ARCHITECTURE AND SEQUENCE STRATIGRAPHY OF LATE TRIASSIC FLUVIAL SYSTEM, ABU SHAYBAH FORMATION, NW LIBYA

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Abstract: The Abu Shaybah Formation (ASF) ranges in age from Carnian to Norian (Late Triassic), and is exposed from the foothill slopes of the Tarhuna-Gharyan scarp stretching west wards to Ar Rabitah and Al Khums to the eastward along the Jabal Nafusah. The Lower boundary is sharp and unconformable with the Al Aziziyah Formation,(marine deposits) and the upper is locally unconformable with the Abu Ghaylan Formation (marine deposits). Seven sections have been measured in the study area and the maximum thickness of Abu Shaybah Formation is about 254m was observed in the Wadi Ghan area. It consists of gravely sandstone, coarse sandstone, silty clay and mainly mudstone facies. Whereas, in Abu Ghaylan road section it is about 21m of mainly mudstone facies. Series of sandstone bodies, fining up ward cycles, from 8 to 12m thick of cycles in fluvial meandering and 20 to 25m thickness of fluvial braided cycles. Four main facies association can be characterized in ASF; Facies Association 1: Fluvial braided, channel deposits (CH). It exhibits extensive sandstone coarse to very coarse grained, pebbly scattered and characterised by graded trough cross stratification, up to 15m thick of channels with no clay content. Facies Association 2: Fluvial meandering, its sandstone is medium to coarse grained highly argillaceous, trough cross stratification point bar deposits overlain by 3 to 5m thick of shale (over bank and crevasse splay deposits), and isolated sand bodies lateral accretion. Facies Association 3: Flood plain and over bank sediments consist of red to green silty shale commonly mottled and content rootlet, upto 30m thick in Wadi Ghan section. Facies Association 4: It seems to be as marine transitional zone. These sediments of ASF deposited under two strongly controlled forces (climate and tectonic), with large subaerial accommodation space rather than increases in subsidence rate in the study area. Sequence startigraphic theory can be applied to these continental deposits, by defining base level and accommodation space, within the context of genetically related, coherent depositional sequences. Amalgamated multi-storey sand bodies are typical of low stand conditions, isolated ribbon sand bodies typify transgressive conditions (subdivided into early and late stages), and isolated multi-lateral sand bodies characterize high stand conditions.

Keywords: Abu Shaybah Formation (ASF), Triassic, Fluvial deposits, Jabal Nafusah.

OUTLINE OF TRIASSIC RESEARCH

The Triassic in a worldwide stage has long been recognised as an important geological period due to the predominance of fluvial red beds and their potential to act as petroleum reservoirs and aquifers. Exploration in Libya has some what neglected the Triassic unlike neighboring North Africa countries (e.g. Algeria TAG-I). However, in recent years there has been going awareness of the important Triassic in the Ghadames Basin, and potential findings in the Sirt and Al Kufrah basins. Much of the Triassic succession in Libya is only found in the subsurface and most previous knowledge is based on seismic and well logged sections. The Abu Shaybah Formation (ASF) of the Jabal Nafusah area produces one of the few well exposed sections of Late Triassic fluvial succession (Fig.1). This study will focus upon the architectural elemental analyses recognized and well defined geometries and bounding surfaces using the methodology of Miall (1996). Fluvial strata provides an objective method for determining the three dimensional geometry of ancient river systems (Allen, 1983; Hirst, 1991; Miall, 1993, 1994). There are, however, relatively few examples from detailed field observations of

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the three-dimensional geometry of an entire braided to meandering fluvial system along the escarpment of Jabal Nafusah. The ASF offers ideal conditions for a detailed architectural study of a braided and meandering fluvial system. The excellent outcrops, the large size and well-established geology allows for detailed analysis of the architecture in the context of structural control and along-strike sediment supply variations. This study focuses on the Late Triassic sediments ASF which was deposited over Hercynian Orogeny in incised valley systems and filled by a thick sequence of stacked amalgamated fluvial channel sandstones, meandering and flood plain deposits. This incised valley was formed by both erosional and tectonic forces and changes lateral to evaporites of the Bir El Ghanam Formation (Late Triassic-Early Jurassic) in the west of Gharyan (Fig.1). These sediments provide a good example for understanding controlled climatically dry, wet and humid seasonal variations during the deposition.

GEOLOGICAL SETTING

Northwestern part of Libya is comprised of two major physiographic units; the Jifarah Basin which is bounded to the north by the Mediterranean Sea and, the escarpment of Jabal Nafusah which forms a prominent escarpment bounding the plain to the south. In broad terms the plain is formed of Pleistocene and Holocene sands and gravels underlain by Miocene and Mesozoic rocks which are exposed in the escarpment (Anketell & Ghellali, 1991 and Fig. 1). Over 1.5km thickness of siliciclastic, carbonate and evaporites sequences are exposed along a 400km's long horseshoe shaped escarpment extending from the town of Al Khums, NW Libya westward to Gabes in Tunisia. Jabal Nafusah elevation ranges from few meters in the east to over 800m in the centre south of Gharyan and descends into 200m in Gabes. The escarpment is a retreating fault scarp, its shape and extension is controlled by the E-W trending Al-Aziziyah fault zone and the Jifarah Arch. The Abu Shaybah Formation (ASF) of Late Triassic (Carnian to Norian), forms the foothill slopes of the Tarhuna-Gharyan scarp stretching west wards to Ar Rabitah and Al Khums to the eastward along the Jabal Nafusah. The lower boundary is sharp and unconformable with the Al Aziziyah Formation, and the upper is locally unconformable with the Abu Ghaylan Formation. The maximum thickness of Abu Shaybah Formation is about 254 m located in Wadi Ghan (Fig. 2).

SEDIMENTOLOGY

The sediments of the ASF are dominated by gravelly coarse-grained sandstones, medium to coarse grained sandstones, fine grained sandstones, siltstones and mudstone and some poorly developed palaeosols. For purpose of this study the sediments have been subdivided into different lithofacies and then later grouped to form architectural elements Table 1 and 2, (Allen, 1983; Miall, 1983, 1988). The data for this study were primarily collected by means of outcrop. Facies analysis performed in six main sections located within the confines of the ASF (Fig. 1). The results of this work, as well as the interpretation of the data, are illustrated in Tables 1 & 2. Previous research has interpreted the Abu Shaybah Formation as a fluvial system (Rubino *et al.*, 2002). However, even casual observation of the sections the fluvial system can be subdivided into braided and meandering stream deposits. Using lithofacies and facies associations this study documents the regional alluvial architecture of the ASF and relates it to the long-term discharge history occurs in the escarpment. The ASF was divided into nine lithofacies (Table 1) which were adapted from Miall (1978). The nine lithofacies were grouped into four facies associations. Each association is described and interpreted utilizing two and three dimensional architecture found in both vertical and lateral profiles. The studied sections show a dominantly clastic succession with lithologies ranging from claystone and shale to sandstones and conglomerate lag deposits. Numerous iron-rich palaeosols horizons occur and assist inter regional climate interpretations for the Triassic. The dominance of a particular lithofacies or group of lithofacies, in different parts of the formation allows the definition of four main facies associations, as outlined below (Table 1).

FACIES ASSOCIATION

Detailed analyses of the sedimentology (i.e. grain size, sedimentary structures body and trace fossils) have allowed four main facies association to be identified within the study area (Fig. 1). These were deposited within four main depositional environments; they are fluvial braided, fluvial meandering, flood plain and transitional marine.

Table 1. Facies associations for the Abu Shaybah Formation, (ASF). Facies code adapted from Mail (1978, 1985, and 1996).

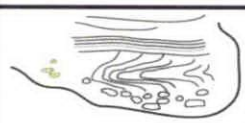
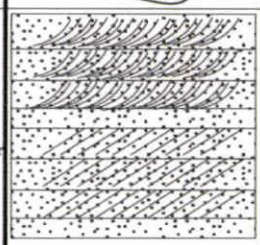
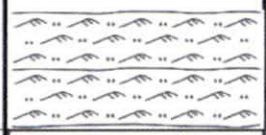
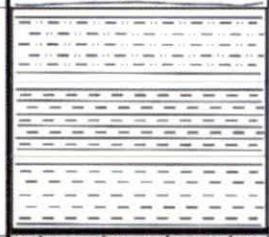
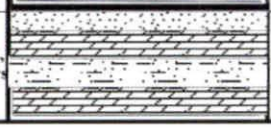
No.	Type of Facies	Description	Sedimentary structures	Interpretation	Thickness (m)
1	**Facies 1a. Conglomerate channel (Gsh)**	Horizontally cross stratification gravels, laterally, and mud intraclast up to .5cm in diameters, scour surfaces (Se).		Channel deposit (CH, Se)	0.1 - 2m
	Facies 1b. Planner cross strati. (Gsp)	Coarse to very coarse grained sandstone, normal gradded planner cross stratification.		Channel deposit (CH, Se)	0.1 -1.5m
	Facies 1c. Trough cross strati. (Gst)	Coarse to very coarse grained sandstone, normal graded trough cross stratification.			
2	**Facies 2a. Trough cross strati. (St)**	Sandstone, medium to coarse grained, pebbly scattered, trough cross stratification (St).		Crevasse Spaly deposit	0.1 -0.5m
	Facies 2b. Planner cross strati. (Sp)	Sandstone, medium to coarse grained, pebbly scattered, planner cross stratification (Sp).		Point bar and/ or channel deposit (SS)	0.1 -1.5m
	Facies 2c. Ripple cross strati. (Sr)	Sandstone, fine to medium grained, horizontal cross stratification, and current ripples.		Point bar and/ or channel deposit (SS).	0.1 -1.5m
3	**Facies 3a. Siltstone - mudstone (Sl)** **Facies 3b. Mudstone (Fsc)**	Clay to silt in size, and sand scattered. Stratification .		Over bank and flood plain.	0.1 -25m
4	**Facies 4a. Wavy ripples (Sr)**	Sandstone, very fine grained inter-calation with clay and dolomite beds, wavy ripples abundant by H. Burrows		**Transitional zone**	20m

Table 2. Summary of facies association and main characterization of each lithofacies in Abu Shaybah Formation (ASF), Wadi Ghan section.

No	Intervals	Lithofacies code	Lithofacies description	Grain size	Thick.
5	(154.5 – 221.5m)	**Sand sheet (SS), Over bank (OF)** Se, St	Ss with clay intervals, -fining upward cycles, -coarsening in small scale moderately to good sorting, trough and planner Xstrata.	Clay, M-C Ss	Total thickness is **67m** (clay thick about 45m, sandstone thickness about 22m)
4	(132.5 -154.5m)	**Channel – fill complex (CH)** Se, Gsp, Gst, St, Sr and Se	Ss, small and large scale of trough cross stratifications, climbing ripples, convolute structures and at the base of channel abundant clasts.	Gravel, Coarse Ss	Total thickness is **22m** (Single channel 2 -2.5 m thick.) No clay in this interval
3	(52 – 132.5m)	**Sand sheet (SS) Over bank (OF)** Se, St, Sr	Ss with clay intervals, -fining upward cycles, -coarsening in small scale moderately to good sorting, trough and planner x.start. and overturned (convolute structure).	Clay, M-C Ss Clay-is reddish colour.	Total thickness is **78m** (Single channel 0.5 -1.5 m thick.) Clay thick about 53.5m Sandstone thickness about 22.5m Mix clay inter sand about 2m
2	(34 – 52m)	**Channel – fill complex (CH)** Se, Gsp, Gst, St and Se	Ss, ferruginous, very poorly sorting, graded trough and planner x. strata., Clasts up 10-15cm in diameters at the base of channel	Gravel, C-VC Ss	Total thickness is **18m** (Single channel 0.5 -2.5 m thick.) No clay in this interval.
1	(0 – 34m)	**Flood plain Fl**	Mudstone, vary coloured, calcareous.	Mud, vary coloured.	Total thickness is **34m**

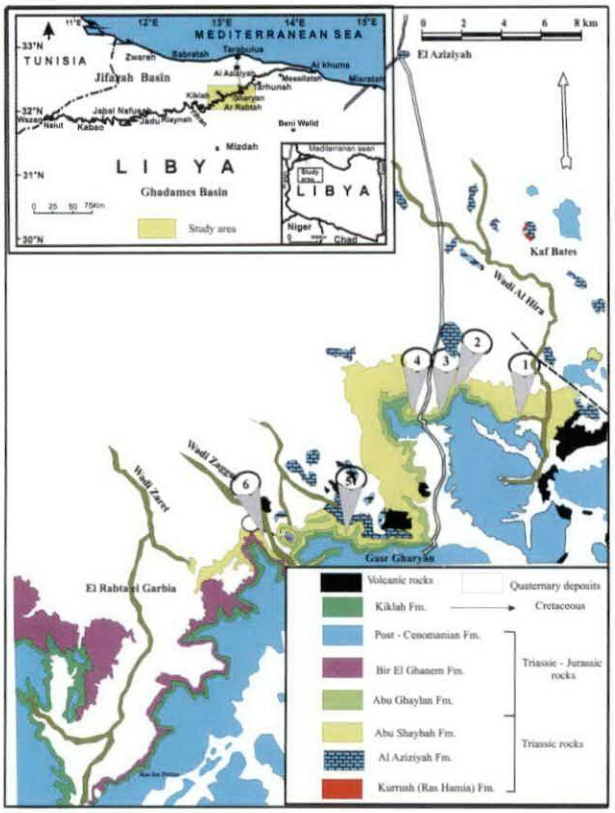


Fig. 1. Geological sketch of study area and location of measured sections, (1) Wadi Ghan section, (2, 3 and 4) Abu Ghaylan Road sections, (5) Gharyan dome section and (6) Abu Rashada road section (Modified from Desio *et al.*, 1963).

Facies Association 1: Fluvial braided (FB) (Fig. 2 & Fig. 3)

This facies association comprises sandstone, coarse grained and gravel or conglomerate facies that were deposited within a fluvial braided system. The facies is formed from approximately 70% sandstone, 30% conglomerate.

Facies 1a. Conglomerate channel (Gh).

Description: This facies is interbedded with lithofacies 1b and 1c and represents less than 30% of thickness (about 3m thick and limited in lateral extention about 25m). This facies is predominantly composed of coarse to very coarse grained sandstone, cross bedded, as single sets, or more often in multi-storey associations (Figs. 3A-F). Multi-storey, cross-bedded, sandstones of lithofacies are often continuous for several hundred meters. However, some examples are laterally truncated or grade into other facies over distances of a few tens of meters. Sharp boundaries between individual cross bed sets and cosets are often marked by thin but persistent siltstone partings (Fig. 3D). Facies 1a, typically grades laterally and vertically into smaller-scale bed packages of facies 1b or 1c and rare siltstone and mudstone found as mud matrix in this facies. Trough cross bed sets is generally 0.3-0.5m thick (rarely up to 1 m) but multi-storey suites reach up to 10m in thickness. Set widths are upto 5m. Grain size are generally bimodal within this facies although a pebble layer is sometimes present at the base of cross-bed sets and a slight reduction in grain size to medium-grained sandstone normal graded cross stratification. Also containing intraclast at the base upto 10-20cm in diameters, are relatively common near the base of multi-storey size, decreases upwards within up section in diameter. Soft-sediment deformation is common in the form of large-scale convoluted bedding (Fig. 3C).

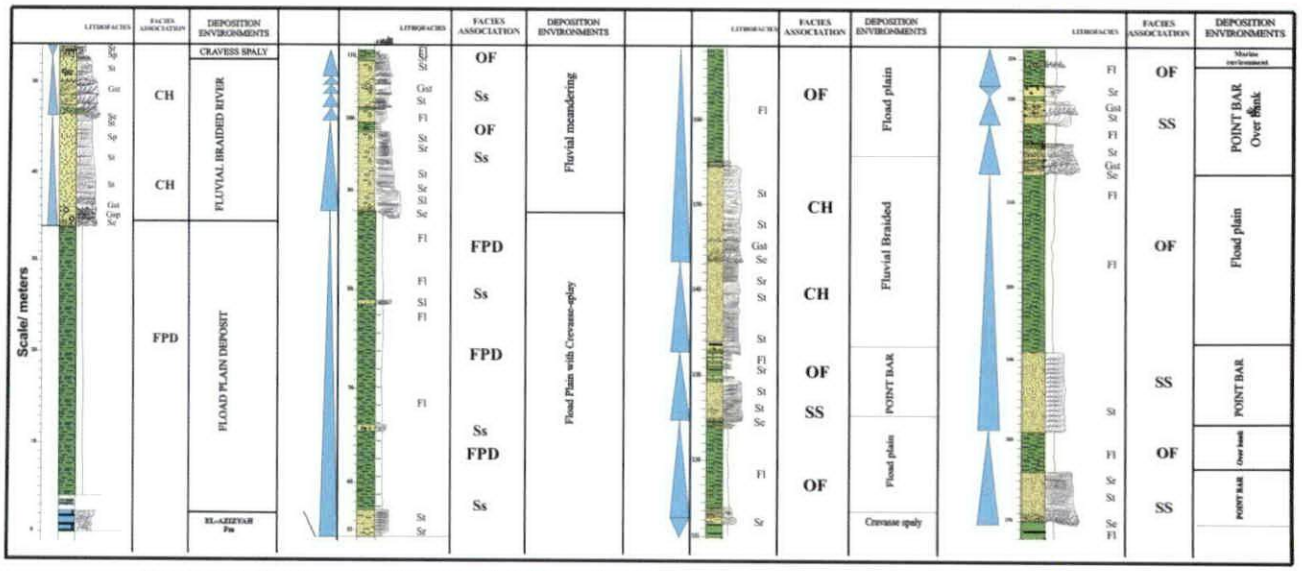


Fig. 2. Detailed logged of Abu Shaybah Formation (ASF) using architectural elements in fluvial systems.

Interpretation: Facies 1a is essentially identical to the massive to horizontal cross stratification, trough and planner cross sets of Miall (1977, 1996) although bedforms reach slightly greater dimensions in the ASF in individual cross bed sets may occasionally reach 1m thick and cosets may reach thicknesses of up to 10m. The predominance of gravel and trough cross bedding in facies 1a suggests deposition within major channels as large migrating dunes (megaripples of Singh & Kumar, 1974). The small size of extraformational clasts and relative frequency of siltstone intraclast above scour surfaces suggests that deposition occurred at a considerable distance from the chief sediment source area. These sediments have been largely reworked from older, mature, sandstone-dominated sedimentary sequences. Paleocurrent for facies 1a chiefly reflects east-west directed sediments transport of fluvial braided unit 1.

Facies 1b. Planner cross stratification gravel-sandstone, (Gp).

Description: This facies consists of coarse to very coarse pebbly and scattered grained sandstone. Planner (Gp) cross-bed sets are generally 0.5-1.5m thick but multi-storey suites reach 10-13m in thickness. Set widths are up to 20m. Grain sizes are generally relatively uniform within this facies although a pebble scattered from quartz grains, white colour, silica, carbonate and ferruginous cemented. (Figs. 3E & F). These sets occasionally occur in multi-story packages up to 3m thick. Sp facies suites are sheet-like, ribbon-like or broadly lenticular and extend laterally for several tens of meters. They lens out laterally or are truncated by low-angle erosion surfaces into wedge-shaped terminations. This facies Gp packages generally rest sharply on other association sandstone facies. Paleocurrent orientations commonly show the flow toward the west direction of cross stratification measurements' Sr, St and Sp (Fig. 4).

Interpretation: Facies 1b corresponds to Miall's (1977) planner cross–bedded sands facies (Facies Sp) and Rust's (1978) low-angle cross-stratified sand facies (facies Sl). Medium to large scale bedforms producing planner cross bedding in modern sandy braided rivers include both linguoide and straight-crested transverse bars

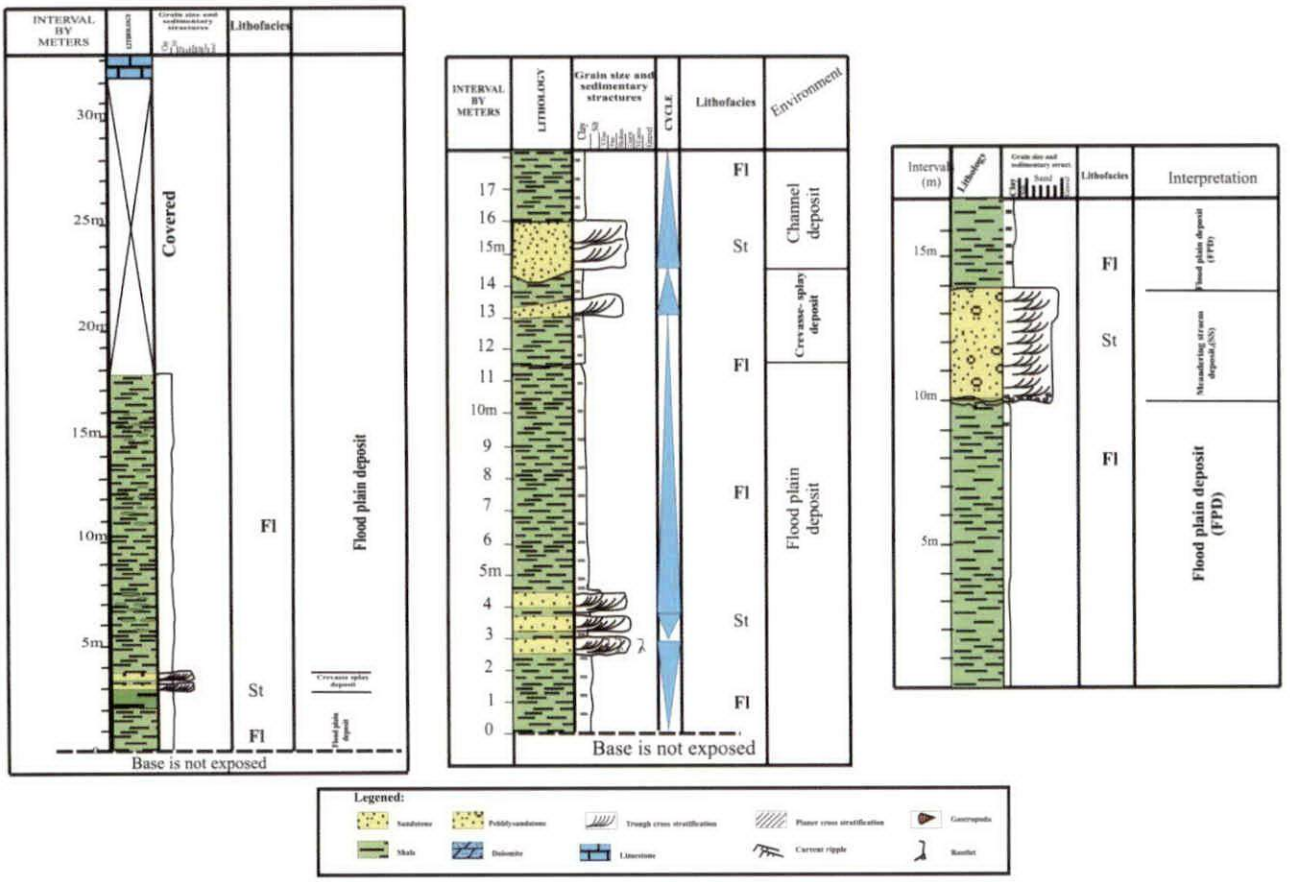


Fig. 4 Graphic logs of the Fluvial meandering, and flood plain deposits in Abu Shaybah Formation (Localities 2, 3 and 4 in Fig. 1).

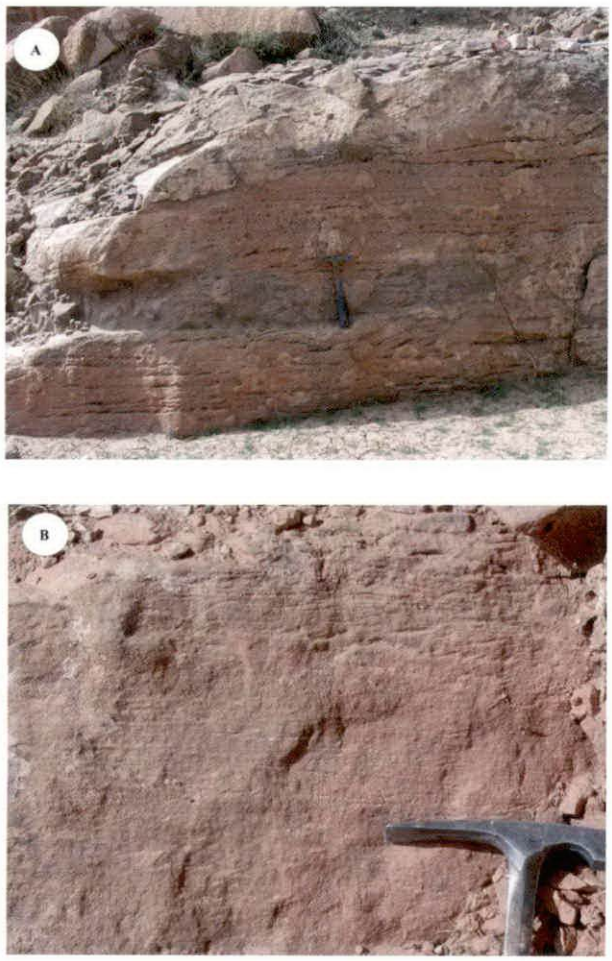


Fig. 5. Facies association 1: fluvial meandering (FM), Photo (A) climbing and photo (B) current ripples in Facies 2c .

(Smith, 1971, 1972). Low angle cross beds may represent deposition under high energy conditions or in special channel location such as the base of longitudinal bars at the intersections of channels.

Facies 1c. Trough crosses stratification gravel -sandstone (Gt).

Description: This facies consists of mostly coarse to very coarse-grained, cross bedded, sandstone and granulestone as single sets, or more often in multi-storey associations. Trough cross bed sets is generally 0.3-0.5m thick rarely up to 1.2m, but multi-storey suites reach 2m in thickness. Set widths are up to 200m. Grain sizes are generally relatively uniform within this facies although a pebble layer is sometimes present at the base of cross-bed sets. Slight reduction in grain size to medium-grained sandstone is sometimes evident at siltstone intraclasts, up to 10-15cm in diameter, are relatively common at the base of multi-storey sandstones suites. Soft sediment deformation is present in the form of large scale convoluted bedding. (Figs. 3 A & C)

Interpretation Facies 1c is essentially identical to the trough cross-bedded sand facies (Facies St) of Miall (1977) although bedforms reach slightly greater dimensions in the ASF (individual cross bed sets may occasionally reach 1.5m thick and cosets may reach thicknesses of up to 5m. The predominance of festoon trough cross bedding in (CH) Facies suggests deposition within major channels as a large migrating dunes (megaripples of Singh & Kumar, 1974). The scarcity and small size of extraformational clasts and relative frequency of siltstone intraclsts above scour surfaces suggest that deposition occurred at a considerable distance from the chief sediment source area or that the sediments have been largely reworked from older, mature, sandstone dominated sedimentary sequences.

Facies Association 2: Fluvial Meandering (FM)

Facies 2a. Trough cross stratification sandstone (St) (Fig. 4)

Description: This facies comprises troughs (St) developed by the migration of 3-D dunes, its content medium to coarse grained sand. Pebbles present in this lithofacies (St), clean quartzitic, well sorted sand and there is commonly a lag of poorly sorted sand with large intraclast at the base of the trough cross stratification consists of curved sets. This channel ranges between 1.5-2m in thickness and extended several ten meters laterally and the paleocurrent direction related to cross bedding is to north.

Interpretation: Facies 2a (St) is troughs developed by the migration of 3-D dunes (Miall 1977, 1996). Bedforms reach slightly greater dimension in the ASF (individual cross bed sets may occasionally reach 1.5m thick and cosets may reach thicknesses of up to 3m in small scale). The predominance of festoon trough cross-bedding in Facies 2a suggests deposition within major channels as large migrating dunes (megaripples of Singh & Kumar, 1974).

Facies 2b. Planner cross stratification sandstone (Sp).

Description: This facies consists of mostly coarse to very coarse-grained, cross bedded, sandstone and granulestone as single sets, or more often in multi-storey associations. Trough cross bed sets is generally 0.3-0.5m thick rarely up to 1.2m, but multi-storey suites reach 2m in thickness. Set widths

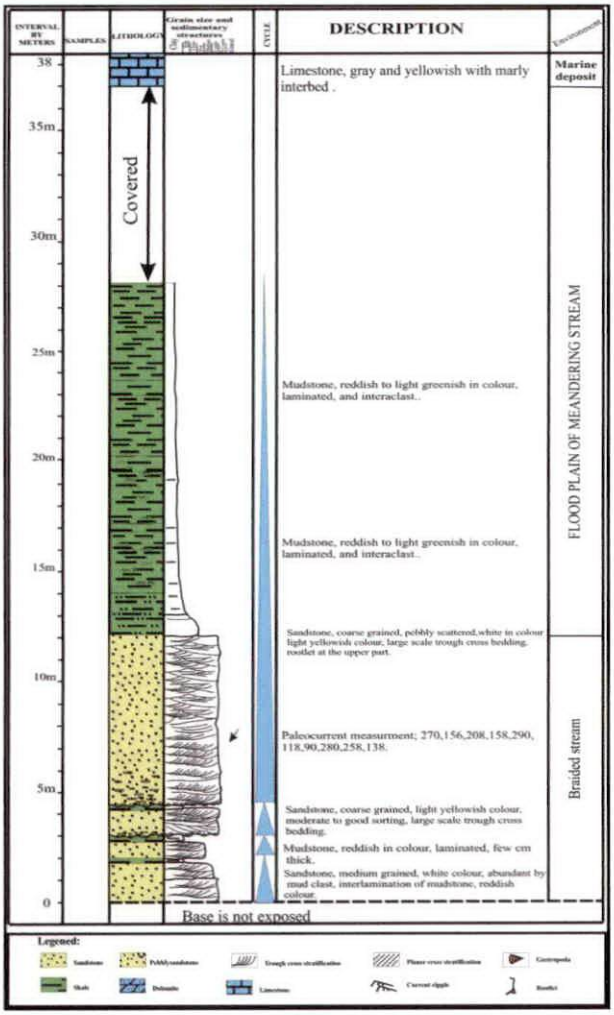


Fig. 6 Outcrop logged section of floodplain facies (FP).

are up to 200m. Grain sizes are generally relatively uniform within this facies although a pebble layer is sometimes present at the base of cross-bed sets. Slight reduction (In grain size to medium-grained sandstone) is sometimes evident at siltstone intraclast, up to 10-15cm in diameter, are relatively common at the base of multi-storey sandstones suites. Soft sediment deformation is present in the form of large scale convoluted bedding.

Interpretation: This facies was formed by the migration of 2-D dunes (Miall, 1996). Sand was transported up the flank of the bedforms by traction and intermittent suspension (commonly forming a carpet of small-scale current ripples), and deposited at the crest, where bed-shear stress drops at the point of flow separation. Cross bedding's angle of this facies is typically 25°-30° (Fig. 3F), with sharp, angular, upper and lower bounding surfaces. They are typically flat, with little evidence of scour surfaces. Sand in this facies is typically sorted by

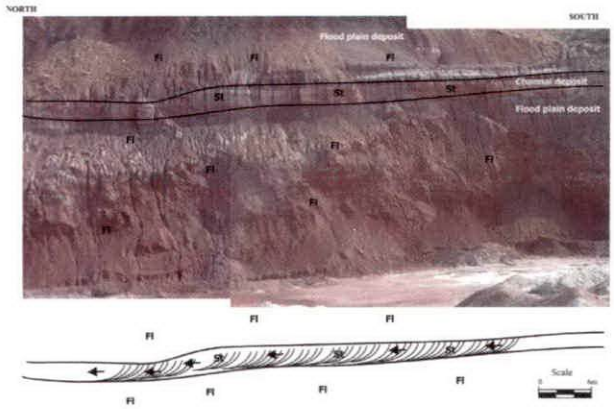


Fig. 7 Facies association 3; Flood plain (FP), facies 3b

the process of ripple migration up the stoss side of the dune, resulting in foresets is which the modal sand grain size may differ by several size classes (Miall, 1996).

Facies 2c. Ripple cross stratification (Sr).

Description: This facies is composed of fine to medium grained sandstones, trough cross bedded and large scale, climbing ripple (Fig. 5), cross laminated sandstones in multi-storey. Individual cross-bed sets and cross laminated beds is typically 5-20cm thick and generally is about 1.5m thickness (Fig. 5). A wide variety of internal structures may be generated from ripple migration, depending on flow velocity and the rate of sediment supply (Jopling and Walker 1968; Allen 1984).

Interpretation: Ripples developed at low flow speeds (< 1 m / s), and are very sensitive to changes in flow conditions (Miall 1996).

Facies Association 3: Flood plain deposit (FP)

Facies Associaction 3 sediments are composed of stacked fining up cycles of clean sand, friable, trough cross bedded sandstones grading into variegated claystone and siltstones representing meandering stream deposits. These grade from the lower sets of medium to coarse grained sandstones highly cross planner and trough stratification (Sp & St) deposited by a braided stream (Fig. 6).

Facies 3a. Siltstone-mudstone-Fine grain facies, (Sl)

Description: This facies consists of thin to moderately 30-50cm thickness of claystone interbedded with fine to medium grained sandstones, reddish to yellowish in colour, massive and laminated and ripples, mud intraclast, calcareous silt and mud. Vertical and horizontal bioturbation are common in

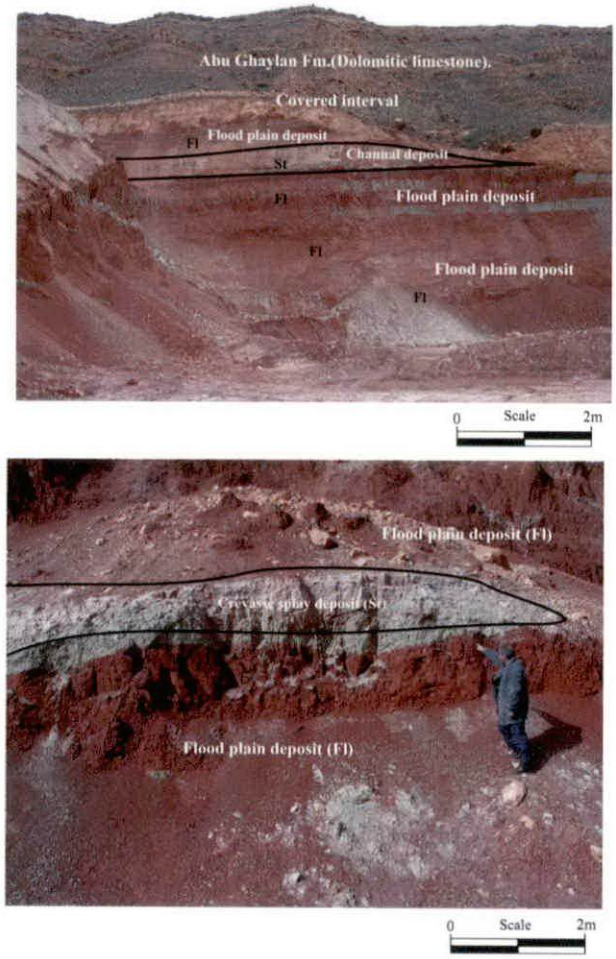


Fig. 8 Facies association 3: Flood plain (FP), facies 3A General viw, 3B Close view of Crevasse splay.

this facies (facies Fm and Fl) of Miall (1977) and Rust (1978). They differ from each other in their content of carbonaceous material (Figs. 7 & 8).
Interpretation: This facies is interpreted as crevasse splay deposits occur throughout sequence of ASF at Wadi Ghan section, and are interpreted to have been deposited in lobes adjacent to channel bodies. They are typically well sorted, fine to very fine grain laminated sandstones. These are locally rich in claystone and bioturbation. Sandstones display ripples cross laminations and syn-sedimentary deformation. Crevasse splay deposits typically range in thickness from 0.2m to 1m.

Facies 3b. Mudstone facies (Fsc) (Fig. 7 & Fig. 8)
Description: This facies (Fsc) consists of massive, reddish mudstone up to 10m thickness and up to 200m extended in Wadi Ghan section (Figs. 7 & 8). That was the main features of this facies which distinguishes it form Fl,

Interpretation: This facies is interpreted as floodplain deposit somewhat more distal relative to clastic sources such as nearby fluvial channels.

Facies Association 4: Transitional zone (marine to continental)
This facies is located in Abu Rashada road in the west of Gharyan Dome (Fig. 1). It exhibits interlayer's dolomitic limestone and fine sandstone with claystone common horizontal burrow (Upper Al Aziziyah Formation and base of ASF) about 21m thick (Fig. 9).

Facies 4a. Wavy ripples (Sr) (Fig. 3.10)
Description: This facies consists of interlaminations of mud, silt, and very fine grained sand. The thickness of particular sharp-based bodies varies from 0.1m to more than 1m. They pass upward into fine grained, wavy ripple bedded sandstone, and interlaminated by dolomite (Fig. 10).
Interpretation: Sediments of this facies were deposited mainly as fine grained, intercalation clay with silt, horizontal burrows and wavy ripples. The most probably represent a transitional zone from marine to continental.

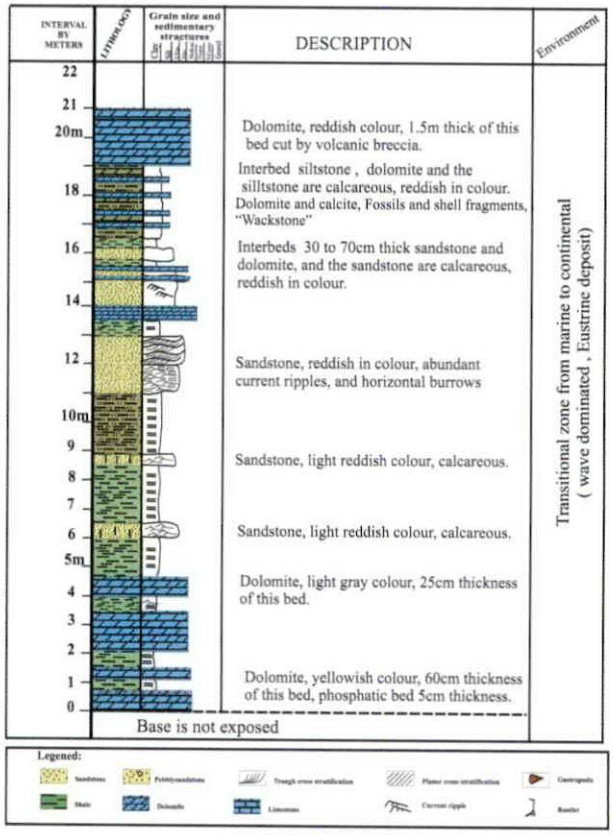


Fig. 9 Logging of Abu Rashada section showing the transitional zone.

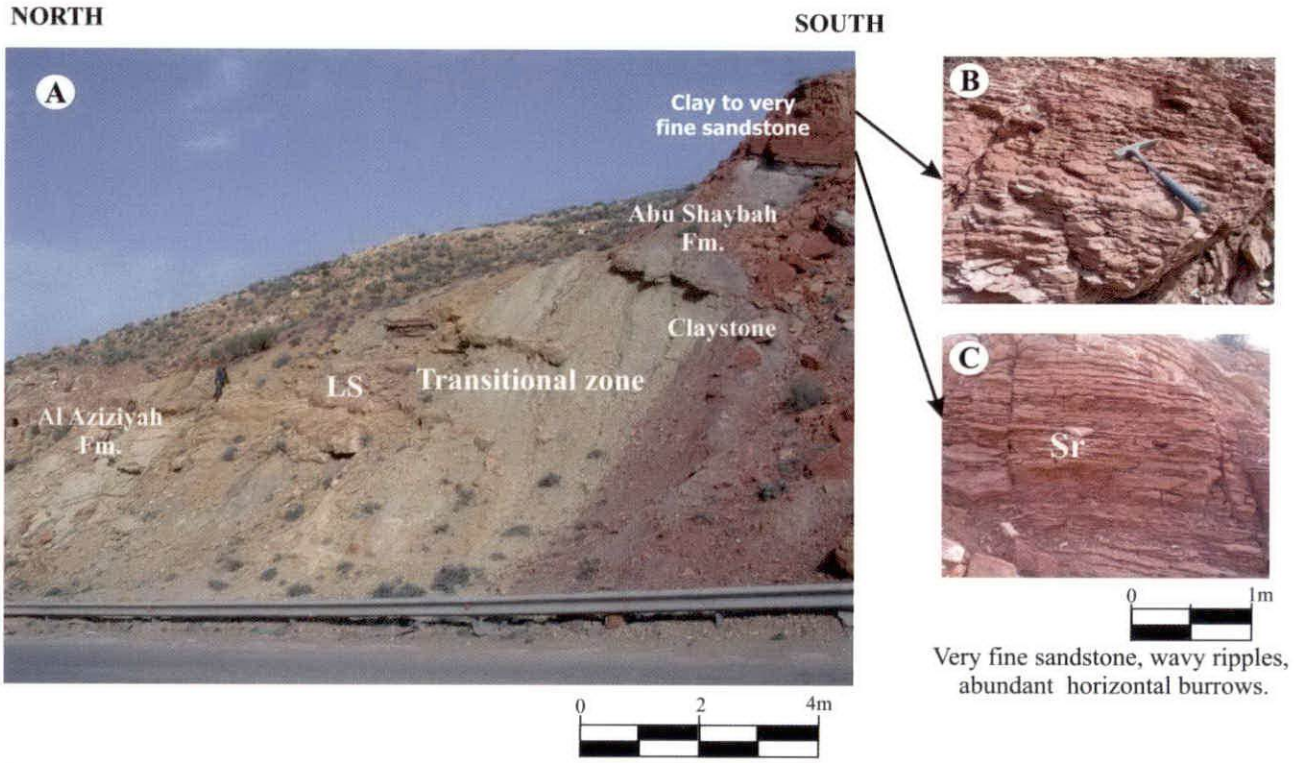


Fig. 10 Facies association 4: (A) Showing transitional marine top of Al Aziziyah and base of Abu Shaybah Formations. light greenish to reddish colour mudstone, (B and C) wavy ripples.

FACIES MODEL OF THE DEPOSITINAL SYSTEM

Wadi Ghan zone area is one of the most spectacular in the region, largely since many of its component faults crop out in the Jabal around Wadi Ghan. The component faults display two dominate trends, NW-SE and WNW-ESE and commonly about against each other to produce a rhomboidal to anastomosing framework NE-SW faults. This zone is approximately 25km wide and can be followed from the southeast, where it appears from under a cover of Tertiary lava flows, for a distance of 50km to northwest towards Al-Aziziyah south of merges with Al Aziziyah Fault zone (Anketell & Ghellali, 1991 and Anketell, 1996). In this region, several major NW trending faults of the Wadi Ghan zone about one against the other, defining a highly characteristics rhomboid pattern. Fig. 11 illustrates the importance for not only analysing the vertical succession, but also the lateral extent of the individual architectural elements. Deposition occurred in a range of fluvial subenvironments. The basal facies is conglomerate, gravely sandstone (Facies 1a-1c) were deposited in fluvial braided system that changed vertically and laterally to facies from massive to horizontal cross stratification (Facies 1a) and associated channellized conglomerate (Facies 1b and 1c) occurred in a fluvial braided, abundant gravely and normal trough and planner cross bedding interpreted as major channels with large migration dune. Depositional of facies association 2a-2c are characterised by broad channel complexes, sand sheets and numerous mid-channel bars with accretionary fore sets (Fig. 11). The increases in grain size, deeper channels and number of macro forms in this middle and upper part profile suggest that the fluvial system had a greater stream power and an increased sediment supply. Trough and small scale planar cross bedding is interpreted as dune fields migrating downstream, which are commonly overlain by clearly defined laterally extensive sheet sands. The large–scale lateral and downstream accretionary foresets are the result of marginal and mid-channel bars. The overbank fine grained sandstones and siltstones are interpreted as having been deposited during flood stages and the immediate following waning stage, for each of the facies association units. Depositional of facies association 3 are characterised by mudstone and siltstone deposited in flood plain. This facies is important in subsurface reservoirs for correlation of well logs.

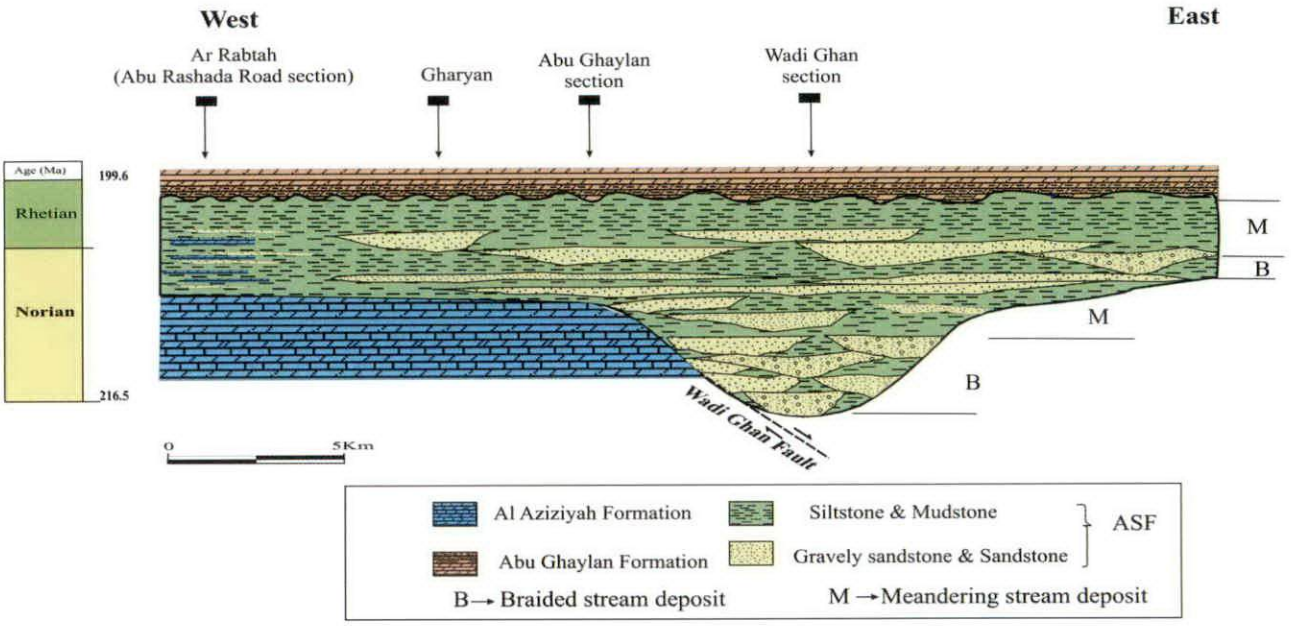


Fig. 11 Depositional model lateral and vertical variation of ASF along Jabal Nafusah, NW Libya.

Four phases interpretation of Early–Late Triassic (249.7 -199.6 Ma)

The boundary between Al Aziziyah Limestone (shallow marine) to continental of Abu Shaybah is unconformity and characterised by deep fluvial erosion, with the development of an incised valley system (Rubino *et al.*, 2002). The upper Al Aziziyah Formation in Wadi Ghan section consists of several meters thick shallowing-upward cycles showing storm and wave dominated features.

First stage, Early Triassic-Middle Triassic (Marine to Non Marine). The first stage of deposition of ASF in Wadi Ghan section in incised valley began after end of marine sequence or surface erosion top of Al Aziziyah Formation, Late Triassic (Carnian 228 -216.5 Ma). The lithostratigraphic formation boundary between the Al Aziziyah and Abu Shaybah formations is marked by a major unconformity and hence it is also a chronostratigraphic boundary. This simplify the communication, although it must be kept in mind that formations are rock units and are normally time-transgressive. The fluvial braided consists of conglomerate sandstone and scattered intraclast at the base of trough and planner cross bedding.

Second stage, Middle-Late Triassic (from braided to meandering system). The second stage started by deposition of the extensive sheets of sandstone complex channel of braided river (CH) (facies association 1a, b and c) in the incised valley. This channel showed that braided system deposits consist of blocky sand units made up of superimposed 1 to 10m thick megaripples deposited by low stand system tract. It changes gradually to meandering system defined by thinning and decreases in grain size and climbing ripples (Facies association 2a, b and c). The channels in this system are clear lateral accretion by trough and planner cross stratification (St, Sp and Sr), intercalation by 0.5-5m thickness of mudstone and siltstone (Floodplain and crevasse splay deposits) facies association 3. This phase is braided river sit on major unconformity and characterized by fluvial erosion, with the development of an incised valley fill system.

Third stage, Middle-Late Triassic (from meandering to braided system). A change from meandering to braided river patterns can be triggered by a number of causes. At a given discharge, braided channels occur on steeper slopes than do meandering channels. On the basis of this relation, a change from meandering to braided morphology can be inferred to reflect an increased channel slope and increases in clastic sediments sandstone body as thick channels of trough cross stratification 3-5m. The vertical evolution of the fluvial system in a single sequence records a strong decreases of the slope angle of the fluvial profile. The sequence is though to record the composite effected by tectonic and climate.

Fourth stage, Late Triassic–Early Jurassic (Continental to marine). This stage is transitional phase from continental (meandering stream deposits)

to marine deposits of Abu Ghaylan Formation, 20cm thickness of limestone with algal mat at the contact of Wadi Ghan section and abundant marine fauna, and contorted interbeds of carbonate and marl. Ripple marks, mud cracks, solution collapse breccias and tepee structures are also observed. The contorted bedding has been related to syn-sedimentary tectonic influences (Hammuda *et al.*, 2000).

SEQUENCE ARCHITECTURE AND STREAM EQUILIBRIUM PROFILE FLUCTUATION IN THE ASF

Figures 12 and 13 show alluvial extensive unconformity surfaces, and their correlative conformities. Deposition of the alluvial suite commences with amalgamation of channel sand bodies due to a lack of accommodation space causing local lateral migration or avulsion of the channel units, floodplain reworking, abandonment and preservation of channel sands before lateral avulsion or migration of the channel system re-occurs. Sequence boundaries in the non-marine realm are caused by a lowering of the alluvial systems Stream Equilibrium Profile (SEP) with respect to the actual stream profile. The extent to which the SEP is lowered relative to the actual stream profile, and the lag time until a response occurs governs whether a confined or unconfined sequence will develop. As in coastal and marine sequence startigraphic, two types of sequence boundary can be differentiated (Fig. 14). The "confined amalgamated channel unit" is the geomorphologic equivalent of the incised valley system and Type I sequence boundary of Van Wagoner *et al.*, (1988). The "unconfined amalgamated channel unit" is the geomorphologic equivalent of the Type II sequence boundary. The terms Type I and type II sequence boundaries are not used here in this model of continental sequence stratigraphy as they imply a dominant relative sea-level control on the depositional system. Similar types of strata bounding surfaces occur within sequences in hinterland regions (Mitchum, 1977). Confined continental sequences are bounded below by an erosional valley surface (caused by SEP Low) and above by a confined

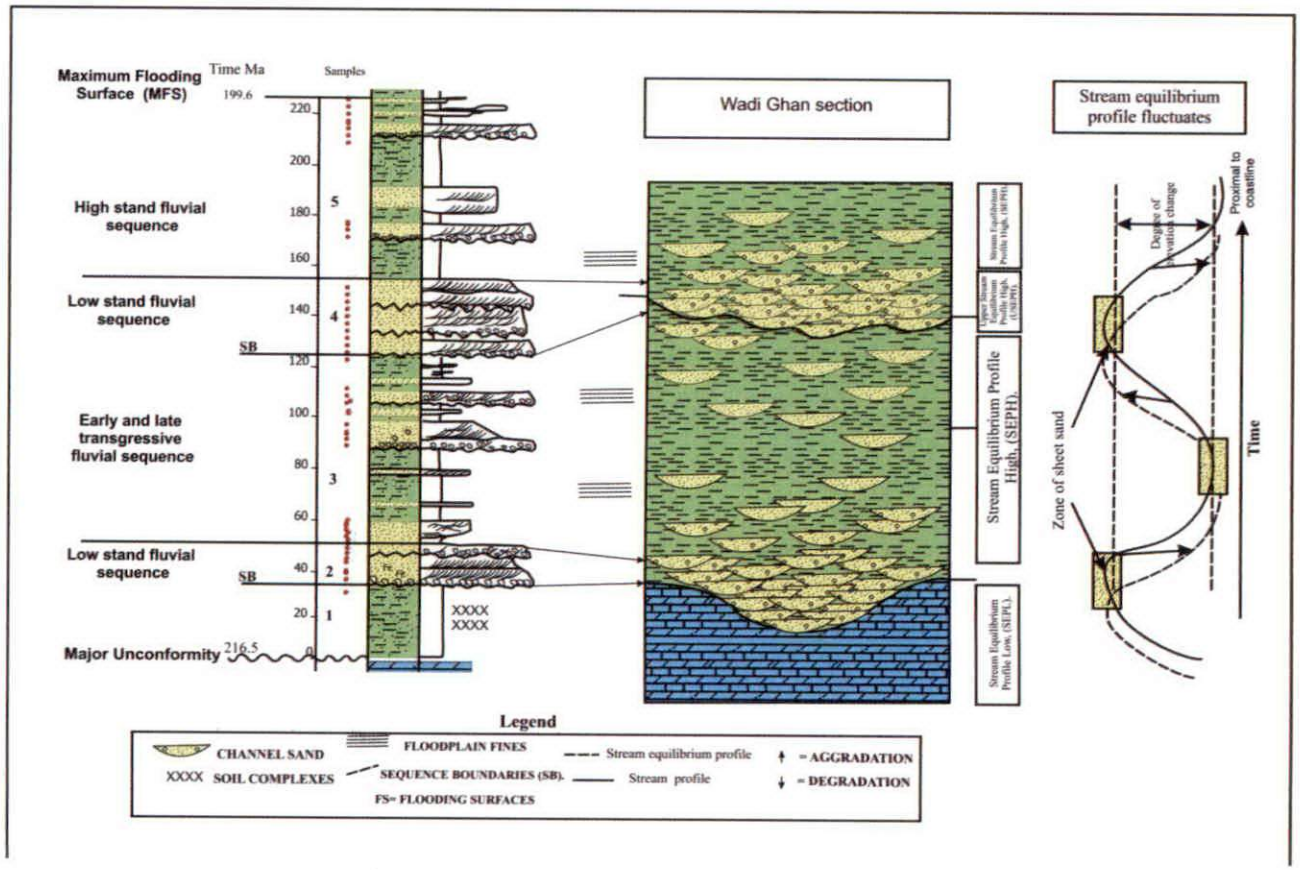


Fig. 12. Illustration of gross sequence architecture and continental systems tracts of Abu Shaybah Formation, (ASF) in Wadi Ghan section, which develop with stream equilibrium profile elevation fluctuation, resulting from alteration of allocyclic controlling mechanisms.

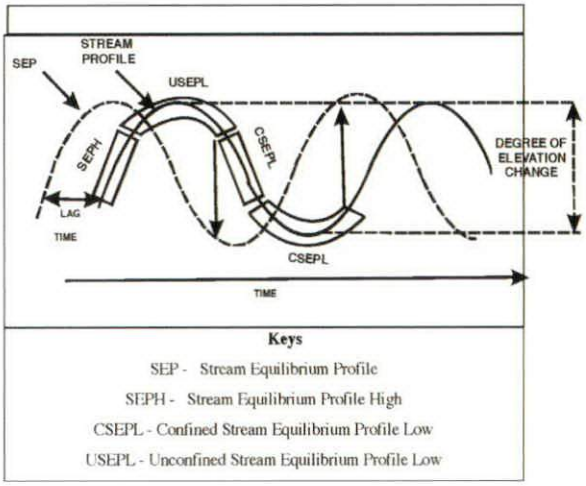


Fig. 13 Continental system tracts and their time of elevation with respect of fluctuation of The stream profile and the stream equilibrium profile.

or unconfined sequence boundary. Unconfined continental sequences are bounded below by an erosional surface (again caused by SEP Low) which follows the bases of the lowermost erosive channel sand units which constitute the amalgamated channel sand sheet resulting from a stream equilibrium profile relative lowstand. An unconfined sequence is bounded above by either a confined or unconfined continental sequence boundary. Unless a confining incised valley can be demonstrated, amalgamated channel sands should be described as being unconfined, SEP Lows can occur without the development of incised valleys. Wright and Marriott (1993) and Shanley and McCabe (1991, 1994) have subdivided continental sequences into lowstand (LST), transgressive (TST), and highstand (HST) systems tract to temporally equate environments. However, use of terminology such as transgressive systems tract in environments where influence of relative transgression on the coastal plain

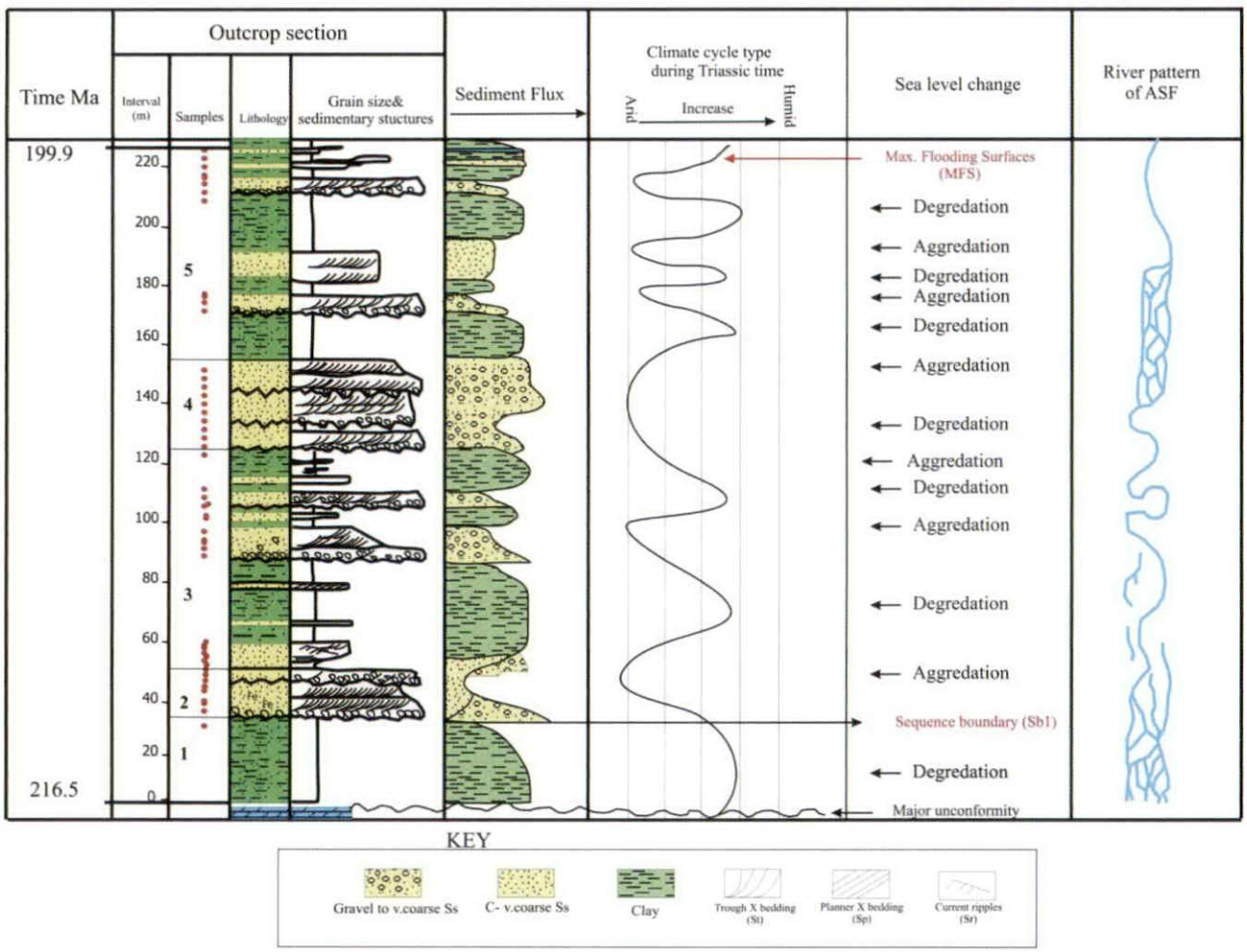


Fig. 14 Relationship between climatically mediated stream discharge and sediment flux under a range of climatic regime during Late Triassic for the Wadi Ghan section, NW Libya (concept adapted from Demko *et al.*, 2002; Meadows, 2006).

has a low probability of being physically expressed further upstream. (i.e., over most of the alluvial plain), can create confusion in correlation of strata surfaces (e.g., the coastal type I; Van Wagoner *et al*, 1988) and regional erosional surfaces that develop entirely within the subaerial realm. Due to the differing importances of allocyclic controls in different reaches of the fluvial system, a sequence boundary developed as a result of a relative sea level fall at the coast. However, the two different sequence boundaries may tie together at some point in the subaerial depositional basin, even though they are not chronostratigraphically equivalent. Figure 14 illustrates the continental phases of deposition and erosion which generate the subaerial equivalent of systems tracts, developing as a result of fluctuation of the stream equilibrium profile. The amalgamated channel sands within an incised valley constitute the initial deposits of the Confined Stream Equilibrium Profile Low (CSEPL) of Fig. 14. The fine grained sediments of this unit have poor preservation potential due to lateral switching of, reworking by, and preservation of channel sands. A CSEPL, essentially generates a continental sequence boundary, or incised valley surface. On the alluvial plain it is unlikely that this will be caused by a drop in relative sea level. Soil horizons may develop (Bown and Kraus, 1987; Wright and Marriott, 1993) on well drained river terraces produced by a low stand event, and these could represent some of the correlative conformities corresponding to the hiatal sequence boundary. The sediments of the CSEPL are comprised mainly of amalgamated channel sand bodies deposited within the confining incised valley system. These sandy units are frequently exploited for mineral and hydrocarbon resources. As aggradation continues, so the incised valley fills. As the stream equilibrium profile fluctuation cycle moves on into the Stream Equilibrium Profile High (SEPH) the rate of aggradation increases, causing channel sand bodies to become more isolated within better preserved fine grained sediments of the floodplain (Figs. 13 & 14). Very early and very late SEPH floodplain deposits, where rates of sedimentation (aggradation) are quite low, may be dominated by soil development. However, when aggradation rates increase, development of thick mature soil horizons will be inhibited, and floodplain fines will be preserved without significant pedification. Posamentier and Vail (1988a & b), Shanley and McCabe 1994 and the present conceptual model all suggest that alluvial flooding surfaces reflect rapidly aggradation. Alluvial flooding surfaces are regionally extensive subaqueously deposited complexes of fine grained floodplain deposits, which exhibit a higher degree of preservation of original sedimentary structure (i.e., have a low degree of pedification). This contradicts the model of Wright and Marriott (1993, Figure 1) which suggests that amalgamated channel sheet sands are generated by a Stream Equilibrium Profile High. Unconfined Stream Equilibrium Profile Lows will develop upon lowering of the rate of aggradation after the relative SEPH, causing a higher degree of channel amalgamation and reworking of any floodplain fines or soil complexes that have developed. Given enough times a regionally extensive amalgamated channel sheet sand will develop due to low rates of elevation change. If the stream profile remains above the stream equilibrium profile then the system will continue to degrade, incising into its previous deposits, possibly generating the deposits of the Confined Stream Equilibrium Profile Low as previously discussed.

DISCUSSION

Climatic controls on fluvial sedimentation

Regional climatic variations arise as a function of plate positions and how they change through time. Climate directly controls aridity, humidity and rainfall patterns and as a direct result perhaps the fluvial environment is one of the most sensitive indicators of climate change in the rock record (Frostick & Jones 2002; Jones & Frostick 2008). Climate has a direct impact on erosion, drainage patterns and deposition within a sedimentary basin. Any changes in climate can have a marked and devastating change for the whole of a river system (Blum & Tornqivst 2000; Hartshorn *et al*, 2002). Studies of climate change controlling fluvial deposition in the Pre-Quaternary are rather sparse in the geological literature compared to the vast array of literature on sea-level and base level changes following the introduction of sequence stratigraphic concepts. However, by far the most widely used climate indicator are palaeosols in floodplain successions as outlined by several workers over recent years (e.g. Retallack, 2001; Kraus, 1999; Wright and Marriott, 1993). Instead, the discussion below focuses firstly on where workers have specifically interpreted depositional sequences in response to climate change and secondly how climate variations can be determined in the fluvial packages of the Late Triassic Abu Shaybah Formation (ASF) in this study. Many workers have inferred climate change through the use of a variety of proxies or transition from fluvial to other strata. These are highlighted

below: 1-Changing from braid plain environments then to a meandering stream dominated setting that pass laterally environments, were attributed to shifts towards from arid and then more humid conditions.

A number of studies also interpret transitions between fluvial and other strata due to climate changes over time (Cojan's 1993; Yang & Nio's, 1993; Olsen & Larsen, 1993; Clemmensen *et al*, 1994; Dubiel *et al*, 1996). 2-Different thickness of floodplain and channels, Olsen (1990, 1994) identified two scales of cyclicity in the thickness of channel sand bodies. 3-Different in sediment supply stages (aggradation and degradation), Smith (1994) suggested that changes in channel sandbody geometry, sand-to-mud ratios, sediment accumulation rates and types of palaeosols in Arizona (USA) occurred during a tectonically quiescent period and might instead reflect climate changes. 4-The relationship between stream discharge and sediment flux under a range of climate regimes (Lane 1955; Bull 1991; Demko *et al*., 2002; Meadows 2006; Jones & Frostick, 2008), in which net fluvial aggradation or degradation is strongly influenced by the relationship between bedload and stream discharge. It is very easy in this study to ascribe the practise as outlined above in 1 to 3 as not only is the ASF located between two marine successions, but also the ASF changed gradually from a braided river as part of an incised valley fill to a meandering stream with isolated channel sandstones enclosed by siltstone and mudstone of floodplain deposits. Such a sequence is similar to that predicted by Shanley and McCabe (1994). It is obvious that climate has played a role in the behaviour of the ASF fluvial systems at a sequence scale, but more important is how climatic changes can be recognised at the outcrop and used in correlation of fluvial facies over 10's kms.

Meadows 2006; Demko *et al*, 2002 have modelled the effects of climatic change on patterns of fluvial discharge and sediment flux under a range of differing climatic regimes. In considering climate change, Demko *et al* (2002) looked at a range of climatic regimes from wet and tropical monsoonal climates through to dry seasonal and desert climates, the types of vegetation associated with these and the relative proportions of chemical and mechanical weathering. In doing so it was concluded that the greatest sediment flux is associated with wet and tropical monsoonal climates, but that the vast majority of this comprises clay-and silt grade material liberated through chemical weathering. With progressively drier climates the equilibrium sediment flux decreases but becomes increasingly dominated by sand-and gravel-grade material liberated by mechanical erosion. If such a methodology is applied to the ASF then it can clearly be demonstrated that a cyclicity exists within the fluvial succession from being wet seasonal through dry seasonal to relatively dry and with an increasing proportion of sand grade material the finer-grained sediment becomes less abundant. The climate change model therefore provides a means by which the maximum sediment flux and the maximum stream discharge are not equilibrium. Rather, there are episodes during which the sediment flux increases dramatically, generating conditions favourable for rapid net deposition and aggradation, and episodes during which discharge increases without a concomitant increase in bedload (Fig. 15). At such times, the river would be likely to undergo net degradation, reworking previously deposited sediment and incising its floodplain. Demko *et al*, (2002) proposed an idealized strata architecture resulting from this imbalance that illustrates the effect of alternating phases dominated by degradation and then aggradation. Interestingly, this also generates incised valley systems filled with stacked amalgamated fluvial channel deposits (Facies association 1-braided stream) overlain by isolated fluvial channel sandstones enclosed within floodplain deposits (Facies association 2 & 3-meandering and flood plain). In this case, it can be inferred that incision occurs during the most pluvial part of the climatic cycle, that sediment flux and discharge become effectively balanced as the climate becomes arid and, presumably, during this phase the river remains trapped within the previously incised valley system. As the climate begins to become wetter, and stream discharge increases, the sediment pulse is released and the river aggrades rapidly, infilling the incised valley until it breaks out onto the winder floodplain. At this stage both the increase area of the floodplain and the declining sediment flux, especially the coarser–grained bedload component, increase the preservation potential of floodplain facies (Facies association 3) and therefore render it more likely to generate isolated channels encased within those deposits. The main climate control on drainage development is through discharge variability It is to be expected that lithofacies heterogeneities will increase with increasing seasonal or long–term variability in discharge, and that the frequency of the minor bounding surface will increase (i.e. second and third order surfaces; Miall, 1996). The lithofacies and change in fluvial style in the ASF during Triassic undoubtedly can be explained by

changes in discharge sediment ratios (or sediment flux) and correspondingly discharge from waning flood events. The succession of facies described here is known to span the time of gradual continental break-up of Pangaea and a change from icehouse to greenhouse conditions with a trend towards more temperature-humid conditions. The gradual change in climate coincides with changes in character of the fluvial systems from dominatingly alluvial fans and coarse-grained braided rivers to meandering streams. However, river react to a number of stimuli, and it is difficult to determine whether a given change in character reflects tectonic or climatic influences, or both (Frostick & Reid, 1989; Frostick & Jones, 2002). The evidence the ASF is affected by climate control is contained in the hot red beds are typical for semi arid regions and many form through the release of iron from mafic minerals during early burial and its precipitation around grains as a hydrated iron oxide, which ages to haematite (Tucker, 2001). The climate change model therefore provides a means by which the maximum sediment flux and the maximum stream discharge are not coincident. Rather, there are episodes during which the sediment flux increases dramatically, generating conditions favourable for rapid net deposition and aggradations, and episodes during which dis-degradation, increases without a concomitant increase in bedload. At such times, the river would be likely to undergo net degradation, reworking previously deposited sediment and incising its floodplain (Demko *et al*, 2002; Meadows 2006). The architecture resulting from this imbalance that, illustrates the effect of alternating phases dominated by degradation and then aggradations. Interestingly, this also generates incised valley systems filled with stacked amalgamated fluvial channel deposits overlain by isolated fluvial channel sandstones enclosed within floodplain deposits Demko *et al.* (2002). In ASF section, it can be inferred that incision occurs during the most fluvial part of the climatic cycle, the sediment flux and discharge become effectively balanced as the climate becomes drier and, presumably, during this phase the river remains trapped within the previously incised valley system. As the climate begins to become humidity, and stream discharge increases, the sediment plus is released and the river aggrades rapidly, infilling the incised valley until it breaks out onto the wider floodplain. At this stage, both the increased area of the floodplain and the declining sediment flux. When interpreting fluvial successions climate alone cannot reliably be used due to the complex interactions and feedback loops associated with tectonism (e.g. Frostick, 1993; Frostick & Jones 2002).

Tectonic control on fluvial successions

Background

Rivers are sensitive indicators of tectonic subsidence, uplift and tilting. In tectonically active areas, and especially during synrift phases of basin evolution, tectonics can be recognised as an important control on gradients, water supply, stream power, shear stress, long profiles, terrace patterns and channel sinuosity (e.g. Seeber & Gortniz, 1983; Ouchi, 1985; Rasanen *et al*, 1987; Jones 2002; Frostick & Jones 2002). Frequently in the literature tectonics is ascribed as one of the main controls on fluvial architecture, geometry of channel sand bodies, spatial distribution of fluvial systems and direct control on sediment flux routing into sedimentary basins (e.g. Gawthorpe & Leeder, 2000). However, process-based models of alluvial stratigraphy have been developed that consider the effects of compaction, tectonic tilting of the floodplain and variation in the aggradation rate with distance from channel belt (Bridge & Leeder, 1979; Mackey & Bridge, 1995). Such predictive process-based models are widely used in understanding fluvial systems and routinely incorporated into reservoir models for petroleum exploration. Mackey and Bridge (1995, p. 28) identified that even with advances in the models several components are still lacking for a complete understanding of ancient fluvial behaviour (e.g. sediment flux, channel diversion occurrence, fluid flow, creation of levees, lakes and crevasse splays). There have been several attempts at developing physical based three-dimensional models of fluvial deposition (reviewed by Kolterman & Gorelick, 1996; North, 1996; Paola, 2000). However, none of these approaches has been able to successfully simulate three-dimensional fluvial architecture to a satisfactory level of detail.

The Jifarah Basin and the ASF

The Jifarah region has previously been discussed by Anketell & Ghellali 1991, but the importance of the tectonics of the region is further emphasised here. Uplift in the southern Jifarah region during the late Triassic accounts for the unconformity at the base of the Abu Shaybah Formation and the onset of continental conditions of sedimentation at this time. Both the NW-SE and E-W structural grains associated with the Caledonian and Hercynian structures in the

Jifarah basin are of importance in their influence on later structural events (Mikbel, 1977; Goudarzi, 1980; Anketell & Ghellali, 1991). Faults within the region display a characteristics *en echelon* arrangement that are interpreted in terms of long-lived reidel shears and imbricate fan splays related to strike-slip fault movements on deep seated basement fractures (Anketell & Ghellali, 1991).

Due to the tectonic activity of the research area and many of the outcrops located near important strike-slip faults along the Jabal Nafusah escarpment (e.g. Coastal zone, the Al Aziziyah zone in the west and central Jifarah, the Tiji zone in the foothills of the Jabal Nafusah and, the Nalut zone exposed at the top of the escarpment), it is tempting to speculate that the fluvial systems of the ASF were strongly controlled by tectonic activity and perhaps many of the coarse beds represent tectonically induced erosion and sediment flux from the hinterland catchments (e.g. Blair and McPherson 1994; Mack and Leeder, 1999; Viseras *et al*, 2003). However, from field observations and geological mapping it is evident that the Late Triassic fault activity is important in controlling the gross geometry of the fluvial succession and hence their drainage patterns for the ASF. Recent studies have highlighted the importance of tectonic grain and changes in fault orientations in controlling drainage patterns and hence outlet spacing into a depositional basin (e.g. Hovius, 1996; Jones, *et al*, 2001; Jones, 2004). Furthermore, the physiographic changes to the landscape, induced by fault activity are likely to have far-reaching implications on fluvial style and flow directions.

The incised valleys fills of ASF are most likely to have formed through a combination of both erosional and tectonic forces (e.g. Stanley, 1994). This is reflected in the basal erosional sequence boundary of the ASF (Fig. 13). The amalgamated fluvial deposits that are confined within the incised valley were further controlled by localized faulted margins. Through the Late Triassic (c. 15.9 Myrs) the fluvial systems changed character and became less influenced by tectonism reflecting fewer multistory/amagalmated fluvial deposits and more isolated channel networks. Any changes in the river behaviour can be attributed to regional gradient changes of the basin floor or minor diversion by reactivation of basement strike slip faults.

Although it has been widely recognised that fault movement, fault geometries and subsidence create a topography control fluvial patterns and deposition, it is climate that exerts a more discrete control on sedimentation of fluvial sequences and their architecture. This is perhaps too easily overlooked in ancient basin settings, but as recognised in this study, climate is a more important control on fluvial sequences once a drainage pattern has been created. This study has demonstrated that although tectonism can induce and control fluvial system development, it is climate that exerts a strong influence upon the nature of the fluvial sequences and how they interrelate to associated facies and can be correlated. This is easily overlooked in the need to identify tectonic events and interpret ancient basin history. Furthermore it is parameters related to climate (e.g. rainfall, stream power) that need to be further understood in ancient successions to improve process based models of fluvial deposition.

CONCLUSION

Lateral and vertical variations in the facies architecture of the fluvial strata of the ASF along Jabal Nafusah, NW Libya can be explained by consideration of allocyclic controls on sedimentation. Tectonism in the source area was probably important in determining the timing and location of the alluvial wedge. Differential subsidence in the depositional basins influenced the location of braided rivers and determined the degree of interconnectedness of sandstone bodies. A gradual climatic change produced change in the style of rivers and the geometry of their resulting facies. Changes in stratigraphic base level resulted from shrinkage and expansion of lacustrine systems downstream from the study area. These changes in base level are interpreted to have caused variations in the rate of creation of accommodation which resulted in a sharp base to the formation and an upward change from thin, highly amalgamated, sheet sandstone bodies to thick, isolated, sheet sandstone bodies. The causes of the fluctuations in lake size are beyond the scope of this study, but it is possible that they were related to climatic shifts or, because of their position on a broad coastal plain, to changes in sea level in the seaway to the north. This study emphasizes the importance of taking a holistic approach to understanding controls on fluvial sedimentation. The role of both upstream and downstream controls on sedimentation needs to be considered in addition to subsidence and climate at the site of deposition. The climate change model therefore provides a means by which the maximum sediment flux and the maximum stream discharge are not coincident. Rather, there are episodes during which

the sediment flux increases dramatically, generating conditions favourable for rapid net deposition and aggradations, and episodes during which discharge increases without a concomitant increase in bedload. At such times, the river would be likely to undergo net degradation, reworking previously deposited sediment and incising its floodplain. Demko *et al* (2002) proposed an idealized strata architecture resulting from this imbalance that illustrates the effect of alternating phases dominated by degradation and than aggradations. Interestingly, this also generates incised valley systems filled with stacked amalgamated fluvial channel deposits overlain by isolated fluvial channel sandstones enclosed within floodplain deposits. In this case, it can be inferred that incision occurs during the most pluvial part of the climatic cycle, that sediment flux and discharge become effectively balanced as the climate becomes drier and, presumably, during this phase the river remains trapped within the previously incised valley system. As the climate begins to become wetter, and stream discharge increases, the sediment pulse is released and the river aggrades rapidly, infilling the incised valley until it breaks out onto the wider floodplain. At this stage, both the increased area of the floodplain and the declining sediment flux, especially the coarse grained bedload component, increase the preservation potential of floodplain facies (sandflats in the case of the ASF) and therefore render it more likely to generate isolated channels encased within those deposits. Several important conclusions can be drawn from the architectural study of the ASF that has implications for the development of drainage networks in the Jifarah Basin.

1. The depositional model comprises of fluvial system by low sinuosity braided and then meandering stream deposited.
2. The architecture of the braided fluvial deposits are dominated by channel –fill complexes (GST & GSp), sands sheet, and associated simple and more complex bar types. The meandering stream sediments record several fining –up successions interpreted as point bars.
3. The braided system was deposited under a more humid climate with high rates of reworking base level is interpreted to have fallen markedly and meandering system was deposited under semi arid climatic conditions, stable fluvial activity and floodplain storage.
4. The geometry and architecture of the two sequences can be described simply as sequence
   (1) of braided system, stacked multi-storey sand bodies, with a sheet like geometry procuring an amalgamate high net / gross (80%) sand body complex. Sequence
   (2) of meandering system, isolated channel-fill sand bodies with multi-storey / multi – lateral component, producing low net to gross (20%) sandstone ribbons, with a low connection potential.
5. Channel (CH). Consists of gravel bars and bed forms (GSp and GSt). Gravel bar and bed form thicknesses are upto 3-5 in most cases and widths are 50m to 150m.
6. Sand bed forms (SB) consist of St, Sp, Sr and SL with sharp base. SB has sheet¬like geometry and is often eroded channels. SB is usually about 1.5-2m thick. Widths vary between 150 and 200m. The average width/thickness ration of 15:1 within the whole studied area.
7. Paleocurrent indicators from the ASF show the flow to ward the west direction of cross stratification measurements' Sr, St and Sp
8. The two main fluvial systems contrast markedly, meandering stream was deposited under semi arid climate conditions, stable fluvial activity and flood plain. And braided stream was deposited under a more humid climate with high rates of reworking base level.
9. Based on the work of Demko *et al.*, 2002 and Meadows 2006 for alternating episodes of incision and aggradation through climatic mediation of the relationship between fluvial discharge and sediment flux controlled by a changing climate. This is supported by recorded changes in thickness of floodplain facies association 2 & 3 in which the humid parts while the channel of sandstones facies association 1 in arid part.

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