canales individuales en torno a 1:7. Los cuerpos de arena están separados por abundantes sedimentos finos (arcillas y limos) de color marrón chocolate que presentan evidencia de formación de suelos y desecación.

El Grupo Clematis, suprayacente sobre el anterior, representa una reorganización del drenaje en la cuenca durante un tiempo de relativa tranquilidad tectónica, teniendo el origen de sus sedimentos localizado en un cratón estable situado al oeste. La unidad muestra un fuerte contraste petrográfico respecto al subyacente Grupo Rewan, de tipo volcánico, mostrando un cambio desde los sistemas deposicionales de tamaño moderado dominados por lodos en el Grupo Rewan a los dominados por arenas en llanuras de tipo entrelazado. Gran parte del Grupo Clematis fue acumulado en amplias llanuras arenosas con sedimentos que llegaron desde el oeste y que ahora constituyen una banda de areniscas que dan un resalte y que cubren la mayor parte del sur de la Cuenca de Bowen. La parte más alta de esta unidad muestra un acusado cambio a un ambiente de tipo lacustre asociado a un evento de inundación principal que afectó a la mayor parte del sur de la citada cuenca (inundación Snake Creek). La relación espesor / anchura que se estima para los depósitos del Grupo Clematis en el área oscila entre 1:30 y 1:70.

La formación suprayacente (Fm. Moolayember) está constituida por depósitos finos (limos y arcillas) laminados y bioturabados, con niveles intercalados de areniscas micáceas de granos de cuarzo con evidencias de actividad combinada de olas y flujos. Un descenso del nivel de base relativo apareció en un periodo de progradación dentro de un lago de amplia circulación que puede ser reconocido sobre gran parte del SO de la Cuenca Bowen. Las facies fluviales anteceden la mayor progradación y están dominadas por depósitos de tamaño moderado, corrientes sinuosas que localmente preservan morfologías de derrame y «scroll bars». Las corrientes estudiadas de la parte superior de la Fm. Moolayember muestran una relación espesor / anchura de 1:9.

Palabras clave: Triásico, Cuenca de Bowen, Australia, elementos arquitecturales

INTRODUCTION

The Bowen Basin of eastern Queensland is a Permo-Triassic sedimentary basin, which was positioned between an active orogenic belt to the east (New England Fold Belt) and a stabilised craton to the west (Fig.1). The New England Fold Belt was formed in a convergent margin setting active at various times between the Devonian and Late Triassic (Coney et al. 1990, Fergusson et al. 1994). The Bowen Basin is contiguous southward with the coeval Gunnedah Basin and the Sydney Basin (Fig.1). The entire Bowen-Gunnedah-Sydney basin complex spans some 2000 km in length and attains a maximum preserved onshore width of ca. 200 km.

The basin history can be divided into three major phases of development commencing with an Early Permian extensional phase, a middle Permian sag phase and a Late Permian to Mid Triassic Foreland basin phase (Ziolkowski & Taylor 1985, Fielding 1990). The current paper is concerned exclusively with sediments accumulated during the foreland phase of basin development.

TRIASSIC STRATIGRAPHY

The stratigraphic nomenclature of the Triassic units in the study area is summarised in Fig.2 together with summary interpretations of depositional

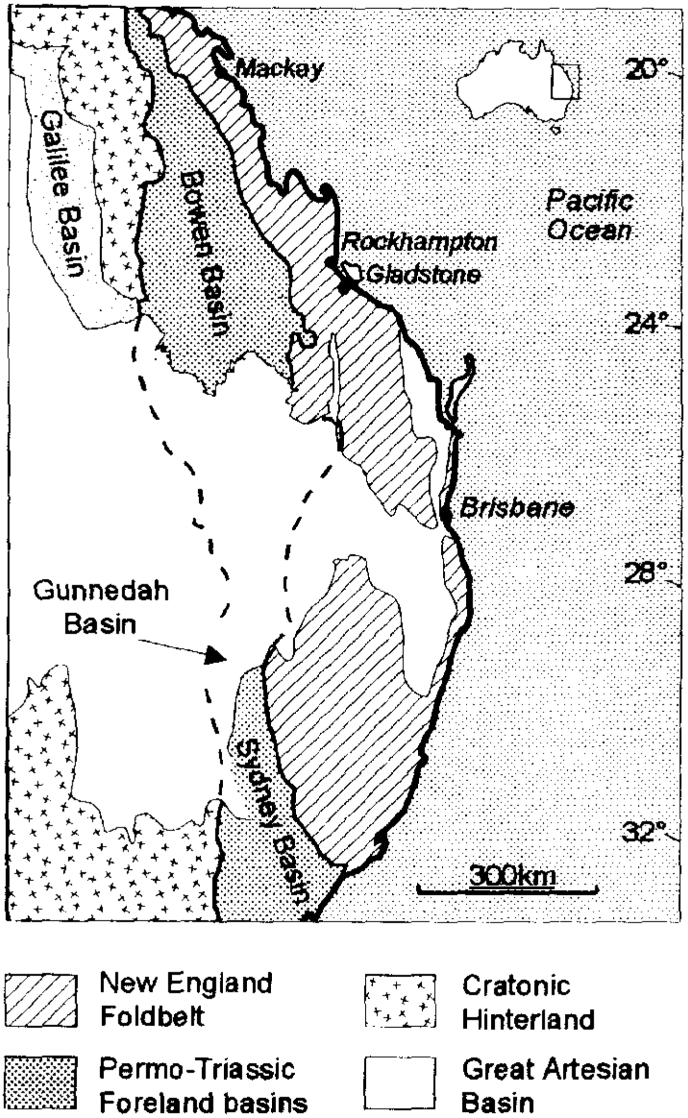


Fig. 1.—Location map of the Bowen Basin. Bowen, Sydney and Gunnedah basins constitute the foreland basin complex to the New England Orogen. During the Triassic the basins were bounded by stable cratonic areas in the west and the active orogen in the east.

Fig. 1.—Mapa de localización de la Cuenca Bowen. Las cuencas de Bowen, Sydney y Gunnedah constituyen el complejo de cuencas de antepais del orógeno de Nueva Inglaterra. Durante el Triásico estas cuencas estaban enmarcadas por una zona de cratón estable al oeste y un orógeno activo en el este.

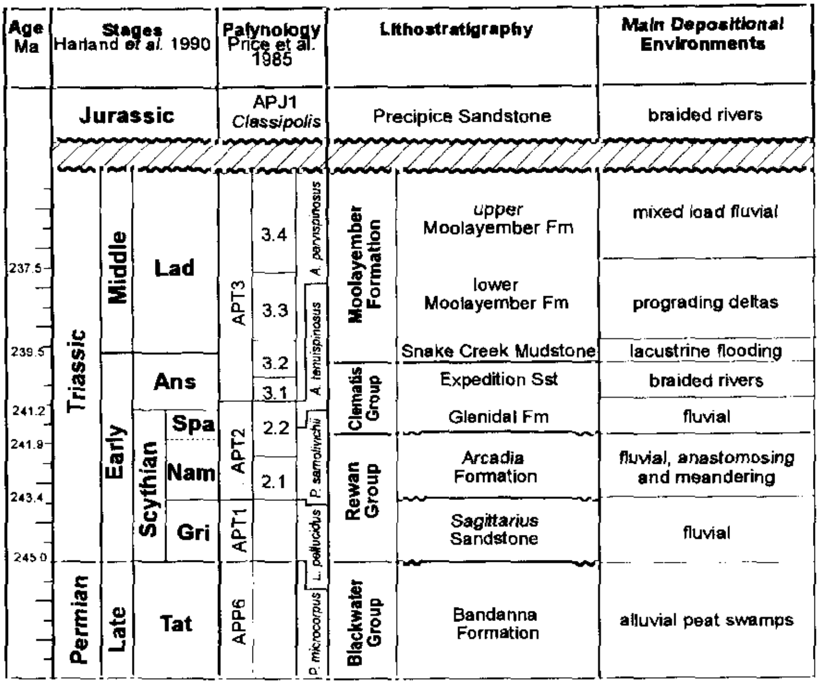


Fig. 2.—Stratigraphic nomenclature for the Triassic and adjoining units in the Bowen Basin.
Fig. 2.—Nomenclatura estratigráfica para el Triásico y unidades contiguas en la Cuenca Bowen

environments. Stratigraphic units are defined by significant changes in grain size and sediment composition. Palynology is the most successful biostratigraphic tool for the succession examined here, due to a near absence of stratigraphically significant macrofossils or other microfossils. Biostratigraphic resolution, however, remains low, partly due to a lack of comprehensive biostratigraphic studies of the Triassic succession.

The succession is considered by most workers to be entirely non-marine, comprising alluvial and lacustrine deposits (Jensen 1975) although the rare occurrence of spinose acritarchs in some mudrock intervals has led some researchers to suggest marine influences for parts of the succession (Schroder 1988, Butcher 1984). Baker, Kassan & Hamilton (1996) recently presented a study of stable isotopes from one acritarch bearing interval of the Rewan Group, and concluded an entirely non-marine origin.

Sediment derivation throughout most of the basin's foreland phase was from the tectonically and volcanically active fold belt to the east. This can be shown by both palaeocurrent analysis and petrographic studies (Fielding 1990, Baker *et al.* 1993). The Early Triassic Rewan Group in particular shows evidence of derivation from the active New England Foldbelt, such as the strongly volcanic-lithic composition of sandstones. A significant change occurred in the Clematis Group of Middle Triassic age (Anisian), which is quartzose and was derived from the cratonic (western) side of the basin. The Moolayember Formation was deposited in fluvial and lacustrine environments, receiving sediment from both margins of the basin, and within the current study area also from a major axial sediment dispersal system, deriving detritus from the northern Bowen Basin (Alcock 1970).

STUDY AREA AND METHODS

Sediments of the Rewan Group, Clematis Group and Moolayember Formation were studied at outcrop and in drill core in an area ca. 100km north of the township of Injune in east central Queensland (Fig.3).

The Clematis Group is exposed as a continuous ridge of mesas (Carnarvon Range) with vertical cliffs along the northern and eastern limits. The Rewan Group forms adjacent lowlands in the north and east and the Moolayember Formation is exposed poorly in the low, hilly country in the immediate west and south of the Clematis exposures.

All outcrops were subdivided into lithofacies (*eg.* Sp-planar cross-bedded sandstone) closely following Miall's (1978) notation, and genetic facies assemblages (*eg.* PF-proximal floodplain assemblage). Details of the facies scheme are provided in Kassan (1993). Wherever possible, controlled photo mosaics were taken of laterally extensive outcrops. These were later traced to delineate the external and internal geometry of sediment bodies. Classification of architectural elements follows Miall's (1985) scheme with modifications (Table 1). Vertical sedimentological sections were measured at accessible points along the outcrops to provide information on lithology and facilitate correlation between outcrop and drill core. Palaeocurrent directions were measured wherever possible and categorised according to the different current generated sedimentary structures.

REWAN GROUP

The Rewan Group comprises predominantly red and variegated mudrocks and greenish cross-bedded lithic and volcanic-lithic sandstones. The unit is distinct from the underlying Permian succession by the absence of coals and the red coloration of the mudrocks.

In the south-west of the basin the base of the Rewan Group is gradational with the underlying Permian Bandanna Formation and is picked at the top of the highest coal seam, since other lithofacies show no distinction between the

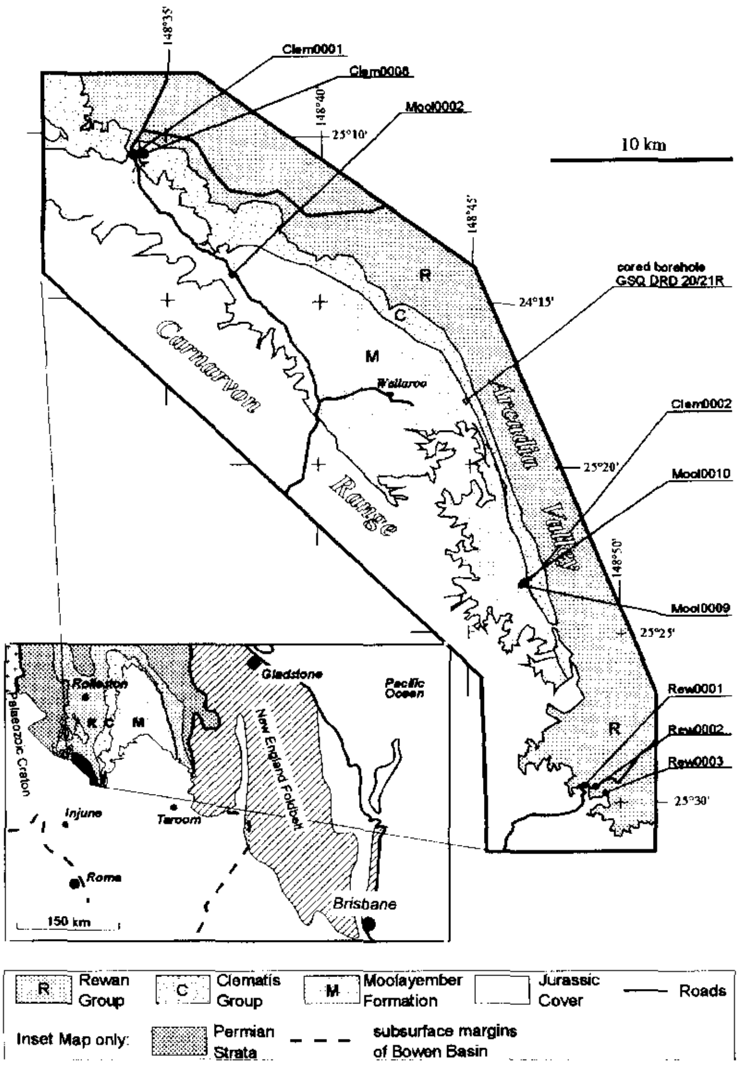


Fig. 3.—Study area in the south-west of the outcrop belt. Locations of exposures discussed in the current study are shown.

Fig. 3.—Zona de estudio al suroeste del cinturón aflorante. Se muestran las localizaciones de los afloramientos que se discuten en el texto.

two units. The Rewan Group is apparently conformable at outcrop with the Bandanna Formation. Palynological studies yielded Late Permian ages for the lowest part of the Rewan Group (Foster 1983) and the base of the Rewan Group is considered to be diachronous. An unconformity between the Rewan

Element	Symbol	Lithofacies Assemblage	Geometry and Comments	Rew	Clem	Mool
Fine grained Deposits	FD	massive, laminated and current deposited mudrocks and matrix rich, flaser and lenticular laminated fine grained sandstones	Concave-up base and flat topped, or sheet-like. Locally mottled, possibly indicating the development of soil profiles	D	m	M
Heterolithic Sheets	HS	ripple cross-laminated and small scale cross-bedded fine to rarely medium grained sandstone; interlaminated sandstone and grey mudrock with a suite of interlamination structures (flaser, linsen, *etc.*), laminated grey mudrocks	Alternating laterally extensive thin sheets and/or wedges of sandstone and mudrock. Sharp base and top. Sedimentary structures reflect deposition by current action and often subsequent deformation due to dewatering effects during compaction	m	m	M
Sand sheets	SS	massive and ripple cross-laminated fine grained sandstones with occasional interlamination of mudrock near top of the unit	Laterally extensive thin sandbodies, sharp or erosively based with sharp to gradational top, entirely encased in overbank mudrocks (Element FD)	m		m
Sandy Bedforms	SB	Planar and trough cross-bedded fine to medium-coarse sandstones and fine grained ripple cross laminated sandstones.	Lensoid often with well developed «wings». Erosive base; both convex-up and concave-up tops occur. Internal architecture may be simple or multi-storey	m	D	M
Foreset Macroforms	FM	Planar and trough cross-bedded medium to coarse grained sandstones, locally very large foresets are developed.	Lensoid often with well developed «wings». Erosive base; both convex-up and concave-up tops occur. Internal architecture is dominated by large foreset laminae, accreted in downstream direction. Simple Bars of Allen (1983)		m	
Channels	CH	Planar and trough cross-bedded sandstones, ripple cross-lamination and interlamination structures occur in interbedded fine grained sandstones and mudrocks.	Erosive concave-up base with often well developed lags of mudrock rip-up clasts. Internal architecture often complex (multistorey). Commonly contain SB, GB, FM and FD	m	m	M
Lateral Accretion Deposit	LA	Massive and faintly cross-bedded fine grained sandstone interbedded with massive and ripple cross-laminated mudrocks	Laterally stacked lenses of mixed lithology occurring inclined at ca. 20° to the depositional horizontal. Dip direction of inclined stratification is coherent within individual lenses, but may differ markedly from HS by limited lateral extent of individual beds (<4.0 m)	m	m	M
Gravelly bedforms	GB	massive and stratified granule to pebble conglomerates, mostly clast supported	Sheets and thin lenses of granule conglomerate	m	m	m

Table 1.—Architectural elements and their relative significance in the three major stratigraphic units of the Triassic in the study area (m=minor, M=major, D=dominant).

Group and underlying Permian sediments is also indicated on regional seismic lines in the southern part of the basin, and from detailed drill core analysis.

Overall poor exposure of the Rewan Group and focus of this study on the Clematis Group, prohibited detailed study of Rewan Group sedimentary rocks over most of the area of study. A series of laterally extensive exposures at the southern approach to Arcadia Valley are here discussed to illustrate features considered to be characteristic for the Arcadia Formation over much of the western part of the Bowen Basin.

DESCRIPTION

Rewan sediments of the Arcadia Formation (Jensen 1975) were studied in a succession of roadcuts (Rew0001 & Rew0002) and natural exposures (Rew0003) near Lonesome National Park in the extreme south-west of the outcrop belt (Fig.3). Here, the lithology is dominated by reddish to chocolate brown siltstone, with interbedded, predominantly sharp bounded bodies of greenish grey, fine to medium grained volcanic lithic sandstone. The sandstones vary from friable to tightly cemented by quartz cement. A stratigraphic section logged in a gully exposure near Lonesome National Park (locality Rew0003, AMG 824787, Sheet 8647) illustrates the vertical sequence aspects of the unit in this area (Fig. 4).

Discernible sedimentary structures in the siltstones are mainly restricted to palaeosol features such as rootlet penetrated horizons and mottled light grey-reddish layers. Siltstones are interbedded with conspicuous light grey, poorly cemented coarse silt-very fine sand layers of 5-30 cm thickness. Structures are preserved very poorly in this labile lithology. Overall fine-grained sediments dominate over coarser clastics. Sedimentary structures in the sandstones are dominated by medium scale trough cross-bedding, ripples and desiccation cracks. Trains of rip-up clasts occur at the base of some sandstone units, indicating reworking of cohesive substrate during channel incision.

INTERPRETATION

Examination of facies associations at Rew0003 (Fig. 4) reveals alternating in-channel deposits and floodplain facies (proximal and distal). Thin intervals of very fine to fine grained sandstone within thick units of floodplain facies are interpreted as distal parts of splay deposits. Cross-bedded channel sandstones are commonly conformably overlain by bar top/channel plug deposits, forming fining-up successions.

Orthogonal photo mosaics were obtained from outcrops Rew0001 (AMG

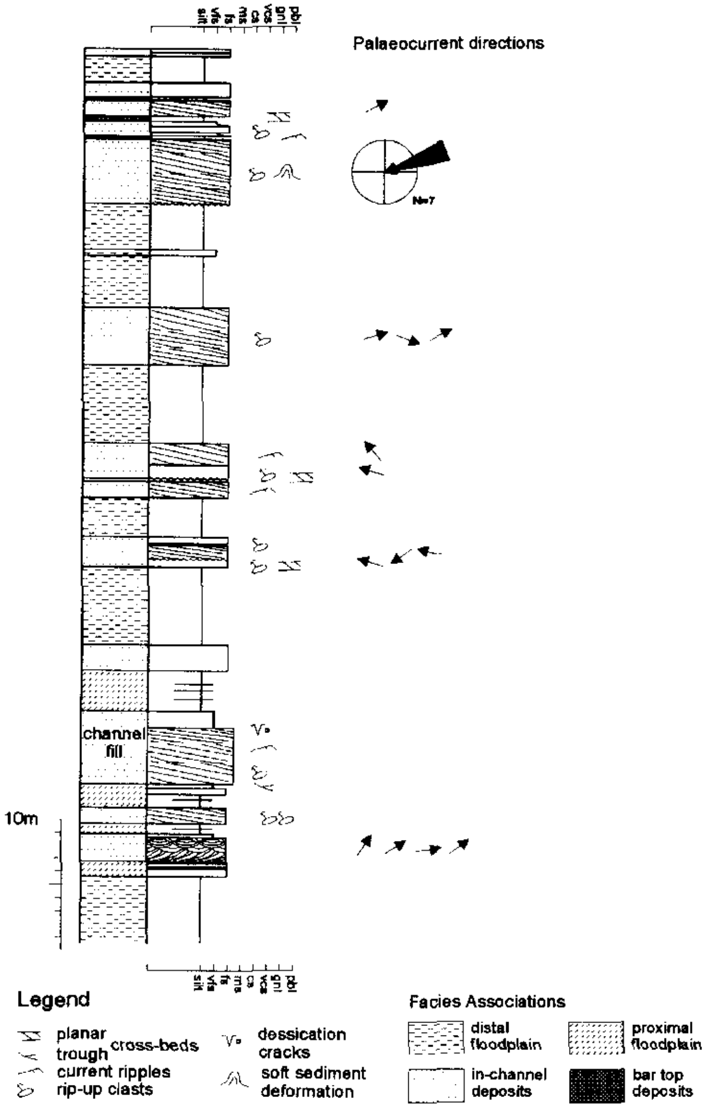


Fig. 4.—Stratigraphic log of the Arcadia Formation exposed at locality Rew0003. The unit is characterised by the high proportion of mudrock and isolated, moderately sized volcanic lithic sandstone units. Arrows indicate individual palaeocurrent readings. Current rose is by area (n=7).

Fig. 4.—Sección estratigráfica de la Formación Arcadia expuesta en el punto Rew0003. La unidad está caracterizada por la alta proporción de lutitas y niveles de tamaño moderado de areniscas volcanoclásticas. Las flechas indican lecturas individuales de paleocorrientes. Las rosas de corrientes representan áreas (n=7).

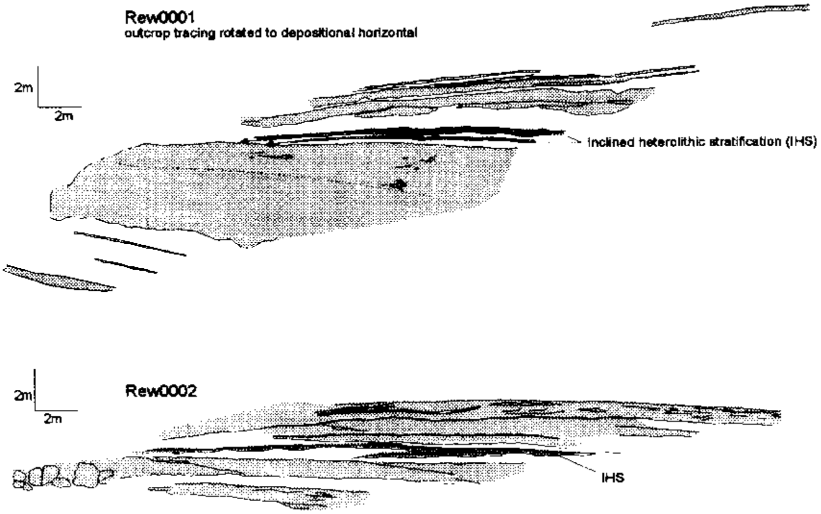


Fig. 5.—Outcrop sketch of exposures Rew0001 and Rew0002, traced from orthogonal photo mosaics. Shaded intervals denote sandstone, rest is red to chocolate brown mudrock with common development of palaeosols. Details of internal architecture are mostly obscured by cementation effects.

Fig. 5.—Esquema de las exposiciones de los afloramientos Rew0001 y Rew0002 obtenidas desde fotomosaicos ortogonales. Los intervalos sombreados indican niveles de arenisca, el resto representa niveles rojo-marrón chocolate con desarrollo de paleosuelos. Los detalles de la arquitectura interna quedan poco patentes debido a los efectos de la cementación.

824794) and Rew0002 (AMG 826792, Sheet 8647) and tracings are provided in Fig. 5. Sandstone bodies are poorly interconnected or offset stacked and isolated by abundant fine grained sediments. Channel margins are characteristically sharp and erode into abundant overbank mudstones or pre-existing channel fills. Sandstone bodies in the Arcadia Formation exhibit complex internal architecture dominated by elements CH and SB (Table 1). Palaeocurrent directions from these sediments indicate transport towards the north-east.

Other exposures of Arcadia Formation were examined during the course of this study, but were not of a quality conducive to detailed analysis. Some of the features determined from the better exposed examples could be recognised in the lower quality outcrops. The abundance of reddish and chocolate brown mudrocks, the channelled nature of coarse grained deposits and the volcanic-lithic composition of the sediments are ubiquitous features.

The depositional style of the described rocks is characterised by:

1. abundance of fine grained overbank deposits (element FD),

2. poorly interconnected sandstone bodies, dominated internally by current generated lower flow regime structures
3. evidence of temporary subaerial exposure,
4. unimodal palaeocurrent directions.

Lateral accretion surfaces of point bars are interpreted in outcrops Rew0001 and Rew 0002, where inclined heterolithic stratification (IHS) dips at 45° to 90° to the prevailing palaeocurrent direction. No palaeocurrent readings of smaller scale sedimentary structures could be obtained from the IHS beds to directly confirm the presence of lateral accretion.

The presence of poorly interconnected sandstone bodies implies episodic discharge and/or frequent and rapid channel switching compared to the local subsidence rate. To account for the limited lateral extent of channel deposits, a strong contribution of vertical accretion has to be inferred.

These characteristics are proposed to be typical for anastomosing rivers by Smith & Smith (1980). Schumm (1981) points out that change from one type of channel to another (meandering to anastomosing) will depend on threshold values for slope and sediment supply. A meandering fluvial system that exists under conditions very close to the threshold may change rapidly and repeatedly to anastomosing and back, reacting to relatively minor changes in sediment supply, slope or vegetation cover.

Based on the evidence presented above, the depositional environment proposed for the Arcadia Formation of the Rewan Group in the south-western part of the basin is a high sinuosity fluvial system, accumulating coarse sediment by lateral accretion and downstream accretion. Individual channels were of the order of tens of meters wide and several meters deep. Accumulation was most significant (by volume of sediment) in inter-channel areas, which were subject to desiccation and soil formation punctuated by intermittent flooding events depositing fine grained sands and muds. No well developed levees could be documented from the outcrops studied. The source area for sediment was to the south-west of the study area and of siliceous to intermediate volcanic provenance.

CLEMATIS GROUP

The exposures studied here form the southernmost outcrop limit of the Clematis Group on the cratonic western side of the basin. The Clematis Group in the Carnarvon Range area was divided into two component formations by Jensen (1975). The stratigraphically lower Glenidal Formation contains a significant, but upward decreasing amount of interbedded mudrocks in a sequence of quartz- and lithic wackes and quartz arenites (sand:mud = 3:2, Jensen 1975).

The current study focussed on the Expedition Sandstone, which comprises fine-grained quartz arenites to quartzose granule conglomerates with subordinate amounts of interbedded grey and red mudrock, which occurs predominantly as thin partings and small lenses. The upper part of the Expedition Sandstone marks a significant reduction in grainsize and depositional energy and consists of fine-grained ripple cross-laminated quartzose sandstones and interbedded laminated and bioturbated, partly organic-rich mudrocks. Jensen (1975) excluded these finer lithologies from the Clematis Group and regarded the Expedition Sandstone as a coarsening-up unit.

Several photo mosaics were obtained from laterally extensive outcrop sections of the Expedition Sandstone in the Carnarvon Range study area, locations are marked in Fig.3. Architectural elements recognised in the Clematis Group in the study area are summarised in Table 1.

LOWER EXPEDITION SANDSTONE (OUTCROP CLEM0001)

Exposure of Clematis Group sediments in a roadcut at Moolayember Dip [AMG 5752148; Sheet 8647 (Arcadia); *see* Fig.3 *for position*] is continuous for some 100 metres. A lateral photo mosaic was obtained from this outcrop and is shown in Fig. 6 together with a scale drawing of the interpretation.

The outcrop is dominated by coarse to medium-grained, cross-bedded, quartzose sandstone. Fine to very fine sandstone and grey and variegated mudrock occur in subordinate amounts and are restricted predominantly to small lenses and thin, laterally discontinuous beds. Mudrock also occurs as elongate rounded rip-up clasts up to 35 cm long (average 2-5 cm long). Granule conglomerate occurs in thin lenses and sheets.

Four orders of bounding surfaces could be differentiated:

1. Surfaces separating cosets of cross-bedded bedforms [first-order sandbodies]
2. Surfaces enveloping lensoid second-order sandbodies, incorporating several cosets and exhibiting a scalloped, concave base and a straight top.
3. Surfaces enveloping one or more second-order sandbodies forming a third-order sandbody. These may have asymmetrically convex-up bases and irregular shapes, where they have been partly eroded by overlying units.
4. Surfaces enveloping several third-order sandbodies and forming fourth-order sandbodies. The overall morphology is typically sheet-like. One margin of a fourth-order sandbody is exposed and displays a stepped and tapered morphology. A minimum of three third-order sandbodies are exposed in the outcrop discussed here.

Delineation of third-order bounding surfaces is often ambiguous, owing to the complex stacking patterns at this level. The two-dimensional nature of exposure in this outcrop prevented the measurement of reliable palaeocurrent readings. Readings obtained at a stratigraphic level immediately above and to the north of the roadcut show westerly current directions for both small (<100 cm) and large ((100 cm) structures. Despite the small number of readings obtained this is interpreted to reflect predominantly downstream accretion in west flowing streams. A transport direction along a west-east axis is also supported by several small channel cross-sections in the roadcut (which trends north-south). The observed geometries in this outcrop are therefore discussed in the context of a westward directed drainage.

Although no fourth-order sandstone body is exposed over its entire width, the geometry of fourth-order lithosomes is clearly sheet-like with a thickness to width ratio exceeding 1:30.

INTERPRETATION CLEM0001

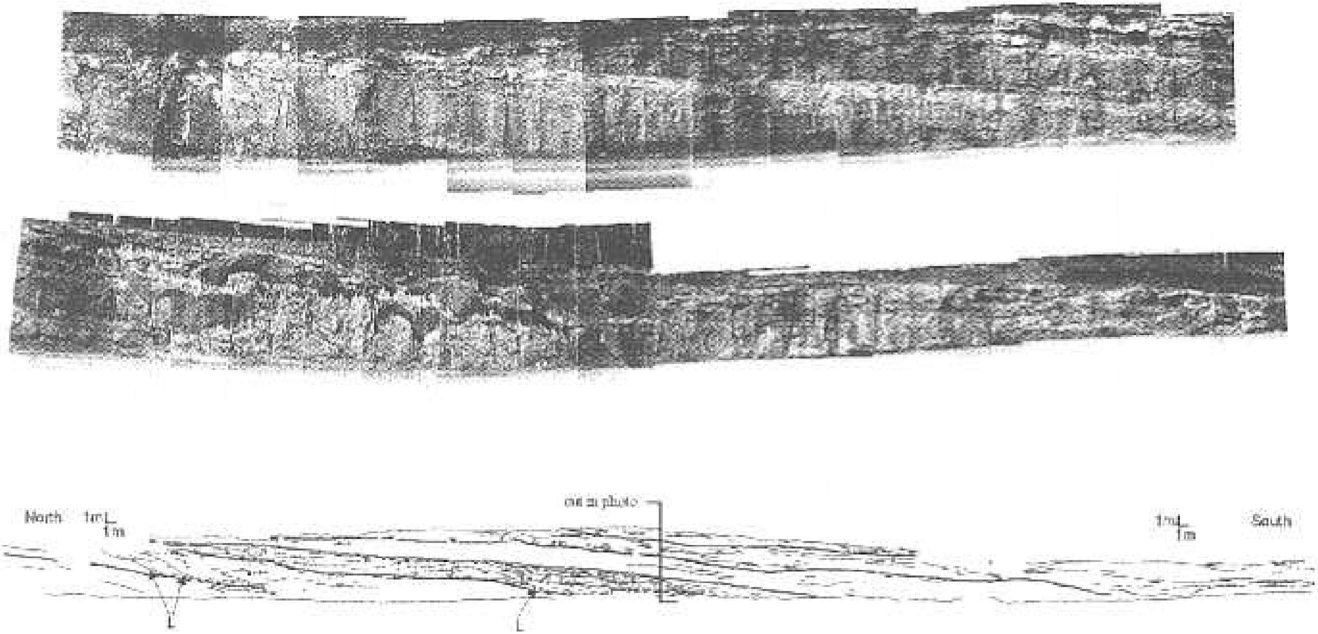
Most of outcrop Clem0001 represents in-channel sediment accumulation. The discontinuous, thin fine member deposits are interpreted as low flowstage drape deposits and plugs of abandoned parts of the channel. Further information on the depositional environment is gained from examination of the facies architecture:

Five architectural elements were identified: FD, SB, FM, CH, and GB. Despite the limited number of architectural elements the depositional style observed is complex, with numerous mutually intersecting lower order sandbodies. Element SB dominates sandbodies of all hierarchical orders.

No full cross sections of large channels are discernible. Multiple phase infills of concave-up scours of fourth-order bounding surfaces are interpreted to result from macroforms infilling «hollows» (*sensu* Friend 1983). The relief on fourth-order bounding surfaces compared to the size of third-order sandbodies suggests that fourth-order surfaces represent channel bases. The absence of clear channel cross sections is attributed to the relatively small size of the outcrop compared to the anticipated width of the channels, and the uniformly sandy nature of sediment, resulting in a loss of distinction between in-channel deposits and inter-channel deposits.

Fig. 6.—Photo mosaic and interpretation (line tracing) of outcrop Clem0001 (Clematis Group). Fourth-order bounding surfaces are shown as thick lines. The exposure is dominated by medium to coarse grained quartzose sandstone with minor granule conglomerate occurring at the southern end. A minimum of three fourth order sandbodies can be differentiated. Internal architecture is complex, with some evidence of lateral accretion surfaces (L). Scale bar on line tracing=1 metre, no vertical exaggeration.

Fig. 6.—Fotomosaico e interpretación (linea de trazo) del afloramiento Clem0001 (Grupo Clematis). Las superficies de cuarto orden quedan indicadas mediante lineas gruesas. La exposición está dominada por una arenisca de granos de cuarzo de tamaño medio con algunos cantos conglomeráticos apareciendo hacia el extremo sur. Pueden llegarse a diferenciar niveles de arenisca de tercer y cuarto orden. La arquitectura interna es compleja con alguna evidencia de superficies de acreción lateral (L). La barra de escala equivale a 1 metro, no habiendo exageración vertical.


North
1m
1m
cut in photo
1m
1m
South
L
L

Accretion of sediment occurred predominantly in a downstream direction. Although no reliable readings could be obtained from the exposure, the attitude of foreset directions in the outcrop as well as palaeocurrent readings from adjacent strata indicates a predominantly westerly directed drainage.

Possible lateral accretion is indicated in some parts of the exposure (L in Fig. 6), where third-order bounding surfaces are inclined at steep angles to the dominant flow direction. No indication of palaeoflow directions could be obtained in the vicinity of these inclined third-order surfaces. However, small scale cross-bedding and ripple cross-lamination occurs at apparently steep angles to the dip direction of some inclined third order bounding surfaces. Complex stacking of small and large sandy bedforms is interpreted to have occurred on composite bars similar to examples described by Ramos, Sopena & Perez-Arlucea (1986).

Fluvial channels were laterally mobile (*sensu* Friend 1983), resulting in complex stacking patterns of facies elements at higher levels of hierarchy. Deposition was episodic, allowing accumulation of fine-grained lithologies as fills of abandoned channels between flooding events. Mudrock clasts incorporated in erosive lags document reworking of earlier deposits.

The bankfull depth of the streams can only be estimated from the preserved height of the largest inclined depositional surfaces (possible lateral accretion at north end of exposure). Depths exceeding 2-3 meters were obtained at least in parts of the channels.

Based on the above findings, the rocks are interpreted to have accumulated in a low sinuosity channel system, dominated by compound bars accreting sediment in both downstream and lateral directions.

EXPEDITION SANDSTONE (OUTCROP CLEM0002)

A controlled, near orthogonal photo mosaic was obtained at a creek exposure in Basin Creek (AMG 793905, Sheet 8647 Arcadia). The outcrop strikes approximately north-south, at a steep angle to the north-easterly palaeoflow direction determined from sparse palaeocurrent data. It exposes as the main feature a sandstone body which lenses out to the south and interfingers with grey, laminated siltstones and fine sandstones to the north (Fig. 7).

Facies architecture shows considerable variation across the outcrop, which is accompanied by changes in lithofacies. Two third order sandbodies were identified in this exposure (A and B in Fig. 7), with sandbody B erosively truncating A.

The northern part of the outcrop is dominated by laterally extensive, ripple cross-laminated and small scale trough cross-bedded, fine and very fine-grained sandstone interbedded with thin, grey mudrock partings. Deformation during compaction is interpreted from the common occurrence of pinchand-swell morphology of bedding planes and small scale soft sediment deformation. Mudrocks locally exhibit deformed starved ripples. Part of the northernmost extent of the outcrop consists entirely of fissile, light grey, very fine grained sandstone and mudrock. Exposure does not permit determination of the geometry of this lithosome. However, the lateral extent is likely to be limited due to the sparsity of similar lithofacies in exposures along strike of Clem0002.

The central part of the outcrop contains several lensoid second-order sandbodies. The dominant lithology is medium-grained, moderately well sorted, quartzose sandstone. Sedimentary structures comprise small and medium scale trough cross-bedding and minor small scale planar cross-bedding. Rip-up clasts of grey very fine sandstone and mudrock occur preferentially along erosional contacts.

Overall, sedimentary structures are poorly to moderately well preserved and in most cases are only discernible by occasional foreset laminae showing a negative relief. This precludes for the most part the collection of palaeocurrent readings. Determination of the predominant mode of sediment accretion (downstream *vs.* lateral accretion) consequently carries some degree of uncertainty.

The southern part of the outcrop is dominated by a third-order sandbody (B, shown shaded in Fig. 7), with a relatively simple internal hierarchy. The lithology is predominantly medium to coarse, moderately well sorted quartzose sandstone, with occasional very coarse and granule-grained foresets and lenses. Sedimentary structures are mostly obscured by cementation of the exposed surfaces, but trough and planar cross-stratification could be identified, as well as grey mudrock clasts, concentrated along erosive surfaces.

INTERPRETATION OF OUTCROP CLEM0002

Analysis of the features documented here allows the identification of several characteristics of the deposits:

No clear channel cross-sections are discernible. Sandbody B, however, can be seen to truncate third- and lower order bounding surfaces of sandbody A. Corroborated by the change in facies assemblage and architecture between the two sandbodies, sandbody B is interpreted as the margin of a channel belt cutting into deposits of environments peripheral to channel influence (discussed below).

The shallow angle of erosion of the channel margin is consistent with the non-cohesive nature of the coarse grained substrate. No information on the sinuosity of the channel can be gained from this exposure, as only a small part of the channel is exposed.

Some element of systematic lateral migration of macroforms is indicated

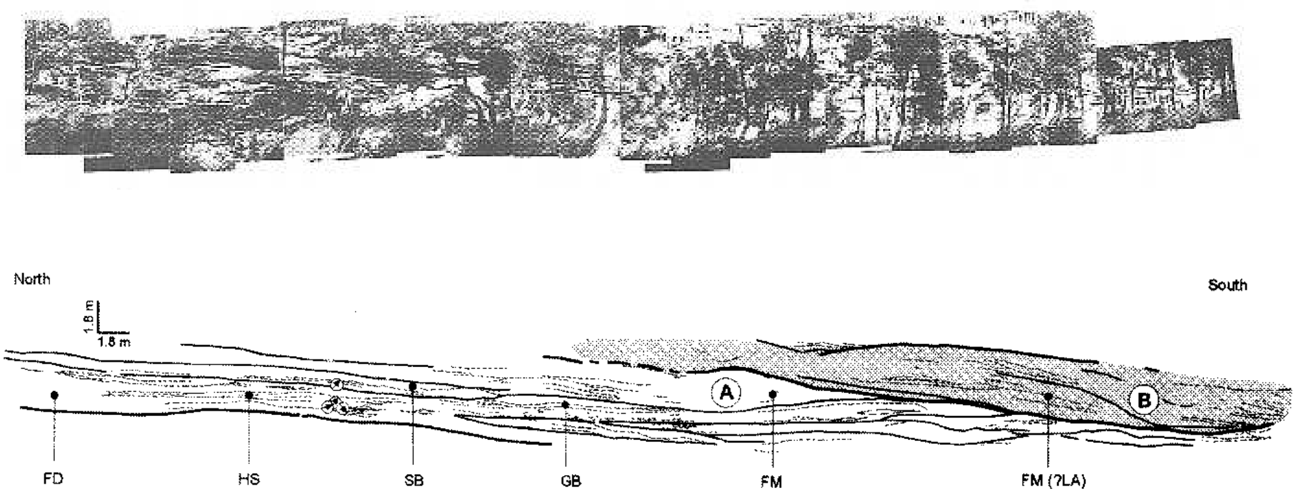


Fig. 7.—a) Orthogonal photo mosaic of outcrop Clem0002, Expedition Sandstone, Basin Creek area. b) Line tracing of Clem0002, annotated for architectural elements (see Table 1). Palaeocurrent orientations shown by circled arrows are based on small scale cross-bedding (top=north). Two major sediment bodies can be identified (**A** & **B**). Both form part of a multi-lateral sheet sand. **A** grades laterally into overbank mudrocks, interpreted to reflect a sedimentation adjacent to a channel margin.

Fig. 7.—a) Fotomosaico ortogonal del afloramiento Clem0002, Arenisca Expedición, área de la Cuenca Creek. b) Las anotaciones de los elementos arquitectónicos señaladas en el esquema aparecen en la tabla 1. Las orientaciónes de las paleocorrientes están señaladas por flechas envueltas en círculos y se han obtenido de estratificaciones cruzadas de pequeña escala (parte superior=norte). Pueden ser identificados dos cuerpos principales sedimentarios (**A** y **B**). Ambos forman parte de un nivel multiprogradacional de arenisca. **A** pasa lateralmente hacia lutitas de derrame interpretadas como depósitos laterales a las márgenes de los canales.

by large scale inclined third-order surfaces in sandbody B. The sparsity of reliable palaeocurrent data from the outcrop prohibits confirmation of lateral accretion. The presence of possible lateral accretion deposits is, however, not taken to necessarily indicate deposition in high sinuosity channels or on point bars. Bristow (1987) showed that lateral accretion on large barforms and channel margins forms a major sediment accumulation process in the braided Brahmaputra River. The non-cohesive nature of the substrate in the exposure and the overall prevalence of coarse member deposits within the Expedition Sandstone are here considered unconducive to the development of stable high-sinuosity (meandering) channels.

The lateral equivalence of element HS (heterolithic sheet) with coarser-grained and more erosively bounded architectural element SB (sandy bedforms) indicates the contemporaneous formation of both lithosomes during the accumulation of the Clematis Group in this area. The prevalence of fine member deposits and sedimentary structures indicative of lower transport energies in architectural element HS (heterolithic sheet) support the interpretation of Kassan & Fielding (1990), who regard this to represent deposits of a channel belt margin environment.

Successions of interbedded sandstones and mudrock (element HS) have preservation potential in the upper part of the Clematis Group (Expeditions Sandstone), in this area. Similar occurrences of interbedded lithologies are documented from a comparable stratigraphic horizon in the fully cored stratigraphic borehole GSQ DRD 20/21R, some 15 km to the north (FIG 3).

UPPER EXPEDITION SANDSTONE (*OUTCROP CLEM0008*)

An outcrop of predominantly fine-grained quartzose lithologies occurs near the top of the dip slope of Clematis cuestas at Moolayember Dip (AMG 584144, Sheet 8647 Arcadia). Approximately 7m of section are exposed in several small, west facing cliff faces.

The base of the outcrop is formed by 1m of thin-bedded, light grey siltstone with minor interbedded lenses and laminae of fine quartzose sandstone. Sedimentary structures are generally obscured in the siltstones, due to recent weathering. Colour mottling can be observed locally, where exposure is less weathered.

This grades upward abruptly into thin-bedded fine-grained quartzose sandstones with thin siltstone partings. Sedimentary structures in the sandstones comprise current-ripple cross lamination, combined flow ripple, wave ripples, flat lamination, trough cross-bedding and low angle lamination, in decreasing order of relative abundance. Bedding planes commonly undulate at both small and large scale. Synaeresis cracks and trace fossils can be observed on exposed bedding planes.

Some exposures exhibit possible small scale hummocky cross-stratification (HCS). These were identified based on the association of flat and undulating lamination and the reworking of bed tops into combined flow ripples.

The depositional environment is interpreted to have been on the margins of a lake of sufficient size and/or orientation to obtain wave fetch. Bioturbated horizons indicate periods of non-deposition or slow sediment accumulation. Small scale HCS is attributed to occasional increased wave energies (storm activity).

MOOLAYEMBER FORMATION

An area of exceptionally good exposure of the Moolayember Formation lies in the southwest of the current Triassic outcrop limit of the Bowen Basin, in the Carnarvon Ranges (Fig.3). The Moolayember Formation typically forms undulating hilly country between the cliff forming Clematis Group and the unconformably overlying Jurassic Precipice Sandstone. Exposure is commonly restricted to creeks and roadcuts.

Alcock (1970) undertook a comprehensive study of the Moolayember Formation in the Carnarvon Range area and concluded the depositional environment to be estuarine to fluvio-deltaic. Felton (1985) came to similar conclusions in an area 30 km south of the current study area. Both workers subdivided the Formation into upper and lower members on the basis of observed facies assemblages and mudrock to sandstone ratios. The lower part of the Moolayember Formation is characterised by thinly interbedded quartz-lithic sandstones and mudrocks, while the upper part comprises initially thick-bedded cross-laminated sandstones and grades upward into a mudrock dominated sequence with rare lithic sandstone beds and lenses.

Sediments of the Moolayember Formation were studied at 10 outcrops in the area. Only one of these will be discussed in detail (Mool0002), and two others (Mool0009 and Mool0010) are briefly referred to here. Outcrops are composed of yellowish grey quartz-lithic, micaceous sandstones (in excess of 40% lithic component) interbedded with light grey to dark grey siltstones and very fine sandstones.

Architectural elements identified in outcrops of Moolayember Formation sediments in the Carnarvon Ranges are summarised in Table 1.

LOWER MOOLAYEMBER FORMATION
(OUTCROPS MOOL0009/0010)

Outcrop Mool0009 is situated in the cutbank of Basin Creek (AMG 789927, Sheet 8647 Arcadia), 50m down-dip (equivalent to 13m of section) from the last prominent exposure of thick-bedded Clematis Group sandstones. Outcrop Mool0010 lies 40m to the north approximate along strike from Mool009. Exposed facies are similar in both exposures and will be discussed together, where differences exist they are pointed out.

The outcrops are dominated by laterally extensive beds of medium grained lithic and micaceous sandstones (coarse member), interbedded with light grey mudrocks (fine member). Together these form architectural element HS (heterolithic sheet) and all of outcrop Mool0009 as well as the majority of Mool0010 is assigned to this element.

Fine member sediments comprise siltstones to very fine sandstones exhibiting abundant current ripples and lenticular and flaser bedding. In the subsurface the lowermost Moolayember is comprised of very dark grey, fine-grained mudrock showing extensive signs of bioturbation (Snake Creek Mudstone). This lithology does not crop out in the Carnarvon Range area, but can be examined at outcrop near Carnarvon Gorge National Park some 50 km west, and was penetrated in drill core within the south-western study area in GSQ DRD 20-21R.

Coarse member sediments comprise sandstones containing abundant evidence of current action such as ripple cross-lamination and trough cross-bedding. Features of extensive reworking, such as rip-up clast conglomerates and erosive pebble lags are locally restricted and occur at Mool0010, where they form part of element CH. The most dominant feature is the great lateral extent (>100m) of individual sand sheets which mostly do not exceed 0.2-0.3m thickness.

INTERPRETATION

Sediments of the lower Moolayember Formation reflect deposition in a low energy environment as manifested by abundant fine-grained sediments and the scarcity of erosive features. The depositional style is very much «layer cake» and is only occasionally interrupted by strongly erosive events (mudclast conglomerates). An environment with a dominant lacustrine or marginal marine component is consistent with these features.

Alcock (1970) concluded an estuarine environment for the lower Moolayember Formation. The marginal marine setting inferred by Alcock (1970) could not be substantiated in the current study due to the absence of any clear marine indicators such as macrofossils, microfossils or clear evidence of tidal activity. This not only applies to the Carnarvon Range study area discussed in the current paper, but also to other areas of the basin including the eastern basin margin and the southern subsurface part of the basin (Kassan 1993).

The lower Moolayember Formation in the study area is here interpreted to have accumulated near the margins of a large open circulation lake, in an area characterised by a complex facies arrangement arising from inter-digitating nearshore lacustrine and fluvial environments. A narrow embayment in the lake margin with one or more streams entering would constitute such a setting.

UPPER MOOLAYEMBER FORMATION
(*OUTCROP MOOL0002*)

Outcrop Mool0002 (AMG 630080, Sheet 8647 Arcadia) is one of a series of roadcuts on the Carnarvon Development Road, which form the type section of the Moolayember Formation. Exposure in outcrop Mool0002 occupies a stratigraphic position in the upper part of the Moolayember Formation in that area. The roadcut exposes a complete cross section of a channel and the adjacent floodplain sediments. Exposure is most complete along the eastern side of the Carnarvon Developmental Road. Palaeocurrent directions from this outcrop indicate a south-easterly to southerly drainage.

A controlled orthogonal photo mosaic was obtained of the eastern side of the roadcut and used to delineate the architectural elements (Fig.8,a).

Five architectural elements were identified: FD, SS, HS, LA, CH (Table 1). Fig.8,b shows a tracing of the photo mosaic, annotated with the observed architectural elements. The outcrop can be divided into four component parts (A to D), based on the geometry and composition of the sediments (Fig.8,b).

INTERVAL A

Grey mudrocks and very fine-grained sandstones are the dominant lithologies in Interval A. Most of the interval consists of facies element FD and exhibits rootlet penetration and ripple cross-lamination in the mudrocks and interbedded thin beds of sandstone. Interbedded sharply bounded, massive sandstone beds up to 0.4m thick are assigned to element SS. These are laterally persistent for some 20m.

The assemblage of facies and architecture represents deposition in low energy conditions occasionally interrupted by high energy events depositing sharp bounded sandstone sheets. Flooding and sediment accumulation occurred sporadically, allowing the development of incipient palaeosols in intervening periods. A proximal alluvial floodplain setting with occasional deposition of crevasse splays is envisaged to account for these deposits.

INTERVAL B

This interval is characterised by mounded (convex-up) heterolithic stratification (HS) of grey mudrock and very fine sandstone. Siltstones show poorly preserved rootlet penetration. Thin (max. 0.15m) sandstone sheets dip away from the crest of convex feature and wedge out into laterally adjacent sediments of proximal floodplain or lateral accretion origin.

The convex-up geometry, heterolithic composition and the intermediate position between floodplain and lateral accretion deposits lead to interpretation of interval B as a levee.

INTERVAL C

Some 40m of lateral exposure occurs in interval C and exposes complex heterolithic stratification, comprising grey mudrock and very fine-grained sandstone. The entire interval was assigned to architectural element LA (lateral accretion deposits). The internal geometry of interval C features «packages» of sediment, bounded by erosional surfaces inclined at 10° to 20° to the depositional horizontal. Bedding dips of thin sandstone sheets in adjacent packages may differ significantly and in some cases exhibit opposite dip directions (Fig 8c).

The position of interval C between levee and channel deposits suggests an environment peripheral to the main channel fill. Consistent inclination of major internal re-activation surfaces subparallel to the channel margin and at steep angles to the dominant palaeocurrent direction additionally indicate a significant contribution of lateral accretion. Parts of interval C can be interpreted as point bar deposits, by analogy with well documented examples and models in the literature (see review on the topic in Allen 1982). Major erosive surfaces (epsilon cross-bedding) in this instance represent major depositional episodes such as flooding events, resulting in erosion and rejuvenation of lateral accretion deposits. In some instances convex-up strata bound the upper termination of depositional packages and can be interpreted as preserved scroll ridges.

However, packages with dip directions of internal strata near opposite the direction of dip on the epsilon cross-bedding do not conform with documented examples and established models of point bar deposition.

Lateral accretion surfaces of opposite inclination occur in opposing alternate bars in near straight channel segments and in adjacent meander loops in high sinuosity channels. An alternate bar origin for the observed patterns appears attractive but is fraught with problems on detailed examination. Interval C documents systematic lateral migration of a channel preserved as Interval D. Systematic lateral migration of straight channel segments is unlikely as no mechanism is documented to account for the lateral migration of channel segments without an increase in sinuosity. The thalweg in straight channels with alternate bars takes a sinuous path, similar to a meandering stream. Lateral migration by mechanisms analogous to meandering streams would result in opposite migration directions for adjacent apexes of the thalweg, resulting in an increase in sinuosity. Additionally, the consistent inclination of re-activation surfaces with the channel margin of interval D is also incompatible with an alternate bar origin.

Fluvial meanders constitute one of the best studied continental depositional environments. Allen (1982) provides the most comprehensive review of work on point bars and free meandering channels to date. In particular the evolution of individual meander loops is of interest here. Allen (1982) recognises two principle modes of point bar development: movement of the meander loop downstream with approximately consistent loop length (*change of phase*); or an increase of loop length by migration and enlargement of the point bar perpendicular to the axis of the meander belt (*change of amplitude*). The interplay of both modes provides a continuous spectrum of loop evolution ranging from simple symmetrical to phase growth only (Fig.9).

The development of individual meander loops consequently does not have to follow a particular evolutionary mode (*change of phase* or *increase in amplitude*) for its entire life span. Variations in sediment supply, discharge or bed cohesiveness (say, due to an increase in vegetation), will determine the bank erosion rate at any point along the cut bank of a meander loop and thus directly influence the relative importance of *change of phase* and *increase in amplitude* to meander loop evolution.

The development of a point bar is recorded in the alignment and shape in plan view of scroll ridges on the bar surface. Scroll ridges are documented from recent point bar deposits and classical published examples include those of the Klarälven (Sundborg 1956) and Beatten River (Hickin & Nanson 1975).

If the relative contributions of both evolutionary modes remain approximately constant over the lifespan of an individual point bar a series of subparallel scroll ridges results, each recording a major depositional episode. Medium to long term changes in the relative importance of *change of phase* and *increase in amplitude* result in arrangements of packages of scroll ridges on the bar surface with internally concordant scroll ridge alignment, but discordance between scroll ridges of adjacent packages. An example of complex

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Fig. 8.—a) Orthogonal photo mosaic of outcrop Mool0002, a road cut in the upper Moolayember Formation. View is to the east. Person for scale (1.8m).

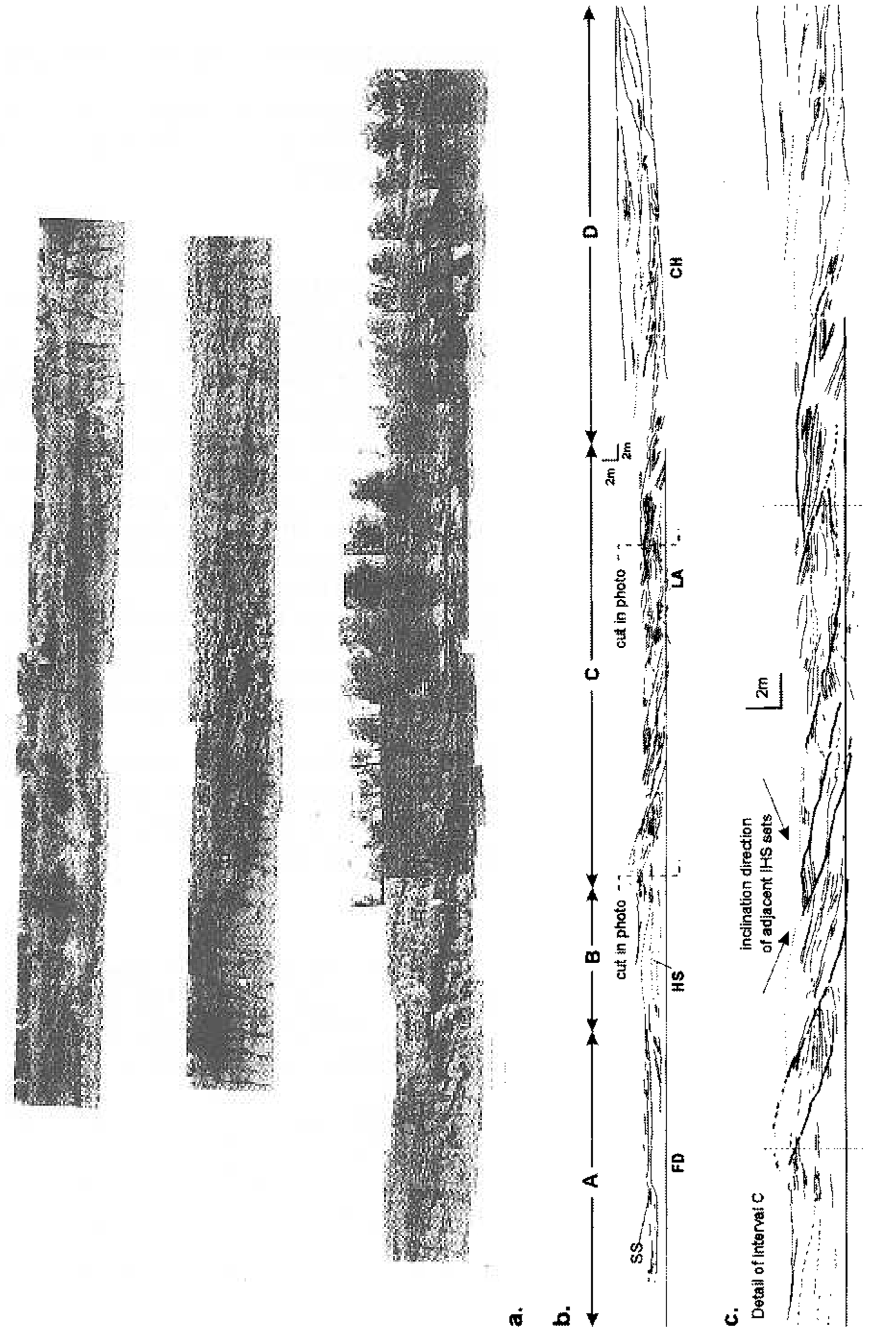
Interpretation (line tracing) of Mool0002. Four major intervals, characterised by architectural elements can be differentiated.

Detail of interval C, which is interpreted to result from complex lateral accretion, preserving some scroll-bar morphology.

Fig. 8.—a) Fotomosaico ortogonal del afloramiento Mool0002. Una carretera corta la parte superior de la Formación Moolayember. La vista es hacia el este. Persona de escala (1,8m).

b) Trazado de lineas interpretando el afloramiento. Pueden diferenciarse cuatro intervalos principales caracterizados por elementos arquitectónicos.

Detalle del intervalo C, interpretado como el resultado de una acreción lateral compleja que ha preservado alguna morfología de cordones de meandro.


a.
b.
A
B
C
D
cut in photo
cut in photo
2m
2m
SS
FD
HS
LA
CH
c.
Detail of Interval C
inclination direction of adjacent IHS sets
2m

arrangement of scroll-ridges from a recent depositional environment is provided in Fig.10.

Interval C is interpreted to represent laterally accreted deposits of a point bar with multiphase development associated with a varying contribution of a *change of phase* to the meander loop development.

INTERVAL D

A sandstone body of cross-bedded quartz-lithic medium and fine-grained sandstones with a concave-up erosive base and a flat sharp top forms interval D. The channel margin opposite interval C (lateral accretion complex) exhibits a marked step and overall steeper angle of inclination. A slight fining-up trend is recognised in the sandstones and the top part of interval D is formed by a thin veneer of argillaceous sandstone with no discernible sedimentary structures. The internal geometry comprises several internal erosion surfaces bounding lower order lenticular sandstone bodies. All are attributed to facies element CH. Sedimentary structures comprise predominantly trough and planar cross-bedding with preserved set height ranging from 0.1 to 0.3m. Loading structures occur locally as do small sandstone dykes.

Interval D is interpreted to represent a channel fill of a meandering channel. Channel abandonment must have been gradual as the channel fill is almost entirely sandstone dominated. Rapid abandonment would be expected to result in the development of standing water condition with associated fine-grained sediments.

The channel is exposed over its entire width (45 m) and most of its depth (3m), although these figures may be slightly distorted due to a possibly non-orthogonal section with regard to the palaeoflow direction, they are considered to provide a reasonable estimate of the true values.

SUMMARY

Depositional styles in Triassic continental sediments of the Bowen Basin, Queensland vary significantly in the study area between the three major stratigraphic units: the Rewan Group, Clematis Group and Moolayember Formation. Fig.11 summarises the pertinent features of deposits from each stratigraphic unit discussed.

The evolution of facies architecture in the area reflects changes in sediment composition and dispersal patterns, which can be recognised basinwide. Fundamental changes in relative base-level and sediment supply are proposed as the driving force of major differences between the main stratigraphic units, while more subtle variations in facies architecture within the Clematis Group and Moolayember Formation are interpreted to result from a combination of local and basinal factors.

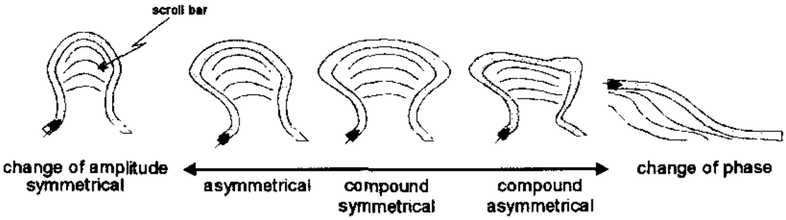


Fig. 9.—Modes of meander migration (after Allen 1982). Modes are not mutually exclusive and may vary in importance throughout the lifespan of a pointbar.
Fig. 9.—Formas de migración de un meandro (de Allen 1982). Estas formas no se excluyen unas a otras y pueden variar en importancia durante el tiempo de expansión de la barra de punta.

Laterally restricted, sharp bounded, poorly interconnected and moderate sized fluvial channels of the upper Rewan Group (Arcadia Formation) reflect relatively high subsidence rates in the basin at the time. This is corroborated by the overall thickness of the unit in the depocentres of the basin, locally exceeding 3km thickness. Overbank areas were subaerially exposed leading to common formation of soil profiles.

The Expedition Sandstone (Clematis Group) in the Carnarvon Ranges comprises predominantly deposits of braided sandy fluvial systems. While no cross-sections through entire channels could be documented in this study, an abundance of indirect evidence points to the presence of extensive channel belts in the Expedition Sandstone in the area. Development of multi-storey and multilateral sheet sandstones was aided by the sparsity of cohesive substrate. In the study area accumulation was initially dominated by downstream accretion on complex bars in channels with low interpreted depth to width ratios. Lateral accretion on the flanks of sandy barforms can locally be inferred and may have contributed significantly to sediment accretion overall. Channel belt margins partly erode sediments accumulated in areas peripheral to the influence of channel sedimentation. Drainage as indicated by foreset dip directions was from the northwest towards the south-southeast, though locally this varied considerably, including a significant subset of palaeocurrent directions indicating a north-east directed drainage.

The upper part of the Expedition Sandstone contains a succession of finer-grained sandstones and interbedded mudrocks, indicating a significant lowering of transport energy. Wave generated ripples and combined flow structures resulting from the concurrent effect of unidirectional currents and oscillatory waves occur in this part of the unit together with bioturbation. In drill cores a continuous fining-up of the upper Expedition Sandstone into the finest part of the overlying Snake Creek Mudstone can be observed (i.e. GSQ

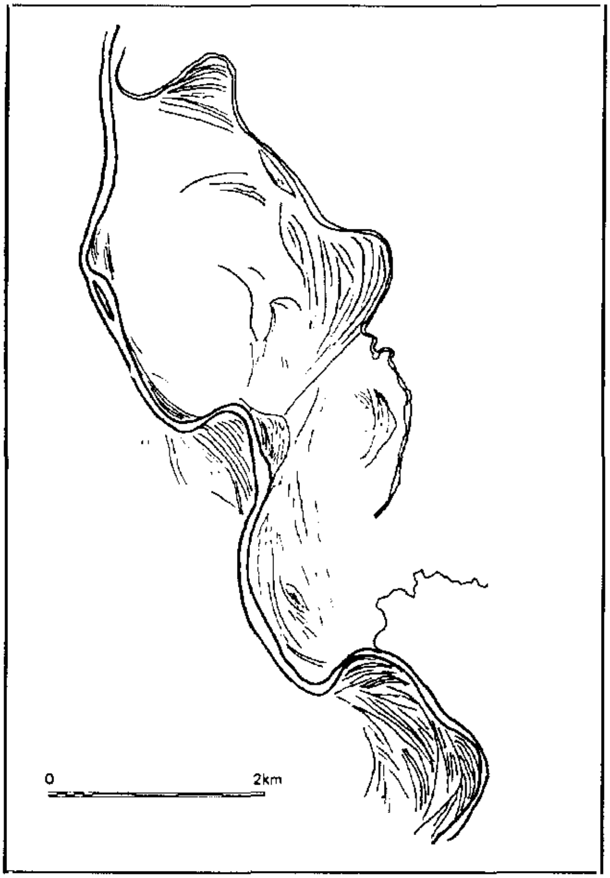


Fig. 10.—Scroll bars of the modern Senegal River. Line tracing from a SPOT satellite image. The laterally accreted complex in outcrop Mool0002 is interpreted to reflect accumulation by complex meander migration, as preserved in scroll ridges along the Senegal River.
Fig. 10.—Cordones de meandro del rio actual Senegal. Las lineas de interpretación están trazadas de una imagen SPOT de satélite. El complejo acrecional del afloramiento MoolOOO2 se interpreta como el reflejo de la acumulación de la migración compleja de un meandro, como los que se preservan en los cordones de meandro del rio Senegal.

DRD 20-21R). This marks a relative rise of the base level throughout the south-western part of the Bowen Basin and the establishment of lacustrine conditions (Snake Creek Lake) in that area, which coincides with the end of the influx of quartzose material and the change to the lithic and micaceous sediments of the Moolayember Formation.

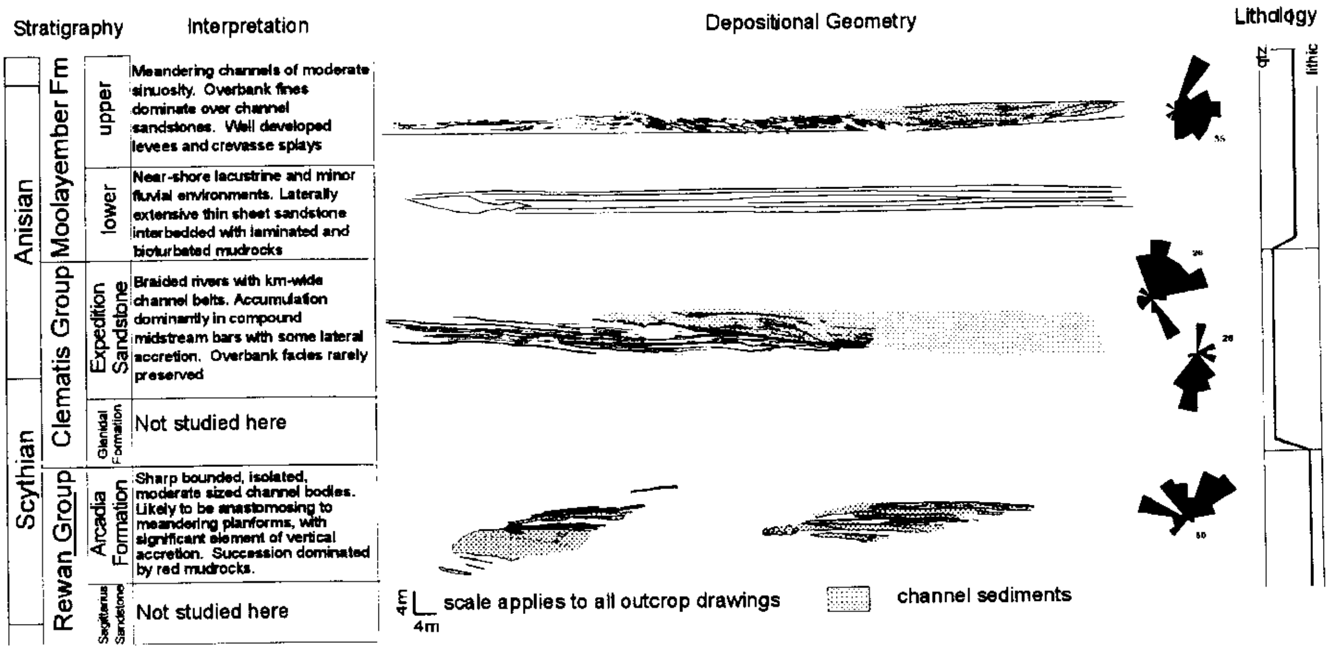


Fig. 11.—Summary diagram of variations in depositional style within the Triassic succession in the south-western Bowen Basin.
Fig. 11.—Diagrama conclusión de las variaciones en el estilo deposicional dentro de la sucesión triásica en el suroeste de la Cuenca Bowen.

Transgression of the lake culminated with accumulation of laminated dark grey and black shales of the Snake Creek Mudstone, which are not exposed in the study area, but are known from numerous fully cored boreholes in the area and other parts of the basin. The overlying lower Moolayember Formation in the study area is formed by laterally extensive near-shore deposits of the Snake Creek Lake, and interfingering fluvial-dominated intervals.

A lowering of baselevel reduced the Snake Creek Lake and progradation of fluvial deposits from the basin margins. Small to moderate sized meandering streams were accumulated predominantly by lateral accretion. Overbank areas were vegetated and received sediment during times of high flowstage.

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Manuscrito recibido: 29-4-1996
Manuscrito aceptado: 23-9-1996