Petroleum Res. J. Vol. 15 (2003); P. 33–48, 6 Figs.

Petrography of the Uppermost Bahi Formation in the West Az Zahrah (B) Field, Az Zahrah - Al Hufrah Platform, NW Sirt Basin, Libya

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بتروغرافية الجزء العلوي من تكوين الباهي بالمنطقة الغربية من حقل الظهرة (ب) بشمال غرب حوض سرت، ليبيا

مفتاح أحمد

يتراوح عمر تكوين الباهي بين المرحلة السينومانية والمرحلة الماسترختية، حيث تتواجد صخور هذا التكوين تحت السطح بمسطح الظهرة – الحفرة، بالجزء الغربي من حوض سرت. ترسب تكوين الباهي فوق تكوين الحفرة (القرقاف)، ويتناقص سمكه تدريجياً حتى يختفي فوق منطقة مرتفع الظهرة. أوضحت دراسة العينات اللبية وجود طبقات رملية متداخلة مع طبقات من طين ووجود بعض الرقائق الدولوماتية في بعض الأجزاء. يتميز أعلى الجزء العلوي من تكوين الباهي بكثرة وجود معدن الجلوكونايت وبمتوسط سمك يصل إلى 30 قدم (9 أمتار) مما يدعم تأثير الترسيب البحري في المنطقة.

بينت الإختبارات البتروغرافية أن هذه الصخور تتكون أساساً من حبيبات من معدن المرو وبمتوسط نسبة حجميه تصل إلى 76% كما يوجد معدن الفلدسبار بنسبة تصل إلى 22%، معظمها من النوع القلوي (أوثوكليس وميكروكلاين)، ونسبة أقل من بلاجوكليس (أوليوكلاس)، بينما يمثل الفتات الصخري ما نسبته 1.6% تقريباً من المكونات الأساسية للصخر، ونتيجة لذلك يمكن أن يصنف أعلى الجزء العلوي من تكوين الباهي بتحت رتبة الأركوزك إلى أركوزك. أما المعادن الثانوية المتمثلة في المايكا والبايرايت وأكاسيد الحيد والزركون والترمالين والروتايل والإلمانيت فتوجد بنسبة حجمية ضئيلة جداً.

توجد عدة أنواع من المعادن الطينية مثل: الكاولونايت، إلآيت والكلورايت، هذه بالإضافة إلى بعض المعادن اللاحمة مثل: الدولومايت والكالسايت والإنهيدرايت. وتسبب تواجد المعادن الطينية واللاحمة بين الحبيبات الرملية في تغير ملحوظ في مسامية الصخور موضع الدراسة.

Abstract : *The Bahi Formation is diachronous in age, range from Cenomanian to Maastrichtian, and occurs in the subsurface of the Az Zahrah – Al Hufrah Platform in the western part of the Sirt Basin. The Bahi Formation onlapping the Al Hufrah Formation /Gargaf Formation and wedged out against the Az Zahrah Palaeo-high area. The core samples from the studied wells record mainly sandstones units interbeded with shales and thin layers of dolomites in some parts. The uppermost portion of the formation is characterised by abundant glauconite, suggestive of a marine influence with an average thickness of about 30 feet (9 m). Petrographic* investigation *shows that the rock compositions of the uppermost Bahi Formation are mainly quartz with an average of 76%; feldspars make up to 22% mostly potassium feldspar (orthoclase and microcline) and minor*

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plagioclase (oligoclase) and rock fragments. The latter represent only 1.6% of the total rock framework composition, as a result the uppermost Bahi Formation is classified as subarkose to arkosic-arenites. Accessory minerals such as pyrite, mica, iron oxides, zircon tourmaline, rutile, ilmenite and apatite are present in a minor amount. Presence of several kinds of clay minerals such as kaolinite, illite, and chlorite, in additional to, other cements such as dolomite, calcite and anhydrite, forming and growing of these minerals in-between sand grains, caused a noticeable changes in the porosity of the studied part from the formation.

INTRODUCTION

The Bahi Formation is present in the subsurface of the northwestern margin of the Az Zahrah - Al Hufrah region. The formation consists of sandstones interbedded with shale and with thin laminae of dolomite in some intervals. It is unconformably underlain by Lower Palaeozoic quartzitic sandstone and in some areas by basement rocks. The formation is diachronous with Cretaceous sediments and in-turn overlain with the Late Cretaceous marine sediments or Tertiary sediments in some areas. The Bahi Formation is equivalent to a number of formations, Maragh Formation in Amal platform and Basal Upper Cretaceous sandstone in the Hameimat trough east of Sirt Basin. The formation age, ranges from Cenomanian to Maastrichtian (Baird, 1964). Barr and Weegar, (1972) studied the stratigraphy of the Bahi Formation in the Bahi oilfield and subdivided it into upper and lower units. The uppermost part of the upper unit is dominated by glauconite, which indicates marine environment. They have recorded, that the Bahi Formation deposits vary in thickness from a few feet to more than 400 feet, and are comprised of inter-bedded sandstones, siltstones, shales and conglomerate. Later work by Sghair, (1990 and 1996), presented a detailed petrographic description of the Bahi Formation in the Az Zahrah - Al Hufrah region, particularly in the Bahi field, and classified the Bahi Formation as subarkosic sandstone, cemented with carbonate and anhydrite and proposed that it was derived from reworking of craton basement and recycled sediments. All previously mentioned authors concluded that the formation is diachronous in age, and its bulk, initially, was as an alluvial and fluvial deposits, which passes into marine-influenced sediments in its uppermost part.

The area of study extends between Az Zahrah Palaeo-high at Az Zahrah "B" field to the east and Zallah trough to the west (Fig.1). Core samples were selected from the six bore holes: JJ1-32, Q1-32, LL1-32, FF1-32, II1-32 and MM1-32 (Table 1).

Detailed petrographical study for the uppermost Bahi Formation in the study area is presented. Several petrographical techniques are applied in studying the selected samples and polished thin sections, such as binocular and polarizing microscope examination, scanning electronic microscopy (SEM). The percentage of component minerals for each thin section was calculated using an automatic point counter. As a result, rock framework minerals, porosity, matrix and cement amounts and types were determined. Percentage contents are expressed in terms of total rock composition (TRC), and total rock framework grains (TRFW).

Table 1. Data base of the study wells; formation thickness, core lengths and number of samples of the uppermost Bahi Formation.

Well name	Subsea depth Bahi Fm	Thickness in ft.	Core length	Samples *
JJ1-32	-3740' to -3931'	191' (58 m)	10.5' (3.2m)	5
Q1-32	-3735' to -3870'	135' (41 m)	21' (6.5 m)	10
LL1-32	-3725' to -3930'	205' (62.5m)	15' (4.6 m)	8
FF1-32	-3723' to -3895'	172' (52.5m)	33' (10.0 m)	13
II1-32	-3777' to -3866'	89' (27.0 m)	35' (10.7 m)	13
MM1-32	-3768' to -3851'	83' (25.3 m)	30' (9.1 m)	11
* The total samples include; 2 samples dolomite and 2 samples shale from FF1 and LL1, and one shale sample from JJ1-32.				60

Geological Setting of the Bahi Formation

The Bahi Formation was penetrated in Concession 32 in the Bahi field area and some parts of the Az Zahrah region, in the northwestern part of the Sirt Basin on high structural area called the Az Zahrah – Al Hufrah Platform. The concession is topographically higher than the surrounding areas that border it to both west southwest and east northeast; the subsurface strata also show thin stratigraphic sections and shallow depths to basement relative to those preserved on both adjacent down thrown sides, the Zallah trough to the west southwest and the Maradah trough to the east northeast (Fig. 1).

The thickness of the Bahi Formation varies from a few feet to 400 feet (122 m). in the Bahi field area, and is about 200 feet (61 m) thick in the south western corner of the Concession -32, at the wells LL1 and FF1-32. It wedges out against the Az Zahrah Palaeo-high to the east at well B1-32 and B2-32 where the Bahi Formation was absent due to non-deposition or to exposing the region to strong erosional events (Figs. 2 and 3). As a result the formation is diachronous and is both overlain by/or equivalent to sediments ranging in ages from Cenomanian to Maastrichtian, or may be younger in some parts (Fig. 4).

PETROGRAPHY OF THE UPPERMOST BAHI FORMATION

General Lithology Description

The uppermost Bahi Formation sandstones are: whitish, grey, to light greenish in colour in hand specimen. They are fine to medium, occasionally coarse in grain size; sub-rounded to sub-angular, occasionally rounded or elongate-shaped grains; moderately to well sorted, but locally poorly sorted. They are moderate to well indurated. Some horizons display oriented grains, which may reflect the direction of flow during deposition. Clay-rich and carbonate-cemented units show random grain orientation with lack of primary porosity. The uppermost part of the sandstone units are thicker, coarser and highly porous with less interstitial clay.

The dominant mineral is quartz followed by feldspar with only minor amounts of rock fragments and micas. Phosphatic fragments and glauconite grains are also present in very small amounts at the upper contact boundary and sparsely within some clay-rich samples, but they are absent in the cleaner sandstone units.

Rock Framework Minerals Composition

Quartz

Both monocrystalline and polycrystalline quartz grains are present throughout the formation.

Monocrystalline quartz: is the most abundant framework mineral in the studied samples of the

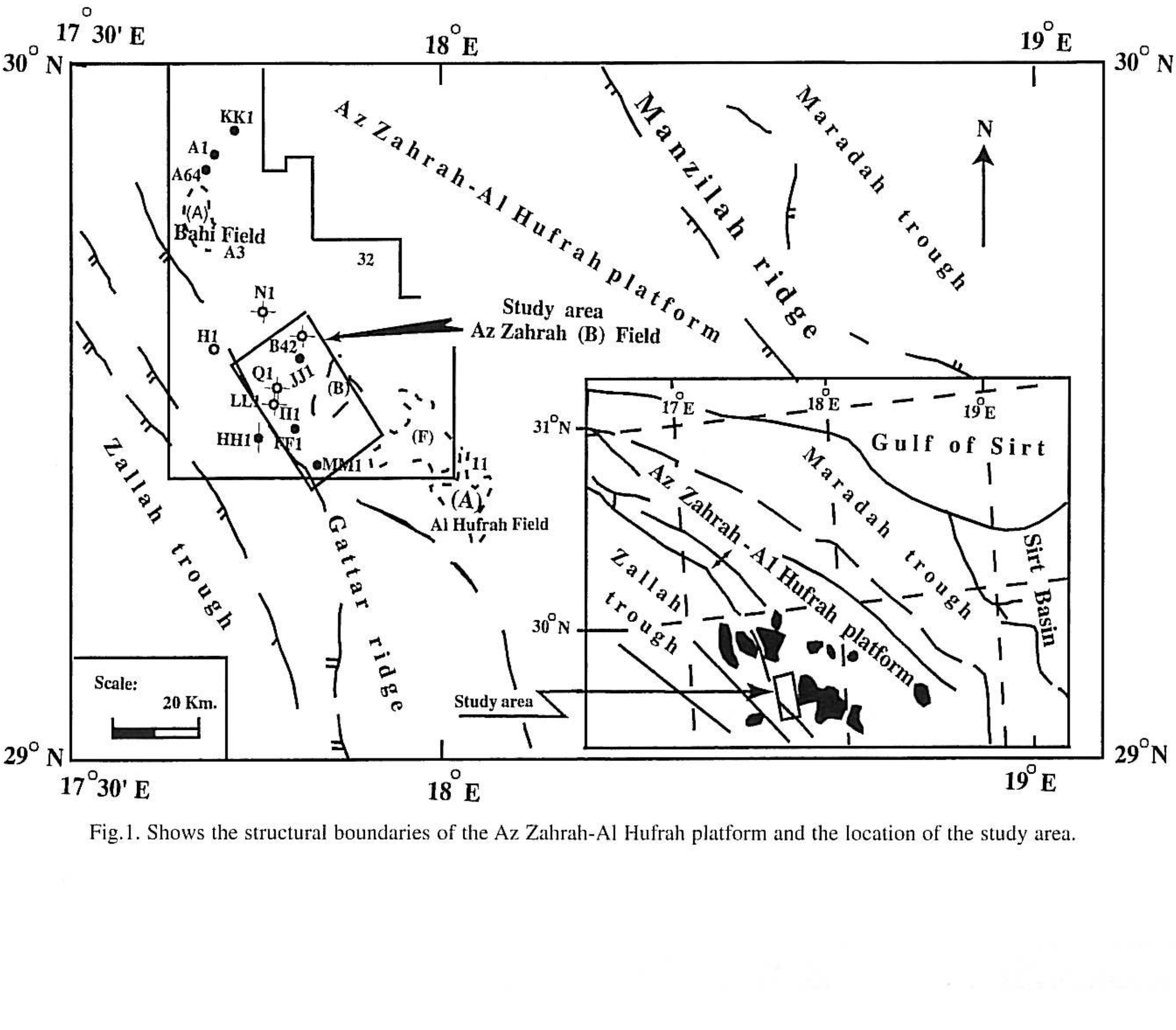


Fig.1. Shows the structural boundaries of the Az Zahrah-Al Hufrah platform and the location of the study area.

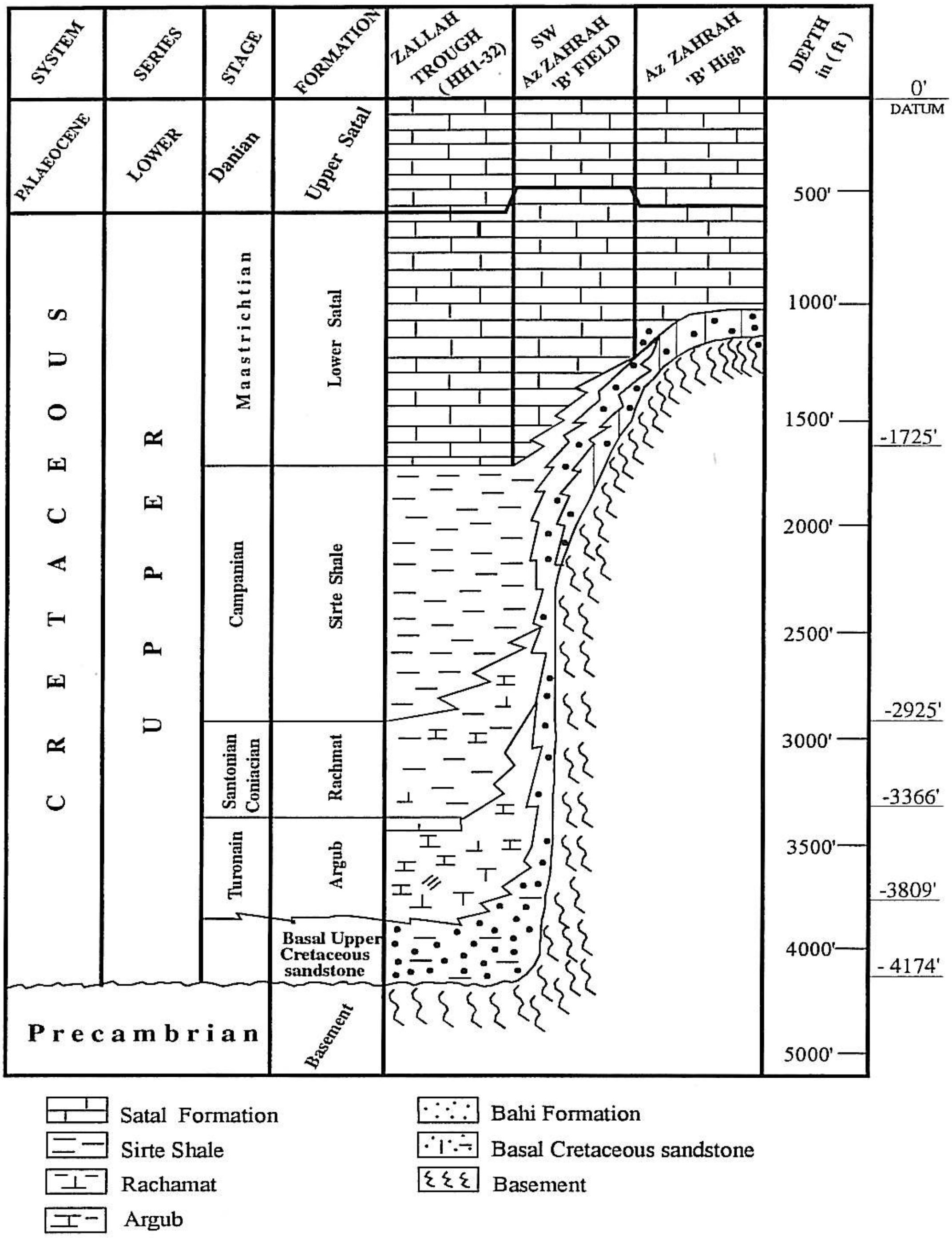


Fig. 2. Shows the correlation between the srtatigraphic columns of the Zallah trough (HH1-32), the SW Az Zahrah (B) field and the Az Zahrah palaeo-high at (B) field.

uppermost Bahi Formation. Table 2, shows the percentage range in each well and indicates that the average percent of total quartz ranges between 68.4 to 81.7%, with an average of 73.4% of the total framework. The grains typically display weak undulosity with rare grains that are moderately undulose. Straight extinction is also rare. Grains commonly contain trails of vacuoles and occasionally microlith inclusions of tourmaline and rutile.

Polycrystalline quartz: is present in the studied samples in minor content only making up 0.87 to 3.2% of the total rock composition with an average of 1.47% (Table 3). The uppermost Bahi Formation is characterized by fine to medium, occasionally coarse polycrystalline quartz. With increase in grain size the percentage of the polycrystalline quartz also increases, ranging from 4.99% of total framework grains in the coarse to

Table 2. Distribution of monocrystalline quartz (Qm) in the various wells (TRC; total rock composition. TRFW; total rock framework).

Well name	Qm % range (TRC)	Aver. (TRC)	Qm % range (TRFW)	Aver. (TRFW)
JJ1-32	47.7 to 55.7	52	73.72 to 87.03	81.7
Q1-32	20.7 to 61	43.3	58.46 to 87.71	75.42
LL1-32	33 to 41.7	37.1	63.64 to 74.86	68.44
II1-32	37.3 to 53.3	46.3	61.39 to 83.56	73.87
FF1-32	37 to 44	39.5	62.08 to 76.14	66.43
MM1-32	33 to 52	43.3	61.97 to 82.14	74.52
Aver. all	34.8 to 51.1	43.6	63.54 to 81.99	73.40

Table 3. Shows distribution of the polycrystalline in comparison with grain size (TRFW; total rock framework. TRC; total rock composition).

Well name	Grain size	Q Poly % (TRFW)	Q Poly % (TRC)	Chert % in (TRC)
JJ1-32	C to VC	4.99	3.2	0.3
Q1-32	C to V (CF-VF)	2.50.73	0.87	0.3
LL1-32	F-M	1.46	0.95	0.4
II1-32	F-V (FM-C)	1.182.9	1.19	0.13
FF1-32	F-M	2.37	1.36	0.1
MM1-32	F-VF (F-m)	1.381.17	0.73	0.2
Average		3.11	1.47	0.9

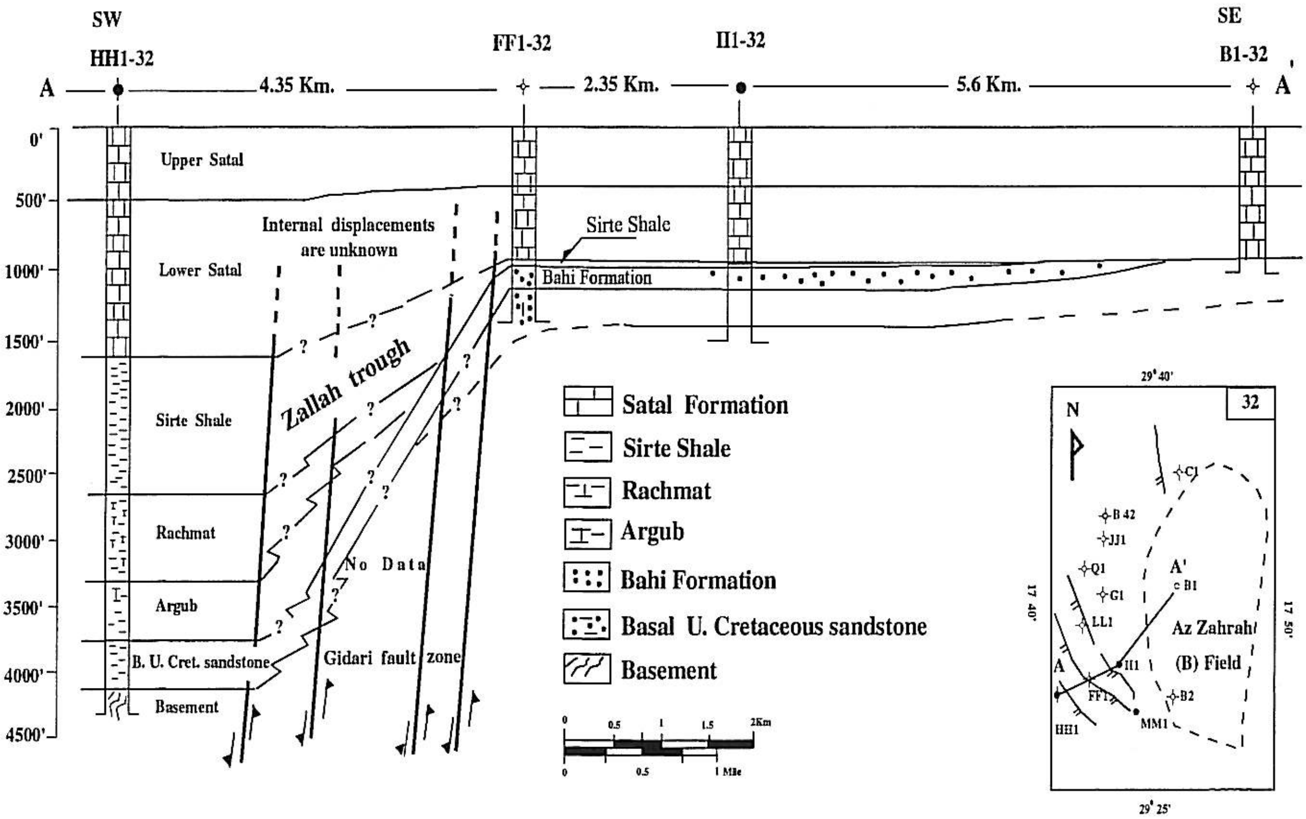


Fig. 3. Geological cross-section A A2 across the Zallah trough (HH1-32), the west of the Az Zahah (B) field (FF1-32 and II1-32) and the Az Zahrah palaeo-high (B1-32), indicates wedging out of the Bahi Formation against the Az Zahrah palaeo-high.

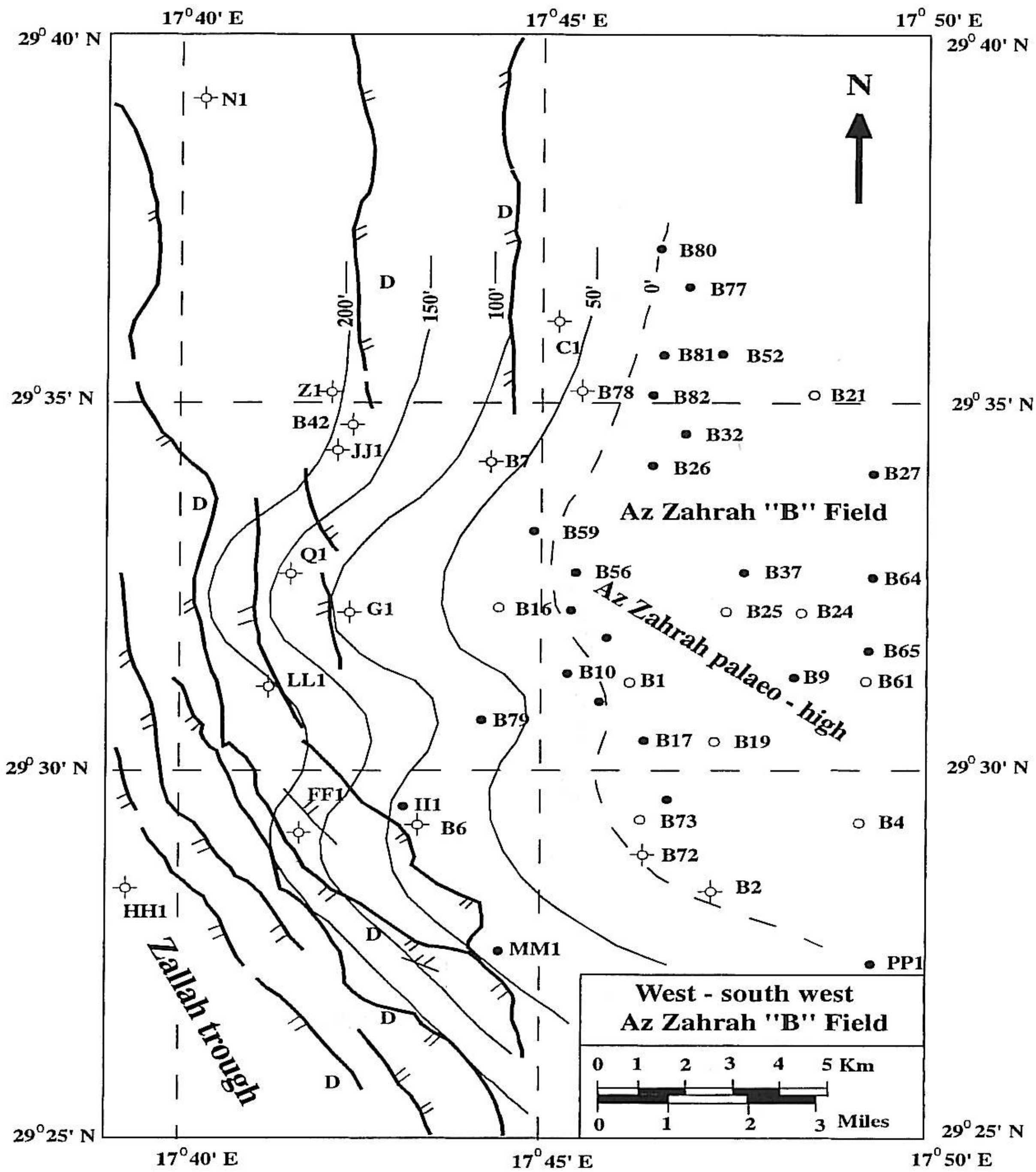


Fig. 4. Isopach map of the Bahi Formation western Sirt Basin, showing the wedging out of the formation against the Az Zahrah palaeo-high.

very coarse sands (JJ1-32), down to 1.17% in the finer sands (MM1-32).

Feldspars

The uppermost Bahi Formation framework mineral counts indicate that feldspar shows variation in amount, which is the inverse of the quartz content (Table 4) reflecting the fact that these are the two dominant minerals in the sandstones.

The average percentage of the total feldspars in the different wells of the total framework ranges between 11.48% in JJ1 to 30.37 % in FF1-32, with an average of 22.318%, (Table 4). Variation in feldspar content may be related to variation in grain size, percentage of primary cement and development of secondary porosity. At the same time, back-scattered electron image analysis shows that the percentage of the feldspar present is often higher than that established using point counting with the

Table 4. The uppermost Bahi Formation framework grains in percent, (total quartz; Qt, total feldspar; Ft, and total rock fragments; Lt).

Well name	Average % of Qt in (TRFW)	Average % of Ft in (TRFW)	Average% of Lt in (TRFW)	General classification
JJ1-32	87.08	11.48	1.45	sub-arkosic arenites
Q1-32	77.96	18.79	3.25	sub-arkosic arenites
LL1-32	70.82	28.18	0.99	arkosic arenites
II1-32	75.9	22.13	1.97	sub-arkosic arenites
FF1-32	68.65	30.37	0.98	arkosic arenites
MM1-32	76.16	22.96	0.88	sub-arkosic arenites
Average	76.096	22.318	1.586	sub-arkosic arenites

petrological microscope. This can be as high as 20 to 30% more in some samples. In fact it is possible that most of the samples are arkosic rather than subarkose according to the classification by (Pettijohn *et al.*, 1987). This highlights the difficulty experienced in identifying some of the feldspars, particularly unaltered orthoclase, which can be mistaken for quartz, and micro-size grains, which may be too small to count.

Plagioclase: is found in all samples in small amounts (Plate I -1); with average range of 0.6 to 1.7% of total rock volume.

Potassium Feldspar: is more chemically stable than plagioclase, and the most abundant feldspars, consist mainly of microcline and orthoclase (Plate I-2). The average percentage of potassium feldspar ranges from 6.03 to 17.03% of total rock volume.

Perthite: is also present, some of the perthite *sensu stricto* the lamellae are well defined (Plate I-3) whereas in the authigenic form the albite lamellae tend to be much more irregular and often grade into discrete patches or crystals of albite (Plate I-4). It is considered that the detrital perthite is rare in the samples whereas the authigenic form occurs in all cored intervals. Even so, the average percentage per rock volume in the studied samples is very low, and ranges from 0.18 to 0.37% of total rock volume.

Rock Fragments

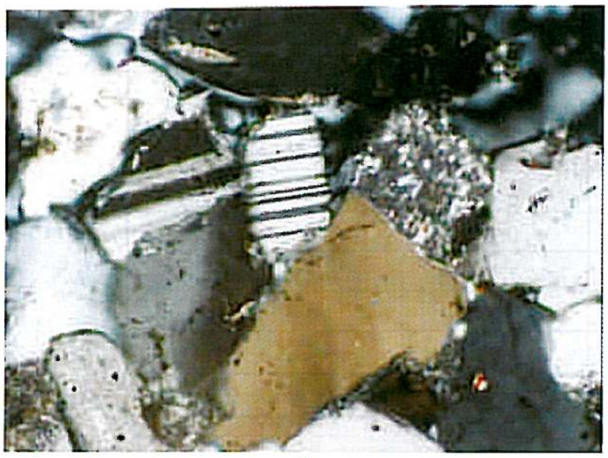
The rock fragments form only a small proportion, ranging between 0.49% to 1.96% with average of 0.97% of total rock volume, and between 0.49% to 3.25%, with average of 1.59% of total rock framework (Table 5).

The abundance of the rock fragments is clearly related to grain size; the coarse-grained sandstones contain more lithic fragments than the fine-grained sediments in which the fragments have been broken down to their individual components. The most common rock fragments are quartz grains with inclusions of stable non-opaque minerals such as tourmaline, zircon and rutile. These fragments could be igneous or metamorphic. The estimated percentage of this lithic type is about 40% of the total average of rock fragments.

Metamorphic Fragments: Polycrystalline quartz aggregates are fine to medium- grained and rarely coarse in size and display sutured,

Table 5. Framework percentage of samples in the study wells, (Qm; monocrystalline quartz, Ft; total feldspar, Lt; total rock fragments, L; rock fragments; igneous, metamorphic and sedimentary).

Well name	Qm % range (TRFW)	Ft % range (TRFW)	Lt % range (TRFW)	Aver. L % (TRC)	Aver. L % (TRFW)
JJ1-32	73.72 - 87.03%	7.09 - 19.63%	4.07 - 8.9%	0.93%	1.45%
Q1-32	58.46.- 87.71%	8.05 - 37.54%	1.16 - 11.44%	1.96%	3.25%
LL1-32	63.64 - 74.86%	20.29 - 33.27%	1.89 - 4.85%	0.55%	0.99%
II1-32	60.75.- 83.56%	10.17 - 35.05%	1.25 - 9.05%	1.26%	1.97%
FF1-32	53.66 - 76.14%	21.87 - 34.56%	1.04 - 5.97%	0.6%	0.98%
MM1	61.97 - 82.64%	16.5 - 35.06%	1.4 - 4.57%	0.49%	0.88%
Average	73.40%	20.73%	3.68%	0.97%	1.59%



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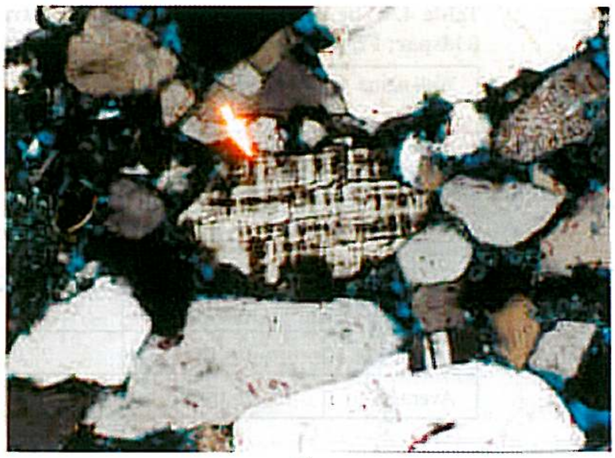

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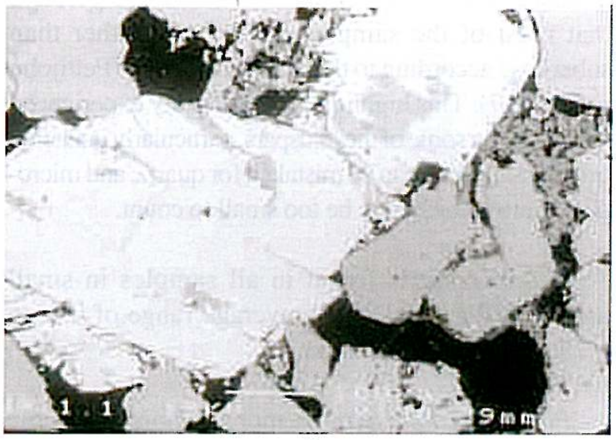

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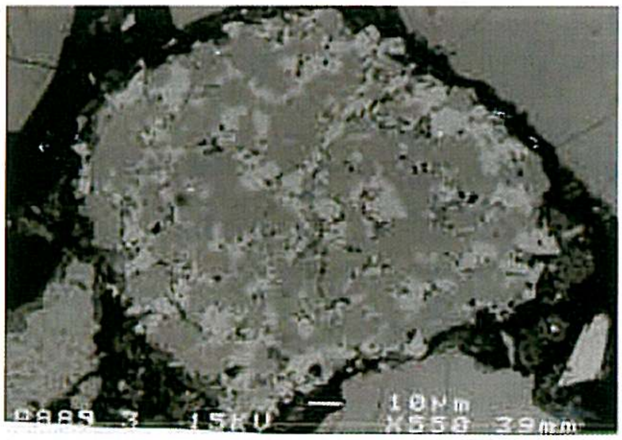

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Plate -I

Plate I-1. Fresh plagioclase with albite twinning (A), orthoclase: cloudy grain (O), MM1-32, 4645' (- 37402), 22' below formation top. Thin section XP x 20.

Plate I-2. Microcline feldspar showing cross-hatch twinning. MM1-32, 4737.5' (-3780.5'), 12.5' below top. Thin section XP x 10.

Plate I-3. Perthite: K-feldspar grain intergrowth with albite along cleavages. MM1-32, 4741' (-3783'), 26' below formation top. Thin section XP x 20.

Plate I-4. Perthite: K feldspar intergrowth with albite in patchy form. JJ1-32, 4921' (3740'), 12' below formation top. BSE.

Plate I-5. Polycrystalline rock fragments with elongated grains components and sutured grain boundaries. FF1-32, 4946' (-3699'), 22' below formation top. Thin section, XP x10.

Plate I-6. Igneous rock fragments: micrograph quartz: quartz intergrowth in mosaic texture with k-feldspare. Q1-32, 4889' , 3' below formation top. SEM (BSE).

crenulated internal grain boundaries (Plate I-5). Such grains, though they are rare, typically metamorphic in origin. These types of fragments make up about 15% of the total average lithic fragments in the studied samples.

Igneous Fragments: A few rock fragments were identified as igneous in origin. Some of these, identified by Back Scattered Image, are polycrystalline quartz with equant grains, granitic in character and consisting of a mosaic texture of about equal percentages of microcrystalline quartz and potassium feldspar (Plate I-6). Others display micrographic textures (Plate II-1) and still others show intergrowth of quartz and perthite (Plate II-2). These kind of fragments make up about 25% of the total rock fragments.

Sedimentary lithic fragments: They represented the major rock fragments detected in the samples, make up about 60 %, or more of the total average rock fragments. They are represented by detrital carbonate aggregate (Plate II-3), mudstone fragments, which are frequent in some sand sequences, especially near sandstone/shale contacts (Plate II-4). Siltstone aggregate (Plate II-5), and chert, which is frequently present in minor amount in some samples varying between 0.3 and 1% of total rock volume, and between 0.1 to 0.4 % of the total rock composition (Table 3) and (Plate II-6). Recycled quartz grains are those derived from older sandstones rather than igneous or metamorphic rocks, they can be distinguished from first generation grains by the degree of roundness and abraded overgrowth (Plate III-1).

Inter-framework Material

The average of the total inter-framework materials including (detrital and authigenic cements such as (calcite, pyrite and iron oxides) are ranged from 18.78 to 33.28%, with an average of 20% of the total rock composition.

Matrix: The uppermost Bahi Formation shows that the framework grains in some samples are found floating in the clay matrix in the clay-rich sandstones. Here the matrix is mainly clay and microcrystalline quartz with very fine feldspar grains (Plate III-2). This clay is contemporaneous with deposition of the sand-size grains or introduced soon after deposition. In some samples, matrix is patchy, which may be interpreted as squashed clay fragments. Clay minerals are detected by SEM and XRD techniques in the most of studied samples, which include kaolinite, illite and traces of chlorite (Fig. 5).

Accessory Minerals

The topmost of the upper Bahi Formation samples contain only very minor amounts of accessory

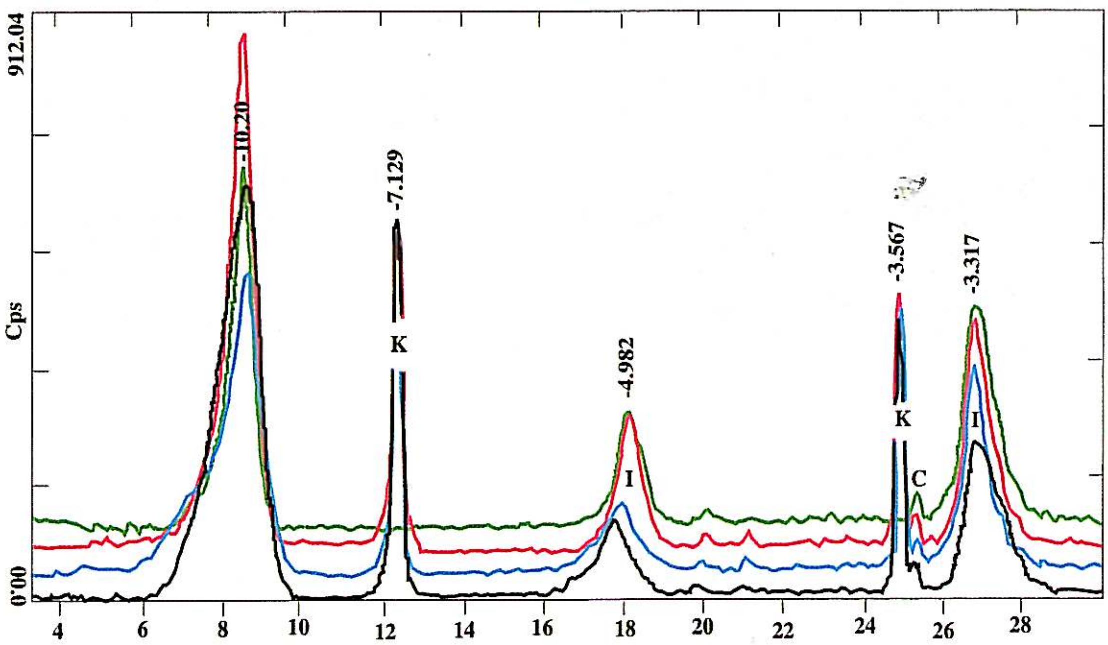

Fig. 5. XRD diffraction patterns of MM1-32, depth 4748', 23' below formation top. Displays illite(I), and kaolinite (K) and traces of chlorite (C). The sample treatment patterns are (black: air dried, blue: glycolation, pink: heating to 350° C and green: heating to 550° C).

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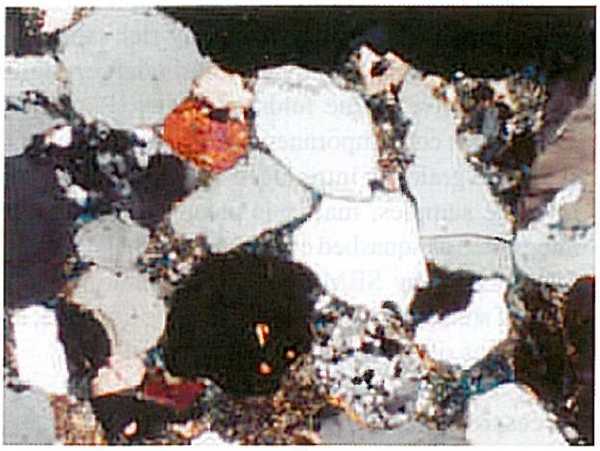

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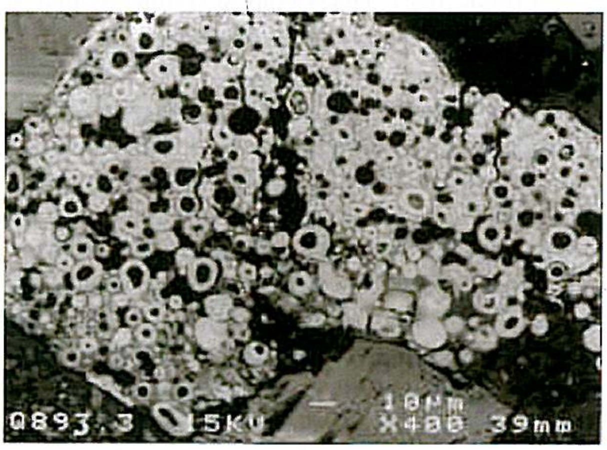

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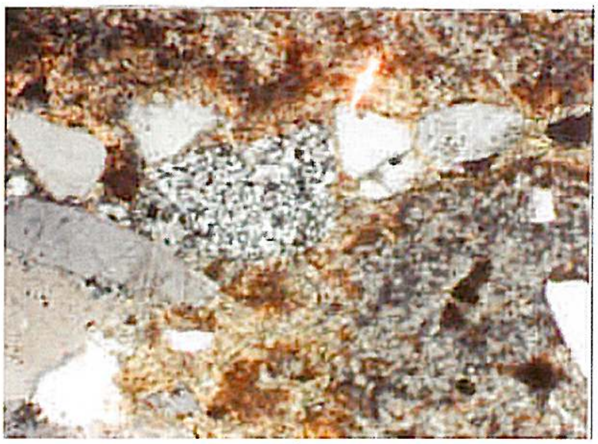

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Plate-II

Plate II-1. Micrographic quartz fragments, suggestive of igneous sources. MM1-32, 4753' (- 3796'), 28' below formation top. Thin section XP x 10.

Plate II-2. Perithite-quartz rock fragments, suggestive of igneous sources. MM1-32, 4753' (- 3796'), 28' below top. Thin section XP x 20.

Plate II-3. Phosphatic rock fragment of micro algae, displaying quasi-oolitic texture, marine sediment source. Q1-32, 4893' (-3742'), 7' below formation top. BSE.

Plate II-4. Clast of silty clay fragments within fine sandstone. FF1-32, 4635' (3730'), 12' below formation top. Thin section XP x 4.

Plate II-5. Siltstone rock fragments, well rounded grains. Q1-32, 4895' (-3747'), 4' below formation top. Thin section X P x 4.

Plate II-6. Chert rock fragments. Q1-32, 4907' (-3756'), 21' below formation top. Thin section XP x 10.

minerals: iron oxides, zircon, tourmaline and rutile with traces of apatite, glauconite, and ilmenite. They show percentage variations range from 0.56 to 1.08% of the total average rock composition.

Mica: Both mica types (muscovite and biotite) are present in the studied samples, as they are quickly removed from their sources (metamorphic or igneous), carried and deposited by various depositional processes in sediments.

Muscovite: is the dominant type of mica in the studied samples, especially in the fine sandstone and clay-rich sequences (Plate III-3). It varies in amount from one well to another; the average value range between 0.58 to 1.8%, with average of 1.31% of total rock volume. The general indication is that the percentage of muscovite mica flakes increases gradually with decreasing sample grain size.

Biotite: it is present as traces in the topmost of the upper Bahi Formation, mainly in the fine-grained sandstone and in clay-rich sequences (Plate III-4). It is rare in coarse grain size beds, high porosity zones, and in the carbonates cemented units. This could be related to strong diagenetic processes, which occurred in these types of sequences, or to hydraulic grain size/shape sorting and separation during transport.

Glauconite: it occurs in the uppermost part of the cores. In the well II1-32, at 4899 feet (1493.6 m); 4904 feet (1495 m) and 4907 feet (1496 m). In the well Q1-32, at depth 4913 feet (1497.8 m). It occurs in traces as small grains, especially in the clay-rich laminae (Plate III-5).

Heavy Minerals

Two different types of heavy minerals; non-opaque and opaque, were distinguished.

***Non-Opaque Minerals*:** The non-opaque minerals such as zircon, tourmaline, rutile and apatite are present in minor amounts or as traces in the cored intervals. Average percentages range from 0.38, to 1.23, 0.56% of the total rock composition, with an average of 0.77% of total rock composition.

Zircon: is the most abundant non-opaque heavy mineral, representing about 60 to 70% of the total percent of the non-opaque heavy minerals (Plate III-6).

Tourmaline: it makes up the second most common non-opaque mineral with an average ranging from 10 to 20% of the total. It is common as inclusions in quartz (Plate IV-1).

Rutile: is also present making up about 15 to 20% of the total non-opaque heavy minerals. It occurs as inclusions in quartz, as tiny single grains in the matrix and in between expanded mica flakes in association with kaolinite alteration (Plate IV-2).

Apatite: this is abundant in the contact zone between the Sirte Shale and the Bahi Formation where it replaces phosphatic fragments, and is also present as traces in the uppermost Bahi Formation samples (Plate IV-3).

Opaque Minerals: are such as iron oxides (heamatite, limonite and magnatite), which formed as a result of oxidation of detrital iron-rich grains during or after deposition. Pyrite which can be derived from dissolved of rich sulphide-iron minerals, or from seas or formations waters, this occasionally precipitates under reduction conditions in marine environments (Berner *et al.*, 1979). The uppermost Bahi Formation shows presence of pyrite, iron-oxides and traces of ilmenite.

Pyrite: Is found scattered in the most of the uppermost Bahi Formation with average range from 0.2 to 1.9%. Most of the wells samples are much the same value except for Q1-32, which shows very low content. These may be related to the depositional environments (Plates IV-4 and 5).

Iron Oxides: are widely spread, usually as coatings on the detrital grains or as authigenic cements; they include haematite and limonite. Haematite cement is present especially in middle and lower parts, which suggests continental depositional environments (Plate IV-6). The studied samples also show limonite, dark brown to yellowish in colour, coating the detrital grains especially in areas surrounding pyrite where it appears to be an alteration product (Plate IV-4). The total percentage of iron oxides is very minor ranging between .05 and 0.39% of the total rock composition. MM1-32 samples have the highest percentage distributed throughout some samples and appear to be absent from FF1 and LL1-32, well samples.

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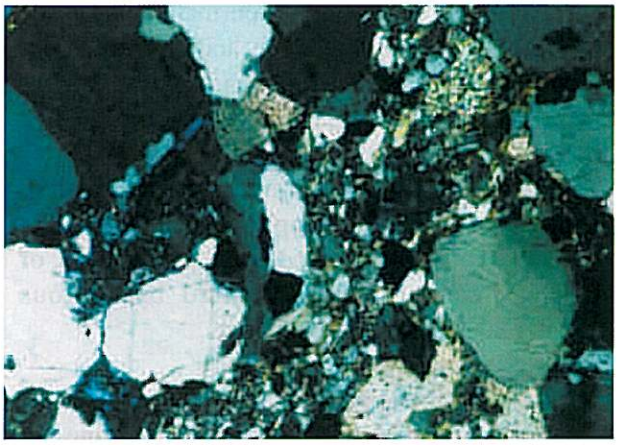

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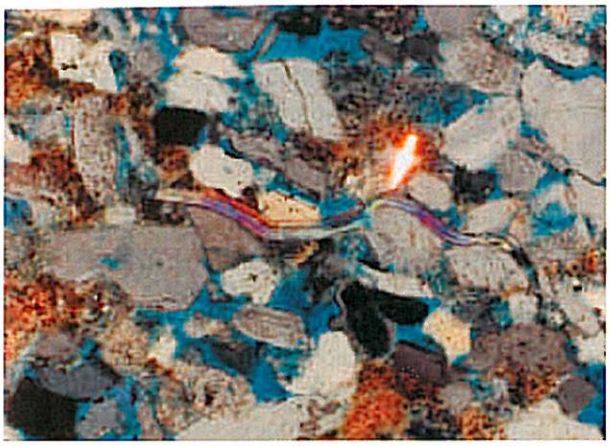

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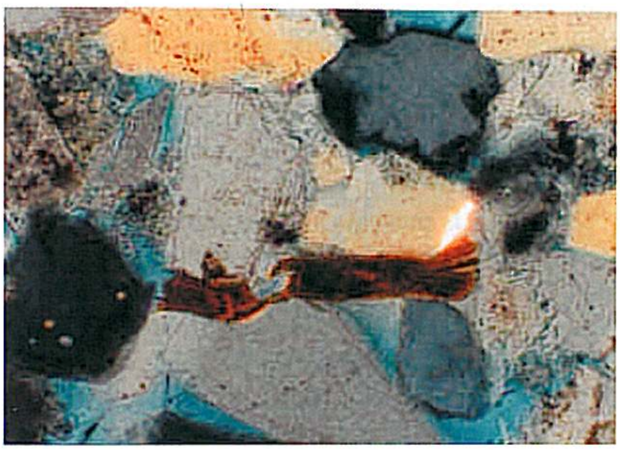

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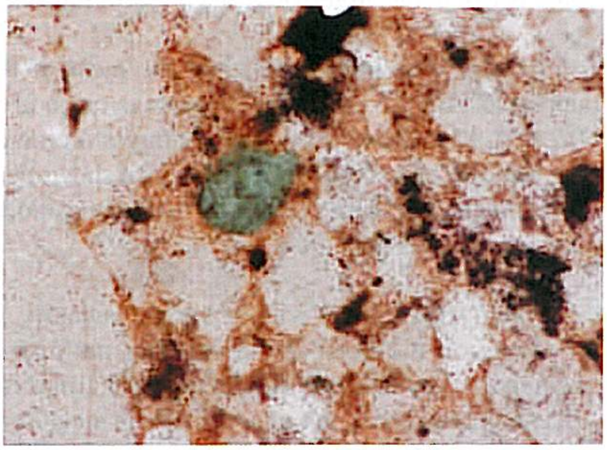

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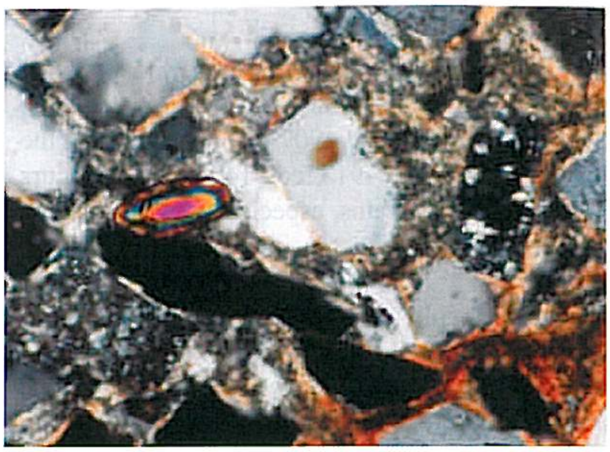

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Plate-III

Plate III-1. Well rounded quartz grains suggesting recycled older sedimentary sources, shows also authigenic quartz overgrowth and anhydrite cement. Q1-32, 4907' (-3756'). 21' below formation top. Thin section XP x 20.

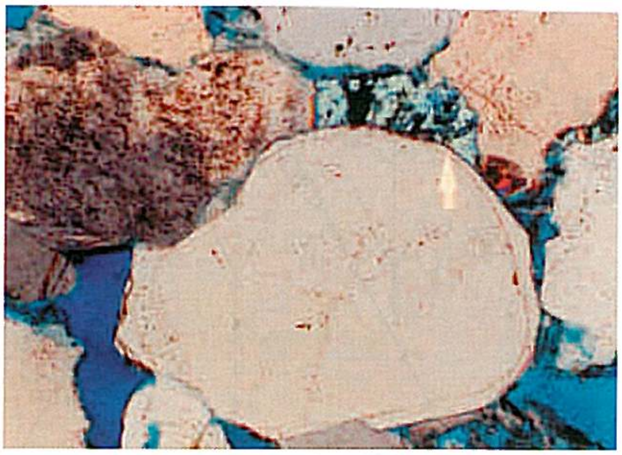
Plate III-2. Matrix and cements; very fine framework grains. Q1-32, 4886' (-3735'), at formation top. Thin section XP x20.

Plate III-3. Mica flakes bending in between detrital quartz grains due to sediments compaction. Q1-32, 4913' (-3762'), 27' below formation top. Thin section XP x10.

Plate III-4. Biotite flakes bending in between detrital grains. MM1-32, 4741' (-3784') 16' below formation top. Thin section XP x10.

Plate III-5. Glaoconite grain Q1-32, 4913' (-3762'), 27' below formation top. Thin section XP x20.

Plate III-6. Zoned zricon in subrounded crystal shape probably recycled. Q1-32, 4905' (-3754'), 19' below formation top. Thin section XP x10.



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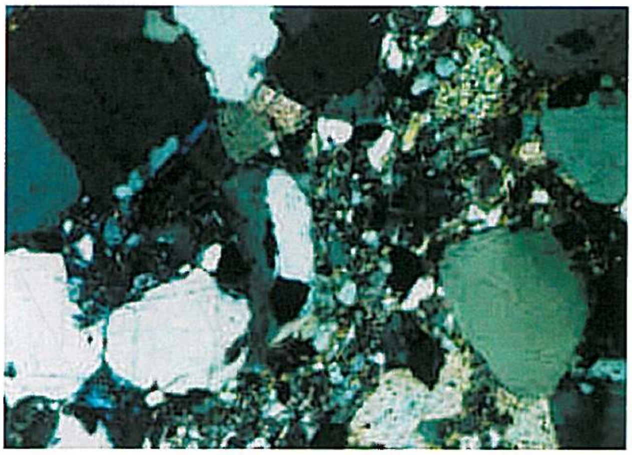

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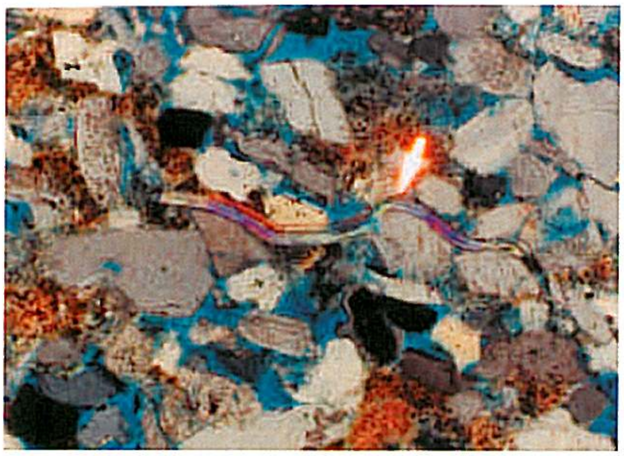

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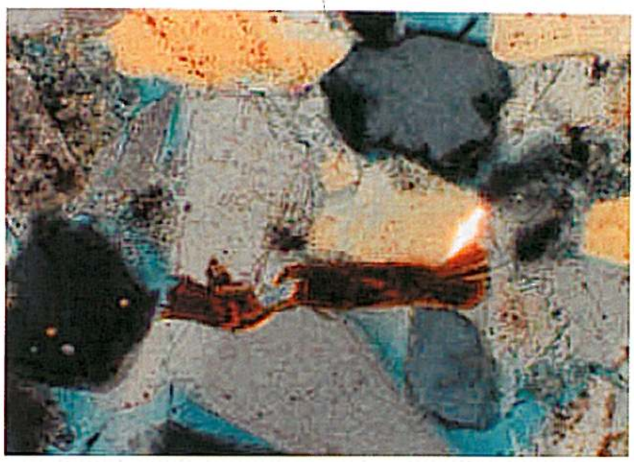

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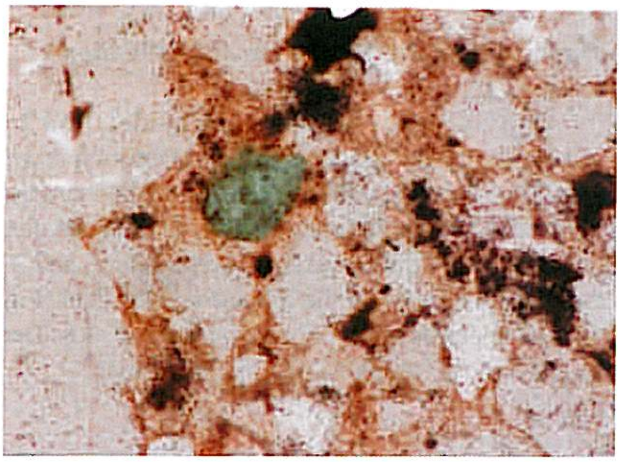

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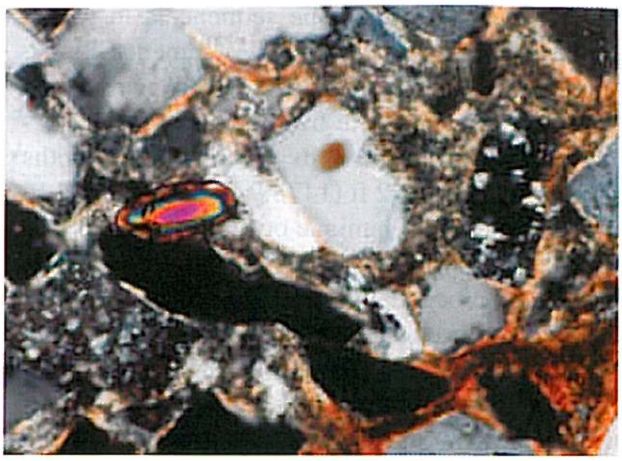

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Plate -IV

Plate IV-1. Tourmaline inclusion in quartz. Q1-32, 4889' (-3738'), 3' below formation top. Thin section XP x10.

Plate IV-2. Needle-shape rutile crystals inclusion in quartz grain. FF1-32, 4645' (-3740'), 22' below formation top. Thin section XP x10.

Plate IV-3. Phosphate – apatite fragment. LL1-32, 4850' (3740'), 15' below formation top. BSE.

Plate IV-4. Discontinuous laminae of pyrite and authigenic limonite. MM1-32, 4729.2' (-3772.2'), 4.2' below formation top. Thin section XP x20.

Plate IV-5. Authigenic formboidal pyrite. FF1-32, 4628' (-3723') at top. SEM.

Plate IV-6. Haematite cement locally precipitated between and around the detrital grains. Q1-32, 4895' (-37442), 9' below formation top. Thin section XP x20.

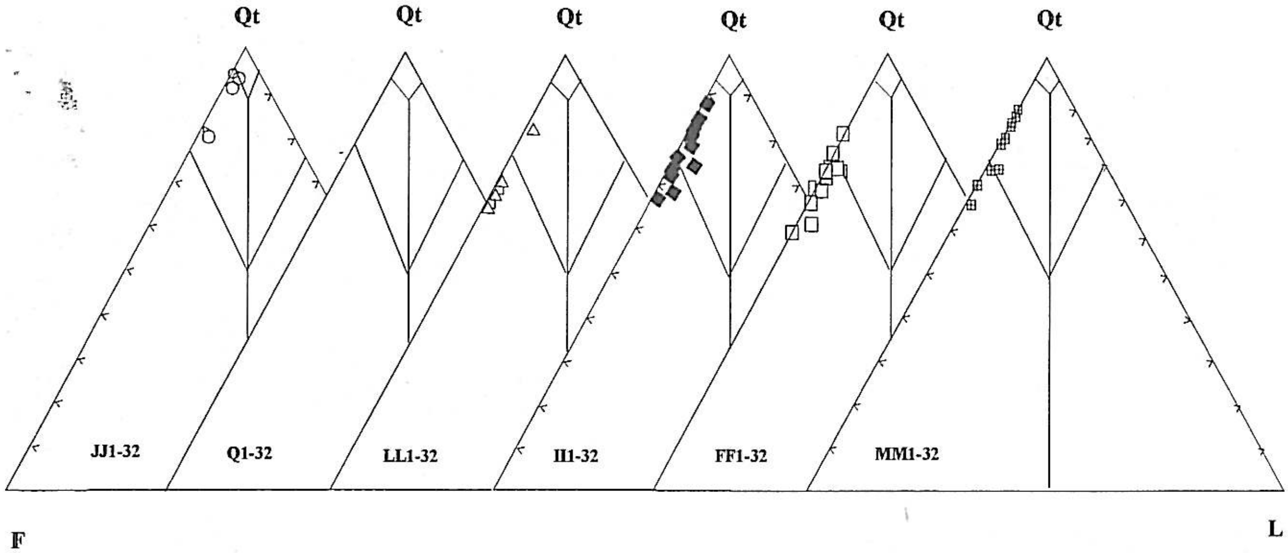


Fig. 6. QLF diagram (after Pettijohn, 1987). for the framework grain composition of the uppermost Bahi Formation samples from the study area wells (JJ1-32, Q1-32, LL1-32, II1-32, FF1-32 and MM1-32. All the samples fall within subarkosic and arkosic fields (Qt: total quartz, F: total feldspars, L: total rock fragments).

Ilmenite: It is present in traces as single and skeletal crystals (Plate V-1).

Dolomite-Rich Units

The uppermost Bahi Formation contains a few thin beds of dolomite and some sands rich in carbonate cement. The dolomite beds range in thickness from 2 to 4 inches (5-10 cm), inter-bedded with the sandstone sequences, in which carbonate (dolomite and calcite) cement fills the porespace between the framework grains and crystals. The dolomite beds occur in well LL1-32, two dolomite thin beds were noted at depths 4850.9 ft and 4852.2 ft (1478.9 and 1479.3 m). In well FF1 dolomite laminae occur at depth 4631 ft (1411.9 m). The dolomite in these thin beds is crypto to microcrystalline, showing almost idiotopic crystals textures with some xenotopic textures (Plate V-2). Widely dispersed, small patches of pyrite occur throughout the beds or as infills of fine fissures, quartz and feldspar grains are scattered through the beds.

Porosities

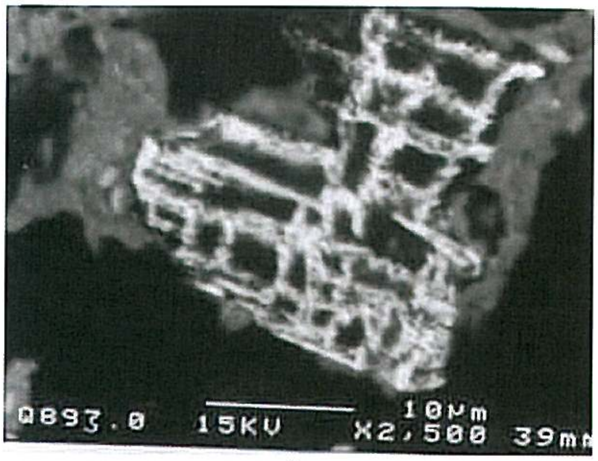
Primary Porosity is not easy to detect primary porosity in the upper Bahi Formation as the sediment has been subjected to a range of diagenetic processes. As a result primary porosity may have been completely plugged by authigenic cements precipitated on detrital grains with interlocking texture (Plate V-3), or by pore-filling cement, which may display detrital grains floating in cements such as in carbonate (Plate V-4). Partial reduction of primary porosity is indicated by precipitation of authigenic cements associated with free pore space (Plate V-5). Enlargement of primary porosity is indicated by alteration and dissolution of detrital grains and matrix (Plate V-6). These changes may be classified as secondary porosity.

Uppermost Bahi Formation Classification

Applying the classification model find by (McBride, 1963) and modified by (Pettijohn *et al.*, 1987), the uppermost Bahi Formation studied samples show that 32 samples out of 55 (58%) of the studied samples fall in the sub-arkosic arenite field, and 23 samples (42%) fall in the arkosic arenite field (Fig. 6). The uppermost Bahi Formation may be classified as sub-arkosic to arkosic-arenite sandstone.

CONCLUSION

The Bahi Formation consists of sandstone sequences interbedded with shale beds, the formation, subdivided to upper and lower units, was deposited mostly under continental conditions. The presence of glauconite in the uppermost part of the upper unit is suggestive of a marine influence. The petrographic investigations of the uppermost Bahi Formation leads to the following conclusions:



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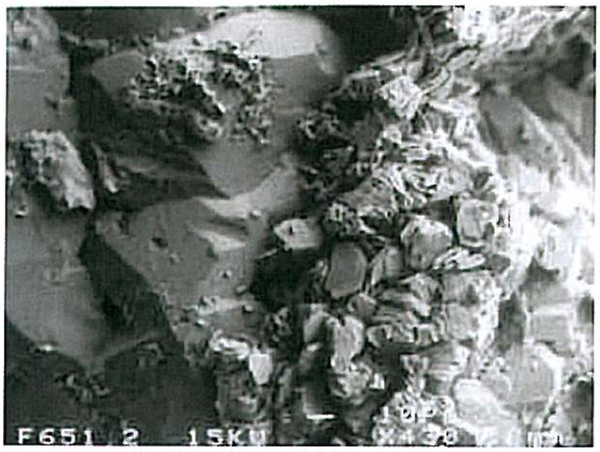

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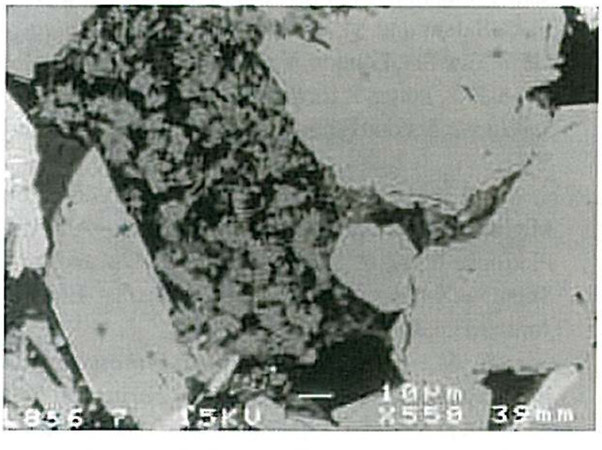

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Plate -V

Plate V-1. Ilmenite mineral structure Q1-32, 4893' (-3742'), 7' below formation top. SEM.

Plate V-2. Dense crypotcrystalline dolomite laminae with fissures filled with relatively coarser idiotopic dolomite crystals, partially replaced by authigenic pyrite. Q1-32, 4895' (-3744'). 9' below formation top. Thin section XPx4.

Plate V-3. Authigenic quartz overgrowth and kaolinite completely filling the pore space between the detrital grains. FF1-32, 4651' (-3746'), 23' below formation top. SEM.

Plate V-4. Framework grains floating in early poikilotopic calcite cement, shows corrosion of quartz grains margins. JJ1-32, 4824' (-3755'), 15' below formation top Thin section XP x 10.

Plate V-5. Authigenic kaolonite pore filling partially occupied part of intergranular porosity, LL1-32, 4856' (-3747'), 7' below formation top. BSE.

Plate V-6. Porosity enlargement due to dissolution of matrix and unstable grains. MM1-32, 4784' (- 3791'), 23' below formation top. Thin section XP x20.

Monocrystalline quartz is the dominant mineral in the uppermost Bahi Formation. It represents up to 76% of the total rock framework; feldspar minerals represent the second mineral represents about 22% and rock fragments display only minor percent. Main feldspar mineral is potassium feldspar (orthoclase and microcline), and less amounts of plagioclase (albite and oligoclase). Perthite grains are largely authigenic, with intergrowth in irregular and patchy forms rather than in a regular pattern within and parallel to the cleavages. In general SEM (BSE) investigation shows that the percentages of feldspars are much higher than the calculated percent by automatic Point Counter, these will affect the classification of the formation.

Rock fragments represent only a minor component, most of these are extrabasinal but some siltstone and mudstone fragments are almost certainly intraclasts formed as rip-up clasts from underlying beds. The presence of polycrystalline aggregates, and other rock fragment is highly controlled by grain size; coarse sandstones display higher percentage of coarsely crystalline fragments than the finer ones.

The common accessory minerals include mica (muscovite and biotite), non-opaque minerals (zircon, tourmaline and rutile); and opaque minerals (iron oxides and ilmenite) are present in trace amounts. The study shows only traces of glauconite, even though the cores are taken near or at the topmost of the upper Bahi Formation, which is described in the literature as glauconitic. The fact of low amount of glauconite in the samples can be related to diagenetic alteration processes. Glauconite is best seen in the well LL1-32 samples, where its presence, in addition to dolomite beds, support the idea that the uppermost part of the Bahi Formation was deposited in marine depositional environments and it is approximate thickness is about 30 feet. These show some differences from the pervious studies, which determined the thickness of these marine sediments with about 20 feet.

Matrix is well developed in some units and comprises a mix of clay minerals, fine grained quartz, feldspars and other minerals. Illite and kaolinite are the dominant clay minerals, whereas few samples indicate the presence of traces of chlorite. The primary porosity is hard to distinguish from the secondary porosity as the formation had been subjected to a complex diagenesis processes. As a result the uppermost Bahi Formation can be classified as subarkosic to arkosic - arenite.

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