BORNO JOURNAL OF GEOLOGY

ISSN 1117 - 6393

Vol. 8, No 1, 2011

Published by
Department of Geology
University of Maiduguri.

Sponsored by:
Petroleum Technology Development Fund
(P. T. D. F)

BORNO JOURNAL OF GEOLOGY VOL, 8, NO.1, 2011
COPYRIGHT (c) DEPARTMENT OF GEOLOGY UNIVERSITY OF MAIDUGURI, PRINTED IN NIGERIA ISSN 1596-6798
www. Unimaidgeology.com

DIAGENESIS AND RESERVOIR QUALITY OF MIXED AEOLIAN AND FLUVIAL SANDSTONE DEPOSITS, ARGANA VALLEY, MOROCCO.

Aliyu Isah Goro
Department of Geology, Federal University of Technology, P.M.B 65 Minna, Niger State, Nigeria.

Abstract

The mudstone-dominated middle and upper parts of the sedimentary fill of Argana basin contains meter-scale sedimentary cycles that usually comprise ephemeral lake shales at the base, playa mudflat mudstones in the intermediate part, and both fluvial and aeolian sandstones at the top. The fluvial and aeolian sandstone facies were petrologically studied. The sandstones are sublitharenites and, less commonly, quartz arenites and lithic arenites with average framework composition of $Q_{85}F_2L_{14}$. The grains are generally moderately to well-sorted, sub rounded to rounded, very fine to coarse grained sands with typically grain-supported fabric. The aeolian facies show little compaction effects whereas the fluvial facies are more compacted. The main diagenetic phases that affected the sandstones were (1) ferruginous clay grain coatings (2) vadose infiltration of some clay into aeolian sands (3) precipitation of poikilotopic cement (4) cementation by anhydrite/gypsum/halite? (5) mechanical compaction through the presence of long contacts and bending or deformation of argillaceous fragments against rigid quartz grains (6) chemical compaction by smearing of argillaceous materials into pore-spaces, long, concavo-convex and suture contacts, pressure solution along quartz to quartz contacts and consequently (7) quartz overgrowth (8) blocky calcite cementation (9) dehydration of gypsum to anhydrite and dissolution of framework grains and cements. The distribution of porosity and reservoir quality is facies controlled with the aeolian facies having average porosities of 25% due to preservation of primary porosity following inhibition of quartz overgrowth by thin ferruginous clay coats or dissolution of eodiagenetic calcite cements. Fluvial facies on the other hand had average porosities of 17% and the poorer reservoir properties were due to pervasive quartz overgrowth, mechanical and chemical compaction and near surface precipitation of eodiagenetic calcite. The reservoir properties of the fluvial sandstones were diagenetically enhanced in some parts by framework grain and cement dissolution.

Introduction

Argana valley is located between the port city of Agadir and Marrakesh in the western part of High Atlas of Morocco (Fig. 1). It is a large physiographic depression, also called 'The Argana Corridor', developed during the Cenozoic when rivers draining southward from the High Atlas and Moroccan Meseta eroded the Cretaceous and Jurassic rocks, exposing 1500 km^2 of underlying Permian and Triassic rocks (Ambroggi, 1963; Tixeront, 1973; Brown, 1980) and forms the eastward extension of the hydrocarbon bearing Essaoura basin (Broughton and Trepanier, 1993) which on a more regional scale belongs to the El Jadida-Agadir basin (Medina, 1995). These outcrops overlie the Paleozoic massif of Ida'ou'Mahmoud in the east and are overlain by the Jurassic tablelands of Ida'ou'Bouzia and Ida'ou'Tanan in the west. The sedimentary succession in the Argana valley represents an early sedimentary response to the initial extensional phase in the area of the western High Atlas (Brown, 1980, Fig. 1). Based on works of Tixeront, 1973; Brown, 1980, Hoffman et al., 1998, and Hoffman et al., 2000, four formations and ten lithostratigraphical members (namely T1 to T10) are present in the Argana Valley (Table 1), they are in order of decreasing age:

1. Ikakern Formation (Members T1 and T2)
2. Timezgadiouine Formation (Members T3 to T5)
3. Bigoudine Formation (Members T6 to T8) and
4. Ameskroud Formation (Members T9 and T10)

Detailed stratigraphic work revealed asymmetrical, metre-scale cycles in mudstone-dominated successions that constitute the intermediate and upper portion of the basin fill (Hoffman et al., 2000, Fig. 1, Table 1). The Sedimentary cycles commonly comprise ephemeral lake

Corresponding author: Aliyu Isah Goro (isahgoro@yahoo.com)
Received 24 June, 2009 - Revision Accepted 14 August, 2010

shales at the base, playa mudflat mudstones in the intermediate part, and both fluvial and aeolian sandstones at the top (Hoffman et al., 2000, Fig. 2). The mixed fluvial and aeolian sandstones generally occur as massive or trough-cross stratified. According to Hoffman et al., 2000, both facies indicate that during the latest stage of the cycle history, the playa surfaces were covered by aeolian sand upon which efflorescent salt crust developed and concluded that the cycle tops formed during arid times when aeolian dunes migrated across the playa.

The present study is based upon a petrographic examination of the mixed aeolian and fluvial facies (that generally top the cycles) in order to unravel their diagenetic history and its implications on the reservoir quality of the sediments.

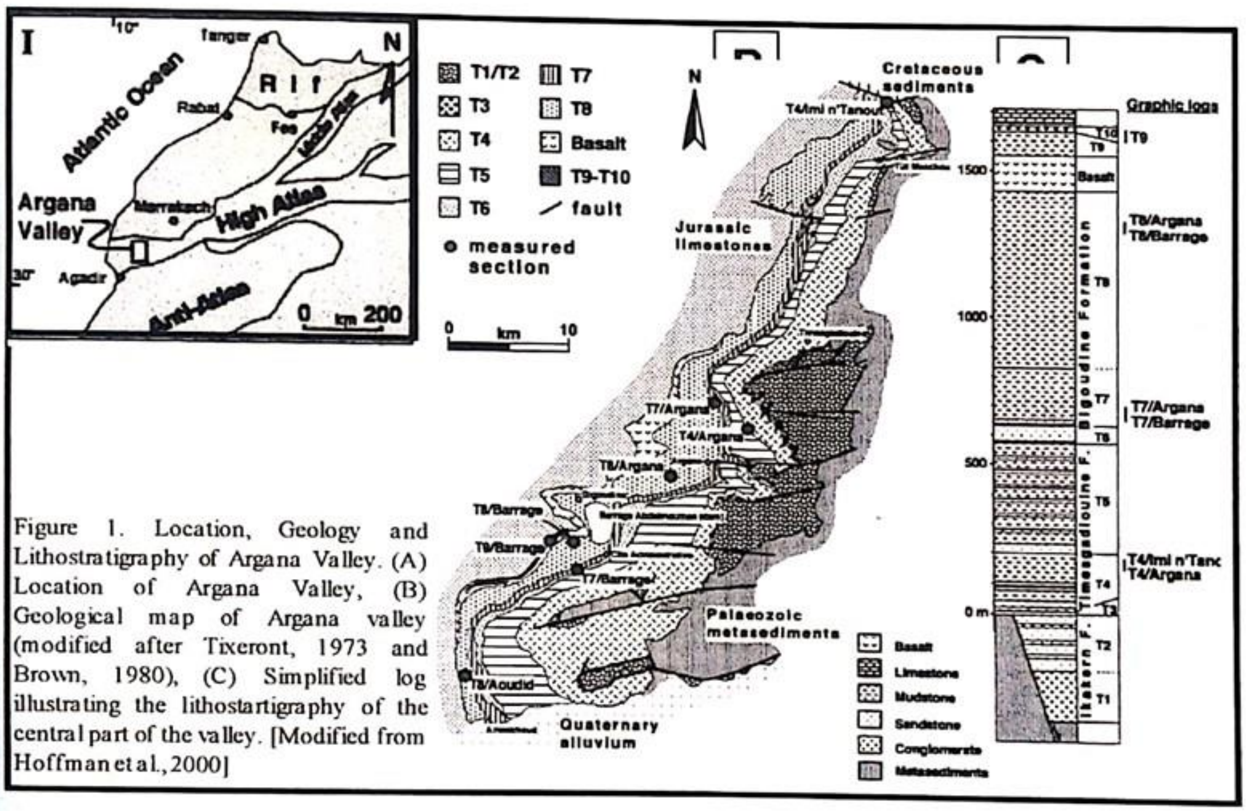

Figure 1. Location, Geology and Lithostratigraphy of Argana Valley. (A) Location of Argana Valley, (B) Geological map of Argana valley (modified after Tixeront, 1973 and Brown, 1980), (C) Simplified log illustrating the lithostartigraphy of the central part of the valley. [Modified from Hoffman et al., 2000]

lethodology

The representative samples were acuum-impregnated with blue epoxy resin rior to thin-section preparation. A total of eventeen polished thin sections were prepared ormal to the bedding direction. The analysis f the thin sections took account of the bservation of depositional textures, detrital omposition and diagenetic features by means of a Polaroid Spirit Scan 35LE scanner and a Nikon OPTHOT petrographic microscope (using transmitted light) with a ProgRes C10 digital camera system attached to it. Quantification of mineralogy was achieved by counting 400 points per thin section using MODEL F point counter. Image J software was used for porosity analysis.

Table 1. Stratigraphic subdivision of the continental red beds of the Argana Valley (data from various sources, Adapted from Hoffman, et. al., 2000)

Chrono-stratigraphy	Formations	Member	Unit	Lithology	Environment
Early Jurassic		Ait Mbarek	(T10)	Quartzite conglomerate	Braided river
	Ameskroud	Imerhrane	(T9)	Cyclically stacked mud-, silt and sandstone	Playa
	Argana Basalt			Tholeiitic basalt	Subaerial flows, intrusive sills
		Ilasreine	T8	Cyclically stacked mud-, silt and sandstone	Playa
Middle?/Late Triassic	Bigoudine	Sidi Mansour	T7	Cyclically stacked mud-, silt and sandstone	Playa
		Tadrart Ouadou	T6	Conglomerate, pebbly sandstone, Sandstones	Braided river, aeolian dune
		Irohalene	T5	Cyclically stacked sandstone with interbedded mudstone floodplain	Meandering river,
	Timezgadiouine	Aglegal	T4	Mudstone interbedded with silt- and sandstone	Playa, ephemeral river
		Timameurt	T3	Volcaniclastic conglomerate	Braided river
Late Permian	Ikakern	Tourbihin	T2	Interbedded pebbly sandstone, siltstone and mudstone floodplain	Meandering river,
		Dous River	T1	Conglomerate	Alluvial fan

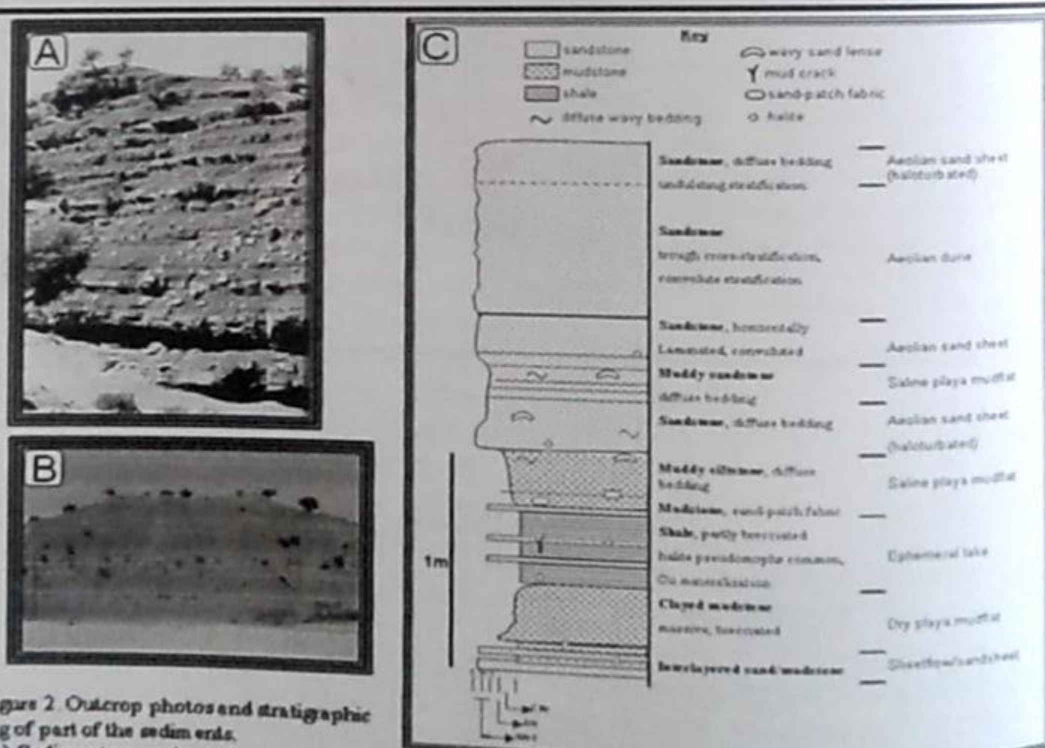

Figure 2. Outcrop photos and stratigraphic log of part of the sediments.
(A) Sedimentary cycles 4 (lower right) to 18 (upper left) of T7/Argana. Height of exposure is 30m. (B) Measured section of T8/Argana indicated with a black line. Aeolian dune sandstone (arrow) is laterally traceable for more than 10 km. Height of exposure is ca. 40 m. (C) Generalised sedimentary cycle of (T9) showing the typical occurrence of ephemeral lake shales at the base, playa mudflat mudstones in the intermediate part, and both fluvial and aeolian sandstones at the top. [Redrawn from Hoffman et. al, 2000]

Petrology and Diagenesis

Texture

The grains are generally moderately to well-sorted, sub rounded to rounded, very fine to coarse sands with typically grain-supported fabric. The aeolian facies typically show bimodal grain size distribution with the finer grains generally showing tighter packing with some clay and silt matrix whereas a more loose packing with minor clay and silt matrix characterise the coarser grains. They show little compaction effects with floating grains and long contacts more common, there is attenuation and sometimes absence of grain coating rims at or near the grain contacts (Fig. 4A, B), and have average thin-section porosities of 25 %. The fluvial facies are more compacted show more varied contacts including floating grain, long contacts, concavo-convex and suture contacts (Fig. 4C, D). Estimated thin section porosities for the sandstones of this facies averages 17 %.

Detrital Composition

The sandstones are sublitharenites and, less commonly, quartz arenites and lithic arenites (Fig. 3) with average modal composition of $Q_{85}F_2L_{14}$. Point counting results (Table 2); show that monocrystalline quartz grains are the most abundant detrital component. Polycrystalline quartz grains constitute minor amount and mostly found within rock fragments. Plagioclase dominates the feldspars and rarely makes up more than 2 % of grains. Lithic grains include predominantly fine grained sandstones, siltstones and subordinate metamorphic and igneous rocks in form of volcanics (Table 2, Fig. 4).

Table 2. Summary of point counting results.
Note: the percentage of monocrystalline (Qm) and polycrystalline quartz grains (Qp) as well as the percentages of igneous (I), sedimentary (S) and metamorphic (M) rock fragments are also shown.

Sample	Facies	Quartz (%)	Feldspar (%)	Rock fragment (%)	Porosity (%)
1	Aeolian	78 Qm = 100, Qp = 0	1	21 I = 0, S = 100, M = 0	28.3
2	Aeolian	84 Qm = 100, Qp = 0	1	15 I = 0, S = 100, M = 0	28.8
3	Aeolian	95 Qm = 100, Qp = 0	1	4 I = 0, S = 100, M = 0	26
4	Aeolian	73 Qm = 83, Qp = 17	2	25 I = 0, S = 100, M = 0	23
5	Aeolian	86 Qm = 100, Qp = 0	4	10 I = 0, S = 100, M = 0	20.8
6	Aeolian	88 Qm = 100, Qp = 0	2	10 I = 0, S = 100, M = 0	21
7	Aeolian	84 Qm = 100, Qp = 0	2	14 I = 0, S = 100, M = 0	26.6
8	Fluvial	90 Qm = 95, Qp = 5	1	9 I = 0, S = 95, M = 5	19
9	Fluvial	68 Qm = 100, Qp = 0	2	30 I = 0, S = 100, M = 0	25
10	Fluvial	84 Qm = 100, Qp = 0	1	15 I = 0, S = 100, M = 0	16.5
11	Fluvial	84 Qm = 100, Qp = 0	1	15 I = 0, S = 100, M = 0	16
12	Fluvial	92 Qm = 100, Qp = 0	1	7 I = 0, S = 100, M = 0	16.5
13	Fluvial	88 Qm = 100, Qp = 0	2	10 I = 10, S = 90, M = 0	16.8
14	Fluvial	85 Qm = 100, Qp = 0	2	13 I = 15, S = 85, M = 0	12
15	Fluvial	58 Qm = 100, Qp = 0	1	41 I = 0, S = 100, M = 0	16.9
16	Fluvial	95 Qm = 100, Qp = 0	0	5 I = 0, S = 100, M = 0	17.6
17	Fluvial	73 Qm = 90, Qp = 10	2	25 I = 0, S = 60, M = 40	17

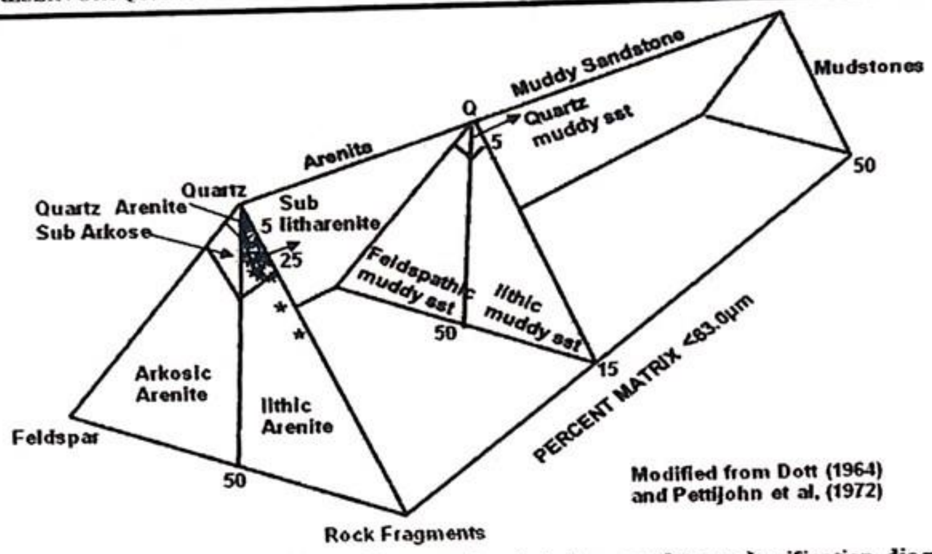

Figure 3. Detrital composition of the samples plotted on sandstone classification diagram.

Diagenetic Phase

The main diagenetic characteristics of these sandstones are reddening by ferruginous grain coatings, quartz and feldspar overgrowth, calcite cements, anhydrite cements, dissolution of detrital grains and cements as well as deformation of argillaceous rock fragments against rigid grains (Fig. 4).

Red-brown grain coating rims are present in all the samples but little or absent in samples that were pervasively affected by quartz overgrowth (e.g. Fig. 4D). The surfaces of the original framework grains are picked out by these rims (Adams, et al., 1984). The sandstones show evidence of both mechanical and chemical compaction. Mechanical compaction is indicated by the presence of long contacts and bending/deformation of argillaceous fragments against rigid quartz grains (Fig. 4B). Chemical compaction effects are identified by squashing/smearing of argillaceous material into pore-spaces, concavo-convex and suture contacts and quartz overgrowth. Carbonate cements are identified by their high relief and cleavage under plane polars and their characteristic high order interference colour when viewed under the crossed polars. They occur as large, single, *poikilotopic* (calcite I) enclosing many framework grains (Fig. 4E), and blocky calcites (calcite II) that fill intergranular pores previously reduced considerably by compaction and quartz overgrowth (Fig. 4F, G). Both calcites show patchy distribution and were observed to replace quartz and feldspar, as well as their overgrowths, and rock fragments at their grain contacts (Fig. F, G).

Authigenic quartz occurs as syntaxial overgrowths in fluvial facies but absent in the aeolian facies. Quartz overgrowths vary in extent from incipient to pervasive. They are incipient or absent where the sandstones are pervasively cemented by carbonates (Fig. E, F) or when the quartz grain coatings are thick (aeolian facies, Fig. 4A, B). Fairly extensive quartz cements that fully cover the detrital quartz grains and block the pore throats occur in sandstones that are fairly or not cemented by calcite (Fig. 4C&D). Anhydrite cements appear as separate and partially dissolved grains showing their typical first-order birefringent colour (Fig. 4D). They are colourless under plane polarized light. Completely and partially dissolved framework grains are common leaving behind oversized pores and relicts of dissolved grains (Fig. 4F, H). Both calcite and quartz cements went through dissolution phase. Dissolved calcite cements appear corroded between framework grains (Fig. 4F) whilst the dissolution of quartz cements are indicated by interconnection of pores in extensively quartz cemented sandstones (e.g. Fig. 4H)

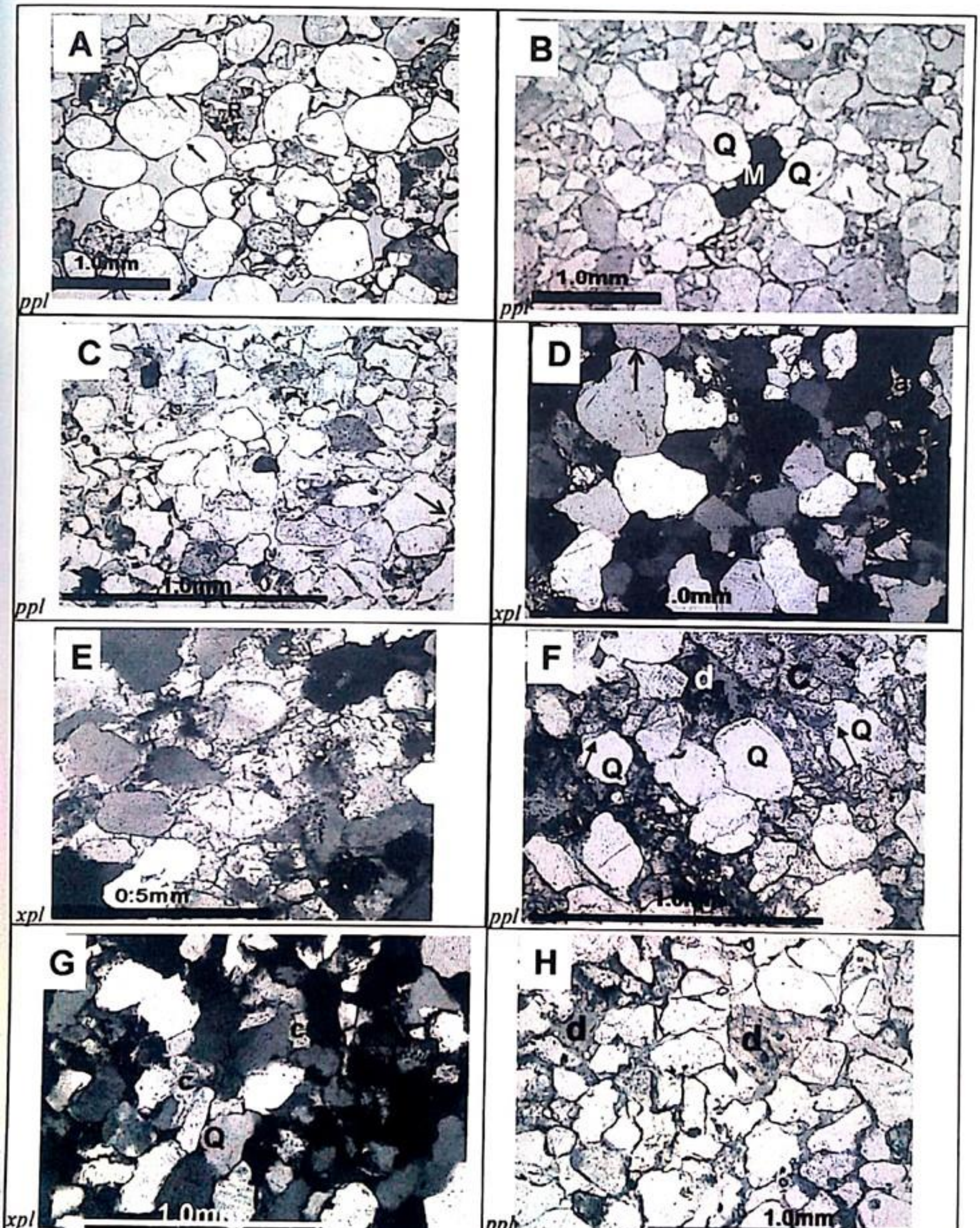

Figure 4. Photomicrographs showing. [A] Typical Aeolian sublithic arenite characterised by well sorted, rounded grains showing thick ferruginous clay coats, absence of cement and lack of compaction texture, arrows =long contact, R=rock fragments, blue areas=pore spaces, Note: the red ferruginous clay grain coatings, PPL, [B] Aeolian facies showing bimodal grain distribution, bent mud clast (m) between quartz grains (Q), [C] Fluvial facies showing extensive quartz cementation and greater compaction. Note: suture contact (arrow). [D] Fluvial facies showing suture contact (arrow), extensive quartz cement that fully covered pore spaces, anhydrite cement (a) at the top right hand side, (E) Fluvial facies showing eugenetic poikilotopic calcite I, cement. Note: the cement is a single crystal that enclosed almost all the framework grains in the field of view. [F] Peripheral replacement of quartz grains by calcite II cement (indicated by arrows), Q=quartz grain, d = relict of dissolved grain leaving behind secondary pore space. [G] Calcite II (c) showing patchy distribution and filling intergranular pores previously reduced considerably by compaction and quartz overgrowth [H] "Diagenetic quartz arenite" formed by pheriferal dissolution of quartz overgrowths and other cements allowing interconnection of pores as indicated by the blue areas, (d) dissolved "feldspar" grains. Note: PPL=plane polarised light, XPL=crossed polarised light.

Discussion

Diagenetic changes are many and complex and affect porosity and permeability of sediments which have direct bearing on the reservoir or aquifer properties of the sediments. Diagenetic processes that govern reservoir properties include the extent of compaction, cementation (mainly by carbonates, quartz, and clay minerals), and dissolution of framework grains and cements (Salem et al., 2000). Also it has been established that diagenetic changes can be explained in terms of early (eodiagenesis), burial (metadiagenesis) and uplift related (telodiagenesis) processes based on a broad framework that relates diagenetic processes to the evolution of sedimentary basins (Morad et al., 2000). In this study, attempt is made to relate the observed diagenetic changes to these phases of basin evolution.

Origin of diagenetic phases

In this study, the aeolian sandstones typically contain very little cement, with only trace amount of pore-lining clay and rare carbonate cement (similar to those of the Sherwood Sandstone Group, UK) which have made the diagenetic history very difficult to resolve (Strong, 1993). The pore-bridging and pore-lining ferruginous clays suggest the influence of early meniscus (vadose) cements (Strong, 1993). The lack of quartz overgrowths in aeolian sandstones may be due to the presence of thick ferruginous grain coating rims that are known to inhibit cementation (Ehrenberg, 1993).

Study of the diagenetic history of these sandstones focuses more on the fluvial sands; for the reason that they show more variable primary fabric and texture.

The reddish-brown grain coating rims are important in the diagenesis of sandstones and are generally interpreted as iron-oxide (in most cases, hematite) or ferruginized clays. Ferruginous grain coating is characteristic of eodiagenesis in present day sediments in hot arid and semi-arid environments (Walker et al., 1978). There has been much discussion on the source and origin of the hematite pigment in red beds, however a detrital origin through transported weathered sediments that are converted to hematite with time is possible or they may be of a purely diagenetic origin where the iron is supplied by dissolution of iron bearing detrital silicates such as olivine, hornblende, augite, chlorite, biotite and magnetite (Tucker, 1994). More detailed work on similar, mixed aeolian and fluvial Navajo Sandstones, Utah, USA., involving petrographic examination of thin sections, x-ray diffraction, and electron microprobe analysis by Parry, et al. (2009), revealed that early diagenetic hematite coatings of the sand grains formed from oxidation of iron minerals (reddening the sand). Illite coatings formed on the sand grains along with incorporation of the fine-grained hematite during deposition and early burial (Parry et al., 2009).

The poikilotopic calcite cements envelop many framework grains with floating contacts (Fig. 4E) indicative of pre-compactional origin. The lose grain packing and the absence of quartz overgrowth in the grains enclosed by them indicate early precipitation. Sources of eodiagenetic carbonate cements in continental siliciclastic sediments are often enigmatic and poorly constrained in the literature (Salem et al., 2000). Pedogenic (calcretes) origin is possible as indicated by textural evidence of early precipitation and patchy distribution. Carbonate cements with similar characteristics occurring in the continental Triassic Sherwood Group sediments were attributed to eodigenesis at shallow burial depths (Strong, 1993). Early calcite cements that were later replaced by dolomite were also identified in similar deposits (e.g., Parry et al., 2009, Strong, 1993).

Mechanical compaction is indicated by the deformation of argillaceous clasts, rearrangement of the grains and long contacts between grains (Fig. 4B). This style of mechanical compaction is dominant in the first 1000 metres and can continue to depths of 2000 – 4000 meters with the reduction of porosities in the range of 25-30 % (Worden et al., 1997). The long, concavo-convex and suture contacts, pressure solution along quartz to quartz contacts and deformation of ductile grains all confirm chemical compaction effects (Fig. 4C, D).

The main growth of quartz overgrowth and cements is here considered as a mesodiagenetic event due to the presence of long, concavo-convex and suture contacts which were related to the compaction phase. Pore solutions become enriched in silica which is precipitated as overgrowth when super saturation is achieved. Quartz cementation is a significant process only at temperatures greater than 70-80 °C (Giles, 2000). The main source of silica for the quartz overgrowths is evidently pressure dissolution of detrital quartz locally along grain contacts.

The Calcite II cements post dates quartz overgrowth as indicated by its partial replacement of the quartz cements (Fig. 4E). The precipitation of blocky carbonate cements in pores that remain after quartz cementation (Boles, 1978; Land et al., 1987) could be attributed to deep mesodiagenesis (Morad et.al, 2000). This observable fact is seen during deep burial stage after chemical compaction and may be related to the different temperature solubility of the two minerals (i.e. quartz and calcite). This is possible because with increasing temperature during progressive burial, quartz become more soluble while calcites tend to precipitate (Morad et.al, 2000).

Anhydrites are formed by the dehydration of gypsum at depths of between 1.5-4 km and temperatures of 50-120 °C depending upon pore fluid, salinity, pressure and thermal gradient (Hadie, 1967; Jowett, 1993) during burial diagenesis. The formation of gypsum in the area of study may perhaps be associated with development of evaporite crusts on top of the sandstones. Dissolution of feldspars especially K-feldspar in sandstones occurs over depth ranges of 1.5 to 4.5 km (temperature ranges from 50 to 150 °C; Wilkinson et al., 2001) but is more commonly extensive by 2.5km burial depth producing so called 'diagenetic quartz arenites' (Harris, 1989) as observed in some of the studied samples (e.g. Fig. 4H). Dissolution of unstable framework grains such as rock fragments, feldspars (Fig. 4F, H), calcite and anhydrite cements may be attributed to deep burial or telodiagenetic alterations.

Based on textural relationships and their interpretation (depth of formation, diagenetic regime of the various reactions) as discussed above, the suggested paragenetic sequence for the sandstones is as follows:

- ✓ Ferruginous clay grain coatings
- ✓ Vadose infiltration of some clay into aeolian sands
- ✓ Calcite I cement in form of calcretes associated with pedogenesis
- ✓ Cementation by anhydrite/gypsum/halite? associated with development of salt crusts at the latest stage of cycle development
- ✓ Mechanical compaction (deformation of clay and other argillaceous lithic grains against rigid grains)
- ✓ Chemical compaction (pressure solution) leading to
- ✓ Quartz overgrowth
- ✓ Calcite II cement (filling pore spaces left by compaction and quartz overgrowth)
- ✓ Dehydration of gypsum to anhydrite and dissolution of framework grains and cements

Implication for reservoir quality

The distribution of porosity and reservoir quality is facies controlled, with the aeolian facies having average thin-section porosities of 25 percent and the fluvial facies having 17 percent. Apart from the depositional environment, the diagenetic alterations induced during the progressive burial and uplift was also observed to govern the distribution of porosity in the sandstones. The best reservoir quality sandstones are those aeolian facies whose primary porosity was preserved due to existence of inhibition of quartz overgrowth and/or possible complete dissolution of eodiagenetic calcite cement. The inhibition of quartz overgrowth was achieved by the development of eodiagenetic ferruginous clay coatings around the grains. On the other hand, local concentration of pore bridging clays can lead to poor interconnection of pores and because clays minerals have abundant micro-porosities, they can induce high water saturation in reservoirs.

Poorer reservoir properties observed in the fluvial facies can be explained in terms of development of pervasive quartz overgrowth, intense mechanical and chemical compaction and near surface precipitation of eodiagenetic calcite (calcite I). Telogenic framework grain (feldspar) and cement dissolution, however, improved the porosities of some of the fluvial sandstones.

Conclusions

Thin section petrography of the mixed aeolian and fluvial sandstones that top the mudstone dominated cycles of the sediments exposed in the middle and upper part of Argana Valley apart from confirming the field observations of grain shape, and rock texture, also show interesting diagenetic histories relevant to reservoir quality.

The main diagenetic transformations of the sandstones are represented basically by eodiagenetic ferruginous clay coatings, pedogenic (calcite I) cement and gypsum/anhydrite cements; mesodiagenetic quartz cementation, blocky calcite II cementation, and secondary/dissolution porosity formation through framework grain/cement dissolution, and lastly, telodiagenetic anhydrite formation and framework as well as cement dissolution.

Preservation of primary porosity owing to presence of inhibition of quartz overgrowth induced better reservoir qualities in the aeolian sandstones having average porosities of 25 %.

Poorer reservoir qualities were induced on fluvial facies by development of pervasive quartz overgrowth, intense mechanical and chemical compaction and near surface precipitation of eodiagenetic calcite. Local enhancement of reservoir quality were achieved through framework grain and cement dissolution in some areas.

It is clear from this studies that diagenetic processes that occurred at near-surface conditions, during burial and subsequent uplift had strong impact on the evolution and distribution of reservoir quality in the Triassic, mixed fluvial-aeolian sandstone facies of Argana valley, Morocco.

Acknowledgement

I thank Prof. Jonathan Redfern of University of Manchester for being my mentor in this project. I also thank Nadine Mader of Ameradas Hess and Andreas Kayser of Schlumberger, Cambridge, for their support in terms of constructive discussion during thin section examination and porosity estimation. My appreciation also goes to the following staff of the University of Manchester, Dr Joe Macquaker for extra lectures on diagenesis, Dr A.E. Adams for the point counter, Mandy Edwards and Dave Plant for the microscope training. I also thank anonymous reviewers for the comments and ideas that helped to improve the original manuscript.

References

Adams A. E., Makenzie, W.S., and Guilford, C. (1984) Atlas of sedimentary rocks under the microscope. Longman Group Limited. 104.

Ambroggi, R. (1963) Etude geologique du versant meridional du Haut-Atlas occidental et de la Plaine du Souss. Notes Memoires Service Geologique Maroc 157, 332.

Arambourg, C., Duffaud, F., (1960). Note sur la decouverte d'un gisement de vertebres continentaux dans le Trias du Haut- Atlas occidental. Bulletin Societe Geologique France **2 (2).** 172-177.

Boles, J. R. (1978) Active ankerite cementation in the subsurface Eocene of southwest Texas: Contributions to Mineralogy and Petrology, **68,** p. 13–22.

Broughton, P., Trepanie´r, A. (1993). Hydrocarbon generation in the Essaouira basin of western Morocco. Bull. Am. Assoc. Petrol. Geol. **77,** 999–1015.

Brown, R. H. (1980). Triassic rocks of Argana valley, Southern Morocco, and their regional structural implications. Bulletin American Association of Petroleum Geologists **64,** 988-1 003.

Dott, R. H., Jr. (1964) Wacke, greywacke and matrux – what approach to immature sandstone classification?. Jour. Sed. Petrology, **34,** 625-632

Ehrenberg, S. N. (1993) Preservation of anomalously high porosity in deeply buried sandstones by grain-coating chlorite: examples from the Norwegian continental shelf: AAPG Bulletin, v. **77,** 1260–1286.

Giles, M. R., Indrelid, S. L., Beynon, G.V. & Amthor, J. (2000) The origin of large scale quartz cementation: evidence from large datasets and coupled heat-fluid mass transport modelling. In: Quartz Cementation in Sandstones (Eds R.H. Wodern & S. Morad). Spec. Publs Int. Assoc. Sediment. Black-Well Science, Oxford. **29**, 21-38

Hadie, L.A. (1967) The gypsum-anhydrite equilibrium at one atmosphere pressure. American Minerologist, **52,** 171-200.

Harris, N.B. (1989) Diagenetic quartz arenites and destruction of secondary porosity: an example from the Middle Jurassic Brent Sandstone of north west Europe. Geology, **17**, 361-364.

Hofmann, A., Tourani, A. & Gaupp, R. (2000) Cyclicity of Triassic to Lower Jurassic Continental red beds of the Argana Valley, Morocco: implications for palaeoclimate and basin evolution. Elsevier. Palaeogeography, Palaeoclimatology, Palaeoecology **161** (2000) 229-266.

Hofmann, A., Tourani, A., Gaupp, R. (1998).Cyclostratigraphic evolution of Triassic to Lower Jurassic continental red beds in a rift-basin setting (Argana Valley, Western Morocco). In: Eigenfield, F. (Ed.), Abstracts Epicontinental Triassic Jowett, E.C., Calthles; L.M. & Davis, B.W. (1993) Predicting the depth of gypsum dehydration in evaporitic sedimemtary basins. AAPG Bulletin, 77, 402-413.

Land, L. S., Milliken, K. L. and McBride, E. F. (1987) Diagenetic evolution of Cenozoic sandstones, Gulf of Mexico sedimentary basin: Sedimentary Geology, **50,** 195–225.

Medina, F. (1995) Syn- and postrift evolution of the El Jadida–Agadir basin (Morocco): constraints for the rifting models of the central Atlantic. Can. J. Earth Sci. **32,** 1273–1291.

Morad, S. [illegible] (2000) Spartial and temporal distribution of diagenetic alterations in Siliclastic rocks: implications for mass transfer in sedimentary basins. [illegible] 47 (Suppl. 1), 95–120.

Parry, W. T., Marjorie A. C., and Barbara P. N. (2009) Diagenetic characteristics of the Jurassic Navajo Sandstone in the Covenant oil field, central Utah thrust belt. AAPG Bulletin, **93,** (8) 1039–1061

Pettijohn, F. J., Potter, P. E., Siever, R. (1972) Sand and sandstone. Springer Verlag. 618

Salem, A.M., Morad, S., Mato, L.F., & Al-Aasm, I.S. (2000) Diagenesis and reservoir-quality evolution of fluvial sandstones during progressive burial and uplift: Evidence from the Upper Jurassic Boipeba Member, Recôncavo Basin, Northeastern Brazil. AAPG Bulletin, **84,** (7) (July 2000), P. 1015–1040.

Strong, G.E., 1993. Diagenesis of Sherwood Sandstone Group, Preston, Lancashire, UK: a possible evaporitic cement precursor to secondary porosity? In: North, C.p. & Prosser, D.J. (eds), 1993, Characterisation of Fluvial and Aeolian Reservoirs, Geological Society Special Publication No 73, pp 279-289.

Tixeront, M. (1973) Lithostratigraphie et mine´ralisation cuprif-e`res et uranife`res stratiformes syngenetiques et familie`res des formations detriques permo-triasiques du Couloir d'Argana (Haut-Atlas occidental, Maroc). Notes Serv. ge´ol. Maroc **249,** 147– 177.

Tucker, M. E. (1994) Sedimentary Petrology. Blackwell sci. publ. 260.

[illegible] Crone, (1978) Diagenesis in first cycle desert alluvium of Cenozoic age, southwestern United States and northwestern Mexico. Geological Society of America Bulletin, 89, 19–32.

Wilkinson, M., Milliken, K.L., & Haszeldine, R.S. (2001) Systematic destruction of K-feldspar in deeply buried rift and passive margin sandstones. Journal of Geological Society, London 158, 675–683.

Worden, R. H., and Morad, S. (2000) Quartz cementation in oil field sandstones: A review of the key controversies, in R. H. Worden and S. Morad, eds., Quartz cementation in sandstones: International Association of Sedimentologists Special Publication **29,** 1–20.

Worden, R.H. Mayall, M.J. & Evans, I.J. (1997) Predicting reservoir quality during exploration: Lithic grain porosity and permeability in Tertiary clastics of sounthern China Sea basin. In: petroleum geology of south east asia (Eds A.J Fraser, S. Mathews and & R.W Murphy) Spec. Publ. Geol. Soc. London **124,** 107-115.