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Late Cretaceous Sub-Marine Fan System in Batain Mélange Zone, the Fayah Formation in Northeastern Oman

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ABSTRACT: The Batain coast along the northeastern margin of Oman between Ra’s Al-Hadd and Ra’s Jibsch, is comprised of Permian to Late Cretaceous complex stratigraphy in a tectonically deformed area recording Permian rifting to late Cretaceous Tethys closure events. These rocks are thrust over Mesozoic and older autochthonous sedimentary cover in the form of a major nappe structure known as the Batain Nappe. The uppermost part of the Batain nappe is comprised of isolated outcrops of early Maastrichtian siliciclastic Fayah Formation dominated by gravity flow deposits. The Fayah Formation in the Jabal Fayah area is over four hundred meters thick and comprised of five distinct facies associations; namely, i) coarsening-up sandstone, ii) conglomerate, iii) debris- flow, iv) turbidite, and v) inter-bedded sandstone and shale lithofacies. These lithofacies associations are repeated many times in the section. The sandstone lithofacies association exhibits a coarsening-upward trend making sequences tens of meters thick in various parts of the formation. Waterscape structures are common along with occasional sandstone dykes and convolute bedding, reflecting fluidized conditions of deposition. The conglomerate lithofacies association is comprised of a series of interbedded coarsening-upward pebble to gravel size conglomerates containing chert, limestone, granite and volcanic clasts ranging a few mm to cm in diameter. Occasionally these are interbedded with sandstone lithofacies. The conglomerate lithofacies was deposited by a high-energy channelized flow in a sub-aqueous setting. The debris-flow lithofacies association is a matrix supported chaotic mixture of clay and boulders of granite, limestone and volcanic rocks, some of which are meter-sized in diameter, and possibly derived from the nearby basement rocks such as the Jabal Ja’alan basement rocks. It constitutes the most dominant part of the formation. These sediments were deposited along a slope setting, possibly as olistostrome formed due to submarine slumping and sliding. The turbidite lithofacies association is comprised of monotonous grayish-green to brown coloured clays tens of meters thick interbedded with thin, clean, well-sorted sandstone. The interbedded sandstone and shale lithofacies association is comprised of a half to one meter thick cross-bedded, burrowed arkosic sandstone and plane laminated shale. The sandstone constitutes about 25% of the association with ripple lamination in the upper part of the unit indicating a fining-upward trend. Dewatering structures are common. This association constitutes the upper 100 m of the formation. These sediments were deposited in shallow water conditions by channelized flows. Based on the lithofacies associations described above, especially the dominance of debris-flow units and turbidites, the greater part of the Fayah Formation are interpreted as having been deposited under a sub-marine fan setting. Only the upper part of the formation was deposited in a shallow water setting before the onset of overlying carbonate deposits. The sub-marine fan system was active during the last stages of the Tethys Ocean closure at the time of onset of the Batain nappe.

Keywords: Batain Mélange; Late Cretaceous; Jabal Fayah; Turbidite; Sub-marine fan.

رواسب مرواح البحر العميق من العصر الطباشيري في شرقية عمان

افتخار احمد عباسي، عبدالرحمن الحارثي ويحيى خليفة الصبحي

ملخص: يحتوي الساحل الشرقي من عمان الممتد من رأس الحد و بإتجاه الجنوب على تشكيلات صخرية متنوعة و تترواح أعمارها من العصر البرمي المتأخر إلى العصر الطباشيري. و تشوهت هذه الطبقات بفعل الحركات التكتونية مسجلة بذلك التصدع المصاحب لتكون محيط التيثش في العصر البرمي إلى مراحل إنغلاق هذا المحيط في أواخر العصر الطباشيري. وتم دفع هذه الصخور قيد الدراسة (مجموعة البطين) بواسطة صدوع عكسية مما أسفر عن إستقرارها فوق صخور القاعدة الرسوبية والتي يترواح عمرها من الدهر الوسيط إلى عصور أكثر قدما. و يتكون الجزء العلوي من مجموعة البطين من تكوين الفياح الذي يظهر على شكل منكشفات صخرية معزولة يعود عمرها الى أوائل العصر المستريخي و يتكون من رواسب فتاتية ترسبت بفعل تيارات الجاذبية. و تحتوي رواسب تكوين الفياح على سحنات متنوعة يزيد سمكها على الأربعمئة متر وهي كالتالي:1-سحنات رملية. 2- الرصيص. 3- رواسب ركامية. 4-رواسب المياه العكرة. 5-متتاليات الطين الصفحي و الرمل. وتتكرر هذه السحنات بشكل مستمر في التكوين. و يلاحظ أن سحنات الحجر الرملي تتميز بإزدياد حجم الحبيبات من الأسفل إلى الأعلى و يبلغ سماكة الطبقات عشرات الأمتار. و تحتوي هذه السحنة على طبقات تشوهت بفعل التدفقات المائية و بها أيضا قواطع رملية وإنثناءات طبقية تشير الى عملية ترسيب سريعة جدًا وعملية تمييع للرواسب. أما سحنة الرصيص فتحتوي على الصوان والحجر الجيري و الجرانيت و مفتاتات بركانية يتراوح قطرها من بضع مليمترات إلى سنتيمرات معدودة. و في بعض الأحيان تتعاقب سحنتا الرصيص و الحجر الرملي. أما من ناحية البيئة فيعتقد أن سحنة الرصيص ترسبت من تيارات مائية عالية السرعة. أما السحنات الركامية فهي الجزء الأبرز من التكوين وهي عبارة عن خليط غير منتظم من الطين و مفتاتات صخرية من الجرانيت والحجر الجيري والصخور البركانية، حيث يصل قطر بعضها إلى المتر، وربما تكون مصدرها صخور القاعدة البلورية لجبل جعلان القريبة من منطقة البحث والدراسة. ومن حيث الترسيب فهي رواسب المنحدرات التي تتكون بفعل الإنزلاقات و الإنهيارات الصخرية تحت الماء. أما سحنات المياه العكرة فتتكون من طبقات طينية يصل سمكها إلى عشرات الأمتار والتي تتعاقب مع طبقات رملية ممتازة الفرز. وأخيرا سحنة المتتاليات من الطين الصفحي و الرمل و تحتوي على صخور رملية بها علامات النيم أو التموج التي يصل إرتفاع بعضها إلى نصف المتر وبها أثار لحافير في الرمل الفلدسباري خصوصاً . وتشكل الرمال ما مجموعه ربع السحنة أما الجزء الأكبر فهو طين صفحي متراص أفقيا. وتوجد سحنة المتتاليات من الطين الصفحي و الرمل في المئة متر العلوية من التكوين. ويعتقد أن هذه السحنة تكونت في مياه بحرية ضحلة. و بإستثناء هذه السحنةمن متتاليات الطين الصفحي و الرمل وبناءً على الدراسات التفصيلية لهذه السحنات السالفة الذكر وعلاقتها ببعضها فقد توصل على إنها عبارة عن راوسب لمراوح مائية تدفقت نحو الأعماق السيحقة للبحر نتيجة الجاذبية الأرضية في فترة إنغلاق محيط التيثش.

مفتاح الكلمات: توربيدايت ، جبل فياح ، سب مارين فان، ليت كريتشيوس و بطين ميلانج.

1. Introduction

The Batain coast in northeastern Oman in Ash-Sharyqiah region (Figure 1) is comprised of diverse stratigraphy due to complex deformation related to the Late Cretaceous-Paleogene deformation of the Arabian Plate and closure of the Tethyan Ocean [1,2,3]. The area is part of a tectonic mélange known as the Batain Mélange [1], comprising Permian to Late Cretaceous rocks later described as the Batain Group of the Batain nappe [4]. The Batain nappe was thrust westward onto the eastern Oman margin at the Cretaceous-Tertiary transition. The Batain Mélange, though initially mapped as the Hawasina Mélange [5], was subsequently identified as a separate unit [6] possibly separated by Jabal Ja'alan Uplift. The rocks exposed along the Batain coast in the mélange sequence are comprised of Permian age Qarari Limestone, Pink limestone, Greenish fossiliferous grits, and Limestone Megabreccias and associated basalt; Triassic age white, pink and red bioclastic lime-mudstones and framestones, claciturbidites; Late Jurassic to Early Cretaceous pillow lava and limestone assemblage; Triassic to Cenomanian cherts and argillites; Cretaceous ophiolitic rocks and Late Cretaceous Fayah Sandstone (Fayah Formation).

This study deals with the upper-most unit of the Batain Mélange sequence, the Fayah Formation and describes the lithofacies association in order to interpret the depositional system of the formation and its tectonic significance during the closure of Tethys Ocean along the northeastern margin of Oman. A number of thin-sections from the sandstone units of the formation are studied to interpret the modal composition and probable provenance of the formation. The study was carried out along a section near Jabal Fayah (type-section) (Figure 2). The stratigraphic thickness was measured along the section located at coordinates $21° 41' 03'' N$ $59° 21' 33'' E$, and dominant lithofacies were described and rock samples collected for thin-section preparation (Figure 2).

2. Lithofacies Association of the Fayah Formation

The Fayah Formation is exposed in isolated outcrops along the Batain coast. The study area is located near Jabal Fayah where the formation is a siliciclastic sequence, about 400 m thick comprising five main lithofacies associations i) coarsening-up sandstone, ii) conglomerate, iii) debris-flow, iv) turbidite, and v) inter-bedded sandstone and shale (Figure 3). The outcrops are covered with migrating dunes in places but the mutual relationship of the lithofacies can be worked out on composite outcrop sections. The most significant feature of the Fayah Formation in the study area is the dominance of the debris flow deposits constituting the major part of the formation. Details of each of the lithofacies association are given below.

i) Coarsening-up Sandstone Lithofacies Association:

This lithofacies association constitutes the lower 60 m of the formation (Figure 3) and is comprised of green coloured coarse-grained arkosic sandstone, micaceous sandstone, buff coloured coarse to pebbly sandstone, gray coloured siltstone, and distinct red coloured matrix-rich beds of rhyolite and granite clasts. The sandstone grains are medium-to coarse-grain, well-cemented, well-sorted and moderately rounded. Sandstone in the upper part of the association shows plane and cross-lamination (Figure 4a, b). Most of the sandstone units show a coarsening-up trend, occasionally passing into conglomerate lithofacies. Bioturbation and water escape structures are common features of this lithofacies (Figure 4c). There are some units (at 30 m level Figure 3) which contain large boulders over 1 m in diameter of granite composition in a sandy matrix (Figure 4d).

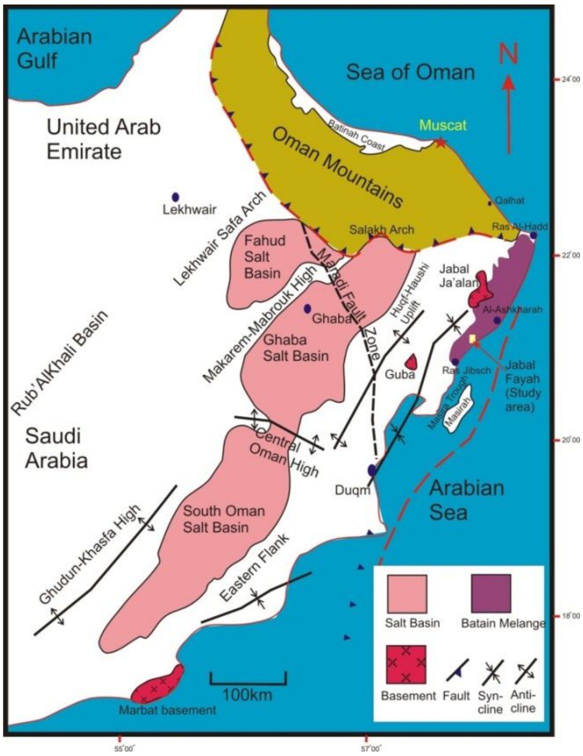

Figure 1. Location map of the study area in Jabal Fayah located in northeast the of Oman, shown as Batain Mélange in Ash-Sharyqiah region (modified after [7]).

The lithofacies association is interpreted to have been deposited under shallow water marine conditions [8]. Coarsening-up sequences show an active supply of sediments and high sedimentation rates. Water escape structures also indicate high sedimentation rates in highly fluidized conditions [9]. The exotic boulder clasts and beds were formed due to debris flows contributed from nearby uplifted terrains.

ii) Conglomerate Lithofacies Association:

The conglomerate lithofacies association is 15-20 m thick in the lower and middle part of the formation (Figure 3).

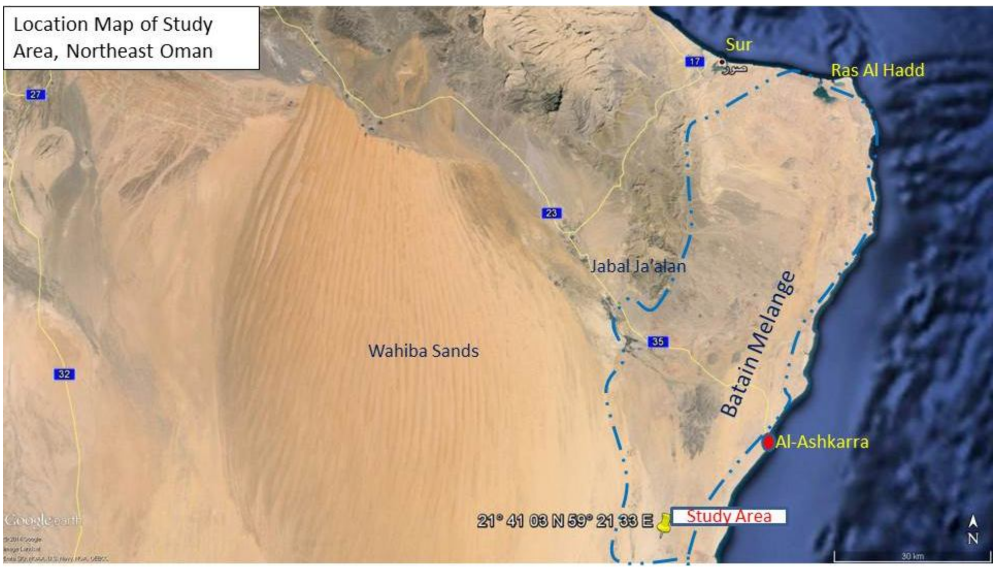

Figure 2. Location of Fayah Formation outcrops in Batain Mélange shown on Google Image.

The lithofacies association in the middle part of the formation is interbedded with thick debris flow deposits. This association is comprised of coarsening-upward conglomerate interbedded with plane bedded arkosic sugary textured white coloured sandstone (Figure 4e). Each coarsening-up sequence is about 2 m thick. The sandstone beds show occasional cross-bedding and burrowing. The clasts in the conglomerate beds are pebble sized and angular to sub-angular in shape (Figure 4f). The clasts are comprised of rhyolite, granite, green and red chert and limestone. Water escape structures are common in the facies association. Convolute bedding and sedimentary dykes (sandstone) are also present in the lithofacies association. The conglomerate lithofacies association was deposited by channelized flows associated with distributary channels draining into the proximal part of a submarine fan system. The sediments were derived from nearby basement escarpments. Abundant chert is derived from obducted oceanic floor sediments of the Batain nappe [10]. Abundant water escape structures, convolute bedding and sandstone dykes were formed due to liquefied conditions and abundant sediment supply in the depositional site. Another possibility is that deposition of the lithofacies along unstable slopes generated slumping.

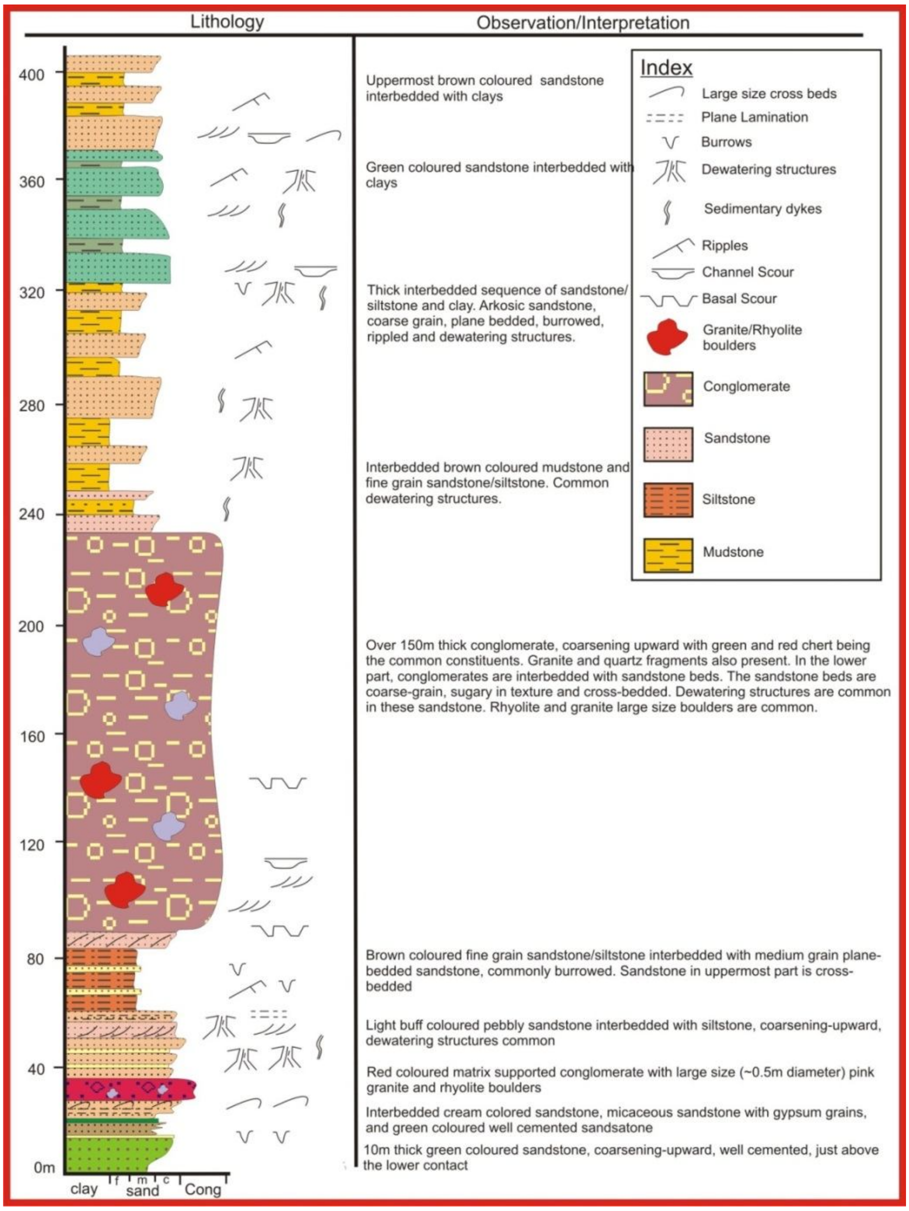

Figure 3. Detailed measured section of the Fayah Formation in the Jabal Fayah area.

iii) Debris flows Lithofacies Association:

The debris flows lithofacies association (debrites) is the most significant rock type in the Fayah Formation, constituting most of middle part of the formation where it is over 150 m thick. It also occurs in the lower and upper parts of the formation being interbedded with other lithologies, such as sandstone lithofacies. The debris flow deposits contain 1-2 m in diameter sized angular boulders of granite and rhyolite floating in the sand-to-mud matrix. Most of the matrix has now been removed, and the boulders are scattered over a large area (Figure 4g). In the middle part of the formation where it constitutes the bulk of the formation, it is interbedded with coarsening-up conglomerate lithofacies. The debris flow lobes are exposed over 200 m in lateral extent and can be traced out at the outcrop scale.

The debris flow deposits (debrites) were formed by mass flow processes in the proximal part of the submarine fan system during high discharge events in streams draining through a nearby source terrain, possibly an escarpment surface, exposing basement rocks.

iv) Turbidite Lithofacies Association:

The turbidite lithofacies consists of grey to greyish-green coloured mudstone interbedded with thin sandstone (Figure 4h). The lithofacies association occurs throughout the formation, and is interbedded with other lithofacies, such as debris flow lithofacies. It occurs dominantly at the 60-80 m level, interbedded with debris flows at the 90-220 m level and also occurs in the upper part of the formation (220-340 m level) (Figure 3). Shale and siltstone constitute about 75% of the association, the rest being the sandstone. The sandstone beds are 0.5 to 1 m thick, arkosic in composition, and fine- to medium-grained. Occasional conglomerate beds are also present. Graded beds, dewatering structures, convolute bedding and trace fossils, such as bedding parallel burrows (planolites), are common in this lithofacies (Figure 4i, j).

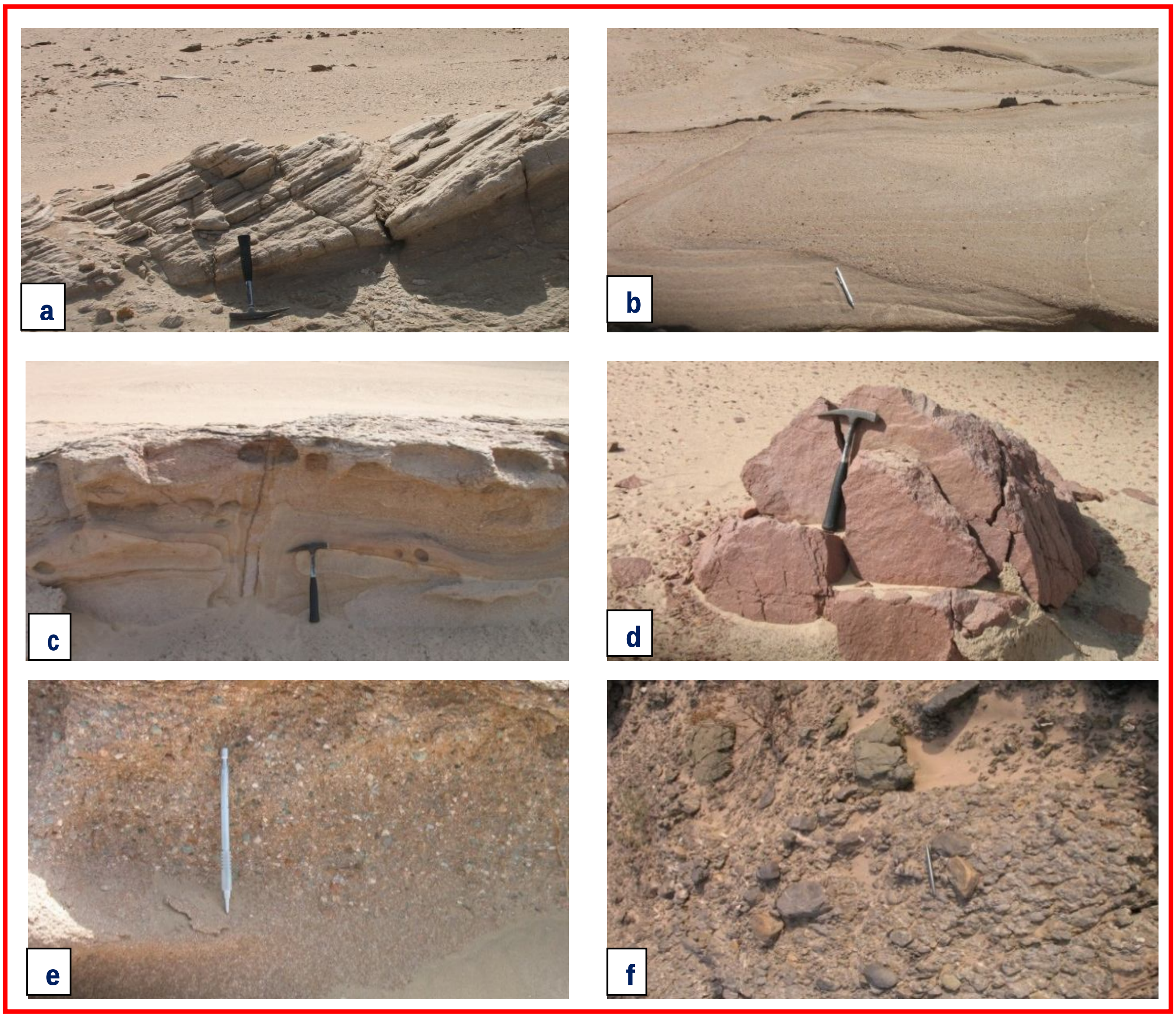

Figure 4…. *Continued*

This lithofacies association is interpreted as having been formed by mass flows deposited by density currents in deep water conditions most probably below the shelf margin [11].

v) Interbedded sandstone and shale Lithofacies Association:

This lithofacies association consists of interbedded green and brown coloured sandstone and shale. The sandstone is medium to coarse-grained. This lithofacies association is common in the upper 100 m or so of the formation (Figure 3).

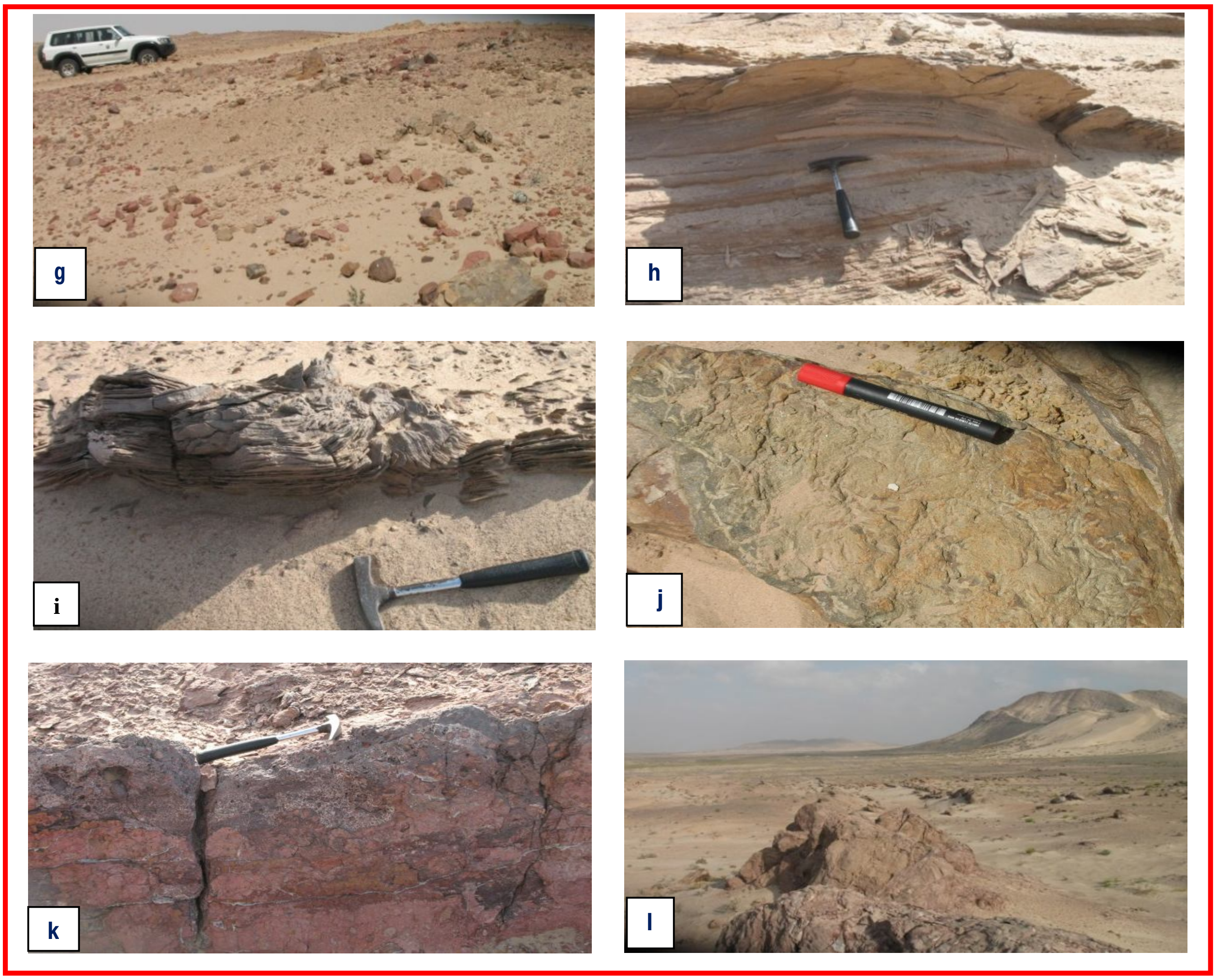

Figure 4. Field photographs of various lithofacies in the Fayah Formation; a) cross-bedded sandstone common in coarsening-up sandstone lithofacies associations, b) plane-bedded sandstone with water-escape structures, c) water-escape structures in various sandstone lithofacies, d) meter sized (~1m in diameter) pink granite boulders in debris flows lithofacies, e) coarsening-up conglomerate. Light coloured clasts are granitic and dark coloured clasts are volcanic and carbonate in composition, f) angular to sub-angular clasts in conglomerate facies, g) pink coloured large clasts of granite in debris flow lithofacies associations. Matrix has been removed and clasts are scattered over the outcrop scale usually in lobe shape, h) Interbedded shale and sandstone of the turbidite lithofacies association, i) convolute bedding in turbidite facies, j) extensive bioturbation in shale beds of turbidite facies, k) oxidized red clays in the upper part of the formation in interbedded sandstone and shale lithofacies association, l) ridge-forming sandstone beds in the upper part of the formation.

The lower 40 m of the lithofacies association is dominated by green coloured sandstone interbedded with shale, whereas the upper 40 m are dominated by brown coloured coarse-grained sandstone interbedded with siltstone. In its uppermost part, the depositional site was occasionally exposed to surface conditions, as shown by oxidized red coloured sandstone and conglomerate beds (Figure 4k). The sandstone in this lithofacies association constitutes about 75% of the unit. The brown coloured sandstone is ridge forming. However it is difficult to trace laterally due to outcrop limitations (Figure 4l).

This lithofacies association was deposited under shallow water conditions by distributary channels during a drop in sea-level. The sediments were deposited in a shallow marine setting. Sandstone was deposited by distributary channels while shale and siltstone were deposited in inter-distributary areas.

3. Modal Composition and Provenance:

Detailed petrographic analyses were conducted on selected samples from various lithofacies, especially sandstone sequences, for detailed modal compositional analyses and to identify probable source terrain for the sediments of the Fayah Formation. A total of 14 thin-sections from the selected samples from bottom to top of the formation were prepared and studied. Texturally and mineralogically the sandstone is immature, having poor sorting, a high percentage of feldspar and sub-angular grains. The modal composition shows that the sandstone is composed of quartz, feldspar, rock fragments, mica and occasional heavy minerals. The modal composition of these samples is presented in Table 1, whereas a brief summary of the various components is given below.

Table 1. Modal composition and texture of sandstone of the Fayah Formation.

Sample no	Quartz	Feldspars	Rock Fragment	Mica	Other	Texture	Sorting/ Roundnes	Cement
F1	55%	35%	3%	5%	2%	Coarse-grain	Well sorted, Subangular	Silica,
F2	50%	40%	4%	5%	1%	Medium-coarse-grain	Poorly sorted, Angular-Subangular	Not visible
F3	35%	45%	15%	3%	1%	Fine-medium grain	Poorly sorted, Angular	calcite
F4	60%	28%	10%	1%	1%	Medium-grain	Angular-subangular	calcite
F5	42%	47%	8%	1%	2%	Very coarse-grain	Angular-subangular	Not visible
F6	40%	45%	10%	2%	3%	Very coarse-grain	Subangular-subrounded	Silica, calcite
F7	50%	35%	12%	1%	2%	Medium-coarse-grain	Well sorted, Subangular-subrounded	Silica
F8	50%	40%	5%	3%	2%	Coarse-grain	Angular-subangular	Mudstone
F9	40%	45%	10%	2%	3%	Coarse-grain	Subangular	Mudstone
F10	45%	40%	9%	1%	5%	Fine-medium grain	Poorly sorted, subangular	Silica
F11	50%	40%	4%	3%	3%	Medium-coarse-grain	Moderately sorted subangular-subrounded	Silica
F13a	45%	35%	10%	7%	3%	Fine-grained	Poorly sorted Angular subangular	Not visible
F14	45%	40%	5%	8%	2%	Medium-coarse-grain	Poorly sorted Subangular-subrounded	Iron oxide, calcite
F15	55%	30%	5%	7%	3%	Coarse -rain	Poorly sorted Angular-subangular	Not visible

Quartz: Quartz grains form the major part of the framework component of the sandstone, constituting on average about 45% (Table 1). Quartz occurs both in mono-crystalline and poly-crystalline form (Figure 5a,b). The quartz grains are sub-angular to sub-rounded in shape, reflecting short transportation distances. The amount of quartz varies from 35-60%, but without any trend in variation from the lower to the upper part of the formation.

Feldspar**:** Feldspar constitutes the second most dominant part (on average about 40%) of the framework component (Table 1). However, in a few samples, it is the most dominant grain type. It occurs as plagioclase, orthoclase and microcline (Figure 5c,d). Plagioclase and orthoclase are common in all thin sections with a minor amount of microcline. Most of the orthoclase and plagioclase grains are altered (Figure 5c).

Rock fragment**:** Rock fragments are the third major framework population, constituting on average about 10% (Table 1). Chert is the most dominant type of the lithic grains (Figure 5e). Granite, rhyolite, mudstone and limestone are other major lithic types in the formation. The lithic clasts are angular to sub-angular.

Mica: Mica is present in small amounts (up to about 5%) in all samples. Muscovite, biotite and chlorite are common types (Figure 5f). Chlorite is the major mica type in many sandstone samples particularly is most common in the green coloured sandstone.

Heavy Minerals/Others: Minute amounts (<1%) of heavy minerals and other opaque minerals are present in all samples. A few grains of zircon and epidote are present in many samples.

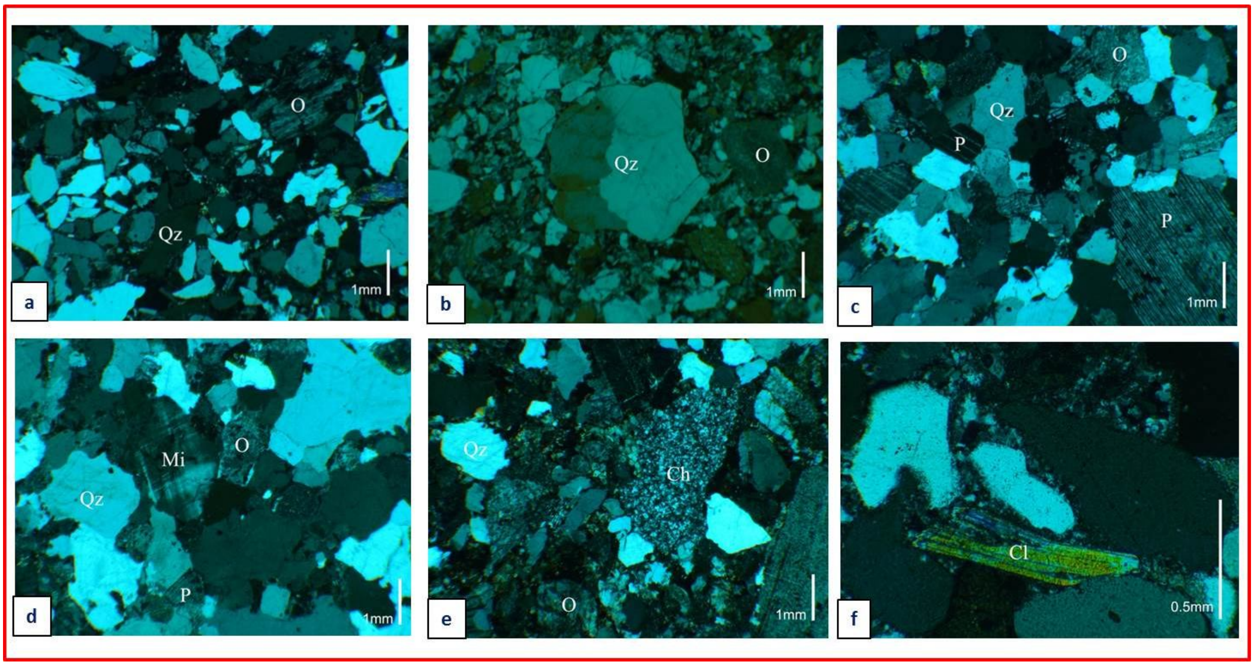

Figure 5. Microphotographs of sandstone sections, a & b) mono-and poly-crystalline quartz, c) diagenetically altered feldspar (O-orthoclase & P-plagioclase) grains, d) microcline (Mi) grain, e) chert (ch) fragments, f) chlorite (Cl) grains.

Cement: Calcite cement occurs in patches in many samples. Silica, clay minerals and iron oxide also act as cement in some samples. In many samples the cement has been leached out.

The composition of the framework components of the Fayah Formation shows that the clasts were derived mainly from the basement rocks exposed in the vicinity. Textural immaturity, especially the grain angularity, reflects short transportation distances. High feldspar and quartz content in the formation is contributed by the basement granitic rocks exposed in the Jabal Ja'alan area [12]. However, large size granitic boulder clasts, over a meter in diameter, in the formation reflect a source area closer to the depositional site.

The only alternative to the Jabal Ja'alan basement outcrops are the Al-Khlata Formation outcrops as a probable nearby source area. The Al-Khlata Formation has a large proportion of granitic and rhyolitic boulders, some of which are many meters in diameter. Reworking of these boulder clasts could be a possible source terrain. The Al-Khlata Formation is not exposed in the nearby area; however the formation may have been exposed during Late Cretaceous time and remnants of it are now buried under a migrating dunes. Chert fragments are derived from oceanic floor sediments obducted along the Batain coast as part of the Batain Mélange [3]. These sediments are rich in red and green coloured chert. The limestone clasts were contributed by a number of carbonate units, such as the Qarari Limestone and the Guwayza Formation exposed in the Batain Mélange. It is, therefore, interpreted that the source area for the Fayah Formation sediments is the Jabal Ja'alan basement sequence and the Batain Mélange thrust nappe.

4. Depositional System and Discussion

The northeastern margin of Oman between Ra's al Hadd and Ra's Jibsch is characterized by a complex stratigraphic setting recording major tectonic events, such as the opening of the Tethys Ocean and the obduction of the

Masirah Ophiolites and associated mélange sequence [2,3]. The Batain Mélange formed due to the closure of the Batain basin and the obduction of the Masirah ophiolite along the northeastern margin of the Arabian Plate during late Maastrichtian-early Paleocene time. The Fayah Formation was deposited in the uppermost part of the Batain basin during the emergence and erosion of the eastern Oman margin, providing siliciclastic sediments in the basin [13].

The lithofacies association of the Fayah Formation, especially the debris flows and turbidite lithofacies associations suggest relatively deep water depositional conditions. The debris flows interbedded with other lithofacies associations, especially the turbidite lithofacies association, were deposited as sediment lobes which are laterally discontinuous even at outcrop scale. Large meter sized boulders of pink granite suggest a major detritus input from the continental basement rocks exposed in the nearby source area. These mass flows were triggered during episodic uplifts associated with some faults or unusually wet conditions. The ophiolitic detritus in the mass flow deposits suggest a contribution from advancing ophiolite nappe such as the Masirah Ophiolites. The debris flow deposits in outcrops have lost their clay matrix and cement, resulting in scattered boulders and pebbles. In contrast to the debris flow deposits, the conglomerate lithofacies association is comprised of pebbles of granite and rhyolite which are only centimeter to few decimeters in size. The small size of the detritus in the conglomerate lithofacies association suggests that the continental basement was providing small size clasts during most of the deposition of the Fayah Formation, except during events of unusual uplift associated with the gravity flow. The interbedded sandstone and shale facies association in the upper part of the formation was deposited by submarine stream flows in shallowing-upward conditions associated with sea-level fall. The Late Cretaceous/early Paleogene carbonate deposition started in the area once the distributary channels seized to exist.

The Fayah Formation is age-equivalent to the Qahlah and Thaqab formations in the Oman Mountains which were deposited as a result of the Samial Ophiolite and Hawasina nappe obduction during Late Cretaceous time [14]. The sediments of the Fayah Formation are interpreted as having been deposited under a marine setting by submarine fans (Figure 6). The sediments were shed by the west-northwestward advancing Masirah Ophiolite nappe and uplifted basement and/or older formation, such as Al-Khlata Formation rocks.

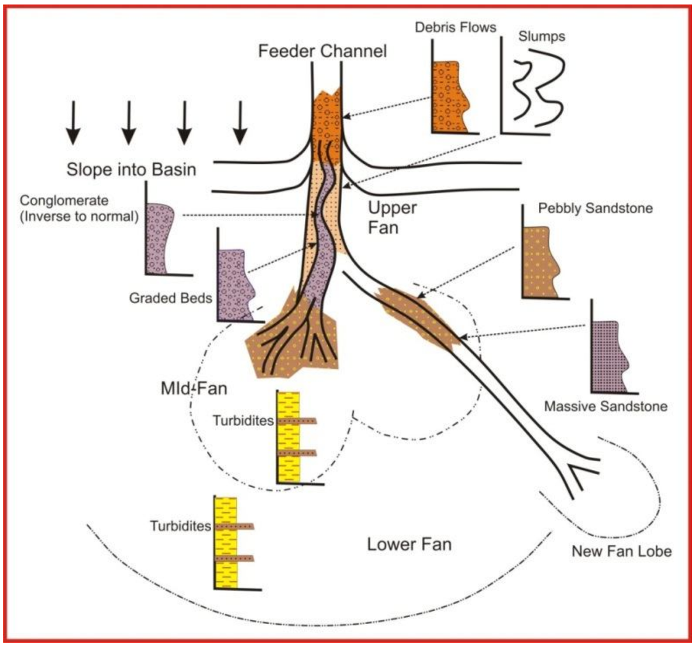

Figure 6. Proposed depositional model for the submarine fan system of the Fayah Formation (modified from [15]).

5. Conclusions

1. The sediments of the Fayah Formation in Jabal Fayah were deposited in the Batain Mélange during Late Cretaceous time during closure of the Neo-Tethys ocean due to the Masirah Ophiolite obduction.
2. The sediments were deposited as a submarine fan system which developed during the final phase of ocean closure. Various lithofacies associations were deposited in different parts of the fan system.
3. The detritus was contributed from advancing nappe and uplifted basement rocks, such as the Jabal Ja'alan rock sequence. Since Jabal Ja'alan basement rocks are located far away from Jabal Fayah, large basement clasts in the Al-Khlata Formation might be a possible alternative source rock.

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