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Sedimentary Facies, Architectural Elements and Trace Fossils of Kashkan Formation, Folded Zagros Zone in SW Iran

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Abstract

The Kashkan Formation (Paleocene to Middle Eocene), consists of conglomerate, sandstone, and siltstone in the Zagros Folded zone, southwest Iran. Type of the sedimentary facies, architectural elements and trace fossils show that Kashkan deposits were formed in a low sinuosity braided stream system, with north to south flow direction. The formation displays coarsening-upward succession reflects an overall regressive sequence. The clast–supported conglomerate is the major components of the formation. A thinning of the coarser–grained sediments toward the south, and southwest indicates that the source for the Kashkan formation was to the north and northwest from the study area. Trace fossils of Kashkan Formation are related to Scoyenia ichnofacies, include *Arenicolites* isp., *Diplocraterion* isp., *Ophiomorpha* isp., *Skolithos* isp., *Steinichnus* isp., *Thalassinoides* isp., Escape structure and vertebrate footprints. Sedimentological analysis and type of the trace fossils indicate the south the stream was restricted by a shoreface environment. Kashkan Formation becomes thinner and fine–grained in the southern part of the study area.

Keywords: Kashkan Formation; Zagros; Trace fossil; Lithofacies; Sedimentology

Introduction

The Zagros folded–thrust belt, which extends for about 2000 kilometers from southeastern Turkey through northern Syria and Iraq to western and southern Iran, with its numerous supergiant hydrocarbon fields, is the most resource–prolific fold–thrust belt of the world [1]. More than a hundred stratigraphic sections have been surveyed in various parts of the Zagros belt. The Kashkan Formation (Paleocene to middle Eocene) is only one of them. The name Kashkan Formation was originally proposed by James and Wynd [32] and has since been adopted as a formal stratigraphic unit by the stratigraphic committee of Iran. The type section of the Kashkan Formation is at the Amiran Anticline in the folded Zagros zone. The

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aims of this paper are to describe lithofacies, architectural elements and trace fossils of Kashkan Formation in order to distinguish of the sedimentary environment. James and Wynd assigned Paleocene–middle Eocene age for this Formation [32]. The Kashkan Formation overlay the Talezang Formation (middle Eocene) and is overlaid by the shallow marine Shahbazan Formation (middle–late Eocene) (Fig. 1). No detailed sedimentological analysis has hitherto been carried out on Kashkan Formation. The major portion of data for this study is derived from seven measured stratigraphic sections in the study area; include Darabi, Domsorkh, Mamoolan, Golgekhalag, Malavi, Moorani and Sepiddasht sections (Fig. 2).

Geological Setting

The study area located in the folded Zagros zone in southwest Iran (Lorestan province). The Kashkan Formation type section was measured by James and wynd [32] at kuh–e Amiran (Amiran anticline), where the Kashkan river cuts through the northeastern flank of the anticline. Kashkan Formation is composed of deep-red colored siltstone, sandstone and conglomerate, which become coarser upward in the type section. The lower contact with the Talezang Formation is abrupted, and upper contact exhibits a prominent limonitic weathered zone by dolomite layers of Shahbazan Formation. This Formation is underlain and overlay by limestone of middle Eocene in the type locality of the Talezang and Shahbazan Formations at the Tang-e Do. Basal conglomerate of Kashkan Formation directly overlies Paleocene Talezang limestone in the Amiran anticline.

Deposition of the Kashkan Formation resulted from orogenesis movements in the area on the northeast [32]. The Formation becomes thinner and fine–grained in the southern part of the study area. Kashkan Formation interfingers by Pabdeh Formation in the southwest from type section area (Fig. 1). It is progressively replaced by limestone layers of the Shahbazan and Talezang Formations toward Khuzestan area. The Kashkan Formation is diminished either in thickness or in age from northwest to southwest. The Kashkan Formation has no index fossils, and it was attributed to Paleocene to middle Eocene in age, based on stratigraphic position [47].

Methodology

This study performed by sedimentary facies analysis, description of trace fossils and architectural elements of the Kashkan Formation. Palaeocurrent directions were determined from large to medium–scale trough cross–stratification or imbrications of particles. Field study of conglomerate has been done, based on several requirements, including:

1) morphology of the outcrop to enhance

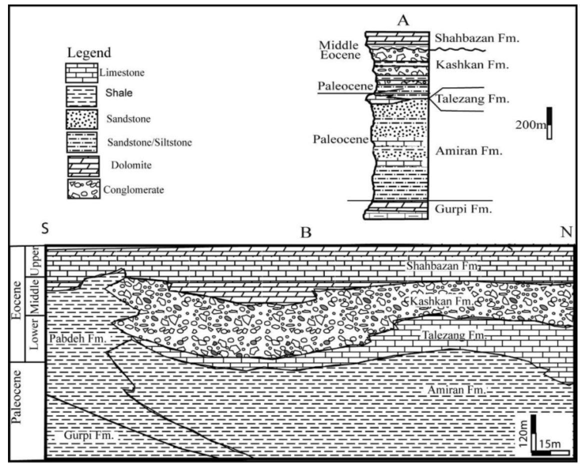

Figure 1. A: Type section of the Kashkan Formation. B: Stratigraphic cross section, showing facies relationships in folded Zagros, Modified from [32].

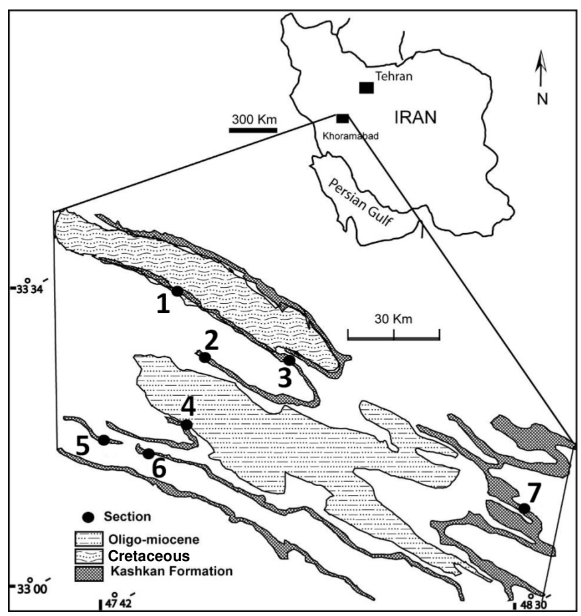

Figure 2. Index and generalized geologic map, showing location of measured stratigraphic sections: 1) Darabi, 2) Domsorkh, 3) Mamoolan, 4) Golgekhalag, 5) Moorani, 6) Malavi, and 7) Sepiddasht.

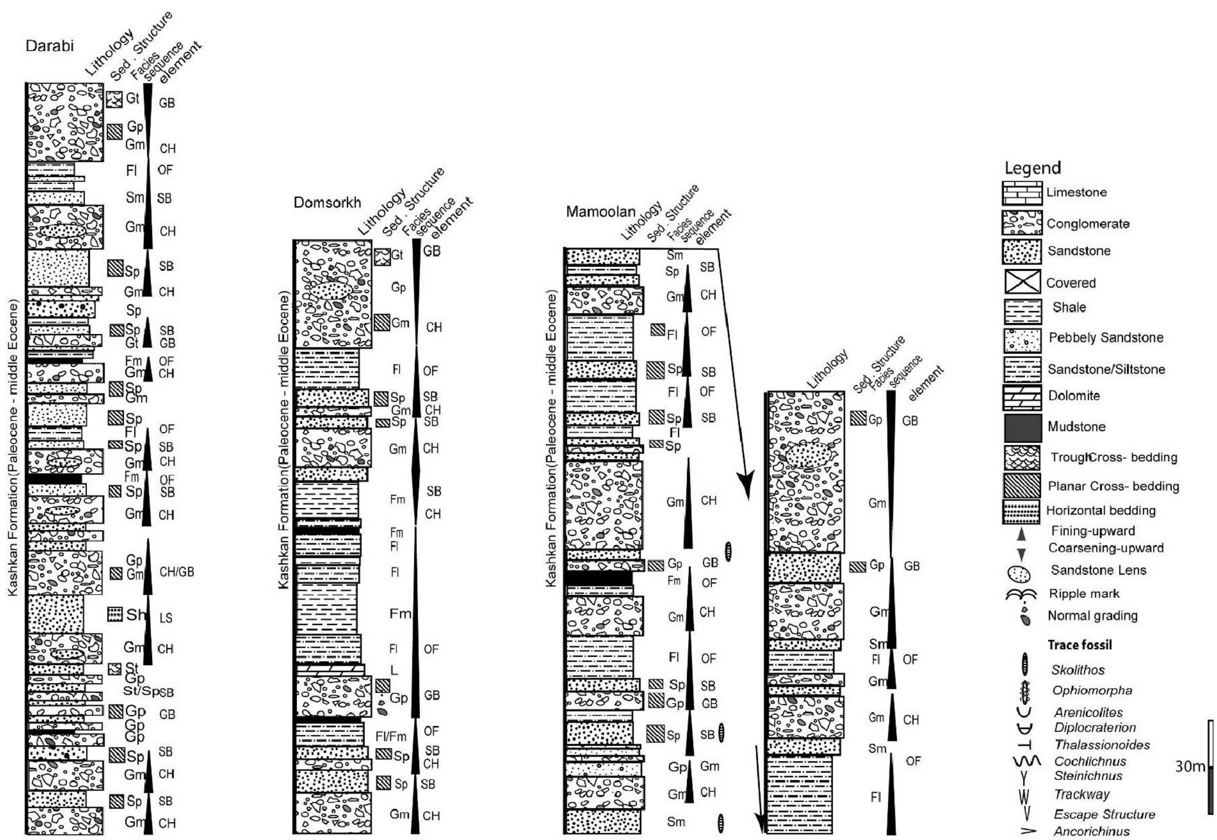

Figure 3. Stratigraphy sections of the Kashkan Formation localities Darabi, Domsorkh and Moorani. For explain of lithofacies and architectural elements, abbreviations see text.

observations of geologic relations, 2) the exposed surface no less than 1 m^2 in the area oriented across bedding in conglomerate 3) presence of a clean surface that was not obscured by a covering of lichens. Kind of preservation and changes of trace fossils examined in the field. Internal structure, size, wall nature, branching of burrows are main attended features of trace fossils.

Lithofacies

Twelve simplified lithofacies were identified here, base on lithofacies codes of Miall [43, 46]. Stratigraphy columns of the Kashkan Formation in the studied sections are shown in Figure 3.

Massive Conglomerate (Lithofacies Gm)

This facies extends over tens of meters across the outcrops and occurs in the middle and upper parts of the Kashkan Formation. It generally consists of massive, clast-supported conglomerate with a matrix of coarse sandstone or gravels (2-4 mm) filling the space between clasts. Clasts size decrease upward in each cycle (Fig. 4A). Clasts are mostly rounded to sub-rounded, fine to coarse pebbles, but cobble- sized clasts also occur in the lower parts (Fig. 4B, C). The basal contact of this facies is erosive and irregular but upper contact is gradational to fine-grained conglomerate. Individual units of this facies are 0.5 m to 6 m in thickness, but some of the units are amalgamated sediments (Fig. 4D). Some lenses of cross-bedded, coarse-grained pebbly sandstone are present within this facies. This conglomerate becomes thinner and finer-grained in the southern part of the study area. Internal features and laterally extensive distribution of facies Gm suggests longitudinal bars in gravelly rivers [29]. This facies is generated by longitudinal bars processing, as described by Williams and Rust [62]. The erosional contact at the base of this facies indicates that current/turbulence fluctuations caused parts of the underlying units to be eroded.

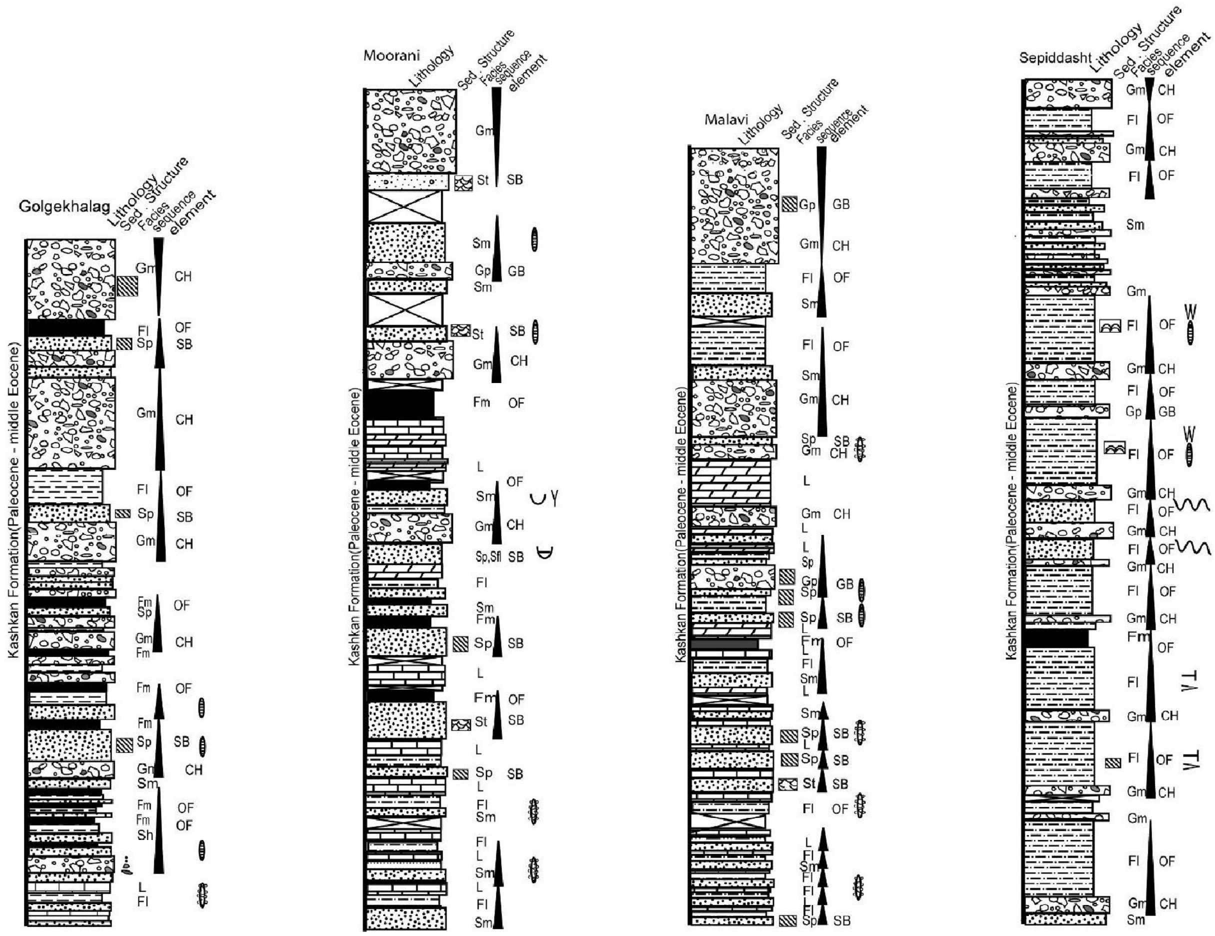

Figure 3. (Continued). Stratigraphy sections of the Kashkan Formation in localities Golgekhalag, Mamoolan, Malavi and Sepiddasht. For explain of lithofacies and architectural elements, abbreviations see text.

Planar Cross-Stratified Conglomerate (Lithofacies GP)

This facies is composed mainly of clast-supported conglomerate with tabular cross- beds. Thickness of this facies is variable from 0.5 to 1.5 m, and the thickness of each set is generally between 25 to 50 cm. The mean cross-set dip is 25° (Fig. 4E, F). The basal contact of this facies is both erosional and nonerosional. The foreset dip is generally toward the southwest. Some of the foresets are separated by erosional surfaces. Cross-sets show normal clast size grading. Some lenses of planar cross-bedded sandstone lithofacies (lithofacies SP) are present within this lithofacies. The GP is interpreted as a product of the down-stream movement of transverse bars in low-sinuosity channels [44].

Through Cross-Stratified Conglomerate (Lithofacies Gt)

This lithofacies is characterized by the clast-supported, trough-crossbedded conglomerate, with symmetrical or asymmetrical concave-up basement (Fig. 5A). Lithological characteristics of gravels are generally similar to those of lithofacies Gm, but clast size is smaller than Gm. The cross-bedded sets are usually graded. Palaeocurrent of trough axis directions is generally towards the southwest. Lenses of Planar to Trough cross- bedded sandstone lithofacies (SP and St lithofacies) are present. Typical dimensions of individual units range over 0.5-1m in thickness and usually 1-3m in lateral extent. This facies resulted by filling of scour hollows or minor channels and the migration of 3-D gravel dunes [42,54].

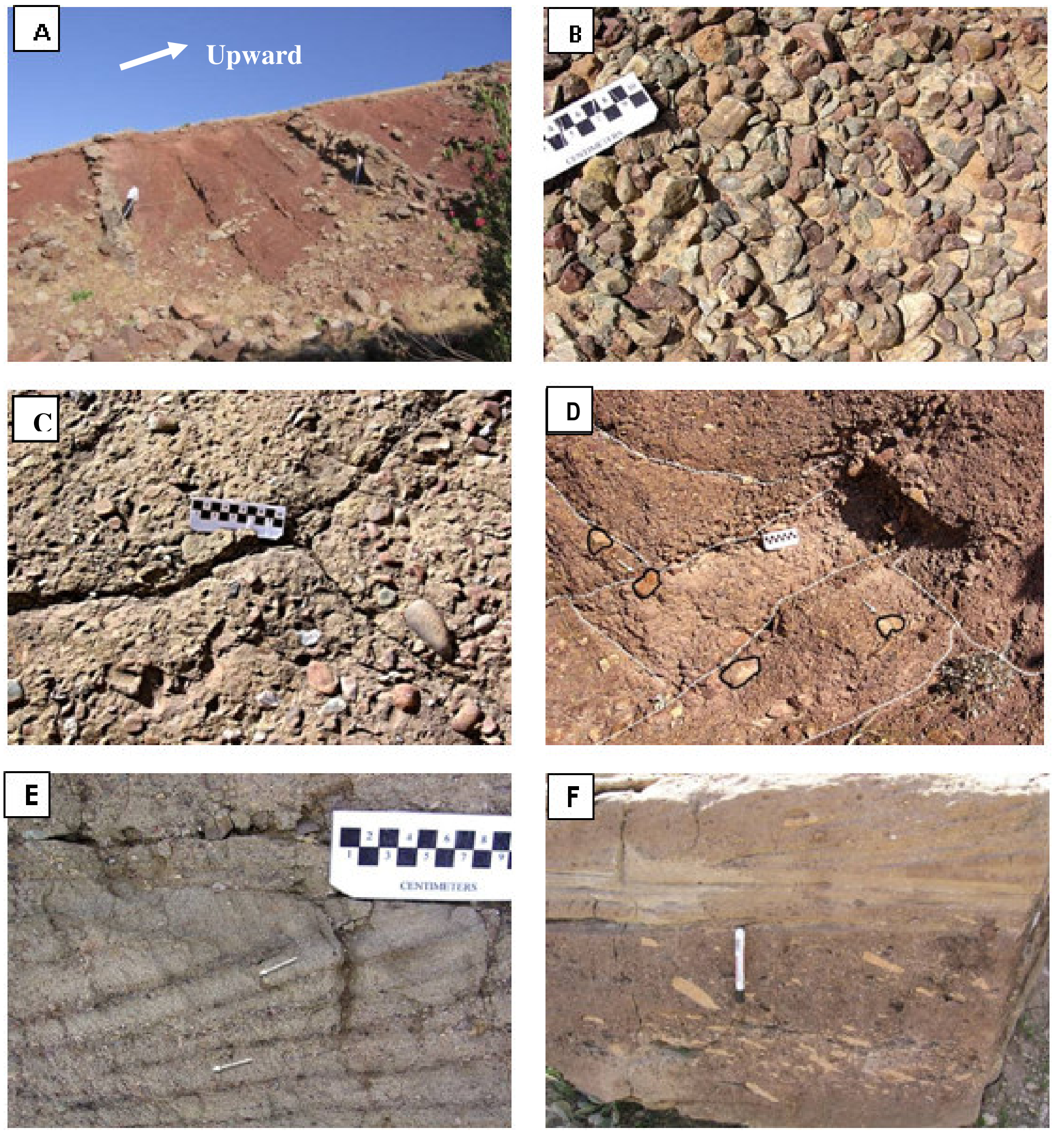

Figure 4. A. Fining – upward sequence from conglomerate to sandstone and siltstone. B. Massive conglomerate lithofacies Gm. C. Lithofacies Gm with fine–grained matrix. D: Amalgamated conglomerate units. E: Planar cross–bedded conglomerate (Lithofacies Gp). F: Lithofacies Gp with imbricated mud clasts. Scales in cm.

Massive Pebbly Sandstone (Lithofacies Sm)

This facies comprises massive beds of medium to coarse-grained, non-organized sandstone. Grains are poorly to well sorted and well-rounded to subrounded in texture. Rare floating pebbles or gravels are present (Fig. 5B). The thickness of single beds varies between 0.2m to 1.5m. This facies may or may not show an erosive lower surface, but the upper surface is commonly sharp and often undulatory or irregular. This facies may be formed by rapid sedimentation by relaxation of heavy sediment- laden flow [33,38,56,57] or by post-depositional deformation [5,19,59]. In here, deformational processes are considered as less important based on the absence of cross- or planar-strata.

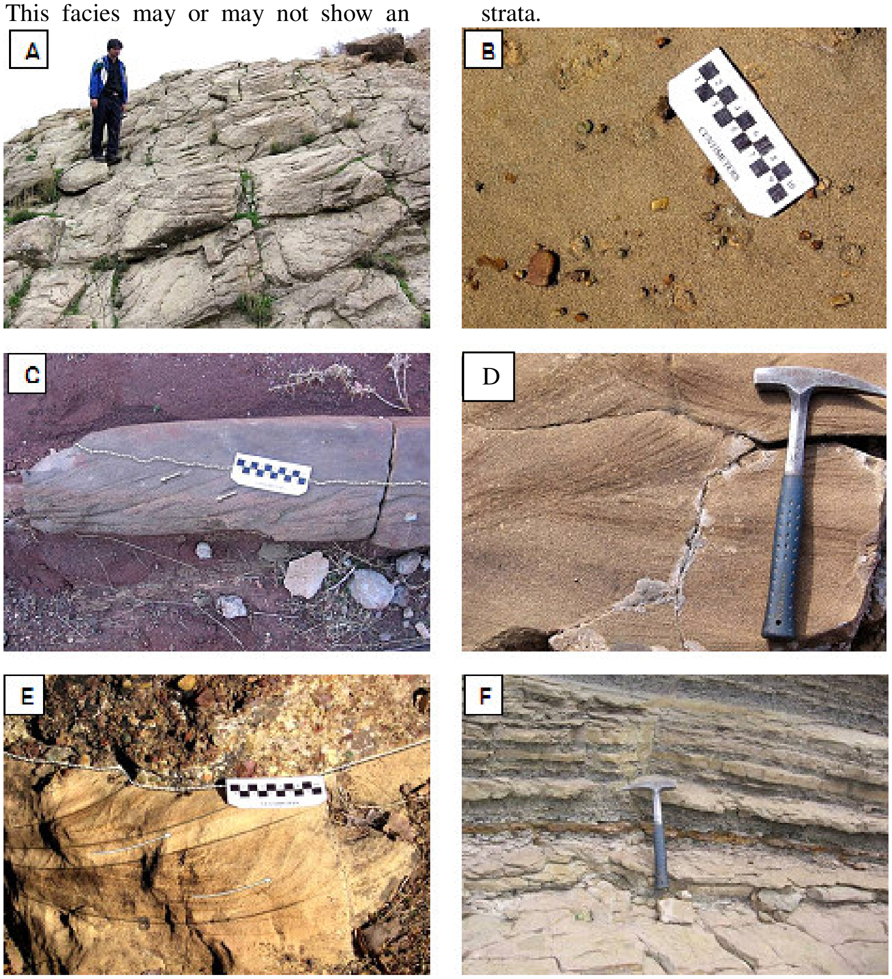

Figure 5. A: Stacked trough conglomerate (lithofacies Gp). B: Massive sandstone (lithofacies Sm). C: Erosional contact between lithofacies Sp and Sm. D, E: close up of lithofacies St F: Horizontal stratified sandstone (lithofacies Sh). Scales in cm.

Planar Ccross-Bedded Sandstone (Lithofacies Sp)

This facies is composed of medium to very coarse-grained sandstone. Scattered quartz pebbles are present in some beds and formed as pebbly sandstone (Fig. 5C). Lenses of conglomeratic sandstone are also present within this facies. The external geometry of facies SP is lenticular or irregularly wedge-shaped. Planar cross-stratification may be present as solitary sets or as cosets. Cross set is 15cm to a few decimeters in thickness. Most of the foresets are fining upward and have a dip toward the southwest. The thickness of planar cross-bedded sets typically decrease with decreasing grain size. The lower contact of this facies is sharp, whereas the upper contact is erosional. This facies is formed by the migration of straight crested dunes or bars deposited in the lower flow regime [46, 14].

Trough Cross-Bedded Sandstone (Lithofacies St)

This facies is composed of medium to very coarse-grained, moderately to poorly sorted sandstone. Some of these sandstone units contain scattered quartz pebbles. Sets of trough cross-beds vary in thickness as 10cm to 80cm (Fig. 5D, E). The cross-beds shows low-angle and long-wavelength troughs (about tens of centimeters). Set thickness generally is proportional to grain size. This facies occurs in sets or cosets, sharp boundaries between individual sets and cosets are marked by thin siltstone layers. Geometrically, this facies occurs as lenticular or wedge-shaped bodies. Trough axis dips generally toward the southwest. Unimodal orientation of trough cross-beds is favorable in a fluvial bed system [20,46]. Trough cross-bedded sandstone is interpreted as the product of 3-D dunes migrating in channels under the conditions of the upper part of the lower- regime or infilling of scour hollows [16, 27, 42].

Horizontally Stratified S (Lithofacies Sh)

This facies is composed of moderately to well sorted, horizontally stratified fine to coarse sandstone. Stratifications consist of alternation of coarse to fine sandstone. This facies is interstratified within all sandstone facies. Parting lineation is formed at the surface of very fine- to fine-grained sandstone (Fig. 5F). Each unit is about decimeters to a few meters in thick. The upper and lower boundaries of the facies are sharp. The bounding surfaces may be traced for tens of meters. This facies has been commonly interpreted as migration of either low-amplitude bed forms or upper flow regime plane bed [4,9]. Alternatively, this facies could be deposited via high-energy sheet floods that spilled into a lower energy environment from channels during flooding of the main fluvial channel system [25].

Ripple Cross-Laminated S (Lithofacies Slr)

This facies is composed of moderately to well sorted and fine to coarse sandstone with thin intercalations of laminated siltstones. This facies shows yellow to chocolate in color (Fig. 6A). The grain size of the sediments of this facies decreases upward with upward-thickening of intercalated siltstone layers. Internal structures of this facies are distinguished by irregularly undulating lamination and thin mud lamina on the top of the sandy beds. Some asymmetrical and symmetrical ripples are seen. This facies is interpreted as an alternating period of ripple migration and deposition from suspension during a tidal cycle [52]. The current-generated ripple beds are common in sandy tidal flats [41].

Flaser Laminated S (Lithofacies Sfl)

This facies mainly consists of moderately sorted, fine sandstone to siltstone; characterized by wavy on lenticular silts and fine sands with thin wavy of yellow mud. In this facies, the muddy sediment occurs as thin and continuous laminae, which are confined to ripple troughs (Fig. 6B). This type of flaser bedding is defined as wavy flaser, that mud flasers cover ripple troughs and crests with no continuous bed form. Flaser bedding are produced by a fluctuating flow regime and a result of interplay of silt/ sand and mud sedimentation. The flaser bedding of different styles is often obtained in sediments of tidal flat environment [7].

Massive Mudstone (Lithofacies Fm)

This facies mainly consists of siltstone, homogeneous mudstone and minor portion of fine to coarse-grained sandstone (Fig. 6C). Fine to coarse-grained sandstones are scattered within this facies and form thin layers of nodular patches. This facies varies in color as brownish red, dark red, purple. The lower boundary is commonly flat and irregular due to the underlying topography. This facies shows sheet-like geometry. Facies Fm is generally massive but contains rain–drop imprints and desiccation cracks. This facies formed because of deposition from suspension in over-bank settings. The presence of rain prints and mud cracks indicate subarial exposure during sedimentation [10, 39]. The red–purple color of this facies is suggestive of well–drained, oxidizing conditions of the floodplains [37, 53].

Laminated Mudstone (Lithofacies Fl)

This facies is composed mostly of parallel laminated siltstone (mudstone) and shale. The lamination is represented by an alternation of mudstone and siltstone. The lower laminae boundaries are erosional or sharp. The lower and upper bed boundaries are generally sharp and planar. Each facies unit ranges in thickness from 10cm to 80cm. This facies is sheet–like in geometry. This facies contains little evidence of bedload deposition and is interpreted as deposition from suspension [30]. The parallel lamination of alternating siltstone and Mudstone, together with their sheet-like geometry, indicates widespread deposition from suspension over the upper parts of sandy badforms or across low relief, abandoned flood plains [2, 31].

Carbonate Mudstone/Wackstone (Lithofacies L)

This facies is characterized by milky white to gray massive mudstone/wackstone with bioclastic fragments such as foraminifera (Figs. 6D, 7A, B). The upper and lower boundaries are sharp and planar and have a few decimeters to a few meters thick. In some cases, selective dolomitization of fossils is occurred. This lithofacies is formed in pond presence on the shoreface environment.

Architectural Analysis

The application of concepts on fluvial architecture and sandstone body-form [3,23,34,43,45,46] has clearly improved the knowledge of fluvial sequences [35]. It has been gradually recognized in the past

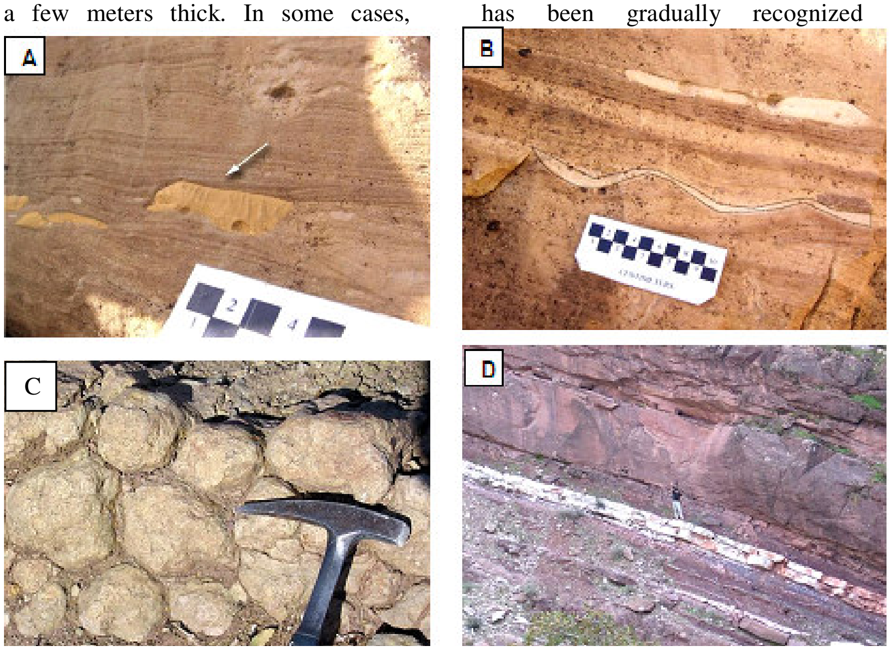

Figure 6. A: Ripple cross laminated sandstone (lithofacies Slr) small arrow shows a mudstone clast. B: Flaser laminated sandstone (lithofacies Sfl). C: Massive mudstone (lithofacies Fm). D: Milky white limestone (lithofacies L). Scales in cm.

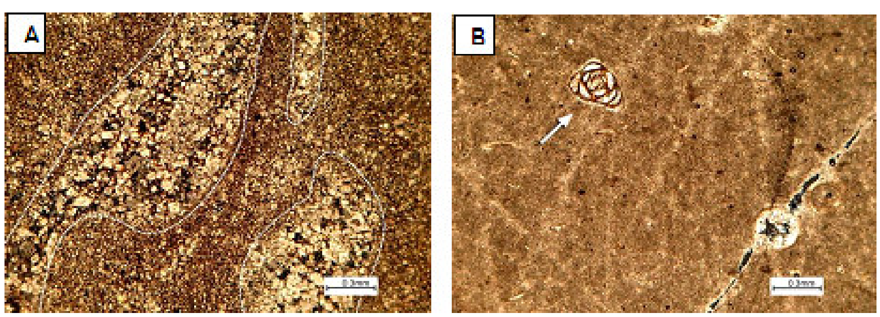

Figure 7. Microscopic photos of lithofacies L, A: Dolomitic fossil fragments. B: Micrite with Miliolid foraminifer (arrow).

decades that a river can produce a wide variety of facies sequences, and similar sequences can be formed in rivers of different styles[8, 46]. Architectural analysis pays particular attention to large scale sedimentary structures that are believed to reflect the type and behavior of bars and channels [3-5,61]. The reorganization of large morphologic features of rivers such as bars and channels by architectural analysis is crucial for the interpretation of ancient fluvial systems [3, 44]. Architectural elements can be defined on a basis of large–scale stratal patterns and constituent facies [44]. The spatial arrangement of an element reflects spatial relationships between the morphologic units and the movement of channels within a channel belt [11, 45]. In the present study, architectural elements are identified in the Kashkan Formation based on Miall's classification [43]. The Architectural elements have a hierarchical arrangement whereby some smaller elements occur nested and stacked within larger elements.

Channel Fill Element (CH)

This element in the Kashkan Formation is characterized by stacked, multistory channel bodies that cut down into the underlying sediments. Its boundaries are usually adulatory, showing low angle-inclined accretion surfaces. A channel fill element often consist of facies Gm, Gt, Gp, with sub–ordinate sets of facies St/Sp that covered by facies Fm and Fl. This element is abundant in the middle and upper parts of the Kashkan Formation and has a lenticular geometry, which can be traced up to 300 m (Fig. 8A).

Gravel Bar Element (GB)

This element is vertically stacked layers of facies Gp and Gt and shows a wedge or lenticular in shape and typically contains a fining–upward trend. This element occurs as isolated forms but is found within element CH (Fig. 8B). Gravel bar element is interpreted as transverse bars with the curved crest line [14].

Sandy Bed form Element (SB)

This element is composed of trough or planar sandstone bodies. It shows wedge or lenticular shape and overlain by thinly bedded, which is often a sheet like medium– to fine–grained sandstones or fine–grained sediments of floodplain. The thickness of sets of facies Sp and St decreases upwards within SB element (Fig. 8C). This element represents the deposits of migratory dune–scale bed forms in either mid–channel bars or on the flanks of point bars [13, 43]. *Diplocraterion* and *Skolithos* trace fossils are found in this element.

Downstream Accretion Element (DA)

This element is found as low–angle accretion units with internal grading and composed of medium– to coarse–grained sandstone arranged into facies Sp. This element is lenticular in shape (Fig. 8D). DA element forms the lower portions as fining–upward cycle and generally shows a convex–up shape either for the entire element or for individual units within a single element [43]. This element is probably formed by migrating linguoid or transverse bars [15]. *Skolithos* trace fossil is found in this element.

Laminated Sand Sheet Element (LS)

This element actually occurrence in the upper portion of the fining–upward cycles. It is usually associated with element Fl (Fig. 8E). This element is up to 0.5m in thickness, and mainly as a sheet shaped. Composition of LS consists of fine–grained sandstones, that laterally continuous for about 15m. Its sheet like geometry and fine–grained lithology suggests that deposited as a bar–top or bar–flank sand sheet [43]. *Laminites kaitiensis, Diplocraterion Ophiomorpha, Thalassinoides and Escape structure* trace fossils are found in this element.

Floodplain Element (OF)

General geometry of this element is a sheet–like shape, which found in the upper parts of all the cycles in the Kashkan Formation. This element is characterized by red shale with interbeds of fine–grained sandstone and can be traced laterally for about 100m. The thickness of this element ranges from 20cm to 105m (Fig. 8E). Sheet like geometry of this element and it's fine grained size indicate deposited in the wide area that was distal to the main channel. The red colored beds occurrence, suggests intense oxidation of this element. *Track way* as a trace fossil is found in this element.

Lateral Accretion Element (LA)

This element is characterized by 1 to 2m thick and 20 m wide units (Fig. 8F). It is dominated by fining–upward packages composed of fine– to medium–grained sandstones, low–angle inclined compound cosets of planar cross–bedding. This element is interpreted as represent components of pointbars [49]. *Skolithos* as a trace fossil is found in this element.

Trace Fossil

There are divers biogenic structures formed by the action of plants and animals. These include irregular disruption of the sediments as bioturbation, discrete organized markings (trace fossils or ichnofossils), and biogenic growth structures. Different organisms occupy different depths in the substrate. Some graze or crawl on the sediment surface, other rest or live just below it, while still others construct much deeper burrows for dwelling or feeding.

Trace fossils frequently are useful in palaeoenvironmental studies, especially as aids in distinguishing between marine and nonmarine environments in the rock record. In general, trace fossils in rocks of marine origin tend to be more abundant, diverse and morphologically distinctive than those in nonmarine deposits [18]. In the many environmental settings where body fossils are poorly preserved, trace fossils may provide the only evidence of past life; they are an integral part of the substrate and cannot readily be transported [17]. Ichnological analysis yields information on: depositional environment and water depth, rates and styles of deposition, sequence stratigraphic markers of environmental change, any limiting stress factors such as oxygen abundance or salinity levels [58]. Trace fossils of the Kashkan Formation are described shortly here, base on their abundance. Table 1 shows distributions of trace fossils in the studied lithofacies.

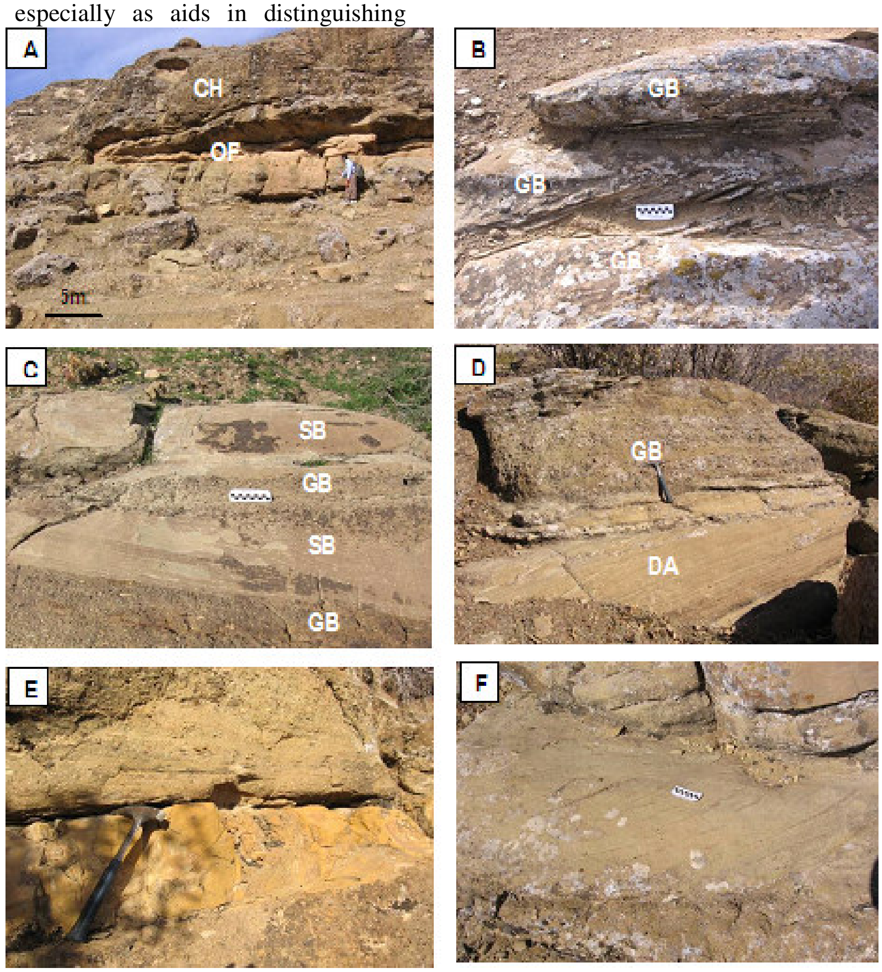

Figure 8. A: Channel fill element (CH) and floodplain element(OF). B: Gravel bar element (GB). C: Gravel bar element (GB) and sandy bed form element (SB). D: Downstream accretion element (DA). E: Laminated sand sheet element (LS). F: Lateral accretion element (LA).

Description of Trace Fossils

Founded trace fossil, mainly include endichnial traces, as following as:

Arenicolites isp.
Plate 1, Fig. B

This trace fossil is as simple, vertical U–shaped tubes with no spreiten between its limbs. Generally preserved in full relief. In plain view, may be recognized by paired openings. In this trace, often the middle of the U-shape is not preserved. *Arenicolites* is generally associated with arenaceous substrates in low energy shoreface or sandy tidal flats [51]. In general, these trace fossils are indicators of high moisture and water table levels, typically above ground water [28]. This trace fossil is abundant in Sm and Sh lithofacies.

Diplocraterion isp.
Plate 1, Fig. D

In the Kashkan Formation, this trace fossil is seen as vertical, U–shape spreiten burrows. Limbs of U-shaped burrow are often divergent. The space between the spreites is filled by yellow mud. Size of this trace fossil range from 5cm to 15cm. Based on analysis of morphological features, *Diplocraterion* interpreted as a dwelling burrow of a suspension–feeding organisms [24]. This trace is a common element in the distal end of the Skolithos ichnofacies in middle shoreface setting and common on sandy tidal flats [51]. This trace fossil is abundant in Sp and Sh lithofacies.

Table 1. Distribution of trace fossils in the lithofacies of Kashkan Formation, for details of lithofacies see text. A: abundant, C: common, R: rare

Lithofacies / Ichnofossils	Gm	GP	Gt	Sm	Sp	St	Sh	Slr	Sfl	Fm	Fl	L
Arenicolites isp.				A			C					
Diplocraterion isp.					R		C					
Laminites kaitiensis				C			R					
Ophiomorpha isp.				C			R					
Skolithos isp.				A	C			R				
Steinichnus isp.				R								
Thalassinoides isp.							C					
Escape structure							R					
Track way				R						C	C	

Laminites kaitiensis
Plate 1, Fig. A

This trace fossil is mainly as simple to horizontal burrows filled with chevron shaped menisci backfill [22]. This trace fossil is reportorial zone [48] and from marginal marine [61] and flysch sequence [26]. This trace fossil is abundant in Sm and Sh lithofacies.

Ophiomorpha isp.
Plate 1, Figs. E, F

Ophiomorpha ranges from simple individual burrows to complex networks consisting of cylindrical tunnels and shafts that typically bifurcate at acute angles [21] Burrows lined with agglutinated peloidal sediment [51]. *Ophiomorpha* is sensitive to substrate stability, grain size, physical energy levels and rates and nature of sedimentation [6]. *Ophiomorpha* of Kashkan Formation is found in some of well-sorted sandstones and interiors of the burrows are generally smooth, but rarely may be irregular due to pellet accumulating. These burrows are supported by a yellow mud lining wall. *Ophiomorpha* represents the dwelling burrow of suspension-feeding shrimp and commonly associated with *Skolithos* ichnofacies, prolific numbers in marine shoreface environments [51]. This trace fossil is abundant in Sm and Sh lithofacies.

Skolithos isp.
Plate 2, Figs. A, B

Skolithos is a vertical to subvertical, straight to curved, unbranched burrows. The burrows are relatively short, ranging to about 20cm in length. The burrows are unlined with generally smooth walls occasionally, changes in diameter occur, also. The burrow fills are composed of fine- grained sediments that less cemented than the host sediment and contain a different color.

This trace fossil is numerous in fine to medium-grained, poorly sorted sandstones(Sm, Sp and Slr lithofacies). *Skolithos* can be constructed by many different kinds of organisms. It is found in virtually every type of

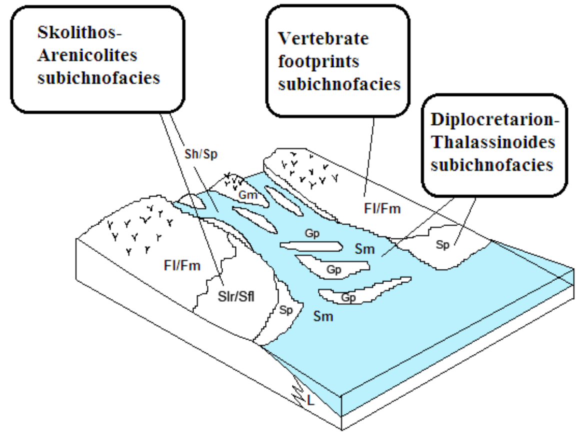

Figure 9. Block diagram of sedimentation model of Kashkan Formation and its Scoyenia subichnofacies (for abbreviations see text).

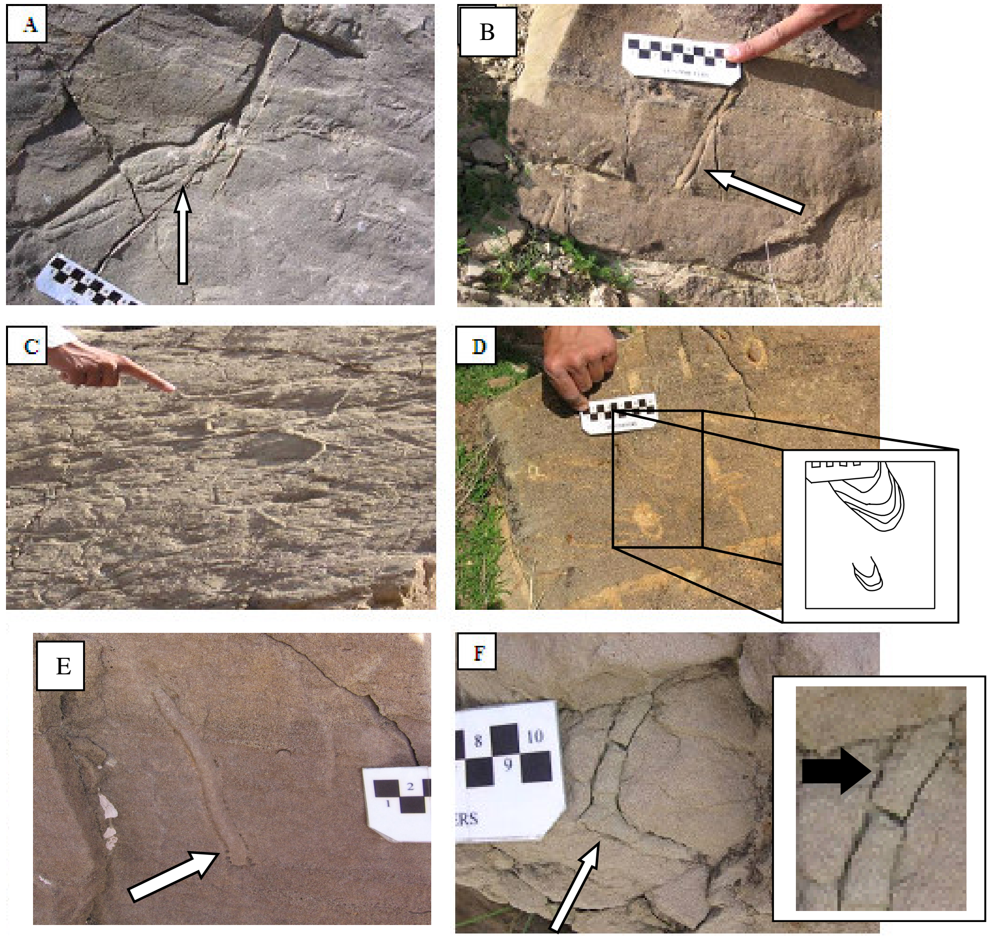

Plate 1. Figures; A: *Laminites kaitiensis* in massive sandstone. B: *Arenicolites*, as simple, vertical U –shape tube. C: ?Mammal track way in sandstone facies. D: *Diplocraterion,* is shown in graphed figure. E:*Ophiomorpha* in sandstone with large pellets on the wall (arrow) . F: *Ophiomorpha* in well – sorted sandstone (light small arrow) with denuded muddy peloidal wall (right figure, large solid arrow). Scales in cm.

environments from marine to nonmarine [51]. This trace fossil is very common in the Kashkan Formation.

Steinichnus isp.
Plate 2, Fig. C

This trace fossil is cylindrical burrows that may or may not show T- and Y-branching. It has been produced by either mud-loving beetles or mole crickets and commonly constructed in wet habitats associated with alluvial and marginal lacustrine environments [28]. This trace fossil is abundant in Sm lithofacies.

Thalassinoides isp.
Plate 2, Fig. D

Thalassinoides of Kashkan Formation is a large branches burrow with smooth surface. These branches are Y To T-shaped, and at points of bifurcation are enlarged. The branch's dimensions are equal. *Thalassinoides* is generally regarded as a dwelling or feeding burrow and associated with the Cruziana ichnofacies in lower shoreface to offshore environments [51]. This trace fossil is abundant in Sh lithofacies.

Escape Structure
Plate 2, Fig. E

This trace fossil made by organism's escape, where suddenly high- sedimentation burial occurred. In this trace fossil, the burrows disturbed as chevron patterns-like laminations, which shows the upward excavation of an organism for escape and release. This trace fossil is abundant in Sh lithofacies.

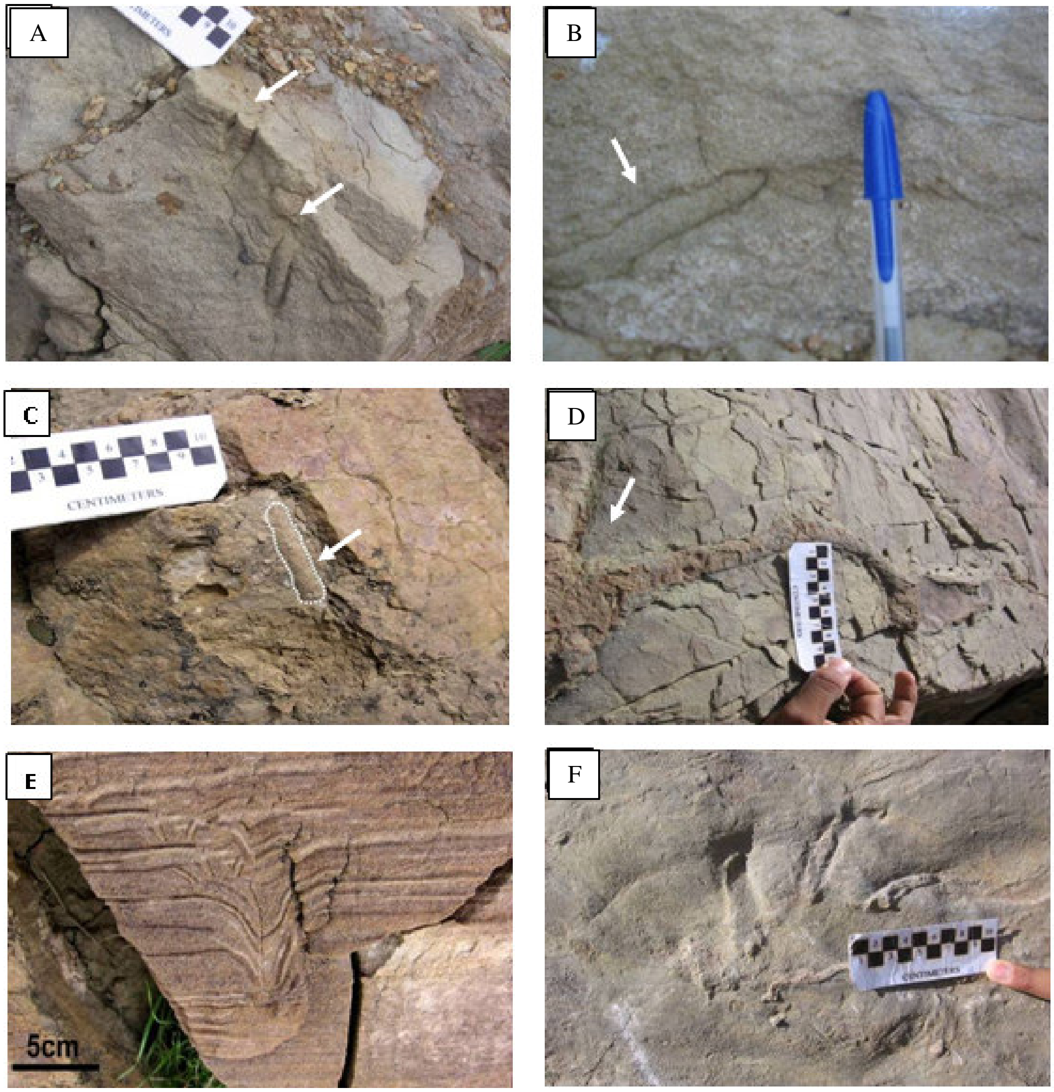

Plate 2. Figures; A: *Skolithos*, as vertical burrow in well – sorted sandstone. B: *Skolithos*, as subvertical burrow. C: *Steinichnus* in massive sandstone. D: *Thalassinoides* in fine–grained sandstone E: *Escape structure* with chevron pattern. F: *Track way* in fine– grained sandstone. Scales in cm.

Track Way

Plate 1, Fig. C and Plate 2, Fig. F

The *Track ways* are related to several types of walking vertebrates. Brides, mammals are just some of the organisms that make tracks. Track represent walking, running, sliding and resting. The tracks are typically found in alluvial, eolian and marginal environments. This trace fossil is abundant in Fm and Fl lithofacies.

Ichnofacies

Trace fossils are classifiable in some groups as ichnofacies. At first, ichnofacies supposed for basin's depth distributions of trace fossils [55]. Concept of Seilacherian ichnofacies is that trace fossils are a manifestation of behavior, which can be modified by the environment. The distribution and behavior of benthic organisms are limited by a number of palaeoecological factors such as: sedimentation rate, nature of substrate, flow regimes and water energy, oxygen level and food resources [51]. Thus, ichnofacies reflect similar environmental conditions during the production of trace fossils and have no evolutionary or time distributaries concepts [50]. Trace fossils of Kashkan Formation are related to Scoyenia ichnofacies. This ichnofacies dominated in the continental soft ground and is characteristic of low-energy settings, which undertake periodically subaerial conditions [36]. Most Scoyenia settings are inundated intermittently with freshwater. Common depositional environments include lake margins, fluvials, and channel margins and overbanks, progressively desiccated crevasse splay and wet interdune areas [12, 22]. Trace fossils of Kashkan Formation are classifiable in three subichnofacies of Scoyenia ichnofacies. Lithofacies, frequency, energy level changes and structures of trace fossils are documents of this classification. Trace makers, degrees of water saturation and firmness of substrate and relationships between trace fossils and trace fossils and sedimentary structures are other factors for distinguishing of Scoyenia subichnofacies [40]. Only, massive pebbly and horizontally sandstones or laminated or massive mudstone lithofacies contains trace fossil. There are any trace fossils in the other lithofacies. It may relate to sedimentary conditions or environmental controls. Figure 9 shows trace fossils' distributions in Kashkan Formation, base on Scoyenia ichnofacies characters.

Skolithos-Arenicolites Subichnofacies

Include abundant *Arenicolites* isp., *Skolithos* isp. trace fossils. *Ophiomorpha* isp., *Laminites kaitiensis* are common in this subichnofacies, and *Steinichnus* isp. or vertebrate tracks may be found, also. This subichnofacies mainly dominated in the Sm lithofacies as lateral accretion and sandy bed form substrates. Skolithos-Arenicolites subichnofacies shows a high energy level with high sandy sediment supply environments in the channel beds.

Diplocraterion-Thalassinoides Subichnofacies

In this subichnofacies *Diplocraterion* isp. and *Thalassinoides* isp. are abundant trace fossils. *Arenicolites* isp., *Skolithos* isp., *Ophiomorpha* isp., and *Laminites kaitiensis* are found also. This subichnofacies developed in the Sh and Slr lithofacies, where sediments deposited in the sheet flow, may periodically energy level change.

Vertebrate Footprints Subichnofacies

Vertebrate foot imprints are the common members of Scoyenia ichnofacies. These trace fossils show subaerial conditions completely. It made by mammal and bird walking in the muddy flood planes or muddy sheets. Thus, this subichnofacies is finding in laminated or massive mudstone lithofacies (Fm and Fl).

Results

The Kashkan Formation (Paleocene–Middle Eocene) in SW Iran mainly consists of coarse–grained, medium–grained and fine–grained lithofacies. In addition, architectural elements such as CH, GB, SB, LS, DA, LA and OF were created in this Formation This Formation shows sedimentary features typical of fluvial deposits such as erosional basal contacts, fining–upward cycles, trough and planar cross–bedded sets with variable thickness. These characteristics associated with the lithofacies architectural elements and unidirectional palaeocurrent show that the formation is formed in a low sinuosity braided stream that flowed the north to the south of the study area. To the south and southeast, this stream has been affected by shoreface environments. This view is confirmed by the abundance of trace fossils and small scale cycles from Gm lithofacies to Fm and L lithofacies.

Discussion

The environmental interpretation of the Kashkan Formation is based on the lithofacies, architectural elements and trace fossils in seven measured surface stratigraphic sections and the lateral relationship observed between them, also. The upper part of the Kashkan Formation is composed mainly by conglomerates. This thick conglomerate unit thins toward the south and southeast. This indicates that the provenance of the conglomerate particles was from north and northwest of the study area. The conglomerate units of the Formation consist mainly of lithofacies Gm, Gp and Gt. The Gm lithofacies was deposited as longitudinal bars and channel lag deposits. The presence of a few lenses of sandstone within the conglomerate indicates periods of decreased stream competency. The Gp lithofacies was formed because of migration of linguoid transverse bars. When a stream discharge was very high, the coarser–grained sediment was deposited and planar cross-bedded conglomerate formed. The Gt lithofacies was formed because of the migration of linguoid and transverse bars in deeper part of a channel and channel fill. The sandstone units of the Kashkan Formation consist mainly of lithofacies Sp, St, Sm, Sh, Sfl and Slr. The Sp lithofacies formed during a lower stage of water discharge as a result of migration of a linguoid or straight–crested transverse bars. In addition, the migration of sinuous crested dunes or sinuous bars may have produced lithofacies St. These cross–bedded sandstones formed when sandy sediments was dominant within the active channel [43]. The Sh lithofacies was formed during a lower stage of flooding in the upper flow regime. The Sfl and Slr lithofacies are related to tidal environments. In the sections near to the source area such as Darabi section, conglomeratic units are very common and the sedimentary cycles mainly consist of CH and GB elements. In Mamoolan and Golgekhalag sections (the southern sections) gradually fine–grained facies is increased and sedimentary cycles show a fuller type of CH, GB, SB and OF elements. Furthermore, in these sections *Skolithos* trace fossil is occurred. In Moorani and Malavi sections carbonate facies such as limestone and dolomite, tidal facies, *Escape structure* and *Diplocraterion* trace fossils are indicative of a shoreface environment. In Sepiddasht section, a part from the abundance of trace fossils such as *Thalassinoides* and *Laminites kaitiensis*, fine–grained facies are very common. In this section, the sedimentary cycles from Gm lithofacies to Fm lithofacies are regular and small–scale. Base on above information, the conglomerate of the Kashkan Formation (a very thick and coarse–grained conglomerate) represent a conglomerate of element CH (channel), GB (gravel bars) of Miall [43], which are characteristic of fluvial deposits. This conglomerate was deposited in low sinuosity, very coarse–grained braided streams that flowed from the north toward the south of study area. The absence of a finer–grained sediment in the upper part of the Kashkan Formation probably resulted from the migration of channels, which eroded fine–grained sediments and deposited coarser material as a sheet. This low sinuosity braided stream to the south and southeast of the study area has been related to a shoreface environment. This interpretation is supported by the presence of small–scale cycles and the different trace fossils in the southeast of the study area.

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