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Review Article

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Phanerozoic Sedimentation Over a Rifted Continental Margin; Wadi Fatima Area, West-Central Saudi Arabia: A Review

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Abstract Wadi-Fatima area (8400 Sq. Km.) located in Makkah-Jeddah province western of Saudi Arabia. It subdivided according to the geographical sittings into four localities namely, Usfan, Hadat Al-Sham, Wadi Al-Sayle, and Wadi Al-Shumaysi, having different elevation above sea level. Twenty-nine stratigraphic sections are measured, sampled, correlated and an idealized log185-meter thick sequence for the entire area is presented. It composed of seven formation separated by three regional unconformity plans. The study area displays several fault blocks controlled by two original fault trends running in two perpendicular directions representing the parallelism to the Red Sea axis and the subsidiary effect of the resulted transform faults. Our review discusses previous stratigraphic work on the sedimentary sequence covering Wadi Fatima area including formation bearing the oolitic-iron ores. Collectively, the studied sequence of sedimentaries made up of two stratigraphic units. The Cambrian-Devonian Al-Shumaysi Formation and the overlaying Oligocene-Miocene Wadi Fatima Group. The lower formation made up of four units, numbered (II to V) settled over a thin weathering product of cold-regions (number I) developed from the underlying crystalline rocks. However, the upper Group made up of two formations, namely, Wadi Fatima Group (newly introduced name), gathering three isochronous formations Vises: Usfan, Sita, and Hadat ash-Sham Formations all are laid unconformably beneath beans type residual-laterite developed from premature phase of basaltic-sheets of Khulays Formation which forms the top of the stratigraphic log at issue. Sedimentation of the studied sequence took place over an active continental margin followed by different vertical movements of fault blocks having maximum difference of displacement attaining 340 meter. Correlation of the complete sequence of sediments in the study area indicates deposition of basal sequence of Paleozoic sediments occurs in the relatively low elevated faults block now situated juxtapose the Red Sea coastal margin and unconformably capped by thicker Tertiary sediments eastwards in the relatively higher fault blocks at the eastern part of the study area. This construction, elucidate the spatial distribution of the stratigraphic units along the continental marginal areas of the Red Sea and proposed two separate Paleozoic and Tertiary megacycles of sedimentation, coincided with further eastward elevation of fault blocks,during the Tertiary times. The present work encourages petroleum companies to explore hydrocarbons within submarine sediments laid over the near shoreline the subsided strike-slip fault blocks in Jadda-Makka quadrangle.

Keywords Stratigraphy, Saudi Arabia, Red sea, Continental margin, Tectonics

Introduction

The whole map of Makkah quadrangle of Moore and Al-Rehaili, [1] is used herein. The famous sedimentary sequence bearing oolitic iron-ore of Makkah quadrangle is known as Wadi (valley) Fatima area (Fig. 1). Resting on the Precambrian basement rocks there is 185 meter thick sequence of sedimentary rocks; its lower rock unite (Shumaysi Formation) bearing oolitic iron-ore key bed sited in varied elevation in different juxtapose fault blocks having vertical elevation values ranging between 18 m. and 299 above sea level with net displacement attaining 281 m. Wadi Fatima area (Fig. 2) located southeast of Jeddah City. It runs 136 Km in NE-SW direction along an uplifted fault block [2]. The main valley oriented perpendicular to the axial trough of the Red Sea and intersected perpendicularly by Wadi Al-Shumaysi and Wadi Al-Sayle marking together a continues faulted area running in NW-SE direction in parallelism with the Red sea axis (Fig. 2). Wadi Al-Sayle extended northerly until Abhor-Usfan quarter. Eastwards, Hadat Al-Shame area is located in higher elevated linear valley running in parallelism with Al-Shumaysi-Al-Sail fault zone .It extended northerly where it faced by more elevated fault-block covering Usfan area.

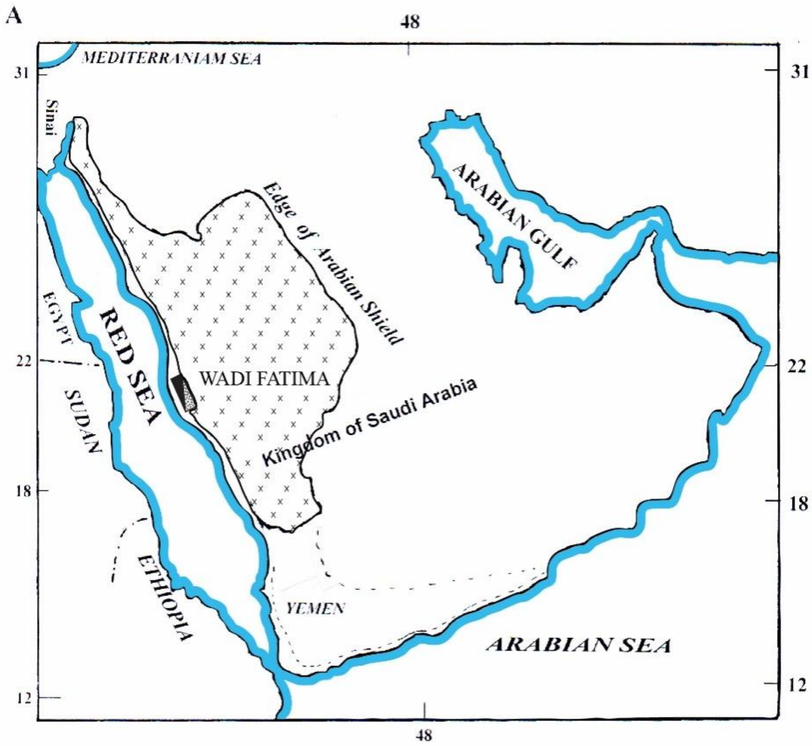

Figure 1: Location map of the study Wadi Fatima area in the rifted western margin of the Arabian Shield

The sedimentary sequence at issue belongs to Suqah group of Moore and Al-Rehaili [1]. This iron-ore bearing sequence outcrops along a distance of about 40 Km. in two linear belts. A good deal of research work on the sedimentary sequence developed over the marginal areas of the Arabo-Nubian Shield was focused mainly on local sedimentological studies with little attention to regional tectonics. Consequently, confusion on age and tectonics have arisen between geologists. The present work reviews the previous schemes of stratigraphic sequence of Wadi Fatima area and its interrelationship with vertical displacements of fault blocks loading the correspondent sedimentary formations.

Geomorphology and Field Work in Wadi Fatima area

Moore than two thousand elevation points from the Makkah quadrangle map of Moore and Al-Rehaili, [1] were imputed in the commercial computer program "Surfer" and used to produce a contour map of the study area. The maximum altitude in the Makkah quadrangle is 2412 meter over sea level, located on top of the Al-Sarrawat Mountains at the southeastern part of the study area. The lowest point, at a height of less than 7meter is located in the southwestern corner of the quadrangle near-by the Red Sea shoreline. The whole area is classified according to the geographical sittings into four localities, namely from south to north, Al-Shumaysi, Wadi Al-Sayle, Hadat Al-Sham, and Usfan (Fig. 2). However, twenty-nine stratigraphic sections from the Wadi-Fatima area were measured in the field, and their sites are detected by GPS instrument and their coordinates are marked in the prepared contour map. Elevations of hard basement rocks forming bases of fifteen measured sections are estimated using the prepared contour map by subtraction of values of the measured total thickness of every sedimentary sequence from the corresponding values of contour elevation at the marked GPS sites. Care has been taken to correlate the rock units of the measure fifteen columnar sections that laid over the Precambrian basement hard rock with regard to the elevation of oolitic iron-ore key bed. Hence, Figure (8) shows the resulted elevation of the basement rocks and thickness of the overlying sediments in the selected stratigraphic logs from the different four localities. A generalized stratigraphic section is also prepared and portrayed in Fig (9). The composite thickness of the sedimentary sequence, including three formations, from base upwards they are, Al Shumaysi, Sita, and Khulays formations having total thickness ranging between 18.3 m and 185 meter. The difference in altitudes of the bases of Al Shumaysi formation over the sea level, in different localities attaining 340 meter, reflecting the maximum displacement value of different fault blocks in the study area.

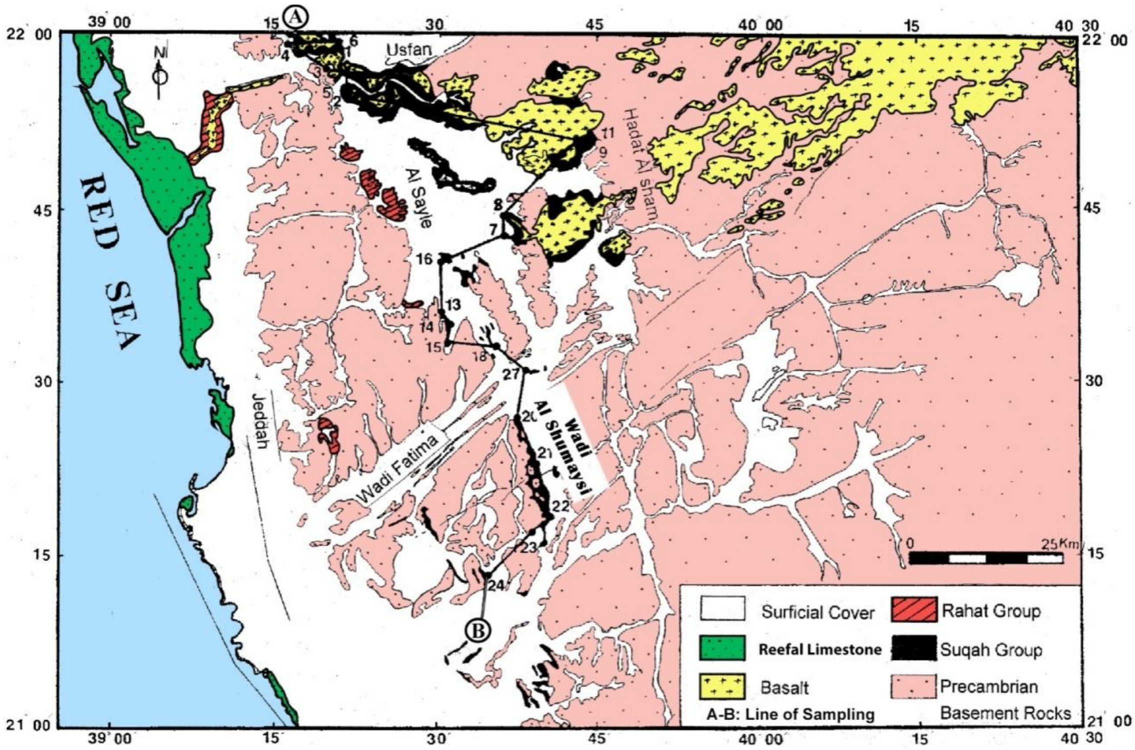

Figure 2: Location of measured sections along A-B line, and the major rock units in Wadi Fatima area

There is no consensus between geologists on the age of the sedimentary sequence of the western region of Saudi Arabia and their interrelationship with tectonism. The present paper reviewing the previous work in regional scale and provide an idealized stratigraphic section of the study area.

Evidence bearing on age of the so-called El-Shumaysi Formation:

The basal stratigraphic unite in the sedimentary sequence of Wadi Fatima is known as El-Shumaysi Formation. However, the lower part of the Phanerozoic sequence in Africa and the Arabian Peninsula is almost entirely unfossiliferous clastics with conglomeratic bands. The sequence is formed mainly of continental sediments with little marine influences. As is true with most continental deposits, dating is extremely difficult. Fossils are fare from common and many of those found tend to be of little value in chronostratigraphy. This has resulted in the widespread application of terms such as "Karroo " in southern and eastern Africa [3], "Nubian " in Egypt and Sudan [4-5], and "Wajid" in Al Sarawat Mountain of the Arabian Shield at Abha environssouthern Saudi Arabia [6]. However, the collective picture indicate that the environmental condition remain relatively uniform over a long period in Africa and the Arabian Peninsula Fig. (3).

Have the Afro-Arabian Shield been covered by Paleozoic rocks?

Paleozoic rocks crop out in many fault-bounded blocks between the coastal plain and the Red Sea escarpment. Carboniferous rocks have been recorded at the Gulf of Suez area [7], and along the Red Sea

coast southwest Arabia [8-9]. Many other Paleozoic formations lying over the Precambrian basement rocks, recorded by several research workers in northeast Africa and Saudi Arabia are recognized in the following sites:
(a) The northern part of Egypt [10]. (b) The Jebel Uweinat area extending into Libya, Sudan and Egypt [10]. (c) Over the eastern and the northern east outcropping edge of the Arabian Shield; the present high land basement rocks of the Arabian shield i.e. Wajid Formation, [11]. (d) The outcrops of the Nawa formation in Kordofan region at Sudan [12]. (e) At the southern east part of Egypt. (f) In the basal part of the Aswan’s clastic sequence, southern Egypt [13-14]. Collectively, complete stratigraphic sequences of the Phanerozoic ages are recorded in surface exposures and at depth; separately in Saudi Arabia [15], in Libya [16], and in the northern part of Egypt [7, 17, 18].

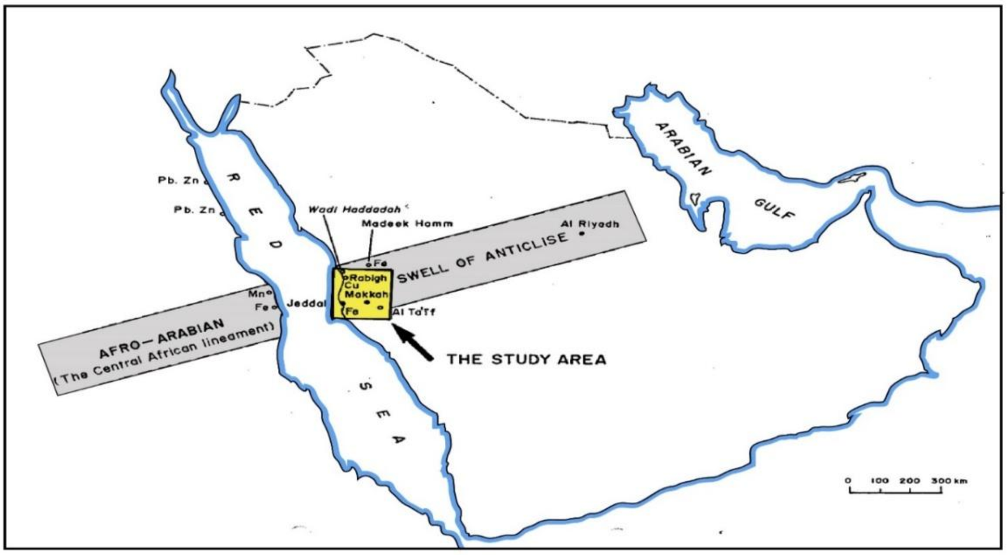

Figure 3: Geographic map showing location of Makkah Quadrangle within the swell of the Afro-Arabian anticlise of Whitman [12]

An incomplete Paleozoic sequence is also recorded both in the western and southern parts of Sudan. On these bases it safely can be suggested that the Paleozoic rocks might be laid over the Arabo-Nubian massif and they were locally eroded due to several subsequent uplifting movements. Clearly, the final word on the Paleozoic geology of northern and eastern Africa as well as that of the Arabian Peninsula has not been written. Though six vertical uplifting movements in different parts of the Arabo-Nubian massif were record, these are: Early Ordovician uplift associated with tectonically emplaced intrusive rocks (490 - 600 m.y) related to Najd Orogeny or Pan African events [19]. The resulted uplift apparently took place in the northern part of the Arabian Shield. However,in Cambro-Ordovician times, paleomagnetic maps indicated that the Arab-world fell in the southern pol region [20] and epicontinental subsidence and widespread peneplanation occurred, following the late Proterozoic uplift, as evidenced by thin cover rocks of tilitic and fluvio-glacial deposits offlapping the Arabian and the Nubian Shields [21].

How much the Phanerozoic seas extended over the present Arabo-Nubian massif?

It is uncertain because of erosion. However, *During the Pan-African Orogeny at East Gondwanaland, compressional event was active between 650 Ma and 500 Ma BP (Early Ordovician), the oceans closed and the continental margins were uplifted. Troughs locally fringed the continents and were filled with molasses-type deposits in the present Red Sea region* (Quoted from AOMR, 1986, page 20 [21]). Moreover, since Late Precambrian until the closing time of Silurian, and prior to Early Devonian, the whole Middle East area had been subjected to the same geological evolution [22]. Several uplifting phases of the Arabian Shield are indicated in the Phanerozoic Eon. The available data of Paleozoic sediments in Egypt, Sudan, Ethiopia, Yemen [23-26] and Kingdom of Saudi Arabia [27] were sufficient to construct distribution maps showing tentative extension of bourders of the investigated Phanerozoic rocks in and around the Present Red Sea area (Fig. 4). Moreover, complete stratigraphic sequence of rocks laid over the Precambrian hard rocks has been investigated in Al-Sarat region at the southern margin of the Arabian shield and extended northward until Al-Aflag region (Fig. 5A). Consequently, uplifting times of the Arabian Shield were assigned in the sedimentary sequence by validating two criterias namely, (1), The occurrence of regional unconformity plans character of ferruginous sediment (laterite), laying between two marine formations both formed during global rising in sea level [28]; together with (2), Adequate correlation with previous workers. Consequently, the southern and central parts of the Arabian Shield had been projected as high mountainy lands in five successive uplifting events (Fig 5-B). Moreover, the northern part of the shield took place after the deposition of sediments into Jubayla depression in Cambrian early Ordovician time. Consequently, according to Moufty and Khedr, [11] together with provision of several research workers, late Devonian unconformity occurs at the top of Wajid Fm. and the base of Khuff Fm. [29] coincided with global rising in sea level. Similarly, Late Permian-Early Triassic regional zone of unconformity occurs between the top of Khuff Fm. and the base of Sudair Fm. [19]. Moreover, Upper Triassic-Early Jurassic unconformity zone occur within Minjur Fm. and/or between Minjur Fm. and the overlying Marrat Fm [19]. Furthermore, Late Cretaceous uplift followed and resulted in a fair projection of highland areas of the southern part of the Arabian Shield [29]. More uplifting events occur in Tertiary period giving rise to emplaced granitic laccoliths all over the Shield, implying relative uplift of the whole Arabian Shield.

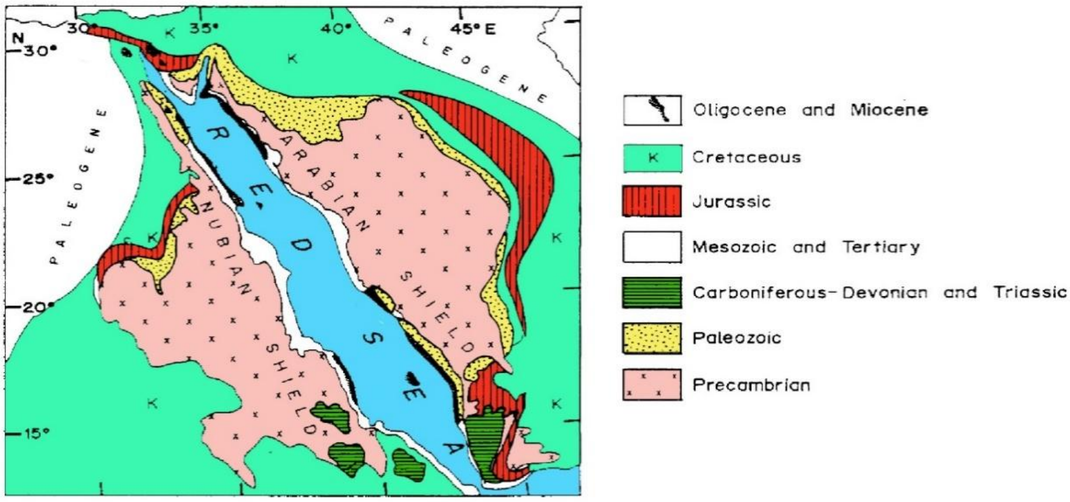

Figure 4: Tentative distribution map of the Phanerozoic sediments in Egypt, Sudan, Ethiopia, Yemen and Saudi Arabia around the Red Sea (after Said, [7], the Geological map of the Arabian Peninsula, [30], Whitman [12], Beyth and Michael [23], Kruck [24]; Blank et. al [27], Issawi [18], and Khedr, [25] and Khedr et. al., [14].

Previous Work on Stratigraphic Succession of the Wadi-Fatima Study-Area.

The bulk of the rocks covering the area at issue belongs to the Precambrian basement rocks. Nebert et al [31] and Moore and Rehaili [1] reported exclusively on the Precambrian basement rocks. In a study of rocks forming the area north of Wadi Fatima, Nebert et al [31] provided the following chronological scheme arranged in ascending order (from youngest to oldest).

-Quaternary fan deposits and fluviatile terraces, aeolian sand alluvial Wadi fillings.

- Unconformity.
- Neogene (?) sediments.
- Unconformity.
- Shumaysi formation (Oligocene).
- Unconformity
- Fatima formation (Upper Precambrian-Infra-Cambrian).
- Unconformity.

-Pre-Fatima Precambrian basement rocks.

Al-Shanti [32] gave little account on the fossil contents of Al-Shumaysi Formation. He (ibid.) carried out a very simple comparative study between the oolitic ironstone of Wadi Fatima area on one hand and those of Aswan, Bahariya (in Egypt), and Rago area (Syria) on the other. He reported on fossils collected only from higher horizons above the ironstone unit and peculiarly assigned a Cretaceous to Eocene age interval for the whole sedimentary sequence. Finally, He (ibid) followed Karposs [33-34] in his view and favors an Oligocene age for Al-Shumaysi Formation. However, it is pertinent in this context to report that there are great debates on the age of the Aswan oolitic ironstone. Though, Khedr [35] followed by Issawi and Jux [36] and Zaghlul [37] assigned it to Devonian age whilst many other research workers favor the upper Cretaceous age. However, fossil remains previously found in or below the ironstone horizons both in Aswan or Wadi Fatima areas are scarce and badly preserved. More recent work on the Aswan's clastic sequence assigned Carboniferous age to the iron ore [14].

- Both of Karposs [33-34] as well as Nebert et al [31], reported that the Shumaysi formation belongs to the Oligocene age (?). They (ibid.) supported their view on basis of radiometric age-determination of basalt covering the Shumaysi Formation. As long time interval and intense erosion could have been occurred prior to the outbreath of basaltic flows, the age of beds underneath this basaltic cap rock should had been taken with great caution.

- On paleonological studies, Moltzar and Binda [38] assigned the Shumaysi formation to Eocene age. The identified spores were embedded within samples collected from layers laid over the oolitic ironstone horizon,

- Basahl et. al., [39], studied some exposures at Usfan locality (Fig. 2) and paid special emphases on lithology and structure of Usfan Formation. Despite the absence of Shumaysi Formation at Usfan locality, they (ibid.) assigned it to the late Cretaceous to early Paleocene age. They also reported on overturning ramparts and clay diaper underneath the Usfan Formation.

-Moore and Al-Rehaili [1] proposed a new stratigraphic scheme for the Makkah Quadrangle including Wadi Fatima area. They categorized six sedimentary formations of Paleocene-Eocene age (?) in one group nomenclated by them as Suqah Group. Consisting of: Hadat Ash Sham, Usfan, Shumaysi, Sita, Khulays and Buraykah Formations. They (ibid.) made a historical view on scientists whom introduced these six formational names in the geology of Saudi Arabia.

From the stratigraphic work done in the study area it seems that there is no consensus on the age of either Usfan Formation or Shumaysi Formation. Karposs [33-34, 40] and Roger [41-45] assigned a Maastrichtian age for Usfan Fm. Whilst Cox (in Al Shanty [32]) considered it as early Eocene to Recent (?). On the other hand, Moore and Al-Rehaili [1] assigned Paleocene to Eocene age to the Shumaysi Formation together with other five different formations, all were included in one group called Suqah group and arranged as follows:

SUQAH GROUP (? Paleocene to Early Eocene)

Buraykah Formation *- Sandstone, poorly consolidated conglomerate.*

Khulays Formation*- Sandstone, argillite, clay, tuff.*

Sita Formation*- Tuff, alkalic and sub-alkalic basalts; minor graywake, shale, and limestone.*

Shumaysi Formation *- Pebbly sandstone, sandstone, ironstone, siltstone, tuff.*

Usfan Formation*- Sandstone, silty shale, coquina limestone, laterite.*

Hadat Ash Sham Formation *- Pebbly sandstone, siltstone.*

Resume

A detailed stratigraphic work on sedimentary sequences that developed over margins of the Arabian shield in three regions namely, Wadi Fatima, As Sarat, and Al Aflag (Fig. 5-A) is provided by Moufty and Khedr [11]. They (ibid) unravel that the Phanerozoic fillings of the eastern basin of Saudi Arabia started in Cambro-Ordovisian time with Glacial and Glacio-fluvial [46] Wajid Formation (Fig. 5-B). Followed upwards either by Khuff Formation in Carboniferous E. Permian or by the equivalent Faw Formation in depth; covered by the Permo-Triassic Sudair Fm. that overlaid by the M. Triassic Jilh Fm., followed upwards by U. Triassic Minjur Fm. and overlaid by the L. Jurassic Marrate formation, followed upwards by the M. Jurassic and U. Jurassic

Dhruma and Tuwaic Formations respectively. However, based on occurrences of five major unconformities in the studied sedimentary cover over the Precambrian hard rocks of the Arabian Shield together with subtle comparison of local and global sea level changes, Khedr and Moufty, [6, 15] proposed that since the Devonian Period to the Oligocene-Miocene Epoch there were five Major tectonic uplifting stages of the Arabian Shield. They (ibid) provided idealized sedimentary sequences developed over the margins of the southern and the west-central parts of the Arabian Shield (Fig. 5-A), including Wadi Fatima area (Fig. 5-B).

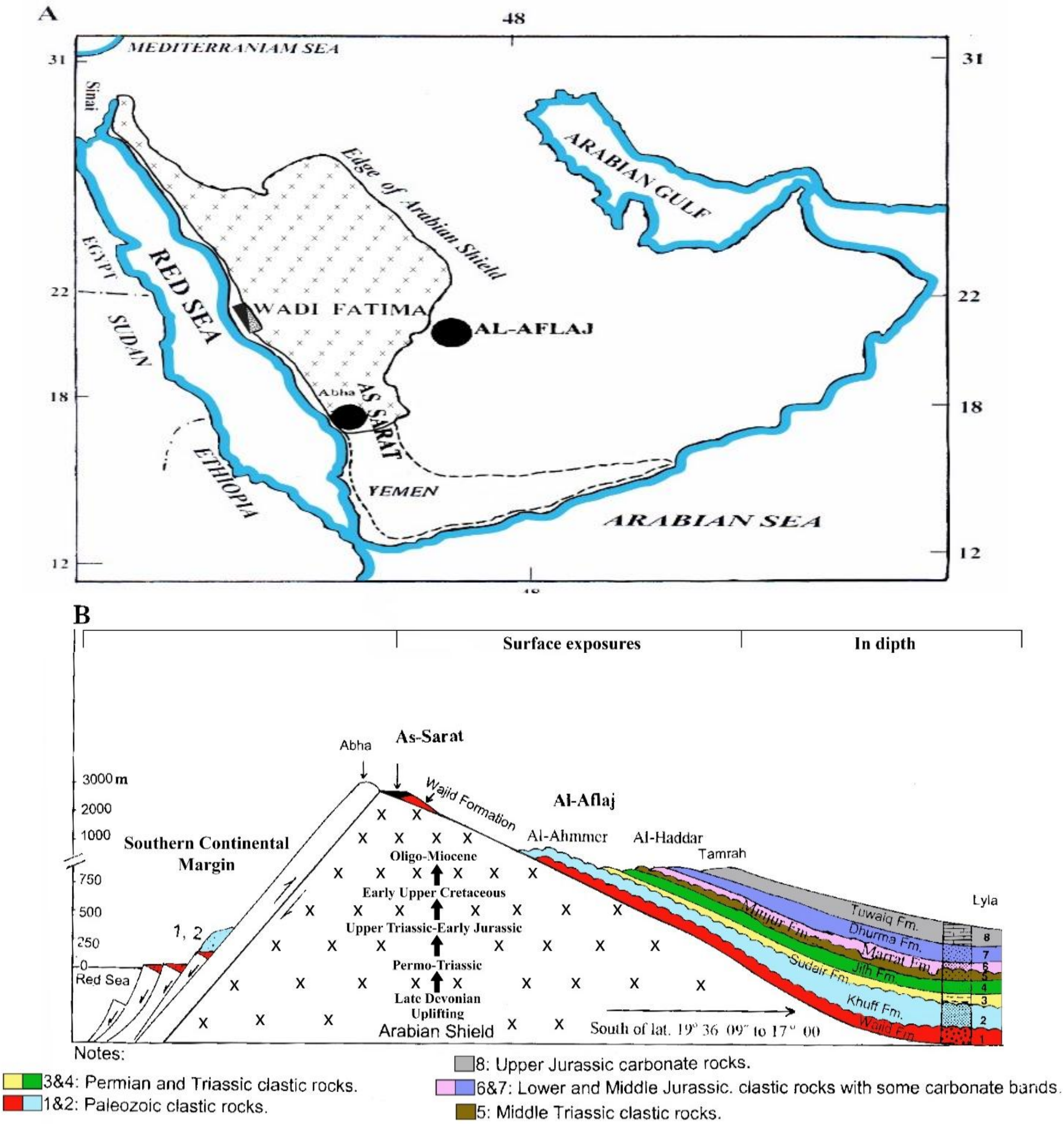

Figure 5a: Key map of the previously studied Phanerozoic sedimentary sequences developed over the edge of Arabian-Shield in three regions. b:Cross-section along the studied three regions showing difference in elevations and sequence stratigraphic Formations at surface exposures and in dipth together with the proposed times of uplifting phases of the Arabian Shield (after Khedr and Moufty [6]).

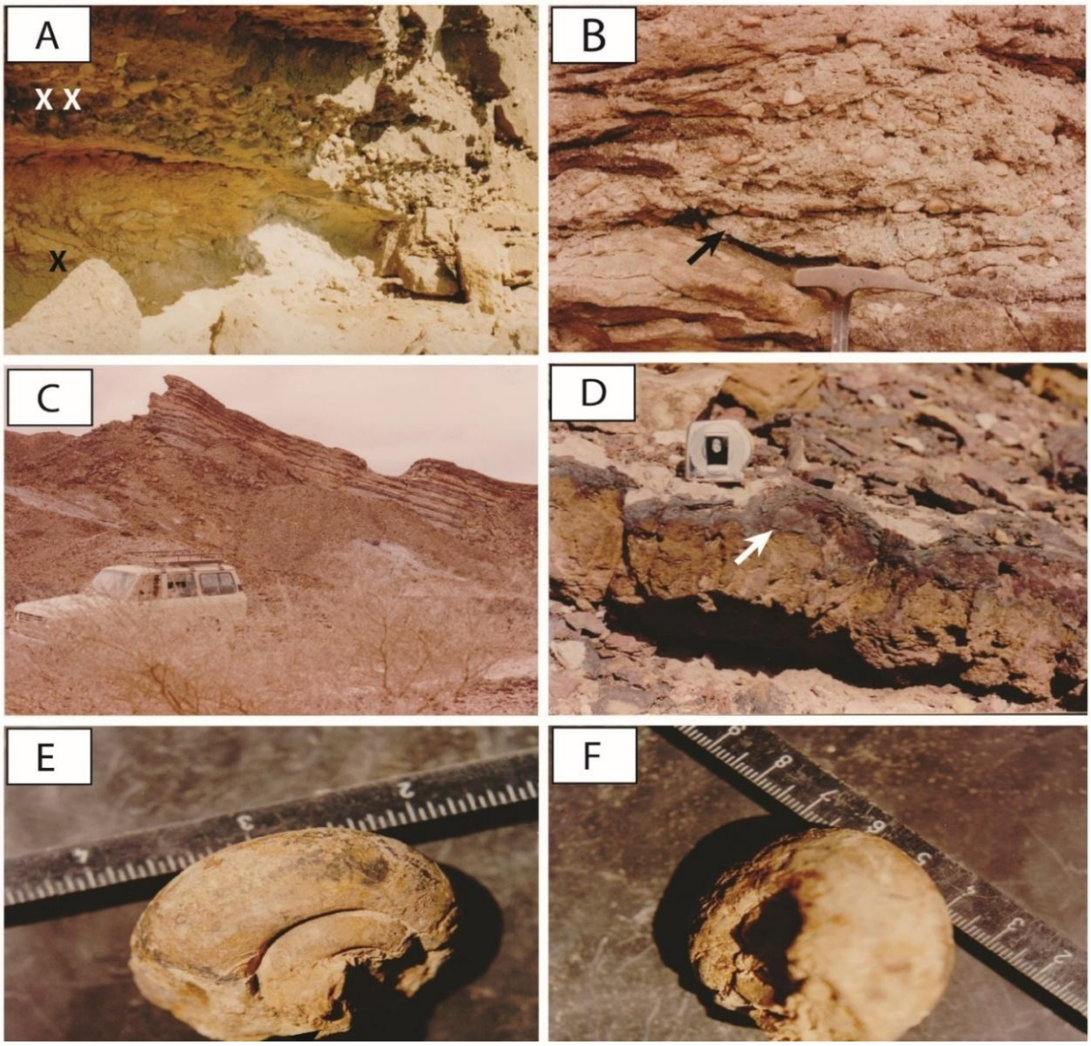

Figure 6: Petrography of (A), the lower weathering unite exemplified by lensoidal kaolin accumulation, marked (x) laid over peneplained basement rock and overlaid by the so called "bottom of the basal conglomerate unite Number (II)" marked (xx) forming tillite deposits in Shi'b Burma at the entrance of Hadat Ash-Sham locality.(B). The basal conglomerate unit No (II) exemplified as gravel embedded in mixture of coarse sandstone and fine silt and kaolin interpreted as an outer facies of terrestrial facies-association of glacial environment. (C) Thinning upward sequence made-up of tilted sequence of alternated sandstone and variegated color shale and siltstone, In Hadat Al Sham Locality.(D) Fossiliferous chert over aeolian sandstone in Al Shumaysi locality suggesting deposition from meteoric water (unit No.V) marking unconformity plan between Paleozoic rock unites and the overlying Tertiary Group, in Al Shumaysi valley. (E and F) Maclurites magnus LeSueur, X3/4. Early Ordovician (Chazy) the shell goes into a reversed spiral that is sunken on one side and flat on the other. From Wadi Al Shumaysi (Abu Azzam locality)

Detail stratigraphic description of the composite sequence of Wadi Fatima area is delineated below in ascending order:

Cambrian-Devonian Shumaysi Formation

I- **Lower weathering Kaolin unit:**

The uppermost part of the Precambrian basement rocks exhibits thin weathering profile (mantle of waste). Thickness of which ranges between zeros to 1.5 meters. In some localities, it seams to be stratified over hydromica with gradational variation in grain size and color. The latter differs between white, violet, and gray;

its uppermost part is usually composed a white thin kaolin band few centimeters in thickness plucked and to accumulates in shallow plucking depression in the unconformity surface of the hard basement rocks in forms of frequent elongate kaolin concretions (25x10 cm) with their long axis laying horizontally (Fig 6-A). No ironstone crust is noticed anywhere at the topmost part of the lower weathering unit in Wadi Fatima area.

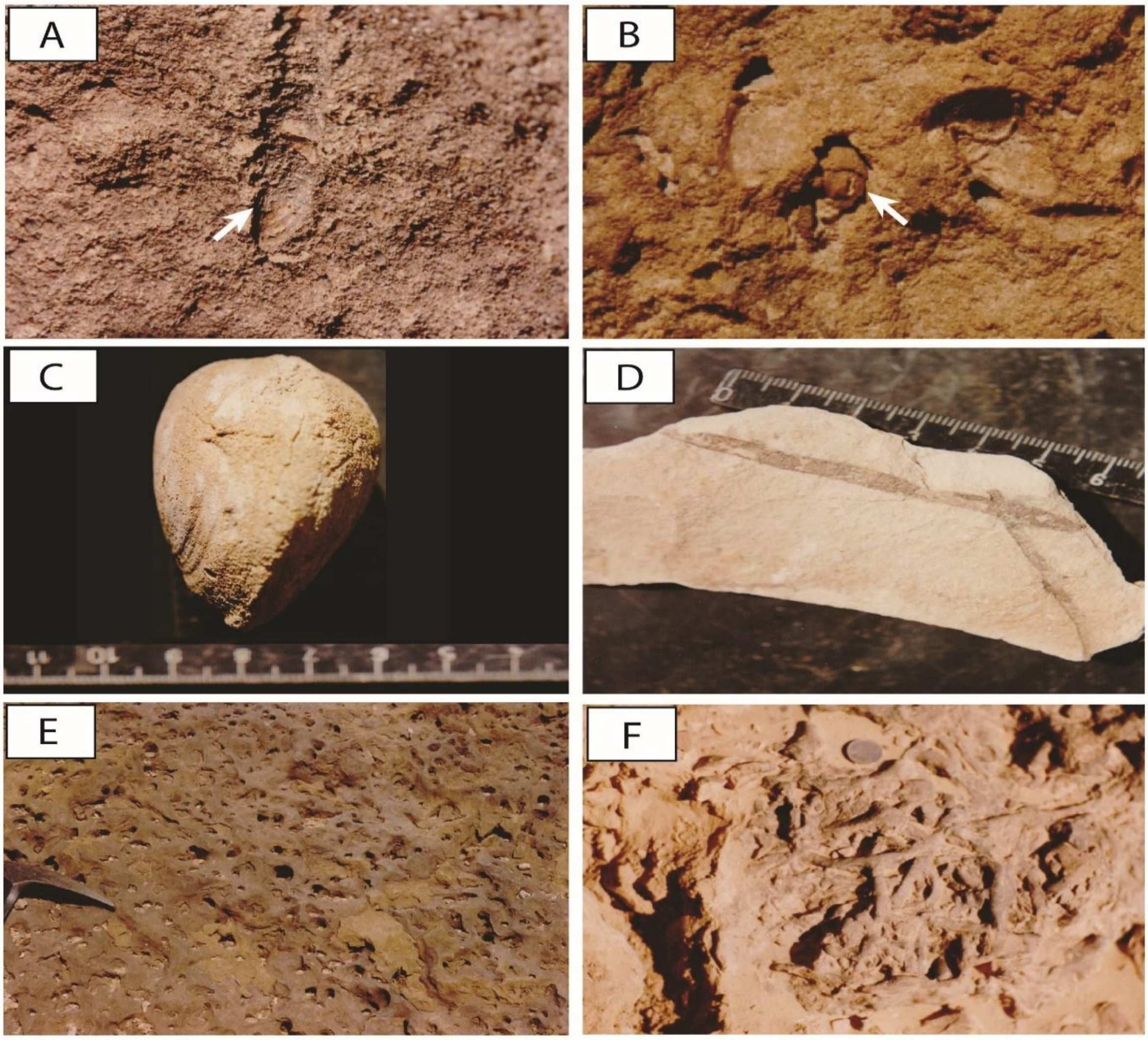

Figure 7: (A), Monocraterion tentaculatus Torell. Early Cambrian (B), Agnostus representative of a diminutive family of trilobites that lived during the Cambrian and Ordovician periods (arrow) the longitudinal furrow in front of the glabella is missing. (C) Edmondia De Koninck, Representative Upper Devonian-Pennsylvanian Pelecypods (dorsal; X1.0). (D) Dicranograptus, Ordovician. Stipe length 5-17 cm. (E) Plan view of slender type Scolithus linearize Haldeman, comparable to those found in Cambrian-Devonian sandstones of Europe, North America and other continents [47] (F) Ordovician genus Batostoma poctai comparable with the Ordovician of southwestern Europe of Prokop (1981), From Al Shumaysi Fm. Similar to horizontal burrows of ichnogenus Harlan IA in shallow marine fine siltstone, comparable with those reported by Silley (2018 P.136) of Cruziana Ordovician ichnogenus from southern Jordan.

II- Basal conglomerate unit:

The basal unit, 1.0 to 51.0 m thick unit composed mainly of friable oligomectic pebbly quartz conglomerate intercalated with lenses of coarse sandstone and crowned by laminated siltstone bed (loess) of varied coloration (yellow, brown, gray, and white). The basal conglomerate unit generally striking in north-south direction, dipping 30^o easterly with maximum dip value of 46 ^{o}. The unique rounded to subangular monomineralic-conglomerate indicate long transportation. Imbricate-structure in the basal conglomerate unit is scarce, but it noticed in Wadi Shumaysi indicating derivation from the west or the southwest directions. The same observation also recorded in Wadi Al-Sayle locality. On contrast, at Hadat Al-Sham the source of large gravel grains indicate derivation from the meridian south. The present authors had not noticed the basal conglomerate unite of the Shumaysi formation in Usfan area. It either eroded or originally not formed. It can be presented in subsurface. Hence, these observations indicate that during deposition of the basal unit of Shumaysi formation in Makkah Quadrangle area, the Usfan region most probably had been uplifted. Lenticular bedform with many scour and fills and channeling structures as well as stratified thin gravel layers intercalation with coarse sandstone beds (Fig 6B) are noticed within the basal conglomerate unit together with eastward dipping cross bedding, rhythmically laminated siltstone and claystone (varves). Following Frye et al., (1965), the collective picture indicate that the basal conglomerate of lower part of Al- Shumaysi formation can be categorized as an outer facies of terrestrial facies-association of glacial environment.

III- Cross-bedded sandstone unit. This unit is made up of finning upward sequence formed of course to fine grained sandstone and occurs in two different isochronous facies. It occurs either as alternation of massive sandstone lenses that draped with a rippled and borrowed veneer of cherty siltstone (Fig 6D), or as a set of cross-bedded sandstone. Identified borrowers are *Monocraterion tentaculatus and Skolithus (Fig 7A,E and F)*of Cambrian-Devonian age interval, whereas the cross bedding is of the planner type and having a general dip towards the east and the northeast directions. The unite extended in the majority of the studied area and disappeared in few localities. Its total thickness range between 1.5 m and 32 m. The collective picture indicate that it derived from a highland province occurs to the west or the southwest direction, i.e. the location of the present Red Sea. This fact indicates that there was a high land area south and southwest of the study area during accumulation of the Paleozoic cross-bedded unit. It is pertinent in this context to report that: The thickness of the sedimentary sequence at Hadat Esh-Sham locality increases eastward with off-lap structure (general eastward dipping and successively eastward appearance of younger strata) extended along a distance of about 20 Km. The present authors believe that the Oligocene-Miocene Hadat Ash-Sham Formation took place over one giant fault-block its western boundary juxtapose Harat Al-Jabiriyah fracture zone (volcanic basalts). The off-lapping structure most probably being due to long lasted syn-tectonic deposition over easterly inclined subsiding fault-block in Hadat Esh-Sham locality. The collective picture indicate that deposition of this Cross-bedded sandstone unit and its subsidence occurred in Ordovician time judged by the presence of genus *Batostoma poctai* (Fig 7F)

IV- The ironstone rock unit:

Only one ironstone bed occurs in the stratigraphic sequence of the study area (Fig. 9) with only two exceptions, in Wadi Al-Sayle (Fig. 2) and Hashafat Al-Quaid. The apparent exposer of two or more ironstone beds in one vertical sedimentary sequence or in bore holes in Wadi Al-Shumaysi [32] are most probably the outcome of crossing the bore hole through reversed fault plane that most probably resulted in repetition of the same ironstone bed. Accordingly, six ironstone beds have been intersected in drill holes from Wadi Al-Shumaysi [32, 48].

The original oolitic ironstone bed at issue occurs in different elevation above sea level all through the study area with measured difference in elevation attaining 340 m, representing the collective value of fault-displacement in Al-Sail and Hadat Al-Sham localities. The lowest elevation being measured in Wadi Fatima whilst the highest elevation is measured in Shi'b Burma at Hadat Esh-Sham (Fig. 6.)

Five types of ironstones were encountered in Wadi Fatima, the majority of which is the pisolitic or oolitic ironstone type of shallow marine to lacustrine environment (Khedr, 1991). Other scarce three types with little economic values are faced in the same stratigraphic sequence of the study area, namely, ironstone crust, iron pyrites, and specular ironstone (specularite in Usfan locality).

V- Upward thinned sandstone.

It ranges in thickness between 22 and 103 meter at El Shumaysi area and Wadi El Sale respectively.

(Fig 8-C). This sedimentary sequence overlay the ironstone unit. It is made-up of alternation of sandstone and variegated color shale and siltstone or silty shale beds with paleosole horizons. All are character of thinning and fining upward sequence; interpreted as alluvial fan deposits. The unit lays under undulated erosional surface of unconformity caped by the Oligocene-Miocene lithic sandstone derived from nearby locality and include representative pelecypos of both Oligocene and Miocene ages as they derived into a coquina limestone bed including *Mercenaria Schumache* (Miocene-Recent) and *Lyropecten Conard* (Oligocene- Recent) at the base of rock unite (No VI) and covered by fine sandstone and tuff rock units (No. VI) that unconformably crowned with the Upper Laterite profile (No. VII). This profile previously was assigned to Khulays formation [1]. However, two types of laterite were encountered. They characterized by the known "Valley-slop beans-type" transported laterite [49]. The original laterite developed at highlands at the northern part of the study area, at Usfan and probably extended further to northern localities out of the scope of the present study. It developed essentially by weathering of volcanic tuff and ash in tropical condition. Most lateritic profiles at Usfan and Wadi Al-Sayle areas could have been formed as reworking products of original highland beans-type laterites. The mean thickness of the highland original laterites at Usfan locality attains 1.5-5.0 meter, whereas the maximum thickness of the transported type as measured in break clay quarry at bottom of Wadi Al-Sayle is 25 m. The laterite profile commenced over subaqueous banded tuffaceous rock and ash including saprolitic volcanic bombs (basaltic) covered by red tuffaceous shale followed upwards by ferruginous beans-type laterite, capped by basaltic flow now formed as clastic boulders. The reworked laterite profile exhibit inverse vertical sequence commenced with beans-type ferruginous mudstone covered by yellow tuff including saprolite clast of boulder sized basalt derived by rolling over slops with small streams, and crowned by kaolinite zone. The highest measured difference in elevation between the original laterite horizons and the transported materials attains 95 meter. The reworked laterite deposits were most probably formed by transportation over slopes from higher sites in the west and eventually deposited into eastward valley floors and tectonically formed depressions. The highest elevation of original laterite being measured in Usfan whilst the lowest elevation of the reworked laterite is measured along the western side of Wadi Al-Sale. Prior to sedimentation of the volcanic tuff and ash, Usfan area was a basin of sedimentation receiving thick sequence (81 m.) of tilted alluvial fan deposit made up mainly of clastic materials and tuff deposits that derived from the west direction. Syndepositional structures recorded as chevron-fold at the middle of the alluvial fan sequence. It gives an evidence of tectonic movement synchronous with deposition of the alluvial fan deposits that subjected to uplifting movement and partially eroded giving rise to undulated erosional-surface over which volcanic tuff and ash took place as thick drape.

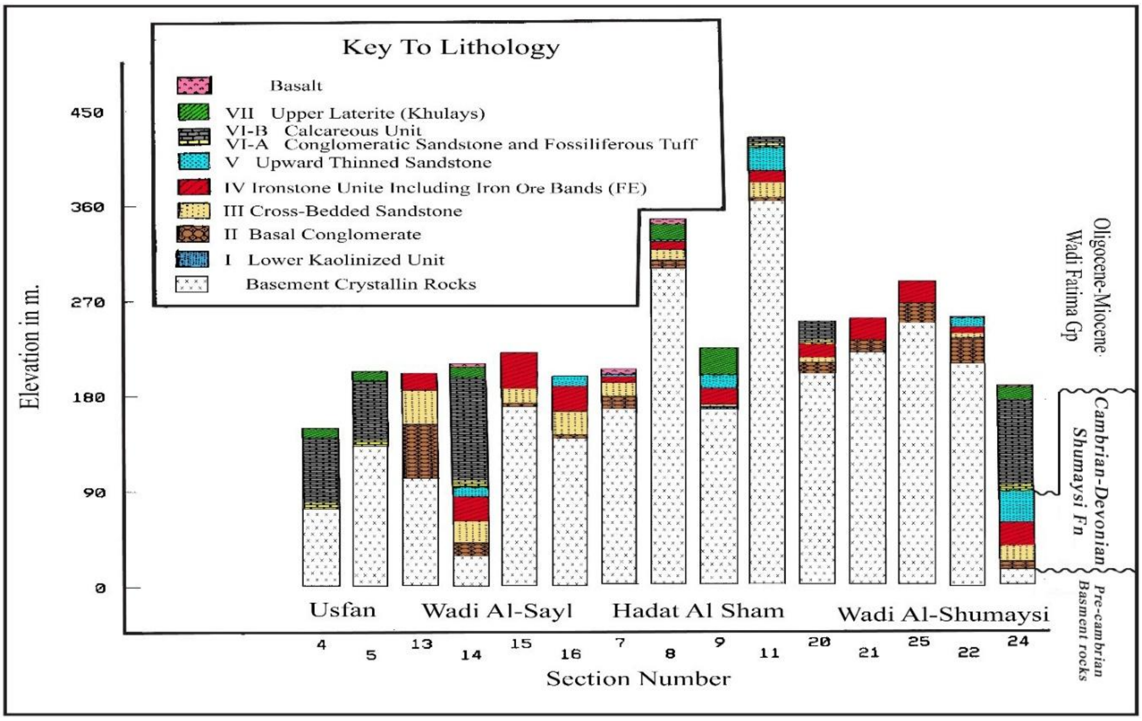

Figure 8: Correlation chart of elevation of bottoms of 15 juxtapose columnar sections from Wadi Fatima area over the Precambrian Crystalline rocks from the four studied localities

From the correlation charts of columnar sections of Wadi Fatima area (Fig. 8), an idealized sedimentary log of Wadi Fatima area is prepared (Fig. 9). From Figure (8), it can be state that, in despite of the great difference in elevation of the plotted logs over the Precambrian Crystalline rocks, there is uttersimilarity in sequence of layering in the lower part of the correlated logs, implying uninformative of the sequential environments of deposition throughout the study area and denoting that deposition of the lower rock units took place prior to the earliest uplifting movements of fault blocks in the study area. To attest this statement on bio stratigraphic and lithostratigraphic bases, the idealized sedimentary log of Wadi Fatima area (Fig. 9) can be subdivided into eight rock units, having a total thickness of maximum 185 meter. Figures (8), listed a summary of the seven rock units in a chronological order from youngest to oldest. More details on this issue are given below:

The generalized sedimentary sequence is divided according to the facies sequence into three groups, from bas upwards these are, the Cambrian-Devonianclastic category of Shumaysi Formation (70, meter thick) including units numbers I to V comprising Lower weathering unit (No. I), covered by basal conglomerate unit (II) graded upward to tillite, and followed upwards by cross bedded sandstone unit (III), then covered by the ironstone rock unit (a, b, and c beds), and caped by the thinning upwards sandstone rock unite (IV) that overlaid by sandstone unite draped by fossiliferous chert band or tuff. The Middle calcareous category number VI of a newly introduced name “Wadi Fatima Formation” attaining 109 meter in thickness, assigned to Oligocene-Miocene age, previously gathering three isochronous formations. In formal stratigraphic bases including identification of fossils and correlation of trace fossils of the study area with similar forms and shapes in a worldwide scale (Fig. 6 & 7), the idealized stratigraphic log (Fig. 9) is divided into two parts. Lower Shumaysi Formation of Cambrian-Devonian age and unconformably covered by the Wadi Fatima Group of Oligocene- Miocene intervals gathering Wadi Fatima Formation and laterite rock unite 109 m, and 6 m. in thickness, respectively. Collectively, the complete section has been vertically classified into seven different rock units, designated in Latin numbers (I to VII in Fig. 9), and crowned with basaltic sheets covering the upper Khulays Formation (laterite unite). However, the basaltic sheets have also been recorded in some places covering either Shumaysi or Wadi Fatima Formations, implying either non-deposition or erosion of Wadi Fatima Formation and Khulays formation prior to the flow of the uppermost basaltic sheets. Alternatively, the variable basaltic flows could have been formed in different times. Isotopic studies carried out by Moore and Al-Rehaili [1] indicate that the basaltic sheets ranges in age between Cretaceous and Miocene interval. The present study indicates that Shumaysi Formation is an individual stratigraphic unit of Cambrian-Devonian age took place prior to the first uplifting movement of fault blocks in the area at issue.

Correlation and Structure

Twenty-nine sections including ironstone deposits have been measured in the so-called Wadi Fatima area (part of Makkah Quadrangle) and stratigraphicaly correlated. Out of the twenty-nine logs, only three sections numbers (3, 26 and 24) are characterized by occurrences of ironstone filling fault plans (load deposits). They include thin ironstone vein loads, 20-25 cm thick, transected the hard basement rocks and the overlaid basal sediments, and developed upward to form stratabound thin pyrite lenses. However, elevation of tops and bottoms of studied and correlated sedimentary sections are illustrated in Fig. (8).

Considering lineaments of photogeological maps obtained from Makkah Quadrangle (Moore and Al-Rehaili, 1989) and field work done in this paper, together with published work (e.g. Nebert et al. 1974,), various trends of regional faults in the area at issue together with pronounced faults were traced, nomenclated and listed in Table (1).

From table (1.) it is obvious that both of the Wadi Shumaysi trend (including Wadi Shumaysi and Wadi Al-Sale) and the Hadat ash-Sham trend are extended evenly parallel to the Red Sea axial trend. On the other hand, both of Wadi Fatima and Gulf of Aden are roughly oriented perpendicular to the Red Sea axial trend implying either later rifting events along transform faulting and contemporaneous triple junction (Bosworth and Burke, 2005) related to rifting phases of the Red Sea.

Table 1: Names of major fault trends in the study area (after Makkah Quadrangle) together with the Red Sea fault trends (after Abd el Gawad, [50])

Area	Fault-Trend	Name of fault Trend
Along Wadi Shumaysi and W. Al-Style	(NW 30^o SE)	1. W. Shumaysi
Along Wadi Fatima	(NE 52^o SW)	2. W. Fatima
Along Darb Al-Gemal and Shi'ib Burma	(NW 26 SE)	3. Hadat ash-Sham.
Along Sharm Abhor to Usfan	(NE 30 SW)	4. Usfan.
Along the low laying lands (Tihama) of Bur Abu Akhdar south of Jeddah to Sharm Abhor	(NW 10 SE)	5. Jeddah City.
Red Sea	(NW 28 SE)	Red Sea Axial Trend
A- Aquaba	(NE 12 SW)	Gulf of Aquaba
B- Suez	(NW 33 SE)	Gulf of Suez
Najed	(NW 55 SE)	Najed fault system

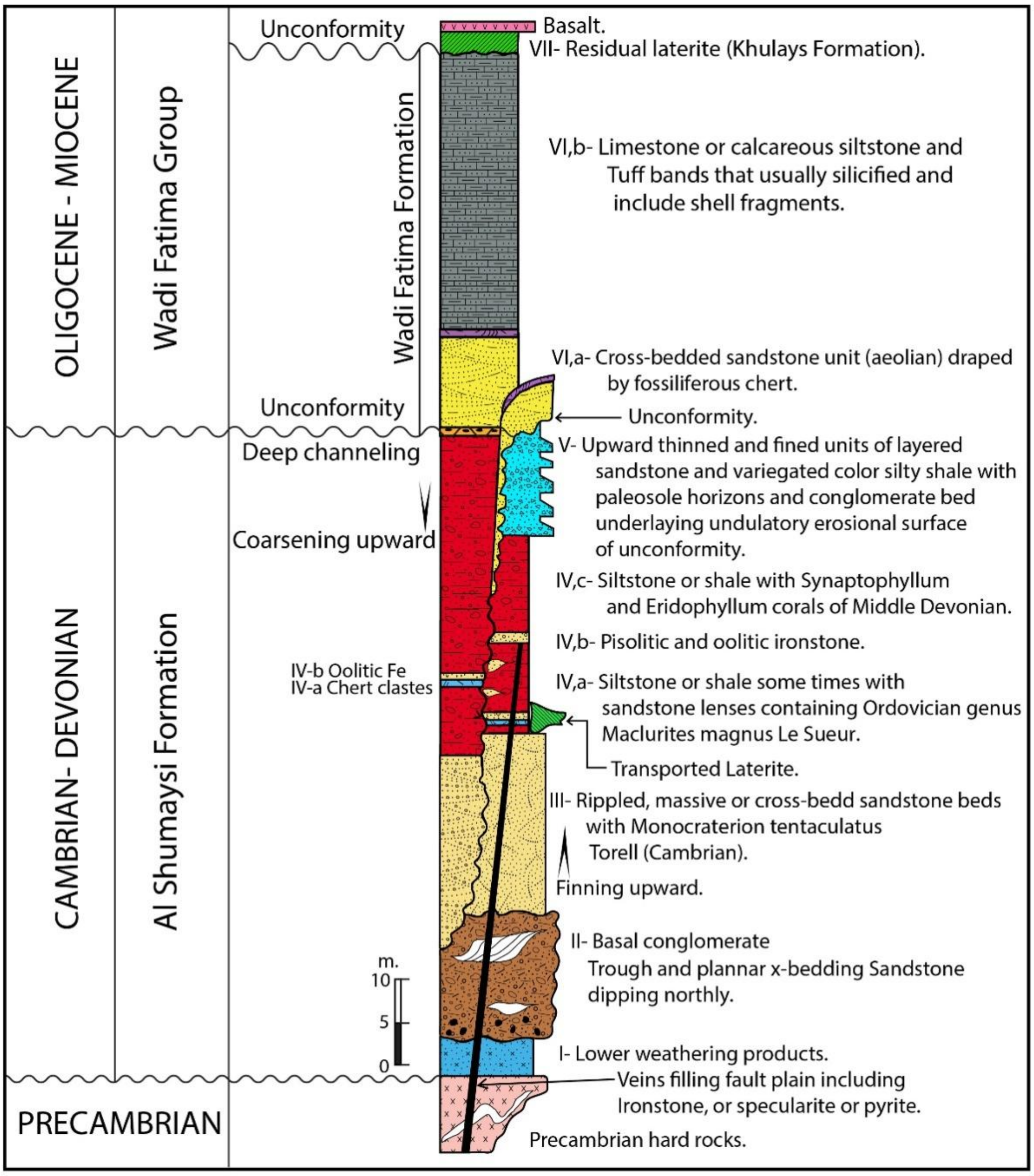

Figure 9: Generalized stratigraphic section of the studied area

The initial forming phases of the Red Sea commenced in Precambrian times [51], whilst the subsequent rifting phases according to Girdler, [52]) started in Carboniferous period. However, Precambrian thrust fault extended in NE direction took place along the northeastern bordering high ground of Wadi Fatima, a witness of southward up-faulted block and northward down-faulted block [2]. These imply compression forces were acting in two opposite directions (NNE against SSW). The outcome of these forces was the initiation of NW-SE trending fault zones running perpendicular to the main direction of Wadi Fatima. In the meantime, perpendicular fault zone took place in the same direction running along the valley floor between the present two scarp faces of Wadi Al-Shumaysi. As Monocraterion trace fossils and other fossils of Early Cambrian-Ordovician age are detected within sediments of Al-shumaysi beds (Fig 8), then the listric-normal faults running parallel to the present course of both of Wadi Al-Shumaysi and Wadi Al-Sayle (Fig. 2), may have been resulted later than Cambrian-Ordovician time. Consequently, sedimentary deposits of the study area are remarkable by narrow rifted troughs which are formed as a consequence of continental breakup started since late Precambrian [51] and rejuvenated in Paleozoic, Mesozoic, and Cenozoic eras [52].

The basal unit and the overlying ironstone unit in all studied sites are dipping easterly at N 30 E direction forming offlape structure with only one exception represented in Wadi Shumaysi. In this locality, the strata dip in two opposite directions separated by faults zone of about 100m in width. The unique dipping direction (east or NE) of the lower units of Al-Shumaysi Formation could have been resulted due to general inclination of one large fault-block covering the whole study area. Subsequent faulting of the large fault-block resulted on the formation of two half-graben basins along both of Hadat ash-Sham in one hand and along both of Wadi Shumaysi and Wadi Al-Sail, on the other. During that time (Paleozoic) Usfan locality was a high land-area suffering erosion and continental deposition. Similarly, the southwestern part of Wadi Fatima was in a higher level than both of Al-Shumaysi and Al-Sayle localities. In Devonian, one major uplifting phase of the southern and central parts of the Arabian Shield took place [11]. Subsequent major tectonic uplift occurred by the Cretaceous time where the southern part of the Arabian Shield had been uplifted relative to the northern part [29]. This tectonic event most probably terminated in the study area by subsidence of Usfan locality, subsequent peneplanation followed by accumulation of a relatively newer deposits of tuff trailed by extrusion of basaltic flows covered the tuff and the previously formed continental deposits. By Oligocene and Miocene times, major rifting events occurred in the area and the Red Sea opened. Marine transgressive phase resulted in deposition of calcareous siltstone and fossiliferous limestone rock-units that unconformably laid over peneplained surfaces of either Paleozoic beds or unfossiliferous continental deposits (Cretaceous ?). If this explanation is true, it can be concluded that since the closing of the Cambrian age until the beginning of the Oligocene period, the uplifts or downthrows tectonic movements of fault blocks at the study area persists in the same directions.

Summary and Discussion

Sedimentation of pisolitic or oolitic ironstone bed in the central west Saudi Arabia with great difference in elevation above the present sea level attaining 281 meter, together with, the occurrence of the Paleozoic Wajid clastic sediment at the top of the Arabian Shield in Al Sarat region southern the Arabian Shield, All had attracted the attention of the authors to study the interrelationship between sedimentation of different rock units and tectonic uplifting of the Arabian Shield.

Said [7] stated that during the Upper Cretaceous and the Eocene-times marine waters invaded the present site of the Red Sea from the north (Tethys) and extended southwards until lat. 26.5^{o} N at Safaga and Quosseir district of Egypt [53]. Other Mesozoic sediments recorded in the western bank of the Red Sea south of lat. 16^{o} N in Sudan and Somalia (Fig. 4). Oligocene and Miocene and later marine sediments are recorded in the northern Red Sea marginal area of Saudi-Arabia [54]. At the southern Red Sea margin in Saudi Arabia, Paleozoic and Mesozoic sediments were recorded [55]. This regional stratigraphic distribution supports Whitman's view (1968) that, the study Wadi Fatima area, is a part of the Afro-Arabian swell of anticlise has been rising since late Precambrian time (Fig. 3). As the swells axes are stretching out in NE-SW direction, it apparently was located at the margin of two separate uprising blocks located to the south and to the north of the Afro-Arabian Swell. The northern part of the Shield had been upraised after the deposition of Jubayla sediments in Cambrian early Ordovician times [21] whilst the preponderance offset of the southern part of the Arabian Shield took place due to uplifting movements occurred in Late Cretaceous [29]. More uplifting events occur in Tertiary period during the rifting movements of the Red Sea [13].

This construction, explain the spatial distribution of the stratigraphic units along the Red Sea marginal areas and denied the formation of any marine deposition of Cretaceous or Eocene ages in Wadi Fatima area.

In a summary of the geologic history of Makkah quadrangle (sheet 21D), Moore and Rahaili [1] considered that Suqah group of Eocene to Paleocene age (?) is correlated with the Jizan group of Gillman [56]), It also correlated with Cambrian early Ordovician formations (Shumaysi) of Bender [57]. Moreover it correlated with Umm Himar formation that developed in top of the Arabian shield east of Wadi Fatima area [58]. Furthermore, it correlated with Sita and Shumaysi formations of Pallister [59]. This correlation covers regional studies achieved by Husseini [60-61] and Schmidt and others [9] as well as other mapped areas adjacent to Makkah quadrangle such as Rabigh (sheet 22D), Turabah at the top of the Arabian shield (sheet 21E) and Al-lithe (sheet 20-D). Interaction between Paleozoic and Tertiary deposits in Suqah group can safely be attributed to deep channeling and peneplanation of Shumaysi Formation that took place long before deposition of the Tertiary Sita Formation. On bases of the available index fossils and trace fossils, specifically *Cruziana* trails and *Tigillites*"*Scolithus* " burrowsand some newly identified fossils (Fig's 6 and 7), the present work suggests a new contribution to the age of the so-called Al-Shumaysi Formation (Fig. 9). Consequently, the Shumaysi Formation can be redefined as Cambrian-Devonianage sediment, 18 to 102 m thick, composed of five rock units and confined between two unconformity planes. Accordingly Resting unconformable over either a glacially weathered horizon (unit-I), a 16 m thick unit of fluvio-glacial basal conglomerate took place (unit-II), and followed upward by 23 m thick unit of massive or cross-bedded sandstone beds with Mono*craterion and Skolithus* borrows (Cambrian) and chert crusts (unit-III) Figures (6 & 7). This unit is followed upward by 30 m thick unit of siltstone or silty shale confining Pyritized oolitic ironstone lenses covered by siltstone with *Synaptophyllum and Eridophyllum* corals of Middle Devonian lacustrine environment (rock unit-IV). The uppermost unit of Shumaysi formation attaining 33 meter thick is made up of layered sandstone and variegated color silty shale with paleosole horizons underlying undulated erosional surface of unconformity character of deep channeling. The lateral boundaries of Shumaysi Formation are usually faulted or mingled with the overlaying Tertiary formation. On correlation with other similar work which carried out on the bases of trace fossils *Tigillites (Scolithus)*; supported by the palynologic studies of Al abouvette and Villemur, [62] and McClure, (1980), and Dabbagh, (1981), (cited in Dabbagh and Rogers [63]; the age of Wajid Sandstone on the flanks of the Arabian Shield has been redefined as Cambrian to Devonian clastic sediments took place prior to the first uplifting movement of the Arabian Shield. The same trace fossils identified within Wajid sandstone from Jizan Quadrangle [27] are discovered herein at the top layers forming the Al- Shumaysi formation in Makkah Quadrangle.

Following Spencer and Vincent [64], transported lateritic horizon unconformable laid over the lower clastic sequence of Usfan is reported herein as a characteristic feature for the top of both of Usfan and Hadat ash-Sham Formations. These two formations laid over an unconformity plain between them and the underlying Shumaysi formation. On the other hand, Al-Shumaysi formation of Moore and Al-Rehaili [1] is covered by Sita formation, which include calcareous siltstone comprising some Tertiary fossils in Wadi Al-Shumaysi. The same fossil association are also occur within a cherty lithologic bed at the base of both the Usfan Formation (Gholah section No 4, see Fig 8), and the Hadat Ash-Sham Formation (section No 11 see Fig 8). Consequently, the three formations, Usfan, Hadat Ash-Sham, and Sita are considered herein as one formation having different isochronous facies, all are crowned by lateritic materials and laid over unconformity plain with deep channeling; Usfan formation at its type locality interpreted by Ba Sahl et al., [39] as overturning ramparts and clay diaper laid above the Shumaysi Formation. However, Shumaysi Formation occurs underneath three isochronous formations. Hence, Usfan, Hadat Ash-Sham, and Sita formations are renamed herein as"Wadi Fatima Formation". However, the original laterites are of the highland beans-type. Many localities exhibit transported laterites particularly in Wadi Al-Sayle area. However, the Shumaysi Formation and the confined oolitic ironstone unit have been formed long before the overlying Wadi-Fatima Formation, which crowned with the laterite formation (previously Khulays Formation).

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