PRJ, Vol. 8 (January 1996); P. 49-60, 3 FIGS, 2 TABLES.

# The pre-Cretaceous (Triassic) Sequence in the Subsurface of Maradah Trough, Eastern Sirt Basin, Libya

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# التتابع الطبقي لصخور ما قبل الحين الكريتاسي (الترياسي) تحت سطح منخفض مرادة ، شرقي حوض سرت — ليبيا

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يقع منخفض مرادة في الجهة الشرقية من حوض سرت بمحاذات الحافة الشرقية لمرتفع الركب الغني بالنفط كما تحده هضبة أمال من الجهة الشرقية. ومن خلال حفر الآبار ب1 وب2 وب3 وب4 بعقد الإمتياز 96 الواقع بنفس المنخفض تم اختراق تتابع صخري من الأحجار الرملية مع تراكمات بسيطة من صخور الطفلة اللتان يعتقد أنهما قد ترسبا أوان ما قبل الحين الكريتاس العلوي.

قامت شركة وينترشل بتقسيم التتابع الطبقي لصخور هذا الحين إلى وحدتين صخريتين هما PUCأ وPUCب كما أعتبرت الشركة أن الوحدة أ أكثر حداثة من الوحدة ب من حيث العمر، حيث يربو سمك الوحدة ب عن 995 قدما وتتكون في مجملها من صخور الحجر الرملي مع تراكمات ضئيلة ونادرة من صخور الطين. أما صخور الوحدة أ فأنها تتكون من صخور من الحجر الرملي والطين، وتغطي هذه الوحدة الصخرية الوحدة ب بسطح عدم توافق. يتراوح سمك الوحدة أ ما بين 510 قدما عند الشرق إلى 765 قدماً عند الناحية الغربية من منطقة الدراسة ويصل سمكها إلى 1450 قدماً في أقصى الغرب عند منطقة جخرة. وبناء على المحتوى الصخري وخواص السرود الجيوفزيائية فقد تم تقسيم صخور هذه الوحدة (أ) إلى أربع وحدات صخرية صغرى.

يتكون التتابع الصخرى للوحدتين أ و ب غالباً من صخور مرو الأرنيت ذات الخواص البتروغرافية المتشابهة إلا أنه بالإمكان فصل صخور هاتين الوحدتين عن بعضها باستعمال بتروغرافية مجمل المحتوى الصخري وتواجدات المعادن الثقيلة وخواص حبوب اللقاح النباتية، حيث تشير الأخيرة (أي حبوب اللقاح) بالرغم من ندرتها أن صخور الوحدة ب كانت قد ترسبت عند أوان دهر الحياة القديمة المبكر (الكامبريان — أو ما قبله). كما تشير المعلومات المستوحاة من دراسة حبوب اللقاح لصخور الوحدة أ أنها تنتمي إلى ترسبات الحين الترياسي المتوسط. وقد يشير هذا ومعلومات أخرى إلى وجود سطح عدم توافق بين صخور الوحدتين أ و ب. ومن المحتمل وبناء على الخواص البتروغرافية والصفات الصخرية وتواجدات حبوب اللقاح، أن صخور الوحدة ب كانت قد ترسبت في منخفض نشط تكتونيا وفي بيئة غير بحرية في وجود الأكسجين أبان ما قبل دهر الحياة القديمة، حيث يبدو أن الصخور الفتاتية معادة الترسيب وأن المنطقة قد تعرضت لظاهرة الرفع والتجوية حتى بداية الحين الترياسي. كما يعتقد أن صخور الوحدة أ قد ترسبت في منخسف تحت ظروف غير بحرية وربما إنتقالية أحياناً تتراوح بين وفرة وندرة الأكسجين أثناء الحين الترياسي الأوسط (الأنيزيان واللادينيان؟). هذا وقد مر المنخسف بفترة تكتونية هادئة أثناء أغلب مرحلة الأنيزيان نتج عنها رواسب من الطين الغير بحري مع صخور ثانوية من الحجر الرملي. كما إشتهرت هذه الفترة الزمنية الأخيرة بهبوط تخلله بعض التأثير من البحر.

تشير زيادة سمك الوحدة أ عند الغرب وازدياد محتواها الرملي أن منخفض مرادة كان غير متناسق وأن الصدوع التي تحدد الجهة الغربية منه كانت أكثر نشاطاً أثناء فترة الحين الترياسي الأوسط. كما يبدو أن الطقس كان أكثر بروداً أثناء أوائل دهر الحياة القديمة عند تواجد صخور الوحدة ب ثم ما لبث أن تغير إلى طقس رطب أثناء تطور الجزء الأسفل من الوحدة أ وتبع ذلك أنواع من الطقس الرطب والجاف في وقت اللادينيان أثناء ترسب الجزء العلوي من الوحدة أ. هذا وقد إشتقت الصخور الفتاتية للوحدتين أ و ب من تتابع صخري من الصخور المتحولة والصخور النارية الحمضية الفقيرة بمعدن الفلدسبار. وقد ترجع تواجدات العناصر المعاد ترسيبها بالوحدة أ إلى صخور قديمة قد تنتمي إلى تكوين القرقاف وربما صخور الوحدة ب أيضاً.

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**Abstract** *A fairly thick sequence of sandstones with very subordinate shales, designated as Pre-Upper Cretaceous (PUC) by the operating company (Wintherhall), are met at B1, B2, B3 and B4-96 in the subsurface of Maradah Trough, Sirt Basin. The Amal Platform defines its eastern limits. The operating company divided the PUC sequence into PUC 'B' (older) and PUC 'A' (younger) units. The PUC 'B' is 995+ feet thick and comprises mainly sandstones with very rare and thin levels of shales. The PUC 'A' unconformably overlies the PUC 'B' and consists of sandstones and shales. It is divisible into Units I–IV on basis of gross lithology and log characteristics. The thickness of PUC 'A' ranges from 510 feet in the east to 765 feet in the west. It thickens to 1450 feet further west towards Jakhira.*

*PUC 'B' and PUC 'A' sequences comprise mostly quartz-arenites of fairly similar petrographic characters. It, however, is possible to resolve one from the other on basis of gross lithologic, and palynologic criteria.*

*The palynofossil assemblage, though scarce, suggests PUC 'B' to be ?Precambrian–Cambrian. The assemblage recovered from PUC 'A' is relatively very rich and referable to Middle Triassic (Anisian and ?Ladinian). These and other data suggest an unconformity between PUC 'B' and the overlying PUC 'A'.*

*Lithologic characters, petrographic attributes and palynofossil contents suggest that PUC 'B' was probably laid in a tectonically active graben under mainly non-marine oxic environments during ?Pre-Cambrian. The detritus appears to be partly recycled. Subsequently, the depositional area underwent uplift and erosion till the close of Early Triassic. The PUC 'A' appears to have been laid in a graben under fluctuating oxic-anoxic and non-marine to at times probable transitional environments during Middle Triassic (Anisian and ?Ladinian). Tectonically the graben was fairly subdued during most of the Anisian and promoted evolution of mainly non-marine shales with subordinate sandstones. The later period was marked by a relatively, accelerated negative tectonism and interludes of marine influence. Westerly increments in thickness and overall increase in sandstone contents of PUC 'A' indicate that the Marada Trough was asymmetric and the faults defining its western fringes were tectonically more active during the Middle Triassic.*

*Relatively colder climates appear to have prevailed during ?Precambrian–Cambrian when the PUC 'B' sequence was developed. The palaeoclimates during the evolution of the lower part of PUC 'A' sequence, dated as Anisian, were mainly hygrophytic. These, however, switched over to mixed hygrophytic-xerophytic types during Ladinian when the upper part of the PUC 'A' sequence was laid.*

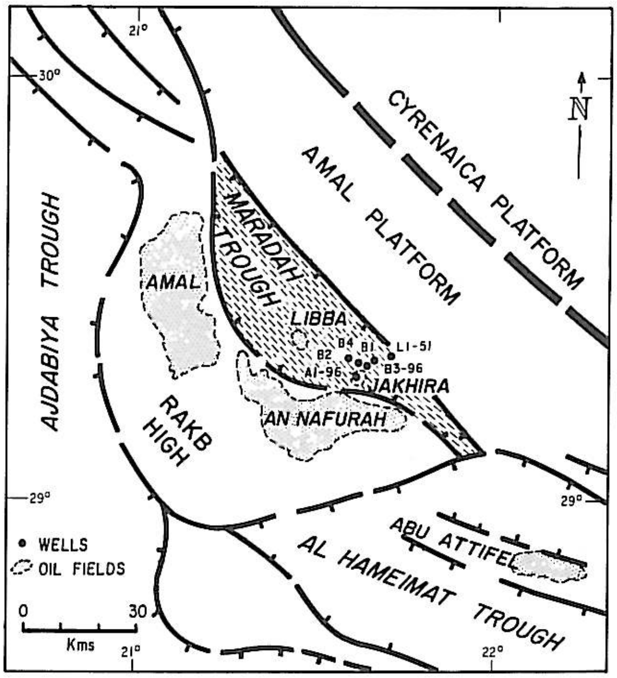
## INTRODUCTION

Sediments of Triassic age are usually considered to be absent in the Sirt Basin (Barr and Weegar, 1972). The geologic period extending from Carboniferous to ?Jurassic is opined to be denoted by non deposition possibly due to continued uplift and erosion of the Sirte anticlise (Massa and Delort, 1984). The adjoining Ghadamis Basin to the west and the Cyrenaica Platform to the east, being syneclises contain a fairly complete record of palaeozoic and Mesozoic sediments (Adloff *et al.*, 1986 Karr *et al.*, 1972; Bellini and Massa, 1980; Brugman *et al.*, 1985 and Brugman and Visscher, 1988).

The Pre-Palaeocene quartzose clastics met in the subsurface of Sirt Basin broadly belong to three ages. The Gargaf–Hofra quartzites and Amal Formation are considered to be of Cambrian–Ordovician age (Roberts, 1970; Barr and Weegar, 1972). The mostly non-marine Nubian-Sarir sandstones and other homotaxial deposits are generally assigned a ?Jurassic – Early Cretaceous age (Bannerjee, 1980). The shallow marine – marine sandstones and shales included into several other formations (e.g. Maragh, Bahi, Etel, Rachamat, Sirte etc.) are dated as Late Cretaceous XX (Barr and Weegar, 1972).

Brugman *et al.*, 1985, and Thusu *et al.*, 1988, reported the presence of Triassic palynomorphs from shale levels in subsurface sandstones met at Al-96 in the Maradah Trough, Eastern Sirt Basin, Libya (Fig. 1).

The present study deals with the occurrence of Triassic sediments in the subsurface from another




FAULTS ARE AFTER MOUZUGHI & TALEB, 1981

Fig. 1. Location map, Maradah Trough, Sirt Basin, Libya.

new locality (B1, B2, B3, and B4-96 wells) in the Maradah Trough and mainly discusses their evolution, age and environment sedimentation. The study is based on lithologic and petrographic investigations by the senior author and palynologic studies by the junior author.

## GENERALISED STRATIGRAPHY

The pre-Late Cretaceous sequence met in the studied wells comprises sandstones and minor shales. The operating company (OPCO) divided these sandstones into Pre-Upper Cretaceous 'B' (older) and PUC 'A' (younger) sequences (Fig. 2). The PUC 'B' comprises mainly sandstones with rare-scarce thin levels of shale. The sandstones are whitish, light gray, grayish brown, moderately hard, sometimes cross-bedded, locally friable, partly quartzitic, medium to coarse grained, rarely fine grained, moderately sorted, at times pebbly (3–4 mm), scarcely argilaceous and micaceous. Graded bedding is common. Detrital grains are generally cemented by silica and at times by barite and comprise angular – subangular and at times subrounded quartz grains. Sub-vertical fractures filled by siliceous matter and barite are present. Shales are rare to scarce. They are present as streaks and thin to very thin beds. They are light grey to dark gray, grayish brown, reddish brown, varicoloured, mottled, subfissile – fissile, brittle, often laminated, silty-sandy and scarcely micaceous. Fissility is more pronounced due east whereas, the micaceous content increases towards the west (Table 1). Siltstones are fairly rare. They are medium gray, light beige, micaceous, argillaceous and display sub-vertical fractures. The thickest (995+ feet) drilled section of PUC 'B' is met at B1-96. Basement is not reached in any of the four wells (Table 1).

The PUC 'A' comprises sandstones, shales and minor siltstones. Sandstones are off-white, greenish gray, occasionally with reddish tint, brownish gray, yellowish brown, light brown, beige, dark gray occasionally variegated, moderately consolidated, fine to medium grained, at times coarse grained, and micromicaceous. Graded bedding and alternation of finer and coarser grained sandstones are fairly common. Subrounded, clear, white and moderately well sorted quartz grains are the most dominant constituent. Ferriginous matter, pyrite, plant remains and claystone clasts are present. Siliceous and carbonate

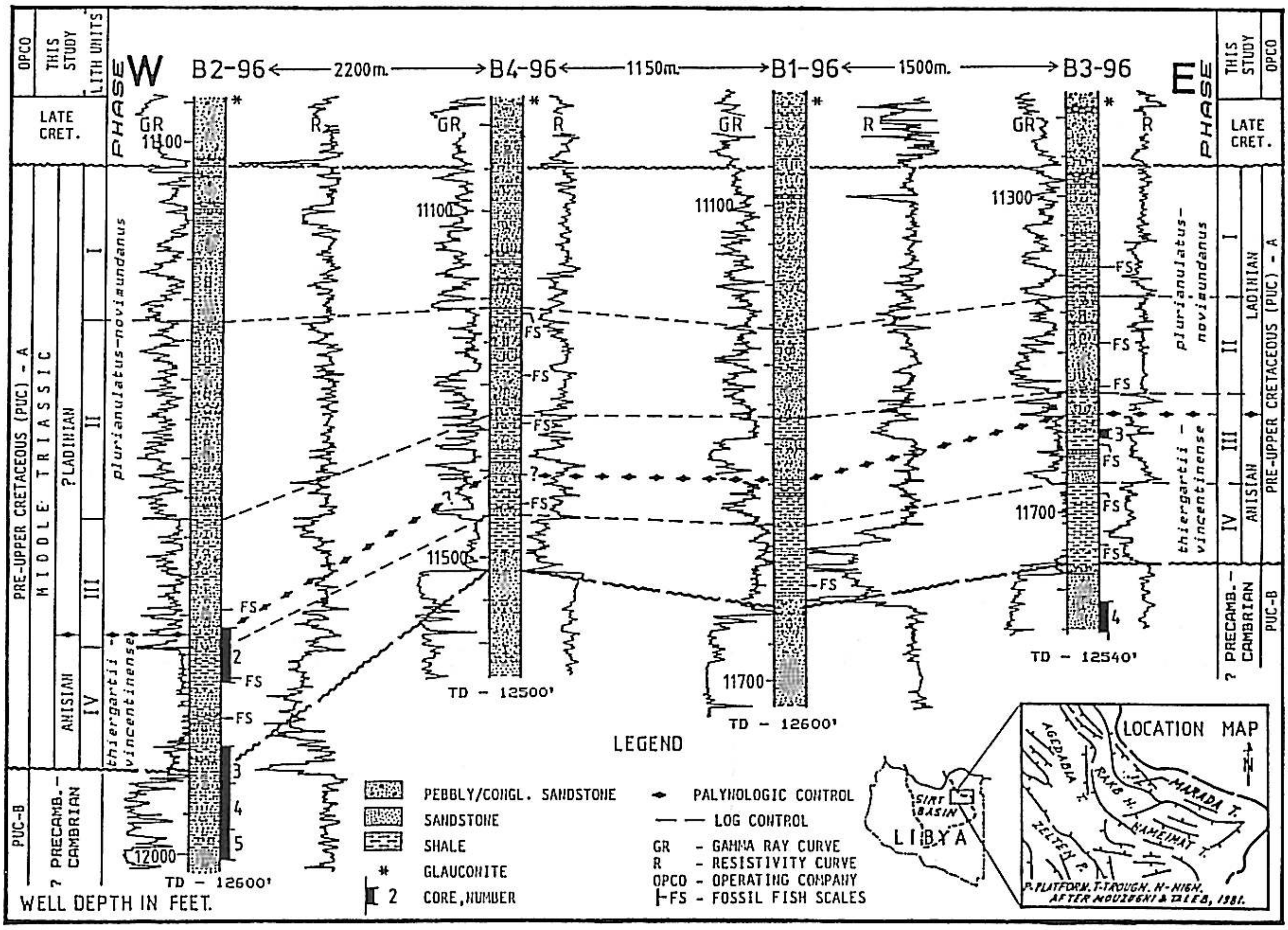



Fig. 2. Stratigraphic section through wells, Maradah Trough, Sirt Basin, Libya.

**Table 1. Gross lithologic characteristics of Pre-Upper Cretaceous (PUC) 'B' and 'A' sequences, Maradah trough, Sirt Basin, Libya.**

| Units | B2-96 | B4-96 | B1-96 | B3-96 | Age |
|---|---|---|---|---|---|
| PRE-UPPER CRETACEOUS (PUC) 'A' — UNIT I | *Sandstone with thin shales*<br>*SST.:* Wh., lt., gr., f. – cse., subang. – subrounded, pyr., fria., poor cement. congl. in upper part.<br>*SHALE:* Med. lt. brn. gr., red. brn., grn. brn., hd., splintary, sli. silty, subfiss.<br>THICKNESS =195 FEET. | *Sandstone with thin shale*<br>*SST.:* Gr., med.-cse., loose, partly congl., sub-rounded, at times alternates with shale.<br>*SHALE:* Brn. gr., beige, dk. brn., blk, silty, pyr., fiss.<br>*SILTST.:* In traces, brn, arg.<br>THICKNESS =160 FEET. | *Sandstone with thin shale*<br>SST.: off wh., dk, red brn., fria., mod, hd., f, – cse., tr. arg., sh. alternations.<br>SHALE: Dk. gr. – grn. gr., fiss., carb., coaly matter, sli. silty, lenses of silt.<br>THICKNESS =250 FEET. | *Sandstone and shale*<br>SST.: Variegated, orange, fria., mod. sorted, arg.<br>SHALE: Variegated, gr. brn., red, ochre, sft., form, fissile, partly carb., pyr., silty, *fish scales.*<br>THICKNESS =120 FEET. | MIDDLE TRIASSIC (ANISIAN-?LADINIAN) |
| UNIT II | *Alternating sandstone and shale*<br>*SST.:* Wh., med. – cse., pebbly, congl., grn. org. matrix, loc. loose, sil cement.<br>*SHALE:* Brn. gr., red. brn, hd., splintery, sh. silty, subfiss.<br>*SILTST.:* Scarce, lt. gr. beige, fria., grad. to sst.<br>THICKNESS =250 FEET. | *Alternating sandstone and shale*<br>*SST.:* Wh., lt. gr., f. – med., siliceous, partly qtzitic.<br>*SHALE.:* Gr. – dk. gr., beige, silty, pyr., v. fissile. *common fish scales.*<br>*SILTST.:* Traces.<br>THICKNESS =125 FEET. | *Alternating sandstone and shale*<br>*SST.:* As above.<br>SHALE: Gr. – dk. brn. gr., mod. hd., fiss., carb. – coaly matter, silty.<br>*SILST.:* Gr. – dk. gr. sli. calc.<br>THICKNESS =105 FEET. | *Alternating sandstone and shale*<br>*SST.:* Variegated, gr. brn., red, ochre, f. – cse., mic.<br>SHALE: Variegated, gr. brn., pale grn., red, sft., fiss., partly carb., mic., sandy, pyr., *fish scales.* sand interbeds.<br>THICKNESS =120 FEET. | |
| UNIT III | *Sandstone with SILTST. & shale*<br>*SST.:* variegated, partly red brn., f. – med. & cse., pyr., org., micromic., siliceous.<br>*SHALE:* Variegated, dk. gr. – brn. gr. laminated, hd., subfiss., splintery, pyr. plant remains, *comm. fish scales,* silty.<br>*SILTST.:* Scarce. Beige gr., fria., grades to f. sst.<br>THICKNESS =165 FEET. | *Sandstone and shale*<br>*SST.:* Wh., f. – med., sil., locally qtzitic.<br>*SHALE:* Beige, lt. – dk. gr., brn. gr., silty., pyr., partly micromic., fiss., *rare fish scales.*<br>THICKNESS =115 FEET. | *Sandstone with shale in lower & upper part*<br>SST.: Off-wh., lt. brn., fria., loose med. – cse., subang. – subrounded, poorly cemented, sh. arg.<br>SHALE: Gr. – dk. brn. gr. mod. hd., fiss., carb. – coaly matter, thin silst.<br>THICKNESS =140 FEET. | *Shale with sandstone levels*<br>SST.: Gr. – med. gr., gr. brn., dk. gr. – blk, f. – cse., firm – fria., arg., calc. – dolotic.<br>SHALE: Dk. gr. – blk., grn, brn., ochre, thinly lamina., fiss., mic., carb., – pyr., silty, tr. coal., *common fish scales.*<br>THICKNESS =110 FEET. | |
| UNIT IV | *Sandstone and shale*<br>*SST.:* Brn. gr., red. brn., cse. – med., pyr. sil., fria.<br>*SHALE.:* Variegated, brn. gr., laminated, med. hd., silty, f. sandy, v. fiss., splintery, *common fish scales,* pyr. plant remains, v. pyr., horiz. burrows, micromicaceous.<br>*SILTST.:* Beige, med. hd., also fria., arg.<br>THICKNESS =155 FEET. | *Shale with sandstone levels*<br>*SST.:* Lt. brn., f. – cse., subang. – subrounded,<br>*SHALE:* Beige, dk. med. gr., v. pyr., subfis., micromic., *rare fish scales.*<br>*SILST.:* Rare, Brn. gr., bituminous.<br>THICKNESS =65 FEET. | *Shale with scarce sandstone*<br>SST.: As above.<br>SHALE: Dk. gr. – blk. gr. firm, mod hd., fissile, splintery, silty, *scarce fish scales.*<br>THICKNESS =105 FEET. | *Sandstone with thin shales at base*<br>SST.: Wh., brn., f. – med., loose – fria., sil., dolotic, arg.<br>SHALE: Med. dk. gr., v. dk. brn., blk., sft., fiss., partly lam., pyr., coaly carb., dolotic., *fish scales, plant remains.*<br>THICKNESS =110 FEET. | ↓ |
| PUC 'B' | *Sandstone with a few shale levels*<br>*SST.:* Wh., lt. brn., med-cse., fria., qtzitic, sili. cement, pyr., mic., ang. – subang., subvertical fractures filled by quartz.<br>*SHALE:* Grn. gr. – beige, red, ochre, sli. pyr., hd., subfiss., plant remains.<br>*SILTST.:* Streaks, grn. gr., v. mic.<br>THICKNESS =700+ FEET. | *Sandstone with a few shale levels*<br>*SST.:* Lt. – med. brn., poorly cemented, partly qtzitic, also fria., med. – cse., subang. – subrounded.<br>*SHALE:* Trace; med.. gr., subfiss.<br>THICKNESS =985+ FEET. | *Sandstone with a few shale levels*<br>SST.: Beige, lt. brn., gr., mod. hd., – hd., locally fria., f. – cse., subrounded, sil. cement, qtzitic., mic., laminated.<br>SHALE: Lt. gr., red. brn., subfiss., occ. v. hd., mic.<br>THICKNESS =995+ FEET. | *Sandstone with a few shale levels*<br>*SST.:* V. lt. gr., brn., pale grn., pale red, qtzitic, sil., fractures, med-cse., filled with barite and anhy.<br>SHALE: Trace; beige, med. dk. gr., brn. gr., variegated, mottled, partly mic., brittle, fissile, silty.<br>THICKNESS =775+ FEET. | ← ?PRECAMB. – CAMB. → |

(dolomitic) cements are observed. Matrix, though low, is argillaceous. The Siltstones are gray to dark brownish gray, greenish gray, light brownish, micromicaceous, argillaceous, often grading to very fine sandstones and silty shales, at times sub-fissile, laminated and locally with abundant organic matter. Thin levels of brownish, fine-medium grained and well consolidated sandstones are present. The shales are gray, medium dark gray-dark brownish, locally greenish brown, reddish, variegated, microfaulted, medium hard, subfissile–fissile, laminated, splintery, often pyritic, silty-sandy and often grade to siltstones. Traces of carbonaceous, coaly matter, pyritised plant remains and streaks–stringers and interbeds of brownish gray, friable sandstones and siltstones with siliceous and dolomitic cements are present. In general, the micaceous content of sandstones and shales increases towards the west (Table 1). Shales are more fissile and paper thin due east. The thickness of PUC 'A' varies from 510 feet in the east to 765 feet in the west (Fig. 2). It rapidly increases to about 1450 feet in A4-96 located very close to A1-96 in another fault block approximately six kilometres south of B2-96 (Fig. 2).

Variations in gamma ray and resistivity curves together with changes in lithologic characters and organization enable classification of PUC 'A' into four units (Fig. 2, Table 1). It is unconformably overlain by pebbly to coarse grained and at times conglomeratic sandstones containing abundant glauconites and levels of greenish gray shales as well as carbonates. These are included into the Maragh Formation of Late Cretaceous age (Fig. 2). The glauconites reported in well cuttings from several levels within the PUC 'A' may be contaminations from the Maragh Formation.

Gross characters of the principal lithologies forming the PUC 'A' and PUC 'B' sequences are summarized in Table 2.

## PETROGRAPHIC STUDY

The study follows the classification and nomenclature of sandstones proposed by Gilbert (1954). Abundance of various detrital components were determined visually using diagrams of Shvestov (Terry and Chillinger, 1955) and Bacelle and Bosellini (1965). Roundness was estimated after the chart of Krumbein (1941).

Sandstones form the bulk of PUC 'B' and PUC 'A' sequences. Compositionally, they are classed as quartz-arenites. Shales are very subordinate in PUC 'B' but relatively more abundant in PUC 'A'. Petrographic differences between the quartz-arenites and shales of PUC 'B' and PUC 'A' sequences are too subtle and they alone cannot be objectively used to identify one from the other. The general petrographic characters of quartz-arenites and shales are as given below.

### Quartz-arenites

The arenites are constituted mainly by quartz and minor amounts of chert, rock fragments and traces of feldspars as well as ore minerals. In general, they are fairly deficient in matrix. A few levels, however, seem to contain up to 5% of clayey-chloritomicaceous-quartzose matrix. Most of the principal detrital fraction is of 200–350 μ size. A few grains larger than 500 μ also are present. Rounding in the 200–350 μ population ranges from 0.3 to 5. Coarser detrital grains are usually better rounded (0.5 to 0.7). Grains with roundness exceeding 0.7 are rare. Some of the detrital grains seem recycled.

Quartz forms nearly 80% of the essential detrital fraction. Various varieties are recognised. Slightly-strongly strained quartz with undulose extinction and inclusions are the most common. The inclusions are generally of rutile, zircon, micas and tourmaline. A few grains also display gaseous inclusions. Quartzitic aggregates, polycrystalline quartz and stretched metamorphic quartz also are present. Unstrained grains with uniform extinction are noticeable. Authigenic growths defined by dust rings and rims caused by dissolution and replacement by carbonates are frequently observed. A few quartz grains are very well rounded and seem recycled. Detrital chert forms 3–5% of the detrital fraction. They usually are fairly well rounded (0.5) and characterised by an aggregate of mutually interfering or interlocking minute silica grains exhibiting characteristic pin-head extinction. A few well rounded broken chert grains are noticeable. Some of the chert grains are ferruginous while a few others are recycled. Feldspars are present only in traces. In most cases they are untwinned and fairly fresh. Their identification could thus be possible only on basis of cleavage traces, at times feeble to very feeble alteration to ?sericite and if possible, the optic sign. Most of the feldspars are marked by small extinction angles suggestive of the albite-oligoclase range. Some of the feldspars exhibit straight extinction and may represent orthoclase. Rock fragments exclusive of chert are usually scarce and seem to form less than 3–5% of the detrital mass. The rounding ranges from 0.3 to 0.5 but a few are very well rounded and seem recycled. Metaquartzites are the most common and those of argillites, quartz-schist, orthoquartzites are very rare. Accessory detrital minerals include a host of heavy minerals and micas. Zircon, tourmaline, sphene and rutile are fairly common and most of these are recycled.

The non detrital constituents include cements. Silica is the most common cement. Clayey, carbonate

**Table 2. Gross characters of arenites and shales of (PUC) 'B' and (PUC) 'A' sequences, Maradah trough, Sirt Basin, Libya.**

| | *Characters etc.* | *PUC 'B' (?Precamb.–Cambrian)* | *PUC 'A' (Middle Triassic)* |
|---|---|---|---|
| Arenite | General | Whitish – lt. gr., hard, med – cse'. qtzitic, pebbly, well compacted, sub – vert, fractures, rarely fria. Grains subrounded, a few well rounded, mod. sorted, and with authegenic growths. Rarely micaceous. Non-calcareous. | Off white – gray, variegated, reddish, f. – med., rarely pebbly, compacted and locally friable. Grains are sub. ang. – subrounded, also very well rounded, with authegenic growths. Micaceous, often calc – dolomitic. |
| | Composition | Strained quartz, tr. fresh alkali feldspars. Chert and qtzitic rock frag. traceable. Strained micas, recycled quartz. | Strained quartz, tr. alkali feldspar, fairly common chert and metaqtzitic and other rock frag. Strained micas, and frequent recycled quartz. |
| | Matrix | Rare, patchy; usually silty; clay altering to micas. | Patchy; usually argill., altered to micas |
| | Diagenesis | Moderately compacted, indurated cemented by silica and ferru. matter. Some fractures filled by barite. Authegenic growths on quartz are common. | Well compacted, cemented by carbonates, silica and ferru. matter. Authegenic growths on quartz grains are less common. |
| | Heavy Mineral Suite | Generally impoverished, scarce to very scarce. Includes rounded zircon, tourmaline, rutile and sphene and a few zoisite, chtd, garnet. Ore minerals are abundant. | Relatively richer and abundant. Flooded by very well rounded zircon, tourmaline, sphene and rutile. Others include epidote, zoitite, chloritoid, staurolite, monazite, allanite and garnet etc. Ore minerals are less abundant. |
| | Glauconite | Absent | Absent |
| Shales | General | Gray, very dark gray, black, hard, fissile, slickensided, non-calc., rarely silty, brittle, often laminated. Generally rare | Gray, very dark gray, black, med. soft, fissile, at times paper thin, slickensided, pyritiferous. Generally more common. |
| | Glauconite | Absent | Absent |
| | Plant Remains | Rare to scarce; often pyritized. | Often present, at times very common, usually pyritized. |
| | Coaly Matter | Absent | Present. Well structured. |
| | Organic Matter | Mainly amorphous, very dark gray to black, very mature to metamorphosed. TAI = 3+ to 5. | Mainly herbaceous, light brn – dk. brown, mature. TAI = 2 to 3+. |
| | Worm Burrows | Not present | Present. Horizontal more common than vertical. |
| | Palynofossils | Ornamentation is obliterated. Grains are corroded. ?*Leiosphaeridia* spp.. and ?*Kildinella ripheica* etc. | Well preserved. Several species are recorded. See text and Appendix I. |
| | Other Fossils | None recorded | *Branchiopods*, fragments of *Conularids*, fishscales and part of fish tooth. |
| | Age | ?Precambrian – Cambrian on basis of palynofossils | Middle Triassic (Anisian and ?Ladinian) on basis of palynofossils. |

and cherty cements are patchy and subordinate. Cementation by ferruginous and chloritomicaceous matter is also observed.

The petrographic characters of arenites forming the PUC 'B' and PUC 'A' sequences are fairly similar to one another. The differences are subtle and these alone cannot be employed to differentiate one from the other. Their principal characters are summarized in Table 2.

### Shales

The shales are dark gray to black, fissile and usually hard. They comprise clay minerals and carbonaceous and bituminous matter. Silt is subordinate. The chloritomicaceous clay minerals occur generally as evenly oriented shred-like and moderately crystalline aggregates. Organic matter is often present. Ferruginous stains are common. Authigenic minerals, other than the micas, mainly include pyrites. These occur generally as anhedral – subhedral crystal grains throughout the shale fabric.

The shales of PUC 'B' and PUC 'A' are fairly similar to one another. They are, however, more abundant in PUC 'A'. Fissility is at times more pronounced and slickensiding is common in shales of PUC 'A'. These shales are fairly rich in comminuted organic remains. Anhedral pyrite is commonly present and evenly disseminated in the clay mineral fabric. It, however, also occurs as stringers, films and less frequently as euhedral crystal aggregates. Several fossils of Branchiopods and plants are pyritized. Diagenetic anhydrite is at times present along some of the shaly planes. The shales of PUC 'B' are hard, extremely low in organic content and fairly deficient in pyrites. Their micaceous content, however, exhibits better crystallinity and orientation.

## DIAGENESIS

### Compaction

Alternating sandstone–shale laminae display the best evidence of compaction megascopically. In quite a few cases (B3-96, core 2, 11593–11606 ft; B2-96, core 2, 11724–11784 ft) the two are squeezed into one another. The laminae exhibit thickness variations due to differential compaction. Compaction and packing, which are reflected by the nature of detrital grain contacts, control porosity (Gilbert, 1949; Taylor, 1950; Thompson, 1950 and Siever, 1959).

The grain contacts in the quartz-arenites are usually concavo-convex. Planar, line or tangential contacts are less common. Sutured contacts formed by interpenetration assisted by pressure solution are very rare. At times, relatively larger (exceeding 350 μ) quartz grains are penetrated by those of silt grade and their contacts seem to be marked by a thin film of ferruginous-argillaceous mass. Fused contacts are usually absent. In general, the arenites exhibit a moderate degree of pre-diagenetic compaction.

### Cementation and Authigenesis

Silica is the most common cement. It occurs as thin films between detrital grains and in some cases, also as interfering authigenic growths. Films are more common in finer and medium grained arenites. Chert cement marked by typical pinhead extinction is also present. Authigenic growths are relatively more common over quartz grains exceeding 350–400 μ and at times form interlocking textures. The original detrital grain boundaries are defined by dust rings. In several cases, the dust rings of adjacent quartz grains are not in contact with one other. This indicates that diagenesis by silica occurred during early burial stage when the detrital mass was inadequately compacted. The quartz grains of arenites with clayey matter are generally devoid of authigenic growths. The presence of clayey matter probably inhibited authigenesis by silica.

Cementation by chloritomicaceous matter is more frequent in finer and medium grained arenites. It is brought about by diagenetic encroachment of clayey minerals into the peripheral regions of detrital quartz grains. Very fine clays fill part of the intergranular voids and act as cement when partially recrystallized.

Cementation by carbonates is very limited and usually patchy. Dolomite appears to be the principal constituent and whenever present, replaces the silica cement. Quartz–carbonate reaction rims surrounding some of the larger detrital quartz grains and displaying several stages of peripheral dissolution are noticeable. Quartz grains floating in poikilitic carbonate cement are observed though rarely.

### Pyritization

Diagenetic pyrite is present in arenites and shales. It, however, is relatively more abundant in the dark grey organically rich fissile shales of PUC 'A' (B2-96, core 2, 11724–11784 ft, B3-96, core 3, 11593–11606 ft). It occurs as evenly distributed disseminations, individual euhedral–anhedral crystals and irregular stringers or films along the fissility planes. Mutually interfering microcrystalline aggregates and nodules are rare. Some of the fossilised plant remains, fish scales and Branchiopods are pyritized.

## PALYNOLOGIC ASSEMBLAGE

Palynofossils were separated using standard techniques involving disintegration of samples, treatment with hydrochloric acid to remove carbonates and ferruginous matters, dissolution of siliceous fractions in hydrofluoric acid (40%), thorough washing to remove the acid, sieving through 10 μ sieves and finally, separation using zinc bromide solution (Sp.Gr. = 2.00).

In general, the assemblage is usually scarce and relatively poor in PUC 'B' but richer in PUC 'A' where several species are recorded (Fig. 3, Appendix I).

### PUC 'B'

The assemblage is very poor, fragmentary, and largely unidentifiable. The palynofossils are usually structureless, with obliterated ornamentation and their peripheral areas are substantially corroded possibly by bacteria. The rest of the organic matter is mostly amorphous, very dark gray to black and thermally over matured with TAI (Staplin, 1969; Geochem, 1980) ranging from 3+ to 5. The reddish brown partly oxidised shales in well B2-96 yielded a sphaeromorph similar to *Leiosphaeridia spp.* and *Kildinella ripheica.*

### PUC 'A'

In general the organic residue is light brown to dark brown with TAI ranging from 2 to 3+. It is mostly herbaceous, algal and woody. Inertinitic matter are minor to subordinate. Palynofossils are more varied (Fig. 3, Appendix I), better preserved and well identifiable. Their ornamentation is fairly intact and largely unobliterated.

The palynologic assemblage includes several species. The more important of these include *Stellapollenites thiergartii, Alisporites* complex, *Platysaccus queenslandii, Lunatisporites*, sp., *Aratrisporites*, sp., *Stroterisporites* sp., *Triadispora crass, Cyadopites* sp., *Calamospora tener*, and *Alisporites magnus* besides several others (Appendix I). *Veryhachium* sp. and *Micrhystridium* sp., though rare and sporadic, are observed in the PUC 'A' met at B2 and B3-96.

## FOSSIL FAUNAL ASSEMBLAGE

The sandstones and shales of PUC 'B' seem to be devoid of fossil fauna. The assemblage recorded in the PUC 'A' (B2-96, cores 2 and 3; B3-96, core 3) comprises numerous Branchiopods (*Lioestheria* sp.), *Conulariids*, fish spine, fish scales and part of fish tooth (M.C. Keen, personal communication, 1993).

## DISCUSSION

### Age

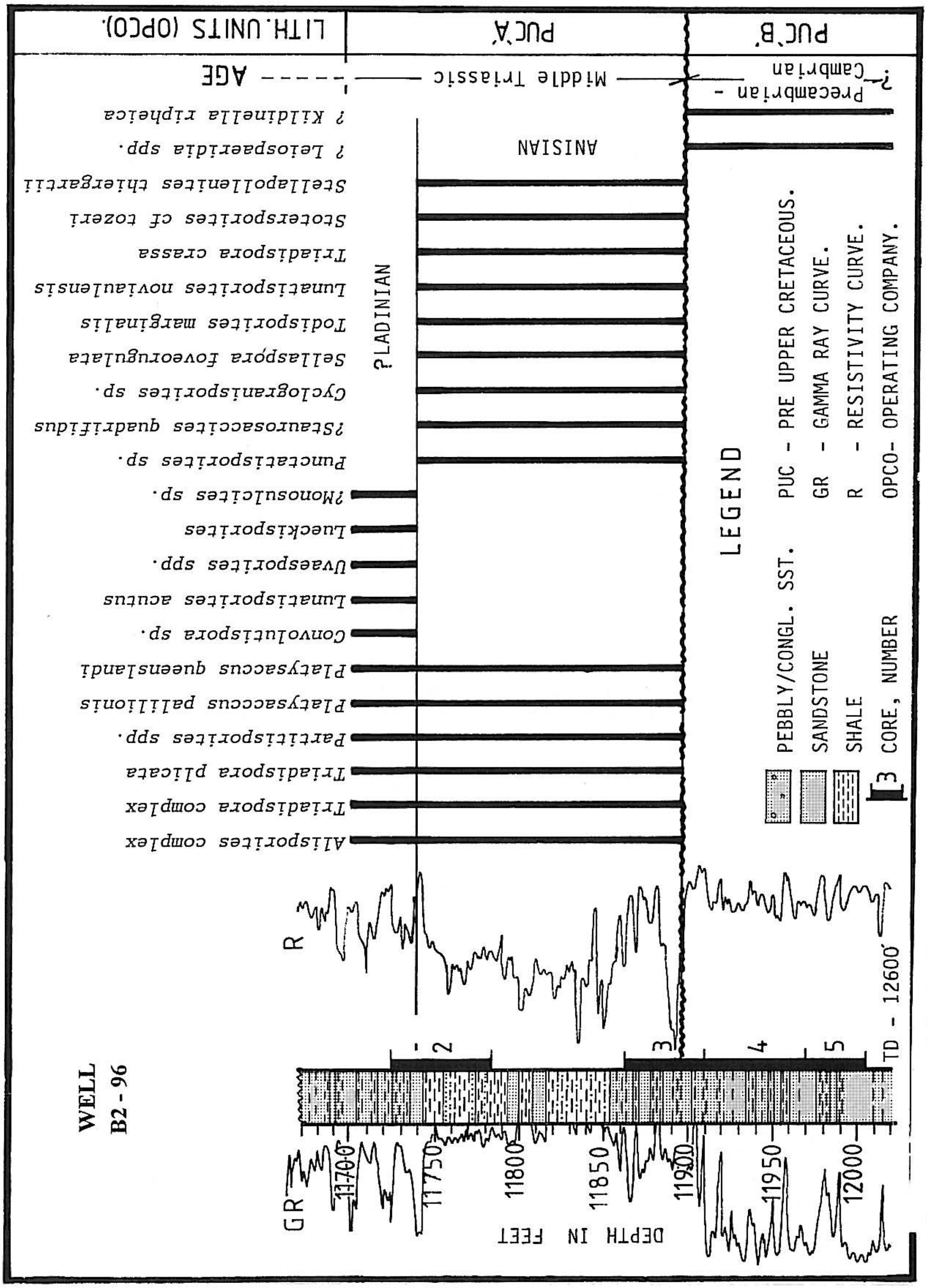
A reddish brown partly oxidised shale in PUC 'B' met in well B2-96 yielded sphaeromorphs similar to *Leiosphearidia* spp. and *Kildinella ripheica. Leiosphearidia* spp. is also reported from the Precambrian–Cambrian succession developed over the Cyrenaica Platform which adjoins the Maradah Trough (Boudet, 1988). The PUC 'B', hence, could be of Precambrian–Cambrian age.

The palynologic assemblage of PUC 'A' is referable to Middle Triassic and enable classification of this sequence into that of Anisian and ?Ladinian ages. The assemblage referable to Anisian is marked by low to fair diversity. It is noted from the intervals 11740–11900 ft in B2-96, ?11410–11515 ft in B4-96, 11440–11605 ft in B1-96 and 11575–11675 ft in B3-96. Diagnostic forms include *Stellapollenites thiergartii, Alisporites* complex, *Platysaccus queenslandii, Lunatisporites* sp., *Aratrisporites* sp., *Stroterisporites* sp., *Triadispora crassa, Cyadopites* sp., *Calamospora tener*, and *Alisporites magnus. Veryhachium* sp. and *Micrhystridium* sp., though rare and sporadic, are observed in the sequence met B3-96.

The assemblage indicative of ?Ladinian is recorded in the succession overlying that of Anisian age and underlying the unconformity separating PUC 'A' from the Maragh Formation (Fig. 2). Typical forms include *Cycadopites* sp., *Lunatisporites* sp., *Calamospora tener, Triadispora crassa, Alisporites magnus, Aratrisporites* sp. and *Partitisporites novimundanus* morphon besides several others (Fig. 3). *Veryhachium* sp. and *Micrhystridium* sp. though rare and sporadic, are observed in sequences met at B2 and B3-96. The assemblages are fairly comparable to those recovered from the Middle Triassic (Anisian and ?Ladinian) met in the subsurface of nearby areas (Brugman and Visscher, 1988 and Thusu *et al.*, 1988).

### Palynological Phases

Evolution of a floral assemblage during a geologic time interval can be traced through several transitionary palynologic associations designated as "phases". The concept of phase, first propagated by Schurman (1977), is employed for inferring palaeoenvironments. According to Van der Zwan (1980), a phase is "any recognisable step in the (local, regional or inter-regional) gradual compositional development of successive (palynological) assemblages". The overall assemblages indicate gross ecology and age but when resolved into phases and sub phases, reflect changes in ecologic parameters during relatively shorter time slices. Qualitative and quantitative compositional characteristics of the palynologic assemblage are important aspects of the "phases" and these are employed for age dating and deducing palaeoenvironments. The concept of phase also helps in bringing out minor changes in palaeoenvironments. Brugman (1986, p. 34), however, opines that "the phases are primarily based on quantitative data concerning (land derived) spores and pollen grains. The phases




Rare occurrences of *Veryhachium* spp. and *Micrhystridium* spp. are noted in PUC 'A'.

Fig. 3. Palynofossils in cores from Triassic & older sequence, Maradah Trough, Sirt Basin, Libya.

reflect the inter-regional floral development and are considered to be indepenent of local environmental gradients. Their characters, may in time, provide a basis for a regional scheme of differentially diagnosed palynological assemblage zones."

Regional changes in ecology are dependent upon tectonic, physicochemical and climatic conditions. All of these effect sedimentation. Variations in phases may be gradual or sudden. All the transitional ecologic regimes may be present or a few may be absent due to changes in geomorphotectonic attributes prevailing in the provenance and the depositional areas. Thus, it may be possible to relate the presence or otherwise or type of "phases" to local and regional tectonic and ecologic conditions attending evolution of the sedimentary pile. Visscher and Van der Zwan (1981) proposed fifteen categories of readily recognisable and environmentally sensitive groups of spores and pollen grains on basis of a study of coals and evaporites. Categories 'A' to 'G' are regarded hygrophytic whereas, 'K' to 'O' reflect xerophytic affinities. The status of categories 'H', 'I' and 'J' is either indifferent, indeterminate or unknown.

The assemblage of palynofossils from PUC 'B', dated as ?Pre-Cambrian–Cambrian is poor and scarce and inadequate for resolution into phases. The assemblage from PUC 'A', dated as Middle Triassic, is relatively richer. It is resoluble into broadly two phases. The older, corresponding to Anisian, is referable to the *thiergartii–vincetinense* phase (Fig. 2). This assemblage is comparable to that of the Anisian recognised in the nearby L4-96 and is compositionally similar to that established in the Alpine Anisian of Italy and Hungary (Brugman and Visscher, 1988 and Brugman, 1986). The taxa are fairly similar to those of the categories 'B'-'G' and include pollens of *Leavigatosporites* sp., *Aratrisporites* sp. and *Cycadopites* sp. These are regarded hygrophytic (Visscher and Van der Zwan, 1981). A very few forms of categories 'K', 'L' and 'O' of xerophytic affinities also are present. The younger phase with a palynofossil assemblage referable to ?Ladinian age exhibits close affinities to *plurianulatus – novimundanus* phase. Its taxa, which include *Lunatisporites* sp., *Triadispora* sp. and *Stellapollenites* sp., seem referable to the categories K-O. A few representing categories B, C, E and G also are present. It may be thus observed that this phase includes a mixed assemblage of hygrophytic and xerophytic types. It is thus evident that the hygrophytic elements indicating humid environments thrived during the Anisian. These were taken over by relatively drier and mixed types during the ?Ladinian as may be inferred from the considerable presence of xerophytic categories (K, L and O) along with those of hygrophytic habitat.

## Palaeovegetation

The palaeovegetation appears to have been fairly varied. Presence of *Platysaccus* sp. and *Alisporites* sp. (Pteridosperms or seed ferns) indicate prevalence of coniferous vegetation (Clement–Westerhof, 1974; Al Ameri, 1990 and Baldoni, 1991). *Aratrisporites* sp., could have been contributed by shrubby Lycopsida plants. *Cycadeles/Bennettitales* also seem to have been present.

## Palaeoenvironment

The data available from the PUC 'B' sequence is largely inconclusive. The sedimentary succession dominated by the quartz-arenites with scarce to rare levels of shales has till date not yielded any palynofossils or fossil fauna diagnostic or indicative of marine or transitional environments. The gross characteristics, such as, grain size, overall composition, traces of fresh feldspars, detrital micaceous content, presence of oxidised–mottled shales, micaceous siltstones, normal graded bedding, planar cross bedding and interlaminated arenites and shales seem to indicate non-marine environments and possible prevalence of colder climates.

PUC 'A' sequence is lithologically more heterogenous. Shales are relatively very common. The overall lithologic suite and palynologic as well as fossil faunal assemblage indicate deposition under largely non-marine environments as is suggested by the presence of oxidised, mottled and variegated shales, detrital micaceous content carbonaceous-coaly matter, at times microconglomeratic contents in arenites, arenite-shale interlaminations, slumps, frequent alternations of very coarse and fine grained arenites and graded bedding etc. The more conclusive evidences for prevalence of non-marine environments, however, are offered by the palynofossils (Fig. 3; Appendix I) and presence of pyritized plant remains. This is further supported by the occurrence of branchiopods, fossil fish scales and fish tooth. The branchiopods, especially the *Lioesthria* sp., "probably indicate a non-marine environment such as presence of fresh water ponds or saline lakes" (M.C. Keen, personal communication 1993).

Occurrences, though rare, of *Veryhachium* sp. and *Microhystridium* sp. at a few levels seem to suggest occasional prevalence of some marine influence, or these few acritarchs are reworked older material.

## Provenance

The sandstones of PUC 'B' and PUC 'A' comprise mainly strained quartz. Feldspars are very rare and those present are usually fresh and include alkali feldspars. The detritus, in general, is subrounded and moderately sorted. Chert and meta quartzite, quartz-schist, argillite and orthoquartzite rock fragments are present. The heavy mineral suite mainly comprises stable minerals, such as zircon, tourmaline, rutile and sphene and some of these are distinctly recycled. All these characteristics indicate that these sandstones were derived from acid igneous and low grade quartz rich metamorphic rocks fairly deficient in feldspars. Presence of recycled grains suggests derivation from sedimentary rocks. The basement met at Rakb High (Fig. 1) comprises mainly quartz rich granites and in all probability, it contributed most of the detritus. Contributions from the Amal Platform region cannot be ruled out.

The presence of recycled grains of quartz, zircon, rutile and tourmaline bespeak significant contributions from pre-existing older sedimentaries, such as Gargaf Quartzite, Amal Sandstone and even the quartz-arenites of PUC 'B' sequence. This is further evidenced by presence of reworked Palaeozoic palynomorphs such as *Dactylofusa* sp., *Multiplicisphaeridium* sp., *Apiculiretusisporites* sp., *Cymatiosphaera* sp., *Dictyotidium* sp., *Leiofusa* sp., *Retusotriletes* sp., *Hymenozonotriletes* sp., *Dibolisporites* sp., *Verricosisporites* sp., and *Calyptosporites* sp. etc. (Bindra Thusu, personal communication–1993, Thusu, 1993).

## CONCLUSIONS

1. The thick sandstone sequence, met in the subsurface of Maradah Trough and classified into Pre-Upper Cretaceous (PUC) 'B' and 'A' units comprises mainly quartz-arenites with subordinate shales and siltstones . The PUC 'A' sequence is classified into four units on basis of lithologic variations and log characters. Each of the four units significantly thickens towards the Rakb High adjoining the western margins of Maradah Trough.
2. The PUC 'B' unit is tentatively dated as Precambrian to Cambrian and the PUC 'A' unit is inferred to be of Middle Triassic (Anisian and ?Ladinian) age on basis of palynofossils.
3. The PUC 'B' sandstones seem largely non-marine. They may also include some fluvioglacial deposits. In general, the PUC 'A' sequence evolved under largely non-marine environments possibly with occasional mild marine influence towards the eastern parts of Maradah Trough. The palaeoclimates were mainly hygrophytic during the Anisian but changed to mixed hygrophytic-xerophytic during the ?Ladinian.
4. The Maradah Trough was assymetrically active with enhanced negative tectonism along the fault separating it from the Rakb High during evolution of the Middle Triassic sequence.
5. The provenance for arenites of PUC 'B' and 'A' units largely comprised feldspar deficient acid igneous and low grade quartzose metamorphic rocks. Contributions from recycling of pre-existing older sedimentaries, which might include Gargaf Quartzite, Amal Sanstone and even the quartz-arenites of PUC 'B' sequence, are significantly displayed by the arenites of PUC 'A' sequence.

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## APPENDIX 1

Selected palynofossils in PUC 'B' and PUC 'A' sequences, Maradah Trough, Sirt Basin, Libya.

Palynomorphs are arranged according to their *principal* distinguishing features.

Pre-Upper Cretaceous 'A' sequence
Azonate smooth trilete spores.

**Leavigate.**
*Calamospora spp.*
*Punctatisporites ssp.*
*Deltoidospora spp.*
*Concavispora sp.*
*Todisporites marginalis.*

**Muronati.**
*Cyclotriletes–Convulutispora* complex
*Convolutispora spp.*
*Uvaesporites spp.*
*?Sellospora rugoverrucata.*

**Smooth monolete spores.**
*Laevigatosporites spp.*

**Sculptured monolete spores.**
*Aratrisporites spp.*

**Monosaccoid pollen.**
*Ovalipollis pseudoalatus*
*Stellapollenites thiergartii*

**Alete bisaccoid pollen.**
*?Voltziaceaesporites heteromorphus*
*Alisporites–Falcisporites complex*
*Platysaccus papilionis*

*Platysaccus queenslandi*
*Vitreisporites pallidus*

**Monolete, dilete and trilete bisaccoid pollen.**
*Argustisulcites grandis*
*Triadispora crassa*
*Triadispora plicata*

**Teaniate bisaccoid pollen.**
Teaniate bisaccoid pollen
*Lunatisporites noviaulensis*

**Asaccate**
**Inaperturate pollen.**
*Partitisporites novimundanus morphon*

**Colpate pollen.**
*Enzonalasporites ssp.*
*Cycadopites spp.*
*Monosulcites spp.*

**Acritarchs**
*Micrhystridium spp.*
*Veryhachium spp.*

**Miscellaneous**
Cyanophytic tubes.

Pre-Upper Cretaceous 'B' sequence
*?Leiosphaeridia spp.*
*?Kildinella ripheica.*

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