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Sedimentological Analysis and Depositional Architecture of the Lower Cretaceous Fluvial Systems (Kiklah Formation), Western Jabal Nafusah, Northwest Libya

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Declaration

I declare that the work contained in this thesis was the result of my independent research except where otherwise stated.

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Abstract

The lower Cretaceous Fluvial system of Kiklah Formation, in western Jabal Nafusah, Northwest Libya, is unconformably overlaying the Jurassic sequence of Kabaw Formation. and unconformambly overlain by Upper Cretaceous (Ain tubi member of Sadi As Said Formation). A detailed sedimentological study was conducted where it focused in detailed analyses of the facies, sedimentary architecture elements, paleocurrent. and construction of depositional model. Nine lithofacies were identified Conglomerate channel (Gt), Trough crossed-stratified sandstone (St), Planar cross stratified sandstone (Sp), Ripple cross-laminated sand (Sr)), Horizontal bedding (Sh), Low-Angle cross bedded sandstone facies (Sl), laminated sand and mud (Fl), Massive Mud & silt (Fm), Paleosoil (P). These lithofacies forming the principle stone of five architectural elements where recognized in detail and interpreted from five localities, CH) channel-fill elements, (SB) sandy bedform elements, (DS) downstream accretion elements, (LA) lateral accretion elements and (OF) overbank elements. The proposed depositional model explains that the lower part of Kiklah Formation is deposited by distal braided type sheet flood, sand-bed River, and these are characteristic of distal plains, particularly in arid regions where ephemeral runoff forms a shallow network. The upper part of Kiklah Formation is deposits by sandy meandering river type Which characteristic The deposits contain numerous internal scour surfaces, and lithofacies Sh and Sl are abundant, indicating the common occurrence of high-energy, shallow flow near the transition from subcritical to supercritical. Mud drapes occur on second- and third-order surfaces. Based on petrographic analyses, textural properties, of the Kiklah Formation suggest that the sandstones are mainly quartz arenite with some subarkose and sublitharenite derived from the older sediments which are found in the south of the study area, especially the Jabal Nafusah represents form northern edge of Hamada basin which contains the large thickness of Triassic, Jurassic and Paleozoic clastic sequences and these were originally derived from the Precambrian terrains of the Hoggar, Tibesti and Gargaf uplifts. Diagenetic cement is mainly in the form of quartz overgrowths, and local Calcite cement. All of which have reduced the porosity. The average of total porosity for all the studied area about 20 – 30 %.

Chapter 1:
Introduction and Geological Background

Chapter 1: Introduction and Geological Background

1.1 Introduction and Previous work.

The Kiklah Formation is regionally well exposed along the Jabal Nafusah. The formation has been studied by different authors, was first described by Christie (1955) from the Gharyan area. Desio et al. (1963); El Hinnawy and Chestive (1975); Novovic,T. (1977); Burollet (1963); Hecht et al. (1964); Hammuda (1969); Goudarzi (1970), and El-Zouki, (1980b). The Formation consists of two major unites; the lower unit is granular rich sandstone, and the upper mudstone unit. The lower unite ranges in thickness from 30 to 45 m and increases gradually towards the west, it is composed of very friable and markedly cross-bedded coarse grained sandstone with granules, the sandstones sometimes stained red to dark brown but where fresh are yellow-white in color. The sandstones near the base is pebbly conglomerate (3m-thick), the middle and lower parts commonly ranges from medium to coarse grained and tend to be fine to very fine grained in the upper parts of this unite, often poorly to moderately sorted. The base of this unit usually contains, petrified wood fragments. The upper part of the Kiklah Formation comprises mainly of mudstone and gradually increases in thickness towards the west to abut 33m. This part is gradually increased in the silt percentage and includes of thin fine-grained sandstone lenses (El-Zouki, 1980). The age of Kiklah Formation is determined as Lower Cretaceous (Aptian to Albian age) by Novovic,T. (1977). The Kiklah Formation and its equivalents recorded a regional distribution throughout the northern Gondwana land which has very important hydrocarbon significance as a reservoir and source rock in the Sirt Basin (Equivalent to Nubian Formation).

1.1.1 Aims of this study

The objective of this study is to describe in details the various sedimentary facies in the outcrops along the western Jabal Nafausah NW libya which extended from arryaina village to Tunisian border in order to achieve an actual depositional architectural model of the Lower Cretaceous Fluvial Kiklah Formation. The principle steps to achieve the objective of this study are as follows:-

1- Field work study, which includes detailed sedimentological description of representative sections.

2- Collected about 100 Samples for laboratory investigations.

3- Correlation the outcrop-sections at (Arryaina, Gnawan, Kabaw, Al Mrabah and Wazen) to clarify the lateral facies extends and environmental variation throughout the study area.

4- Construction of the depositional model and facies architecture of the Formation within the study area.

1.1.2 Location of the study area

The study area is located on the western Jabal Nafusah, NW. Libya extending from Arryaina village to the Tunisian border and this area bounded by the coordinates of latitude of (31° 45´to 32° 05' N and longitude of 10°40´ to 12°30´ E). (Fig.1.1)

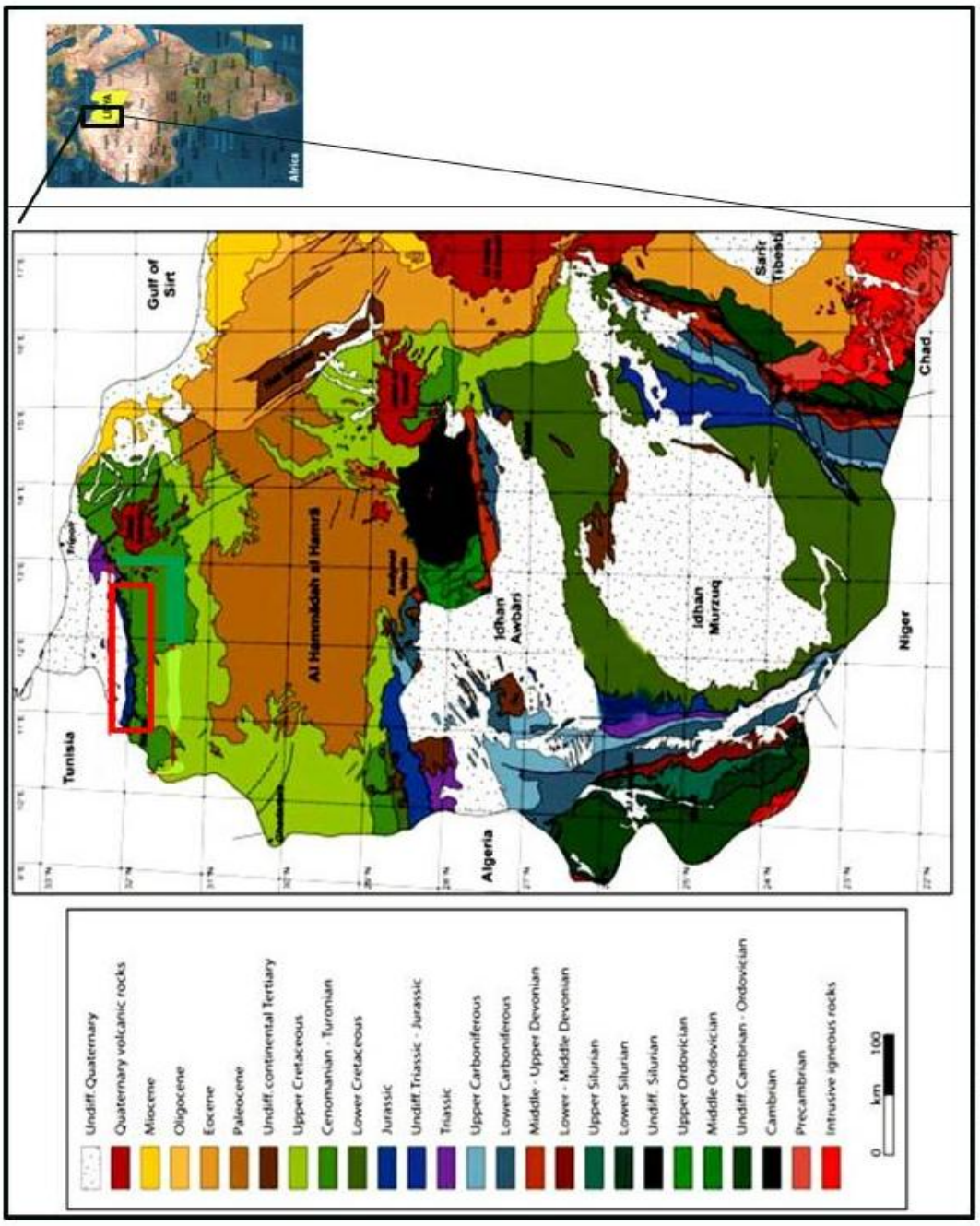


Fig 1.1 Geological Map of west Libya, showing the Location of the study area. By Industrial Research Centre

1.1.3 Methodology of study

Reconnaissance field trips were first organized to the outcrop area along the western Jabal Nafusah NW Libya, which extended from Arryaina village to the Tunisian border, to establish the ideal sections for sedimentology logging and sampling. About 5 field sections were selected and described sedimentologically where these sections represent Arryaina area (Arr), Genawan area (Gn), Kabaw area (Ka), Al Mrabah area (AlM), Wazen area (W) (Appendix 2). Reading and recording of grid reference defining data collection sites or field localities use UTM coordinate, derived from a Global Positioning System (GPS) and applied on the Geological maps of (Trabulus Sheet NI 33-13, Nalut Sheet NH 32-4, Mizdah Sheet NH33-1, Ras Ajdir Seet NI32-16), which published by Industrial Research Centre, (1977-1993). The sedimentological description started from the lower formation boundary unconformity just above the lacastrine facies of the uppermost part of Kabaw Formation. The outcrop sections are variable in thickness, ranging from 20 to 80 m-thick. Based on the format of sedimentological description presented by Tucker (2003) the studied sections include description of unit thickness, Grain size, textures, colour, sedimentary structures (e.g. cross-beds, ripples etc.), lithofacies, samples and the nature of bedding surface. The description scale was at 1:100 scales. Lithofacies, depositional environments and systems were described in details to document the depositional models. Outcrop photography frequently used to capture lithological details to illustrate lithofacies characteristics. All the data then transferred to Corel Draw X13 software to prepare posters for each section. (appendix 2). The outcrop sections are interpreted and stratigraphically correlated to show the lateral distribution, the geometry, and eventually the architecture of the various lithofacies of depositional environments.

The criteria used for defining the facies depend on Miall (1978) schema, which have been principally based on grain sizes and sedimentary structures and the geometry of sedimentary bodies. The codes used for facies also fellow with those used by Miall (1996).

Our analysis of the bounding Surface and sedimentary architecture generally follows the approach of Miall (1985 & 1996), but outcrop- scale features are described more simply for cleared by Bridge (1993). They were identified from studied outcrops and are indicated in general view. These general views were prepared as montages of

partly overlapping photographs taken from a distance of several tens of metres to avoid distortion. The facies and structural elements are indicated in the general view. Widths and thicknesses of the architectural elements were measured on the general view, and ratios of these dimensions are given. The relation of the actual width of an object to that measured on the general view. Construction of the architectural depositional model is used according to Miall (1985)

20 samples were collected from the five studied areas (Arr, Gn, Ka, AlM, & W) for petrographic study. These samples were selected to produce thin sections: 7 representative samples from Al M area, 6 from Ka area, 3 from Gn area, 3 from Arr area and only one from W area. The thin sections were blue dye impregnated to highlight porosity distribution and stained with potassium ferricyanide and alizarin red-S to assist in carbonates minerals differentiation. The thin sections were, investigated quantitatively using charts for visual estimation of constituents under the microscope, (modified from Terry and Chilingar 1955), also in order to determine the texture, occurrence habits, and paragenetic sequences among the diagenetic minerals.

1.1 Geological background

1.2.1 Gondwana Development during Mesozoic times

The collision between western Gondwana and Laurasia resulted in the formation of a supercontinent which included virtually all of the world's continental plates. This supercontinent, which was named Pangaea by Wegener in 1912, persisted until the Jurassic. The surrounding 'world ocean' was called Panthalassa (Figure 1.2). The collision involved a significant strike-slip component, and a major dextral shear-zone developed along the line of contact. The configuration of several of the Triassic basins along the North African margin is controlled by the pull-apart geometry propagated by the shear-zone (De Wit, et al. 1988). Pangaea, unlike Gondwana, was a relatively unstable assemblage. A large oceanic gulf (Palaeo-Tethys) extended deep into Pangaea from the east, along the line of the dextral shear zone, and from this gulf the Tethys Ocean ultimately developed. The gulf was occupied by oceanic crust which acted as a transit plate on which fragments of Gondwana were transported across the Palaeo-Tethys gulf and accreted onto the Siberian and Southeast Asian plates. This process was in operation during the early Permian and perhaps represents a continuation of the calving process which had operated in the same area during the

Palaeozoic. Even during Permian time rifting extended westwards from the gulf along the line of the Gondwana Laurasian suture, and oceanic crust was probably present as far west as the future eastern Mediterranean (Ricou, 1994 and Dercourt, et al, 1986).

1.2.2 Paleogeography, tectonic history and related sedimentation.

Break-up of Pangaea began in the Triassic. In Appalachia rift grabens are filled with late Triassic clastics, and in North Africa there is evidence of Triassic rifting in Tunisia and Libya. The North African continental margin at this time was characterized by extension and crustal thinning. In Algeria a blanket of Triassic fluvial sands and shale was deposited on the eroded Paleozoic surface and these sands are overlain by extensive evaporites, which in turn are overlain by shelf carbonates. This sequence illustrates a progressive deepening of the sea due to post-rift thermal subsidence. Break-apart also began in the late Triassic between the former components of East and West Gondwana, with rifting along the southern margin of the Arabian plate, and along the eastern margin of Africa (Ricou, 1994). The break-up of Pangaea involved the establishment of a spreading axis throughout the Mediterranean region. Associated igneous activity in Libya has been reported from the Waddan Platform (granodiorite 230 Ma) and from the Amal oilfield (granodiorite 207 Ma). These events correspond to the initial rifting phase in the Mediterranean region. Tensional faults of Triassic age are present both in offshore and onshore in Libya, and several unconformities are present within the Triassic succession. Evidence from eastern Libya shows the presence of Triassic sediments which may represent the earliest deposits in incipient syn-rift grabens. Triassic rocks are present in the offshore Libyan basins and thin onto the Jabal Nafusah Uplift which again marks the effective Tethyan shoreline. Over the rest of Libya Triassic rocks are almost entirely continental in character (Wilson and Guiraud, 1998).

1.2.3 Gondwana development and pale geography (The Development of Tethys)

There are abundant publications on the evolution of the Mediterranean sector of Tethys. the following review largely follows the work of (Dercourt and Ricou) in the early Jurassic, before the break through of Tethys in the Mediterranean region (Dercourt, et al. 1986)., Sea floor spreading in the Mediterranean began in the Bathonian Callovian with a spreading axis developing between the Briancon terrane (French Alps) to the north and the Austrian and Lombard terranes to the south.

(Dercourt, et al. 1986). In the western Mediterranean a spreading axis developed between the Iberian terrenes and the Morocco-Oran-Tunisian terrenes (Figure 1.2). In Tunisia the opening of the Tethys seaway induced a sinistral transtensional regime which broke up the Triassic and Jurassic platform sequences and produced flowage within the Triassic salt deposits (Morgan, et al. 1998). In Libya evidence of continental Jurassic is scarce, but the incipient rifts of the Triassic probably continued to develop. Jurassic rocks in the Jabal Nafusah have a more marine aspect than in the Triassic, but quickly pass into continental equivalents to the south (Banerjee, 1980). In Algeria evaporite deposition ended in the early Jurassic and was succeeded by a marine transgression which spread carbonates and shales over the platform margin (Boote, et al. 1998).

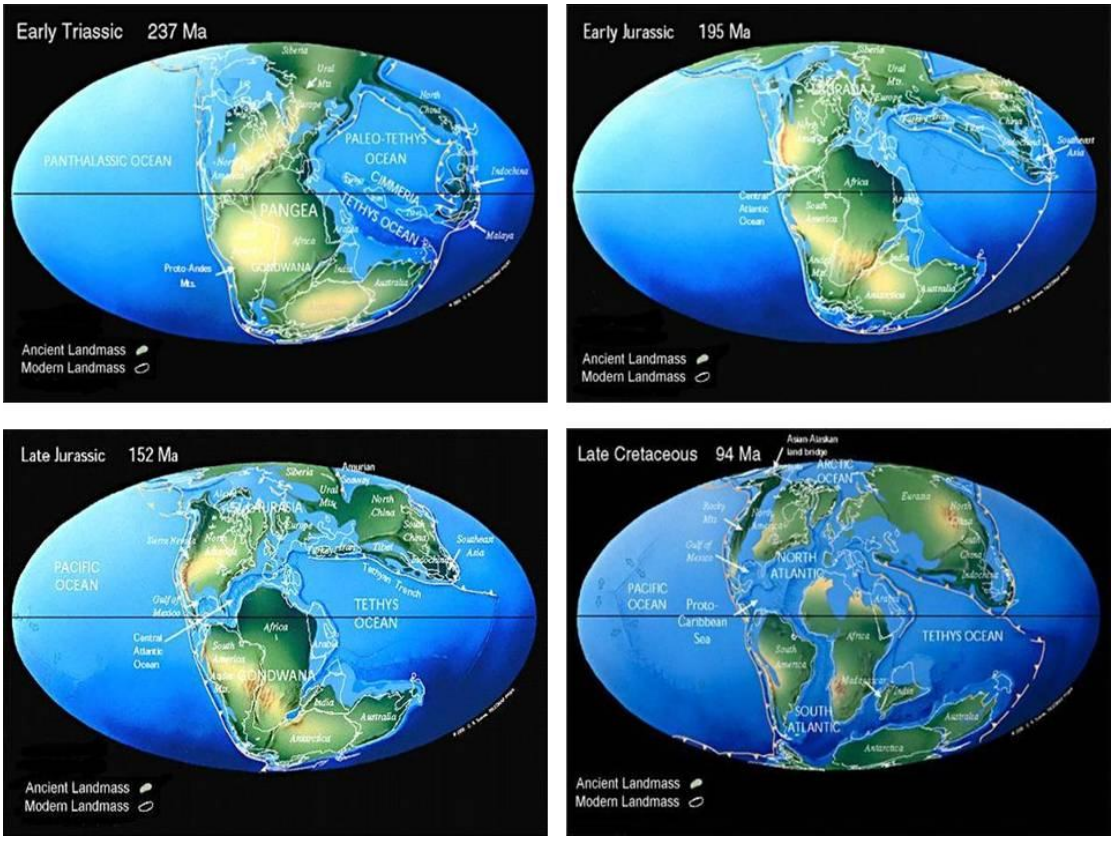


Fig. 1.2 Paleogeographic of the world in the, Early Triassic and early Jurassic & Late Cretaceous after C.R. Scotese, PALEOMAP Project'\'www.scotese.com).

The establishment of seafloor spreading in the central Atlantic in the early Cretaceous produced major changes in the Mediterranean segment of Tethys. The change from an ESE to an easterly drift of Africa relative to Europe induced a major shift in the

position of the main Mediterranean spreading axis (Figure 1.2). The former spreading axis in the Alpine region was obliterated by the northward movement of the Apulian plate comprising the Lombard. (Dercourt, et al. 1986). During the early Cretaceous the eastward displacement of Africa continued at a rate calculated by of about 2.5cm/year. There is evidence A of subsidence and pull-apart in the Hameimat and As Sarir troughs in the Neocomian and Barremian, and extensive areas of continental sands were deposited which form one of the most important hydrocarbon reservoirs in the country. Marine early Cretaceous rocks are limited to the northern margin of Libya. The stresses produced by the detachment of the Turkish, Balkan and Lombard terranes (Apulia Plate), (Gras and Thusu, 1998) active sea-floor spreading adjacent to the African margin, and the eastwards movement of Africa led to the stretching and collapse of the Sirt Arch in the mid-Cretaceous, and seaward tilting of the northern margin of the African plate (Figure 1.2). (El Makhrouf, 1996) The southern prong of the Apulia Plate may have originally been located In the Gulf of Sirt. The entire northern area of the Arch foundered to form the Sirt Basin, and a series of northwest-southeast horsts and grabens was established. Gulf of Sirt, the direction determined by shearing stresses along the northern margin of the African plate. Thermal sag led to marine conditions which flooded the basin, and by Cenomanian times much of northern Libya was covered by a shallow epicontinental sea. The syn-rift phase of tectonic development was brought to a close by the marine incursion, and the subsequent tectonic development can be assigned to the post-rift phase. Gulf of Sirt: Del Ben, 1991). And (Van Houten 1983) proposed a different explanation for the collapse of the Sirt Arch. He suggested that the collapse was caused by crustal thinning due to the region residing for a Long period of time over a fixed mantle hotspot.(Burke1977) proposed that the Sirt Basin represents the failed southern arm of a triple junction between the Eurasian, African and Tethyan plates. It has been suggested that the Sirt Basin itself could represent a triple junction formed by the northwestern trend of the Cretaceous horsts and grabens, the southwestern trend of the Abu Tumayam Trough and the eastwest trend of the Hameimat Trough, resulting from crustal thinning over a fixed mantle hotspot during the late Jurassic-early Cretaceous. These events are also reflected in magmatic activity in the Sirt Basin. Granite intrusions dated between 152 and 122 Ma (Tithonian to Aptian) and volcanic rocks from the interval 148 to 127 Ma correspond to this period. Magmatic activity increased in the late Cretaceous in response to extensive rifting and sinistral strike-slip

faulting on the offshore Pelagian Shelf. Volcanic rocks of Aptian to Paleocene age have been encountered in offshore wells, and in the Sirt Basin trachytes have been dated at 103 Ma (Albian). (Wilson and Guiraud 1998). In Libya the Cenomanian marine transgression was controlled by the rugged horst and graben topography left by the collapse of the Sirt Arch. Initially shallow marine rocks were deposited in the grabens, but as the transgression progressed deeper water conditions invaded the troughs whilst shallow water sediments gradually on lapped the horsts. It was in these troughs that the euxinic Sirt Shale was deposited, forming the source rock for most of the hydrocarbons in the Sirt Basin. Gentle uplift in western Libya led to a progressive with drawal of marine conditions from this area. The Turonian – Coniacian represents a tectonically quiet period, but in the Santonian a phase of compression, associated with the continued northeastward movement of the African plate, produced basin inversion in the Jabal Akhdar, (Guiraud, 1998) in the Atlas Mountains and in Egypt. Tension again became the dominant regime in the late Cretaceous along the southern margin of Tethys. By the end of the Cretaceous the grabens of the Sirt Basin had been largely in filled, and most of the horsts had been covered by shallow marine sediments, some of which form important hydrocarbon reservoirs. (Boote, et al. 1998)

1.2.4 Climate during Cretaceous

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 and Tornqivst, 2000). 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 to climate change and secondly how climate variations can be determined in the fluvial packages of the lower cretaceous of Kiklah formation. Globally, the climate during the Cretaceous Period, like the Jurassic and Triassic, was much warmer than today. Dinosaurs and palm trees were present north of the Antarctica and southern Australia. Though there may have been some at the poles during the Early Cretaceous, there were no large ice

caps at any time during the Mesozoic Era. These mild climatic conditions were in part due to the fact shallow seaways covered the continents during the Cretaceous. Warm water from the equatorial regions was also transported northward, warming the Polar Regions. These seaways also tended to make local climates milder, much like the modern Mediterranean Sea, which has an ameliorating effect on the climate of Europe. Shallow seaways covered the continents because sea level was 100 - 200 meters higher than today. Higher sea level was due, in part, to the creation of new rifts in the ocean basins that, displaced water onto the continents.

1.3 Presentation of Jefarah and Ghadamis Basin

1.3.1. Jifarah Basin

The Jifarah basin (Fig 1.3) is bounded by the Jifarah Fault and Nafusah Uplift to the south and the Sabratah-Cyrenaica fault system and Sabratah Basin to the north, and represents a down faulted terrace on the unstable continental margin. It underlies the Jifarah Plain and extends westwards into Tunisia north of the Dahar Uplift it is covering an area of 15,000 Km², more than half of which is in Tunisia, (Echikh, 1998). The stratigraphy extending from Paleozoic to Jurassic in age, overlain by a thick Miocene cover. The Mesozoic basin -fill of the Jifarah Basin was affected by syn-depositional faulting during the Triassic and by shearing during the Neocomian which reflect major tectonic activity along the southern margin of Tethys. Anketell and Ghellali (1991) demonstrated that the dominant fault directions in the Mesozoic section are east-west and NNW-SSE with an echelon arrangement which they interpreted as riedel shears and imbricte fan splays formed as a result of strike-slip movement on the South Atlas-Jifarah dislocation. They developed a model which suggested an analogy between the imbrica fan splays visible in the Wadi Ghan area south of AI Aziziyah with the strikingly similar fault trends in the Sirt Basin, and attributed both to strike-slip faulting associated with underlying basement dislocations. Sedimentation continued until the Palaeocene, but the basin was caught up in the Eocene tectonism which reactivated the Nafusah Arch and introduced a new generation of faulting in the Jifarah Basin. Extensive pre-Miocene erosion removed much of the Mesozoic sediments from the basin, and the pre-Miocene subcrop shows a complex pattern. Wells show Miocene rocks resting on Lower Jurassic Bir al Ghanam Formation, whereas water wells to the west of well Al-131 show Miocene rocks resting on Middle Triassic Kurrush Formation. By comparison, on the Nafusah escarpment south of the Jifarah Fault, almost the entire early Mesozoic sequence is preserved since the beginning of the Miocene the basin has been subsiding towards the north. (Kruseman and Floegel, 1980)

1.3.2 Ghadames Basin

The Ghadames Basin (Fig. 1.3), like the AI Kufrah and Murzuq Basins, is a large intracratonic sag basin developed on the passive northern margin of Gondwana. It

covers an area of 350,000 km², with the basin centre located in Algeria.The Libyan portion represents the eastern flank of the basin, rising towards the Tripoli-Tibisti Uplift, with a small sub-basin, the Zamzam Depression extending towards Misratah. The basin contains up to 6000 m of the basin fill in Algeria, but not more than 5200 m in Libya. The basin is bounded in the west by the Amguid -El Biod Uplift in Algeria, to the south by the Hoggar Massif in Algeria and the Gargaf Arch in Libya, and to the north by the Dahar-Nafusah Uplift. To the east the basin wedges out beneath the western part of the Sirt Basin.The most conspicuous feature of the basin is the Hercynian unconformity which truncates the Paleozoic succession and is overlain by a Mesozoic basin (the Hamadah Basin in Libya) with a markedly different basin configuration to that of the Paleozoic. The tectonic history of the basin has some similarities with the Murzuq Basin. (Echikh, 1998),

1.3.3 Al Qarqaf Arch

Al Qarqaf Arch (Fig.1.3) is a conspicuous WSW-ENE structural feature separating the Murzuq Basin from the Ghadamis Basin. It covers an area of 25,000km at outcrop and its core is formed by the Jabal Hasawnah, rising to an elevation of 800m. The present-day structure of the arch shows a major uplift (but not a horst) which exposes Paleozoic and Precambrian rocks at an elevation of +800m, compared with a depth to basement of -5180m in the Ghadamis Basin to the north. Well evidence shows that the Arch plunges in the subsurface both to the southwest and northeast. The arch is on lapped by Ordovician rocks on the western plunging nose and by late Devonian rocks on the southern flank. The Northern flank is concealed beneath a Cretaceous cover. Outcrop and photogeological studies show a fault and fracture pattern with a dominant WSW-ESE trend. Five small inliers of Precambrian basement are present on Jabal Hasawnah. These comprise anorogenic granites and low grade metasediments, which have been dated as Pan-African (551 to 476 Ma). Both the granites and metasediments retain evidence of early Proterozoic relict ages. (Oun, et al. 2000). Paleozoic sediments deposited in the area expose variable situation of Al Qarqaf Arch where it is suggest that Al Qarqaf was not positive feature during the early Paleozoic. Its situation changed into complicated by the mid to late Paleozoic where it probably continued to influence sedimentation to the present day.

1.3.4 Nafusah Uplift

The Nafusah Uplift (Fig.1.3) is a major east-west ridge which separates the Ghadamis Basin from the Jifarah Basin. It extends for 400 km from Misratah to the Tunisian border, and continues in Tunisia as the Dahar Uplift and in Algeria as the Talemzane Arch. It is bounded to the north by the Jifarah Fault and the Jifarah Basin and to the south by the Ghadamis Basin. The southern margin is also partially faulted. During the early Palaeozoic the area of the Nafusah Uplift formed part of the Ghadamis Basin and a thick sequence of Palaeozoic rocks was deposited. (Echikh, 1998),

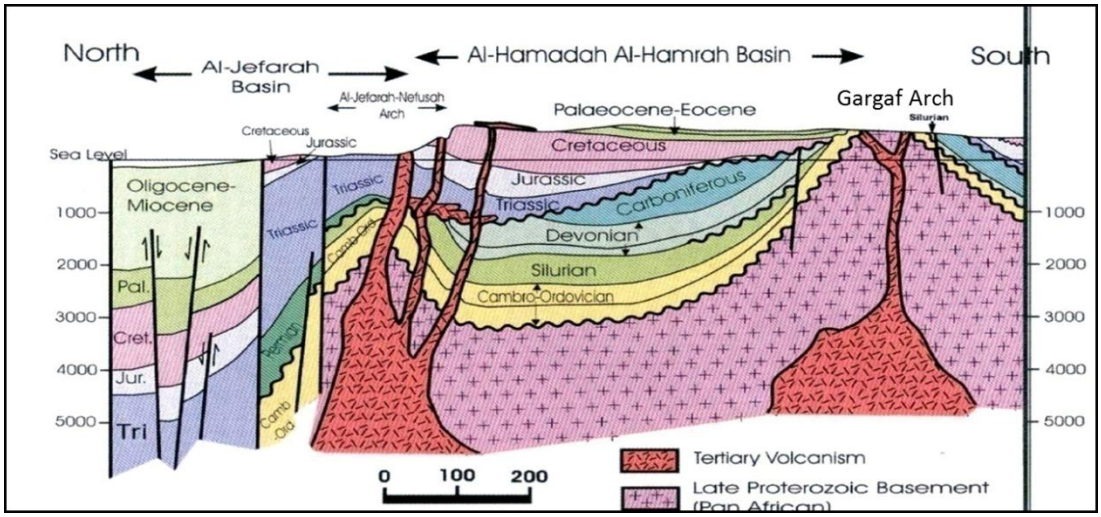


Figure 1.3 N-S cross-section showing the sedimentary sequence within Al-Hamadah Al-hamrah, Jefarah and offshore basins, NW Libya (Boot, 1998).

During the Permian the Nafusah Uplift formed a barrier between the marine sequences of the Tethys Ocean to the north and the Continental Post Tassilien rocks to the south. By Triassic times the arch had been greatly reduced in elevation and Triassic, Jurassic and early Cretaceous sediments were deposited over the arch and into the Mesozoic Hamadah Basin to the south. The arch was covered by the Cenomanian transgression and deposition of marine rocks continued until Eocene times (Singh, 1980). The Nafusah Arch was reactivated during the mid-Tertiary in response to the closing of Tethys. It was subjected to uplift accompanied by wrench faulting on the Jifarah Fault (Figure 1.3). Dextral strike-slip faulting can be seen at several locations along the line of the fault. Eocene tectonism also led to the

production of basaltic sills and flows near Gharyan, and the volcanic activity has continued until recent times. A major escarpment formed along the line of the Jifarah Fault and Jurassic and Triassic rocks outcrop both on the escarpment and on the Jifarah Plain. (Anketell and Ghellali, 1991)

1.3.5 Evoluation of the Ghadamis Basin during Phanerzoic times.

The Palaeozoic history of the basin was controlled by the northwest-southeast Pan-African tectonic trend, although little evidence of this has come to light due to the thickness of the overlying sediments The basin narrows southwards, confined between the Tripoli-Tibisti Tihamboka Uplift, into the Murzuq Basin. To the east the Palaeozoic section pinches-out against the Tripoli-Tibisti Uplift, but to the west the Tihemboka Uplift did not extend further north, and the basin widened into a broad depocentre extending into Tunisia and Algeria west of the Tihemboka Uplift. Basement in much of this area is formed by Pharusian accreted terranes, but further south, and particularly in the Illizi Basin of Algeria, it is represented by rocks of the Pan-African remobilized belt (Klitzsch, 1971). The final pulses of Pan African tectonism continued into the Ordovician. During Landeilian times, uplift and erosion occurred on the Tihemboka Arch and the Ahara Uplift in Algeria, and during the Caradocian, folding, faulting, uplift and erosion occurred which removed much of the early and middle Ordovician section on the Dahar Uplift in Tunisia. It was onto this irregular surface that the Late Ordovician ice-sheet encroached from the south. Volcanic rocks were produced during these final tectonic phases which have been penetrated in several wells in the eastern Illizi Basin. (Vail, 1991) Tanzuft shales were deposited throughout the basin; Early Devonian tectonic activity led to uplift and erosion of the Akakus Formation over large parts the basin. This is evident from well evidence in the Illizi Basin where only the Lower Akakus Sandstone is preserved, and similar truncation has been recorded in Libya. Folding of this age is evident on the Kabir trend, in Libya where early Devonian sandstones unconformably overlie folded Akakus sands, Awaynat Wanin Formation present in the southern Ghadamis Basin (Echikh 1998) Over most of the Ghadames Basin rocks of Tournaisian age are absent and in the Illizi Basin there is evidence of thickness variations and erosion on the northwest flank of the Tihemboka Uplift which indicate continued tectonic activity during the early Carboniferous. The Hercynian orogeny reached its peak during the Late Carboniferous and major new tectonic elements were formed,

including the Qargaf and Nafusah Uplifts in Libya, the Dahar Arch in Tunisia and the Talemzane and El Biod Arches in Algeria. The entire area was uplifted and subjected to intens erosion during the Permian which left the basin surrounded by highs which, in the case of the Nafusah and Qarqaf Arches, were eroded to their Cambro-Ordovician Rocks. Where a complete section up to Late Carboniferous is preserved. Within the Libyan part of the basin structural trends with a northeast- southwest alignment were formed during the Hercynian upheaval. (Echikh, 1998) Thick successions of Mesozoic continental deposits, including Triassic sandstones and evaporites, were deposited in the post Hercynian sag basin (Known as the Triassic Basin in Algeria and the Hamadah Basin in Libya) in which the depocentre was located much further north than during the Paleozoic. Jurassic transgressive sequences are followed by an early Cretaceous regression which was terminated by deformation during the Aptian related to the opening of the Mediterranean Sea spreading axis in the southern Tethys. Wrenching and uplift of Aptian age has been reported from the Illizi Basin and the Tihemboka Uplift was reactivated faulted and uplifted. (Echikh, 1998) A major marine transgression followed the Aptian deformation in which late Cretaceous and Palaeocene sediments spread as far south as the Qarqaf Arch, but thereafter the area was gently uplifted and tilted and has been emergent since the mid-Palaeocene. In Algeria and Tunisia the Atlas Basin was inverted in the early Eocene as the western Tethys closed, culminating in thrusting and nappe formation as the Kabylie terrane was welded onto the African plate during the Miocene. This fold belt forms the northern margin of the Ghadamis Basin in Algeria. Dercourt, et al. 1986

1.4 Mesozoic lithostratigraphy in Northwestern Libya

The Mesozoic strata outcrop in northwestern Libya and south-eastern Tunisia (Fig1.4) where an almost complete sequence from Triassic to Cretaceous is known, one of the few areas in the whole African continent, in northwest Libya, Mesozoic rocks are exposed along the Jabal Nefusa escarpment for a distance of some 400 km, (Fig 1.4 and 1.5) they also occur in the subsurface of the Jifarah plains, and the northern Ghadamis Basin, which extending westwards into Tunisia (Bishop, 1988). The Mesozoic rocks has been influenced by extensional events in Jifarah basin in NW Libya, particularly during the Triassic and Jurassic and cretaceous rock.

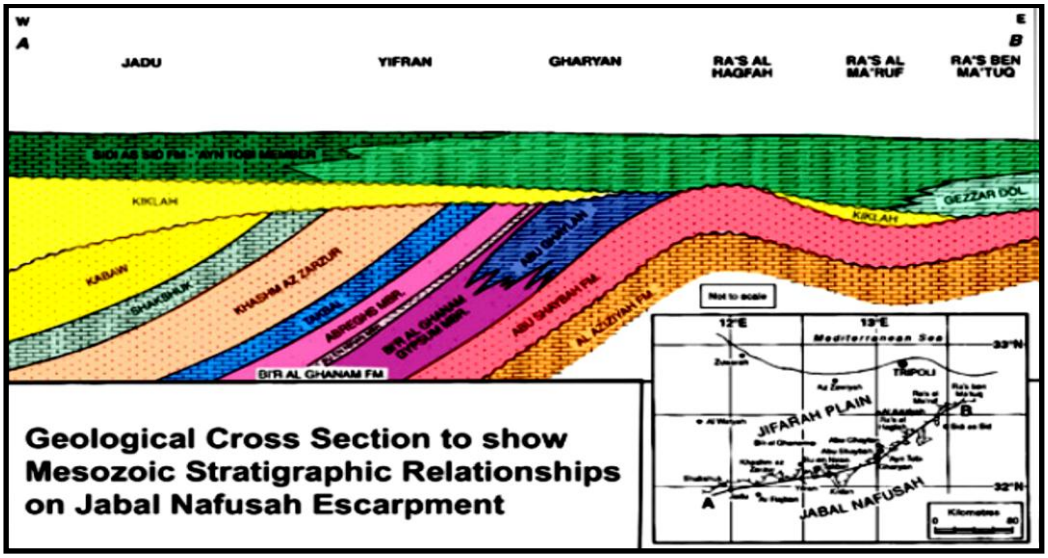


Fig. 1.4 Geological Cross-Section to show Mesozoic Stratigraphic relationships on the Jabal Natusah Escarpment (Fatmi & Sbeta, 1991, El Zouki, 1980, Assereto & Benelli, 1970, Hammuda, 1971)

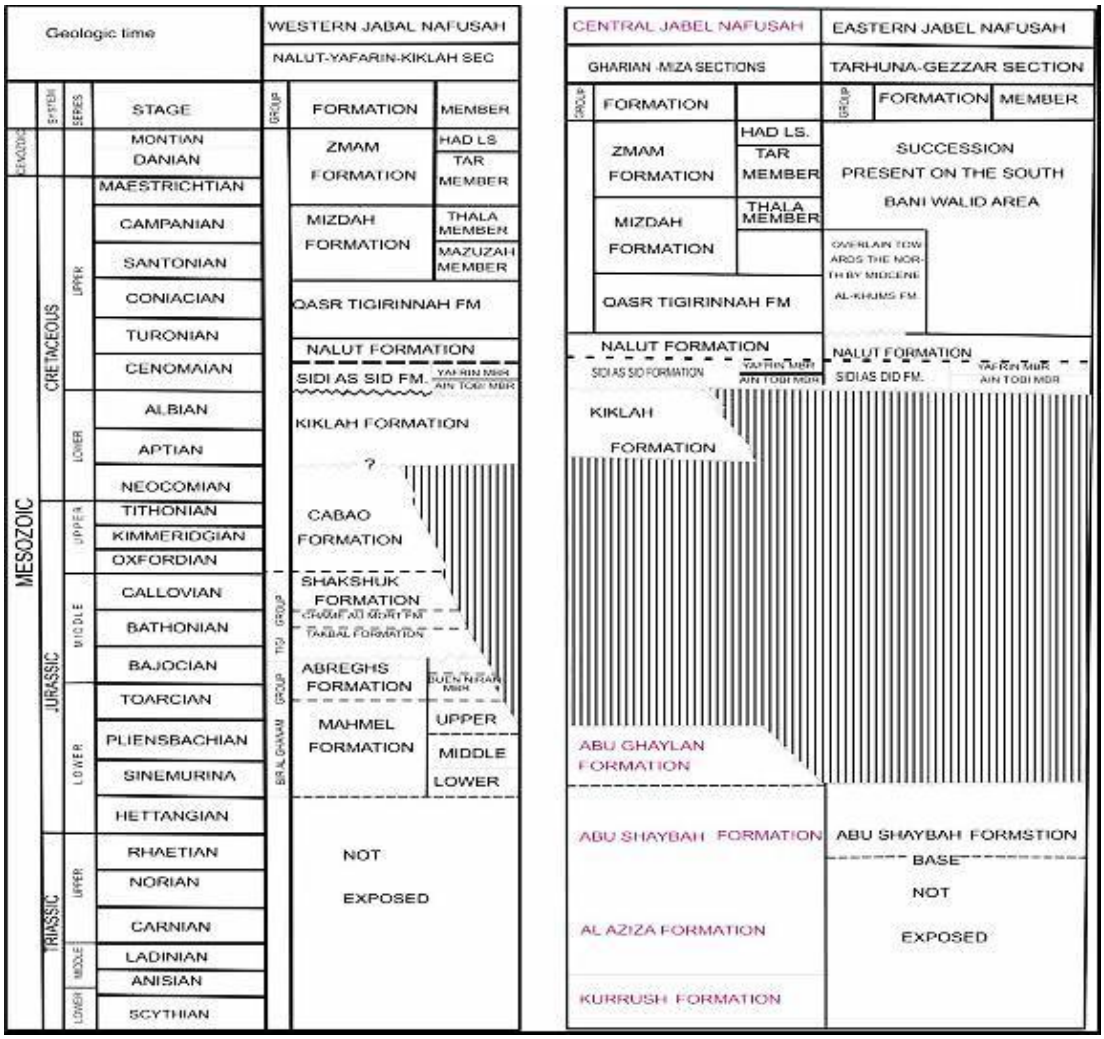


Fig 1.5 The Mesozoic succession of Jabel Nafusah, showing the stratigraphic variation from west to east (from the Industrial Research Centre, 1975).

1.4.1 Triassic Lithostratigraphy

1.4.1.1 Al Guidr (Ouled Chebbi) Formation

The oldest Triassic rocks in northwest Libya were described from the subsurface in the Jifarah Basin. The formation comprises 244m of fine- to medium-grained lignitic sandstones with minor grey, green and reddish micaceous shale's; the sandstones contain rare dolomite bands and are pyritic towards the base. The formation is probably unconformable with the underlying late Permian Bi'r al Jaja. The environment of deposition appears to be continental to marginal marine, (Hammuda, et al. 1985). It is overlain conformably by the middle Triassic Kurrush Formation. The formation is unfossiliferous and its assignment to the early Triassic is based solely on stratigraphic position, although (Rubino, et al 2000).

1.4.1.2 Kurrush (Ra's Hamia) Formation

Kurrush Formation is reddish, fine grained, micaceous sandstones, silty shales and dolomitic limestones exposed in several small domal inliers north of Gharyan. It's about 40m thick the base is not seen. The upper contact with the Al Aziziyah Formation is gradational. The formation is present in the subsurface of the Jifarah Basin. And has a wide distribution in the subsurface of the Ghadamis Basin which equivalent to Ras Hamia Formation. (El Hinnawy and Cheshitev, 1975),

1.4.1.3 Al Aziziyah Formation

The Al Aziziyah Formation Comprises 160m thick of dark grey, hard, dolomitic limestones with occasional marls, claystones and chert bands. The base was taken at the first appearance of carbonates overlying the Kurrush Formation. The upper boundary was defined at the unconformity with the overlying continental sandstones of the AbuShaybah Formation. As redefined at the type locality the top is marked by a thin unit with phosphate bands. The formation are Ladinian/Carnian age.(El Hinnawy and Cheshitev, 1975),

1.4.1.4 Abu Shaybah Formation

At outcrop in the Gharyan area, the Al Aziziyah Formation is unconformably overlain by 125m of red fluvial sandstones and conglomerates which were named the Bu Sceba Group by Christie. As currently defined the formation comprises varicoloured

fine to coarse-grained cross-bedded sandstones with a few thin dolomite and calcareous horizons towards the top. The lower contact with the Abu Shaybah Formation is distinctly unconformable, but the upper contact with the Jurassic Abu Ghaylan Formation is conformable. The formation outcrops at the foot of the escarpment North of Gharyan, and in three small inliers south of Ra's Ajdir. The attribution to the late Triassic-early Jurassic is based solely on stratigraphic position. .(El Hinnawy and Cheshitev, 1975), The Abu Shaybah Formation can be traced across the northern part of the Ghadamis Basin. (Belhaj, 1996)

1.4.2 Jurassic Lithostratigraphy

1.4.2.1 ABU Ghaylan Formation

The carbonate overlying the Abu Shaybah Formation. It outcrops at Abu Ghaylan, North of Gharyan, and for about 20km along the escarpment. At the type locality, 60m of dolomitic limestone are exposed, interbedded with marls thin sandstones and breccias. The contact with the underlying Triassic Abu Shaybah Formation is abrupt, but the upper contact is variable. Where it is overlain by Bi'r al Ghanam evaporites the contact is conformable, but where it is overlain by the Kiklah Formation the contact is unconformabl. The age was assumed by Christie to be early Jurassic.(Christie, 1955)

1.4.2.2 Bi'r al Ghanam Formation

In the area west of the Wadi Zaggut on the escarpment west of Gharyan the Abu Shaybah Formation is overlain by a thick evaporate sequence first described and named the Bir al Ghnem Group by de Lapparent. Christie subsequently showed that it appears to be the lateral equivalent of the Abu Ghaylan Formation in the Gharyan area (De Lapparent, 1952). The current view is that the formation can be divided into three members in the type area, from bottom to top the Bi'r al Ghanam Gypsum, the Bu en Niran and the Abreghs Gypsum members. In this area the formation is about 370 m in thickness. In the type area the formation rests on the Abu Shaybah Formation, but further east it is underlain by the Abu Ghaylan Formation. It is overlain in the west by the Takbal Formation and in the east by the Kiklah Formation; (El Hinnawy and Cheshitev, 1975)

1.4.2.3 Takbal Formation

The formation outcrops along the escarpment east and west of Kiklah. It was remapped by El Hinnawy and Cheshitev who described a 22m section comprising varicoloured shales, thin marly limestones, dolomites and occasional beds of gypsum near the base. The formation contains a fauna of pelecypods, echinoid fragments, fish scales and shark's teeth which indicate a Bathonian age. The basal contact is conformable with the Bi'r al Ghanam Formation but the upper contact is clearly unconformable with the Kiklah Formation. Further west, towards Yifran, it is comformably overlain by the Khashm az Zarzur Formation. (El Hinnawy and Cheshitev, 1975)

1.4.2.4 Khashm az Zarzur Formation

The Khashm az Zarzur Formation was named by El Hinnawy and Cheshitev for the two units overlying the Takbal Formation which were formerly known as the Giosc Shale and the Chameau Mort Sandstone. It is best developed in the area near Yifran where it is 110m thick. Further west near Jadu a 70m section is present with the base not visible. It continues to outcrop westwards to the Tunisian border. El Hinnawy and Cheshitev, 1975) However palynological analysis of samples from outcrop near Yifran yielded a Bathonian to Tithonian age. (Novovic, 1977b).

1.4.2.5 Shakshuk Formation

The Shakshuk Formation was originally defined by Burollet from near Jadu where it comprises alternating limestones and claystones with occasional sandy horizons. The thickness at the type locality is 25m. It contains a rich fauna of pelecypods, gastropods, brachiopods, foraminifera, echinoids, and plant debris, which give an age variously interpreted as Bathonian to Kimmeridgian, but the fauna from the Nalut area suggests a Bathonian-Callovian age. In the subsurface area east of Tripoli the A1-86 and A1-42 wells both penetrated continental sandstones, mudstones and coals with abundant miospores of Callovian to Kimmeridgian age which are assumed to be partly equivalent to the Shakshuk Formation. In the Ghadamis Basin the Shakshuk Formation can be traced as far south as wells Kl-90 and KKl-66, and as far east as well Cl-70 El Hinnawy and Cheshitev, 1975).

1.4.2.6 Kabaw Formation

The Kabaw Formation was defined by Burollet in the Jadu area. It consists of poorly consolidated, cross-bedded sandstones, becoming finer grained and more silty towards the top. Thin cherty, brecciated dolomites are present in the Nalut area. The total thickness at Jadu is 90m, but the formation thickens westwards towards Nalut and southern Tunisia. It contains lignite, wood fragments, and a rich assortment of teeth, bones and reptilian remains. Hammuda reported that in Tunisia the lower part contains the index fossil *Pseudocyclammina jaccardi* which marks the Jurassic-Cretaceous boundary in Algeria. Kabaw Formation ranges from late Jurassic to Neocomian in age. (Burollet, 1963b).

1.4.3 Lower Cretaceou

1.4.3.1 Kiklah Formation

The Kiklah Formation was first described by Christie from the Gharyan area. It is present on the Jabal Nafusah escarpment for almost 400km from the Tunisian border to east of Gharyan. It overlies the early Cretaceous, Jurassic and Triassic sediments of the Jabal Nafusah with marked unconformity, and in turn is uncomfortably overlain by the Sidi as Sid Formation. In the Gharyan area the Kiklah Formation overlies the Abu Ghaylan Formation. Further west at Yifran it overlies the Khashm az Zarzur Formation and at Jadu it overlies the Kabaw Formation. The thickness varies from 60m at Gharyan, 30m at Yifran, 50m at Jadu and thickens westward towards the Tunisian border. It has been demonstrated that both the Kiklah and Abu Ghaylan formations extend further east than was previously thought. The age of the Kiklah Formation has not been established with any certainty, but a palynological study at Nalut has yielded a Barremian-Aptian assemblage in the lower part, and late Aptian to Albian age assemblage in the upper part 55(Hinnawy and Cheshitev, 1975). In the Gharyan area the Kiklah Formation is composed of impersistent beds of mudstone, sandstone and conglomerate which were probably deposited in a braided-river system carrying high sediment loads, with frequent migration of the principal channels. SEM studies show pitting and breakage characters on the sand grains which are diagnostic of a fluvial environment. In the Yifran area the dominant lithology is micaceous mudstone which has been interpreted as a flood plain deposit. Further west, from Jadu to the Tunisian border the lower part of the formation is dominated by coarse, cross-bedded sandstones with pebbles lining the principal scour channels. The upper part is

largely made up of siltstones and mudstones containing gypsum. This sedimentological pattern is interpreted as a long meandering river system with the mudstones representing overbank deposits. (El Zouki, 1980)

1.4.4 Upper Cretaceous

1.4.4.1 Sadi As Said Formation

The sidi as sid formation is one of the most widely distributed rock units of Jabal nafusah the Sidi as Sid Formation was named and described by El Hinnawy and Cheshitev for a marine sequence in the Gharyan area overlying the Kiklah Formation in the west and the Abu Shaybah Formation in the east, the formation comprises two members, a lower carbonate unit named the Ayn Tobi Member, and an upper marlstone unit, the Yifran Member. (Hinnawy and Cheshitev, 1975).

Ayn Tubi Member

A type section for the 'Ayn Tobi Member was designated on the Gharyan Dome, as a replacement for the previous composite type section selected by Christie. At this location the member comprises 100m of grey and yellow crystalline limestones and dolomites with thin marlstone interbeds the base is marked by a thin sandstone horizon which contains quartz pebbles derived from the underlying Kiklah Formation, the lower contact is unconformable, the upper contact with the Yifran Member is gradational, a cenomania age. (Hinnawy and Cheshitev, 1975).

-Yfrin Member

The Yafrin member conformably overlies the ayn tobi member. a type section for the Yifran Member, close to the village of Yifran. This unit is composed of 70m of soft, thinly bedded alternations of marly limestone, claystones, marlstones and bedded gypsum. The age is almost certainly Cenomanian, the environment of deposition ranges from lagoonal in the west through littoral to low-energy neritic in the east.
(Hinnawy and Cheshitev, 1975) The formation outcrops along the entire length of the Jabal Nafusah escarpment from Al Khums to the Tunisian border, (Novovic, 1977)

1.4.4.2 Nalut formation

In the western Jabal Nafusah the Sidi as Sid Formation is overlain by 30 to 40m of dolomitic limestone named the Nalut Limestone by Zaccagna, the equivalent section

near Gharyan was named the Garian Limestone, but the former name has priority and has been adopted by the surveyors of the Geological Map of Libya, A type section was defined east of Gharyan where 53m of hard, crystalline, dolomitic limestone overlie the Yifran Member of the Sidi as Sid Formation, the formation contains bands of chert and concretions, it contains rare, badly preserved pelecypods, which suggest a late Cenomanian to Turonian age, (Hinnawy and Cheshitev, 1975).

1.4.4.3 Qasr Tigrinah formation

The term was introduced by Christic (1955) as Qasr Tigrinah Formation In the Gharyan area the Nalut Formation is overlain by a predominantly marly sequence which was first described by Christie and is now called the Qasr Taghrinnah Formation, a type section to the southeast of the village of Qasr Taghrinnah where 71m of soft yellow marls interbedded with hard crystalline to marly limestones are exposed, the formation is a Turonian to early Santonian age, (El Hinnawy and Cheshitev, 1975).

Chapter 2

Sedimentology and Depositional Environment

2. Sedimentology and depositional Environment

2.1. Introduction

Kiklah Formation consists of arenaceous sediments display a great variability in sediment and structures. These sediments descripd in details and devided into nine lithofacies based on the outcrop observation. The data for this study were primarily collected by means of outcrop facies analysis performed on five main sections located within the confines of the Kiklah Formation along the western of Jabal Nafusah (Fig. 2.1.). The results of this work as well as the interpretation of the data are illustrated in Table.2.1. Previous studies have interpreted the Kiklah Formation at the western of jabal Nafusah as a meandering stream deposits (El–Zouki, 1976- 1980).

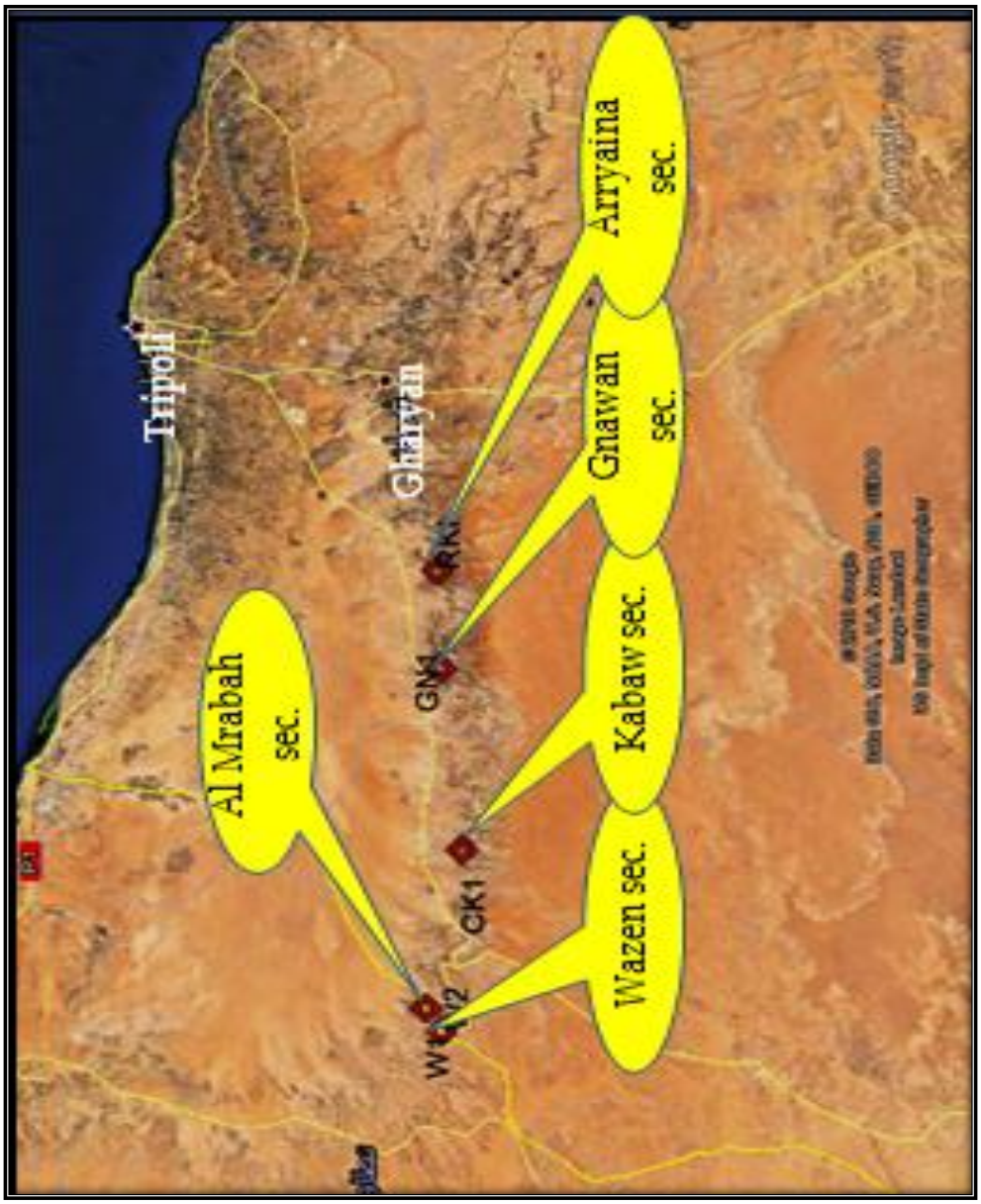


Fig 2.1. Satellite image showing Location of the studies section along the western Jabal Nafusah

2.2 Facies

The Kiklah Formation lithofacies (Table 2.1) which were adapted from Miall (1978c). Formed within three depositional setting where described in details based on their texture, sedimentary structures and vertical and lateral relationship of the staking patterns.

Table 2.1. Summary of lithofacies classification and main characterization of each lithofacies in the Kiklah Formation according to (Miall 1978c).

Facies code	Facies	Sedimentary structures	interpretation
Gt	Conglomerate channel	Horizontal bedding, Trough crossbedes	**Mainer channel fills**
St	Sand, medium to v.coarse,may be pebbly	Trough crossbedes	**Lower flow regime**
Sp	Sandstone ,medium to v.coarse may be pebbly	Planer crossbedes	**Languid, transverse bars, sand waves(lower flow regime)**
Sr	Sandstone, very fine to medium	Ripple marks of all types	**Ripples (lower flow regime)**
Sh	Sandstone, fine to medium may be pebbly	Horizontal cross stratification, and current ripples.	**Planer bed flow (l. and u.flow regime)**
Sl	Sandstone , fine	Low angle crossbeds	**Scour fills, crevasse splays,antidunes**
Fl	Sandstone, silt, mud	Fine lamination, very small ripples	**Overbank or waning flood deposits**
Fm	Mud, silt	Massive, desiccation cracks	**Overbank or drape deposits**
P	Siliceous, silt ,sand	Poorly bed	**Soil**

2.2.1. Gt- Lithofacies (Conglomerate channel)

Description: This lithofacies composed of conglomerate (Orthoconglomerates**)**, yellow to grayish white colour, consisting of individual clasts (pebble and granules), medium to coarse-grained matrix that have become cemented together, subrounded to rounded, very poorly sorted, display through cross bedded, their base is sharp and erosional, this lithofacies is often less than 1 meter thick, and represents

less than 2 % of the total thickness its extend lateral to about 5m. However, pebbly conglomeratic sandstone near the base of Kiklah Formation characterized by medium scale through cross bedding pebble and conglomerates (>4mm in grain size) are distributed through all the bedsets but tend to concentrate more along the base. This facies wedge shaped laterally which is often truncated and often grade into other facies over distances of a few meters. Sharp boundaries between individual cross bed sets (Fig. 2.2, 2.3). Facies Gt. typically grades vertically into smaller scale bed packages of facies St or Sp. Trough cross-bed is compound sets generally 0.2-0.3 m thick but multi-storey suites reach up to 2 m in thickness. Sets width are up to 5 m. Paleocurrent for (Gt) Lithofacies a chiefly reflect from northern west to northern east directed sediment transport in fluvial braided.

Interpretation: Gt Lithofacies is essentially identical to the massive, horizontal cross stratification, trough and planar cross-sets of Miall (1977, 1996) although bedforms reach slightly not greater dimensions in the lower part of the Kiklah Formation in individual cross bed sets may occasionally reach 0.5 m in thickness and cosets may reach thicknesses of up to 1m. The predominance of pebbly and trough cross-bedding in Gt Lithofacies suggests deposition within major channels as migrating dunes.

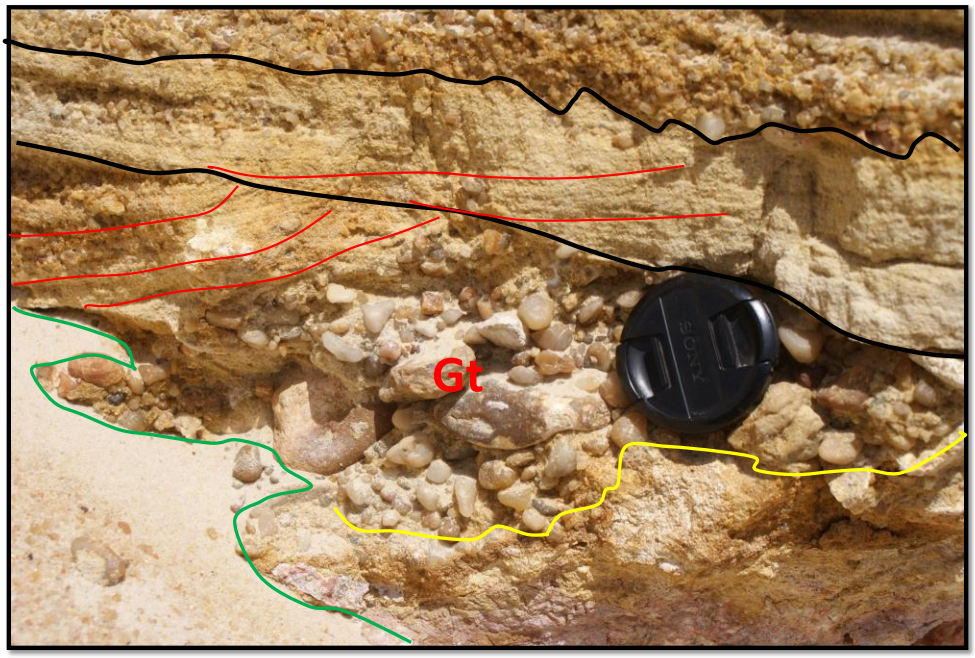


Fig 2.2 Gt- Lithofacies consisting of individual clasts (pebble and gravel), within a medium to very coarse-grained matrix that have become cemented together.

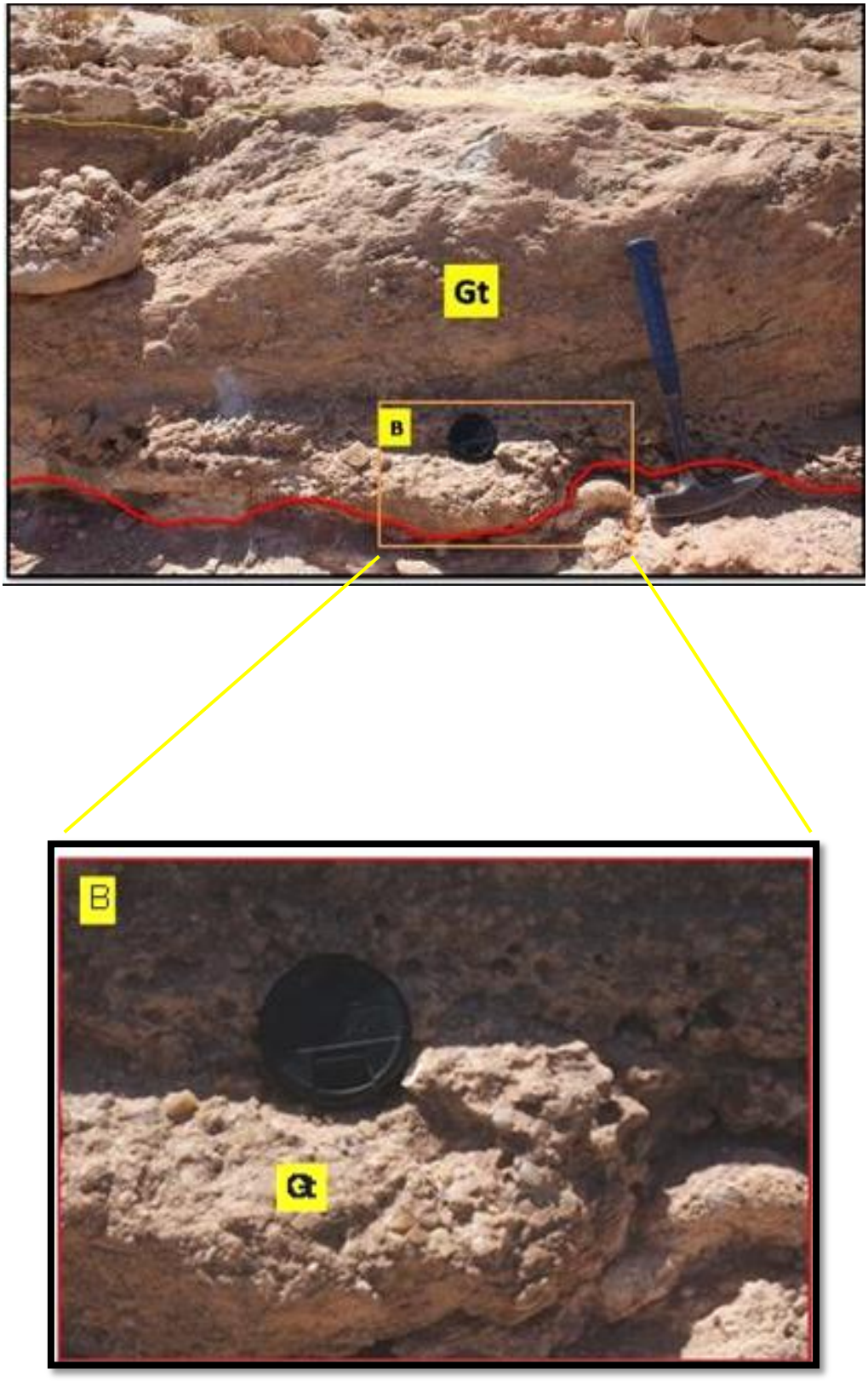


Fig 2.3 A Gt- Lithofacies Conglomerate channel poorly sorted, trough cross bedded. **B** close view of the outlined area in the in the previous figure showing the Conglomeratic sandstone at the base of lithofacies Gt.

2.2.2. St- Lithofacies (trough cross-stratified sandstone)

Description: This lithofacies is widely distributed in Kiklah Formation composed of sandstone, it consists grayish white and pale yellow coloured sandstone, medium to very coarse-grained, rounded to well rounded, poorly to moderately sorted, display through cross bedded, This facies expose sharp boundaries which often end upward by thin siltstone layers, this facies occasionally exhibit wedge-shaped bodies, Pebbles scattered and intraclasts of siltstone and/or mudstone usually concentrated at the base of trough or scattered in this lithofacies St. also rich by roots where these roots seems to be growth after deposition, the trough cross bedding develop by the migration of 3-D dunes, with Paleocurrent directions (310 ˚ ,35 ˚ ,350 ˚). At the basee of this facies commonly a lag of large intraclast (2-4cm in diameter), the lithofacies usually ranging 1-2 m in thickness and extending over several meter laterally. Individual cross bed sets may occasionally reach 0.5 m thickness and cosets may reach thicknesses of up to 1.5m in small scale (Fig 2.4A and B)

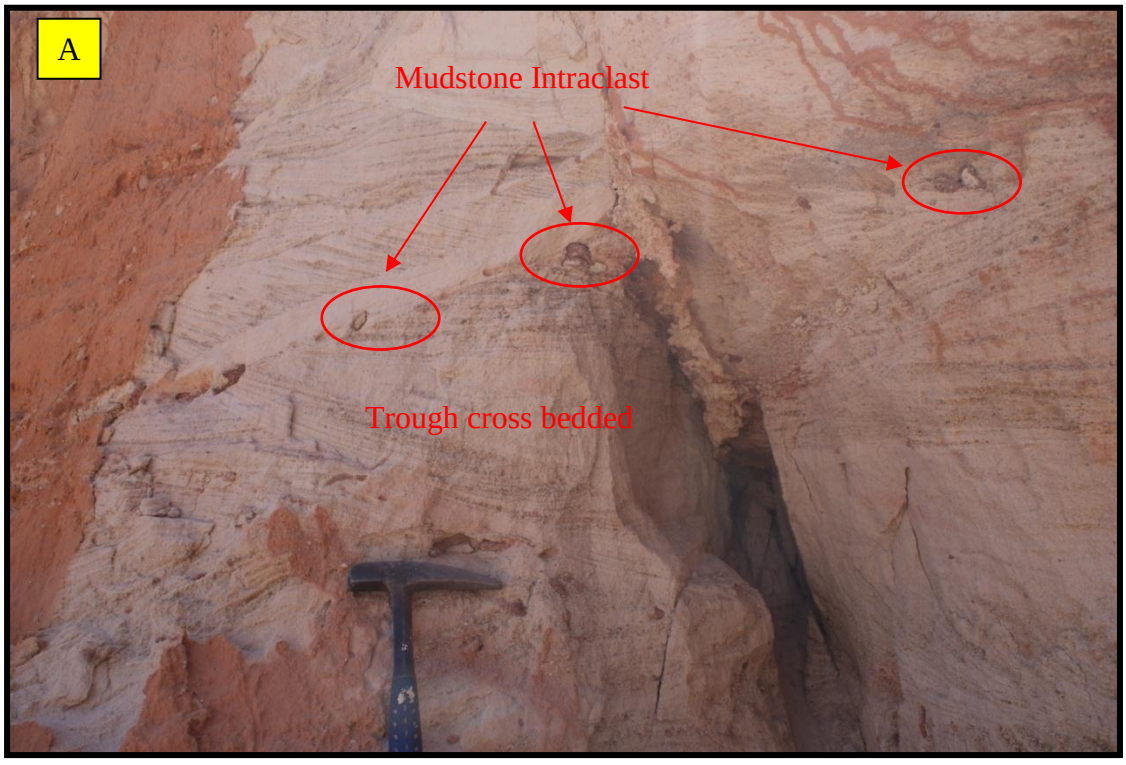


Fig. 2.4 A St- Lithofacies showing trough cross bedding with large intraclasts at the base (red arrows).

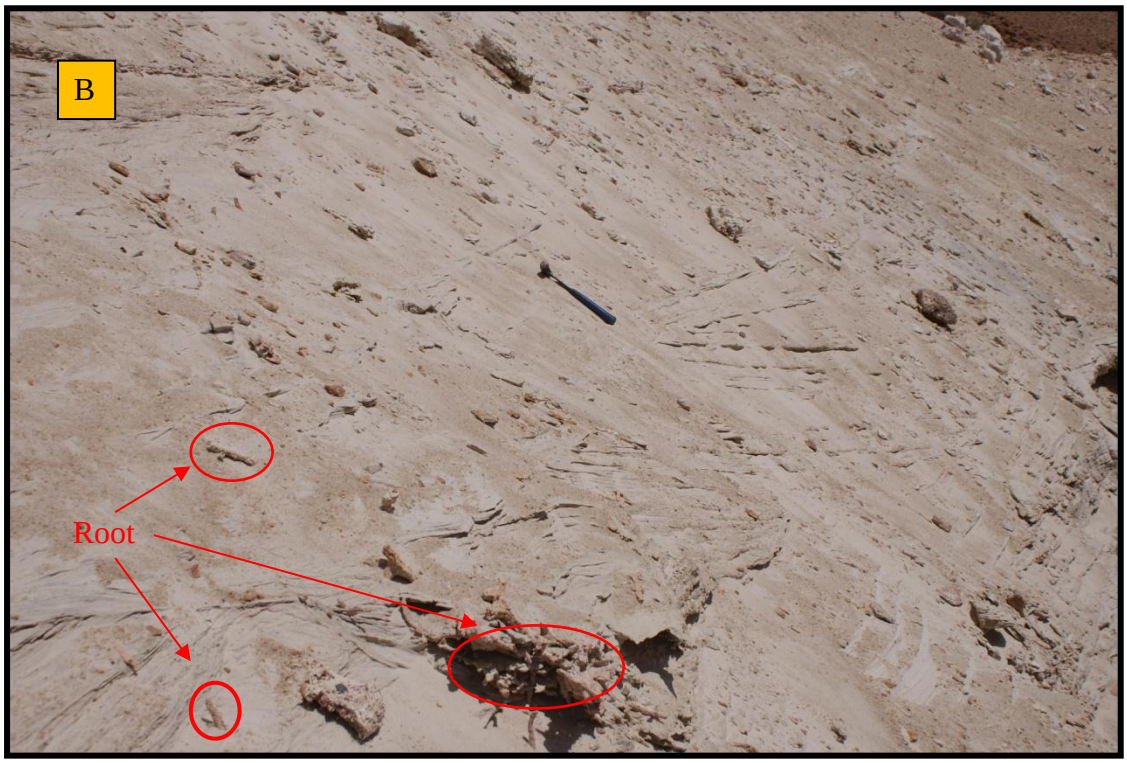


Fig 2.4 B St- Lithofacies trough cross - stratification sandstone with some roots.

Interpretation. According to (Miall 1978c) (St) lithofacies formed by Sinuous – crested and linguoid (3-D) dunes. Troughs develop by the migration of 3D dunes Bedforms reach slightly greater dimension in the Kiklah Formation. The predominance trough cross-bedding in (St) Facies suggests deposition within major braided channels as large migrating dunes (mega ripples of Singh & Kumar, 1974)

2.2.3. Sp-Lithofacies (planar stratified sandstone)

Description: This Lithofacies composed of sandstone, grayish white and yellow coloured consists of mostly medium to very coarse grained, rounded to well rounded, moderately sorted, with roots, display planer cross-bedded, (Fig. 2.5). The planer cross-bedding are generally 0.2-1.5 m thick, rarely up to 2 m. But multi-storey reaches 5 m in thickness. Set width is up to 20 m. granule and pebbles layer is sometimes present at the base of cross- bed sets. Siltstone intraclast, up to 2 cm in diameter are relatively common at the base of Multi-storey sandstones, Soft sediment

deformation is present in the form of medium scale convoluted bedding, and the lower base and upper contacts of this facies is usually erosional.

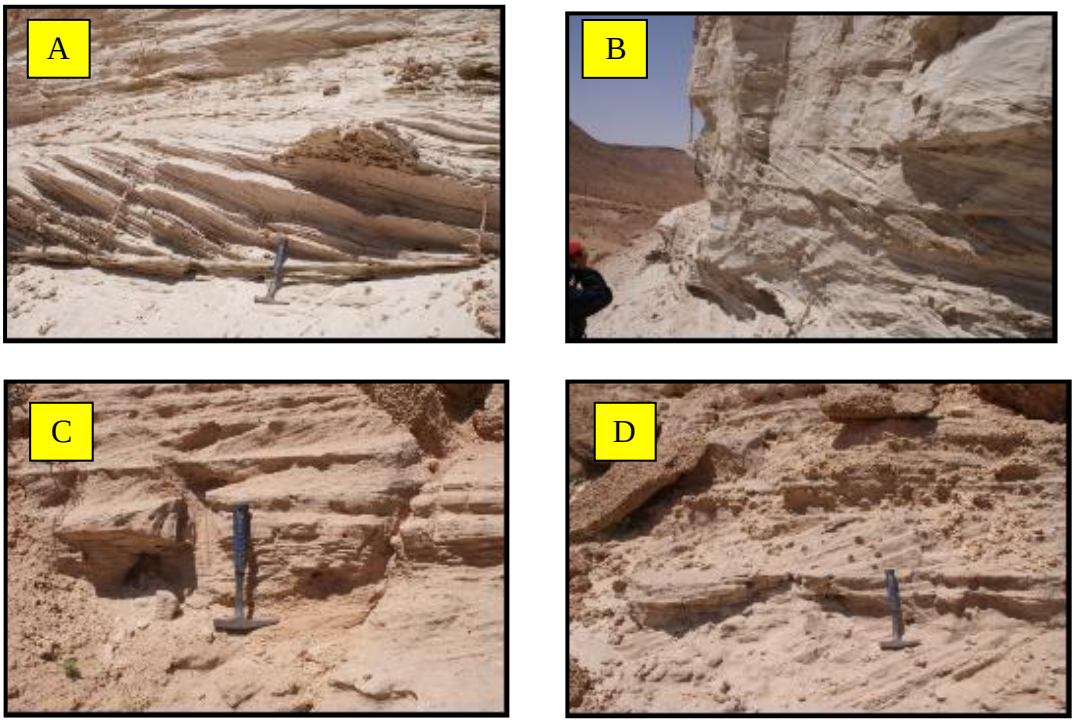


Fig 2.5 Sp- Facies Planar cross stratified sandstone, (A) single sets planer crosses bed (B, C, D) multi-storey Planer cross-bed sets

Interpretation: This lithofacies forms by transverse and linguoid bed forms migration of 2-D dunes (Miall 1978c). Sand is transported up the flank of the bed forms 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. Large scale cross-bedding of this facies 30° (Fig 2.5 A), with sharp, angular bases, upper and lower bounding surfaces are typically flat, with little evidence of scour surfaces. Sandstone in this facies is typically sorted by 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)

2.2.4. Sr- Lithofacies (Ripple cross-laminated sand)

Description: This Lithofacies composed of sandstone, white and pale brown in colour consists of very fine to coarse but mostly fine to medium-grained, rounded to well rounded, poorly sorted, with root, variety of asymmetrical ripple type and large-scale ripple (Fig. 2.6.D), cross laminated sandstones. Individual cross-bed sets and cross laminated beds are typically 5 - 20 cm thick. Generally this lithofacies attained about 1.5 m thick (Fig. 2.6A, B, C, D).

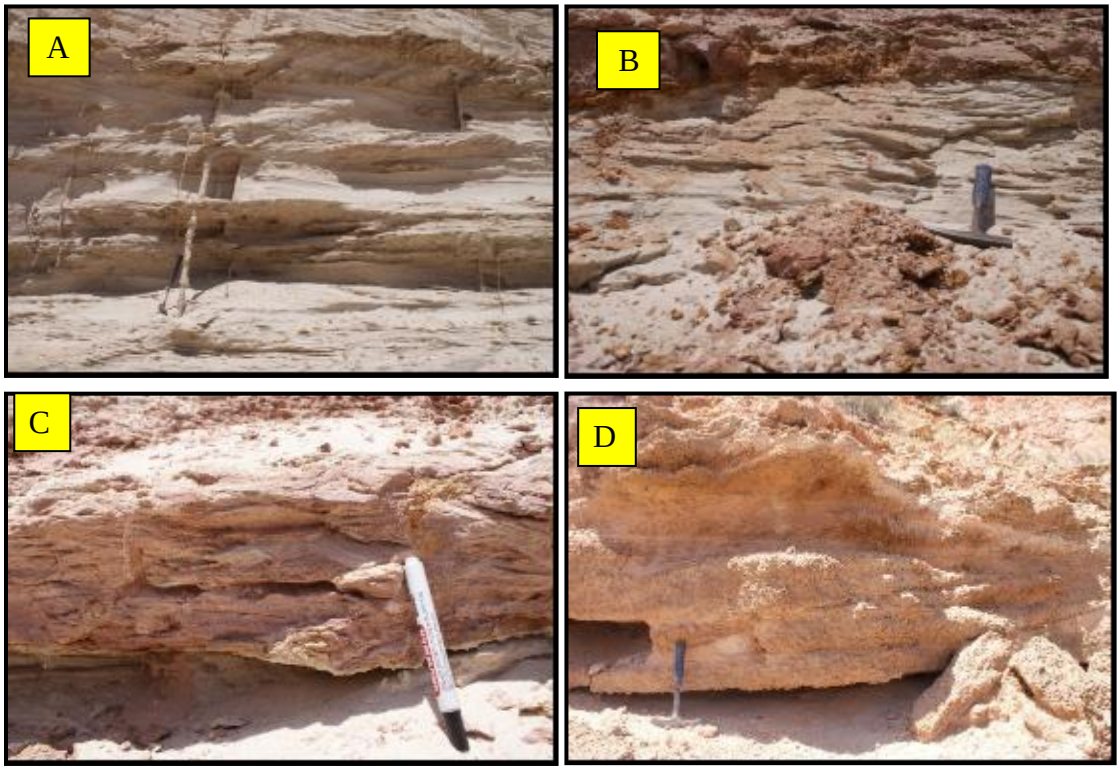


Fig. 2.6 Sr Lithofacies, Ripple cross-laminated sand (Sr). A, B, C, variety of asymmetrical ripple type and (D) large-scale ripple

Interpretation.

The ripples sediments probably develop at low flow speeds (< 1 m *I* s), and are very sensitive to changes in flow conditions (Miall 1996). A wide variety of internal structures may be generated from ripple migration, and attributed to variable flow velocity and the rate of sediment supply (Jopling and Walker 1968; Allen 1984).Where sediment is added from suspension during ripple migration, mutual erosion of the ripples is incomplete, leading to partial preservation of the stoss sides of ripple.

2.2.5. Sh- Lithofacies (Horizontal bedding)

Description: This Lithofacies composed of sandstone, white and reddish brown in colour, consists of very fine to coarse grained, rarely pebble in some parts. This lithofacies display horizontal bedded (Fig 2.7), very thinly bedded 1 - 30 cm thick. This lithofacies generally attained 1 m thick (Fig.2.7). The upper and lower boundaries of the facies are sharp**.**



Fig 2.7 Sh- Lithofacies Horizontal bedding with parting lineation.

Interpretation. The horizontal bedded of this lithofacies probably occurs under two quite different conditions. The most important is that which represented the upper plane bed condition, at the transition from subcritical to supercritical flow. This commonly with different indicated flow direction. Erosion by minor waves and surface runoff as dune emerges leads to rounding of dune crest, But also occurs at lower velocities at shallower depths. The coarse grains sand and pebbles are rarely observed which probably emplaced by being rolled along in the sand traction carpet.

2.2.6. Sl- Lithofacies (Low-Angle cross bedded sandstone facies)

Description: This Lithofacies composed of sandstone, white and reddish brown in colour consists of very fine to coarse grained, good sorting (Fig 2.8) display low angle cross bedded, the beds usually 10-30 cm thick, sometimes attain 1m thick, the low-angle cross-bedding dipping less than 15 ˚.

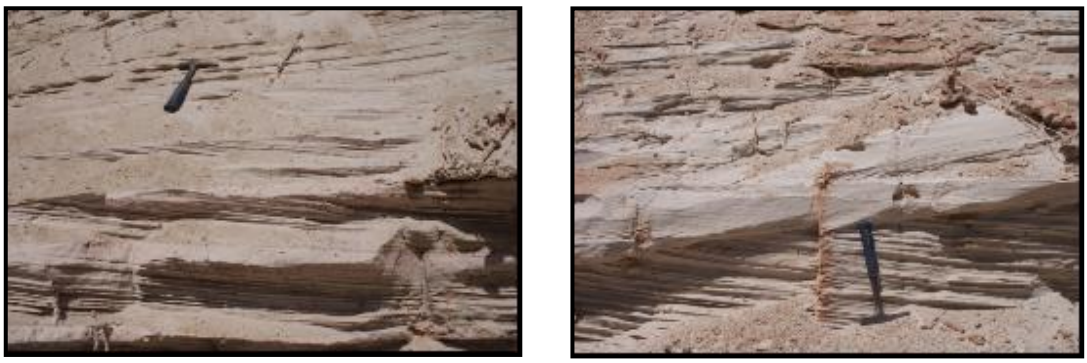


Fig. 2.8 Sl- Lithofacies Low-Angle cross bedded sandstone facies.

Interpretation. This Lithofacies is interpreted to represent plane beds deposited on initially dipping surfaces such as scour hollows. In other cases the lithofacies represents distinct bedform geometries. The washed - out dunes and humpback dunes that occur at the transition between subcritical and supercritical flow. (Miall 1977, 1978c)

2.2.7. Fl- Lithofacies (laminated sand, and mud)

Description: This Lithofacies composed of sandstone and Mud, varicoloured, (pinkish, grayish, white, grayish and violet) the sandstone consist very fine-grained often interbedded with siltstone and mudstone, display thinly to medium bedded, horizontally laminated structure, bed thickness ranges from 10-50 cm, some of sandstone and siltstone display very small-scale ripples, The lower bed boundaries often erosional, and sometimes exhibit load casts, gutters and/or grooves, probably foot print and bioturbation are common in this facies (Fig 2.9A, B, C, D). These are locally rich in claystone, mud and Sandstones and syn-sedimentary deformation. Crevasse splay deposits typically range in thickness from 0.2 m to 1 m.

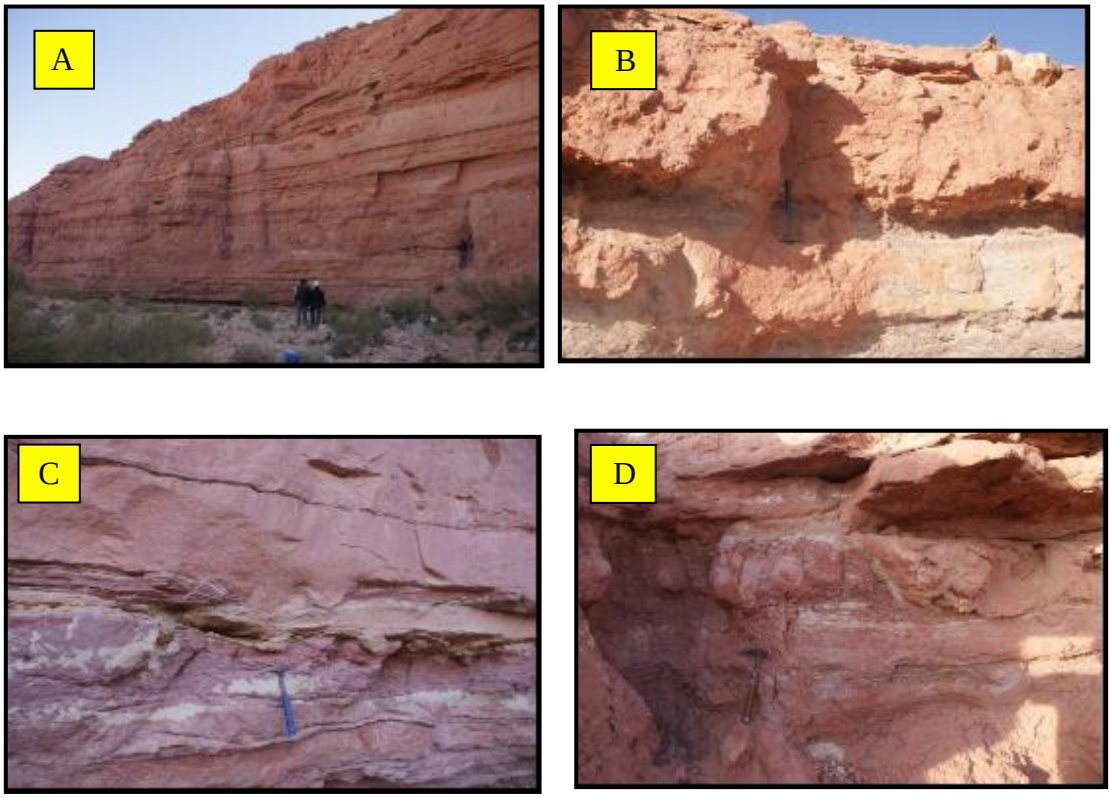


Fig 2.9 Fl- Lithofacies: laminated sand, and mud intercolation.

Interpretation: This Lithofacies is common in overbank areas and represents deposition from suspension and from weak traction currents. (Miall 1978c) and are interpreted to have been deposited in lobes adjacent to floodplain. This lithofacies display crevasse splay, levees deposits throughout sequence, however in the studied area this lithofacies occur at the Wazen section (W2).

2.2.8. Fm- Lithofacies (Massive Mud and silt)

Description: This Lithofacies (Fm) consists of mud, silt, reddish brown, light green in colour, display massive or structureless bedded, this lithofacies attained 2-20m thickness which is observed throughout the whole study area (Fig. 2.10) sometimes display badly preserved horizontal bedded .

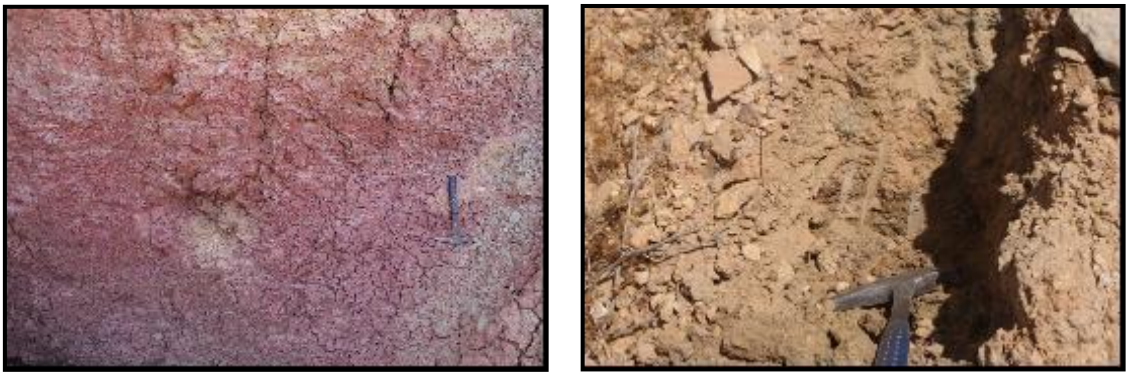


Fig 2.10 (Fm) Lithofacies: Massive, silt, clay (Mud)

Interpretation: This facies is suggests as floodplain deposit somewhat more distal relative to clastic sources such as nearby fluvial channels. Rust (1978b)

2.2.9. P- Lithofacies (Paleosoil)

Description. This Facies consists varicolored (Red, grey, yellow, grayish white) mixture of sand, silt and clay, poorly bedded, sometimes convoluted siliceous and ferruginous cemented, chert, Geodite nodule are common, very hard often include rock fragments variable clast shape (angular to well rounded) also some bone, shell fragment, shark teeth and petrified wood are observed especially in the Al Mrabah, Kabaw, Genawan sections, This Lithofacies usually well exposure as a mark bed at the lower part of Kiklah formation with different thickness about 0.5-2m (Fig. 2.11)



Fig. 2.11 P- Lithofacies Paleosoil exposure as a mark bed at the lower part of Kiklah formation

Interpretation: A wide variety of textures and structures develops where flood-plains are exposed to surface weathering processes for extended periods of time (thousands of years). Rain infiltration leaches dissolvable ions of silica and iron downward, whereas evaporation and capillary groundwater flow during arid periods concentrate the same ions near the surface**.** Bones, shell fragment, shark teeth and petrified wood which observed in description its erosion and transport from the old formations.

2.3 Analysis of the sedimentary architectural elements

2.3.1 Bounding surfaces

Slicaiclastic sediment bodies commonly consist of hierarchical subdivisions corresponding to various scales of depositional elements. Recognition of bounding surfaces that delineate elements is important in distinguish and describing a depositional hierarchy. A hierarchy that is open-ended toward large features allows more flexibility in studying outcrops. Six order of bounding surface were recognized within Kiklah formation and classified using the framework of (Miall 1991b), (Fig 2.12) Brief description of these bounding surfaces, their order, and characteristics are summarized in table 2.2

Table 2.2

Bounding surface hierarchy and characteristics applied to the Kiklah Formation based Miall (1991b)

Rank of bounding surface	**Deposition unite**	**Typical Thickness (m)**	**Characters of bounding surface**	**Facies characteristics**
1st-ord	Bed-form set, ripple (microform) to dune increment reactivation surface	0.2-0.5	Flat and non- erosion	Single facies type
2nd-ord	Bed-form coset, dune (mesoform)	0.8-3	Flat and non- erosion	Stacked units of the different facies type
3rd-ord	Macroform growth increments ,seasonal deposit	1-8	Minor erosional surface	Secession bounded minor erosional ,lag Deposites and often fine up
4th-ord	Macroform, minor channel or sheet deposit, immature palaeosol	1-8	Convex-up top surface difning completion and abandonment of macrofrom. Commonly truncated by subsequent erosional event.	Complex bedforms and minor channeles lag deposits at base and mud drips at top. typically shows accretionary geometry
5th-ord	Main channel or sheet deposit, major flood unit, sometimes mature palaesole	1-12	Concave-up basal surface, with steep or gently dipping sides, cut-fill erosion very common	Simple channel- fill or complex- fill with macroforms and associated overbank deposits
6th-ord	Channel-belt, main bounding surface, palaeovally, high-order sequence.	20-80	Regional erosional surface.	Channel complex with associated overbank deposits.

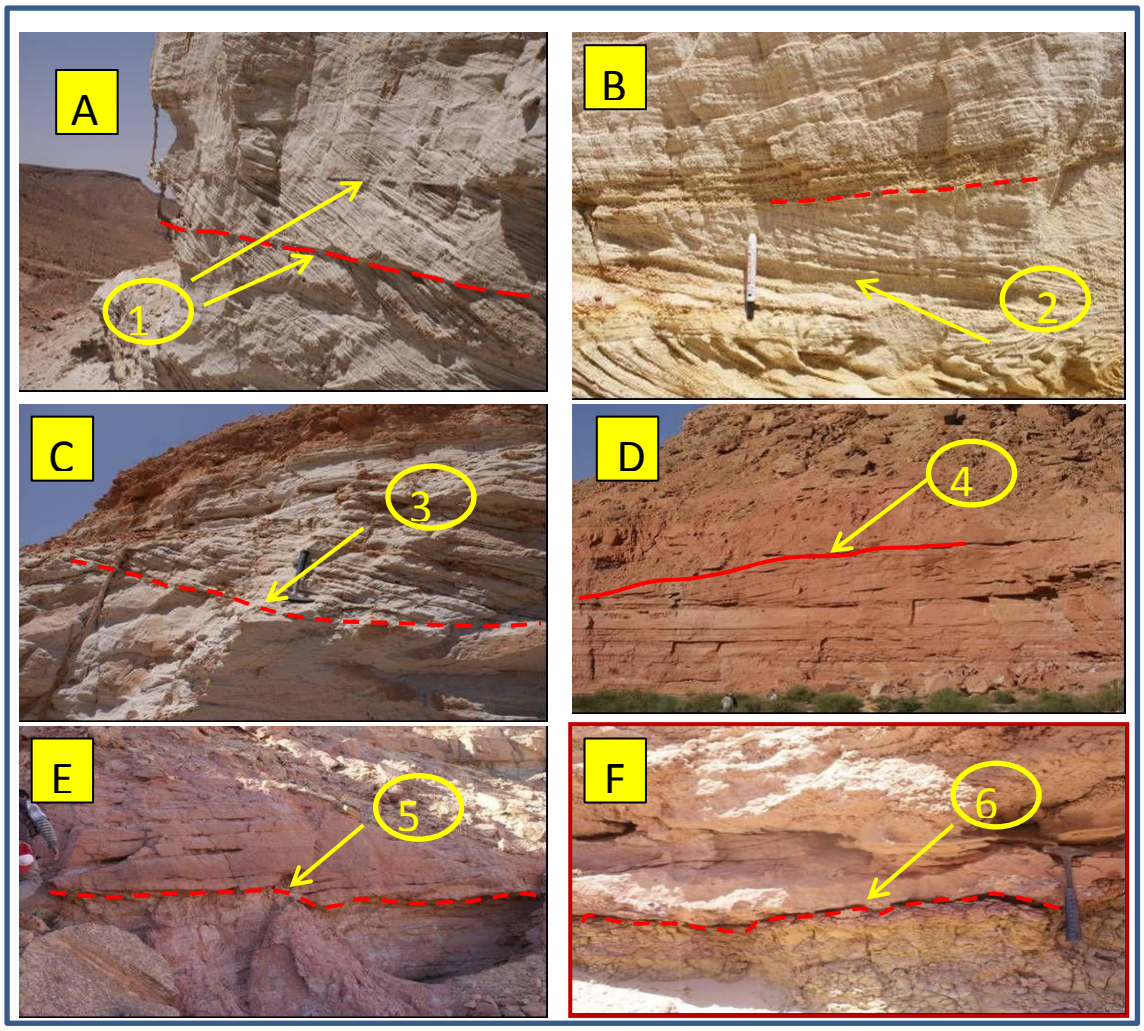


Fig 2.12 A (lithofacies Sp) showing first- order bounding surface (1). Al Mrabah section. **B** second order- surface (2). **C** third –order surface within sandstone Sp lithofacies (3). **D** forth – order surface and lateral-accretion macroform (LA element) At Wazen section (4). **E** fifth –order surface at the base of lateral accretion elements (5). **F** sixth-order surface (arrows) at the lower contact between Kabaw and Kiklah formation (6).

2.3.1.1 First – order surface

Record boundaries of cross – bed set (Fig 2.12A) where little or no internal erosion is apparent at these boundaries, and they represented the virtually continuous sedimentation of secession of bedform of similar type.

2.3.1.2 Second-order surface

Simple cosset bounding surfaces, indicatr changes in flow conditions or change in flow direction but with no significant time break (Fig 2.12B), lithofacies above and below the surface are different; these surfaces may be distinguished from first-order surface by change in lithofacies.

2.3.1.3 Third-order surface

Cross cutting erosion surface with macroforms that dip at low angle (< 15 ˚) or may truncate underlying cross-bedding at low angle (Fig 2.12C) they may cut through more than one cross-bed set. This type of surface commonly draped with mudstone and followed by intrclasts breccias. Facies assemblages above and below the surface are the similar. Third–order surface may also develop at the top of minor bar or bedform sequences.

2.3.1.4 Fourth-order surface

Represent the upper bounding surface of macroforms in the original scheme of (Miall 1988a, b). The fourth – order surface are typically flat convex-upward (Fig 2.12D), underlying bedding surface first- to third bounding surface are truncated at a low angle or may be locally parallel to the upper bounding surface, indicating that they are surface of lateral or downstream accretion.

2.3.1.5 Fifth-order surface

Those are bounding major sand sheets, such as broad channels and channel-fill complexes(Fig 2.12E) they are generally flat to slightly concave-upward, but may be marked by local cut-and fill relief and by basal lag gravels. Many paleosoil horizons may be correlated with specific channels, indicating contemporaneous development. These horizons within floodplain sequences may therefore be classified as fifth- order surface.

2.3.1.6 Sixth-order surface

Define group of channels or paleovalleys. mappable stratigraphic units such as members or sub members are bounded by sixth order surface (Fig 2.12F) surface of sixth- order and higher rank were not defined by Allen (1983). Decelles et al., (1991) defined the major bounding surface enclosing enter alluvial fans as sixth- order surface.

2.3.2 Architectural elements

The architectural elements of Kiklah Formation are reconstructed using bounding surfaces, lithofacies assemblages and paleocurrent information. Five architectural elements were recognized within Kiklah Formation. Channels, sand bed forms, lateral accretion, downstream accretion macroforms and overbank elements. Not all of these features were observed at each outcrop (Table 3.3.1). These elements, defined by their geometries and bounding surfaces (Miall, 1996), form the basis for interpreting depositional environments. Individual elements represent different levels in terms of classification; for example, sand and gravel beds form channels, channels form downstream accretion macroforms, while some gravel bars do not represent channel fill but are evaluated as inter-channel elements.

Table 2.3
Architectural element classification used in this study, adapted from Miall (1985; 1996)

Architectural element	Lithofacies description	Grain size	Geometry	Bounding surface
Channel-fill complex(CH)	Gt, St, Sp, Solitary or grouped sets of St, with Sp climbing or stacked over the top. usually from amulti-storey coplex that grdes upward into sheet sand or overbank.	medium to coarse - grained sandstone with pebbles and lags.	Well-defined channels with often cut-banks and erosional bases. Vriable scale from 50->100 m wide and 2-7m deep.	**Basal fifth –order bounding surface. Erosively based with lags and irregular planer upper surface.**
Sand bedforms(SB)	Sr, Sh, and Sl with minor Sp, St Flat bedded sandstone, with grade upward into low-angle planar or trough cross-bedding	Fine to medium grained sandstone with pebbly lags and rare mud.	Sheet-like bodies may extend >100m laterally and 2-4 m thick.	**Erosively to slightly concave basal surface and eroded .fifth-orded surface separate SB elements with internal fourth and third-order surface.**
Lateral accretion (LA)	St,Sp,Sh. Low-angle accretion units with distinctive internal grading from medium to v.fine grained sandstone	Medium- grained sandstone.	In cross- section wedge shaped lenses of medium sandstone. Accretion laterally across channel or overbank.	**Bounded by fourth-order surface.**
Downstream accretion macroforms(DS)	St,Sp,Sh, low-angle accretion units with internal grading. Sets 0.5-2m thick	Coarse –grained sandstone and pebbles.	Tapered wedge –like elements, associated with gravel and sand bars. Accretion in downstream direction.	**Bounded by forth-order surfaces and internal third-order surfaces between accretion elements.**
Overbank fines (OF)	Fl, Fm, with minor Sh, Sl and rare St, SP lamination, varicolour with paleosols.	Fine- grained sandstone, siltstone, mudstone	Sheet- like bodies laterally extensive >150m and 10-20m thick	Surface usually planer or gently concave-convex to sharp distinct bases. Top erosively irregular. First, second &Fifth order may recognized with this elements.

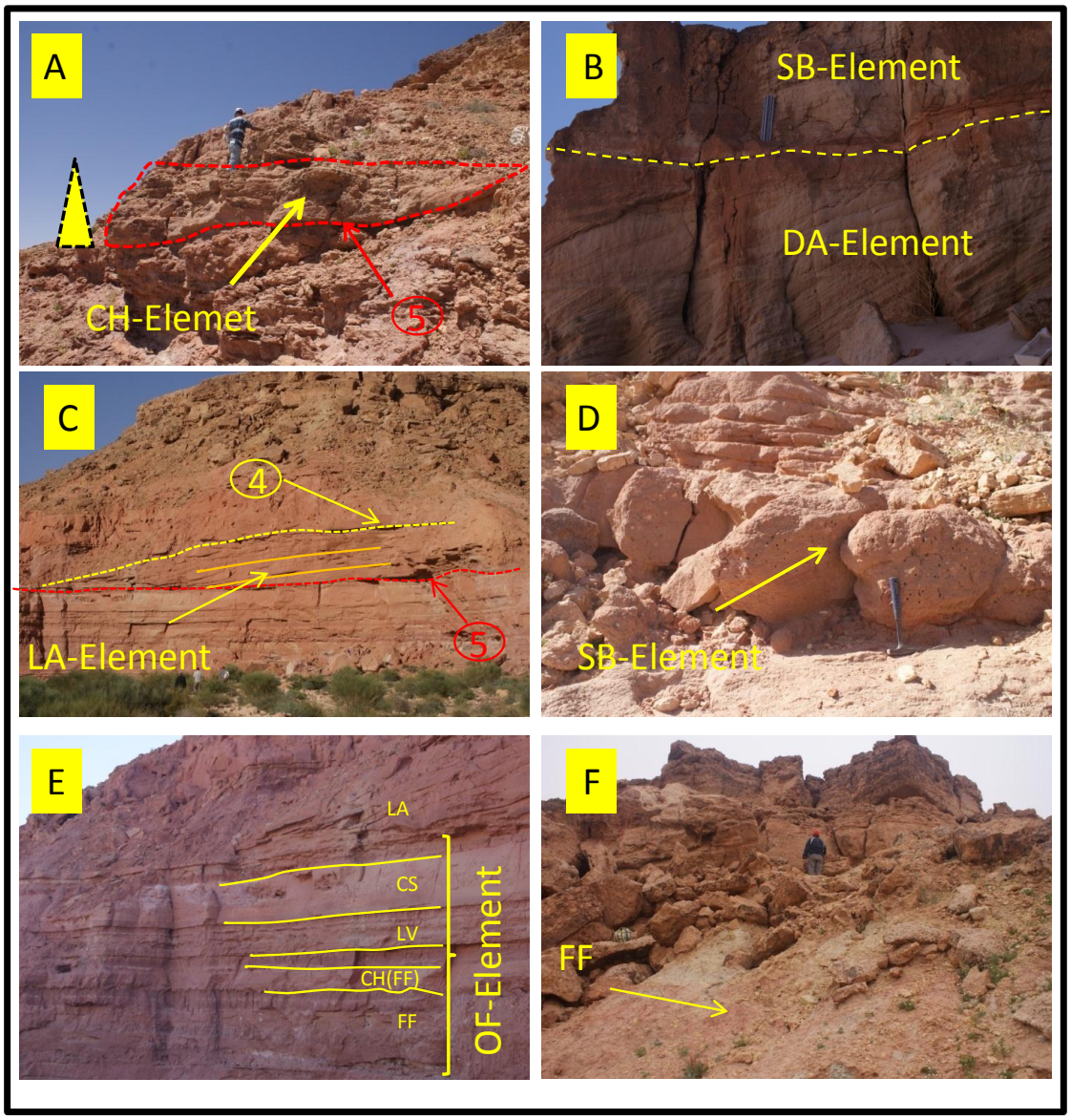


Fig 2.13 A channel (CH) cut and fill Basal fifth –order bounding surface. Erosively based with lags and irregular. **B** sandy bedform (SB) and Downstream accretion Elements separate with fifth – order surface. **C** lateral accretion (LA), fifth order surface at the base and fourth order surface at the top**. D** sandy bedform (SB). **E** overbank element (OF). CS crevasse splay, LV levee, abandoned channel CH (FF). **F** Floodplain element (FF).

2.3.2.1. Channel – fill elements (CH)

The rock units between fifth-order bounding surfaces are interpreted as deposits of major channels. Although complete major channel forms were not found relatively steep erosional surfaces. Unidirectional palecurrent from strata overlying fifth-order surface support a channel interpretation (Fig 2.13A) a Channel elements are best seen in study area. A fining-upward trend is apparent with channel fills which comprise lithofacies Gt, and St, Sp. Few abandoned channels in the Al Mrabah area are filled with Sr and Sh lithofacies. Channel deposits have sharp erosional bases with relief of about 2 m at the Gnawan, and Al Mrabah, but only 1.5 m at the Kabaw locality. Their geometry is of the concave-up channel shape, occasionally forming multi-storey channel geometry. Channel thicknesses are up to 4 m in the study area, and rarely reach up to 8 m. Channel widths vary between 150 and 300 m. The average width/thickness ratio is 15.6 within the whole studied area, 21.4 at Al Mrabah area, and 14.2 at Kabaw and at the Gnawan section the area reaches to 11.1. Regional observation record decreasing width/thickness ratios from the Al Mrabah to the Gnawan area direction.

2.3.2.2. Sandy bedforms elements (SB).

The sheet-like bodies of sand beds show an upward transition from a scoured base through Sh, Sp or St, to Sr and Fl or directly to Fl . They have sharp bases and are often eroded by channels (Fig 2.13 B, D).The erosional relief of the sand bed forms can be up to 1 m, though at Gnawan it is only between 0.1 and 0.6 m. Sand bed forms are usually about 3 m thick, but occasionally reach the thicknesses of up to 7 m (at Al Mrabah area). Their widths vary between 150 and 250 m in most cases at the Al Mrabah, Kabaw and Gnawan sections, whereas at the Al Mrabah locality the thickness is only between 3 and 10 m. The average width/thickness ratio is 28.5 within the whole studied area.

2.3.2.3. Lateral accretion macroforms elements (LA).

The lateral accretion elements deposited depending on the grain size of the sediment load , and the meander geometry, transverse flow across the accreting point bar. In the study area there is large panoramic view of point bar lateral accretion in Wazen section. (Fig 2.13C, E) LA accretion elements with thickness about 8 m laterally extend about 30 m. and separated from the other overbank element the base by fifth –

order surface and fourth- order surface from the top. At Al Mrabah section LA elements well occur at the upper part with thickness about 2m and width about 5m.

2.3.2.4. Downstream accretion macroforms elements (DA).

The downstream accretion microforms comprise facies St, Sp and Sh (sandstone bed form deposits). Downstream accretion macroforms record channel deposition, their geometry is sheet-like. (Fig 2.13B). Which are recognized in Al Mrabah and Kabaw sections only. Downstream accretion macroform thicknesses are up to 2 m, and widths vary between 100 and 150 m. Accretion surface interpretation is based on knowledge of the paleocurrent direction, in cases where paleocurrent directions are sub parallel to the accretion surfaces, they are considered as downstream accretion.(Miall 1996).

2.3.2.5. Overbank elements (OF).

The overbank deposits are particularly essential components of the deposits of rivers bearing a fine - grained sediments load, including fine-grained meandering rivers. The upper parts of Kiklah Formation are characterized by dominant overbank deposits which indicate of meandering river. OF elements comprise lithofacies Fl, Fm, with minor Sh, Sl and varicolored. They have usually planer or gently concave-convex to sharp distinct bases and top is erosively. Overbank elements are usually > 10 m thickness but occasionally reach to the thicknesses of up to 20 m at Wazen area. And their widths vary between 150 and 250 m. which consist of levee (LV), crevasse splay (CS) and abandoned channel (CH (FF). (Fig 2.13 E, F).

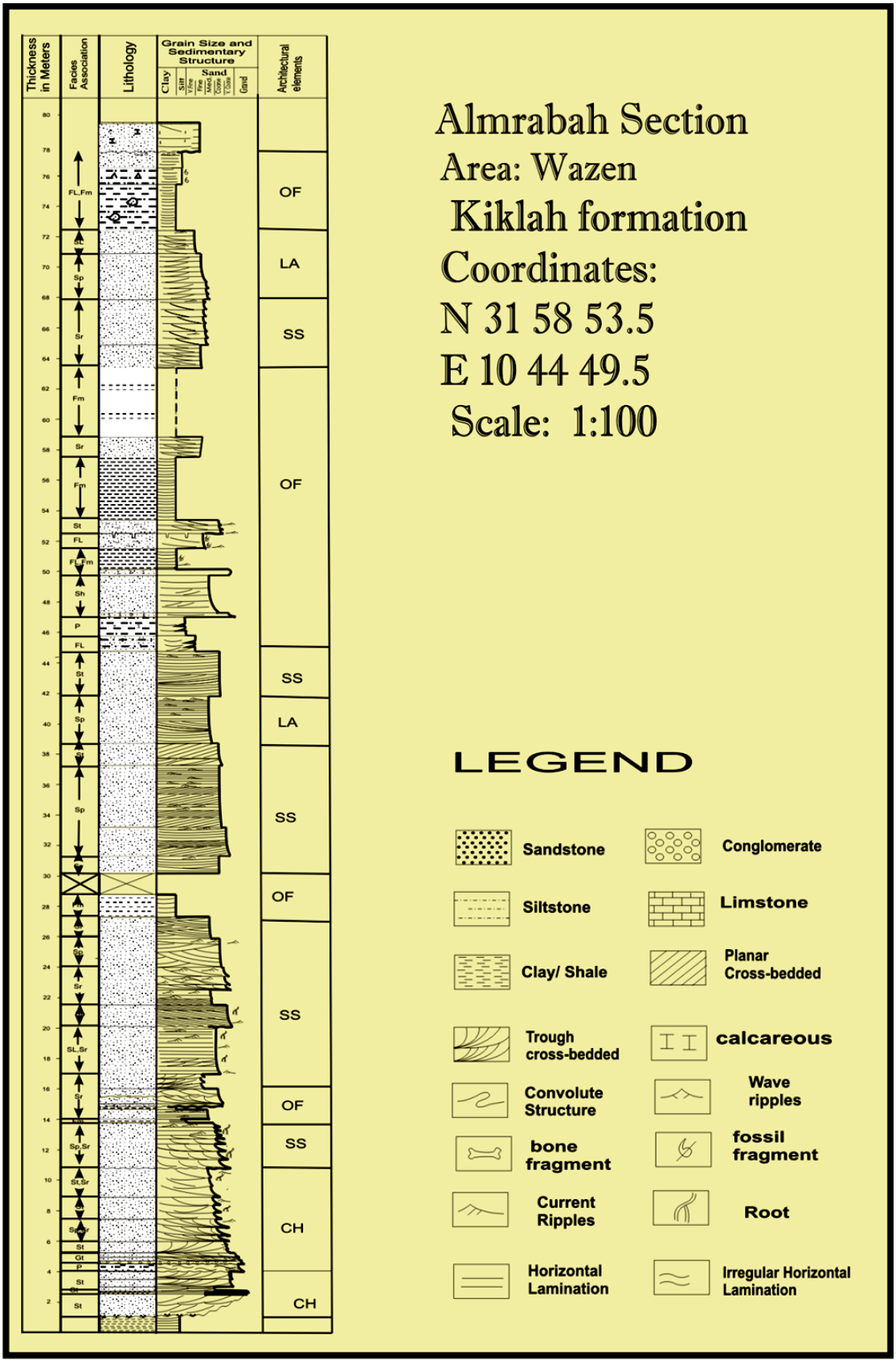
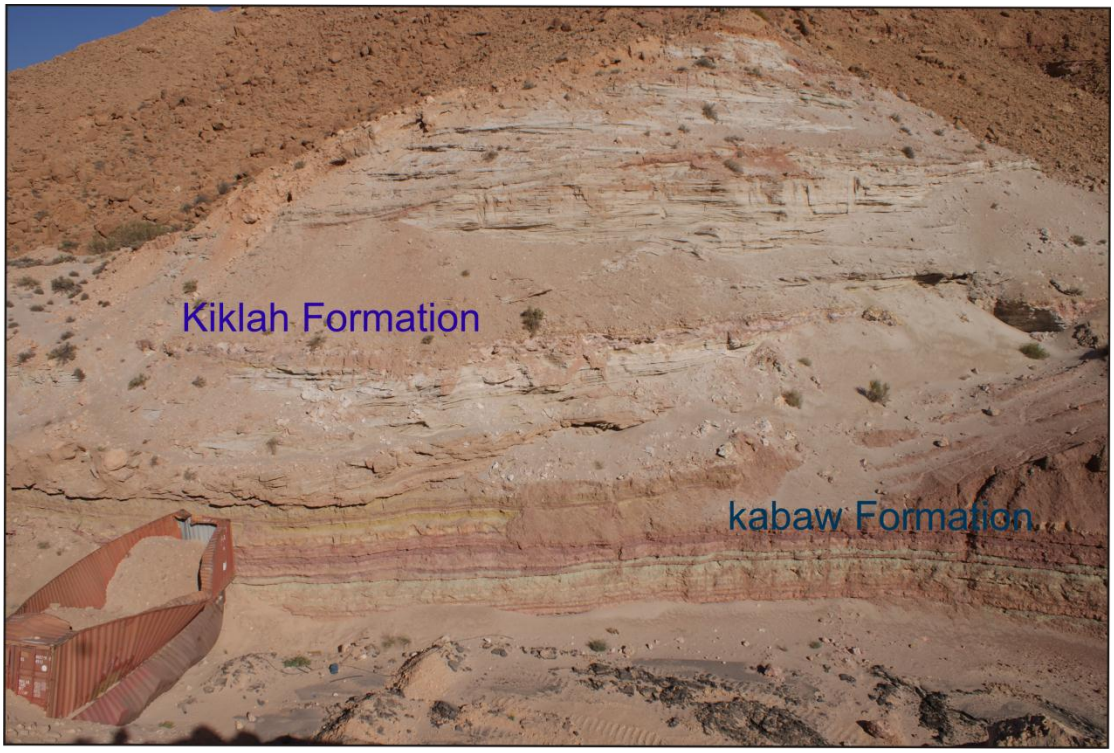


Fig. 2.14 Vertical Al Mrabah section at the Wazen area showing the stacking patterns sand architecture Element**.**



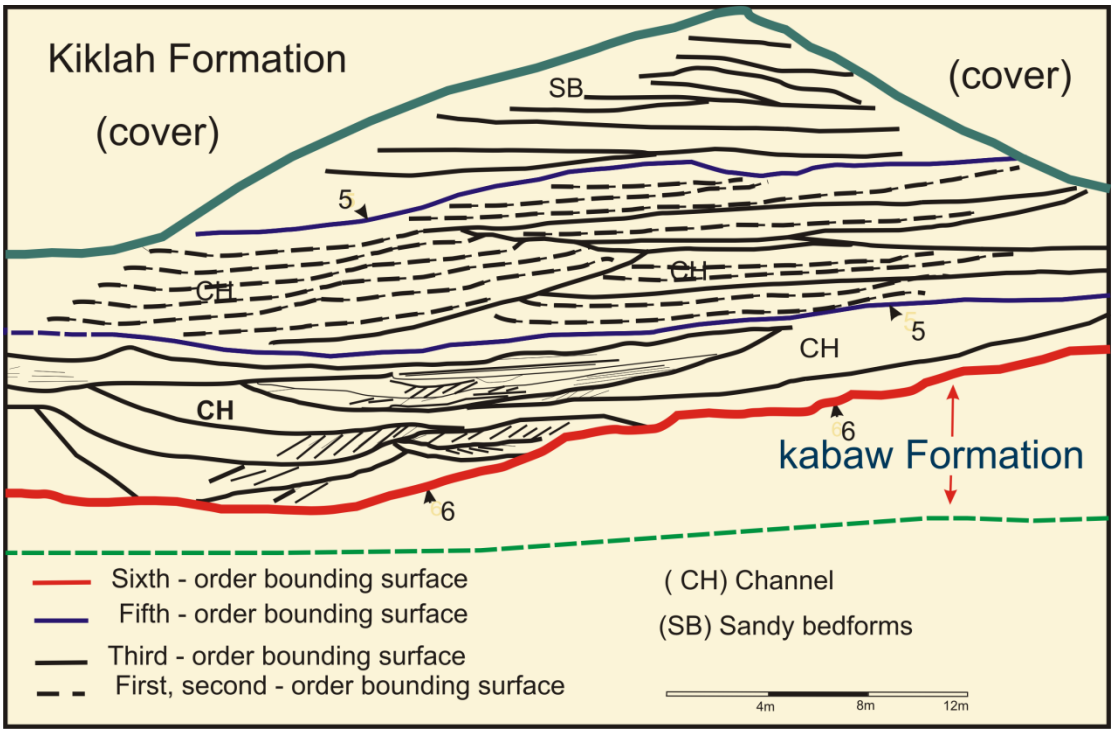


Fig. 2.15 General view lower part of Kiklah Formation at Al Mrabah section and its interpretion.

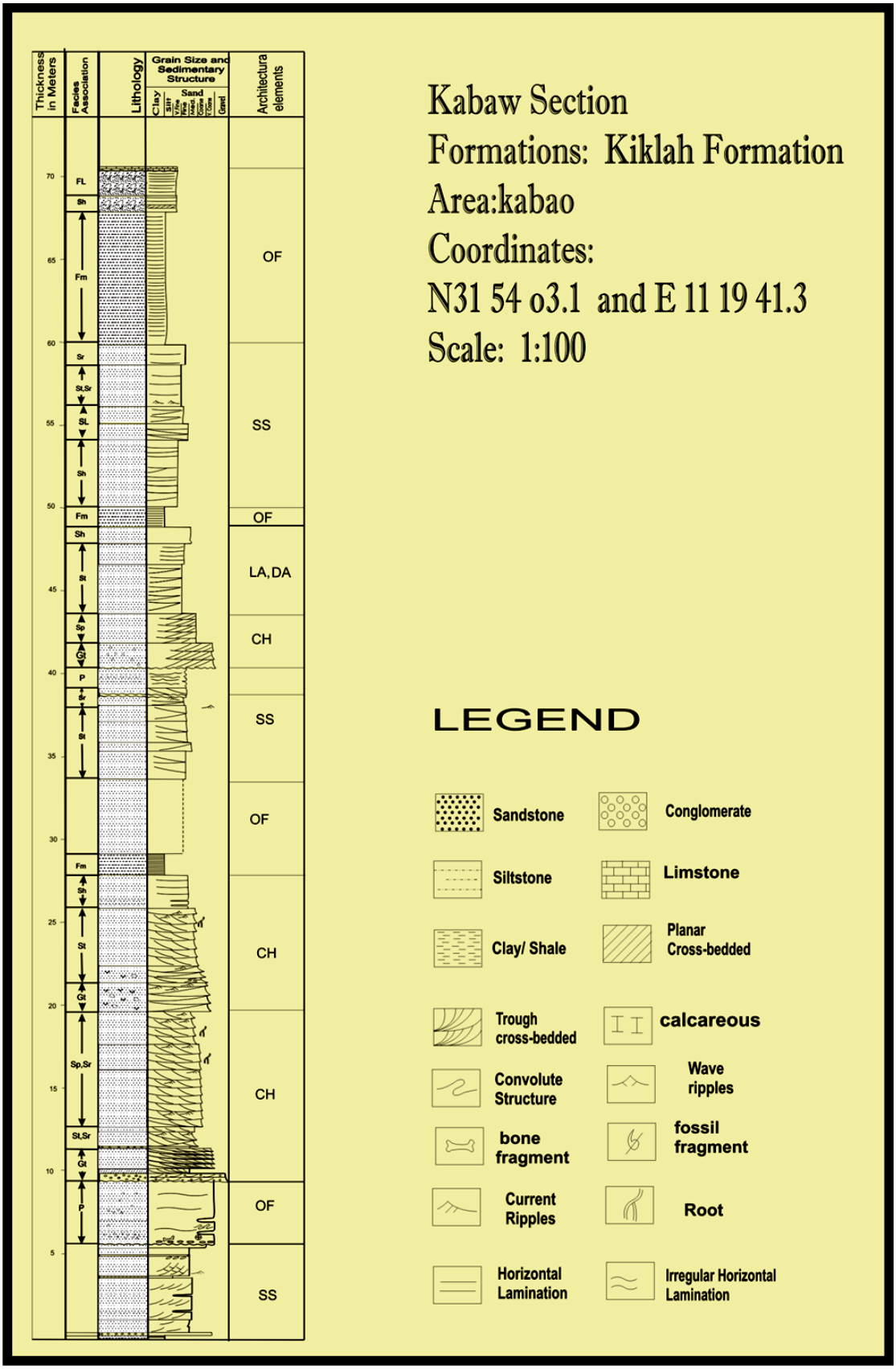
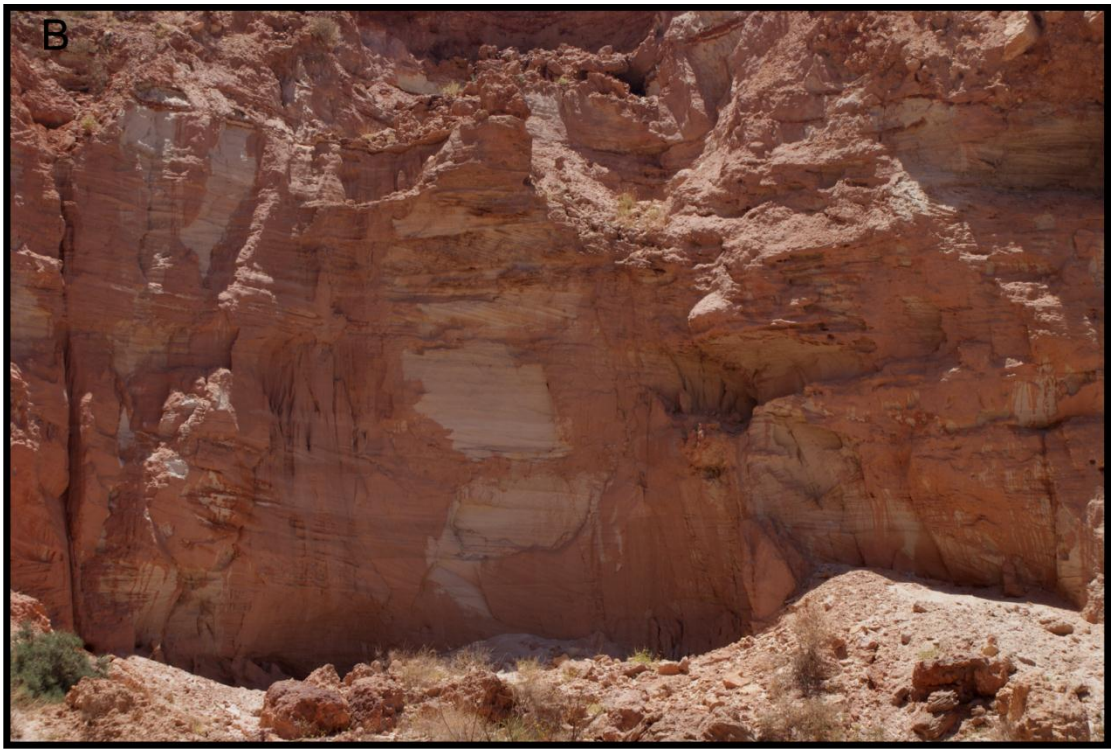


Fig. 2.16 Vertical section at the Kabaw area showing architecture elements.



Fig. 2.17 General view of lower part of Kiklah Formation at Kabaw section and its interpretion.



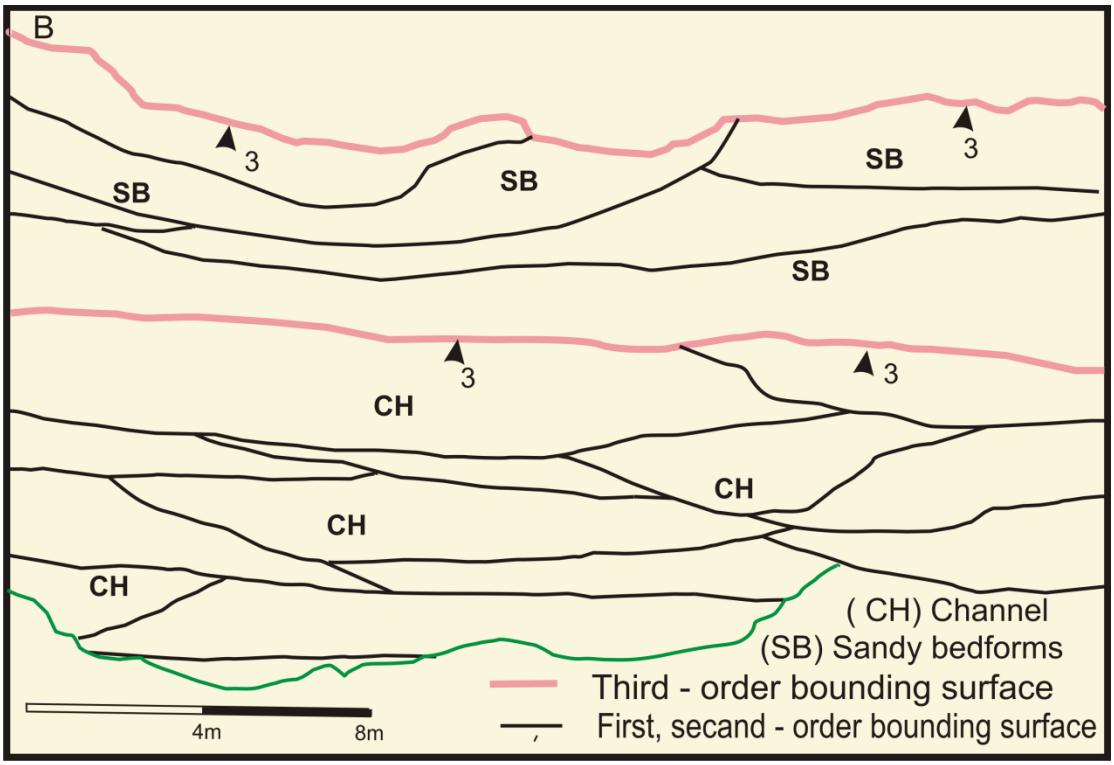


Fig. 2.18 General view of the outlined area (B) in Fig. 2.17 showing the lower part of Kiklah Formation at Kabaw section and its interpretion

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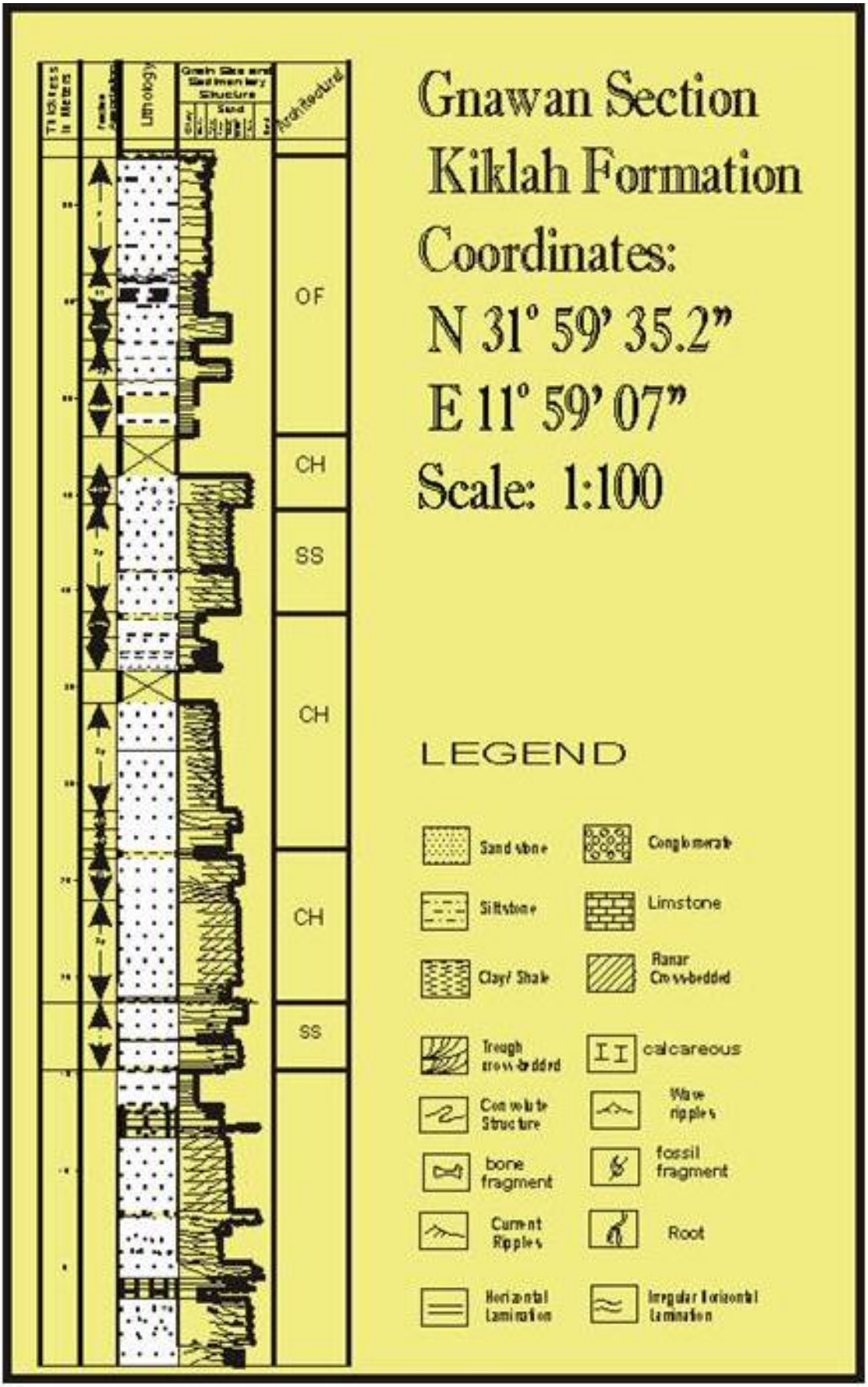


Fig. 2.19 Gnawan section at the Jadu area showing stacking patterns architecture elements.



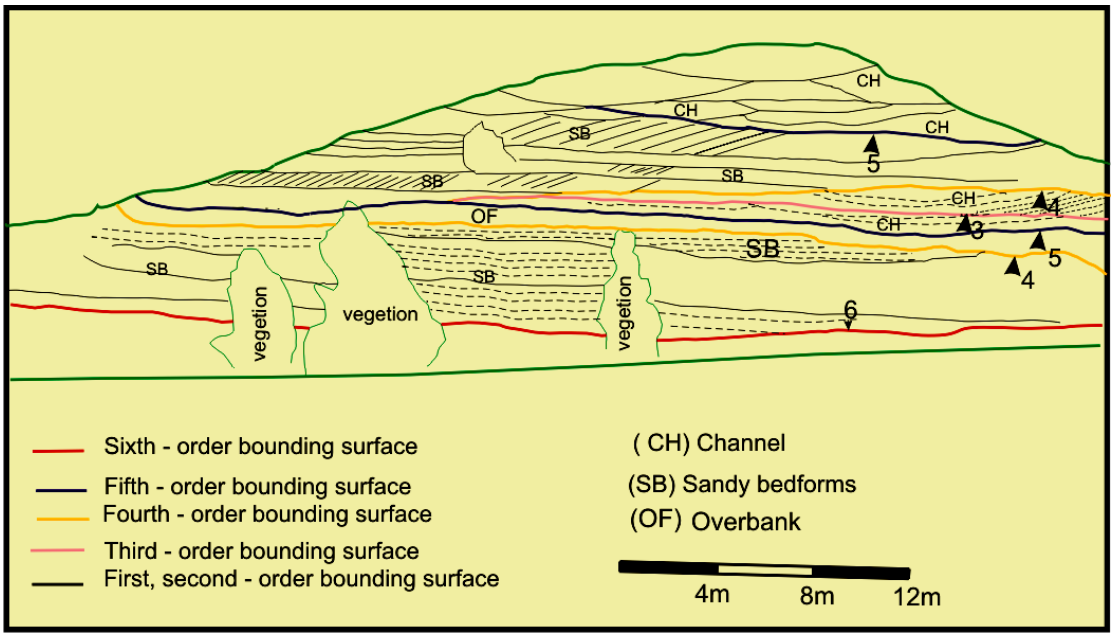


Fig. 2.20 General view of lower part of Kiklah Formation at Genawan section and its framework interpretation.

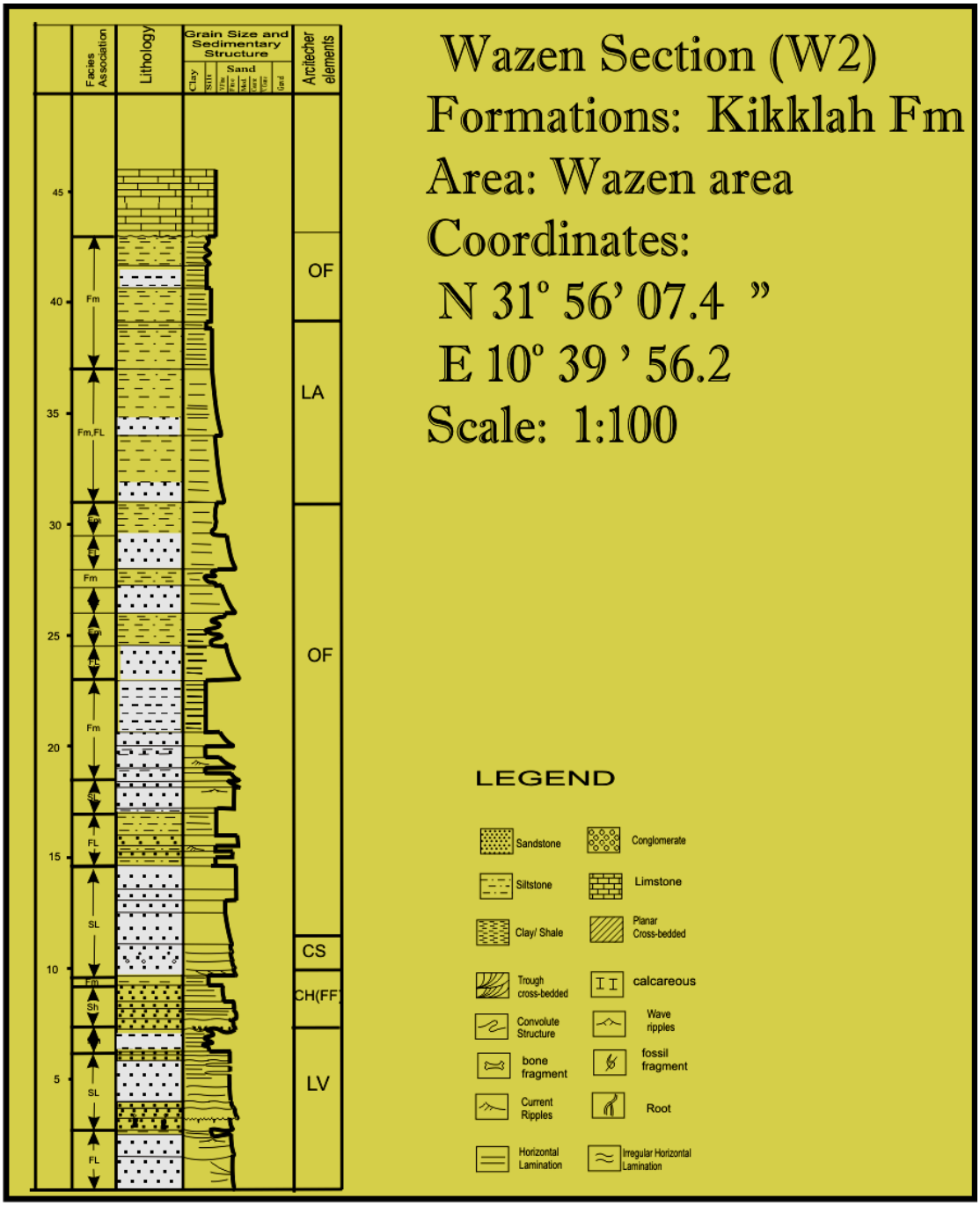


Fig. 2.21 Wazen section showing stacking patterns and architecture elements.

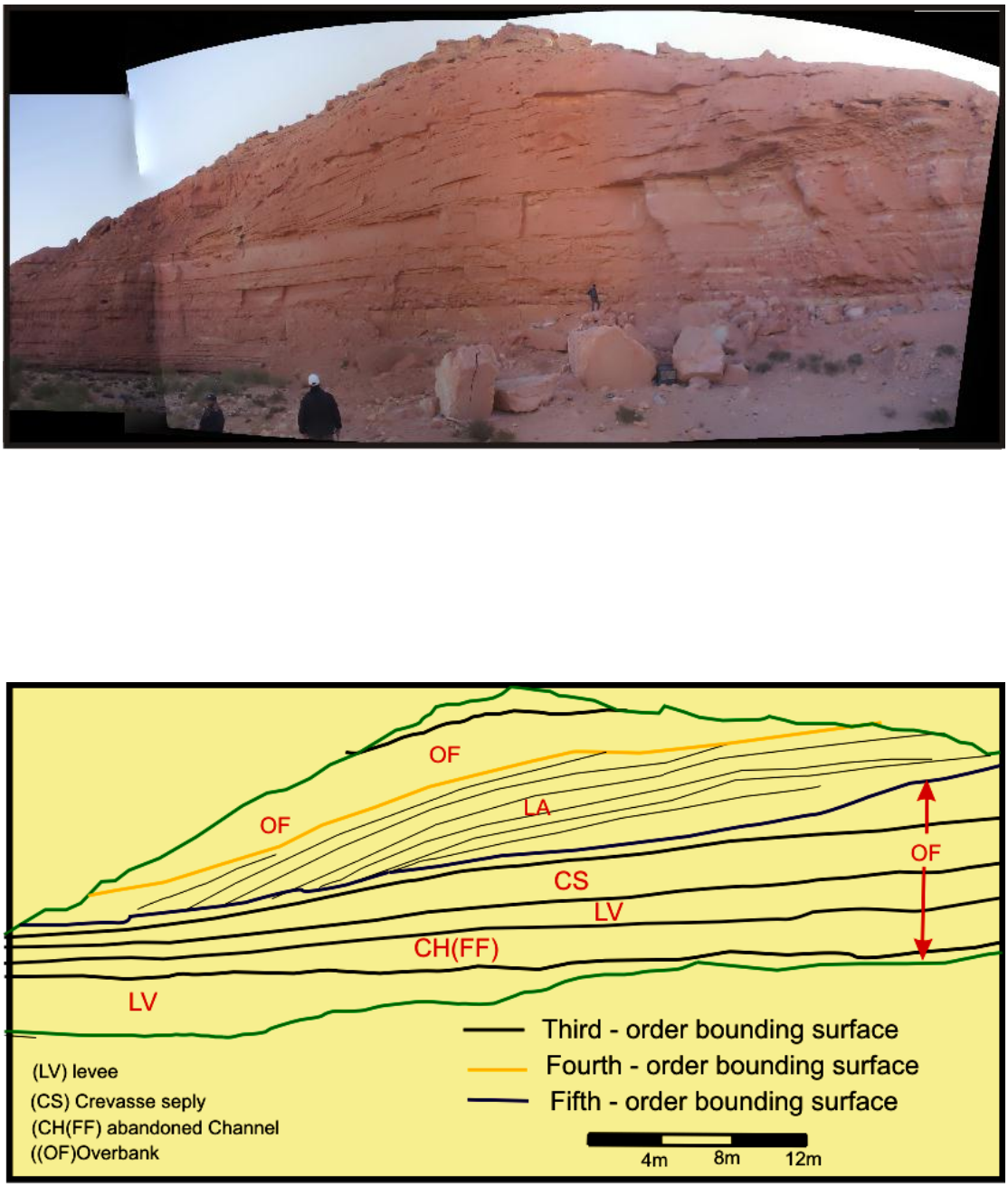


Fig. 2.22 Profile 4 of the Wazen section General view of meandering system including architecture elements and bounding surface.

2.4 Depositional Systems

The studied sedimentological sections are correlated together through the study area in order to understand the distribution of majer systems that acted during Kiklah Formation deposition. Three major depositional systems are recognized, these are: Braided river system, Meandring river system, and Flood plain system.

2.4.1 Braided river system

The low sinuosity braided river descriped from the lower part of the Kiklah Formation (Fig. 2.23), and is well preserved in outcrops throughout the study area. The maximum measured thickness of the low sinuosity braided river is 35 - 40m. The braided river system comprises five lithofacies Gt, St, Sp, Sr and F. which stacked in four architectural elements CH elements, (SB) elements, (DA) elements and rarely (OF) elements, which exposured in four localities Al Mrabah, Kabaw, Gnawan and Arryaina (Fig. 2.26). The described lithofacies are usually arranged in finning-and thining upward successions, characterizing waning-flood sycles beging with a coarse-grained and pebble of large scale trough and planer cross bedded sandstone (lithofacies Gt, St, Sp) followed by small scale trough and planer cross bedded together making up almost the whole of the cycle, in case of well-preserved cycle, the top of cycle often is formed of a ripple cross lamination fine grained sandstone (lithofacies Sr) followed by a mudstone layers (lithofacies F) usually no complete cycle have been found in the field area, where the cycle are terminated only by lithofacies St, Sp and usually Sr. The development of lithofacies Sr, F must have been limited because the coarse mean grain size of the sedimens would not have permitted to formed of current ripples and Mud. The cycle thicknesses vary from 1.5 to 11 m, but are commonly 3.0 to 7.0 m, the finning upward cycle always bounded by erosional surface, which can sometime be traced laterally throughout considerable distance; the rising-flood phase continually scoured the alluvial surface and eroded parts of the top of the preceding cycle. Based on Miall 1985 classification, The Lower part of Kiklah formation interpreted as distal, sheet flood, sand-bed River. This Model is characteristic of distal plains, particularly in arid regions where ephemeral runoff forms a network of shallow. An architectural model is given in (Fig. 2.23) the

sediments are dominated by sheets, lenses and wedges of elements SB, consisting of a wide range of sandy lithofacies, flood cycles up to a few meters thick may be preserved (Miall and Gibling 1978, Munoz et al. 1992)

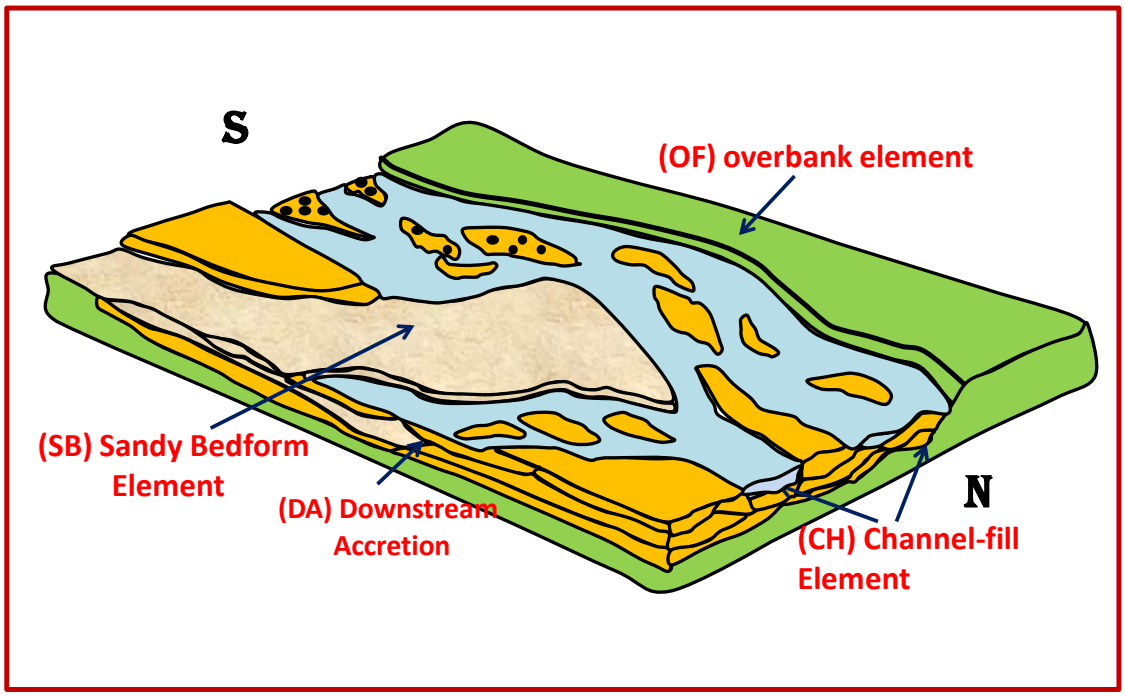


Fig. 2.23 Proposed Depositional model of the lower part of Kiklah Formation.Modified after Miall 1985.

2.4.2 Meandering River system

The high sinuosity Meandering River occurs in the upper part of the Kiklah Formation unconformably overlying the braided river system of the lower part of Kiklah Formation (Fig. 2.24), and is well preserved in outcrops throughout the study area. (Fig. 2.26). The thickness of meandering river system ranging from 4-25m, where its maximam thickness is measured from wazen area. The meandering river system comprises six lithofacies (St, Sp, Sh, Sl, Fl, Fm). Where are stacked in Three architectural elements. LA lateral accretion, DA downstream accretion macroforms and OF overbank elements exposed in the whole study area. In the western part of the study area an excellent outcrops of lateral accretion are observed in Wazen area, (Fig 2.13C,E) with thickness of about 8 m and laterally extend to about 30 m. where are

separated from the overbank element at the base by fifth – order surface and from the top by fourth- order surface. Also, at the lower part of this section illustrated levee (LV) extend laterally about 100m, consist of rhythmically bedded of silt, Mud, ripple-laminated sand a few centimeters thick (Fl lithofacies), levee element may reach 8m in thickness, crevasse splay (CS) also well expose in the same section, form lens-shaped up to 30m wide and typically 2-3 m thick, probably cut by their feeder crevasse channel and interfinger at their margins with fine-grained floodplain deposits, the bounding surface of suplay is fourth- order surface. (Fig 2.13 E&F). According to architectural characteristics of some fluvial styles described by Miall (1985), the above description probably resembles the sandy meandering type.

2.4.3 Flood plain

The flooding plain occurs in the upper part of Kiklah Formation is well preserved in outcrops and laterally extended through all study area and various in the thickness about 20-25 m in Wazen, Al Mrabah area, 10-15 m in Kabaw, Gnawan and Arryaina area, composed of mud, silt, reddish brown, light green in colour, massive, poorly bedded in some parts, which composed essentially from Fm lithofacies, FF elements, (Fig. 24, 26).

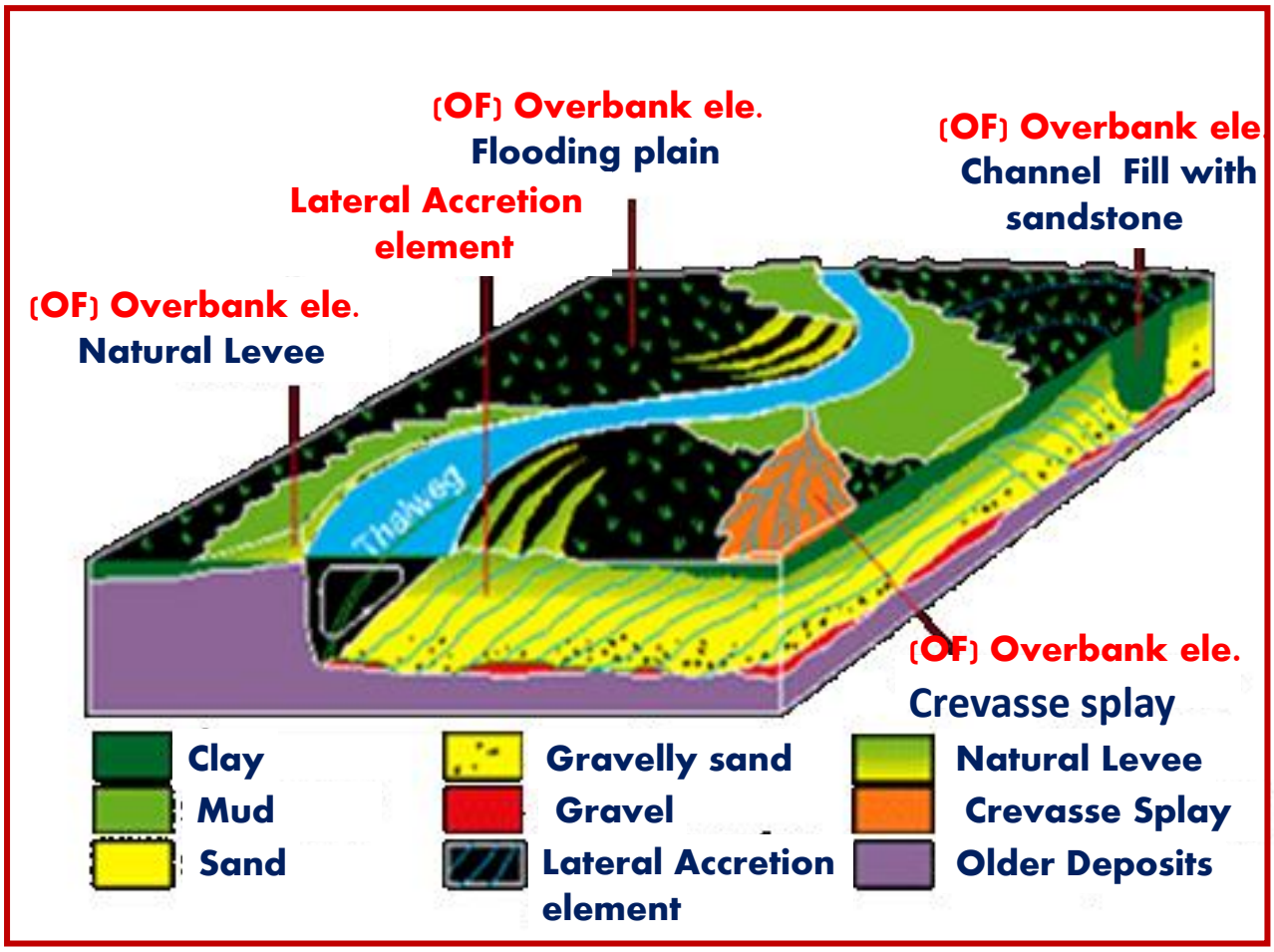


Fig. 2.24 Architectural model for sand –bed meandering stream. after Miall (1985) represent the upper part of Kiklah Formation.

2.4.4 Paleocurrent

Paleocurrent measurment were taken from trough cross stratification (lithofacies St), planar cross stratification (lithofacies Sp) and from pebble orientations in (lithofacies Gt). Show mostly unidirectional trend, (Fig 2.25). The mean paleoflow is essentially toward the northwest. This is consistent with previous studies conducted by such (El-Zouki, 1980).

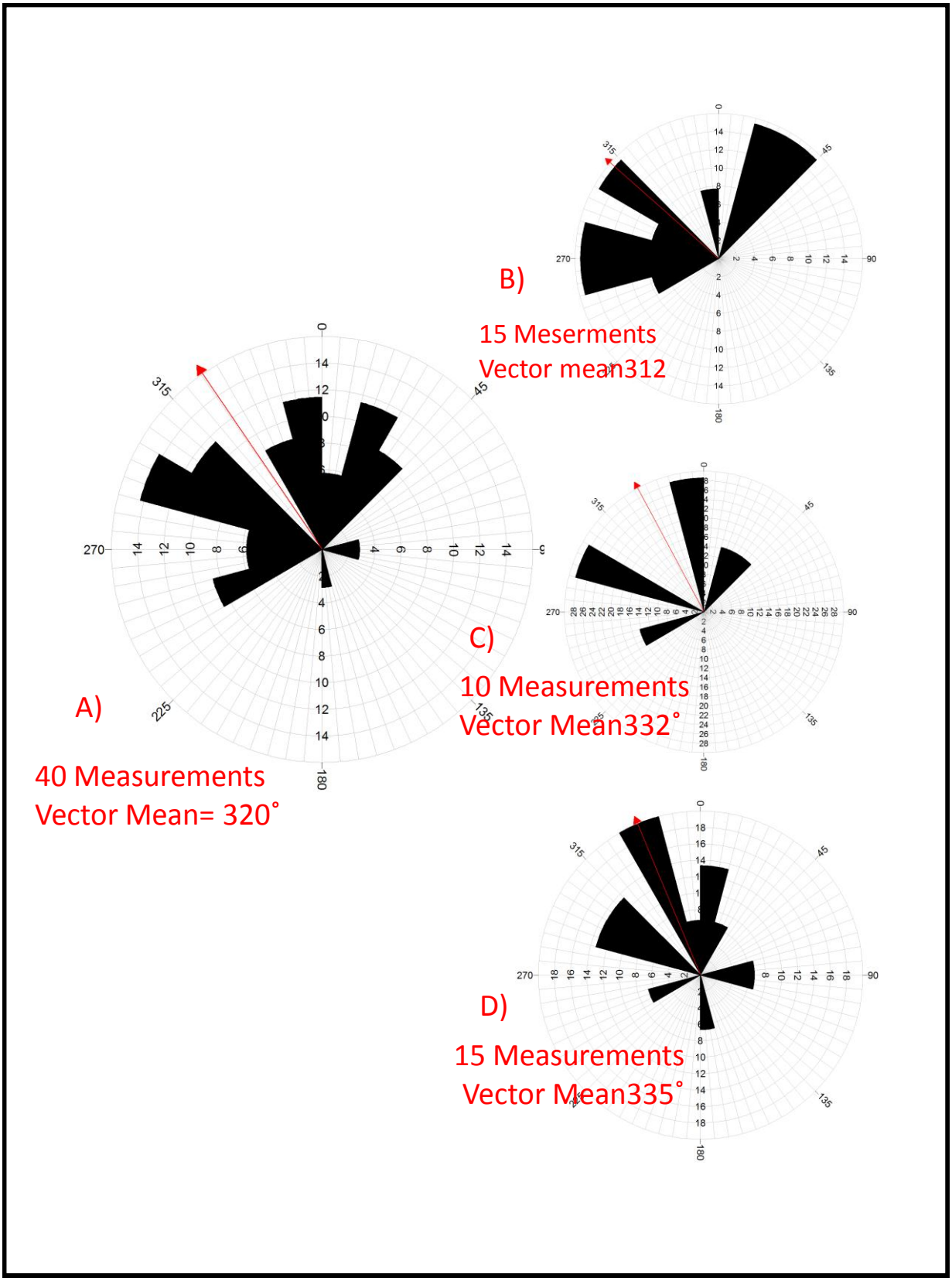


Fig. 2.25 Paleocurrent data from the lower part (braided system) of Kiklah Formation. Rose diagram (A) summarizes 40 reading from the whole studied area diagram (B) is from Al Mrabah section (C) from the Kabaw section, and (D) from Gnawan section.

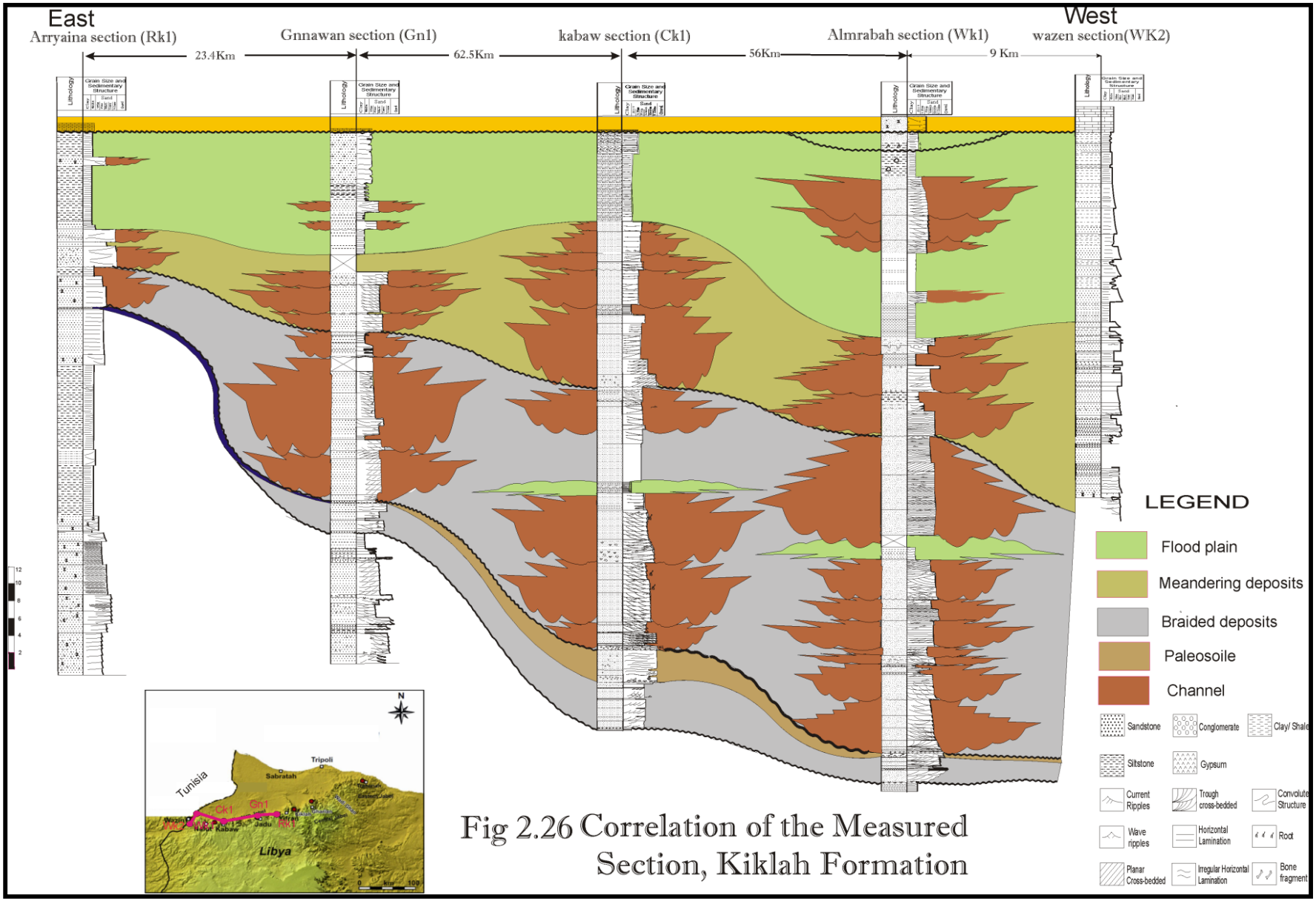


Fig 2.26 Correlation of the Measured Section, Kiklah Formation

Chapter 3

Petrographic Study

3. Petrography Study

3.1 Introduction

The sediments of Kiklah Formation can act as reservoirs for hydrocarbon, which can be correlated to the very important hydrocarbon reservoir Nubian and/or Sarir Formations in Sirt Basin. The studied samples expose variable reservoir properties most likely related to several complex interrelation factors such as depositional texture, climate, mineralogy, tectonic situation, basin burial history (Morad et al., 2000). As mentioned earlier Kiklah Formation were deposited into three Geological setting; braided river system, meandering River and Flood plain, This section describes the detrital and diagenetic composition using polarized microscope to improve our understanding of the diagenetic history and its relationships with depositional architecture. This petrographic study will focus on the lower and middle parts of Kiklah Formation which were deposited by braided and Meandering Rivers.

3.2 Petrography of Braided System

3.2.1 Sandstone Classification

11 samples were selected from the lower part of Kiklah Formation (braided system). And prepared for petrographic study (for methodology of study see chapter 1) using the polarized microscope.

Using the Dott (1964) scheme of sandstone classification, modified by Pettijohn (1974) (Figs.3.1) the samples plot in the fields of quartz arenite (8 samples), subarkose (1 samples), Sublitharenite (2 sample). Monocrystalline quartz grains 75-95%, and feldspar content 1-10%; with detrital matrix between 1 to15% of the total framework.

3.2.2 Texture

The samples usually show a wide range of textural properties, however, the St Lithofacies and Sp lithofacies reflect more homogenous textural properties than the Gt lithofacies (petrographic data sheet of braided river in appendex 4). In Gt lithofacies the sediments show a wide grain size ranging from very fine-upper to coarse-lower grain sizes. The grain size mode is very fine to medium-grained in the St, Sp, while the Sr are characterized by very fine lower to medium grain size. The sorting is poorly to good and very good in the Sr lithofacies, usually moderately sorting with few poor in the Gt lithofacies (Fig. 3.2 A and B). The sandstone is usually grain-supported, and the grains

show subangular to subrounded grain shapes with straight to point and concavo-convex grain contacts. (Fig. 3.2 A, B and C). The sandstones are often structureless at the microscopic scale few are laminated, in the Sr, Sl lithofacies. The majority of the samples contain no detrital matrix only 3 samples in the St, Sr display1-15% of detrital mud matrix. (Fig. 3.3 D, E and F).

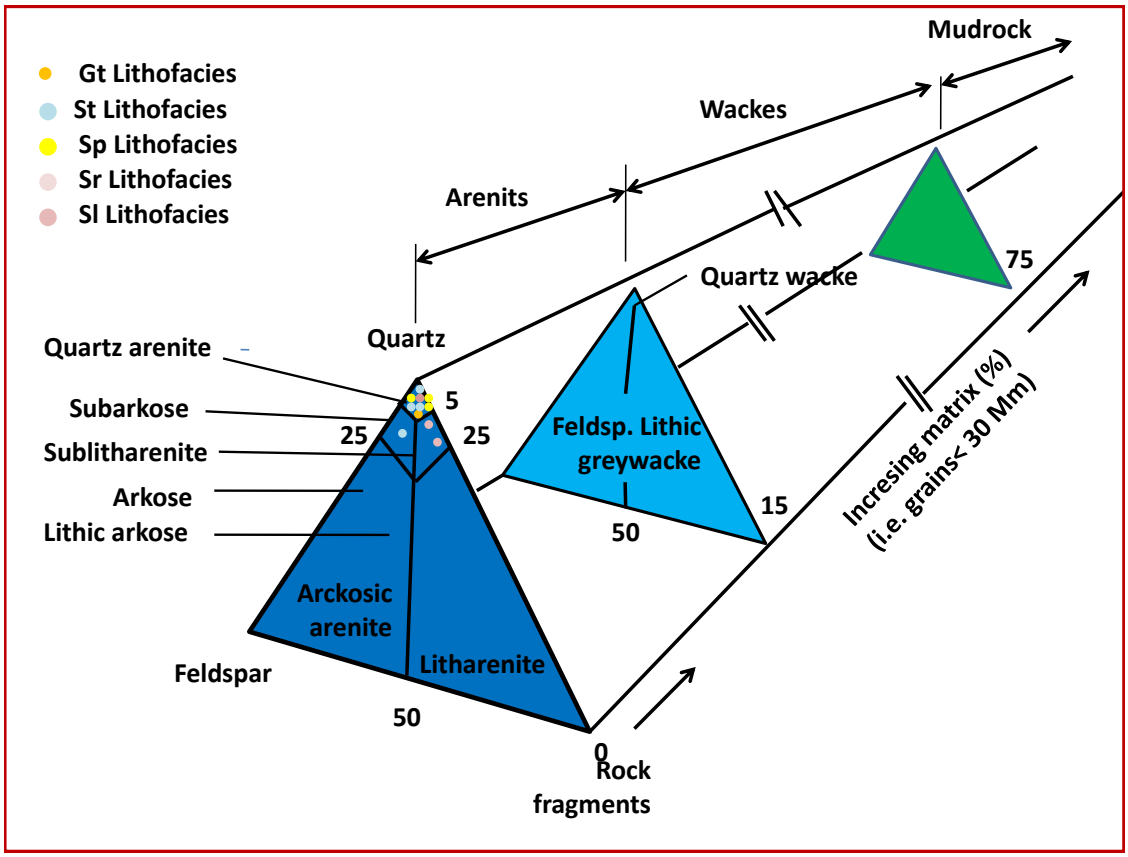


Fig .3.1 Classification diagram showing the detrital composition of the Lower part of Kiklah Formation along the study area

3.2.3 Detrital Composition

3.2.3.1 Monocrystalline quartzes the principal detrital components (petrographic data sheet of braided river in appendex 4).) Represented by strained and unstrained grains, up-to 95% of the detrital grains (fig. 3.2 A, b & C). They generally form 50- 65% of the total framework (in Gt lithofacies) and 55-75% (in St, Sp, Sr lithofacies) of the total volume. In some cases, the samples contain minor percentage of monocrystalline quartzs (1-30%) per total volume. The percentage directly relates to the sorting where better sorting sandstones show higher percentage of quartz grains.

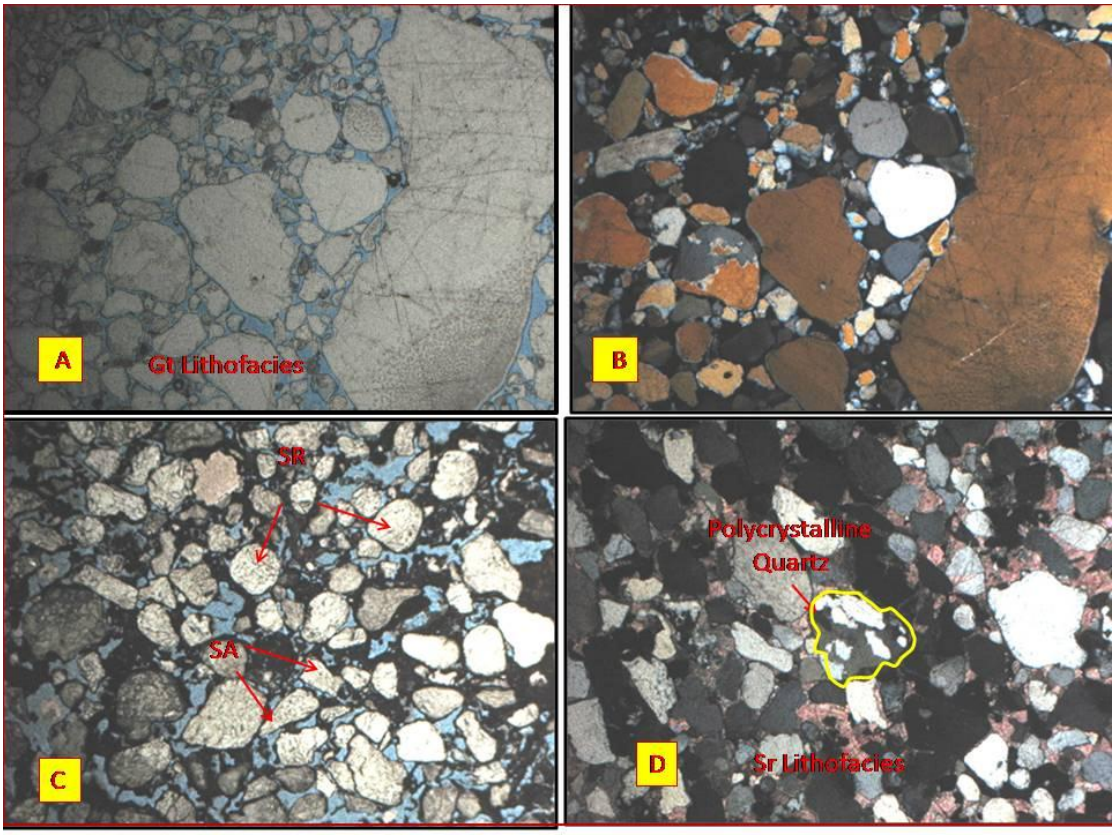


Figure 3. 2. A) this figure shows monocrystalline quartz grains, Poorly sorted sediments with subangular to subrounded grained in Gt Lithofacies. Plane polarized light (PPL), field of view = 2.5 mm. **B)** the same of previous figure but with crossed polarized light (XPL). **C)** This figure shows Sr Lithofacies quartz, subangular to subrounded, concavo- convex and point contacts with clay content. PPL, field of view = 10 mm. **D)** This figure shows Polycrysalline Quartz graine in Sr Lithofacies, moderately sorting, with straight contact in some grains. XPL, field of view = 2.5 mm.

3.2.3.2 Polycrystalline quartz essentially consists of composite subcrystals found at trace- very little levels in the Gt lithofacies sediments. The St Lithofacies contain minor amounts (0-4%) of the detrital framework and (0 to 2%) of the total volume (fig. 3.2D);

3.2.3.3 Feldspar grains are usually absent in Gt lithofacies, but they are observed in the St Lithofacies where they account for 0-7% per total volume. Feldspar proportions are 0-5% in Sp lithofacies and 0-2% in Sl lithofacies, Feldspar are often non-twinning (probably orthoclase; (figs.3.3C), sometimes plagioclase and microcline (fig. 3.3A). The St, Sp lithofacies shows higher amounts of feldspars (0- 9 %) of the detrital grains and (0-7%) per total volume, mostly represented by non-twinning (probably orthoclase). In the western of study area (Al Mrabah, Wazen section) the feldspar grains are rare or absent in all Lithofacies except in the uppermost Sl lithofacies where they represent 0-

2.5% of the detrital grains and 0-2% per total volume. They are generally non-twinning (probably orthoclase).

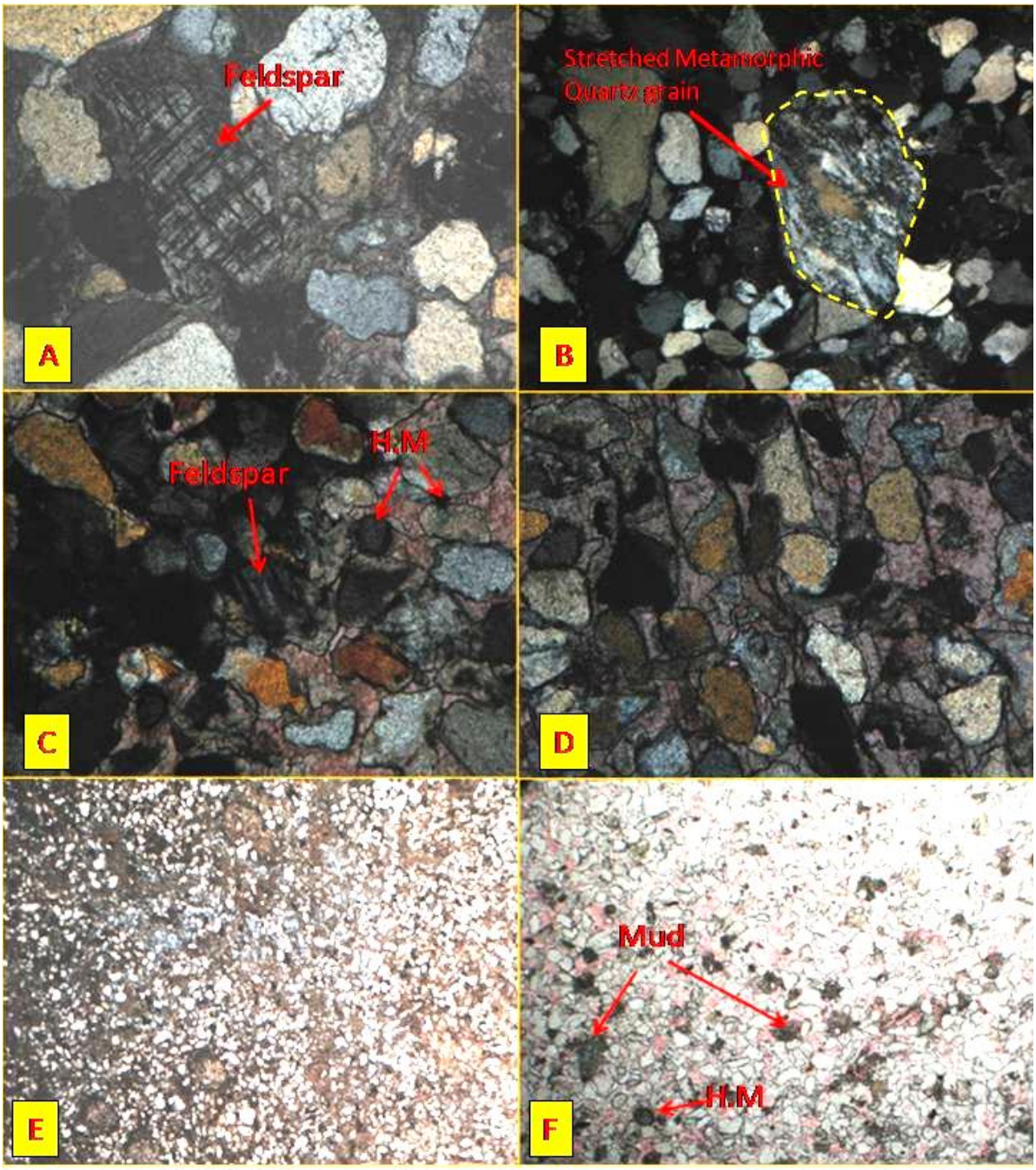


Figure 3. 3. A) this figure shows content of detrital feldspar where are not alternated. XPL, field of view = 20 mm. **B)** This figure shows content of Stretched Metamorphic Quartz grain, XPL, field of view = 2.5 mm. **C)** This figure shows content of detrital Quartz ,feldspar partial cemented with calcite with rear Heavy minerals. XPL, field of view = 10 mm. **D)** This figure shows calcite cemented with lamination structure. XPL, at thickness 1m., field of view = 10 mm. **E)** This figure shows Mud support filling porosity PPL, field of view = 2.5 mm. **F)** Mud intraclast shows partial cemented with calcite with rear Heavy minerals. PPL, field of view = 2.5 mm.

Rock fragments are absent in all the studied samples.

Heavy minerals represent 0-3% of total volume. They almost found in all of the lithofacies in Gt lithofacies are 3% where probably 0-2% in all another lithofacies (fig. 3.3 C and F)

Detrital mica are absent in all the studied samples

Detrital mud (clay-silt) are observed in the St, Sp lithofacies which contain minor amounts(2 to 7%) of the total volume, where they contain (7-15%) in Sr lithofacies (fig. 3.3 E, F); but appears locally in the Sl lithofacies (10-70%) while counted (1-95%) in Fl, Fm lithofacies directly proportional to the sorting and lithofacies.

3.2.4 Authigenic Composition – Diagenesis

Diagenetic regimes used in this study, Morad et al. (2000) include: (i) eodiagenesis, which includes diagenetic alterations occurring at temperatures ≤ 70ºC (approximate depth is 2 km) and mediated by slightly modified depositional waters, (ii) mesodiagenesis, which includes diagenetic alterations occurring at temperatures > 70 ºC and mediated by evolved formation waters, and (iii) telodiagenesis, which includes diagenetic alterations occurring during uplift and incursion of surface waters into the sedimentary succession. There is unfortunately, no burial history curve available for the studied succession. Thus the burial depths and temperatures encountered during diagenesis will be inferred based on the type of diagenetic alterations.

3.2.4.1. Quartz overgrowth

The quartz overgrowth is the first diagenetic precipitate and characterizes early burial (Siever et al., 1962), but it can occur at any time in the diagenetic sequence (Hancock et al, 1978). The early quartz overgrowths can be seen under the microscope by a dust rim but good crystal terminations are rare or scarce (Fig. 3.4A). Late stage quartz overgrowths can be distinguished by the quartz filling the pore space which usually destroying the porosity, and being surrounded by crystals on the other sides, such kind of quartz overgrowth is not seen in the studied sample. Generally Quartz overgrowth is rare occurs in the studied samples, in Gt lithofacies where they account for 1-5% per total volume, where probably 1-3% in another lithofacies (St, Sp, Sr, Sl).

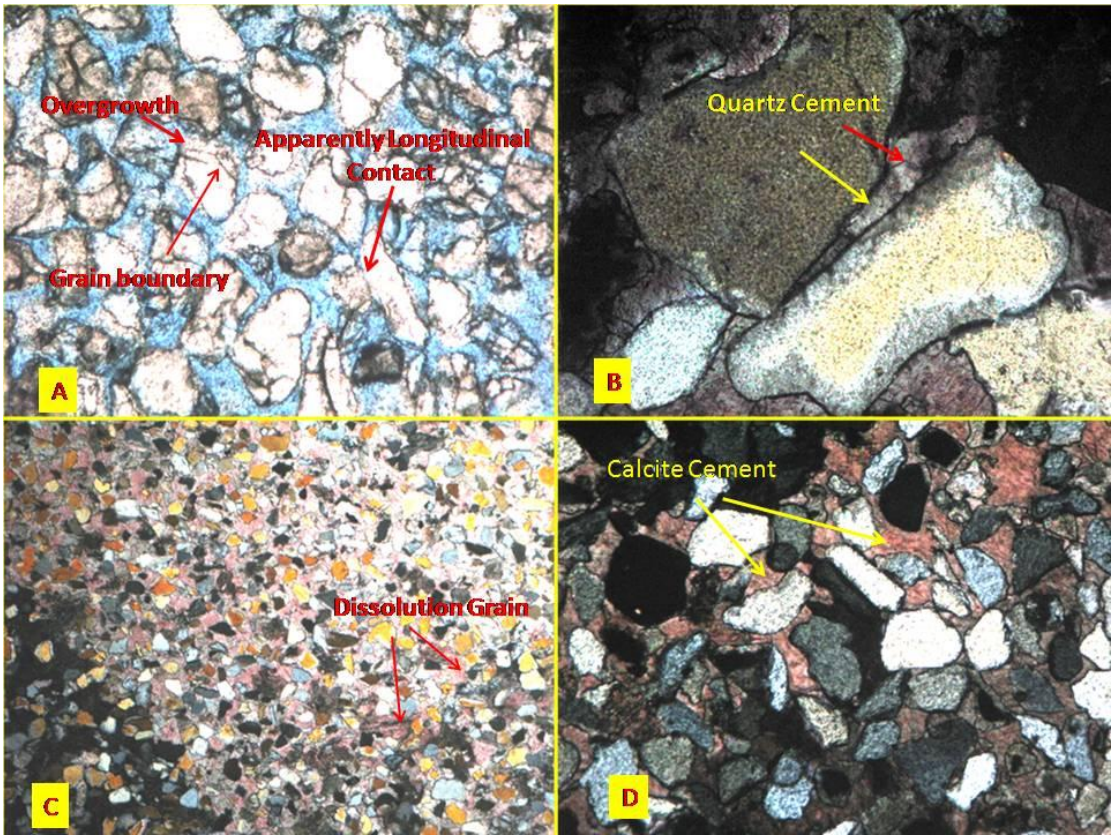


Figure 3.4. **A)** This figure showing quartz overgrowth probably of early stage, PPL, field of view = 2.5 mm. **B)** This figure shows silica cement which Partial of the primary porosity have been obliterated by quartz overgrowth, XPL, field of view = 20 mm. **C**) This figure shows authigenic Calcite filling porosity, and dissolution of feldspar grain , PPL, field of view = 2.5 mm.. **D)** This figure shows authigenic Calcite cement and filling porosity, XPL, field of view = 10 mm.

3.2.4.2 Calcite:

In some cases the blocky calcite crystals are riddled with tiny Fe-oxyhydroxide pigment and/or tiny remnants dolomite. Hence, these calcite crystals are, interpreted to have formed by calcitization of Fe-dolomite under oxic conditions, which is typically, mediated by meteoric waters during telodiagenesis (Morad, 1998). the calcite cement mostly observed in studied samples about (20-30%) per total volume, in St lithofacies where they account for 0-20% per total volume. 15-25% in St lithofacies, and 20-30% in Sp, Sr, Sl lithofacies.

3.2.5 Porosity

Absolute porosity refers to the total void space, but since some of this will be within grains, effective porosity is more important. It is the latter which determines the

reservoir properties of a rock, together with its permeability and the ability of sediment to transmit fluid (Tucker, 1991). Porosity in sandstone can be divided into three types, primary porosity, secondary porosity and microporosity.

In The studied samples usually show two types of porosity, primary and secondary porosity, however the primary porosity occur in the Gt lithofacies ranging (2-25%), where they contain (5-30%) in St, Sp lithofacies, and about 8% in Sr, Sl. The secondary porosity developed in the Sp, Sr, Sl lithofacies with (1-8%) per total volume which observed through the alteration of unstable detrital grains, especially feldspar. Secondary porosity after feldspar can be recognized in the thin section (Fig. 3.5 A, B, C, D). Where the lower part of study area (braided river) contain little detital mud and showing better sorting, render the dissolution process more effective to the porosity . The cement and matrix dissolution porosity were mostly found in braided river deposits. Therefore the braided river should be represented good reservoir of hydrocarbons.

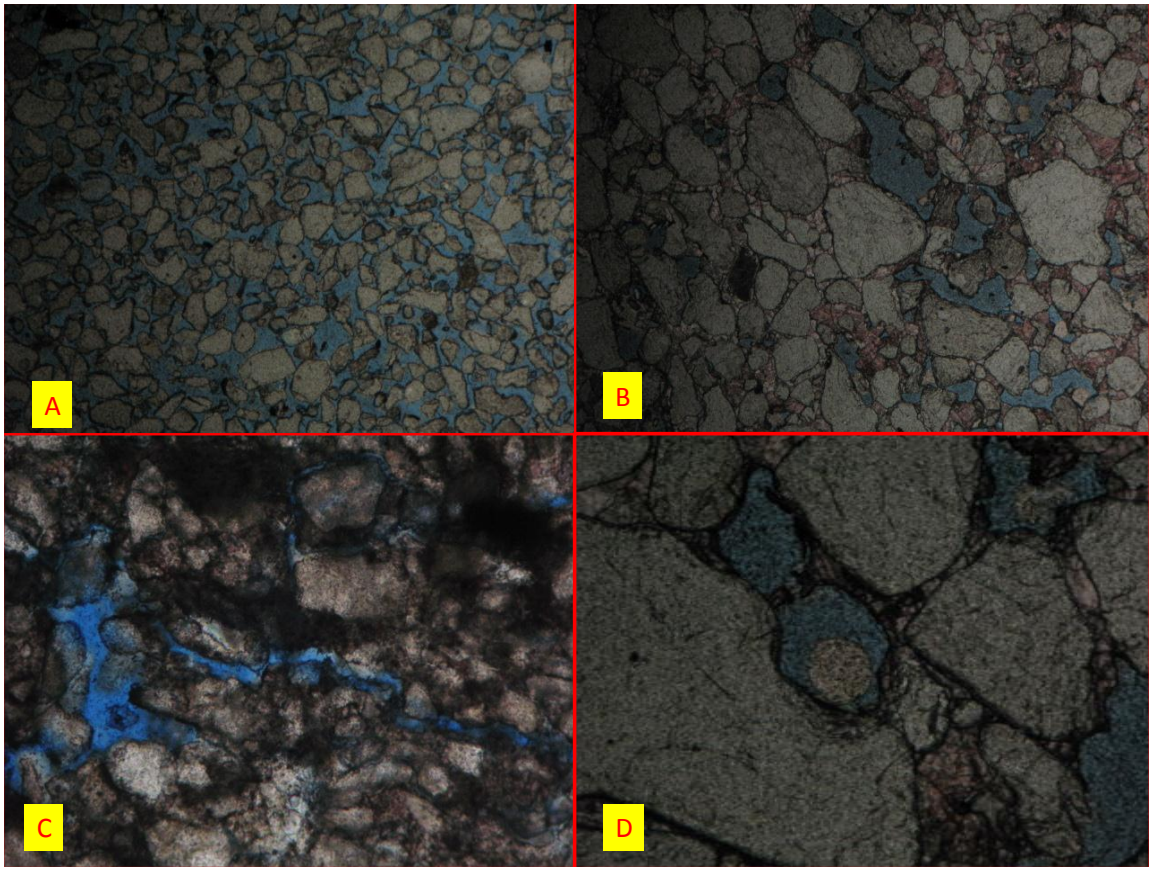


Figure 3.5 **A)** this figure shows high remnant intergraular porosity (marked with blue),). PPL, field of view = 2.5 mm. **B)** Dissolution of unstable detrital grains forms the essential type of the porosity. PPL, field of view = 2.5 mm. **C)** Dissolution processes are resulted excellent secondary porosity. PPL, field of view = 10 mm. **D)** unstable detrital grains show complete dissolution .PPL, field of view = 10 mm.

3.2 Petrography of Meandering System

3.2.1 Sandstone Classification

Only 3 samples were selected from the meddle part of Kiklah Formation (Meandring system). Because most of samples are friable, and prepared for petrographic study using the polarized microscope.

Using the Dott (1964) scheme of sandstone classification, modified by Pettijohn (1974) (figs.3.6) the samples plot in the fields of Quartz arenite (2 sample) and Quartz wackes (1 samples). Monocrystalline quartz grains 50-63%, and feldspar content 0-1%; with detrital matrix between 2 to7 % of the total framework.

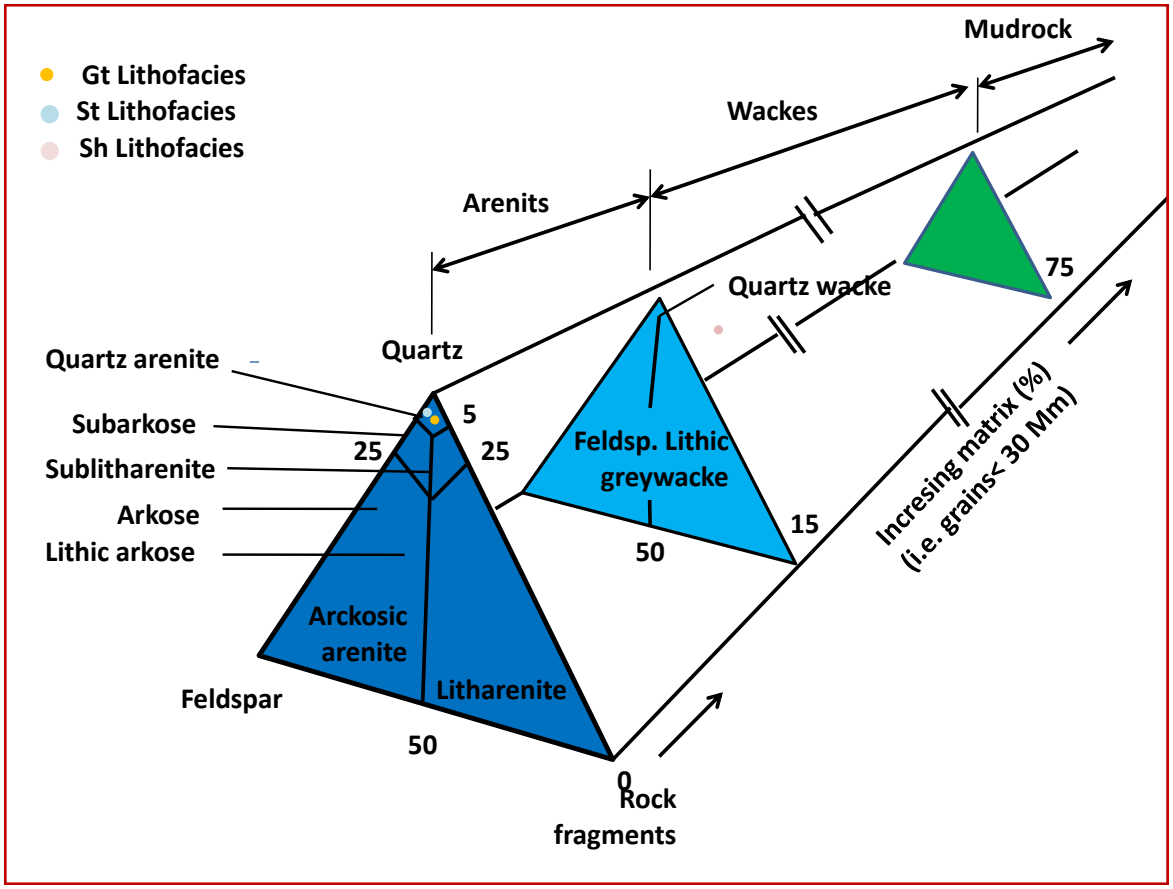


Fig.3.6 classification diagram showing the detrital composition of the upper part of Kiklah Formation along the study area.

3.2.2 Texture

Usually in Meandring study sample there is not show a wide range of textural properties exceptin Gt Facies, however the St Lithofacies and Sh lithofacies reflect more homogenous textural properties than the Gt lithofacies (appendex.4). In Gt lithofacies the sediments show a wide grain size ranging from very fine-upper to very coarse grain sizes. The grain size mode is very fine-upper to medium in the St, while the Sh are characterized by silt to very fine lower grain size. The sorting is moderately to poorly in the St, Sh lithofacies, usually moderately with few poor in the Gt lithofacies. Sediment is usually grain-supported. The grains show subangular to subrounded grain shapes with straight and point grain contacts. (fig. 3.7 B). The majority of the samples contain no detrital matrix only one samples in the St, display1-7% of detrital mud matrix. (fig 3.7 B).

3.2.3 Detrital Composition

3.2.3.1 Monocrystalline quartzes is the principal detrital components (petrographic data sheet of Meandring river in appendex 4). Represented by strained and unstrained grains, up-to 95% of the detrital grains (fig. 3.7). They generally form 50- 55% of the total framework in (Gt lithofacies) and 60-63% in St Lithofacies of the total volume. In Sh sample contain minor percentage of monocrystalline quartzs (1-27%) per total volume. The percentage directly relates to the sorting where better sorting sandstones show higher percentage of quartz grains**.**

3.2.3.2 Polycrystalline quartz essentially consists of composite subcrystals found at trace- very little levels in the Gt lithofacies sediments. The St Lithofacies contain minor amounts (0-0.5%) of the detrital framework and (0 to 1%) of the total volume.

3.2.3.3 Feldspar grains are usually absent in most of lithofacies, but they are observed in the Gt lithofacies where they account for 0-1% per total volume. (fig. 3.7 A), where they represent 0-1.8% of the detrital grains, mostly represented by non-twinning (probably orthoclase). In the western of study area (Al Mrabah, Wazen section) the feldspar grains are rare or absent in all Lithofacies.

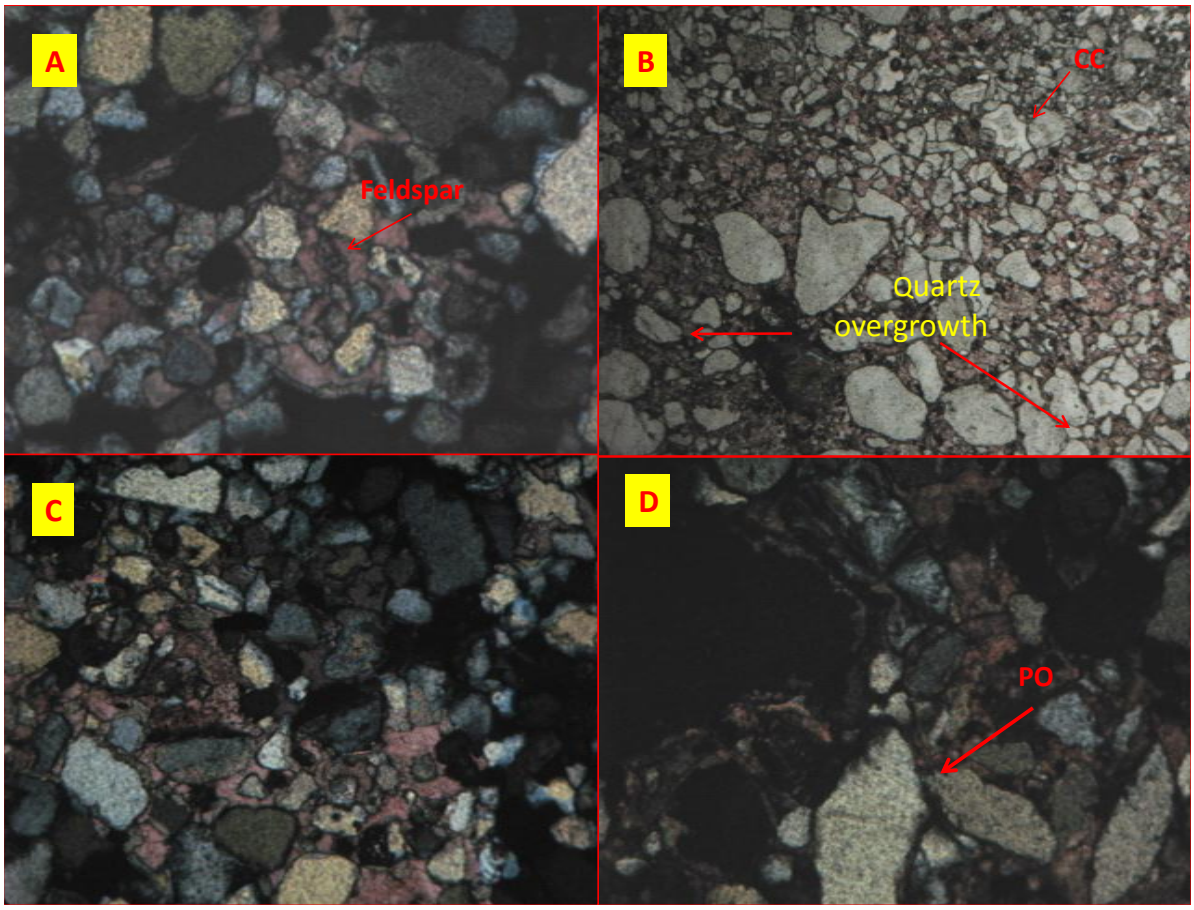


Figure 3.7 A) This figure shows content of detrital feldspar where are not alterated. XPL, field of view = 10 mm. **B)** This figure shows monocrystalline quartz grains, Poorly sorted sediments with silica cement, Quartz overgrowth, subangular to subrounded grained concavo- convex contacts in St Lithofacies, (PPL), field of view = 2.5 mm. **C)** This figure shows authigenic Calcite filling porosity, and dissolution of unstable grains probable feldspar grain , XPL, field of view = 10 mm... **D)** This figure shows St Lithofacies quartz, subangular to subrounded, and point contacts XPL, field of view = 10 mm.

Rock fragments are absent in all studied samples.

Heavy minerals represent 1-3% of total volume. They almost found in all of the lithofacies in Gt lithofacies are 3% of whole framework constitutes where probably 0-2% in all another lithofacies (fig. 3.7 B)

Detrital mica are absent in all the studied samples.

Detrital mud (clay-silt) are observed in the St, lithofacies which cntain minor amounts (0 to 7%) of the total volume, where they contain (0-9.5%) of the detrital grains (fig. 3.7 B)**.**

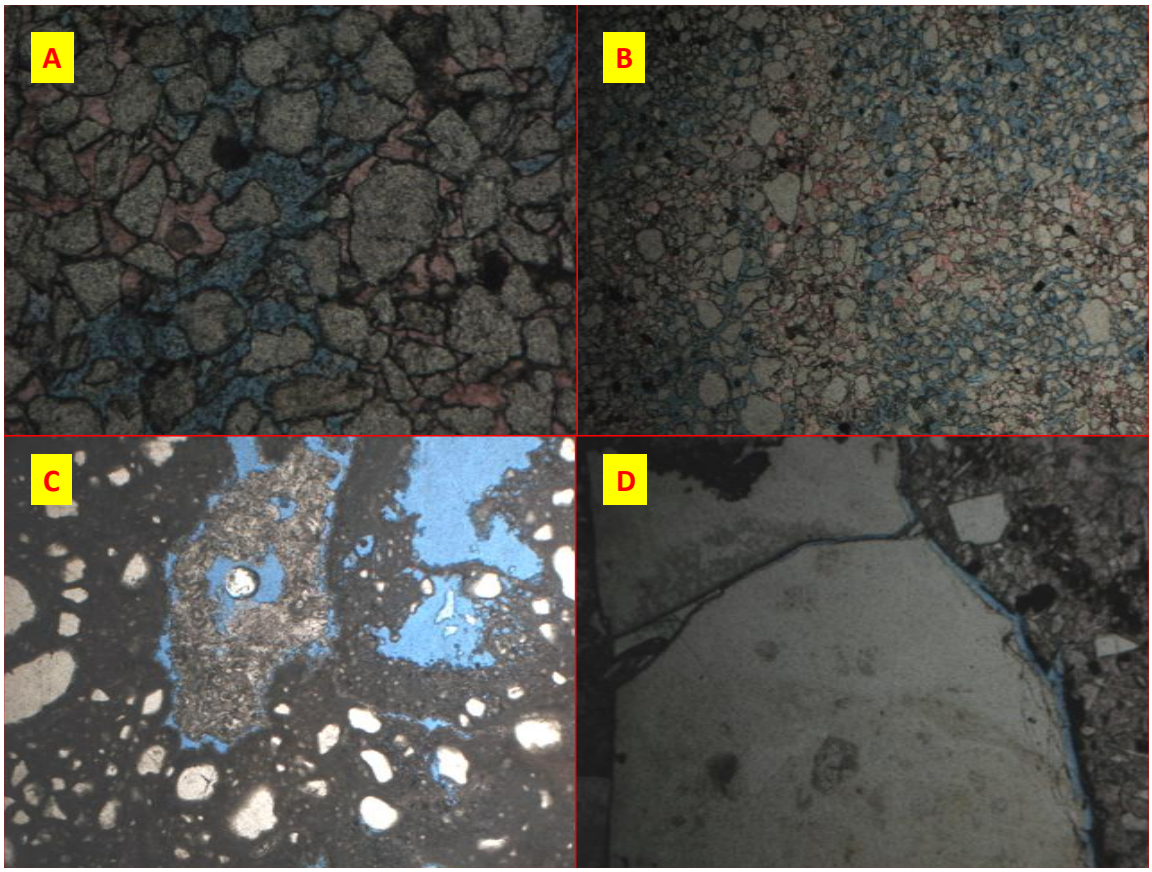
3.2.4 Authigenic Composition – Diagenesis

3.2.4.1. Quartz overgrowth

Generally Quartz overgrowth is rare occurs in the studied samples, in Gt lithofacies where they account for 0-1% per total volume, where probably absent in the studied samples in another lithofacies. (Fig. 3.7 B).

3.2.4.2 Calcite:

The calcite cement mostly observed in studied samples about (20-24%) per total volume, in Gt lithofacies where they account for 0-20% per total volume. 0 -24% in St lithofacies. (Fig. 3.7 A, B and C).



Figur 3. 8. A) This figure shows high remnant intergraular porosity (marked with blue), with authigenic Calcite filling porosity, PPL, field of view = 10 mm. **B)** This figure shows primary intergraular porosity (marked with blue), with authigenic Calcite filling porosity and heavy minerals, PPL, field of view = 2.5 mm. **C)** dissolution processes are resulted excellent secondary porosity. PPL, field of view = 2.5 mm. **D)** This figure show fraction in grains to contain secondary porosity. PPL, field of view = 2.5 mm.

3.2.5 Porosity

In The studied samples usually show two types of porosity, primary and secondary porosity, however the primary porosity occur in the Gt lithofacies ranging (0-25%), where they contain (0-3%) in St, lithofacies. (Fig. 3.8 A and B) The secondary porosity developed in the Sh lithofacies with (1-7%) per total volume which observed through the alteration of unstable detrital grains, probably feldspar. (Fig. 3.8 C) Secondary porosity can be recognized in fraction grains in the thin section (Fig 3.8 D). Where the point bar deposits in the middle part of study area (Meandering River) contain little detital mud and showing better sorting, render the dissolution process more effective to the porosity. Therefore the point bar in Meandering river should be represented good reservoir of hydrocarbons.

Chapter.4
Discussion and Conclusions

Chapter.4

Discussion and Conclusions

4.1 Discussion

Generally sediments of the Kiklah Formation exposed at all of the studied localities. Exposed differences in stacking patterns, variable grain size and the presence/absence Of fine-grained facies however, all these features suggest the lower part of the studied sediments deposited in a relatively high flow regime of braided river system with low sinuosity channels indicate existence in distal setting types of braided rivers. The sediments are characterized by increased, very coarse to coarse grained facies and the absence of fine grained facies deposited from suspension, with Paleocurrent data show a range of directions toward the majority of NNW to WNW with minor of NNE,. This is with the assumed location of the main source area to the southeast. The upper part of study area is higher sinuosity meandering river and well exposed at localities in Wazen section and also in the upper part of the Al Mrabah, Kabaw and Gnawan sections. It is marked by a generally finer grain size of sediments, forming lithofacies (Fm, Sh, Fl) where interpreted as an abandoned channel, point bar Lateral accreation and the floodplain sediments. The petrography study of the sandstone, mainly comprise recycled quartz graind and very resistant heavy mineral species. This indicates that the sediments carried from older ones which are found in the southeast of the study area, especially that the southern Libya Paleozoic rocks cover large area, and these were originally derived from the Precambrian terrains of the Hoggar, Tibesti and Gargaf uplifts.

The extent of the study area, does not allow us to decide whether these changes in the character of the braided rivers were basin-wide or only local, or whether they were related to local tectonic or paleogeographic conditions. Answering of these questions will require further studies of other localities, and their correlation to boreholes samples from the subsurface of Jefarah and Ghdamis basins. The thickness of the studied succession, which measured stratigraphically from the base of the Kiklah formation to the upper contact with Sidi as Sid Formation is estimated to be about 50–80 m, whereas the cumulative thickness of the stratigraphic succession exposed in the al Mrabah section is about 80m.

4.2 Conclousions

The Lower Cretaceous Kiklah Formation has been studied in outcrop localities along the western part of the Jabal Nafusah Escarpment, NW Libya. Which illustrated lithofacies change and the bounding surface that separates between the architectural elements of fluvial systems along the studied area and petrography of the some selected sandstone. The conclusions of this study include:

1. Nine sedimentary facies are recognized, these are conglomerate channel (Gt), trough crossed-stratified sandstone (St), planar cross stratified sandstone (Sp), ripple cross-laminated sand (Sr)), horizontal bedding (Sh), low-Angle cross bedded sandstone facies (Sl), laminated sand, and mud, (Fl), massive mud, silt (Fm), and paleosoil (P).

2. Six possible Bounding surface hierarchy characteristics distinguished and applied to the Kiklah Formation based on, (Miall 1991b).
3. The Kiklah Formation in the studied area display five architectural elements, (CH) channel-fill elements, (SB) sandy bedform elements, (DS) downstream accretion elements, (LA) lateral accretion elements and (OF) overbank elements.
4. The Lower part of Kiklah Formation is deposited by sheet flood distal braided type, Sheet flood, sand-bed River, and characteristic of distal plains, particularly in arid regions where ephemeral runoff forms a network of shallow. The upper part of Kiklah Formation is deposits by sandy meandering type.
5. Previous studies have considered Kiklah Formation start from the paleosoil, but this study suggests the Kiklah begin before the paleosoil. Because the paleosoil is considered one of lithofacies which indicate a period of non-deposition within Kiklah Formation, and the lower boundary of the Formation decieded was the first unconformity just above the lacastrine facies of upper Kabaw Formation.
6. The correlation of the studid sections can be distinguished four regional stratigraphic surfaces along the study area, first the contact between Kabaw and Kiklah Formations, the second is unconformity erosion surface represented by the paleosoil. The third is the surface between braided and meandering systems, and the fourth is the contact between Kiklah Formation and Ain Tubi Member.
7. Petrographic data shows that the lower Kiklah Formation consists mainly quartz arenite, sublitharenite with local subarkoses.

8. The detrital mineral components are essentially monocrystalline quartz with subordinate polycrystalline quartz, feldspar, and rare heavy minerals.
9. Diagenetic cement is mainly in the form of quartz overgrowths, and local Calcite cement. All of which have reduced the porosity.
10. The average of total porosity of the lower Kiklah formation for the all the studied area about 20 – 30 %.
11. The lower part of study area (braided river) contain little detital mud and showing better sorting, the dissolution process importing to the porosity. Where the cement and matrix dissolution porosity mostly found in braided river deposits. Therefore the braided river should be represented good reservoir for hydrocarbons and principle water aquifer.

4.3 Recommendation

Future work should focus on the detailed sedimentological study of the other outcrops along Jabal Nafousah escarpment, and the correlation of exposed strata to wireline log and core data derived from boreholes in the vicinity of sedimentary basines Such as Ghadamis Basin, this will clarify the lateral relations in regional scale.

-Gamma ray field measurements are highly recommended in the future field work to correlate outcrop to subsurface rocks.

-Petrography study should include subsurface samples in orded to beter understanding of the diagenetic paragenesis of reservoir properties.

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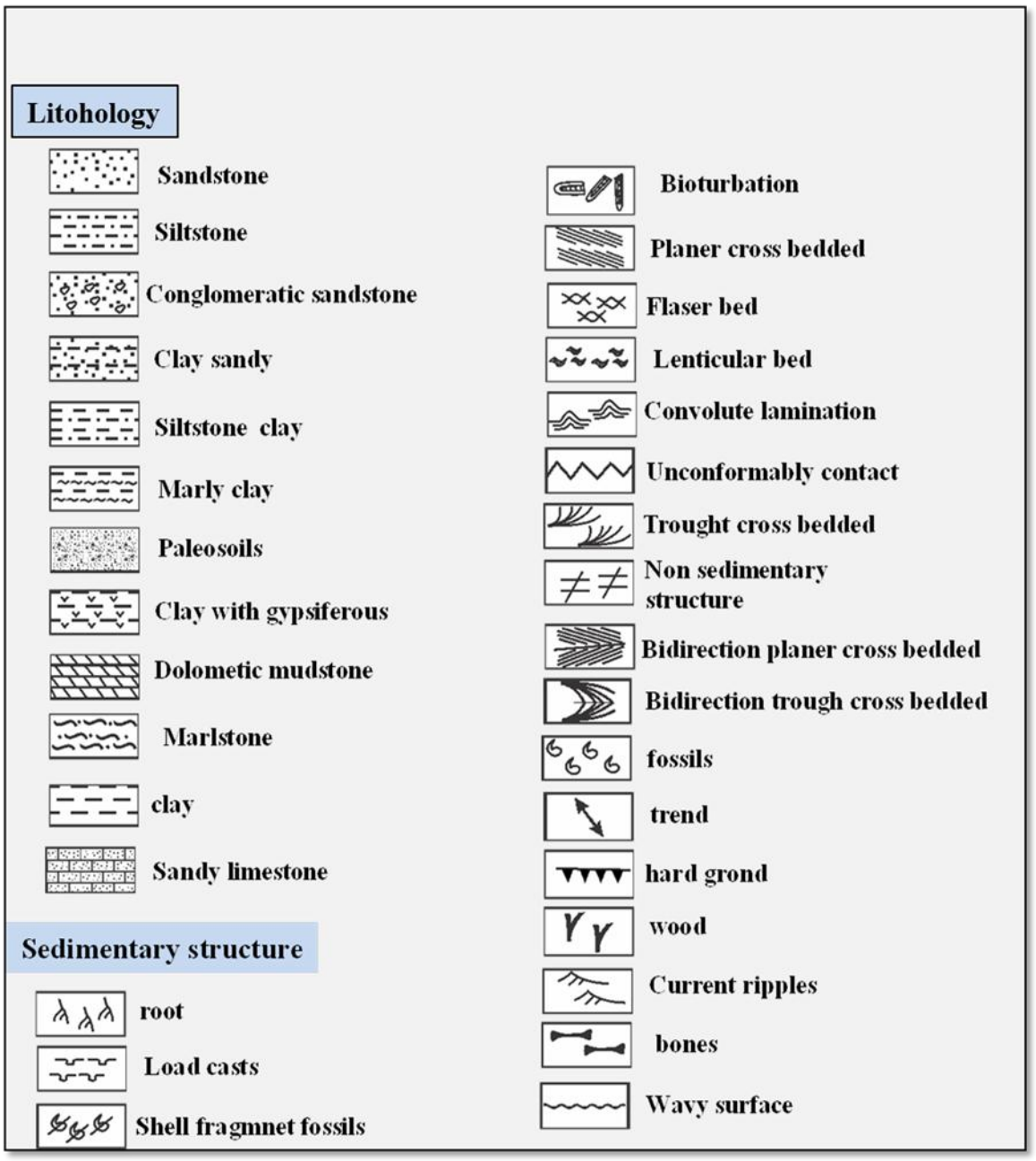
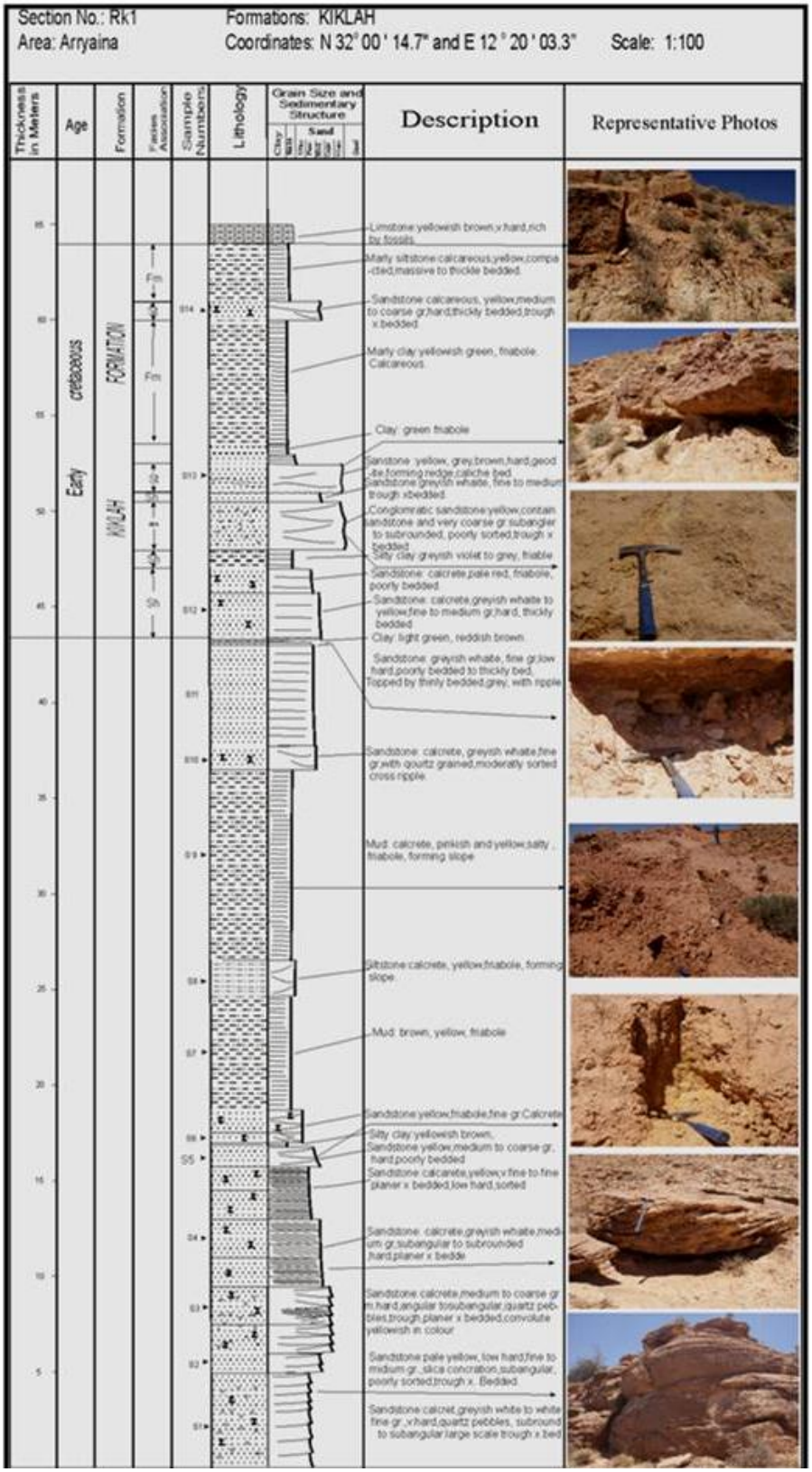
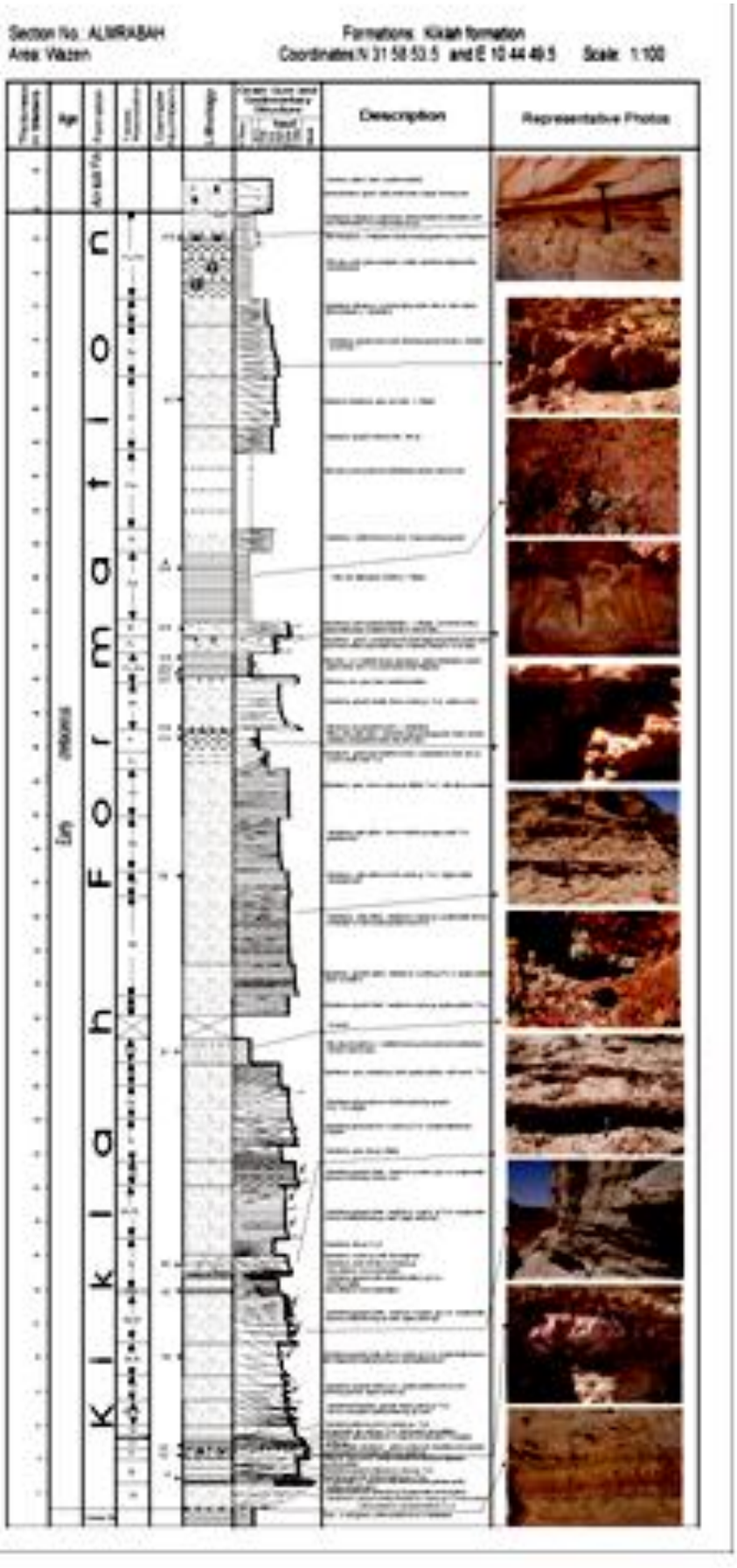
APPENDIX: 1
Lithology and sedimentary structure legend


Litohology
Sandstone
Siltstone
Conglomeratic sandstone
Clay sandy
Siltstone clay
Marly clay
Paleosoils
Clay with gypsiferous
Dolometic mudstone
Marlstone
clay
Sandy limestone
Sedimentary structure
root
Load casts
Shell fragmnet fossils
Bioturbation
Planer cross bedded
Flaser bed
Lenticular bed
Convolute lamination
Unconformably contact
Trought cross bedded
Non sedimentary structure
Bidirection planer cross bedded
Bidirection trough cross bedded
fossils
trend
hard grond
wood
Current ripples
bones
Wavy surface

APPENDIX: **2**

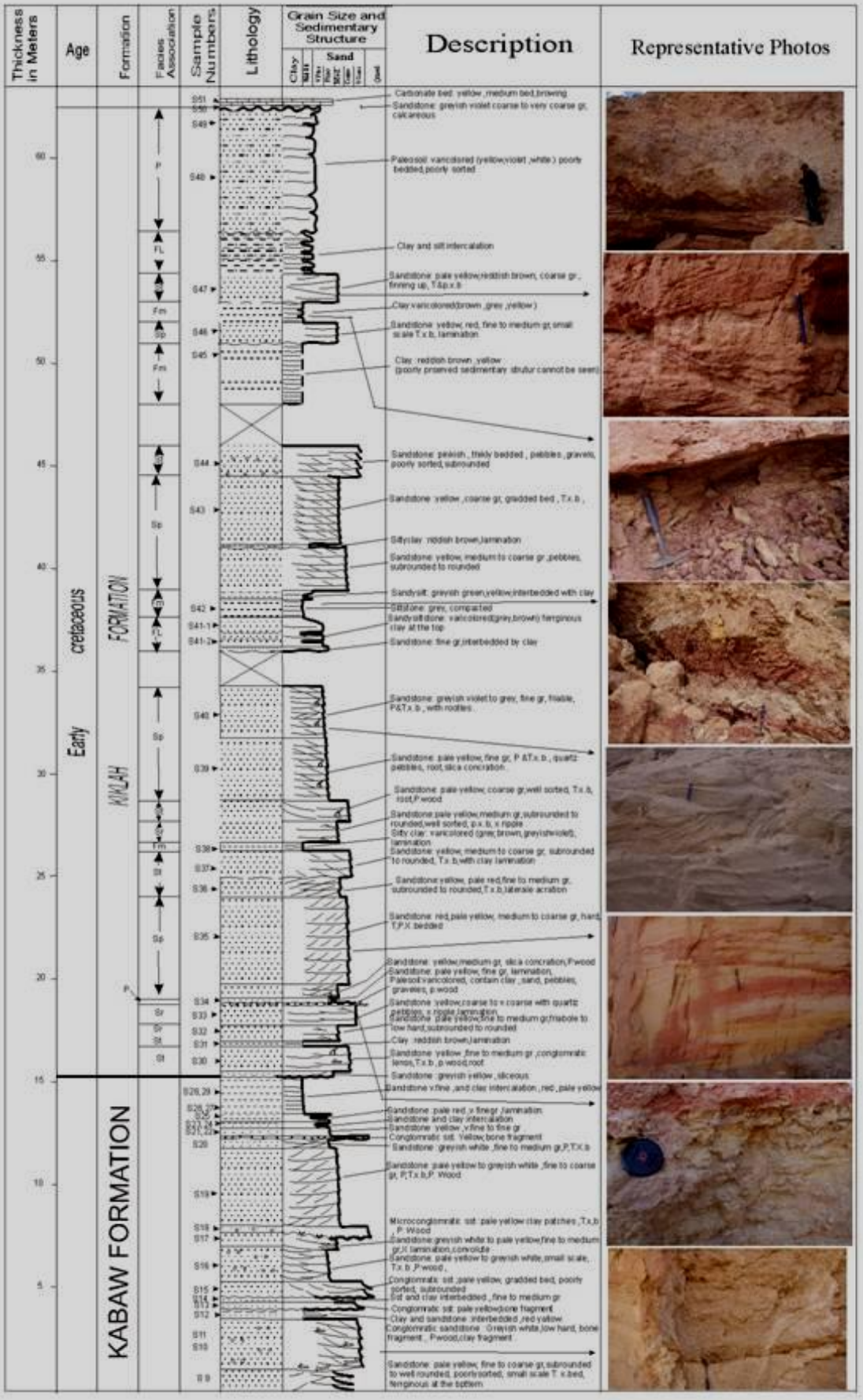

Section No.: Rk1
Area: Arryaina
Formations: KIKLAH
Coordinates: N 32° 00 ' 14.7" and E 12 ° 20 ' 03.3"
Scale: 1:100
Thickness in Meters
Age
Formation
Facies Association
Sample Numbers
Lithology
Grain Size and Sedimentary Structure
Description
Representative Photos
Early
cretaceous
KIKLAH
FORMATION
Fm
Fm
Sh
Limstone yellowish brown,v.hard,rich by fossils
Marly siltstone calcareous,yellow,compa -cted,massive to thickle bedded.
Sandstone calcareous, yellow,medium to coarse gr,hard,thickly bedded,trough x bedded
Marly clay yellowish green, friabole. Calcareous
Clay: green friabole
Sandstone :yellow, grey,brown,hard,geod -ite forming,redge,caliche bed
Sandstone greyish whaite, fine to medium trough xbedded
Conglomratic sandstone:yellow,contain sandstone and very coarse gr.subangler to subrounded, poorly sorted,trough x bedded
Silty clay greyish violet to grey, friable
Sandstone: calcrete,pale red, friabole, poorly bedded
Sandstone: calcrete,greyish whaite to yellow,fine to medium gr,hard, thickly bedded
Clay: light green, reddish brown
Sandstone: greyish whaite, fine gr,low hard,poorly bedded to thickly bed, Topped by thinly bedded,grey, with ripple
Sandstone: calcrete, greyish whaite,fine gr,with quartz grained,moderatly sorted cross ripple
Mud: calcrete, pinkish and yellow,salty , friabole, forming slope
Siltstone:calcrete, yellow,friabole, forming slope
Mud: brown, yellow, friabole
Sandstone:yellow,friabole,fine gr.Calcrete
Silty clay:yellowish brown,
Sandstone:yellow,medium to coarse gr, hard,poorly bedded
Sandstone: calcarete,yellow,v fine to fine planer x bedded,low hard,sorted
Sandstone: calcrete,greyish whaite,medi -um gr,subangular to subrounded hard,planer x bedde
Sandstone:calcrete,medium to coarse gr m.hard,angular tosubangular,quartz peb- bles,trough,planer x bedded,convolute yellowish in colour
Sandstone:pale yellow, low hard,fine to midium gr.,silica concration,subangular, poorly sorted,trough x. Bedded.
Sandstone:calcret,greyish white to white fine gr.,v.hard,quartz pebbles, subround to subangular,large scale trough x bed

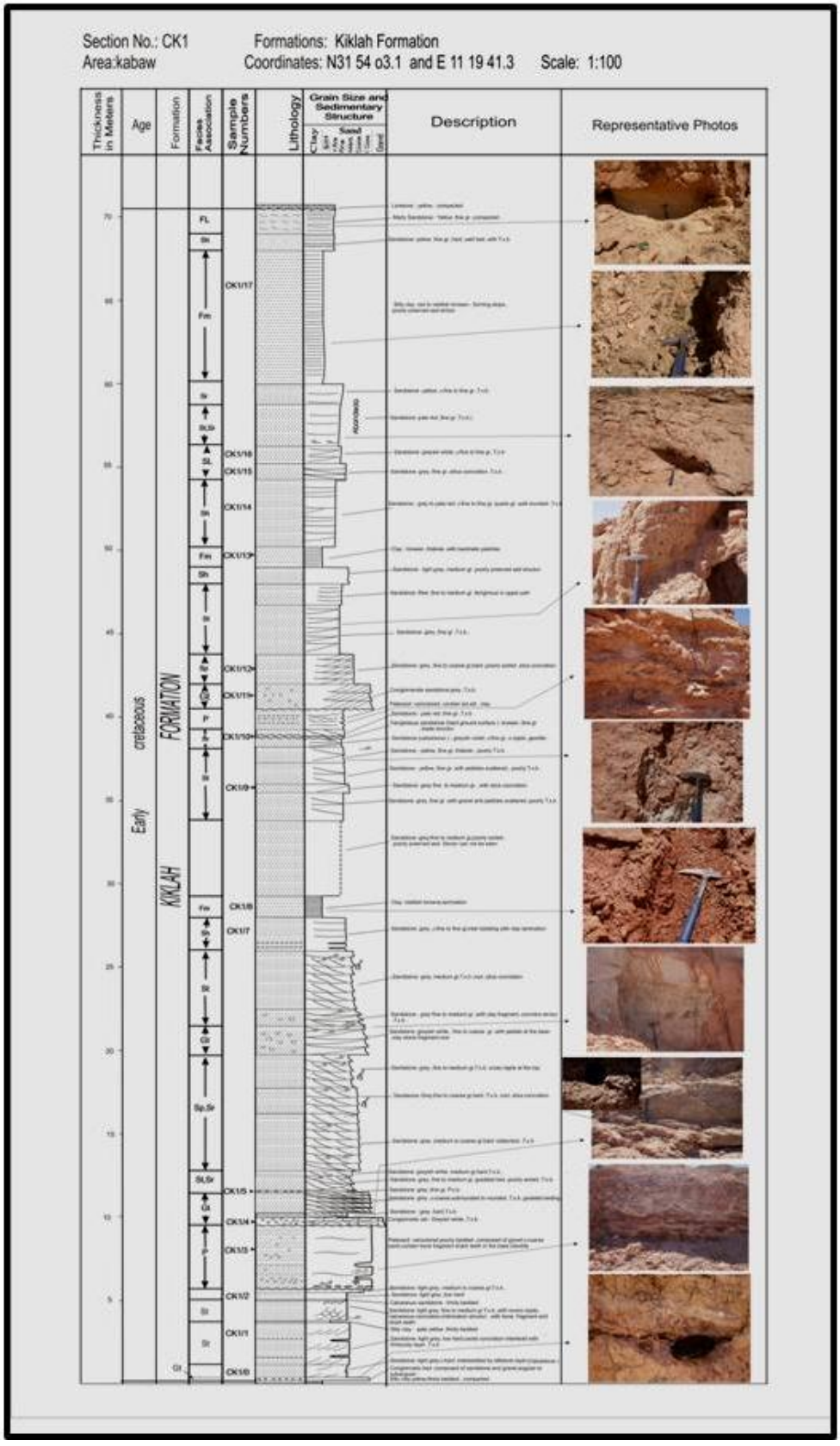

Section No. ALMRABAH
Area: Wazen
Formations: Kikah formation
Coordinates:N 31 58 53.5 and E 10 44 49.5
Scale: 1:100
Description
Representative Photos
Kikah formation
Eocene

Section No.: Genawan
Area: Genawan

Formations: KIKLAH FORMATION
Coordinates: N 31° 59' 35.2" and E 11° 59' 07"

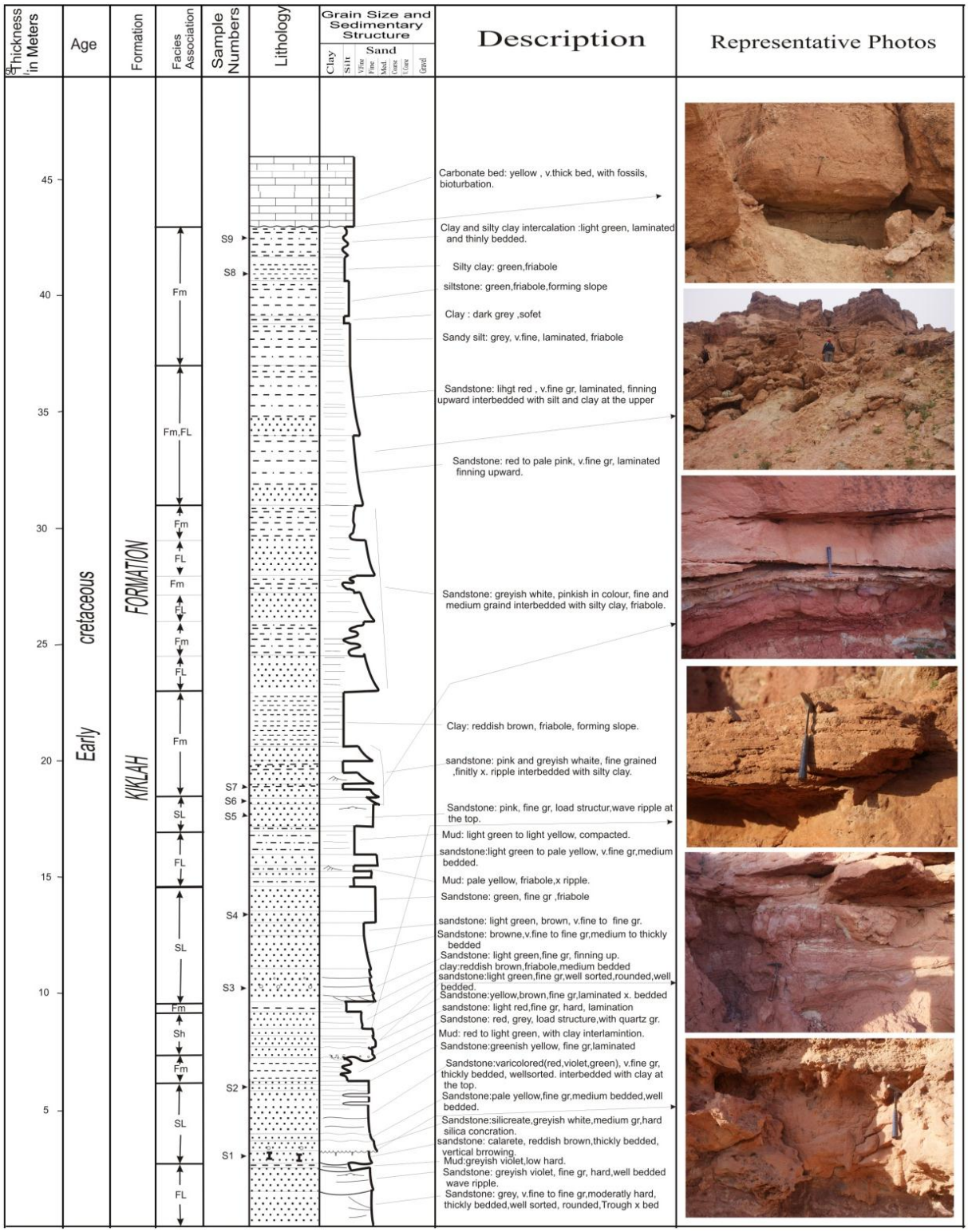
Scale: 1:100




Section No.: CK1
Area:kabaw
Formations: Kiklah Formation
Coordinates: N31 54 o3.1 and E 11 19 41.3
Scale: 1:100
Thickness in Meters
Age
Formation
Facies Association
Sample Numbers
Lithology
Grain Size and Sedimentary Structure
Clay
Sand
Description
Representative Photos
Early cretaceous
KIKLAH FORMATION

Section No.: W2 Formations: Kikklah Fm

Area: Wazen area Coordinates: N X31° 56' 07.4 " and E 10° 39 ' 56.2 Scale: 1:100



APPENDIX: **3**

PETROGRAPHIC LEGEND

TEXTURE

GRAIN / PORE SIZE

Code	Description
P	Pebble
G	Granule
VCU	Very coarse upper
VC	Very coarse
VCL	Very coarse lower
CU	Coarse upper
C	Coarse
CL	Coarse lower
MU	Medium upper
M	Medium
ML	Medium lower
FU	Fine upper
F	Fine
FL	Fine lower
VFU	Very fine upper
VF	Very fine
VFL	Very fine lower
S	Silt (grain size only)
EX	Extra fine (Pore size only)
MD	Mud (grain size only)
MX	Microcrystalline

ROUNDNESS

Code	Description
A	Angular
SA	Subangular
SR	Subrounded
R	Rounded
WR	Well rounded

SORTING

Code	Description
VG	Very good
GO	Good
MG	Moderately good
MT	Moderate
MP	Moderately poor
PO	Poor

GRAIN CONTACT

Code	Description
MS	Matrix supported
T	Tangential
SG	straight
CC	concave-convex
SS	Slightly sutured
SU	Sutured

STRUCTURE

Code	Description
B	Burrowed
D	Disrupted
FT	Fractured
GR	Graded
L	Laminated
MA	Massive
SL	Strongly laminated
SY	Stylolitic

LASSIFICATION

Dott, 1964 modified by Pettijohn el al, 1975.

Code	Description
ARAR	Arkosicarenite
LIAR	Litharenite
QZAR	Quartz arenite
SARK	Subarkose
SLAR	Sublitharenite
FDWK	Felspathic greywacke
LIWK	Lithic greywacke
QZWK	Quartz wacke
MDST	Mudstone
ARKS	Arkose
LIAK	Lithic arkose

Grain Size	Diagenetic Grain Size	Pore Size	Size in Microns
Pebble (P)			
Granules (G)	Extremely coarsely crystalline (EC)	Extremely coarse (EC)	4000
			2000
Very coarse upper (VCU)	Very coarse crystalline upper (VCU)	Very coarse upper (VCU)	
			1410
very coarse lower (VCL)	very coarse crystalline lower (VCL)	very coarse lower (VCL)	
			1000
Coarse upper (CU)	Coarse crystalline upper (CU)	Coarse upper (CU)	
			710
Coarse lower (CL)	Coarse crystalline lower (CL)	Coarse lower (CL)	
			500
Medium upper (MU)	Medium crystalline upper (MU)	Medium upper (MU)	
			350
Medium lower (ML)	Medium crystalline lower (ML)	Medium lower (ML)	
			250
Fine upper (FU)	Fine crystalline upper (FU)	Fine upper (FU)	
			177
Fine lower (FL)	Fine crystalline lower (FL)	Fine lower (FL)	
			125
Very fine upper (VFU)	Very fine crystalline upper (VFU)	Very fine upper (VFU)	
			82
Very fine lower (VFL)	Very fine crystalline lower (VFL)	Very fine lower (VFL)	
			63
Extremely fine/ Silt(EF/S)	Extremely finely crystalline (EF/S)	Extremely fine (EF)	
			20
Microcrystalline mud/clay (MX)	Microcrystalline (MX)	Microcrystalline (MX)	

APPENDIX: **4**