**Bayerische Julius-Maximilians-Universität**
**Würzburg**

# Stratigraphy, ichnology, and sedimentary environments of the Late Bajocian-Late Bathonian Kashafrud Formation, Northeastern Iran

**Dissertation zur Erlangung des**
**Naturwissenschaftlichen Doktorgrades**

**der Bayerischen Julius-Maximilians-Universität Würzburg**

vorgelegt von
**Jafar Taheri**
aus
**Mashhad**

**Würzburg, 30. 6. 2009**

**To my parents,**

**Who have given me a precious gift named "life".**

**I'll always be grateful to them.**

**To my thoughtful (kind-dear) wife**

**For her dedication during my studies,**

**For her; who patiently accepted unavoidable problems,**

**For being my eternal companion step by step during of my life.**

**And to my children,**

**Who according to our culture, should have a tranquil father for supporting them during the best period of their life,**

**and with hope for them to create greater success for themselves and their community.**

**Acknowledgments**

I acknowledge financial support by the German Research Society (Deutsche Forschungsgemeinschaft), grant FU 131/32. I thank In particular, my supervisor, Prof. F.T. FÜRSICH, who provided the opportunity to study in Würzburg. I benefitted from his valuable discussions, critical review and constructive comments on the manuscript. I also appreciate the help, hospitality, and kindness of his family toward my family during our stay in Würzburg. Prof. Dr. M. WILMSEN had an effective role in scientific discussions and interpretation of the data. I appreciate his helpful comments, and valuable discussions.

I also would like to thank the staff of the Institut für Paläontologie und Geologie der Universität Würzburg, Prof. H. DE WALL, and Dr. M. HEINZE for their help and Mrs. H. SCHÖNIG, for precise photographic work.

I thank to Prof. K. SEYED-EMAMI (Tehran University), for his precious discussions and determination of some of the ammonites. I would like to thank, M. HOSAINIUN and Dr. M. MAJIDIFARD for their help and determination of ammonites which have collected from the Kashafrud Formation.

I am grateful to Dr. B. NIEBUHR (SARAH), for help in the field of some software and kindness towards my family. My appreciation goes to M. T. KOREIE, Head of the Geological Survey of Iran, and to Dr. M. MEHR PARTOW, past exploration Deputy, for their full support, to J. ROWSHANRAVAN, the present head of Mashhad GSI, for his organization of field trips, and to my co-workers at GSINET (Geological Survey of Iran, North-East Territory) for their help in fieldwork in Iran.

And, finally, I am indebted to all teachers who contributed to my education, from the first stage to the present one; I would like to thank them for all their kindness and……

**Abstract**. The Upper Bajocian-Bathonian Kashafrud Formation is a thick package of siliciclastic sediments that crops out in NE Iran from the southeast, near the Afghanistan border, to north- northwestern areas around the city of Mashhad. The thickness ranges from less than 300 m in a deltaic succession (Kuh-e-Radar) to more than 2500 m in the Maiamay area, but the normal thickness in Ghal-e-Sangi, Kol-e-Malekabad, and Fraizi areas is about 1200-1300 m. It is the fill of an elongated basin, which extended for more than 200 km in NW-SE direction and a width of at least 50 km along the southern margin of the Koppeh Dagh.

Prior to this study, little information existed about the sedimentary environments and other characters, especially the geometry of the basin. Exact biostratigraphic data from the top of the Kashafrud Formation were rare. Based on the macrofauna from the lower part of the overlying Chamanbid Formation the upper boundary of the Kashafrud Formation had been attributed to the ?Late Bathonian and/or Early Callovian, but now the upper limit of the Kashafrud Formation is defined as Late Bathonian in age, based on ammonite biostratigraphy.

Except for chapter one, which deals with the introduction and related sub-titles, in the following chapters, step by step, field observations and data were surveyed according to the questions to solve.

In order to reconstruct the facies architecture and the geometry of the basin, a number of sections have been logged in detail (see chapter 3, "The sections"). The exact biostratigraphic setting is discussed in chapter 4 ("Biostratigraphy").

Sedimentary environments range from non-marine alluvial fans and braided rivers in the basal part of the succession to deltas, storm-dominated shelf, slope and deep-marine basin. The latter comprises the largest part of the basin fill, consisting of monotonous mudstones, siltstones and proximal to distal turbidities. The only continuous carbonate unit (~30 m) locally formed at Tappenader. Other localities in which thin fossil-bearing carbonate strata occur are Torbat-e-Jam (benthic fauna) and, to a lesser extent, Ghal-e-Sangi. These rare shallow-water carbonates, which also contain corals, represent only short intervals (see chapter 5," Facies association and sedimentary environments").

Relative changes in sea level were reconstructed on the basis of deepening- and shallowing-upward trends. Sequence boundaries and parasequences have been distinguished and analyzed in chapter 6 ("Sequence stratigraphy"). In most areas, the basin rapidly evolved from a shallow marine, transgressive succession to a deep-marine, basinal succession. The only area

where shallow conditions persisted from the Late Bajocian to the Late Bathonian, and even into the Early Callovian is the Kuh-e-Radar area which corresponds to a fan-delta setting.

A trace fossil analysis has been carried out to obtain additional evidence on the bathymetry of the basin (see chapter 7, "Ichnology"). Altogether 29 ichnospecies belonging to 15 ichnogenera have been identified, as well as 10 ichnogenera, which were determined only at genus level. They can be grouped in the well-known "Seilacherian ichnofacies".

Very high subsidence rates and strong lateral thickness variations suggest that the Kashafrud Formation is a rift related basin that formed as the eastern extension of the South Caspian Basin. The basin evolution is reviewed, the eastern and western continuations of the basin were checked in the field and also in the literature (see chapter 8, "Basin evolution").

In all, the present study provided new insights into the development of the Kashafrud Formation, e.g. more biostratigraphic data from the base and the top of the succession, a relatively complete picture of the trace fossil associations, a better recognition and reconstruction of the sedimentary environments in different parts of the basin. Finally this research project will be a good basis for further investigations, especially towards the west, as parts of the Kashafrud Formation are source rocks of a hydrocarbon reservoir in NE Iran.

## Contents

## Introduction

The name Kashafrud Formation started to appear in the Iranian geological nomenclature when GOLDSCHMID (1956) informally named a sequence of shales and sandstones in NE Iran. Subsequently, other geologists used this name for such successions in NE Iran without studying them in detail.

MADANI (1977) measured a section at 15 km east of small village Baghbaghu and designated it as type section of the Kashafrud Foration.

EFTEKHARNEZHAD & BEHRUZI (1991) mapped this stratigraphic unit in the Torbat-e-Jam geological sheet at a scale of 1:250,000. HOSAINIUN (1996) studied the Kashafrud strata at several localities such as Tappenader, Ghal-e-Sangi, and Senjedak. The newest published data about this succession is by POURSOLTANI (2007).

In the framework of the present investigations, numerous field observations were made and 10 sections were measured, distributed from the south-eastern part of the outcrop area, near the Afganistan border, to the Fraizi district in the west.

In Chapters 1 and 2, a general review of the stratigraphy and geological setting shows the main features of the study area and discusses the material and methods. In Chapter 3 the sections are reviewed including thickness, lithofacies and some other main characters of the strata.

During logging the Kashafrud strata bed by bed, special attention has been paid to collect biostratigraphic data, especially ammonites. For the first time, age-diagnostic fossils were recovered from the top of the formation at several localities (for details see Chapter 4), and also from the lowermost part (e.g., at Kuh-e-Radar, and Torbat-e-Jam). Data from the base and the top of the Kashafrud Formation reveal Late Bajocian to Late Bathonian age for the succession in the study area.

In Chapter 5 facies associations are analysed and different marine environments ranging from shallow to deep are distinguished, based on characteristic sedimentary features. A brief sequence stratigraphic interpretation of the succession is found in Chapter 6, an aspect which deserved to be studied in more detail in the future.

Trace fossils (Chapter 7) are one of the main aspects of this study. It includes apart from ichnotaxonomy also their arrangement in different ichnofacies. In Chapter 8 the evolution of the Kashafrud Basin is discussed, followed by surveyed the conclusions (Chapter 9).

Characteristic features of the Kashafrud Formation will be discussed in different parts of the thesis. They reveal sedimentary processes which prevailed within the basin.

As the Kashafrud Basin formed in a relatively active geodynamic setting and at the same time in a short time span, i.e. less than 5 m. y. it is a nice case study, especially considering that it is a source rock of hydrocarbon gas in northeastern Iran.

This study presents a model for the Kashafrud Basin in NE Iran and attempts to retrace the geological history of the area during Middle Jurassic, especially the post Mid-Cimmerian tectonic activity, in the eastern Alborz. The field data show that such investigations can be extended to the main tectono-sedimentary zone of the western Kopp-e-Dagh.

## 1.1 Geological setting

From the Late Bajocian to the Late Bathonian, a succession of mostly siliciclastic sediments, the Kashafrud Formation and equivalents, were deposited within a NW-SE trending basin in northeastern Iran, which is named as Kashafrud Basin (TAHERI et al., 2009; Fig 1.1).

This basin is located between two main tectono-sedimentary zones named Koppeh Dagh in the north and Binalud (the eastern prolongation of the Alborz mountain belt) in the south.

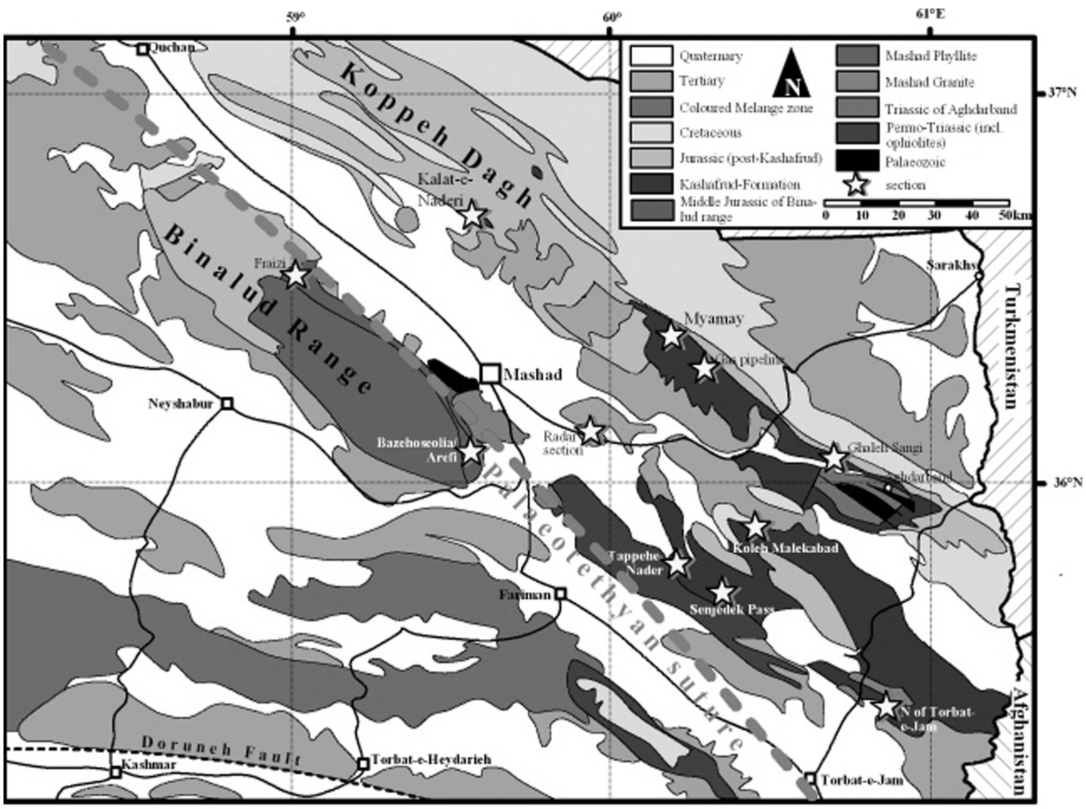



Fig. 1.1 General geological map of the study area and the section localities.

These two zones are separated by the Palaeo-Tethys suture zone and ophiolites, which are located just south of the city of Mashhad. The main stratigraphic and geologic units which outcrop in and in the neighborhood of the study area are:

- Palaeo-Tethys remnants and Permian metaturbidites;
- the erosional window of Aghdarband, northeast of the study area;
- the Mashhad Phyllite;
- an un-metamorphosed siliciclastic rock unit (Arefi and Bazehowz formations) which vertically grades into the Aghonj Formation (Arefi area, Wilmsen et al., 2009a);
- the granitoid rocks of the Mashhad and Torbat-e-Jam area;
- the Koppe Dagh and post Mid-Cimmerian sediments in this area.

Obviously each of the above mentioned units comprises different characters and aspects, which will not be well understood without profound background information and a large data base.

Palaeo-Tethys remnants and Permian metaturbidites

Initially, ophiolites of Palaeo-Tethys origin, which are well known along the Alpine-Himalayan fold belt including the Alborz Mountain chain, were hardly known (STÖCKLIN, 1974). However, during the last decades, the ophiolites of the Mashhad area were studied in detail and recognized as such by numerous geologists (e.g., ALAVI 1979; MAJIDI 1981; EFTEKHARNEZHAD & BEHROUZI 1989; GHAZI et al., 2003).

These ophiolitic rocks crop out south and west of Mashhad, north of Fariman and also north of Torbat-e-Jam, extending for a distance of about 150 km. The Mashhad Ophiolite includes metaperidotites, metapyroxenites, metagabbros and metabasalts with pillow lavas as well as lherzolites and werlites (TAHERI & GHAEMI 1994). Serpentinization and uralitization are quite common, which makes identification of primary minerals and texture very difficult. Metasediments, which are sandwiched between different slices of basic and ultrabasic rocks, are cherts, tuffs, metasandstones and schists. A relatively thick unit of olistolite is exposed in the village Sarcheshme, south of Mashhad.

MAJIDI (1981) regarded this succession as Devonian-Carboniferous in age. In the absence of reliable data and based on new finds of Permian (Sakmarian) fossils in a similar succession in the Torbat-e-Jam area by EFTEKHARNEZHAD & BEHROOZI (1989), ALAVI (1991) attributed them to the pre-Late Triassic. However, later on TAHERI & GHAEMI (1994), while mapping the Mashhad sheet, discovered the following microfossils among less metamorphosed, thin-bedded limestone in the Khalaj area (near Mainush small farm): *Staffella* sp., *Parafusulina* sp., *Schubertella* sp., and *Textularia* sp.

Based on radiometric dates of the Mashhad ophiolite (mainly basalts), GHAZI et al. (2001, 2003), determined a late Pennsylvanian age for the oceanic crust. This age is more or less comparable with the Sakmarian age that EFTEKHARNEZHAD & BEHROOZI (1989) postulated for ophiolites in the Torbat-e-Jam area, SE of Mashhad, but greater than that of the turbidite unit. This problem could be explained by the long time elapsed between oceanic crustal production to the end of the Wilson cycle and abduction of the crust.

**Erosional window of Aghdarband**

The Aghdarband erosional window, located east of the study area, plays a key role, not only for the palaeogeographic reconstruction of NE Iran, but also for evaluating the geological history of the southern margin of Laurasia and its relationship with Gondwana (RUTTNER, 1991, 1993; EFTEKHARNEZHAD & BEHROOZI, 1991; BAUD & STAMPFLI, 1989; BAUD et al., 1991).

The Aghdarband window is, in fact, one of the rare outcrops of Turan Plate basement and also a locality where a succession of pre-Jurassic rocks in the southeastern part of the Koppe Dagh range is exposed. These rock units that belong to the Devonian and Triassic are also reported from deep boreholes in the eastern Koppe Dagh in south Turkmenistan (LYBERIS & MANBY, 1999: 1145).

RUTTNER (1991) edited the results of the geological mapping (EFTEKHARNEZHAD & BEHROOZI, 1991) and stratigraphic investigations in the Aghdarband area (BAUD et al., 1991a) and published a paper (1991b) about the geodynamic significance of the area. According to him, rock units of the Aghdarbad area represent at least two different successions:

1- A Palaeozoic rock succession consisting of volcaniclastics with limestone intercalations (Frasnian-Famenian) and recrystallized limestone (Tournaisian).

2- A relatively thick succession of Triassic rocks, which from base to top includes the

- Qara Gheitan Formation (Scythian in age) that is composed of more than 1000 m of red shales, sandstones, and conglomerates;
- Sefidkuh Formation (Late Scythian), which includes limestones;

- Nazarkardeh Formation (Early Anisian), which consists of nodular limestone and tuffaceous shale/sandstone beds, and the - Sina Formation, which includes a volcaniclastic-turbiditic succession.

The thick succession of about 1000 m of terrigenous rocks and the volcaniclastic units in the Aghdarband area show that a volcanic arc existed at the southern margin of Laurasia, the origin of which is traceable from the southern Causasus through the Koppe Dagh to the Pamirs (BAUD et al. 1991a), where the Palaeo-Tethys Ocean no longer existed in Triassic times (the Darre Anjir mélange, which is covered by Triassic strata, confirms this conclusion).

**Mashhad Phyllite**

The Mashhad Phyllite is a thick succession of blackish, low-grade metamorphosed rocks including metasandstones, slates, and phyllites in the Binalud Mountains, which extends between Mashhad and Neyshabur from the crest of the Binalud Mountains towards the north (Fig. 1.1).

Although the age of the rock unit has not been established yet with certainty, it has been mapped on the geological sheets as Upper Triassic-Lower Jurassic. WENDT et al. (2005: 48) found the plant fossils *Clathropteris menisciodes* and *Anthrophyopsis crassinervis* (determined by H. J. SCHWEITZER, Bonn) which apparently indicate a late Rhaetian age for the base of this unit (as he believed).

However, WILMSEN et al., (2005) suggest that the alternation of polymictic conglomerates, coal-bearing shales and sandstones as well the quartz conglomerate which crops out around the small village Arefi south of Mashhad is an equivalent of the middle and upper Shemshak Group, in accord with the data of WENDT et al. (2005). Thus, the question of the precise age of the Mashhad Phyllite and its covering strata is unknown. The recent data on the biostratigraphy of the Mashhad Phyllite will be discussed in Chapter 4.

**Un-metamorphosed siliciclastic rocks of the Arefi area**

The succession of un-metamorphosed rocks starts with a poorly sorted, moderate to well rounded, polymictic conglomerate, which most components being 20-30 cm in diameter, but occasionally some cobbles are more than 1 m in diameter (Arefi Foramtion). It is followed by a unit of sandstones and micro-conglomerates with coal-bearing shale and lenses (Bazehowz Formation) which grade up-section into the Aghonj Formation (quartz conglomerates). Although this unit extends toward NW along two main faults, the main outcrop is visible around Arefi and Derakht-Tut. This unit overlies the so-called "Mashhad Phyllite" with obvious angular unconformity (Wilmsen et al., 2009a).

BOLURIAN & JAFARI (2008) reported the plants *Chytroeiphaeidia* aff. *Chytroeides*, ?*Escharisphaeridia* sp., and *Pareodinia* sp. aff. *P. ceratophora.* They assumed a Middle to Upper Jurassic age for the unit (specimens were determined by TAVAKKOLI in GSI). In contrast, VAEZ JAVADI & POURLATIFI (2004) distinguished the following plant fossils from Golmakan (near the small village of Hasan Aghe): *Coniopteris hymenophylloides, Klulia westi, Sphenobaira longifolia, Sphenobaiera* cf. *pulchella, Czekanowskia rigida, Nilssonia acuminata, Nilssonia feriziensis,* and *Nolssonia macrophylla,* and attributed this rock unit to the Late Liassic-Early Middle Jurassic.

KHATOONI MOLLAYOUSOFI (2000), in his master thesis, studied the plant fossils of this unit in the Shandiz area and suggested that the plant fossil assemblage is Toarcian-Aalenian in age.

Some beds of this unit near the small village Bazehouse contain abundant plant fossils but attempts to get them determined in Germany were not successful, due to their low diversity and poor preservation.

If the Rhaetian age attributed to the Mashhad Phyllite by WENDT (2005), is correct, then this un-metamorphosed non-marine siliciclastic unit, which overlies older rocks with distinct angular unconformity, should be younger. This is confirmed by the above mentioned data but the precise relationship between these units (Mashhad Phyllite and the un-metamorphosed Jurassic rocks), and the exact position of the Early Cimmerian and the Mid-Cimmerian orogenic events are unclear and need to be investigated in more detail (see Chapter 4 for a more extensive discusion).

**Mashhad and Torbat-e-Jam granitoid plutons**

Relatively large plutons of granite and granodiorite crop out south of Mashhad covering an area of about 190 square km, and granodiorites to monzogranites are exposed for about 75 square km north of Torbat-e-Jam. The Mashhad Granite is composed of at least of two main phases with final pegmatite-aplite veins, especially in the Khaje-Morad area. There is no direct relationship of these granitic rocks with the Upper Bajocian-Upper Bathonian Kashafrud strata in the Mashhad district, but at the Kuh-e-radar locality, pebbles and boulders of these granitoid rocks occur in the lower part of Kashafrud Formation. In the Torbat-e-Jam area, sediments of the lower Kashafrud Formation directly overlie the granitoid rocks (Fig. 1.2).

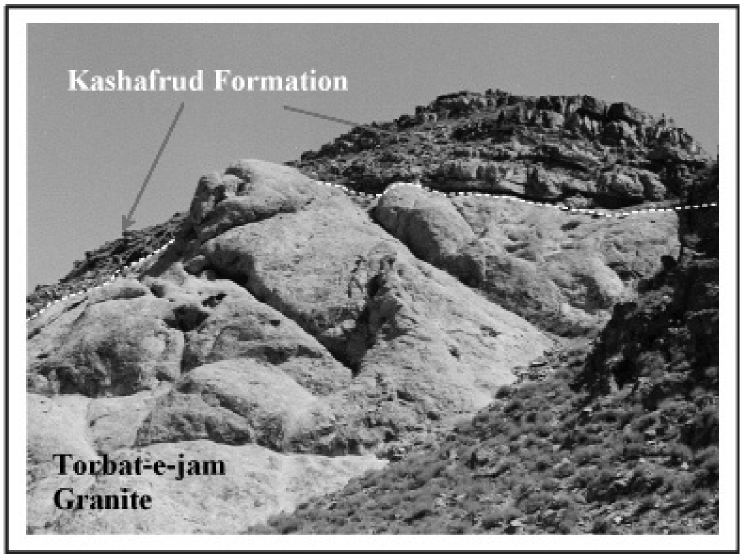



Fig. 1.2 Kashafrud strata resting on Torbat-e-Jam Granite, north Torbat-e-Jam Granite, near Gol Banu coal mine.

ALBERTI et al. (1973) determined the absolute age of the Mashhad Granite based on K-Ar isotopes in four specimens. They yielded ages of 145, 120, 135, and 146 (±3) m.y., which corresponds to the Late Jurassic to Early Cretaceous. This age determination cannot be correct, because of the presence of such granitoid pebbles in the Upper Bajocian strata of the Kashafrud Formation. ALBERTI & MOAZEZ (1974) published the first petrographic study of the Mashhad Granite. MAJIDI (1978) distinguished three metamorphic stages and two phases of granite emplacement in the Binalud region.

MIRNEZHAD (1991) studied the petrology and geochemistry of the Mashhad Granite and concluded that the pluton is composed of tonalite, granodiorite, and monzonite which has been intruded by pegmatite and aplite veins. He also related the pluton to the three tectono-magmatic settings, i.e. orogenic type, continental arc type, and to collision-related type. IRANMANESH & SETHNA (1998) carried out a general study on the Mashhad Granites. Finally, KARIMPOUR et al. (2006) studied major and trace elements and REE geochemistry of the Palaeo-Tethys collision-related granitoid rocks of the Mashhad area.

As present, the age of the Mashhad Granite is still controversial: The emplacement of the plutons in the Mashhad and Torbat-e-Jam areas is regarded as post-Rhaetian (intrusion into the Miankuhi Formation) pre-Late Bajocian until new radiometric age determinations become available.

**Koppe Dagh**

The Koppe Dagh sedimentary basin is one the most important tectono-sedimentary zones in the region, located in northeast Iran, south Turkmenistan, and north Afghanistan (Fig. 1.1 ). The basin has been investigated by numerous geologists (e.g., AFSHAR-HARB, 1970, 1979, 1983, 1994; HUBER 1976; JENNY 1981; KALANTARI 1969; MADANI 1977; STAMPFLI 1978 and numerous unpublished master theses, especially in the field of stratigraphy).

One of the main features of this basin is the hydrocarbon reservoir, which extends alone in Iran for more than 55,000 km$^2$ (AFSHAR-HARB, 1994).

The total thickness of the Mesozoic and Cenozoic succession is more than 8000 m. AFSHAR-HARB (1994) reported rocks of the Shemshak Group and also Palaeozoic rocks at the southern border of the basin, but the geological relationship of these rock units to the Koppe Dagh is not clear.

Clearly, a sedimentary mega-cycle extends from the Late Bajocian, with a minor gap in the Late Tithonian-Early berriasian until the Early Oligocene with marine conditions prevailing in the area for about 135 m.y. The final regression was diachronous in different parts of the basin.

Thus, the Kashafrud Formation does not only form a bridge between pre- and post-collision events in the Late Triassic in northeast Iran, but will also reveal the post-collisional evolution, including the Mid- and Late Cimmerian events in NE Iran, especially post-collisional movements following the closure of the Palaeo-Tethys (WILMSEN et al., 2005; 2009b).

## 1.2 Stratigraphy

Based on an unpublished report of the National Iranian Oil Company, AFSHAR-HARB (1969) introduced the Kashafrud Formation in the literature for an alteration of sandstones and shales. Subsequently the term was used by geologists dealing with the stratigraphy and geology of the area (e.g., AGHANABATI 1998). However, no formal type section was ever proposed. MADANI (1977) interpreted a section near the village Baghbaghou as representing flysch deposits. AFSHAR-HARB (1983), AGHANABATI et al. (1986) and EFTEKHAR-NEZHAD & BEHROUZI (1993) mapped the Kashafrud Formation on the Sarakhs, Mashhad and Torbat-e-

Jam quadrangle sheets, respectively. TAHERI & GHAEMI (1994) used it also on the Mashhad 1:100,000 sheet. SEYED-EMAMI et al. (1994, 1996) and HOSAINIUN (1996) studied ammonites of the formation in Tappe Nader and Ghal-e-Sangi areas. TAHERI et al. (2006) and WILMSEN et al. (2006) gave a brief account of the stratigraphy, facies and origin of the Kashafrud Formation. Recently, POURSOLTANI et al. (2007) characterized the rocks of the formation as representing deep-water fans and Taheri et al. (2009) discussed the stratigraphy, depositional environments of the formation.

The Kashafrud Formation overlies different older rocks with angular unconformity and is followed gradually by the Callovian Chamanbid Formation, a unit consisting of silty marl and argillaceous limestones, and, in the eastern part of the basin, by limestones (Kol-e-Malekabad area) or sandy limestones (Ghal-e-Sangi area) of the Upper Jurassic Mozduran Formation (Fig. 1.4). The age of the base of the formation is Late Bajocian, as is documented by ammonites such as *Orthogarantiana, Garantiana,* and *Parkinsonia* (SEYED-EMAMI et al. 1994, 1996; HOSAINIUN 1996). The Late Bathonian age of the upper part of the Kashafrud Formation is indicated by the ammonites *Prohecticoceras haugi* (Provici-Hatzeg), *Cadomites claramontanus* (Kopik), *Procerites (Siemiradzkia)* sp., and *Homoeoplanulites* sp., found in the Jizabad and Gas-pipeline sections. This age has been confirmed by the occurrence of *Macrocephalites* near the base of the overlying Chaman Bid Formation at Kuh-e-Radar and Fraizi localities. The thickness of the Kashafrud Formation varies from about 300 m (Kuh-e-Radar section) to possibly more than 2,900 m (Maiamay section).

Towards the west, the Kashafrud Formation interfingers with the more marly-calcareous Dalichai Formation (a unit which is widespread in the Alborz Mountains of northern Iran; see SEYED-EMAMI et al., 2001; FÜRSICH et al., 2009). In the Fraizi area (Fig. 1.1), a transitional facies is developed consisting of marly silt with intercalations of sandstones, which has been mapped as Dalichai Formation on the geological maps (e.g., AGHANABATI et al. 1986), but corresponds more closely to the lithology of the Kashafrud Formation than the Dalichai Formation. At this locality, the Kashafrud Formation is overlain by platform limestones of the Lar Formation (Fig. 1.3). Additional information and new data will be presented in the next sections.

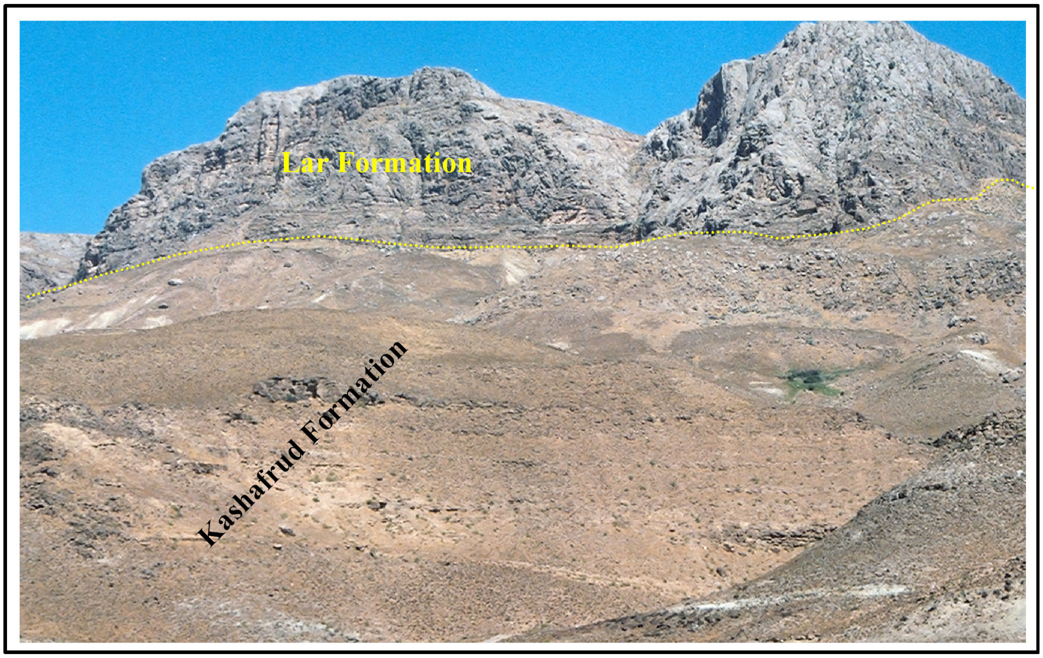



Fig. 1.3 General view of the upper part of Fraizi section west of the small village Khij.

**Localities**

During a reconnaissance phase, the study area was surveyed and ten localities were selected for section logging (Table 1.1). The most important aspects for choosing the section points were previous studies and sections, the distribution of the sections over the study area, and special features of outcrops which provided new data on the Kashafrud Basin. The distribution of the sections is shown in Fig 1.1.

The first sections were measured at Ghal-e-Sangi, Tapp-e-Nader, and Senjedak. From these localities, Upper Bajocian ammonites have been recorded by HOSSAINIUN (1996) and SEYED-EMAMI et al. (1994, 1996). The Jizabad section is considered as part of a composite section with Tapp-e-Nader, as field observations showed that they are closely related. To obtain more information in the southeastern part of the basin, the lower part of Kashafrud Formation was measured north of Torbat-e-Jam (near the Afghan border). In the Kol-e-Malekabad area, south of Darre Anjir, another section was logged. The sixth section (Maiamay) was measured in the northwestern part of the study area, another section in the Fraizi area along a transect from Hassan Aghe toward NW. The thickest section is in the Maiamay area, and for the tenth section, the Kuh-e-Radar locality east of Mashhad has been chosen. General information on the sections is shown in Table 1.1.

Table 1.1 General information on sections.

| | **Section** | **Locality** | **Thick-ness (m)** | **Lower contact** | **Top** |
|---|---|---|---|---|---|
| **1** | **Tappenader** | Tappenader | 103.5 | Ophiolite | Covered |
| **2** | **Jizabad** | SE Mashhad | 875 | Faulted | ?Upper Jurassic |
| **3** | **Senjedak** | NE Fariman | 660 | Volcanic | Not measured |
| **4** | **Ghal-e-Sangi** | Ghal-e-Sangi | 1308 | Sina Formation | Mozduran Formation |
| **5** | **Torbat-e-Jam** | N Golbanou | 169 | Granitoid | Folded and faulted |
| **6** | **Maiamay** | Maiamay | 2914 | | Folded and faulted |
| **7** | **Gas-Pipline** | | ~ 800 | Folded and faulted | Chamanbid Formation |
| **8** | **Kol-e-Malekabad** | S Darre Anjir | 1271 | Darre Anjir Ophiolite | Mozduran Formation |
| **9** | **Fraizi** | Hassan Aghe | 1650 (marine part) | Non-marine Jurassic strata | Lar Formation |
| **10** | **Radar** | E Mashhad | 275 | Covered | Chamanbid Formation |

## 1.4 Purpose of study

The main purpose of the study was a detailed reconstruction of the sedimentary and biotic evolution of the Kashadfrud Basin. In more detail, this involved the following aspects:

* Development of a biostratigraphic framework in order to enable a high-resolution correlation of the sections across the basin (based mostly on ammonites).

* Reconstruction of the sedimentary environments of the Kashafrud Basin.

* Evaluation of the subsidence rate based on section logging in order to detect tectonic pulses.

* Identification of the tectonic processes that controlled the development of the basin.

* Identification of trace fossils and analysis of their environmental significance.

The data obtained through field work and in the laboratory were used to test the following hypotheses:

1- The marine basinal sediments of the Kashafrud Formation of the Koppe Dagh and the non-marine (mainly fluvial) sediments of the northern Binalud that rest on the Mashhad Phyllite are part of a single depositional basin, i.e. the Kashafrud Basin.

2- Is the Kashafrud Basin was a syn-orogenic basin?.

3- The Kashafrud Basin is a rift-related basin that developed after the Mid-Cimmerian tectonic phase.

4- No lateral movements occurred at the Early-Cimmerian suture between the Turan and the Iran plates since the Middle Jurassic (after deposition of the Kashafrud Formation).

Right from the beginning of the study it became clear that extensive field work was required to achieve the goal.

## 2. Material and methods

According to the goals of the study the following tasks were carried out in the field:

(1) detailed logging of sections;

(2) sampling of trace fossils;

(3) taking samples for thin-sections;

(4) sampling macrofossils, especially ammonites;

(5) sampling plant fossils in the sections which are located at the northern margin of the Binalud Mountains.

(6) taking samples for palynology.

Altogether more than 170 specimens of trace fossils representing a moderately diverse ichnofauna have been collected, of which about 120 specimens could be identified (Table 2.1).

From the ten sections with a cumulative thickness of about 10500 m, 180 thin-sections were prepared (Table 2.2).

One of the major problems in the siliciclastic successions is the scarcity of fossils and their poor preservation. As a biostratigraphic framework of the succession is essential for reconstructing the sedimentary evolution of the basin, much affort was spent to collect ammonites and other macroinvertebrates. They are listed in Table 4.2.

Some plant fossils, (altogether at least 13 samples) representing a low diversity flora, have been recovered from the non-marine rocks at the northern margin of the Binalud Mountains, from two main localities in the Baze House and Fraizi areas, south and west of Mashhad, respectively.

Attempts to get the specimens identified at the Senckenberg Museum in Frankfurt were not successful.

Prervious age determination of such floras range from Early to Early-Middle Jurassic so that no precise age determination is possible. This leads to an ambiguity in the interpretation (see discussion in Chapter 4). After having been labelled and packed in the field, the samples were transported to the GSINET (Geological Survey of Iran – North-East Territory), where primary preparation and processing were done. Subsequently, these samples were sent to the Palaeontological Institute of the University of Würzburg by air freight. The trace fossils and macrofossils have been deposited in the collections of the Palaeontological Institute (prefix PIW), which are now housed at the Bayerrische Staatsammlung für Paläontolologie und Geologie in Munich.

The bivalve fauna has been determined by ROMAN BRÜTTING and FRANZ FÜRSICH (Erlangen) and the ammonites by M. MAJIDIFARD (Tehran) and M. HOSSAINIUN (Mashhad). The ammonite identifications were checked by K. SEYED-EMAMI (Tehran).

The palynomorphs were processed by J. SABOORI and B. FARAHANI at the Geological Survey of Iran, Tehran. All sections were checked several times during 2005-2008 to obtain a high quality dataset.

Table 2.1 Trace fossil specimens recovered in the study area.

| Row | Field No: | Lab. No: | Trace fossil name |
|---|---|---|---|
| **1** | 04,F,1318-29E | 04,F,14e | *Chondrites intricatus* BRONGNIART, 1823 |
| **2** | 04,F,1836.541A | 04,F,20a | *Chondrites intricatus* BRONGNIART, 1823 |
| **3** | 04,M,167 | 04,M,5a | *Chondrites intricatus* BRONGNIART, 1823 |
| **4** | 04,M,167-174 | 04,M,6a | *Chondrites intricatus* BRONGNIART, 1823 |
| **5** | 04,F,west KhijC | 04,F,45 | *Curvolithus* isp. |
| **6** | 04,Ch.A,1200 | 04,K,16a | ? *Curvolithus* isp. |
| **7** | 04,Ch.A,822 | 04,K,10a | *Curvolithus simplex* BUATOIS, MANGANO, MIKULAS & MAPLES |
| **8** | 04,Gh,721.5 | 04,Gh,6a | *Curvolithus simplex* BUATOIS, MANGANO, MIKULAS & MAPLES |
| **9** | 05,M,2275-85 | 05,M,35a | *Curvolithus simplex* BUATOIS, MANGANO, MIKULAS & MAPLES |
| **10** | 04,F,1836.5-41H | 04,F,20h | *Diplocraterion* isp. |
| **11** | 04,Jiz,13 | 04,Jiz,1a | *Diplocraterion* isp. |
| **12** | 05,M,2431 | 05,M,43 | *Diplocraterion* isp. |
| **13** | 05,M,member5 | 05,M,37b | *Biformites* isp. |
| **14** | 04,Gh,1200 | 04,Gh,15a | *Gyrochorte comosa* HEER,1865 |
| **15** | 04,Gh,1225-30b | 04,Gh,16b | *Gyrochorte comosa* HEER, 1865 |
| **16** | 06,F,900-1000 | 04,F,2a | *Gyrochorte comosa* HEER, 1865 |
| **17** | 04,Gh,678 | 04,Gh,5a | *Gyrochorte comosa* HEER, 1865 |
| **18** | 04,Ch.A,1180-1200b | 04,K,15b | *Gyrochorte* isp.? |
| **19** | 04,Gh,1225-30 | 04,Gh,16 | *Gyrochorte* isp.? |
| **20** | 04,Gh,944 | 04,Gh,13a | *Gyrochorte* isp.? |
| **21** | 04,F,1836.5-41 | 04,F,20c | *Helminthopsis abeli* |
| **22** | 04,Ch.A,101.4-113 | 04,K,3a | *Helminthopsis* isp? |
| **23** | 04,M,170 | 04,M,7 | *Helminthorhaphe crassa* SCHAFHÄUTL, 1851 |
| **24** | 04,M,180 | 04,M,8 | *Helminthorhaphe crassa* SCHAFHÄUTL, 1851 |
| **25** | 04,M,76-113B | 04,M,1b | *Helminthorhaphe crassa* SCHAFHÄUTL, 1851 |
| **26** | 04,M,76-113H | 04,M,1h | *Helminthorhaphe crassa* SCHAFHÄUTL, 1851 |
| **27** | 05,MG,30 | 05,MG,38 | *Helminthorhaphe japonica* TANAKA, 1970 |

| | | | |
|---|---|---|---|
| **28** | 04,F,1358 | 04,F,15 | highly bioturbated, undeterminable |
| **29** | 04,F,1367 | 04,F,16 | highly bioturbated, undeterminable |
| **30** | 04,Ch.A,137 | 04,K,6a | *Lophoctenium* Richter, 1850 |
| **31** | 04,F,1836.5-41 | 04,F,20b | *Lophoctenium* Richter, 1850 |
| **32** | 04,F,1910-38 | 04,F,24a | *Lophoctenium* Richter, 1850 |
| **33** | 04,F,1920 | 04,F,22a | *Lophoctenium* Richter, 1850 |
| **34** | 04,Ch.A,114-122 | 04,K,4e | *Lophoctenium richteri* Delgado, 1910 |
| **35** | 04,F,1960 | 04,F,30a | *Lophoctenium richteri* Delgado, 1910 |
| **36** | 04,F,1972 | 04,F,25a | *Lophoctenium richteri* Delgado, 1910 |
| **37** | 04,Gh,784 | 04,Gh,11a | *Lophoctenium richteri* Delgado, 1910 |
| **38** | 04,Ch.A,123-137 | 04,K,5a | *?Lophoctenium richteri* Delgado, 1910 |
| **39** | 04,Ch.A,1140-1160 | 04,K,14 | *Moncraterion* isp. |
| **40** | 04,Ch.A,114-122b | 04,K,4f | *Neonereites multiserialis* PICKERILL & HARLAND, 1988 |
| **41** | 04,Ch.A,123-137b | 04,K,5b | *Neonereites multiserialis* PICKERILL & HARLAND, 1988 |
| **42** | 04,Se,273-278 | 04,Se,1a | *Neonereites multiserialis* PICKERILL & HARLAND, 1988 |
| **43** | 05,M,2170-90a | 05,M,30a | *Neonereites multiserialis* PICKERILL & HARLAND, 1988 |
| **44** | 04,Ch.A,114122d | 04,K,4b | *Neonereites multiserialis Nereites missouriensis* |
| **45** | 04,M,76-113G | 04,M,1g | *Neonereites multiserialis?* |
| **46** | 04,Se,273-278B | 04,Se,1b | *Neonereites multiserialis?* |
| **47** | 04,Se,55-65 | 04,Se,2a | *Nereites* cf. *macleayi* |
| **48** | 04,M,76-113A | 04,M,1a | *Nereites irregularis* |
| **49** | 04,M,76-113c | 04,M,1c | *Nereites irregularis* |
| **50** | 04,M,76-113d | 04,M,1d | *Nereites irregularis* |
| **51** | 04,Ch.A,101.4-113c | 04,K,3b | *Nereites* isp. |
| **52** | 04,Ch.A,101.4-113d | 04,K,3d | *Nereites* isp. |
| **53** | 05,M,2170-90c | 05,M,30c | *Nereites* isp.*?* |
| **54** | 04,Ch.A,114-122a | 04,K,4a | *Nereites missouriensis* WELLER, 1899 |
| **55** | 04,Ch.A,123-137C | 04,K,5c | *Nereites missouriensis* WELLER, 1899 |
| **56** | 05,D,59.5 | 05,D,3 | *Ophiomorpha* isp. |
| **57** | 04,F,1318-29a | 04,F,14a | *Ophiomorpha borneensis* Keij, 1965 |
| **58** | 04,F,1318-29b | 04,F,14b | *Ophiomorpha borneensis* Keij, 1965 |
| **59** | 04,F,1318-29D | 04,F,14d | *Ophiomorpha borneensis* Keij, 1965 |
| **60** | 04,F,1318-29F | 04,F,14f | *Ophiomorpha borneensis* Keij, 1965 |
| **61** | 04,F,1874-80 | 04,F,21a | *Ophiomorpha borneensis* Keij, 1965 |
| **62** | 04,F,1325 | 04,F,13b | *Ophiomorpha* isp. |
| **63** | 04,F,1420 | 04,F,17a | *Ophiomorpha* isp. |

| | | | |
|---|---|---|---|
| **64** | 04,F,1420B | 04,F,17b | *Ophiomorpha* isp. |
| **65** | 04,F,1803 | 04,F,19a | *Ophiomorpha* isp. |
| **66** | 04,F,1803B | 04,F,19b | *Ophiomorpha* isp. |
| **67** | 05,D,87 | 05,D,8a | *Ophiomorpha* isp. |
| **68** | 04,Gh,722 | 04, Gh, 7 | *Ophiomorpha regulair* FREY, HOWARD & PRYOR, 1978 |
| **69** | 04,Gh,738 | 04,Gh,10 | *Ophiomorpha* isp.? |
| **70** | 04,Ch.A,1117-1132 | 04,K,12a | *Ophiomorpha nodosa* Lundgren, 1891 |
| **71** | 04,Ch.A,885 | 04,K,13a | *Ophiomorpha nodosa* Lundgren, 1891 |
| **72** | 04,F,2010-38 | 04,F,26a | *Ophiomorpha nodosa* Lundgren, 1891 |
| **73** | 04,F,west Khij | 04,F,31b | *Ophiomorpha nodosa* Lundgren, 1891 |
| **74** | 05,M,1192 | 05,M,16 | *Ophiomorpha nodosa* Lundgren, 1891 |
| **75** | 05,M,1197-1200 | 05,M,16a | *Ophiomorpha nodosa* Lundgren, 1891 |
| **76** | 04,F,1136 | 04,F,12 | *Paleodictyon maximum* EICHWALD, 1868 |
| **77** | 04,F,1400 | 04,F,31b | *Paleodictyon maximum* EICHWALD, 1868 |
| **78** | 04,F,2250 | 04,F,33 | *Paleodictyon maximum* EICHWALD, 1868 |
| **79** | 05,M,member5 | 05,M,37c | *Paleodictyon maximum* EICHWALD, 1868 |
| **80** | 04,F,2090B | 04,F,28b | *Paleodictyon miocenicum* SACCO, 1886 |
| **81** | 04,Ch.A,114-122G | 04,K,4g | *Paleodictyon strozzii* MENEGHINI, 1850 |
| **82** | 04,F,2200 | 04,F,32 | *Paleodictyon strozzii ,* MENEGHINI, 1850 |
| **83** | 04,F,2300 | 04,F,34 | *Paleodictyon strozzii* MENEGHINI, 1850 |
| **84** | 05,M,1406-39B | 05,M,19b | ?*Planolites* isp. |
| **85** | 05,M,1732 | 05,M,24b | ?*Planolites* isp. |
| **86** | 05,M,1772 | 05,M,24 | ?*Planolites* isp.? |
| **87** | 04,Ch.A,860.2 | 04,K,11 | ?*Planolites* isp.? |
| **88** | 05,D,110 | 05,D,12 | ?*Planolites* isp.? |
| **89** | 05,M,834-850B | 05,M,13b | ?*Planolites isp.?* |
| **90** | 05,M,690-700 | 05,M,10 | ?*Planolites* isp.? |
| **91** | 05,M,1435 | 05,M,21a | *Protovirgularia* cf. *dzulynskii* KSIAZKIEWICZ, 1977 |
| **92** | 04,M,^154 | 04,M,3a | *Protovirgularia dichotoma* MC COY, 1850 |
| **93** | 04,M,140 | 04,M,2a | *Protovirgularia dichotoma* MC COY, 1850 |
| **94** | 05,M,1010-1030 | 05,M,14a | *Protovirgularia dichotoma* MC COY, 1850 |
| **95** | 05,M,1010-1030 | 05,M,14b | *Protovirgularia dichotoma* MC COY, 1850 |
| **96** | 05,M,1406-39 | 05,M,19a | *Protovirgularia dichotoma* MC COY, 1850 |
| **97** | 05,M,m4b | 05,M,41 | *Protovirgularia dichotoma* MC COY, 1850 |
| **98** | 05,M,m4c | 05,M,42 | *Protovirgularia dichotoma* MC COY, 1850 |
| **99** | 05,M,1458 | 05,M,22a | *Protovirgularia rugosa* MILLER & DYER, 1878 |
| **100** | 04,Gh,1230 | 04,Gh,17 | *Rhizocorallium* isp. |
| **101** | 04,Ch.A,70.2-82 | 04,K,1a | *Scalarituba missouriensis* WELLER, 1899 |

| | | | |
|---|---|---|---|
| **102** | 04,Ch.A,83-93a | 04,K,2a | *Scalarituba missouriensis* WELLER, 1899 |
| **103** | 04,Ch.A,83-93b | 04,K,2b | *Scalarituba missouriensis* WELLER, 1899 |
| **104** | 04,Ch.A,114-122H | 04,K,4h | *Helminthorhaphe* isp. |
| **105** | 04,F,1836.5-41G | 04,F,20d | *Taenidium isp.* |
| **106** | 04,Gh,1285b | 04,Gh,18b | *Taenidium serpentinum* HEER, 1877 |
| **107** | 04,Gh,557 | 04,Gh,4a | *Taenidium satanassi* D'ALESSANDRO & BROMLEY, 1987 |
| **108** | 04, Ch.A, | 04, K, 16b | *Taenidium serpentinum* HEER, 1877 |
| **109** | 04,Ch.A,1180-1200a | 04,K,15a | *Thalassinoides* isp. |
| **110** | 05,M,690-708 | 05,M,11a | *Thalassinoides* isp. |
| **111** | 04,Ch.A,70.2-82b | 04,K,1b | *Thalassinoides suevicus* RIETH, 1932 |
| **112** | 04,F,1318-29C | 04,F,14c | *Thalassinoides suevicus* RIETH, 1932 |
| **113** | 05,D,112 | 05,D,13a | *Thalassinoides suevicus* RIETH, 1932 |
| **114** | 05,M,1915 | 05,M,25a | *Thalassinoides suevicus* RIETH, 1932 |
| **115** | 05,m,2160 | 05,M,29a | *Thalassinoides suevicus* RIETH, 1932 |
| **116** | 05,M,745 | 05,M,12a | *Thalassinoides suevicus* RIETH, 1932 |
| **117** | 05,M,834-850 | 05,M,13a | *Thalassinoides suevicus* RIETH, 1932 |
| **118** | 04,Gh,1100-1134 | 04,Gh,14 | *thalassinoides, Ophiomorpha?* |
| **119** | 04,F,west KhijB | 04,F,44 | *Zoophycos* isp. |
| **120** | 05,M,m5 | 05,M,45 | *Zoophycos* isp. |
| **121** | 04,Ch.A,1117-1130 | 04,K,12b | *Helminthopsis* isp. |

Table 2.2. List of thin-section specimens collected in the study area for petrographic analysis.

| Row | Field NO: | latitude | longitude |
|---|---|---|---|
| 1 | 04,Ch.A,49.8 | 35˚,54´,48˝ | 60˚,43´,25˝ |
| 2 | 04,Ch.A,70 | 35˚,54´,48˝ | 60˚,43´,25˝ |
| 3 | 04,Ch.A,82 | 35˚,54´,48˝ | 60˚,43´,25˝ |
| 4 | 04,Ch.A,155 | 35˚,54´,48˝ | 60˚,43´,25˝ |
| 5 | 04,Ch.A,187 | 35˚,54´,48˝ | 60˚,43´,25˝ |
| 6 | 04,Ch.A,554 | 35˚,54´,17˝ | 60˚,43´,18˝ |
| 7 | 04,Ch.A,738 | 35˚,54´,17˝ | 60˚,43´,18˝ |
| 8 | 04,Ch.A,899 | 35˚,54´,18˝ | 60˚,43´,01˝ |
| 9 | 04,Ch.A,1162 | 35˚,53´,59˝ | 60˚,43´,09˝ |
| 10 | 04,Ch.A,1223 | 35˚,53´,59˝ | 60˚,43´,09˝ |
| 11 | 04,Ch.A,1260 | 35˚,53´,59˝ | 60˚,43´,08˝ |
| 12 | 05,D,1 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 13 | 05,D,6 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 14 | 05,D,24 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 15 | 05,D,27 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 16 | 05,D,93 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 17 | 05,D,120.4 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 18 | 05,D,147 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 19 | 05,D,174 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 20 | 05,D,205 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 21 | 05,D,234 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 22 | 05,D,240 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 23 | 05,D,242 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 24 | 05,D,273.5 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 25 | 05,D,289 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 26 | 05,D,297 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 27 | 05,D,318 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 28 | 05,D,367.7 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 29 | 05,D,373 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 30 | 05,D,407 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 31 | 05,D,421 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 32 | 05,D,486 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 33 | 05,D,503 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 34 | 05,D,528 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 35 | 05,D,547 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 36 | 05,D,581 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 37 | 05,D,583 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 38 | 05,D,595 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 39 | 05,D,599 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 40 | 05,D,606 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 41 | 05,D,622 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 42 | 05,D,631.8 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 43 | 05,D,633a | 36˚,41,06˝ | 59˚,45´,45˝ |
| 44 | 05,D,633b | 36˚,41,06˝ | 59˚,45´,45˝ |
| 45 | 05,D,638 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 46 | 05,D,644 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 47 | 05,Db,71 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 48 | 05,Db,121.5 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 49 | 05,Db,136.8 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 50 | 05,Db,162 | 36˚,41,06˝ | 59˚,45´,45˝ |
| 51 | 04,F,56 | 36˚,28´,10˝ | 59˚,06´,07˝ |
| 52 | 04,F,141A | 36˚,28´,10˝ | 59˚,06´,07˝ |
| 53 | 04,F,141B | 36˚,28´,10˝ | 59˚,06´,07˝ |
| 54 | 04,F,141C | 36˚,28´,10˝ | 59˚,06´,07˝ |
| 55 | 04,F,332 | 36˚,28´,10˝ | 59˚,06´,07˝ |
| 56 | 04,F,586 | 36˚,28´,10˝ | 59˚,06´,07˝ |
| 57 | 04,F,836 | 36˚,29´,12˝ | 59˚,06´,17˝ |
| 58 | 04,F,1138 | 36˚,29´,12˝ | 59˚,06´,17˝ |
| 59 | 04,F,1320 | 36˚,29´,12˝ | 59˚,06´,17˝ |
| 60 | 04,F,1325 | 36˚,29´,12˝ | 59˚,06´,17˝ |
| 61 | 04,F,1332 | 36˚,29´,12˝ | 59˚,06´,17˝ |
| 62 | 04,F,1420 | 36˚,29´,05˝ | 59˚,04´,31˝ |
| 63 | 04,F,1833 | 36˚,31´,56˝ | 59˚,01´,41˝ |
| 64 | 04,F,1878 | 36˚,31´,56˝ | 59˚,01´,41˝ |
| 65 | 04,F,1930 | 36˚,32´,35˝ | 59˚,06´,17˝ |
| 66 | 04,F,1984 | 36˚,32´,35˝ | 59˚,06´,17˝ |
| 67 | 04,F,2092 | 36˚,32´,35˝ | 59˚,06´,17˝ |
| 68 | 04,F,2300 | 36˚,32´,35˝ | 59˚,06´,17˝ |
| 69 | 04,Gh,25 | 36˚,01´,21˝ | 60˚,43´,54˝ |

| Row | Field NO: | 36˚,41,06˝ | 59˚,45΄,45˝ |
|---|---|---|---|
| **70** | 04,Gh,213 | 36˚,01΄,31˝ | 60˚,43΄,51˝ |
| **71** | 04,Gh,221 | 36˚,01΄,31˝ | 60˚,43΄,51˝ |
| **72** | 04,Gh,237 | 36˚,01΄,31˝ | 60˚,43΄,51˝ |
| **73** | 04,Gh,345 | 36˚,01΄,51˝ | 60˚,43΄,48˝ |
| **74** | 04,Gh,448 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **75** | 04,Gh,502 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **76** | 04,Gh,503 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **77** | 04,Gh,505 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **78** | 04,Gh,545 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **79** | 04,Gh,572.5 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **80** | 04,Gh,575.5 | 36˚,01΄,59˝ | 60˚,43΄,39˝ |
| **81** | 04,Gh,598.4 | 36˚,02΄,03˝ | 60˚,43΄,51˝ |
| **82** | 04,Gh,610 | 36˚,02΄,03˝ | 60˚,43΄,51˝ |
| **83** | 04,Gh,643 | 36˚,02΄,03˝ | 60˚,43΄,51˝ |
| **84** | 04,Gh,726.5 | 36˚,02΄,24˝ | 60˚,44΄,00˝ |
| **85** | 04,Gh,744.5 | 36˚,02΄,24˝ | 60˚,44΄,00˝ |
| **86** | 04,Gh,819 | 36˚,02΄,24˝ | 60˚,44΄,00˝ |
| **87** | 04,Gh,939.5 | 36˚,02΄,46˝ | 60˚,43΄,59˝ |
| **88** | 04,Gh,989 | 36˚,02΄,46˝ | 60˚,43΄,59˝ |
| **89** | 04,Gh,1100 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **90** | 04,Gh,1128 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **91** | 04,Gh,1130 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **92** | 04,Gh,1134 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **93** | 04,Gh,1139 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **94** | 04,Gh,1200 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **95** | 04,Gh,1225 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **96** | 04,Gh,1228 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **97** | 04,Gh,1231 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **98** | 04,Gh,1275 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **99** | 04,Gh,1301 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **100** | 04,Gh,t1 | 36˚,01΄,21˝ | 60˚,43΄,54˝ |
| **101** | 04,Gh,t2 | 36˚,01΄,21˝ | 60˚,43΄,54˝ |
| **102** | 04,Gh,t4 | 36˚,01΄,21˝ | 60˚,43΄,54˝ |
| **103** | 04,Gh,t5 | 36˚,01΄,21˝ | 60˚,43΄,54˝ |
| **104** | 04,Gh,MZ1 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **105** | 04,Gh,MZ2 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |

| Row | Field NO: | latitude | longitude |
|---|---|---|---|
| **106** | 04,Gh,MZ3 | 36˚,03΄,05˝ | 60˚,44΄,12˝ |
| **107** | 04,Gh,38 | 36˚,01΄,21˝ | 60˚,43΄,54˝ |
| **108** | 05,M,710 | 36,15΄,50˝ | 60,09΄,41˝ |
| **109** | 05,M,782 | 36˚,15΄,52˝ | 60˚,09΄,50˝ |
| **110** | 05,M,797 | 36˚,15΄,52˝ | 60˚,09΄,50˝ |
| **111** | 05,M,834 | 36˚,15΄,52˝ | 60˚,09΄,55˝ |
| **112** | 05,M,872 | 36˚,15΄,52˝ | 60˚,09΄,55˝ |
| **113** | 05,M,897 | 36˚,15΄,53˝ | 60˚,10΄,01˝ |
| **114** | 05,M,914 | 36˚,15΄,53˝ | 60˚,10΄,01˝ |
| **115** | 05,M,973 | 36˚,15΄,55˝ | 60˚,10΄,01˝ |
| **116** | 05,M,1030 | 36˚,15΄,55˝ | 60˚,10΄,07˝ |
| **117** | 05,M,1057 | 36˚,15΄,59˝ | 60˚,10΄,07˝ |
| **118** | 05,M,1089 | 36˚,16΄,01˝ | 60˚,10΄,26˝ |
| **119** | 05,M,1160 | 36˚,16΄,03˝ | 60˚,10΄,29˝ |
| **120** | 05,M,1164 | 36˚,16΄,30˝ | 60˚,10΄,26˝ |
| **121** | 05,M,1201 | 36˚,16΄,34˝ | 60˚,10΄,25˝ |
| **122** | 05,M,1207 | 36˚,16΄,38˝ | 60˚,10΄,32˝ |
| **123** | 05,M,1245 | 36˚,16΄,38˝ | 60˚,10΄,32˝ |
| **124** | 05,M,1350 | 36˚,16΄,43˝ | 60˚,10΄,39˝ |
| **125** | 05,M,1362 | 36˚,16΄,43˝ | 60˚,10΄,39˝ |
| **126** | 05,M,1363 | 36˚,16΄,43˝ | 60˚,10΄,39˝ |
| **127** | 05,M,1364 | 36˚,16΄,43˝ | 60˚,10΄,39˝ |
| **128** | 05,M,1368 | 36˚,16΄,43˝ | 60˚,10΄,39˝ |
| **129** | 05,M,1460 | 36˚,16΄,46˝ | 60˚,10΄,43˝ |
| **130** | 05,M,1569 | 36˚,16΄,47˝ | 60˚,10΄,51˝ |
| **131** | 05,M,1595 | 36˚,16΄,51˝ | 60˚,10΄,52˝ |
| **132** | 05,M,1596 | 36˚,16΄,51˝ | 60˚,10΄,52˝ |
| **133** | 05,M,1766 | 36˚,17΄,03˝ | 60˚,10΄,59˝ |
| **134** | 05,M,1828 | 36˚,17΄,06˝ | 60˚,11΄,00˝ |
| **135** | 05,M,1854 | 36˚,17΄,08˝ | 60˚,11΄,01˝ |
| **136** | 05,M,1890 | 36˚,17΄,14˝ | 60˚,10΄,56˝ |
| **137** | 05,M,1952 | 36˚,17΄,15˝ | 60˚,10΄,58˝ |
| **138** | 05,M,2000 | 36˚,17΄,17˝ | 60˚,11΄,01˝ |
| **139** | 05,M,2043 | 36˚,17΄,17˝ | 60˚,11΄,01˝ |
| **140** | 05,M,2099 | 36˚,17΄,17˝ | 60˚,11΄,01˝ |
| **141** | 05,M,2321 | 36˚,17΄,20˝ | 60˚,11΄,18˝ |

| Row | Field NO: | latitude | longitude |
|---|---|---|---|
| **142** | 05,M,2328 | 36˚,17´,20˝ | 60˚,11´,18˝ |
| **143** | 05,M,2332 | 36˚,17´,20˝ | 60˚,11´,18˝ |
| **144** | 04,gh,T,Str.,1 | 36˚,01´,21˝ | 60˚,43´,54˝ |
| **145** | 04,gh,T,Str.,2 | 36˚,01´,21˝ | 60˚,43´,54˝ |
| **146** | 04,gh,T,Str.,3 | 36˚,01´,21˝ | 60˚,43´,54˝ |
| **147** | 04,Jiz,59 | 35˚,50´,00˝ | 60˚,09´,03˝ |
| **148** | 04,Jiz,185.2 | 35˚,50´,00˝ | 60˚,09´,03˝ |
| **149** | 04,Jiz,424 | 35˚,50´,00˝ | 60˚,09´,03˝ |
| **150** | 04,Jiz,428 | 35˚,50´,00˝ | 60˚,09´,03˝ |
| **151** | 04,M,B1 | 36˚,14´,49˝ | 60˚,09´,18˝ |
| **152** | 04,M,45 | 36˚,14´,49˝ | 60˚,09´,18˝ |
| **153** | 04,M,80 | 36˚,14´,49˝ | 60˚,09´,18˝ |
| **154** | 04,M,95 | 36˚,14´,49˝ | 60˚,09´,18˝ |
| **155** | 04,M,156 | 36˚,14´,57˝ | 60˚,09´,35˝ |
| **156** | 04,M,166 | 36˚,14´,57˝ | 60˚,09´,35˝ |
| **157** | 04,M,170 | 36˚,14´,57˝ | 60˚,09´,35˝ |
| **158** | 04,M,175 | 36˚,14´,57˝ | 60˚,09´,35˝ |
| **159** | 04,M,192 | 36˚,14´,57˝ | 60˚,09´,35˝ |
| **160** | 05,M,282 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **161** | 05,M,319 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **162** | 05,M,348 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **163** | 05,M,353 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **164** | 05,M,390 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **165** | 05,M,392 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **166** | 05,M,395 | 36˚,15´,34˝ | 60˚,09´,15˝ |
| **167** | 05,M,423 | 36˚,15´,35˝ | 60˚,09´,17˝ |
| **168** | 05,M,433.5 | 36˚,15´,35˝ | 60˚,09´,19˝ |
| **169** | 05,M,442 | 36˚,15´,35˝ | 60˚,09´,19˝ |
| **170** | 05,M,443 | 36˚,15´,35˝ | 60˚,09´,19˝ |
| **171** | 05,M,462 | 36˚,15´,41˝ | 60˚,09´,19˝ |
| **172** | 05,M,473 | 36˚,15´,41˝ | 60˚,09´,35˝ |
| **173** | 05,M,517 | 36˚,15´,40˝ | 60˚,09´,35˝ |
| **174** | 05,M,543 | 36˚,15´,40˝ | 60˚,09´,35˝ |
| **175** | 05,M,558 | 36˚,15´,40˝ | 60˚,09´,35˝ |
| **176** | 05,M,569 | 36˚,15´,40˝ | 60˚,09´,34˝ |
| **177** | 05,M,585 | 36˚,15´,49˝ | 60˚,09´,34˝ |
| **178** | 05,M,600 | 36˚,15´,49˝ | 60˚,09´,41˝ |
| **179** | 05,M,677 | 36˚,15´,50˝ | 60˚,09´,41˝ |
| **180** | 05,M,2628 | 36˚,17´,21˝ | 60˚,11´,18˝ |

# Chapter 3

## The Sections

**3.1 Tappenader-Jizabad composite section**

**3.2 Senjedak**

**3.3 Ghal-e-Sangi**

**3.4 Kol-e-Malekabad**

**3.5 Maiamay**

**3.6 Kuh-e-Radar**

**3.7 Danesh**

**3.8 Gas-pipeline**

**3.9 Fraizi**

**3.10 Torbat-e-Jam**

## 3. The Sections

In the course of the field work, several sections were found, which comprised all or a substantial part of the Kashafrud Formation and were not or only little tectonically disturbed. These sections depict different environments of the formation, ranging shallow to deep-marine and to alluvial-fluvial.

General information of the sections is presented in Table 1.1. The following account provides information on the sections and a brief review of the facies succession.

### 3.1. Tappenader-Jizabad composite section

The section was measured at two adjacent localities (Fig. 3.1). The lower part has been measured west of the abandoned village Tappenader, and from horizon 103.5 m onwards logging has been shifted towards the south-east, near the small village Jizabad (Fig. 3.2). There, an additional 428 m have been measured.

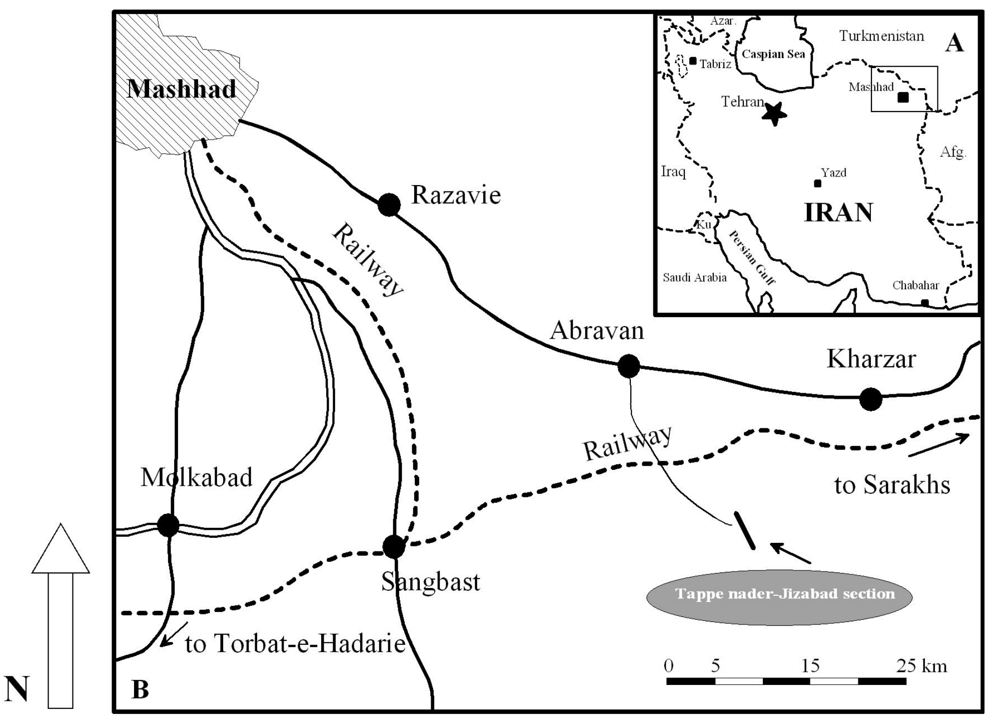



Fig. 3.1. **A:** Position of field area. **B:** Position of the Tappenader-Jizabad section. For details see Fig. 3.2.

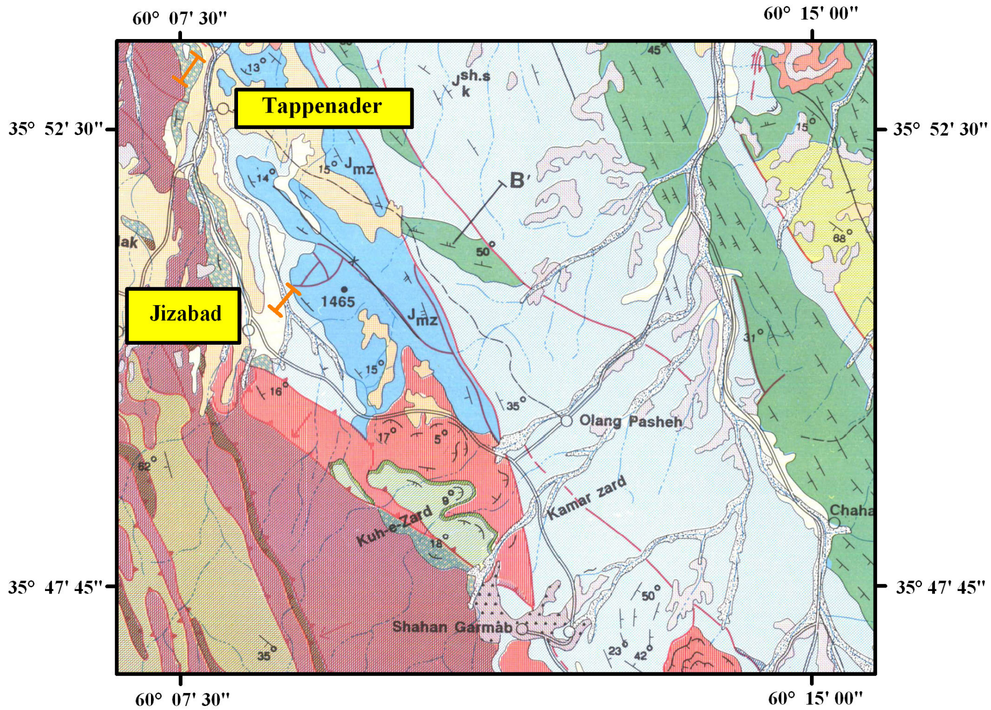



Fig. 3.2 Geological map of the Tappenader-Jizabad composite section at a scale of 1:100,000 (part of the Sefidsang sheet, GHAEMI 1999)

The Tappenader-Jizabad composite section has been divided into seven units (Fig. 3.3). The basal 5 m at Tappenader consist of a transgressive conglomerate (Figs. 3.4A-C). Pebbles are mostly ophiolites. They are sub-rounded, poorly sorted, and range from 2-30 cm. The conglomerate is followed by 8 m of green to dark-green, highly bioturbated, pebbly sandstones (unit 1; 0-19 m). At 15 m there is a 0.5 m thick bed of polymictic conglomerate, with pebble sizes from 1-5 cm, followed by about 4 m of brownish, massive bio-grainstone. From 19-61.5 m (unit 2) brown to light-brown, medium-bedded limestone and occasionally sandy limestone occur, which contain shells and wood fragments. Macrofossils include bivalves, gastropods, corals, belemnites, and ammonites.

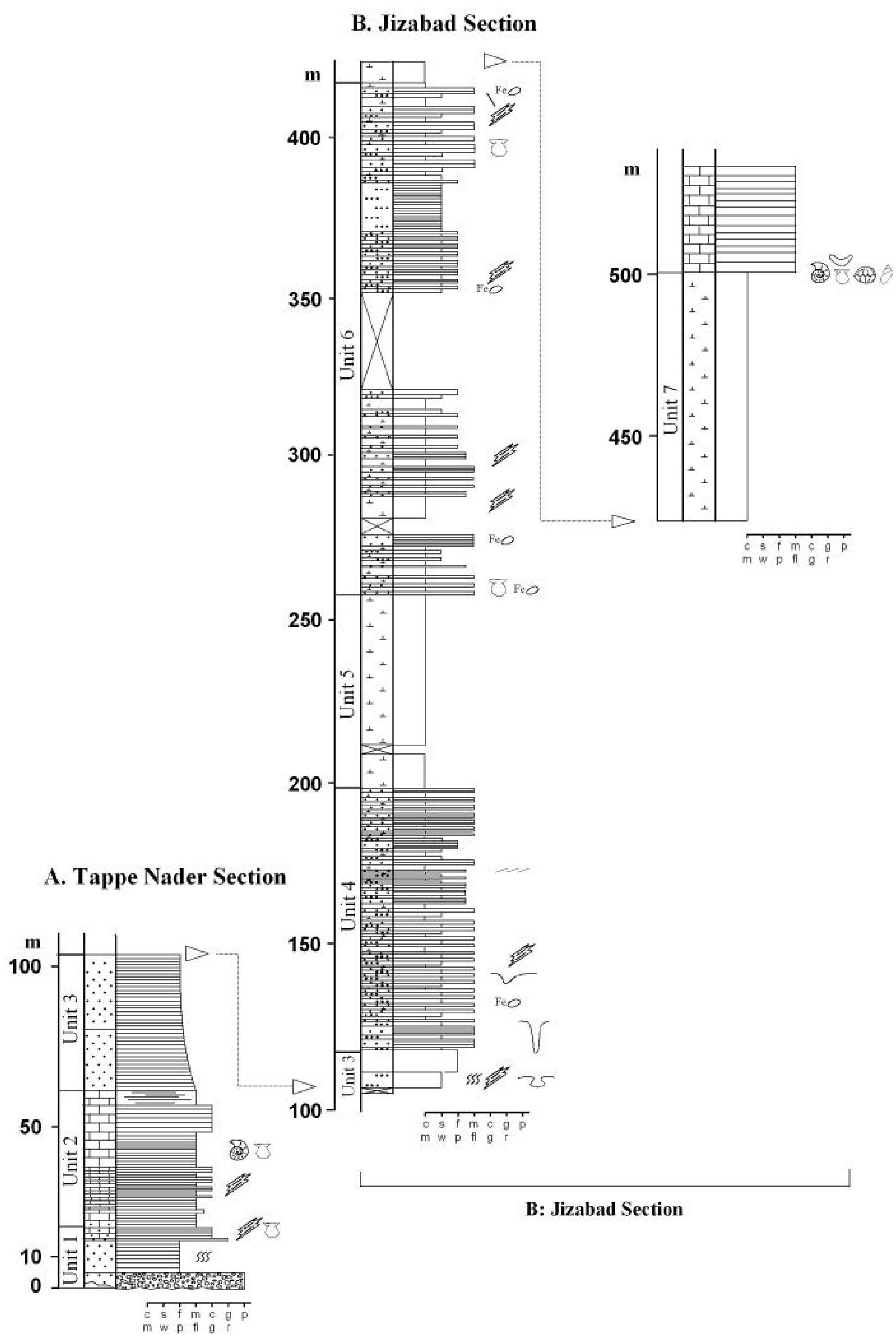



Fig. 3.3. Composite section of the Kashafrud Formation at Tappenader (A) and Jizabad (B). Key of symbols in Fig. 3.51.

The uppermost beds of this unit (57-61.5 m) are shaly in character. From horizon 61.5 m onwards sandstone beds start to appear, which fine upwards (unit 3). Finally, the succession in this area is covered by Quaternary soil and terraces (Fig. 3.3).

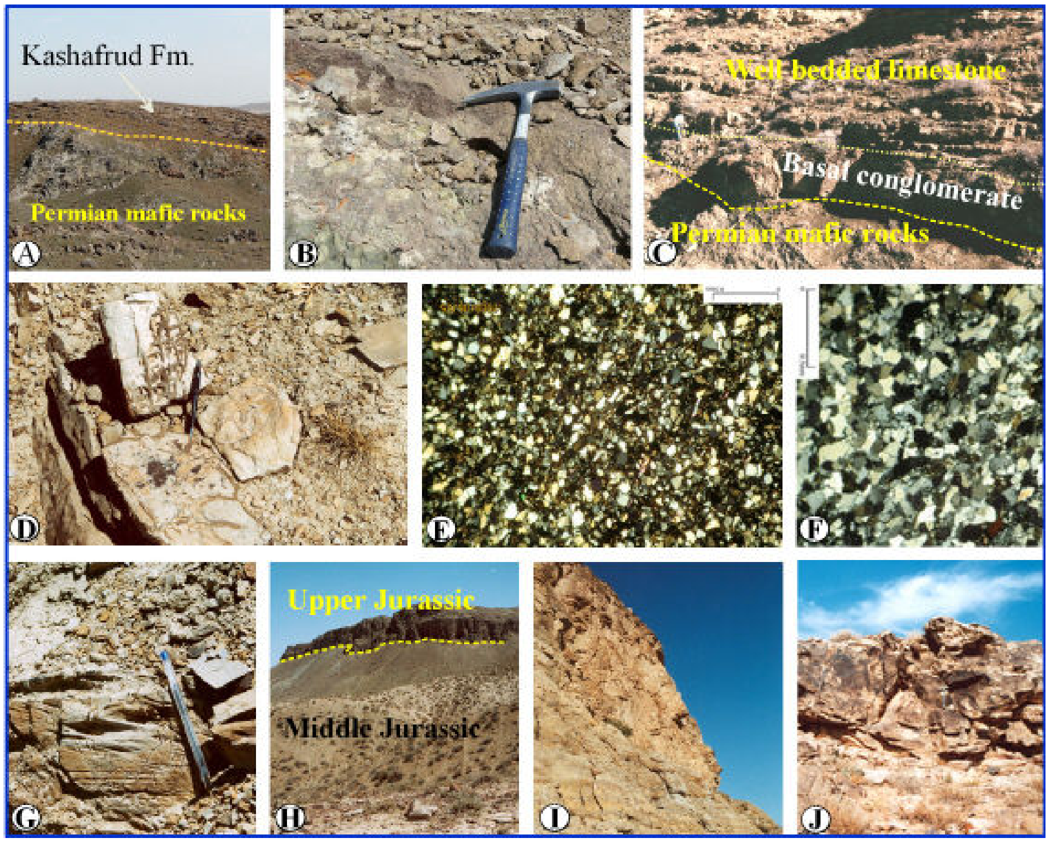



Fig. 3.4. Features of the Tappenader-Jizabad composite section. **A**. General view of the Kashafrud Formation overling Permian mafic rocks at Tappenader. **B**. Basal conglomerate; Tappenader area. **C**. Carbonate beds in the lowermost Tappenader section. **D**. Concentration of iron minerals; litharenite to sub-litharenite. **E**. Fine-grained, iron enreachment sandstone at horizon 60 m. **F**. Medium-grained sandstone at horizon 185 m.
**G**. Cross-laminated sandstone, member 1 of Jizabad section; length of pen 14.5 cm. **H**. Middle and upper part of the Kashafrud Formation and the Upper Jurassic cap in the Jizabad area. **I**. Thick to massive beds of Upper Jurassic limestone at Jizabad. **J**. Cross-bedded quartzarenite near the top of the Jizabad section.

The main feature of the Tappenader section is its calcareous nature in contrast to other localities, were carbonates are rare or absent (Fig. 3.3A). The succession continuous near the small village of Jizabad. Some meters of the succession may be missing, but the stratigraphic relationship between these two section segments is more or less correct, and documented by the trend of strata and stratigraphic situation which showed late Bathonian fossils in the uppermost part of the Kashafrud Formation there.

The Jizabad part of the composite section starts with an intercalation of thin- to medium-bedded sandstones and siltstones with plant debris, concretions and concentrations of iron minerals (Fig. 3.3D-F; unit 4). Sedimentary structures such as flute casts, load casts and small-scale cross-stratification are visible in this part of the section (Fig. 3.3G). Marl interbeds in this part are not conspicuous, but from 170 m onwards they increase up-section and at about 198 m (top of unit 4) marl prevails until 258 m (unit 5). From there onwards thin- to medium-bedded, fine-grained grayish sandstone and siltstone alternate with marl (unit 6: 258-433 m).

The last unit of the section (433-500 m) consists of marl (unit 7). The lower 22.5 m of this marl unit is olive in colour and the upper 45 m are dark-grey and include septarian nodules (Fig. 3.4H).

The Kashafrud Formation is here covered by crème-coloured, medium- to thick-bedded limestone (Fig. 3.4H-I) with a sharp base, rich in fossils (ammonites and bivalves). In general, the roundness and maturity of the litharenites in this section are higher and the amount of lithic fragments lower than in other sections (Fig. 3.4F). Ammonites give a Late Bathonian age for the top of the section (see also Chapter 4). They occur at the base of a thick to massive sandy oobiosparite which corresponds to the Lar/Mozduran Formation (Fig. 3.4 I). The Jurassic strata end with cross-bedded quartzarenites to quartz microconglomerates (Fig. 3.4J).

**Senjedak Section**

The Senjedak section was measured SE of Mashhad and NE of the small town Fariman (Fig. 3.6). The section has been studied for the first time by HOSSAINIUN (1996). She reported a thickness of about 1700 m and attributed the strata to the Upper Bajocian-Lower Bathonian time span.

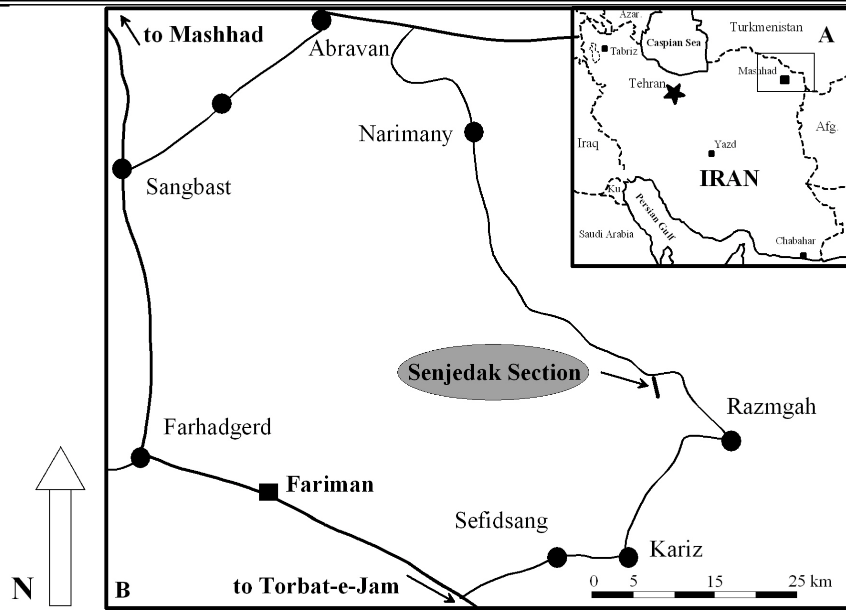



Fig. 3.6 **A**. Position of the field area. **B**. Position of the Senjedak section. For detail see Fig. 3.7.

Fig. 3.7 shows a geological map of the area. The Kashafrud Formation rests, with an obvious angular unconformity, on the Permian volcanic rocks and phyllites. The top of the formation is cut by thrust fault followed by reddish Cretaceous limestone (Fig. 3.8A).

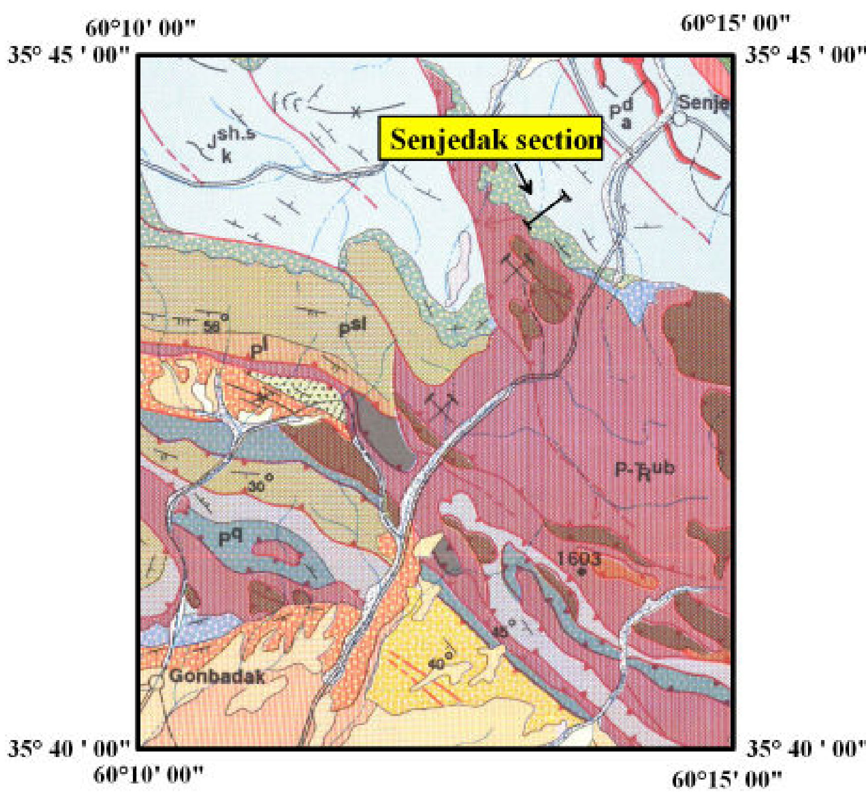



Fig. 3.7 Geological map of the Senjedak area at the scale of 1:100000 (from the Sefidsang sheet; GHAEMI 1999).

The basal conglomerate is rather thin, composed of moderately to well rounded, well sorted pebbles of dark limestone, mafic rocks, and andesitic volcanic rocks and cemented by carbonate. The size of pebbles ranges from 2-20 cm, but most of them are 5-10 cm in diameter (Fig. 3.8B). After this basal conglomerate rapidly fining-upward strata occur (Fig. 3.8D). They largly consist of olive to dark-green, monotonous siltstones (Fig. 3.8C). This feature can be traced also to some other localities, e.g., Kol-e-Malekabad and Ghal-e-Sangi. Only a part of the Kashafrud Formation, about 660 m, has been measured here. After the Maiamay section (see below), the Senjedak area is the region, in which the Kashafrud Formation is thickest and composed of sediments which represent deeper-water conditions than at other localities. In general, dark-grey to olive silty shale with thin interbeds of sandstone represent the bulk of this section (for more information see Fig. 3.9), although the amount of sandstone may vary. Ammonites indicative of the Upper Bajocian occur in the lower part of the succession. Bioturbation is moderate to high, but trace fossils are not well preserved.

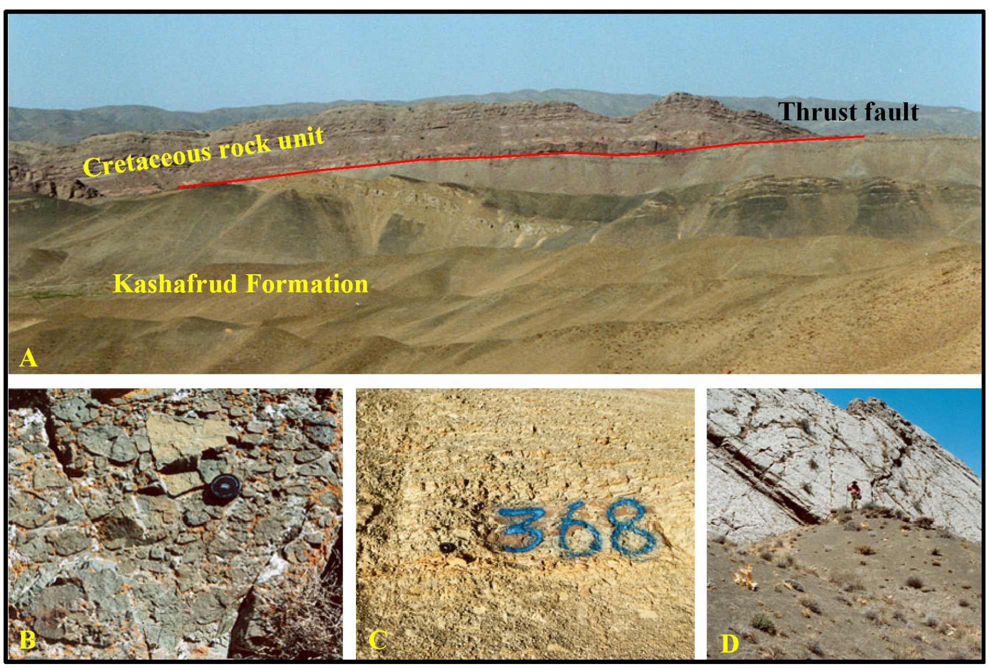



Fig. 3.8 Features of the Kashafrud Formation at Senjedak A. Thrust-faulted contact between the Kashafrud Formation and Cretaceous rocks. B. Basal conglomerate of the formation. Diameter of lens cap is 6 cm. C. Intercalation of sandy silt and fine-grained sandstone. D. Sudden change to fine-grained sediments in the lower part of the Formation.

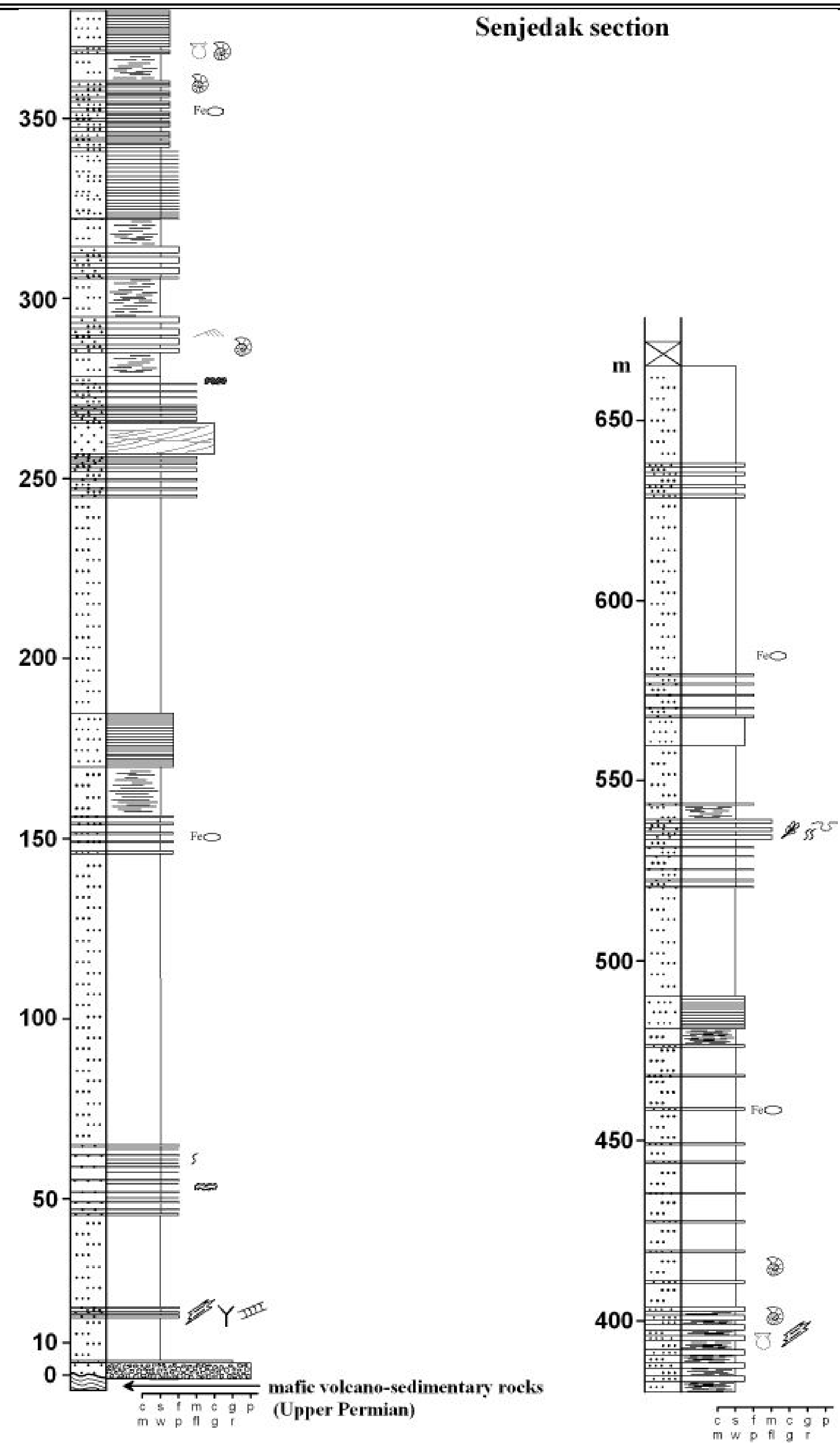



Fig. 3.9. Section through the lower part of the Kashafrud Formation in the Senjedak area. For key of the symbols see Fig. 3.51. →

**3.3 Ghal-e-Sangi Section**

This section was measured in the eastern part of the Koppe Dagh, near abandoned rock making (Sangi in Farsi) castle (Ghale in Farsi), north of the Aghdarband erosional window (Fig. 3.10).

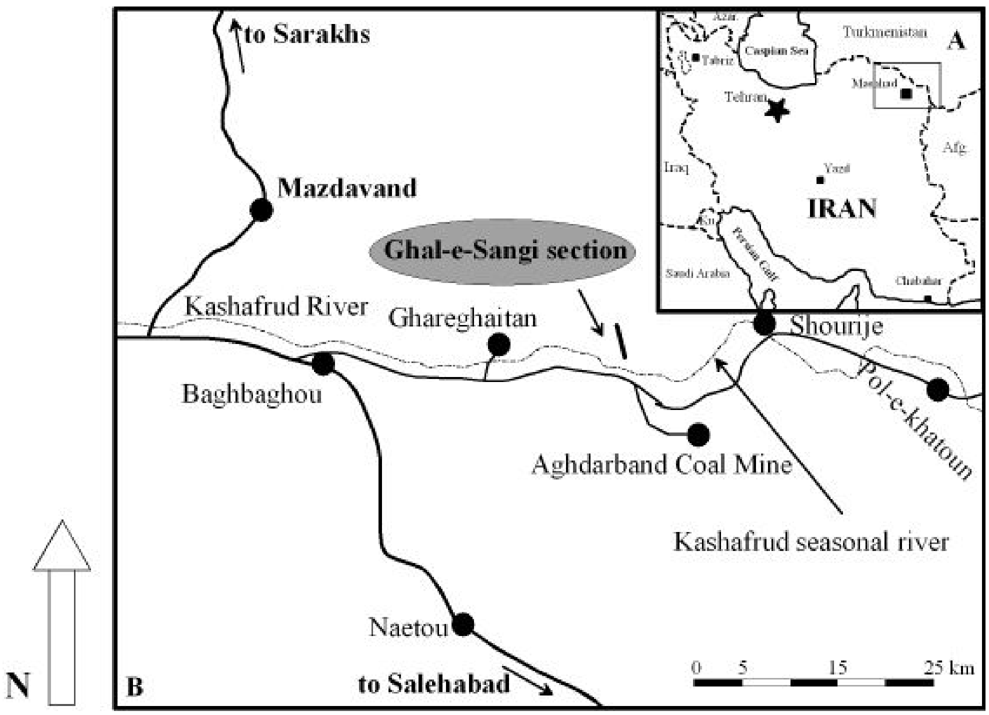



Fig. 3.10. Position of the study area (A) and locality of the Ghal-e-Sangi section (B).

At this locality, the Kashafrud Formation overlies the Triassic volcano-sedimentary Sina Formation (Late Ladinian; RUTTNER 1991, 1993) and is covered by the Mozduran Formation. The total thickness is 1309 m. Fig. 3.11 shows a geological map of the area. The Ghal-e-Sangi section has been divided into five informal members, based on lithology and vertical variation.

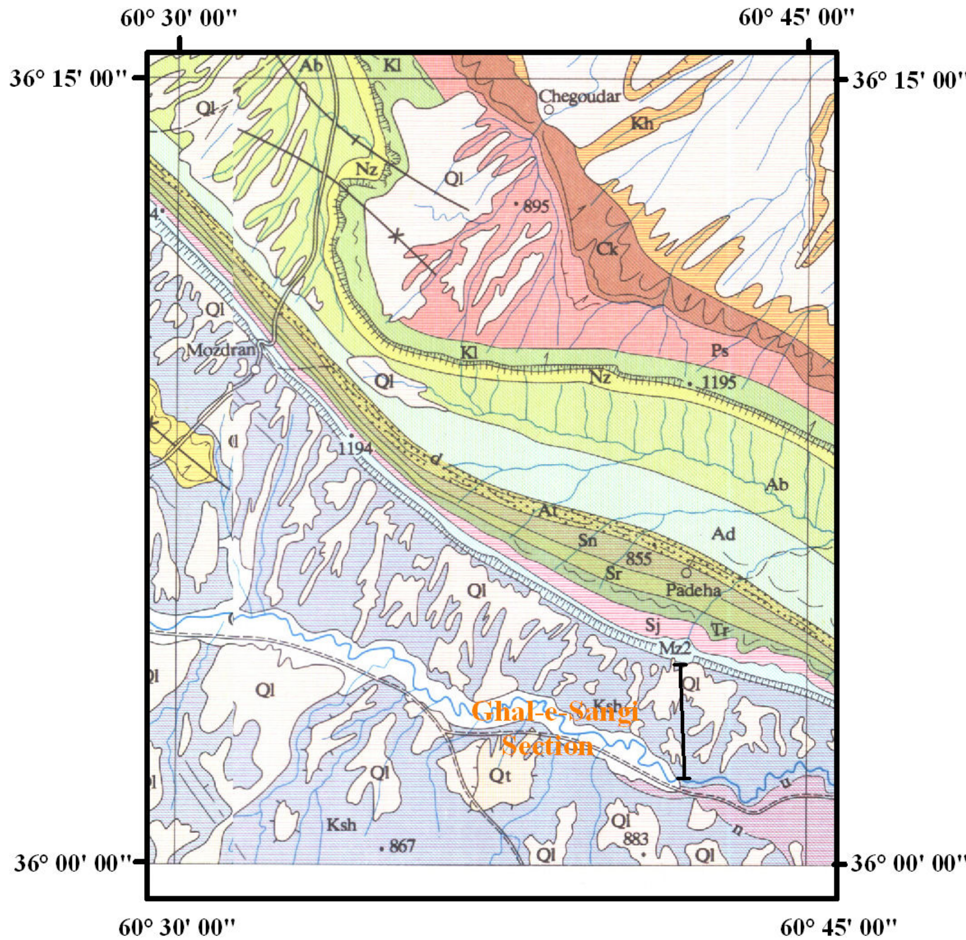



Fig. 3.11 Geological map of the Ghal-e-Sangi area at the scale of 1:250000 (part of the Sarakhs sheet; AFSHAR HARB 1983).

## Member 1 (0-86 m)

Member (1) starts with a basal conglomerate (24 m thick), which is polymictic, poorly cemented, well rounded, and poorly sorted (Fig.3.12A). Pebbles are mostly phyllite, metasandstone, components of Triassic Ghareghaitan conglomerate, altered diabas, volcanics especially tuff, and rarely quartz. They range from 5-15 cm in diameter (Fig. 3.12B).

The next lithofacies of member 1 are sandstone beds which are medium- to coarse-grained, immature to submature litharenites (Fig. 3.12C-D), although in some beds sandstones are rich in quartz grains and exhibit cross-stratification (at 68-69 m, Fig. 3.12E-F).

A microconglomerate to coarse-grained sandstone at 38 m is composed of lithic clasts such as chert, dacite, rhyodacite, granite, and trachyandesite, which point to mostly a volcanoplutonic source (Figs. 3.12C, 3.13). The top of the member at 86 m contains corals (Fig. 3.12G-H; for details see Chapter 4).

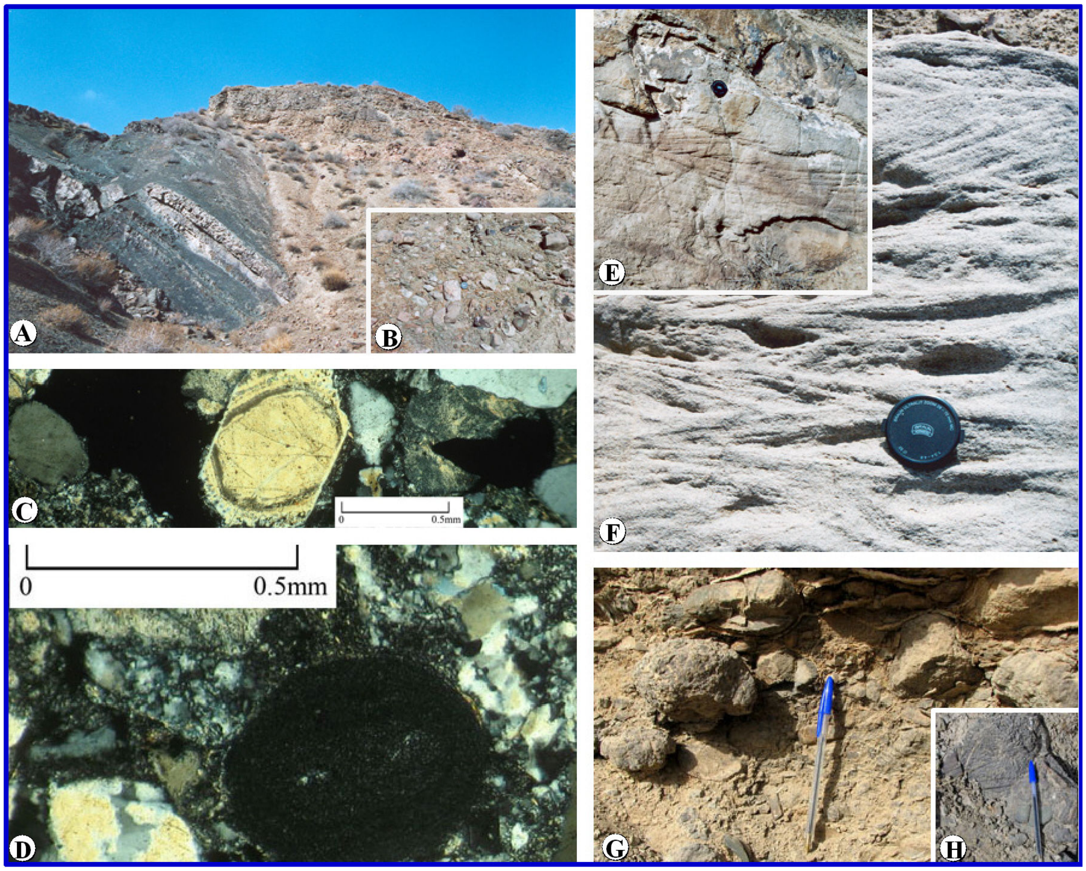



Fig. 3.12. Features of the Kashafrud Formation at Ghal-e-Sangi **A-B.** Basal conglomerate of member 1. **C.** Zonation of feldspar minerals. **D.** Thin-section of coarse-grained sandstone (member 1) at 38 m with chert, poly-crystalline quartz, and other lithoclasts. **E-F.** Quartz-rich cross-bedded sandstone of member 1. Diameter of lens cap is 6 cm. **G-H.** Coral-bearing bed at 86 m. Length of pen 17 cm.

### Member 2 (86-388 m)

The sudden change to a finer grain size observed near the base of the Senjedak section may correspond to base of member 2 (Fig. 3.13A-B). This part of the section consists mostly of dark green siltstone and, brownish mudstone, occasionally with thin interbeds of turbiditic, fine-grained, calcareous, rarely ferruginous, and immature to submature litharenite (Fig. 3.17A).

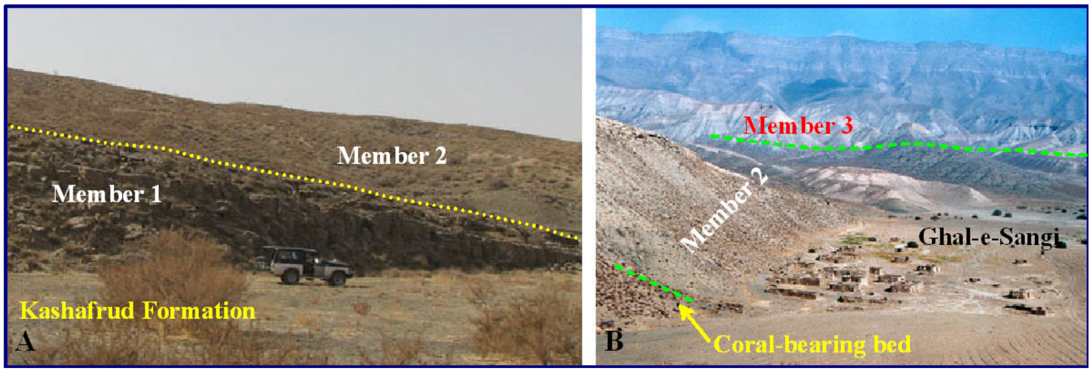



Fig. 3.13. **A.** Relatively sudden decrease in grain size between members (1) and (2), interpreted as deepening upwards; Ghal-e-Sangi section. **B.** Lower and middle parts of the Kashafrud Formation in the Ghal-e-Sangi area.

**Member 3 (388-745 m)**

From the end of member 2 towards the top of member 3 at 745 m the amount of sandstone increases. Storm beds are visible in this part of the section and bioturbation is more common (Fig. 3.15).

Sandstone beds are mostly fine- to medium-grained, calcareous to ferruginous, immature to submature litharenites (Fig. 3.17N), although occasionally sandy biosparite (at 448, 572.5, 598, 610, and 726.5 m; Figs. 3.17E-G), and rarely volcaniclastic-arenite (at 448 m, Fig. 3.17O) may occur. Shell fragments larger than 2 mm are also observed (Fig. 3.17G). Occasionally, beds are graded (e.g., at 744.5 m; Fig. 3.14), but its origin is related to tempestite processes rather than to turbiditic flows. Trace fossils are also more common than in previous members.

**Member 4 (745-970 m)**

Mudstones with yellowish nodules constitute the main lithofacies of member 4, although also some ripple-bedded, poorly cemented, fine-grained, calcareous sandstone beds occur, as do rare beds of sandy mudstone (e.g., at 819 m, Fig.3.17J). It seems that member 4 has formed in a deeper setting and lower energy conditions than member 3.

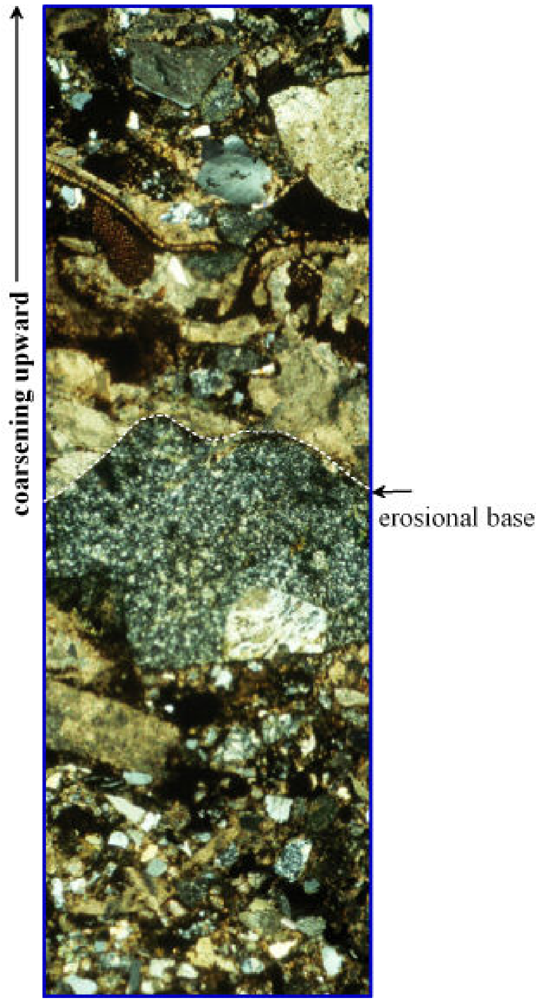



Fig.3.14. Graded storm bed, followed by coarse lag of another storm layer. At 744.5 m, Ghal-e-Sangi section.

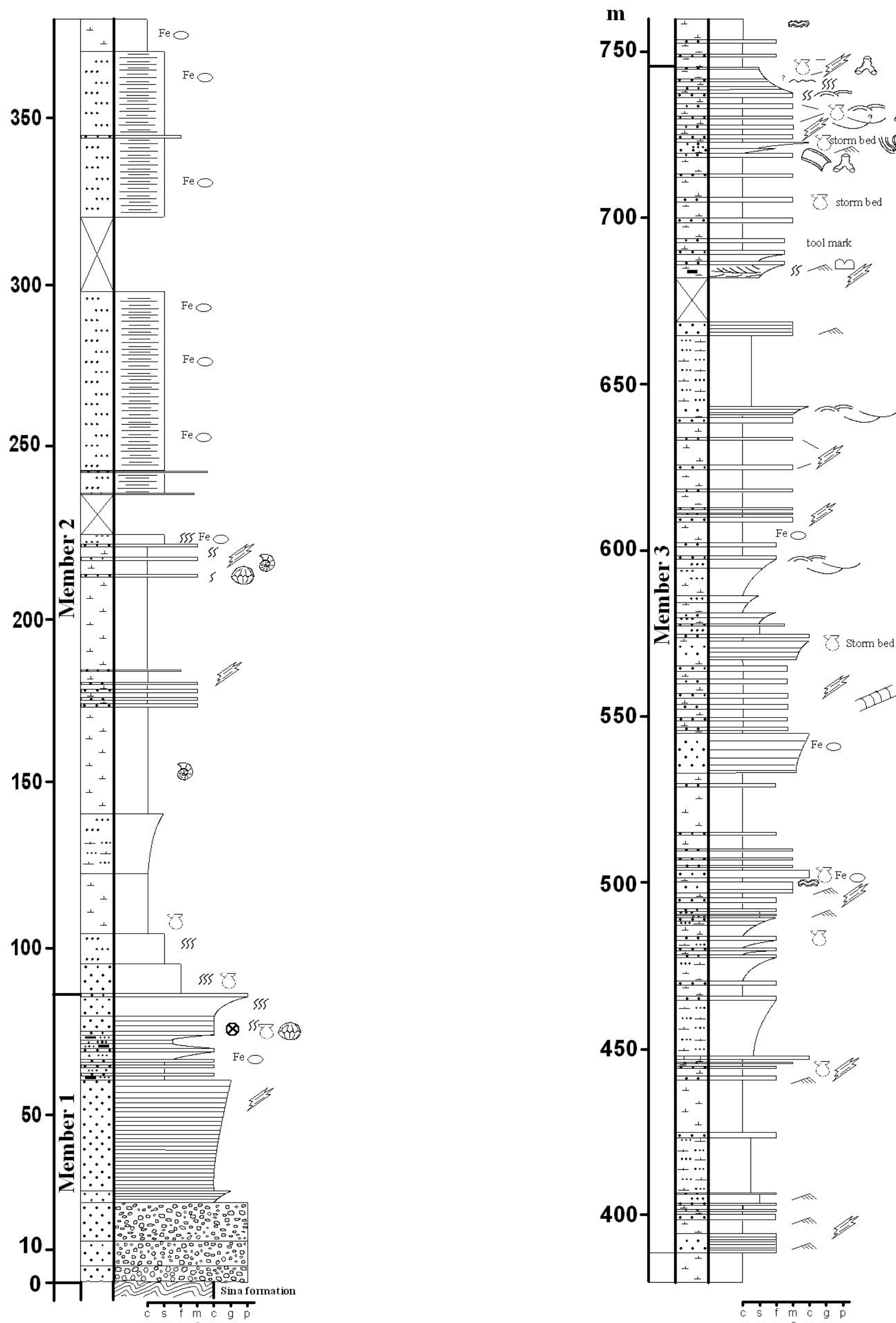



Fig. 3.15. Stratigraphic column of the Kashafrud Formation at Ghal-e-Sangi.
For key of symbols see Fig 3.51

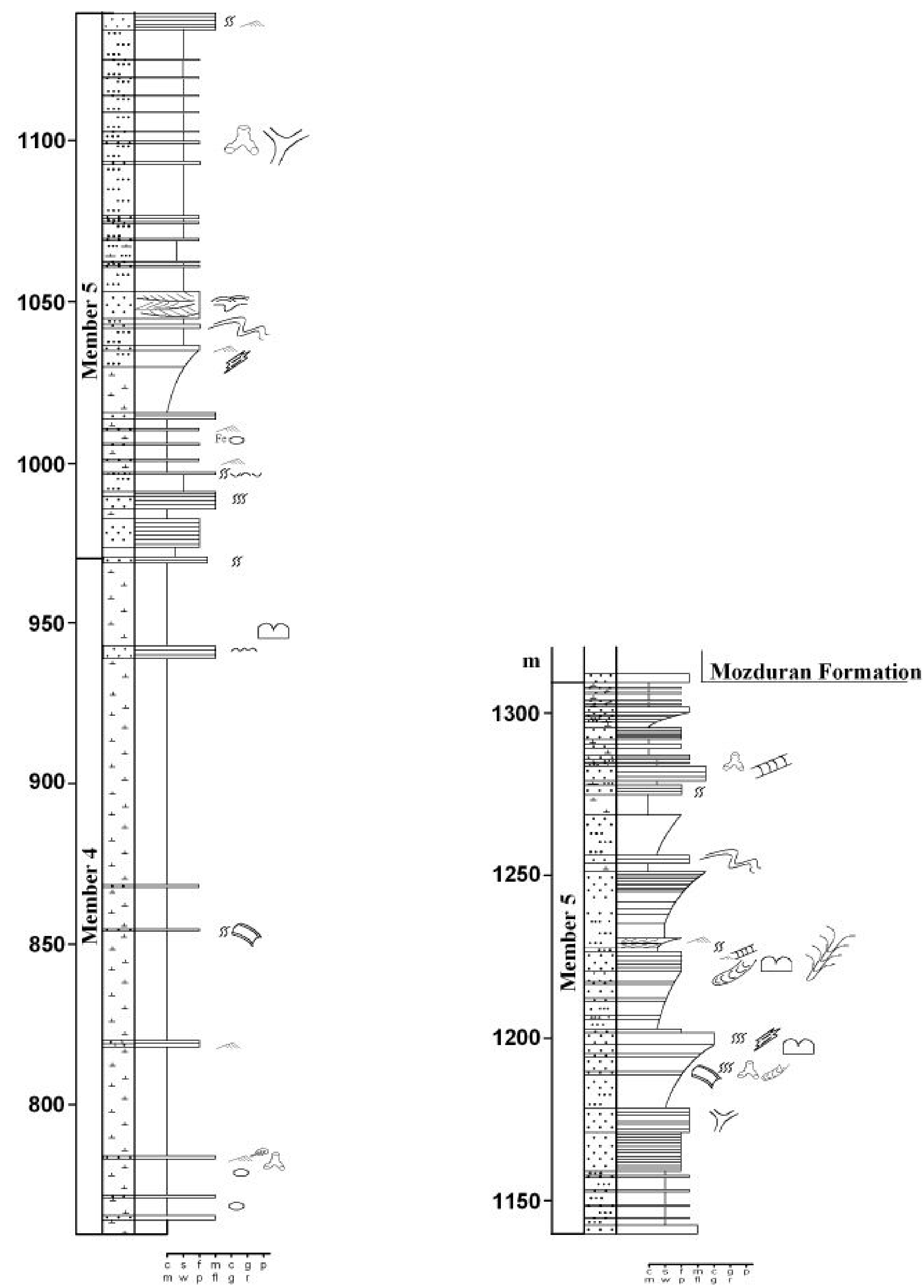

1100
1050
1000
950
900
850
800
Member 5
Member 4
Fe
c s f m c g p
m w p fl g r
m
Mozduran Formation
1300
1250
1200
1150
Member 5
c s f m c g p
m w p fl g r

Fig. 3.15 cont.

**Member 5 (970-1309 m)**

Member 5 extends up to the Mozduran Formation, which is not as calcareous as in the type section and its equivalents. In this member sandstone units again become more abundant (Fig. 3.16.A-B), but except in the uppermost part, the sandstone units are not as densely as packed in the third member. Coarsening- and thickening-upward sequences are developed, which correspond to progradational cycles. The sandstone beds are ferruginous, sandy biosparites to calcareous, sub-mature litharenites or lithic arkoses, in which the amount of feldspar grains occasionally increases upwards (e.g. at 1228 and 1230 m). This member is transitional to the Mozduran Formation (Fig. 3.14 and Fig. 3.17P).

Trace fossils mostly belong to the Skolithos and Cruziana ichnofacies, e.g. *Ophiomorpha*, *Curvolithus*, *Gyrochorte,* and *Thalassinoides*.

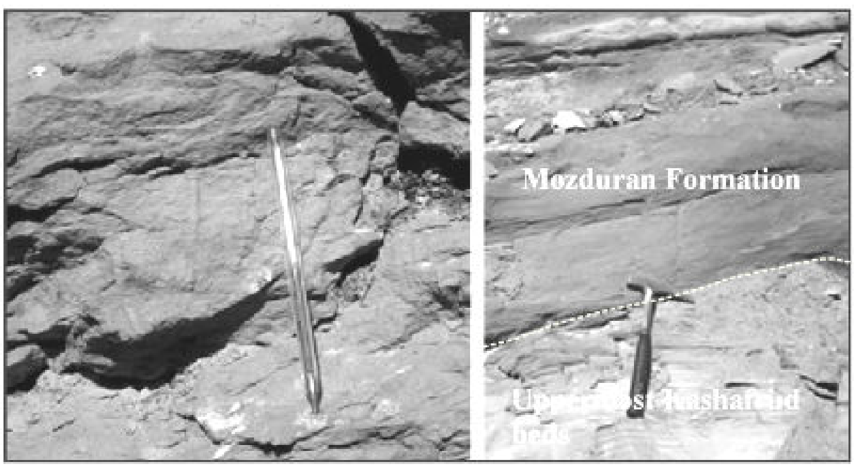
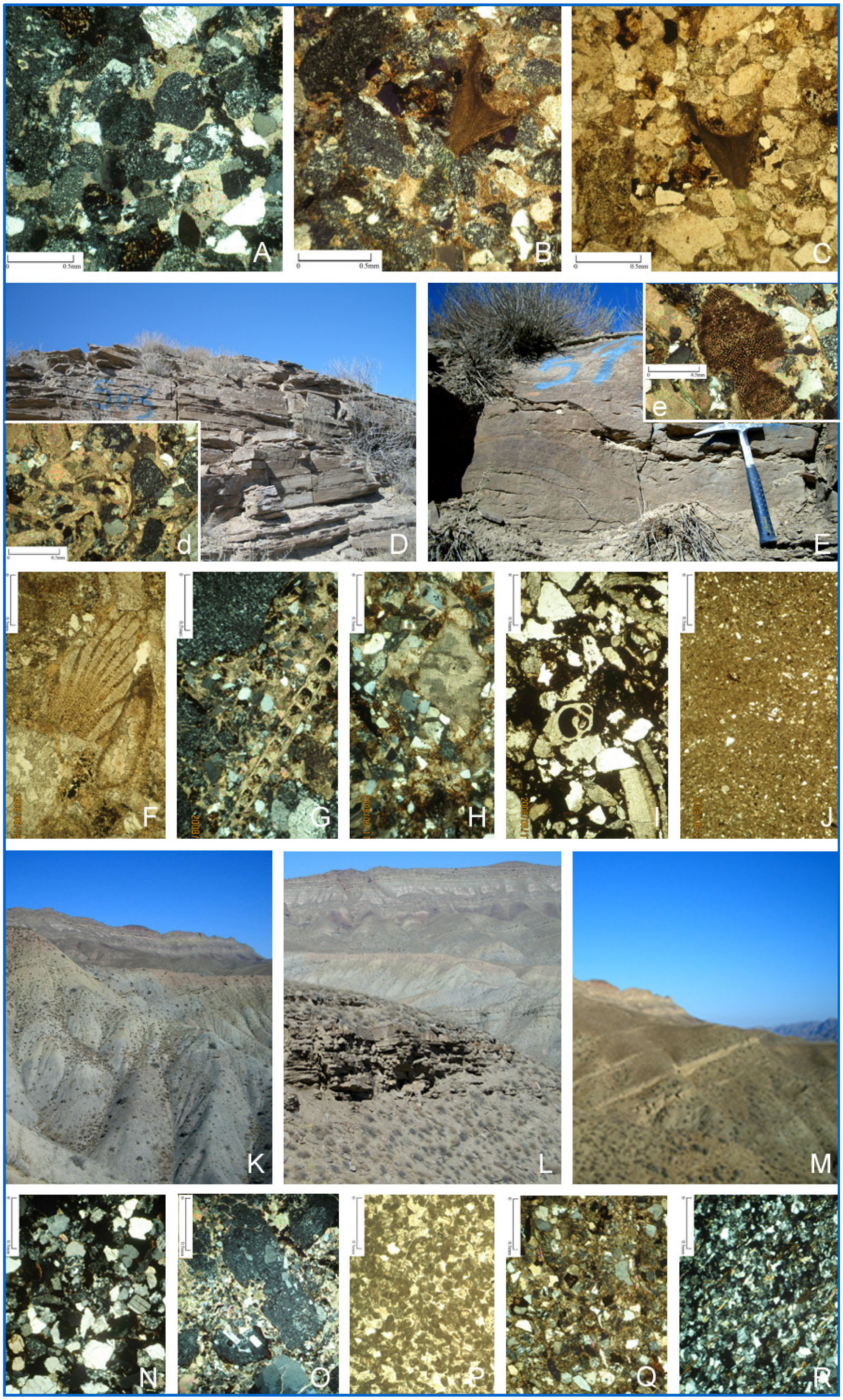



Fig. 3.16. *Ophiomorpha* isp. (**A**) and sandy limestone (**B**) in the uppermost Kashafrud or lowermost Mozduran Formation; Ghal-e-Sangi section at 1300 m. Length of pen 14.5 cm.

1. Fig. 3.17. Features of the Ghal-e-Sangi section. **A**: Calcareous, slightly ferruginous litharenite at 221 m. **B-C**. Thin section at 237 m with bioclasts; polarized and normal light, respectively. **D-d**. Sandstone beds around at 503 m with thin-section with relatively high amount of bioclasts (d), scale 0.5 mm. **E-e.** and also horizon 572.5 (e), scale 0.5 mm. **F-I:** Thin sections of sandy biosparite at 598 m (F), 448 m (G), 726 m (H), and 610 m (I), scales 0.5 mm. **J:** Sandy mudstone at 819m. **N:** Thin section of ine- to medium-grained litharenite at 1093 m, scale 0.5 mm. **O:** Thin section of volcaniciclastic arenite at 448 m, scale 0.3 mm. **P-Q:** Thin section of Feruginous litharenite at 1100 m, scale 0.5 mm. **R:** Thin section of litharenite from upper part of the section at 1223m. →


A
B
C
D
d
E
e
F
G
H
I
J
K
L
M
N
O
P
Q
R

### 3.4 Kol-e-Malekabad Section

This section was measured in the Cheshme Anjir area, which is located east of the small village Kol-e-Malekabad (Fig. 3.18). One of the most important aspects of this locality is the outcropping Darre Anjir Ophiolite (EFTEKHARNEZHAD & BEHROOZI, 1991, 1993; RUTTNER 1993).

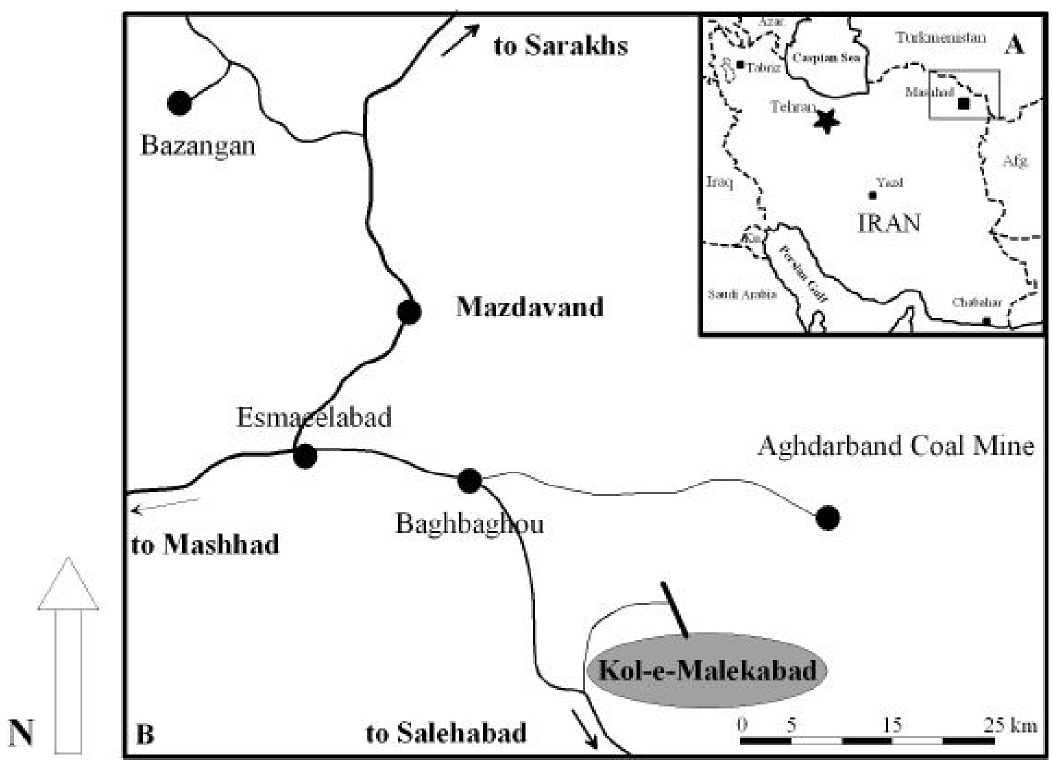



Fig. 3.18 Position of field area (A) and Locality of the **Kol-e-Malekabad** section (B).

In this area, the Kashafrud Formation overlies Triassic metasandstones and the Darre Anjir ophiolite, and in turn is overlain by dolomitic limestone of the Mozduran Formation (Figs. 3.19-3.20E-F). The total thickness is 1271 m. The Kol-e-Malekabad section has been subdivided into five informal members.

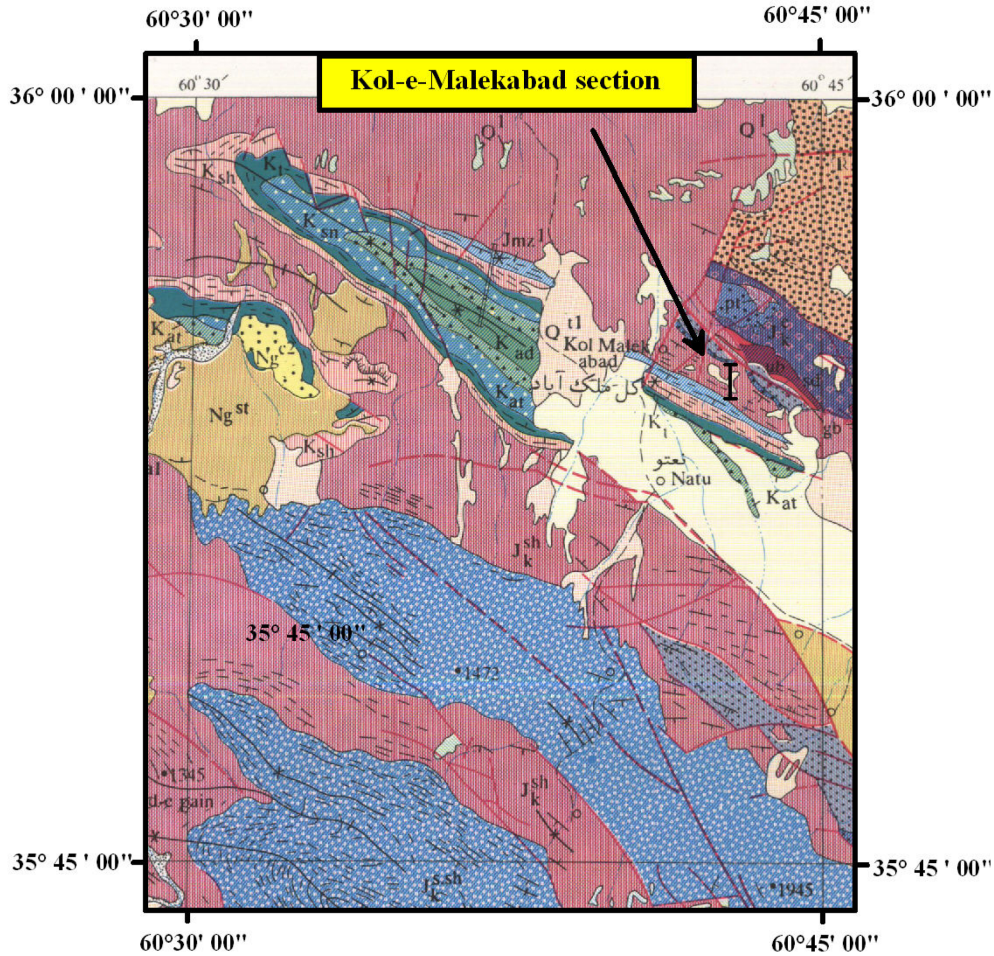



Fig. 3.19 Geological map of the Kol-e-Malekabad area at the scale of 1:250000 (part of the Torbat-e-Jam sheet; EFTEKHARNEZHAD & BEHROOZI 1993).

**Member 1 (0-50 m)**

The thickness of the basal conglomerate and coarse-grained sandstone beds is about 27 m, but the basal unit is composed of two conglomeratic units separated by an intercalation of brownish sandstone and olive siltstone. The next unit is a coarse-grained to gravelly sandstone with sharp erosional base which contains wood and shell fragments and exhibits low angle cross-stratification (Fig. 3.20 A, H).

**Member 2 (50-472 m)**

The deepening event, which can be observed throughout the basin, is recorded at the base of member 2 at 50 m. The member comprises olive to dark-green, calcareous siltstone and thin turbiditic fine-grained sandstone (Figs.3.20G, 3.23A). The sandstones are mostly calcareous-ferruginous, immature to submature litharenites. Rock fragments are mainly of volcanic, metamorphic or, rarely, of chert origin (Fig. 3.20 B, D). The volcanic rock fragments are comparable those of the Ghal-e-Sangi area and are composed of andesite, trachy-andesite to trachyte and quartz-andesite.

Bioturbation is quite common. Compared to the Ghal-e-Sangi section, the trace fossil assemblage indicates a greater water depth than in the Kol-e-Malekabad area. Characteristic ichnofauna include *Nereites missouriensis*, *Lophoctenium richteri*, *Planolites*, *Helminthopsis*, and *Neonereites multiserialis.*

Wood debris is also found at several horizons (Fig. 3.22). The bivalve *Bositra* and ammonite debris occur in this unit, especially in the nodules. In general, the monotonous silt succession and the trace fossils suggest that the deepest part of the sedimentary basin along this succession was at this level. The water depth may have reached about 1000 m or more.

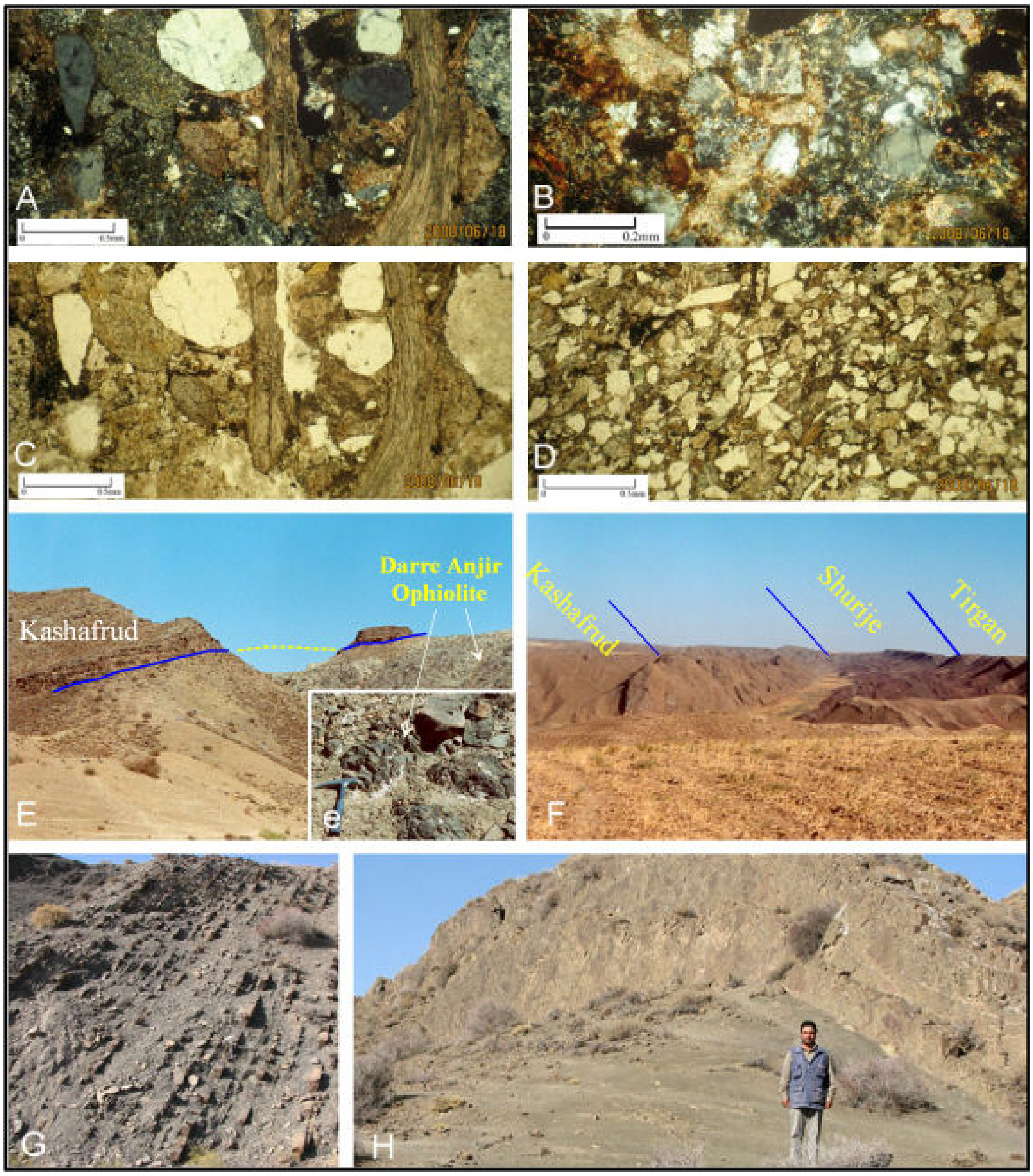



Fig. 3.20. Features of the Kol-e-Malekabad section. **A, C**: Litharenite with bioclasts from top of member 1, under polarized light. **B**. Altered feldspar grains now replaced by carbonate in member 2, A in polarized light. **D**. Ferruginous, angular, fine-grained litharenite, member 2, x63; **E-e**. Basal conglomerate overlying Darre Anjir ophiolites. **F**. Top of the Kashafrud Formation and overlying units in the Kol-e-Malekabad area **G**. Classic turbidite succession in the lower part of member 2 **H**. Sudden decrease in grain size at the base of member 2.

## Member 3 (472-988 m)

Member (3) is sandier than member (2) and, based on sedimentary structures such as hummocky cross-stratification (HCS) and on trace fossils, has been deposited under shallower conditions. However, as there are slumping units and channels (Fig. 3.23D) it may at least partly correspond to outer shelf/ upper slope environments. Numerous parasequences are developed in this part of the section (Fig. 3.23B-C). Bioturbation affected the tops of most sandstone beds, and where the rate of sedimentation was low this process also affected thicker parts of sandstone beds. *Ophiomorpha* and *Thalassinoides* occur in this unit (Fig. 3.21A, B). Wood fragments are relatively common.

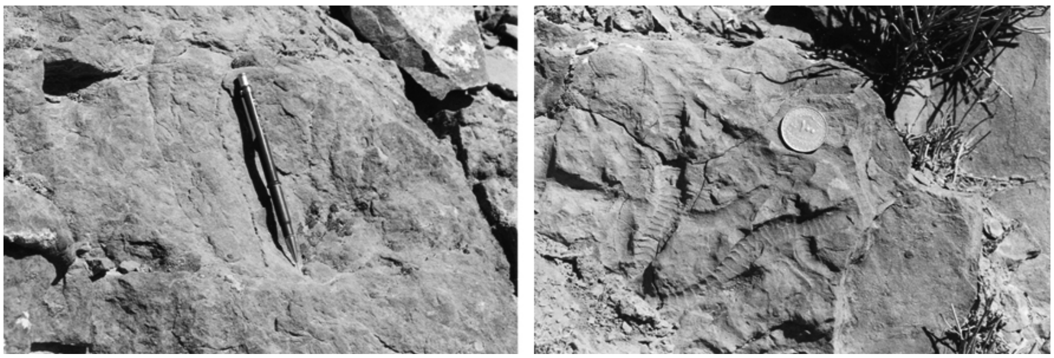


Fig. 3.21. Trace fossils in member (3) of the Kashafrud Formation at Kol-e-Malekabad A. *Ophiomorpha* isp. Length of pencil 14 cm. B. *Taenidium* isp. Diameter of coin 2.8 cm.

**Member 4 (988-1134 m)**

In this part of the section fine-grained sediment prevailed in the basin. The main feature of the lithofacies is dark-grey to greenish siltstone with thin interbeds of fine-grained sandstone (Fig. 3.22F), although some thick, structureless, medium-grained sandstone beds also occur. Bioturbation is moderate.

**Kol-e-Malekabad section**

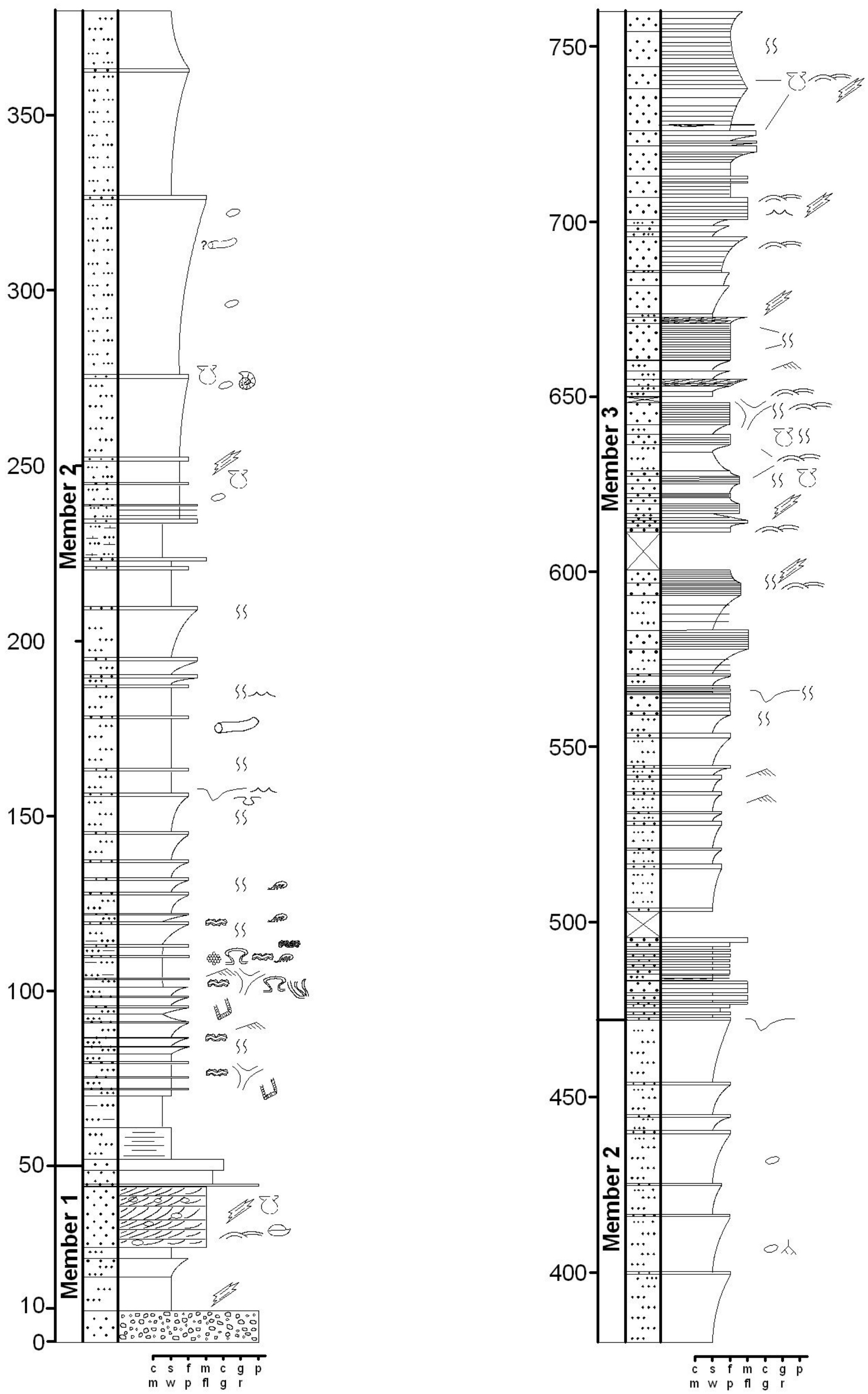



Fig. 3.22. Stratigraphic log of the Kol-e-Malekabad section. For key of symbols see Fig. 3.51

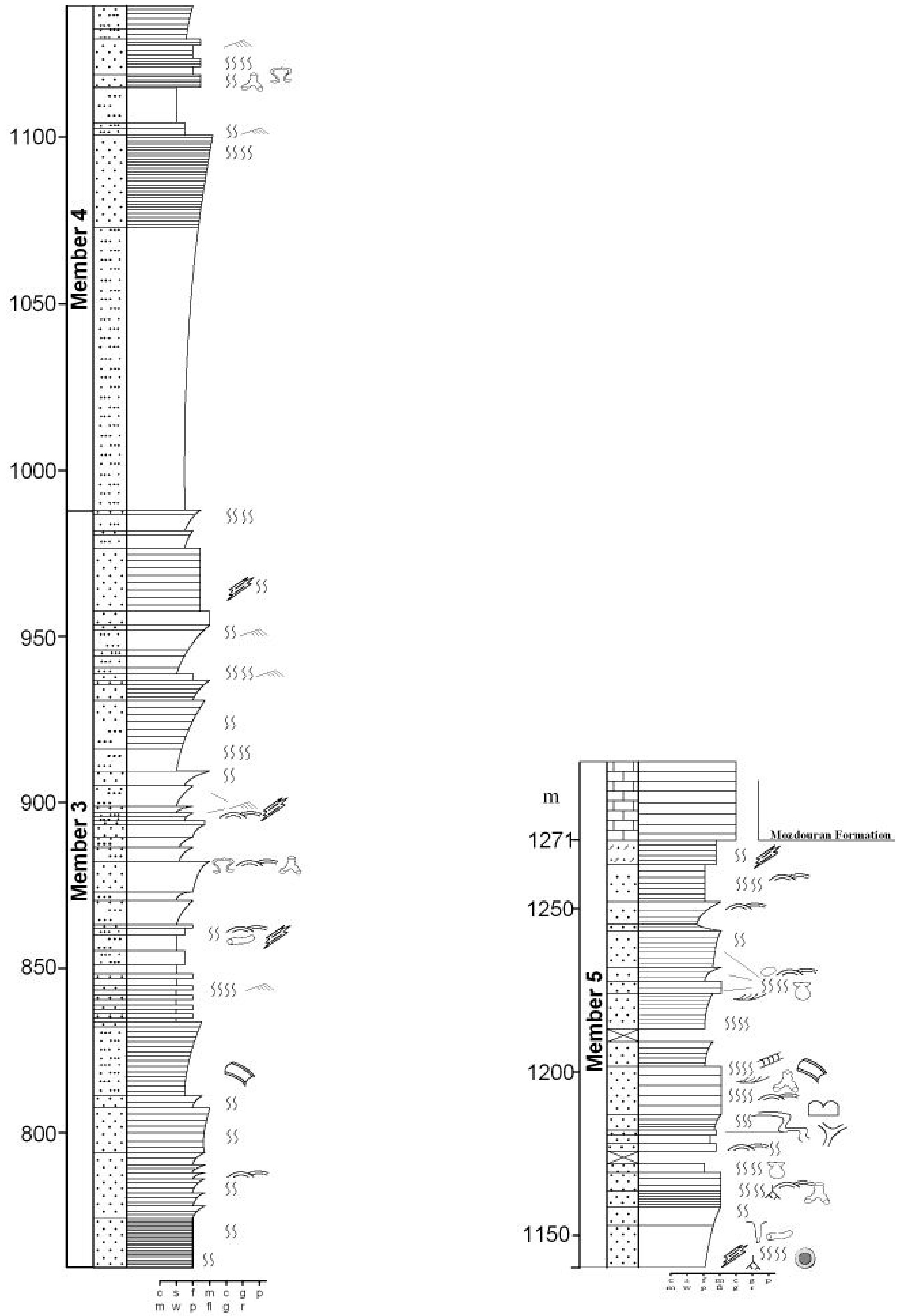
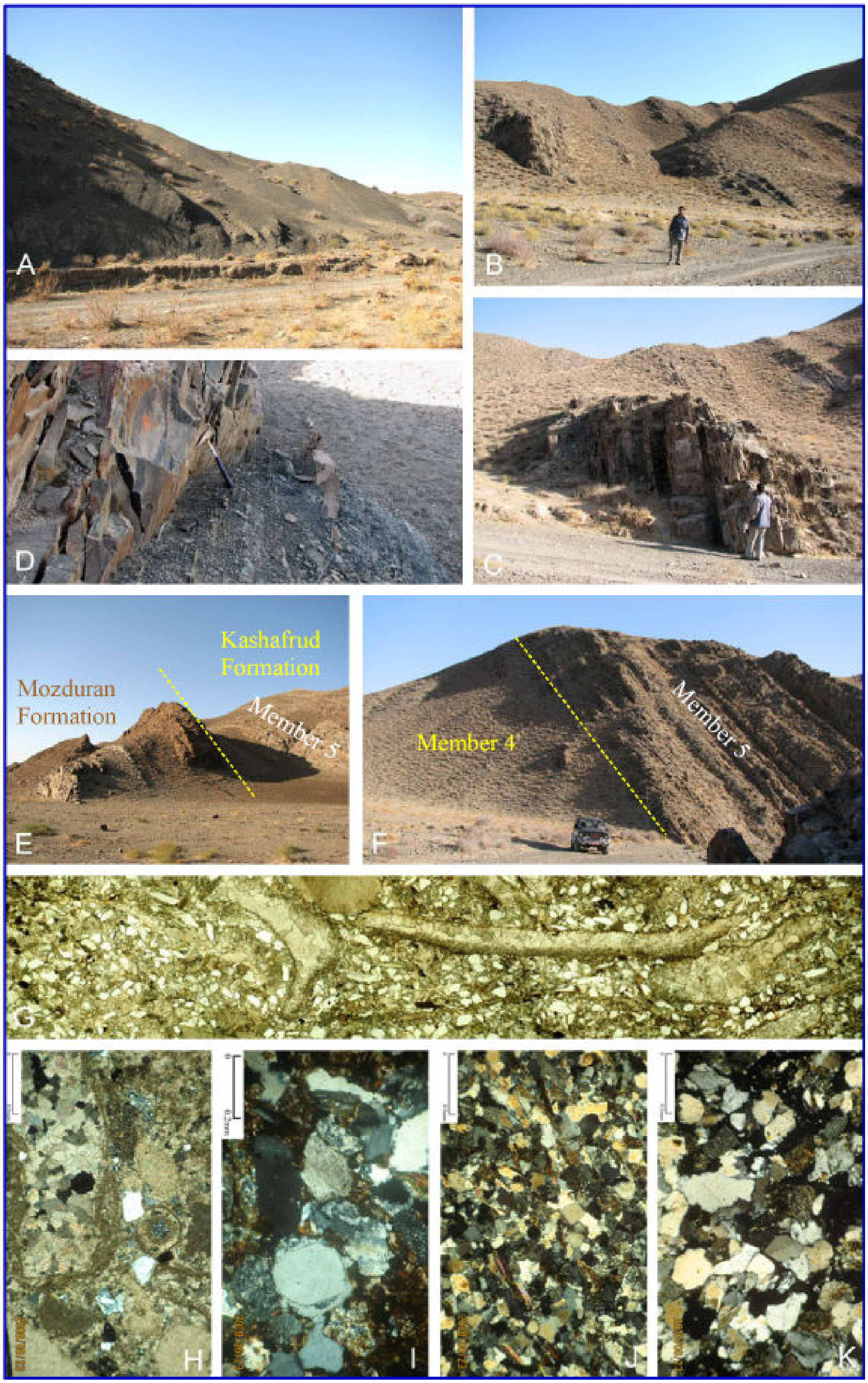

1100
1050
1000
950
900
850
800
Member 4
Member 3
c s f m c g p
m w p fl g r
m
1271
1250
1200
1150
Member 5
Mozdouran Formation

Fig. 3.22. Cont.

**Member 5 (1134-1271 m)**

Member (5) is again sandier, and bioturbation is more pronounced than in the previous member. Sandstone beds range from fine-grained, immature lithic arkoses to medium-grained, calcareous-ferruginous, immature to sub-mature, arkosic litharenites. This member grades into sandy dolomite and sandy limestone of the Mozduran Formation (Fig. 3.22E).

Fig. 3.23. Features of the Kashafrud Formation of the Kol-e-Malekabad section. A. Monotonous, olive siltstone of member 2. B, C. Parasequences in member (3). D. Erosional channel sandstone with sharp base. Hammer for scale. E. Relationship between the uppermost Kashafrud Formation and the overlying Mozduran Formation F. Members 4 and 5. G-I. Thin-section photographs of sandstones from member 4 at 738 (G), 899.5 (H), and 1130 m (D), respectively. J-K. Thin-section photographs of sandstones of member (5) at 1200 and 1301 m, respectively.→


A
B
D
C
Kashafrud Formation
Mozduran Formation
Member 5
E
Member 4
Member 5
F
G
H
I
J
K

### 3.5 Maiamay Section

The Maiamay area is located approximately 55 km NE of Mashhad (Fig. 3.24), between the Kuh-e-Radar section of deltaic origin in the south and the deep basinal succession of the Gas-pipeline locality in the north. The lower part of the succession is covered by fluvial terraces and the uppermost part of the section is faulted and folded (Fig. 3.25). As the several 1000 m thick succession is important for understanding the palaeogeography, the section was measured in a less tectonized direction.

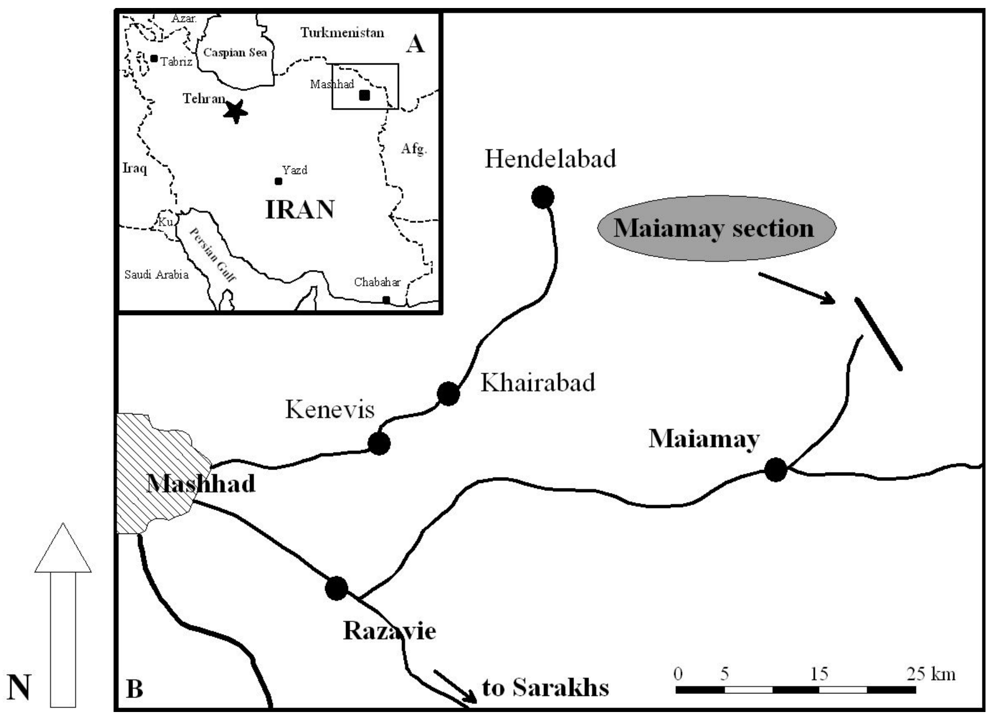



Fig. 3.24. Position of field area (A) and the locality of the Maiamay section (B).

At this locality, the Kashafrud Formation exhibits the greatest thickness within the study area and has been subdivided into seven informal members (Fig 3.29).

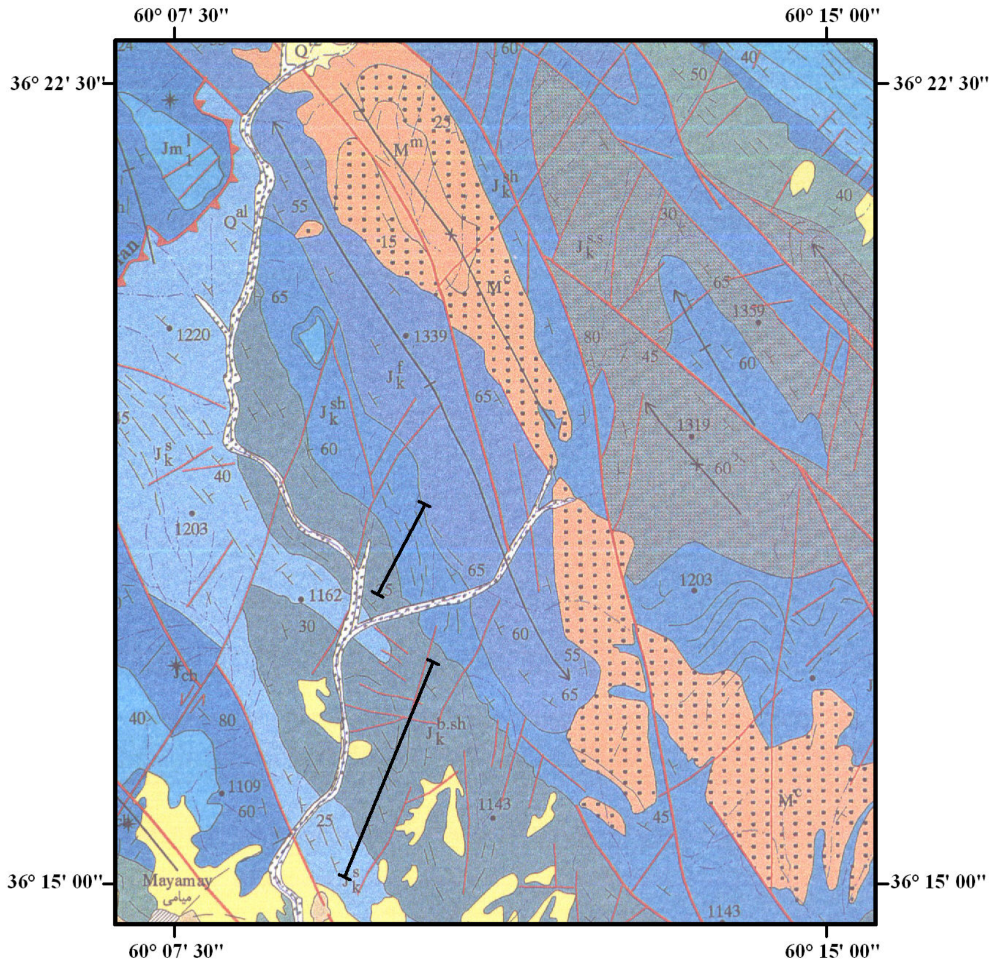



Fig. 3.25 Geological map of the Maiamay area at the scale of 1:100000 (part of the Bazangan sheet; ROWSHANRAVAN, 2006).

**Member 1 (0-158 m)**

The first member recognized in the Maiamay section comprises of black siltstone and fine-grained sandstone (Fig.3.27A), with sedimentary structures such as flute casts, and load casts, and a trace fossil fauna (e.g., *Nereites irregularis, Helminthorhaphe crassa, ?Neonereites multiserialis*) that indicates relatively deep waters.

In the upper part of the member, around 38 m, the sandstones exhibit well developed graded bedding, which seems to be related partly to proximal and partly to distal turbiditic flows (Fig. 3.27C).

Although the relationship of these strata to the lowermost units is not seen due to faulting and a cover of young terraces, a regional correlation allows comparing this unit to the similar succession in the second members of other localities, which represent deeper water conditions after the basal conglomeratic and coarse-grained sandstone units. This conclusion is supported by two facts: First, by the coarse-grained sandstone units which crop out south of the small village Maiamay and, secondly, by isolated calcareous sandstone beds with ooids, which occur at a level below the measured section (Fig. 3.27C)

**Member 2 (158-570 m)**

The second member consists of medium- to thick-bedded, fine- to medium-grained, occasionally ferruginous and rarely calcareous, immature to sub-mature litharenites, which occasionally turned into arkosic litharenites. Sandstone beds show well developed channel structures (Fig. 3.27D-E) which cut each other (for more details see Chapter 5). In general, this part of the section is poor in trace fossils. Thickening- and coarsening-upward packages are visible toward the top of this member. The uppermost portion of the member is relatively fine-grained and well bedded, and the bedding surfaces are fairly planar (Fig. 3.27F).

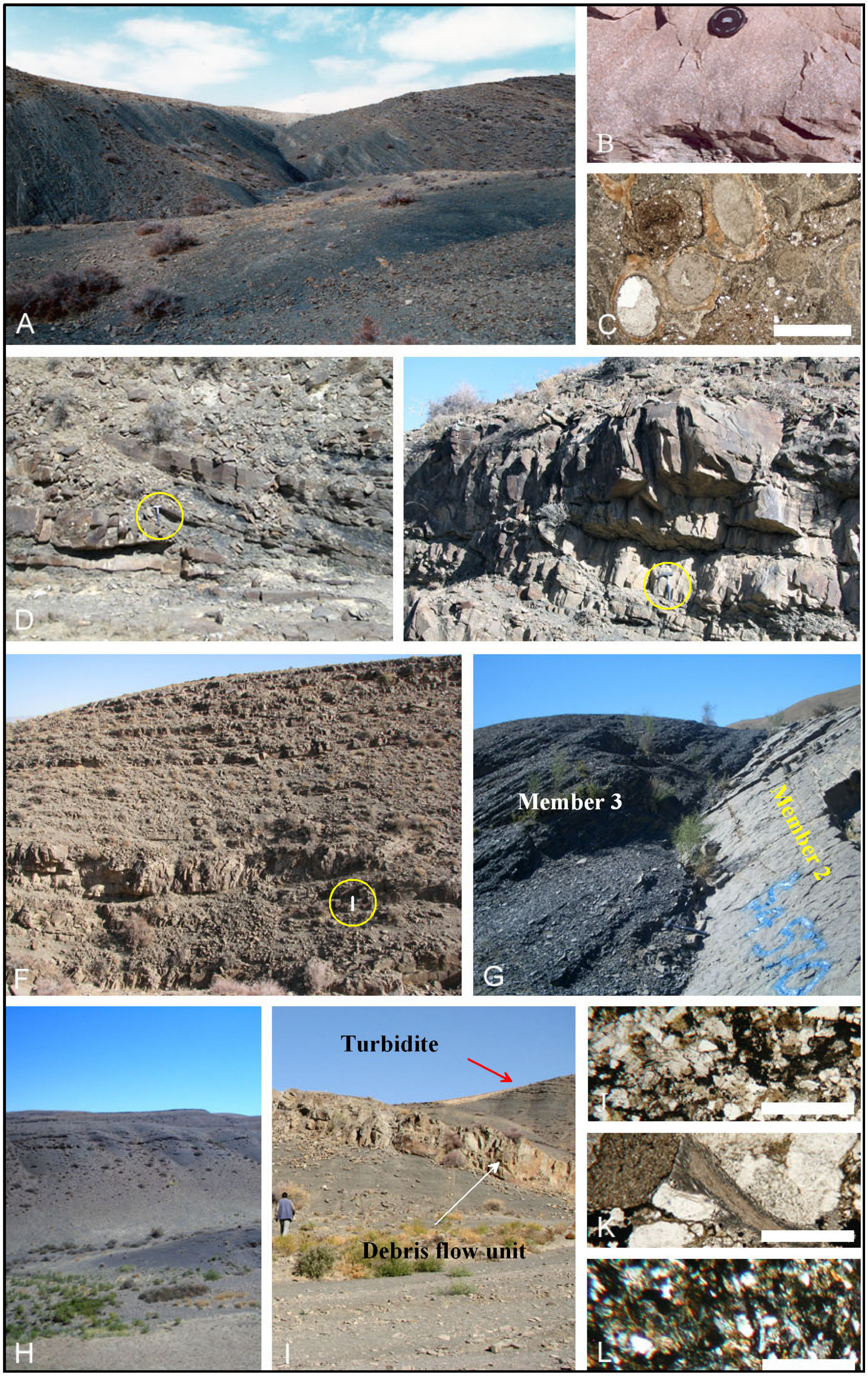
**Member 3 (570-1439 m)**

Member (3) begins with an intercalation of black siltstone and very fine- to fine-grained, ferruginous litharenites (Fig. 3.27G). In the upper part, fine- to medium-grained, occasionally coarse-grained, immature to sub-mature, partly moderately sorted, subangular to subrounded, occasionally mica-bearing (Fig. 3.27J) sublitharenites to litharenites occur. Coarsening- and thickening-upward is also visible in places (e.g., at 1363-1368 m).

In some cases calcareous-ferruginous sandstone beds are seen (e.g., at 1030 m; Fig. 3.27L). Classic turbidites with a background sedimentation represented by grey to greenish-grey siltstones are the main lithofacies of this member. In addition, some debris flow deposits are also visible in this part (Fig. 3.27H-I). In the upper part of this member the amount of sand increases. The sandstones are organized in channels, but these channels are wider than channel structures that are found in member 2 (Fig. 3.29). At 1366 m, a 20 cm thick, brownish sandstone bed with cone-in-cone structures was observed (Fig. 3.26). Except for the sandy upper part, olive to dark-green monotonous silty shale prevails in this unit and bioturbation is quite common throughout the member. *Protovirgularia* isp. and *Nereites* isp. were observed in the turbiditic succession and *Ophiomorpha nodosa* was distinguished in the upper part, which is sandier and probably reflects shallower conditions or is related to post-turbidite bioturbation. Upper Bajocian ammonites were recorded between 1028 to 1245 m. This means that marine conditions started in this area earlier in comparison to localities further south or that a tectonic duplication of the section has occurred (a discussion of this problem is found in chapters 4 and 8).

Fig. 3.26. Cone-in-cone structure in member 3 at 1366 m; Maiamay section. Length of pen 14.5 cm.

Fig. 3.27. Features of the Kashafrud Formation at Maiamay area. **A.** Alteration of black siltstone and thin-bedded, fine-grained sandstone in the lower and middle part of member 1. **B.** Graded bedding in proximal turbidite at ~50 m of the measured section. Diameter of lens cap 6 cm. **C.** Ooids in the lowermost exposed beds of the Kashafrud Formation. Isolated outcrop near the base of the measured section; scale 0.5 mm. **D-E.** Medium-bedded sandstone with channel structure in member 2 at 160-200 m of the section. Hammer as scale. **F.** Well-bedded sandstone in the upper part of member 2, white scale 40 cm. **G.** Base of member 3 at 570 m. **H-I.** General view of member 3. **J.** Fine-grained, ferruginous, mica-bearing immature litharenite, at 585 m; scale: 0.3 mm. **K.** Coarse-grained, poorly sorted litharenite with bioclasts, at 782 m; scale 0.3 mm **I.** Ferruginous, subrounded, immature litharenite, at 1030 m member 3; scale 0.6 mm. →


A
B
C
D
F
G
Member 3
Member 2
H
I
Turbidite
Debris flow unit
K
L

**Member 4 (1439-1871 m)**

The main lithofacies of member 4 are alternations of very fine- to occasionally medium-grained, ripple-bedded sandstones which are immature, poorly to moderately sorted, ferruginous and calcareous litharenites and siltstones (Fig. 3.28C). Bioturbation is moderate and *Protovirgularia* is the main trace fossil. The sandstone beds are thin, but more common than in the following member (Fig. 3.29). Metamorphic rock fragments appear to increase up-section, especially at 1854 m (Fig. 3.28G). At some levels the iron content of the rocks is higher than in the rest of the member (e.g. at 1766 m).

**Member 5 (1871-2285 m)**

Member 5 differs from adjacent units by a decrease of sandstone beds (Fig.3.29), the appearance of *Thalassinoides* in several beds, and the change from the greenish-grey silt to dark-green, occasionally olive, silty shale. Sandstone interbeds are mostly fine-grained, occasionally medium-grained, immature, poorly to moderate sorted, ferruginous, rarely calcareous, angular to subangular, mica-bearing litharenites. Occasionally, the iron-oxid content is distinctly elevated (e.g., at 1952 and 2099 m; Fig. 3.28A-B). At 2099 m a lens of a conglomeratic slump unit containing bivalves and corals occurs.

The member ends with medium-bedded ripple-laminated sandstones (Fig. 3.28D).

**Member 6 (2285-2662 m)**

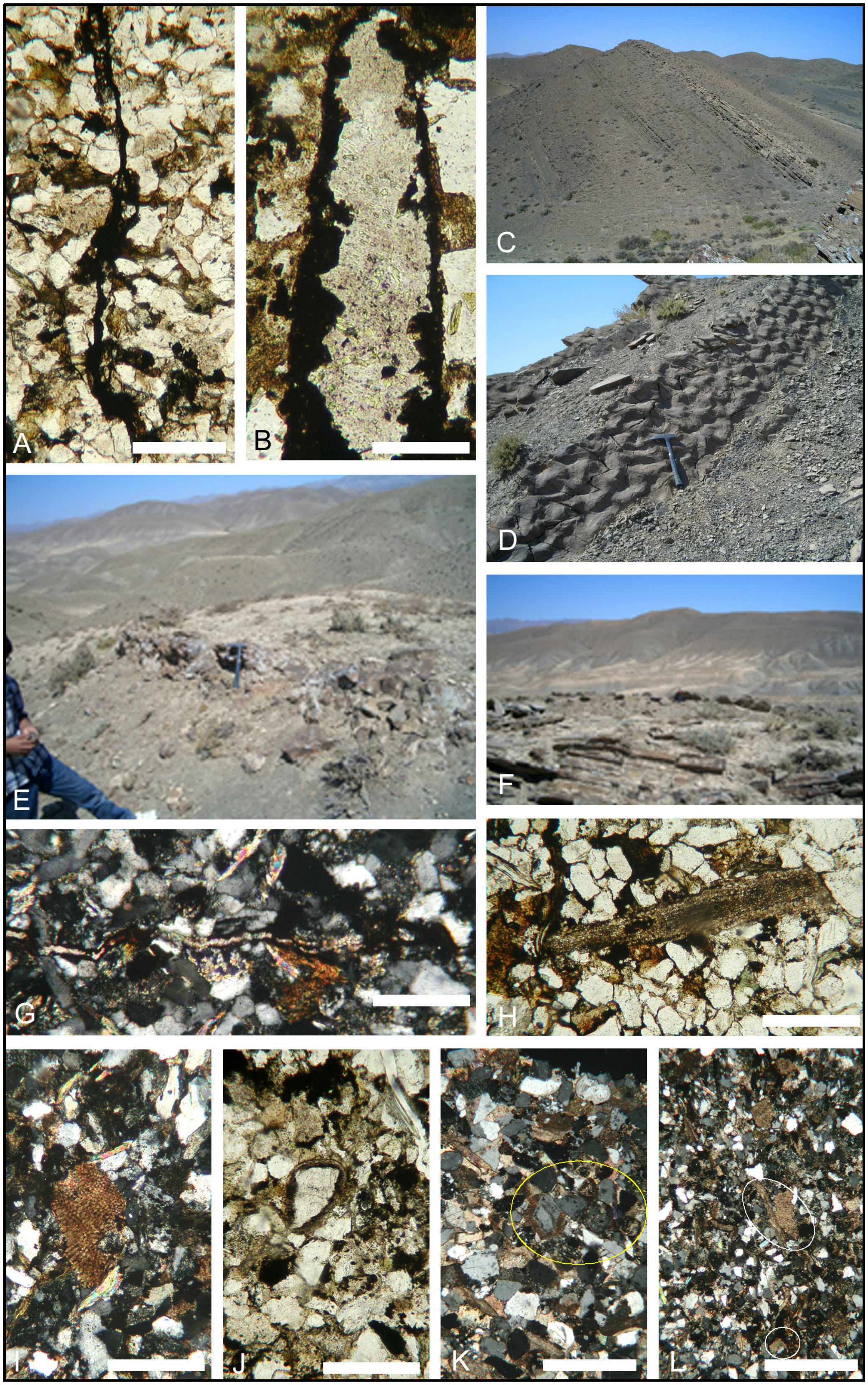
The main distinguishing feature of this member is the appearances of grayish silty marl, which is the most common lithofacies (Fig. 3.28E-F). Some of the rare sandstone beds in the lower part of the member are fine- to medium-grained, immature, subangular, calcareous litharenites.

From 2330 m onwards bioclasts appear and increase in abundance toward the top of the section (e.g., Fig. 3.28 H, I, L).

**Member 7 (2662-2914 m)**

Member (7) consists of an alteration of thin- to medium-bedded, grayish ripple-bedded sandstone beds and marly silt and marl (Fig. 3.28M). The sandstones are calcareous, ferruginous, fine- to medium-grained, immature litharenites. At 2682 and 2720 m of the section oolitic sandstone beds appear for the first time since the base of the section and indicate shallowing by an increase in water energy at this level (Fig. 3.28J-K). In addition to oolitic sandstone, storm beds are also observed in this member (Fig. 3.29). *Tomaculum* and *Thalassinoides* are characteristic trace fossils of this member.

Fig. 3.28. Features of the Kashafrud Formation in the Maiamay section. **A-B.** Iron-enriched sandstones at 1952 m; scale 0.3 mm (A) and 2099 m; scale 0.125 mm(B). **C.** General view of member 4. **D.** Interference ripples on a sandstone bed at the top of member 5. **E-F.** Members 5-7. **G.** Sandstone rich in metamorphic lithic fragments at 1854 m; thin-section, scale 0.125 mm. **H-I.** Bioclasts in sandstone at 2332 m; thin-section, scale 0.125 mm. **J.** Ooids in sandstone at 2682 m; thin-section, scale 0.125 mm. **K.** Ooids with nuclei of feldspar grains at 2720 m; thin-section, scale 0.3 mm. **L**. Bioclasts in the uppermost beds at 2728 m; thin-section, scale 0.3 mm.→


A
B
C
D
E
F
G
H
I
J
K
L

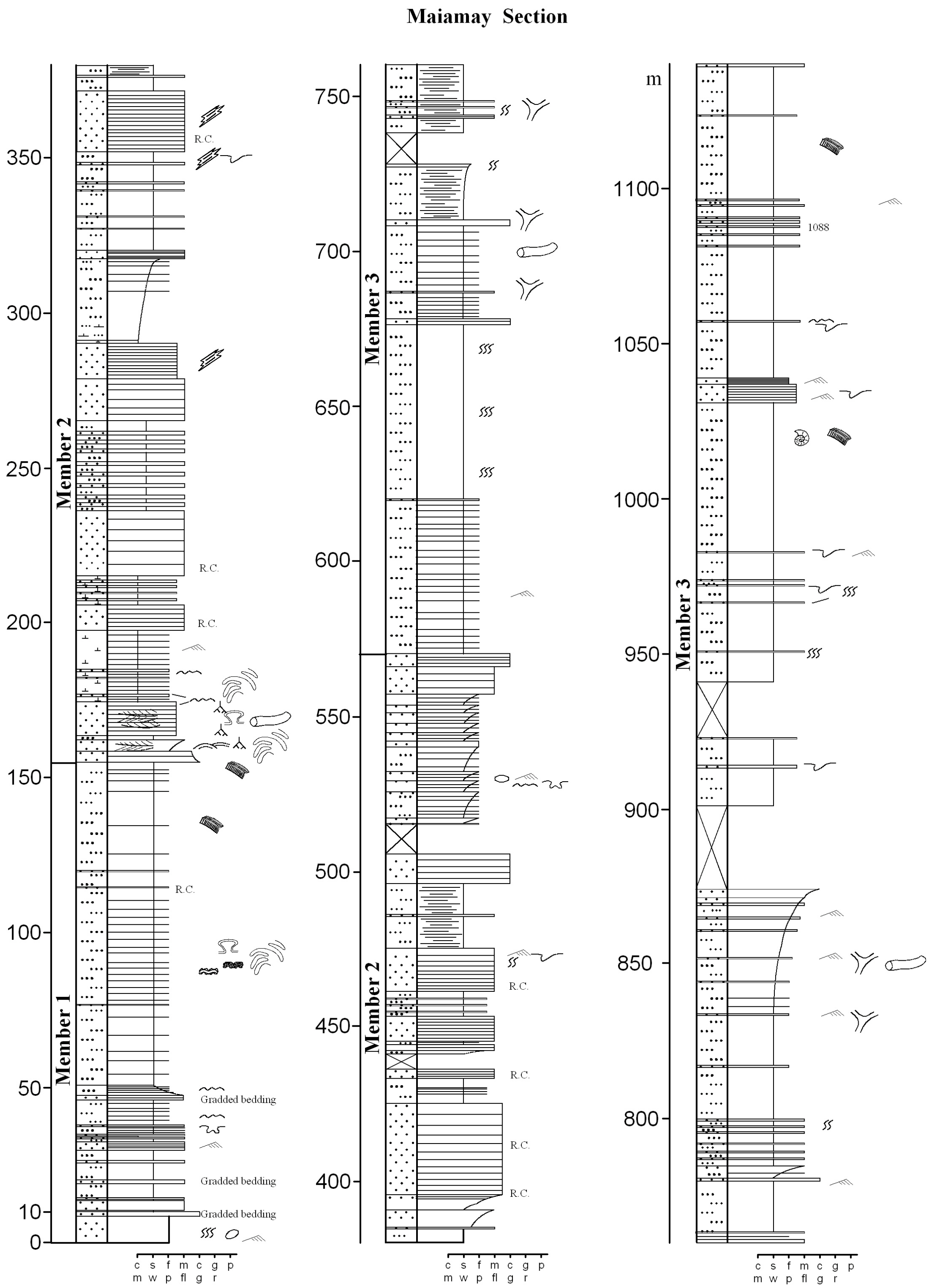
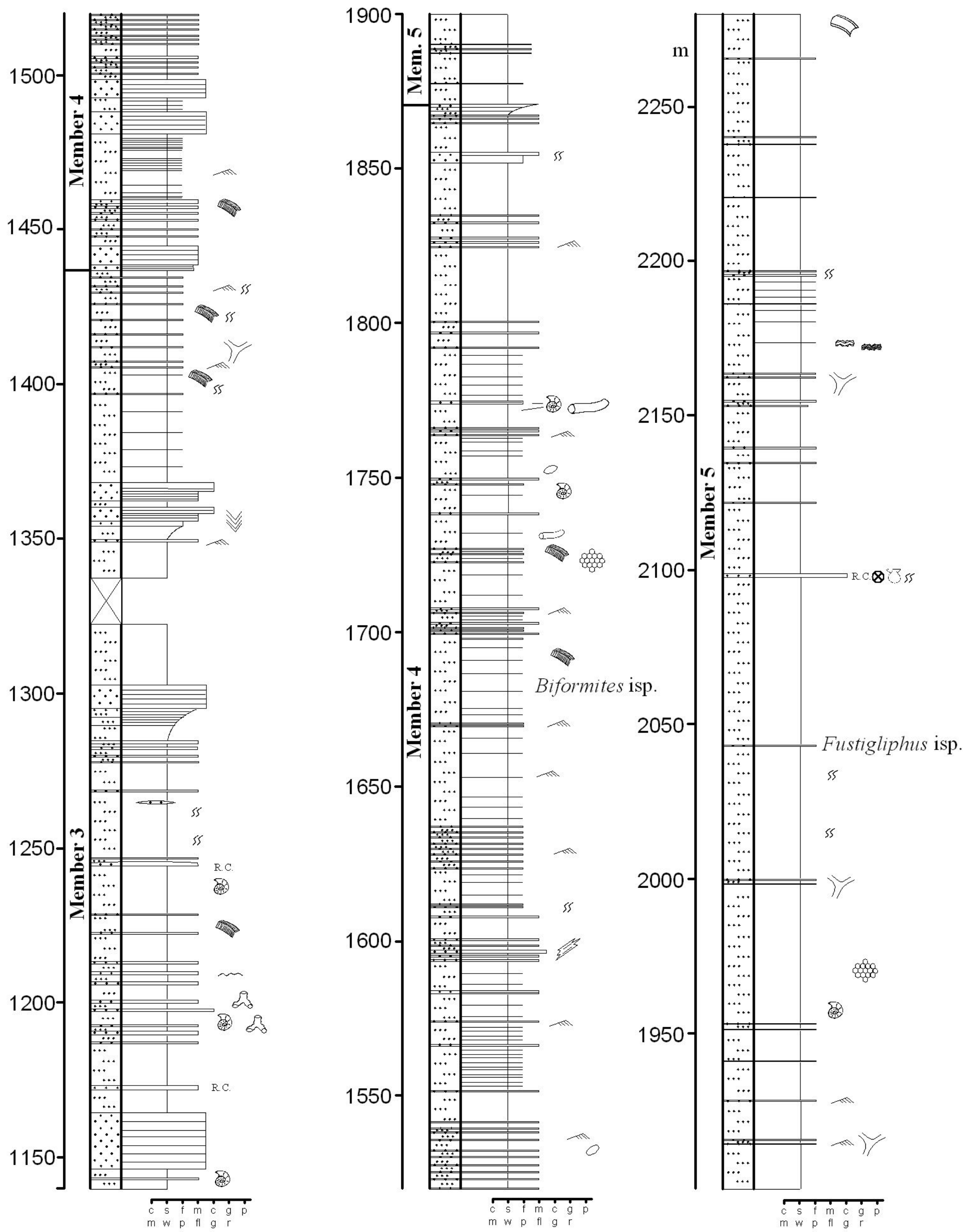



Fig. 3.29. Stratigraphic log of the Kashafrud Formation in the Maiamay area. For key of symbols see Fig. 3.51



Member 4
Member 3
Mem. 5
Member 4
Member 5
m
R.C.
Biformites isp.
Fustigliphus isp.
c s f m c g p
m w p fl g r


Fig. 3.29. cont.

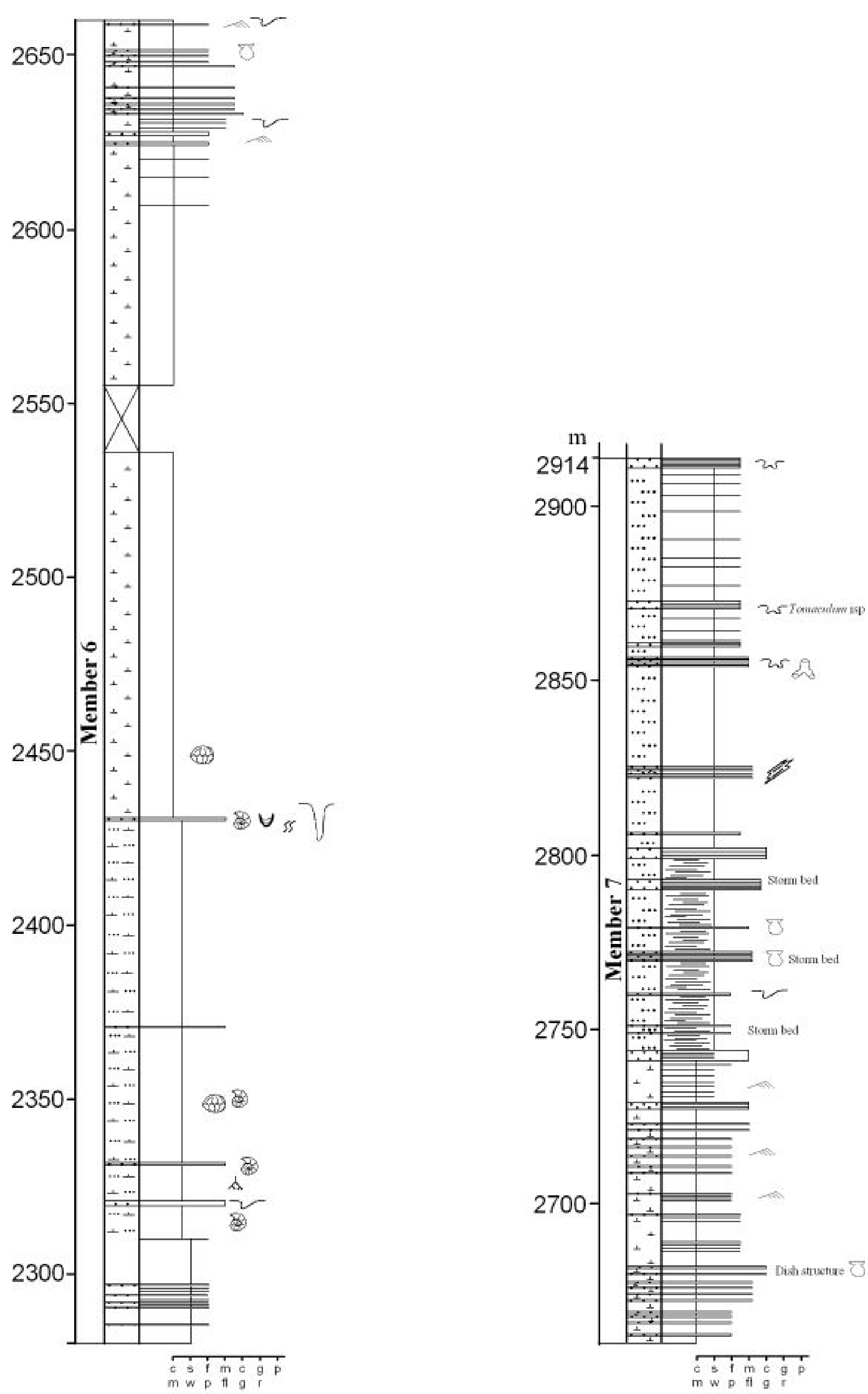

2650
2600
2550
2500
2450
2400
2350
2300
Member 6
m
2914
2900
2850
2800
2750
2700
Member 7
Tomaculum isp
Storm bed
Storm bed
Storm bed
Dish structure
c s f m c g p
m w p fl g r

Fig. 3.29. cont.

### 3.6 Kuh-e-Radar section

The Kuh-e-Radar section was measured in a hill, about 20 km east of Mashhad, near the small village of Tangalshur along the Sarakhs-Mashhad main road (Fig. 3.30).

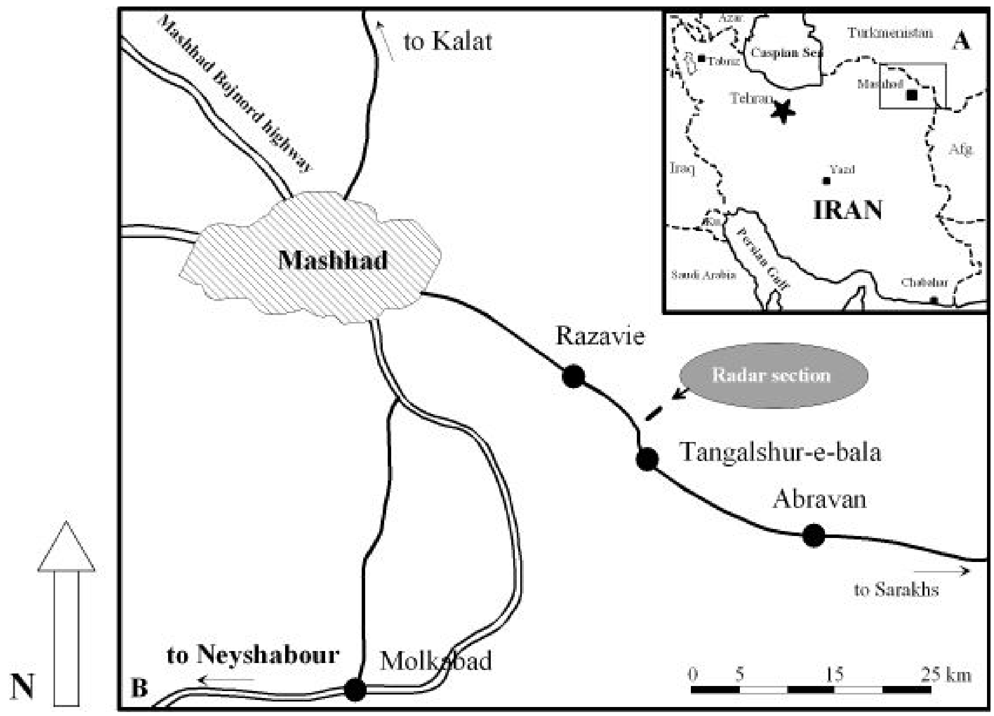



Fig. 3.30. Position of the field area (A) and locality of the Kuh-e-Radar section (B).

Taheri & Ghaemi (1994) reported Middle Jurassic strata of the Kashafrud Formation in the Kuh-e-Radar area for the first time. During a subsequent reconnaissance trip 2004 a facies succession was encountered that differed distinctly from that at other localities of the formation.

Although the lowermost Kashafrud strata are covered by Quaternary deposits here, the ammonites found in the lower marly unit (Figs. 3.33 and 3.34) yielded an Upper Bajocian age and are thus comparable with the base of other Kashafrud sections (Fig. 3.33B-C). The Kashafrud Formation in this region is overlain by sandy limestones and limestones of the Chamanbid Formation. Based on fossil data, the thickness of the exposed Kashafrud Formation in this area is 286 m. Finds of the ammonite *Macrocephalites* in the sandy limestone point to a transitional contact of the Chamanbid and Kashafrud formations in the area.

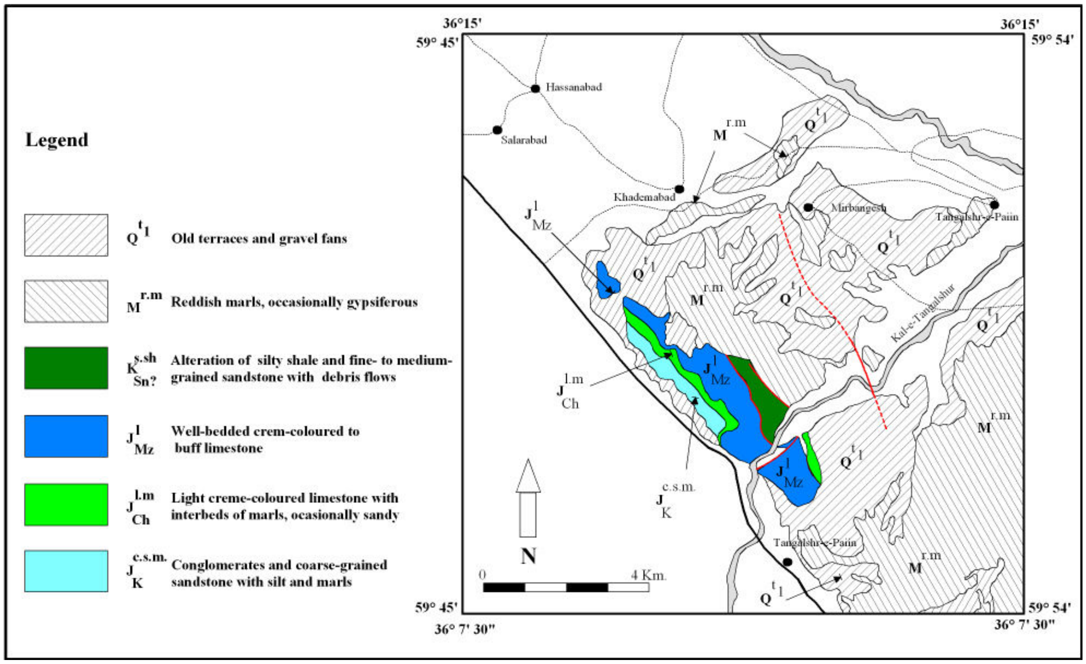



Fig. 3.31. Geological map of the Kuh-e- Radar area (modified after TAHERI & GHAEMI 1994) at the scale 1: 100,000.

At Kuh-e-Radar, wide, lenticular structures, 0.5-4 m thick, consist of partly convoluted, fine- to coarse-grained sandstone and conglomerate beds containing wood pieces (Fig. 3.33A). The architecture of the units resembles cross-sections of fan lobes, which are composed of stacked channel fills (Fig. 3.33I). Angular pebbles, cobbles, and large boulders of Mashhad granitoids and pegmatitic rocks in the sediments are a characteristic feature and indicate a very short transport distance.

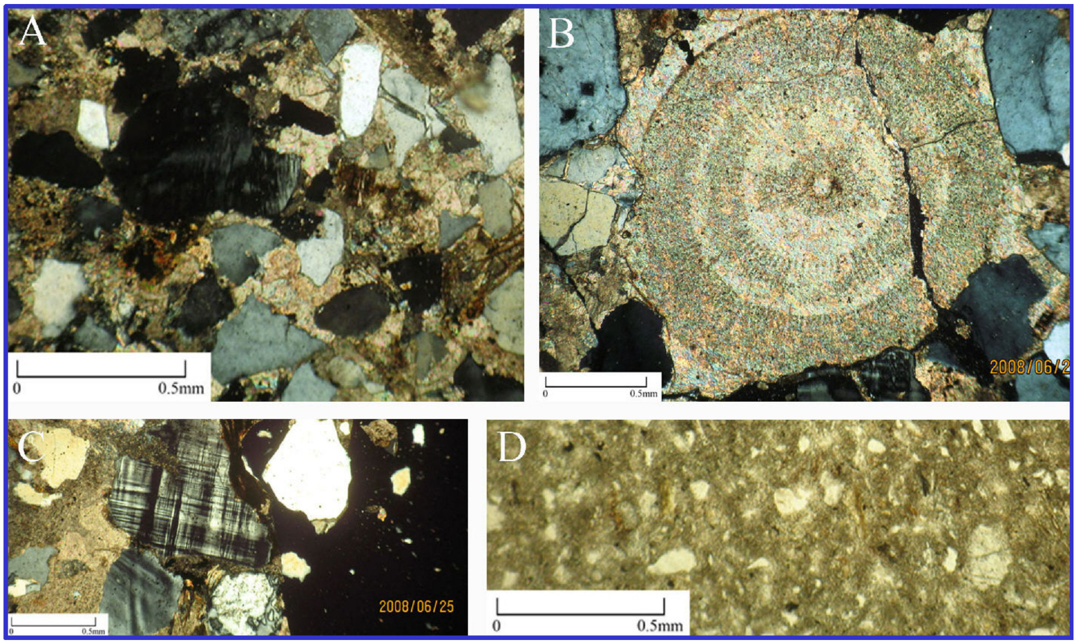
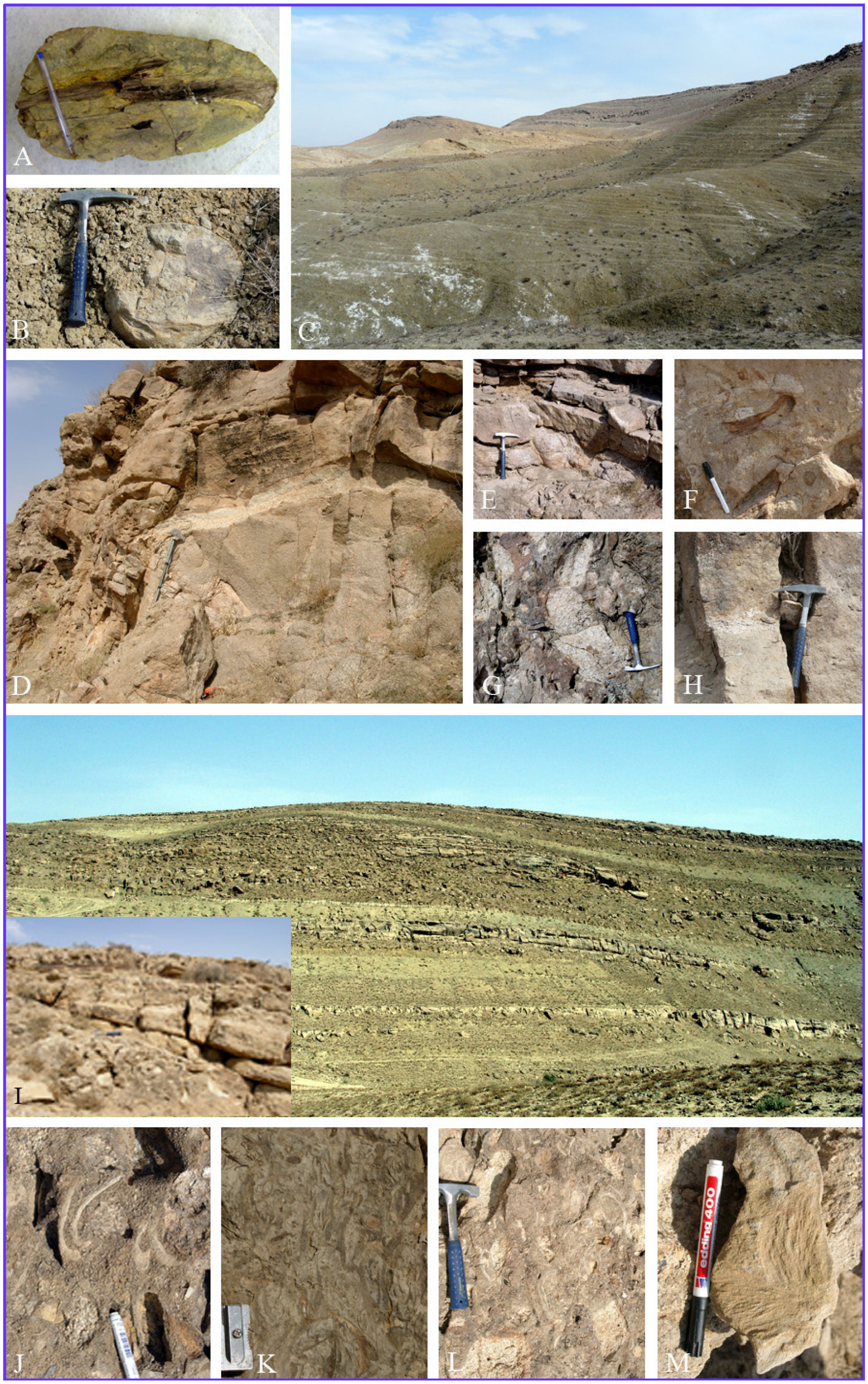



Fig. 3.32. Features of the Kashafrud Formation at Kuh-e-Radar. Thin-sections, Scale: 0.5 mm. A. Calcareous lithic greywacke from the base of the section. B. Large ooid in feldspatic greywacke at 31 m. C. Microcline in a lithic greywacke, at 1.5 m of the section. D. Sandy microsparite at 95 m.

-----------------------------------------------------------------------------------------------------------

Fig. 3.33. Features of the Kashafrud Formation at Kuh-e-Radar. **A, B**. Nodules with wood pieces. Length of pen 14.5 cm. **C**. Lower olive, silty, ammonite-bearing marl, of the Upper Bajocian. **D**. Large boulder of Mashhad granitod boulder in sandstone, at 128 m. Jacob staff 1.5 m. **E-H.** Different lithoclasts in sandy limestone. Length of marker 14.5 cm. **I**. General aspect of lobe structure of deltaic succession; inset shows channel fill deposits**. J-L**. Large bivalve shells in the upper part of the section, Length of pencil sharpner 2.5 cm; Diameter of pen 6 cm. **M**. *Zoophycos* at 40 m. Length of marker 14.5 cm.→


A
B
C
D
E
F
G
H
I
J
K
L
M
edding 400

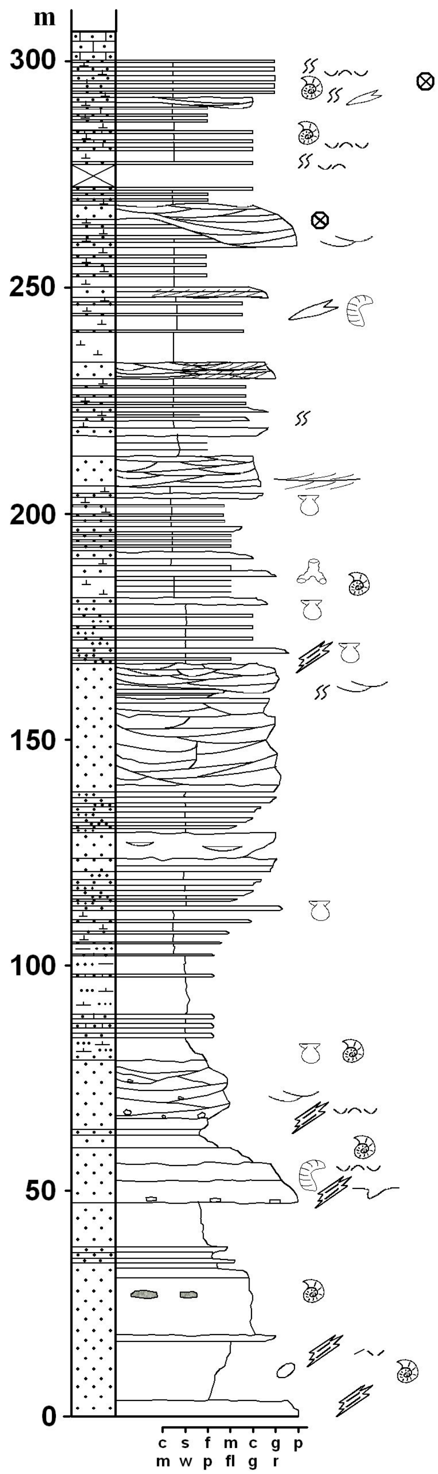



Fig 3.34. Lithology of the Kashafrud Formation at Kuh-e-Radar .
For key of symbols see Fig. 3.51.

**3.7- Danesh Section**

This section was measured north of Mashhad, near the small village Danesh along the Kalat-e-Arabha road (Fig. 3.35).

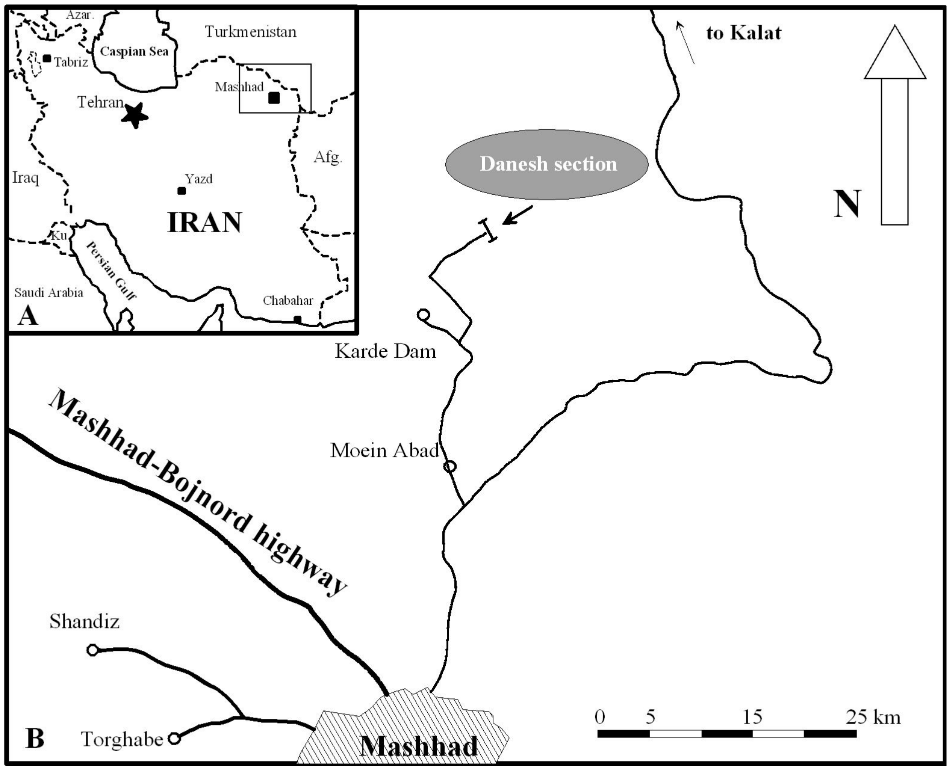



Fig. 3.35. Position of the field area (A) and locality map of the Danesh section (B).

The Kashafrud Formation in this area in general is a sandstone-dominated unit with a lower faulted contact with the Mozduran Formation (Figs.3.36 and 3.37A). The upper contact with the Chamanbid Formation is gradual. As the lower part of the formation is missing, only about 800 m of siliciclastic Kashafrud beds could be measured (Fig. 3.38). Based on the lithofacies and field observation it was possible to divide the total succession into four informal members.

**Member 1 (0-260 m)**

The main lithofacies of this member consists of alternations of dark-grey to black silty shale and fine- to medium-grained turbiditic sandstone beds which are partly convoluted. Some of sandstone beds are brown to reddish in colour. Flute casts and load casts are common features. At 326 m iron oxides are concentrated in layers producing a pattern of dark and light stripes (Fig. 3.37E).

The sandstones are poorly sorted, ferruginous, rarely calcareous, immature litharenites. No fossils were found in this member.

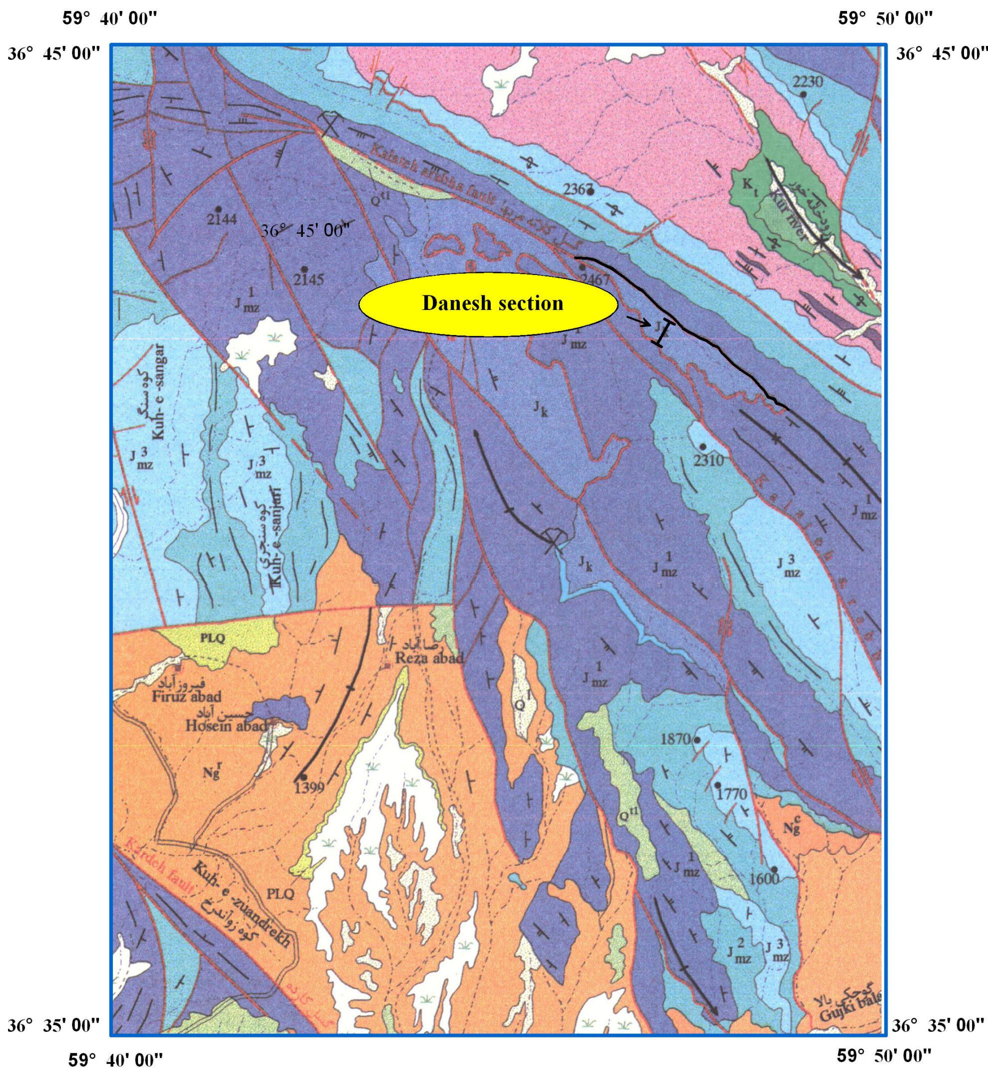



Fig. 3.36. Geological map of the Danesh area at the scale of 1:100,000 (part of Kalat-e-Naderi sheet; NABAVIEH 1998).

## Member 2 (260-450 m)

In member 2 sandstone beds become more abundant (Fig. 3.37B), some of them are ripple-bedded and of turbidite origin, others are structureless and possibly related to debris flow mechanisms. In general, sandstones in this member are coarser than in member 1, although they are still fine-grained. Some of the sandstone units show channel structures. They are poorly sorted, calcareous-ferruginous, immature litharenites. Para-sequences are another characteristic feature of this member and partly also of the next member (Fig. 3.37G, N).

**Member 3 (450-550 m)**

Member (3) consists of fine-grained, thin-bedded sandstone and clayey silt to silty shale and represents relatively deep conditions. Based on field observations and evaluation of the lithofacies, the member ends with the first channel sandstone at 550 m. The sediments in this part are comparatively ferruginous (Fig. 3.37D). In some sandstone beds, feldspars have been altered to carbonate. This may reflect a diagenetic source for the carbonate (Fig. 3.37F).

**Member 4 (550-876 m)**

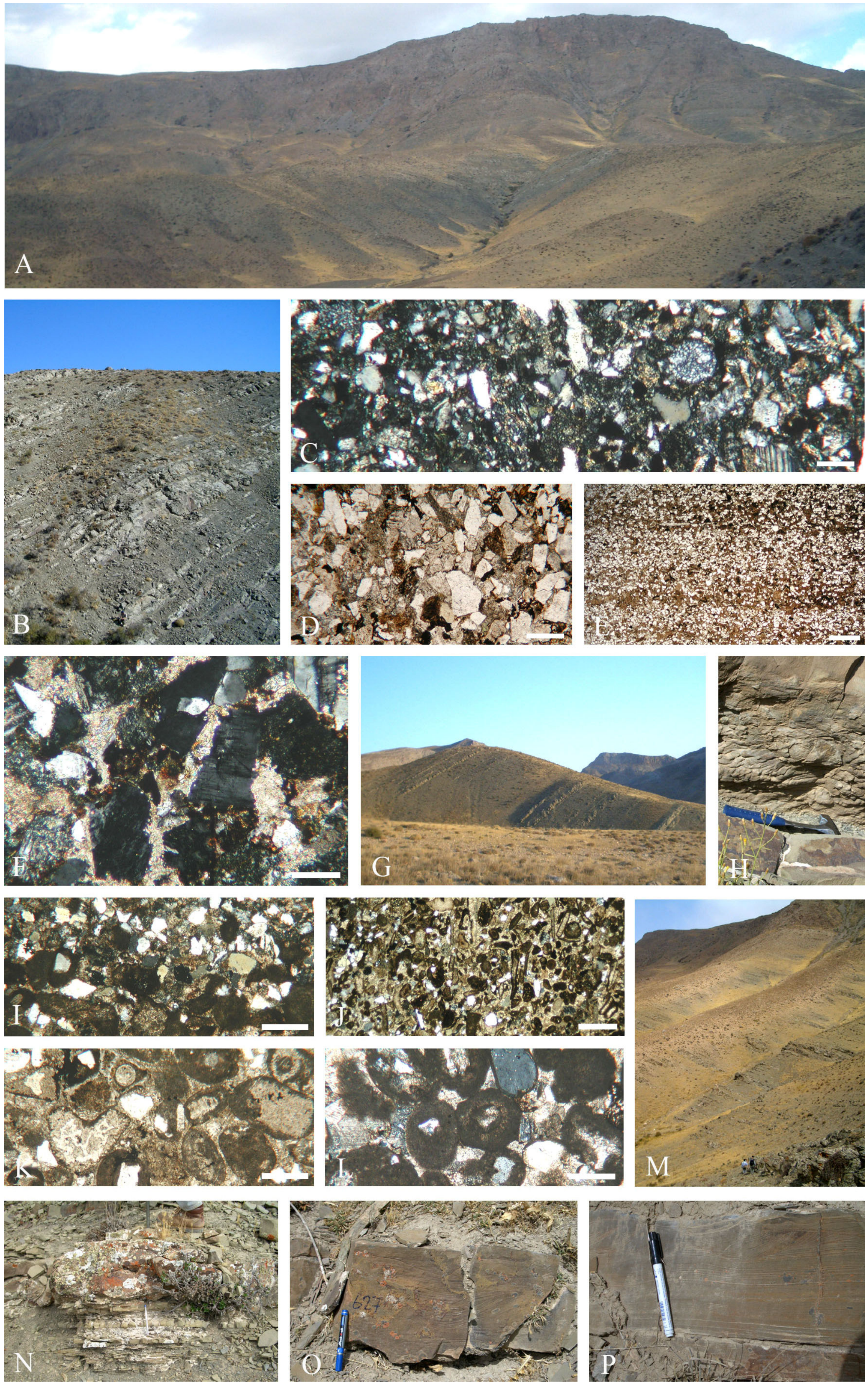
Member 4 is sandier than the previous member but still contains silt and marly silt intervals. Sedimentary structures such as flute casts (Fig. 3.37H) and load casts as well as wood fragments are common. Greenish sandstones that occasionally represent channel fills are mostly poorly sorted fine- to medium-grained, rarely coarse-grained litharenites.

The top 100 m of member 4 is a transitional zone between the typical siliciclastic succession of the Kashafrud Formation and the marls and marly limestones of the Chamanbid Formation (Fig. 3.37M). In this transitional part, rock fragments, quartz, feldspar, and other accessory minerals decrease and ooids, bioclasts, and the carbonate content increase (Fig. 3.37I-L), although some pulses of terrigenous input still occurred, e.g. at 828 m in the middle part of the transitional zone. Ooids occasionally show aggregate composed of composite ooids (Fig. 3.37K).

*Zoophycos* is a characteristic trace fossil of this unit. Well developed HCS (hummocky cross-stratification) is also seen in the upper transitional zone between the Kashafrud and Chamanbid formations (Fig. 3.37O-P).

---

Fig. 3.37. Features of the Danesh section. **A.** View of the section. **B.** Sandstone beds of member 2. **C.** Thin-section of litharenite from 212 m, scale: 0.3 mm. **D, F.** Thin-section of ferruginous, calcareous, poorly sorted, fine- to medium-grained litharenite from 503 m; scales: 0,3 (D) 1.0 mm (F). **E.** Thin-section of fine-grained, ferruginous litharenite, scale: 1.0 mm. **G, N.** Para-sequences ranging from several tens of meters (G), to several centimeters in thickness (N), length of pen 14.5 cm.. **H.** Flute casts in member 4. **I-L.** Thin-section of ooids in member 5, scales: 0.3 mm (I, K, & L) and 1.0 mm (J). **M.** Top part of the section.
**O-P.** Hummocky cross-stratification in the upper transitional part. Length of pen 14.5 cm. →


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P

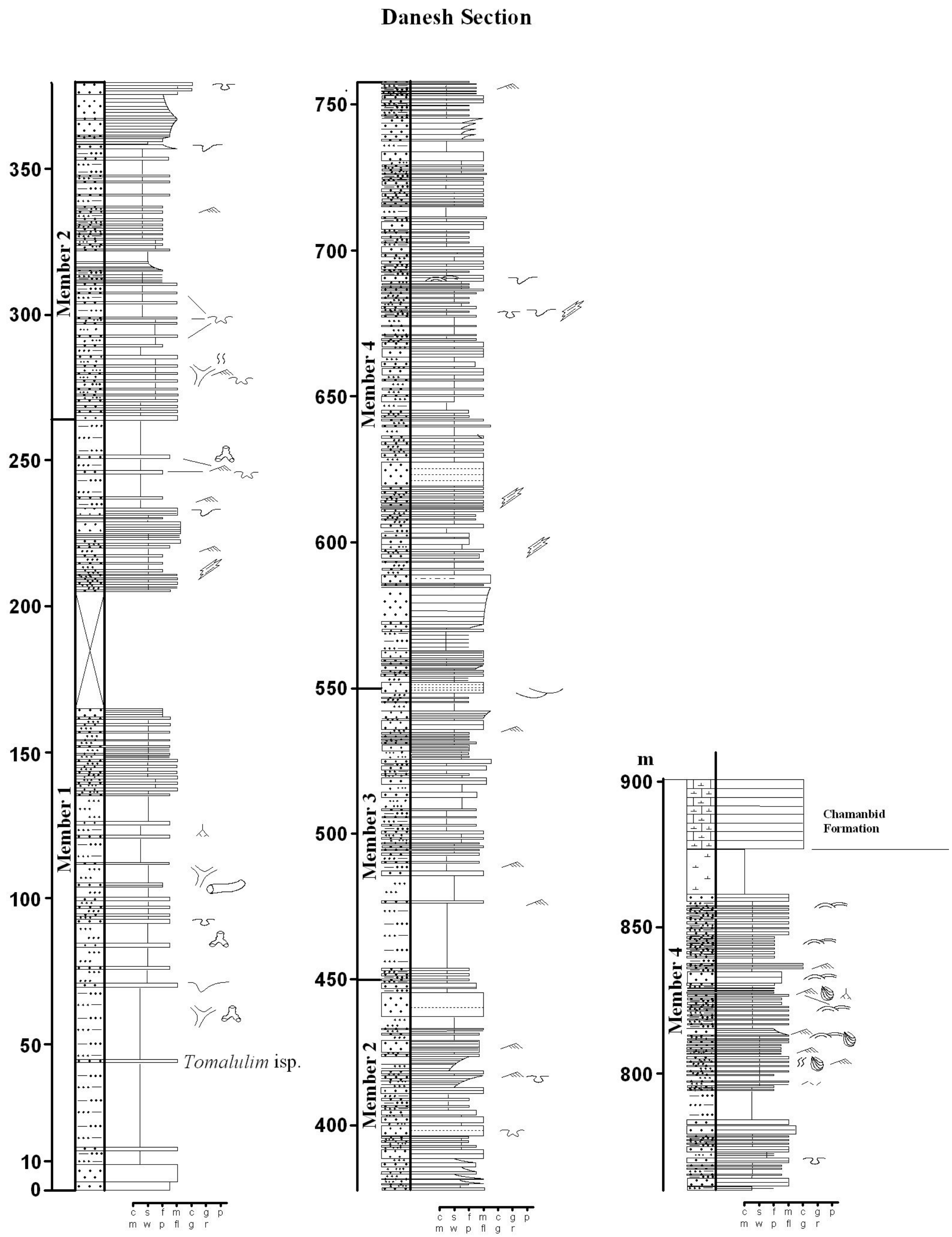



**Fig 3.38. Lithology of the Kashafrud Formation at the Danesh section. For key of symbols see Fig. 3.51.**

### 3.8 Gas-pipeline Section

The Gas-pipeline section is the northernmost section measured (Fig. 3.39). The lower part is cut by a major NW-SE running fault. The Kashafrud Formation is overlain by marl and marly limestone of the Chamanbid Formation (Fig. 3.40).

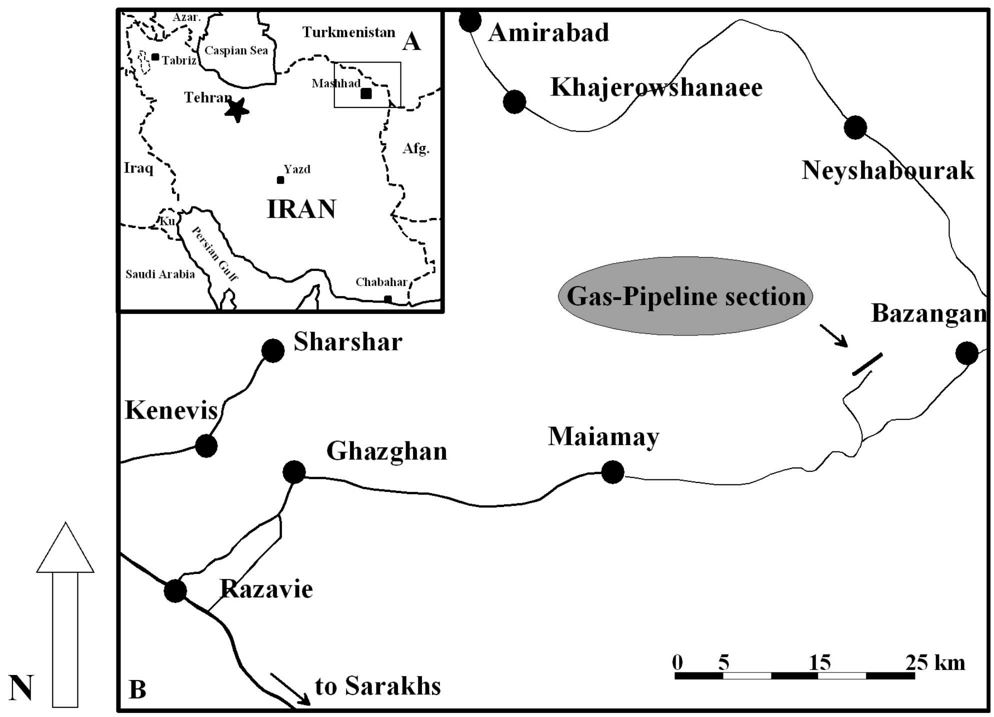



Fig. 3.39. Position of the study area (A) and locality of the Gas pipeline section (B).

The strata represent one of the deepest lithofacies in the Kashafrud Basin (Fig. 3.41A). As these strata are mostly monotonous, dark-green silty shale with thin interbeds of sandstone, it is difficult to divide the section into several members, although the sandstone content differs within the section (Fig. 3.42).

The section logging started at the co-ordinates 36° 15′ 22″ N – 60° 21′ 52″ E and ended with a dark-brown limestone of Late Bathonian age (age based on ammonites; for more information see Chapter 4). This limestone marker bed is a sandy intra-bio-oosparite (Fig. 3.41G-I).

Sandstone beds throughout the section are mostly very fine- to fine-grained, ferruginous (occasionally very highly ferruginous), calcareous, immature litharenites (Fig. 3.41D-F).

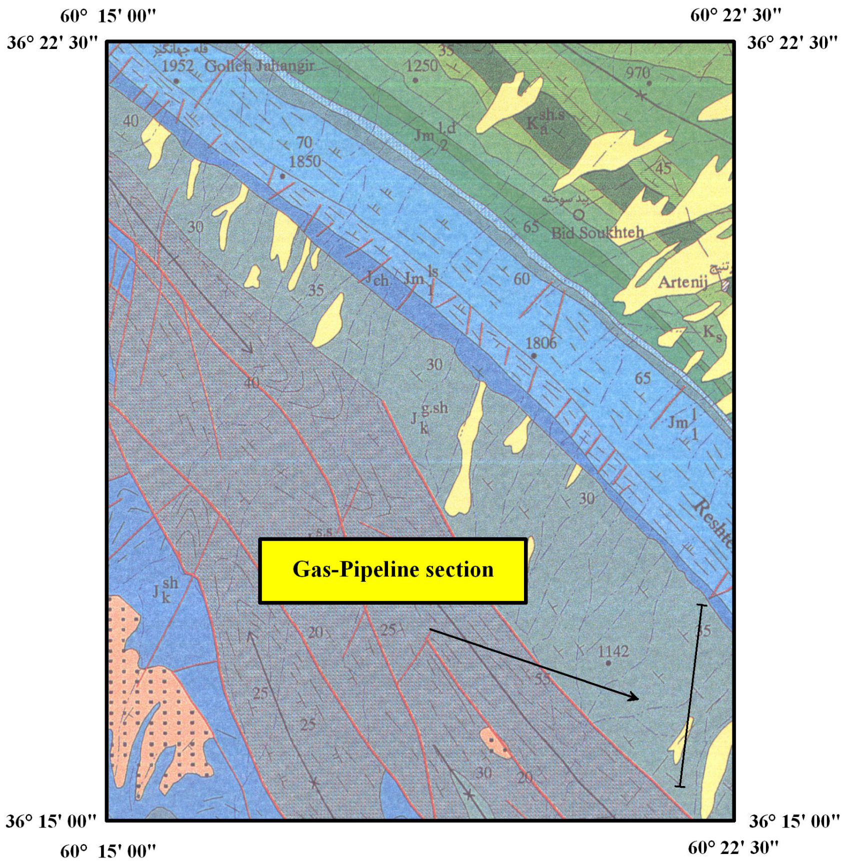



Fig. 3.40. Geological map of the Gas-pipeline area at the scale of 1:100000 (part of the Bazangan sheet; ROWSHANRAVAN 2006).

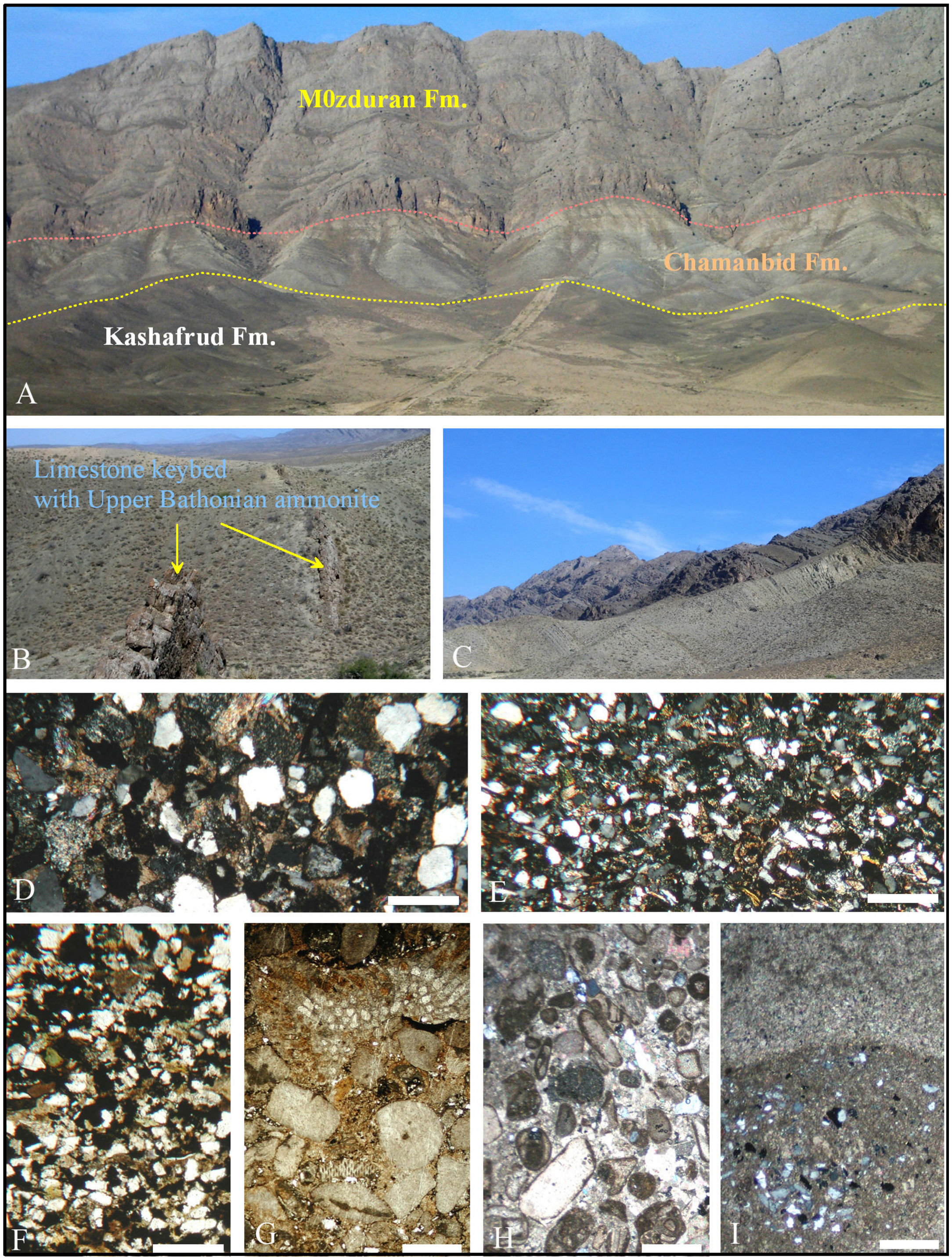



Fig. 3.41. Features of the Gas-pipeline section. **A.** Middle to Upper Jurassic succession. **B.** Limestone marker bed near the top of the formation. **C.** Marl and marly limestone of the Chamanbid Formation below thick to massive limestone of the Mozduran Formation. **D-F.** Thin-sections of sandstones; scale 0.3 mm. **G-H.** Thin-sections of sandy bio-oo-sparite of limestone marker bed; scale 1.0 mm. **I.** Dismicrite at 1260 m; scale 1.0 mm.

### 3.9- Fraizi section

The Fraizi section was measured about 40 km west of Mashhad city east of the small village Fraizi (Fig. 3.43). At this locality a thick succession of siliciclastic rocks is exposed, which consists of a major “non-marine” and a major “marine” part.

The non-marine part includes a nearly 250 m thick boulder and conglomerate unit overlying the Mashhad Phyllite (Fig. 3.44, Fig.3.45d) that probably forms the base of the Kashafrud Formation. Most of the components are meta-sandstones of Mashhad Phyllite, but other metamorphic and non-metamorphic components also occur (Fig. 3.45A-C).

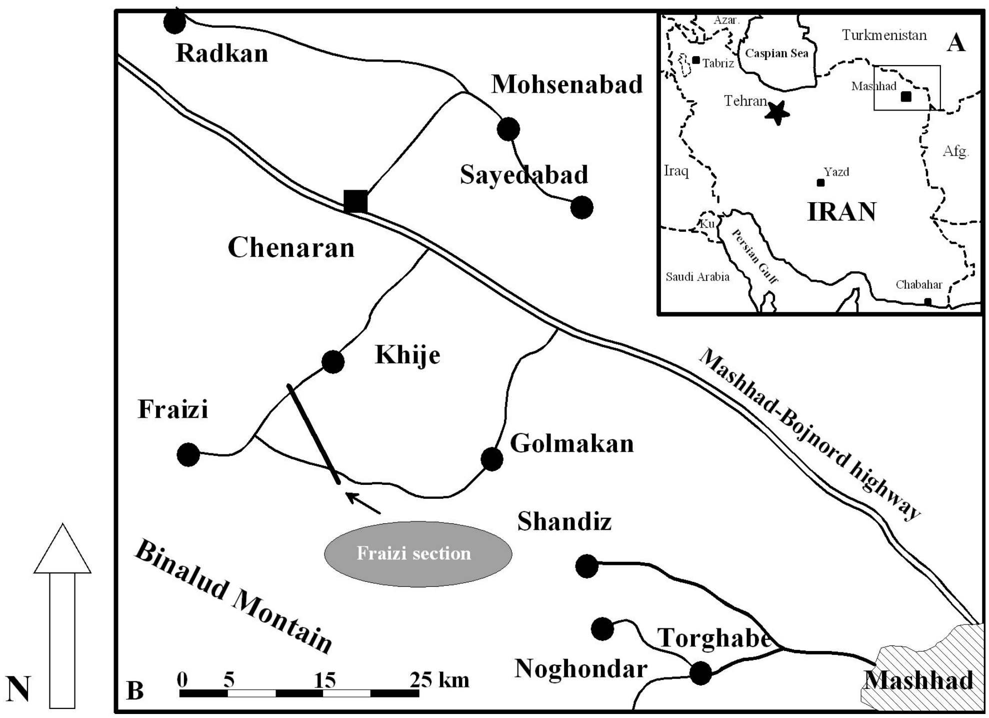


Fig. 3.43. Position of study area (A) and locality of the Fraizi section (B).

The second non-marine unit in the Fraizi area is a nearly 700 m thick succession of meter- to decameter-thick, lenticular packages of sandstones and fine conglomerates, which overlies the basal conglomerate. Occasionally, finer interbeds with plant fossils (Fig. 3.45F-H) occur in this facies (especially along the Golmakan-Fraizi road, within a grayish silty marl unit).

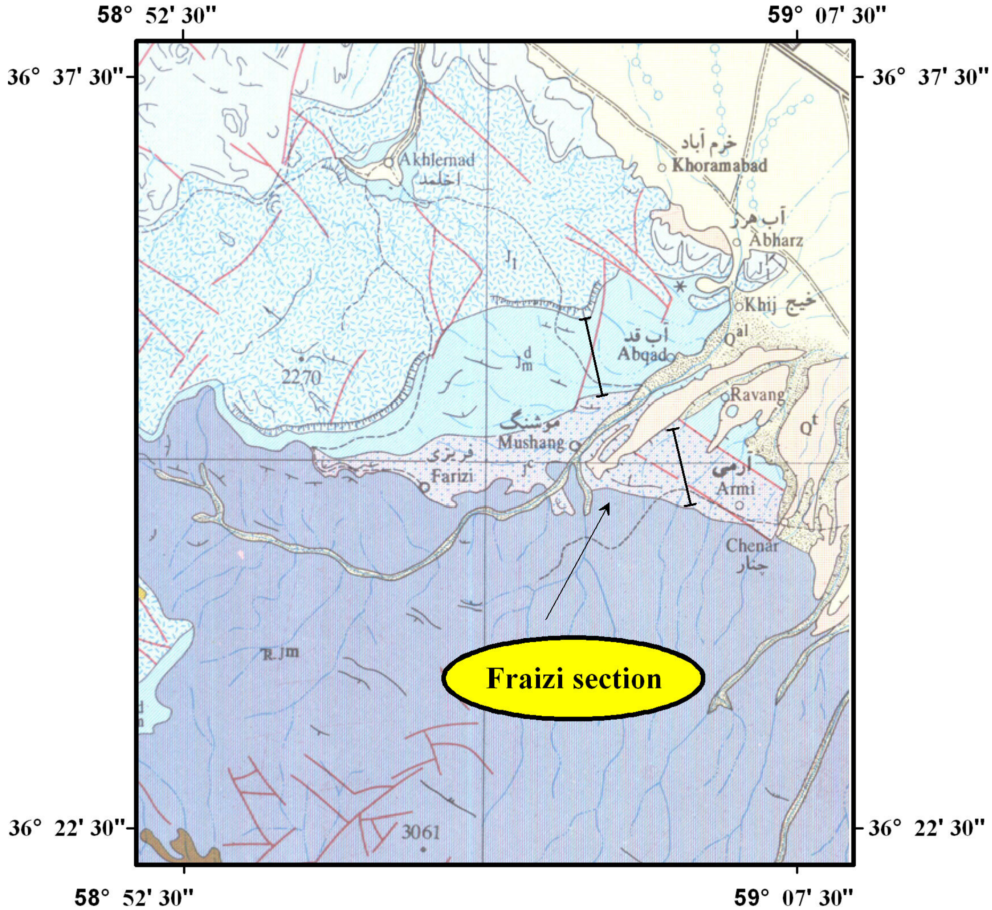



Fig. 3.44. Geological map of the Fraizi area at the scale 1:250,000 (part of the Mashhad sheet; AGHANABATI 1986).

Although the relationship of the thick conglomerate unit and the overlying package of coarse-grained arkosic sandstones with the marine part of the Kashafrud Formation (marine part) is not documented by index fossils, this unit is tentatively placed at the base of the Kashafrud Formation, because no unconformity or any other distinct change between the non-marine and the marine (Late Bajocian-Bathonian) part of the succession in the Fraizi area could be detected. It may well be that a large fluvial system entered the basin in the area. Foe a final interpretation and new data on the biostratigraphy see Chapter 4.

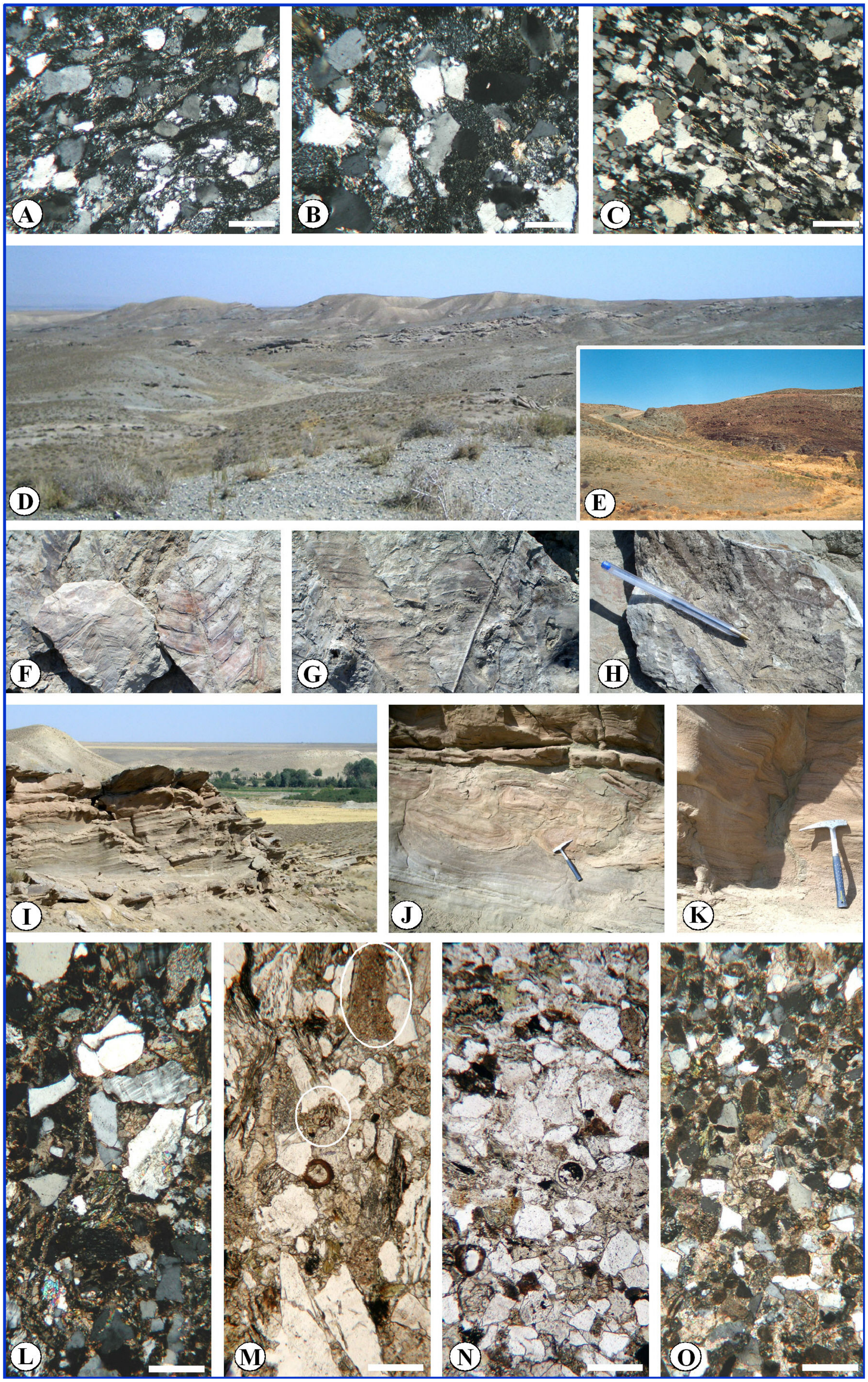
The marine part of the Fraizi section starts with large convolute bedding and flame structures in a thick coarse-grained sandstone. Bivalve shells a few meters below are the first sign of marine influence and indicate rapid sedimentation in an upper delta-front environment (Fig. 3.45I-K).

The best outcrop of the marine- and non-marine contact is seen near the small farm Abbasabad southeast of Khij. Bivalves, brachiopods, gastropods, belemnite guards, and rare fragments of ammonites are observed there. A late Bajocian age is documented for this part based on a fragment of *Cadomites*. Another fragment has been found in marly beds 300 m above this level.

In general, the Fraizi section is 2343 m thick, of which about 970 m belong to the non-marine and deltaic succession, the remaining part consisting of marine sediments.

In the marine part, sandstone beds are calcareous, immature litharenite to lithic arkoses (Figs. 3.45L-O).

Fig. 3.45. Features of the Kashafrud Formation at Fraizi. **A-C**. Thin-sections of metamorphic and non-metamorphic components in the basal conglomerate unit, at 50-75 m from base of the section; scale 0.3 mm. **D-E**. View of alluvial fan conglomerates which overlie the Mashhad Phyllite (E) and braided river succession. **F-H**. Plant fossils at 528 m; length of pen 14.5 cm. **I**. Deltaic sediments at the base of the marine part of the Fraizi section. **J**. Convolute bedding about 900 m. **K**. Flame structures in deltaic sediments at 980 m. **L**. Thin-section of feldspatic litharenite at 836 m. **M** Bioclast in sandstone at 1984 m; thin- section; scale 0.3 mm **N**. Bioclasts and ooids in sandstone at 2099 m; thin-section, scale 0.3 mm **O**. Calcareous sandstone with peloids and ooids at the top of the section, at 2300 m. Scale in Thin-sections 0.3 mm . →


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

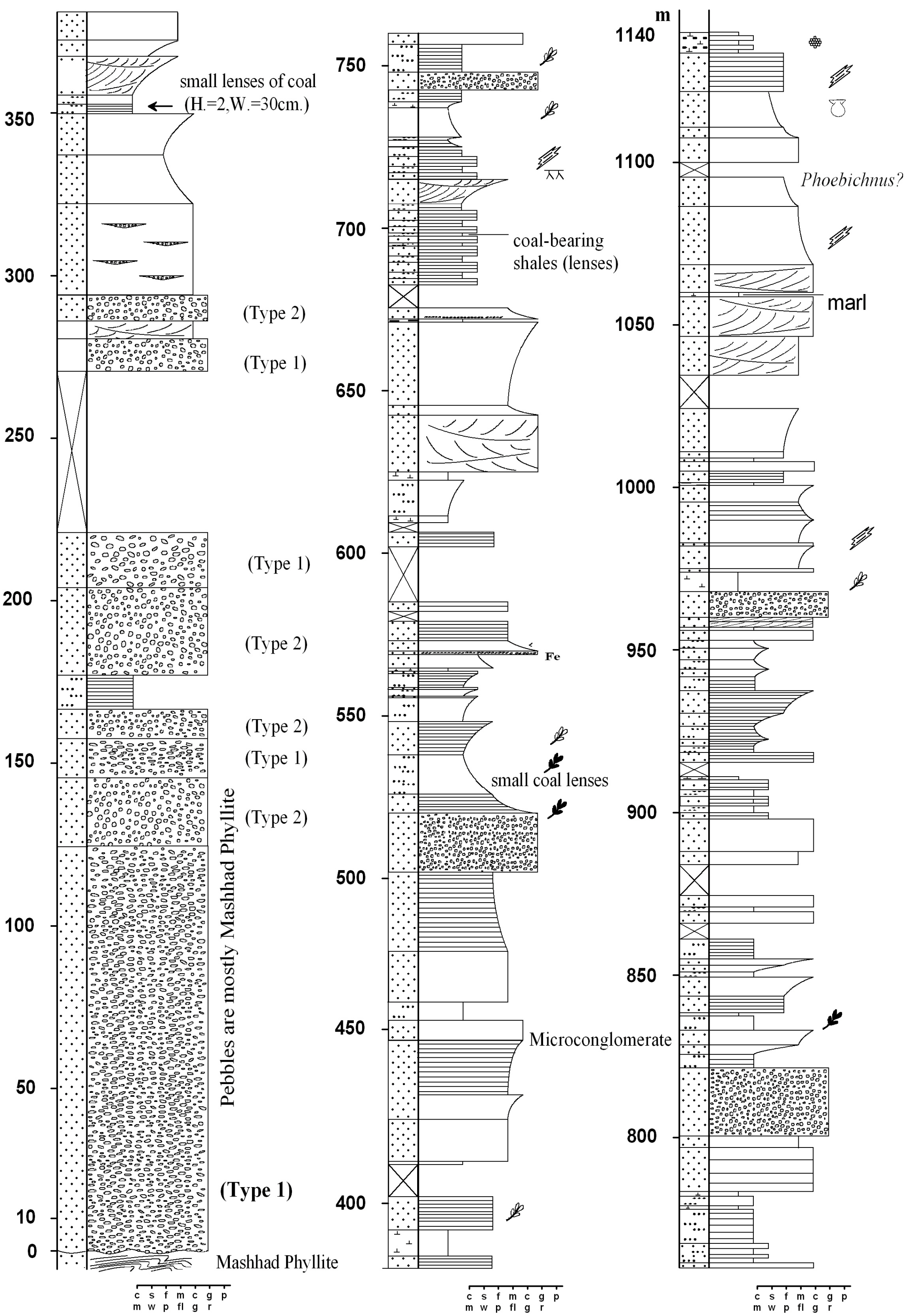



Fig. 3.46. Lithology of the Kashafrud Formation at Fraizi. For key of symbols see Fig. 3.51.

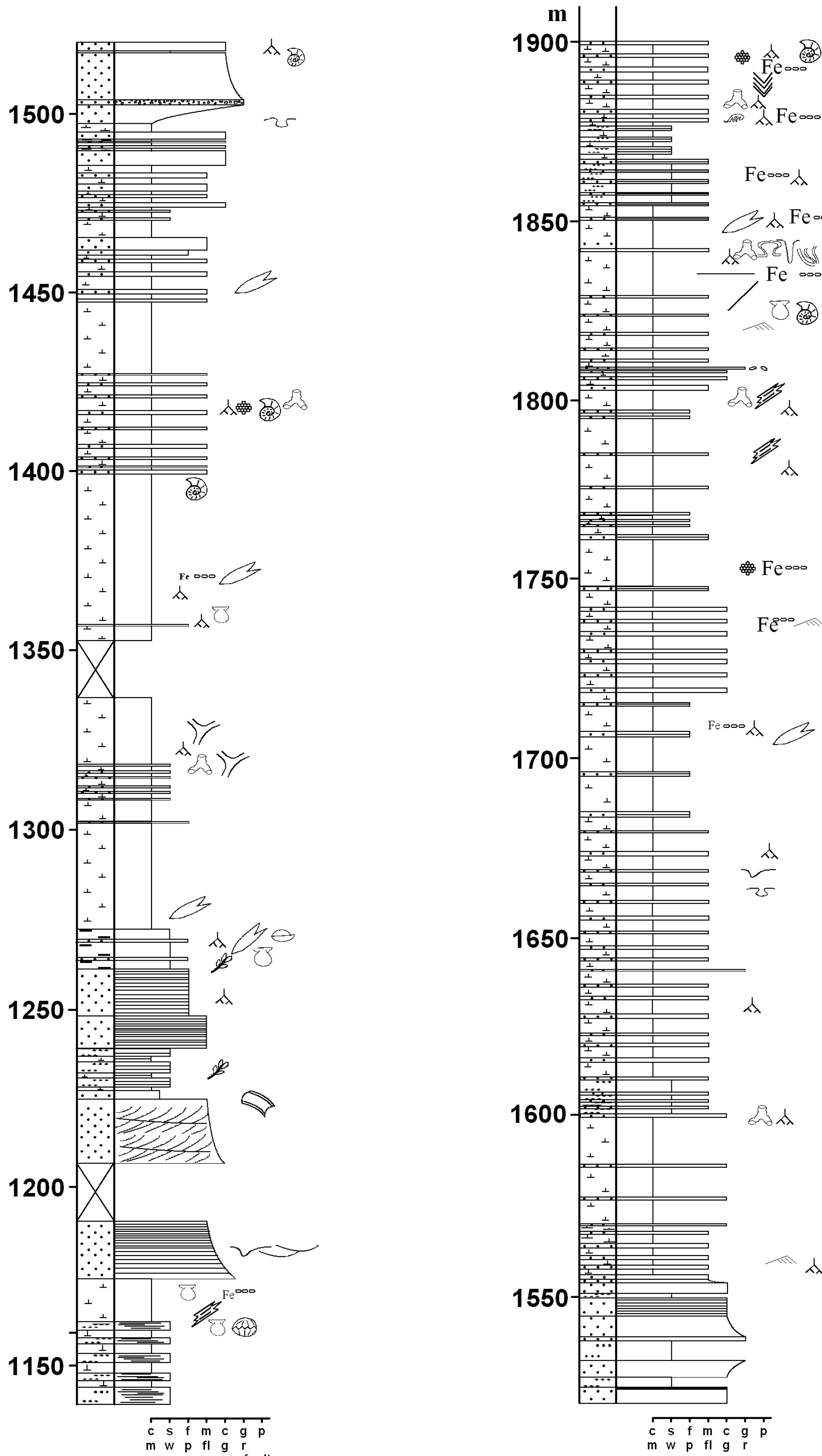

m
1500
1450
1400
1350
1300
1250
1200
1150
1900
1850
1800
1750
1700
1650
1600
1550
Fe
c s f m c g p
m w p fl g r
fault

Fig. 3.46. Cont.

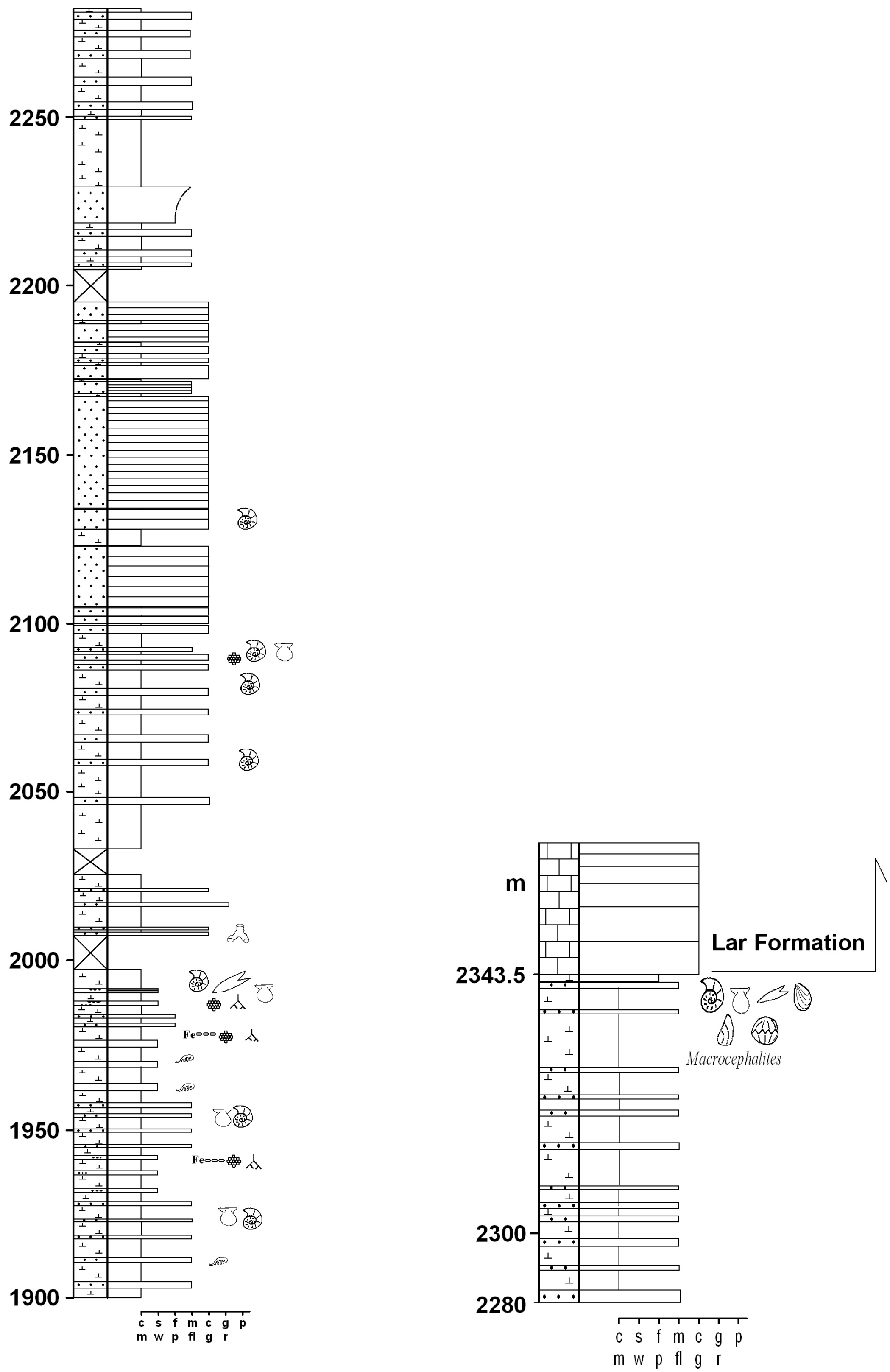

2250
2200
2150
2100
2050
2000
1950
1900
Fe
c s f m c g p
m w p fl g r
m
Lar Formation
2343.5
Macrocephalites
2300
2280
c s f m c g p
m w p fl g r

**Fig. 3.46. Cont.**

From 1984 m onwards bioclasts start to appear (Fig. 3.45M). They are also visible, for example, at 2099 (Fig. 3.45N). At 2300 m, at the top of the section, peloids and ooids occur in the sandstones (Fig. 3.45O).

Within the marine part of the Fraizi section the segment from 1160-1560 m is more marly whereas higher up sandstone beds are more common than marly interbeds (Fig. 3.46). Bioturbation is quite common and trace fossils are well preserved. Characteristic ichnogenera are *Ophiomorpha*, *Thalassinoides, Curvolithus*, *Zoophycos*, *Chondrites*, *Diplocraterion,* and *Paleodictyon*.

### 3.10 Torbat-e-Jam section

The Torbat-e-Jam section was measured near the abandoned Gol Banu coal mine, north of Torbat-e-Jam (Fig. 3.47). It is the southeastern-most locality of the study area. The Kashafrud Formation overlies the Torbat-e-Jam granite (Figs. 3.48, 3.49A) and starts with a microconglomerate to pebbly sandstone (Fig. 3.49B).

As the Kashafrud strata are folded and faulted in this area only the lowermost part of the succession has been measured. These lower strata are fossiliferous and contain scattered brachiopods, corals, gastropods, belemnites, ammonites, and wood fragments. Occasionally the size of the wood pieces reaches 25 cm in diameter and a length of more than one metre (Fig. 3.50). Rarely some sandy fossiliferous limestone is encountered at this locality (Fig. 3.49C).

In this area mafic and diabasic lavas are intercalated between the beds of the Kashafrud Formation and show evidence of submarine flows. This suggests the existence of synsedimentary volcanism during the Middle Jurassic in the Kashafrud Basin (Fig. 3.49D-E). This aspect will be more closely discussed in Chapter 8.

The basal coarse-grained and pebbly sandstone units, which represent nearshore, shallow marine deposits, fine upwards into an alternation of turbiditic sandstones and silty shales indicating rapid deepening of the basin. Graded bedding in the lower unit is of tempestite rather than turbidite origin (Fig. 3.49F).

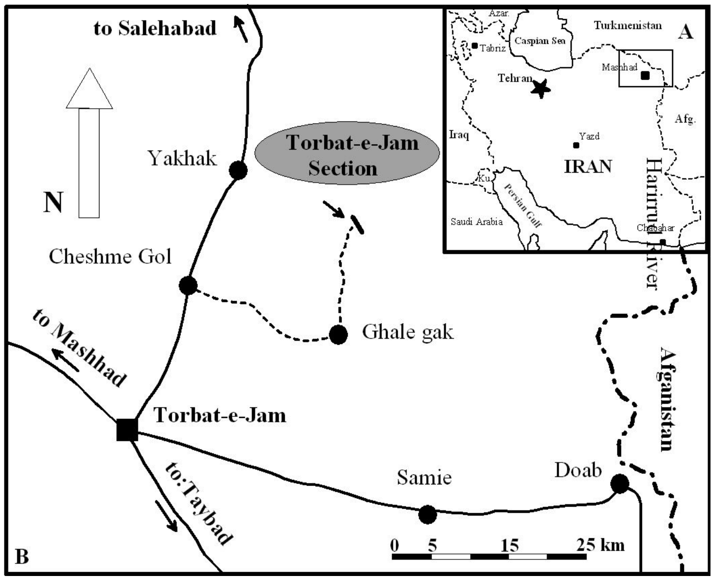



Fig. 3.47. Position of the study area (A) and locality of the Torbat-e-Jam section (B).

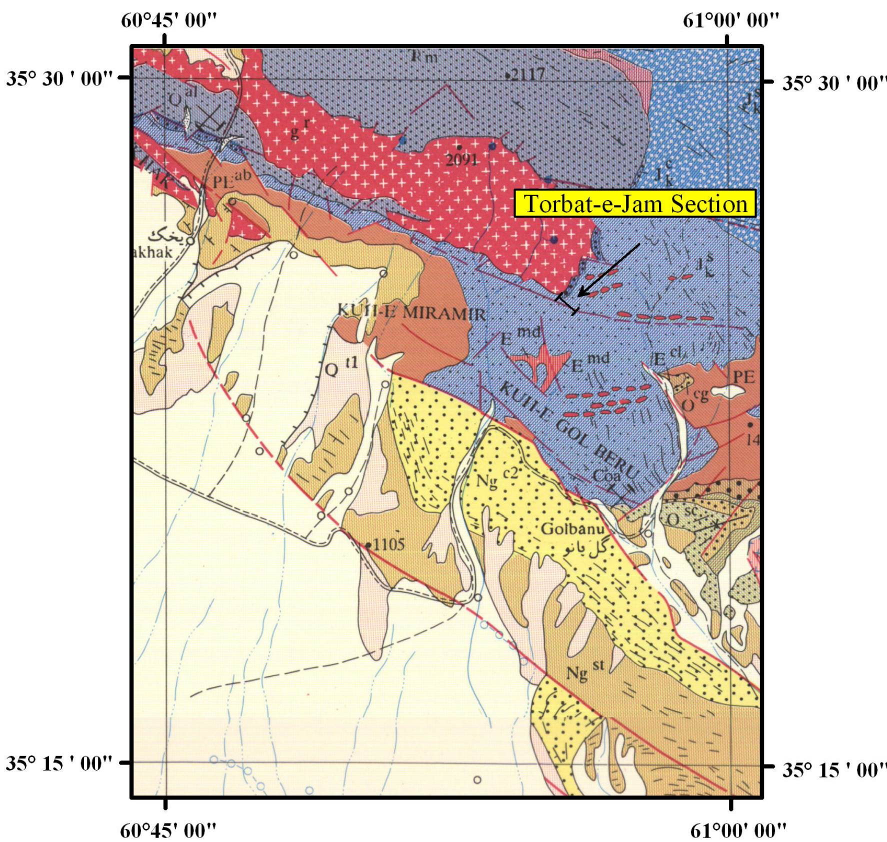
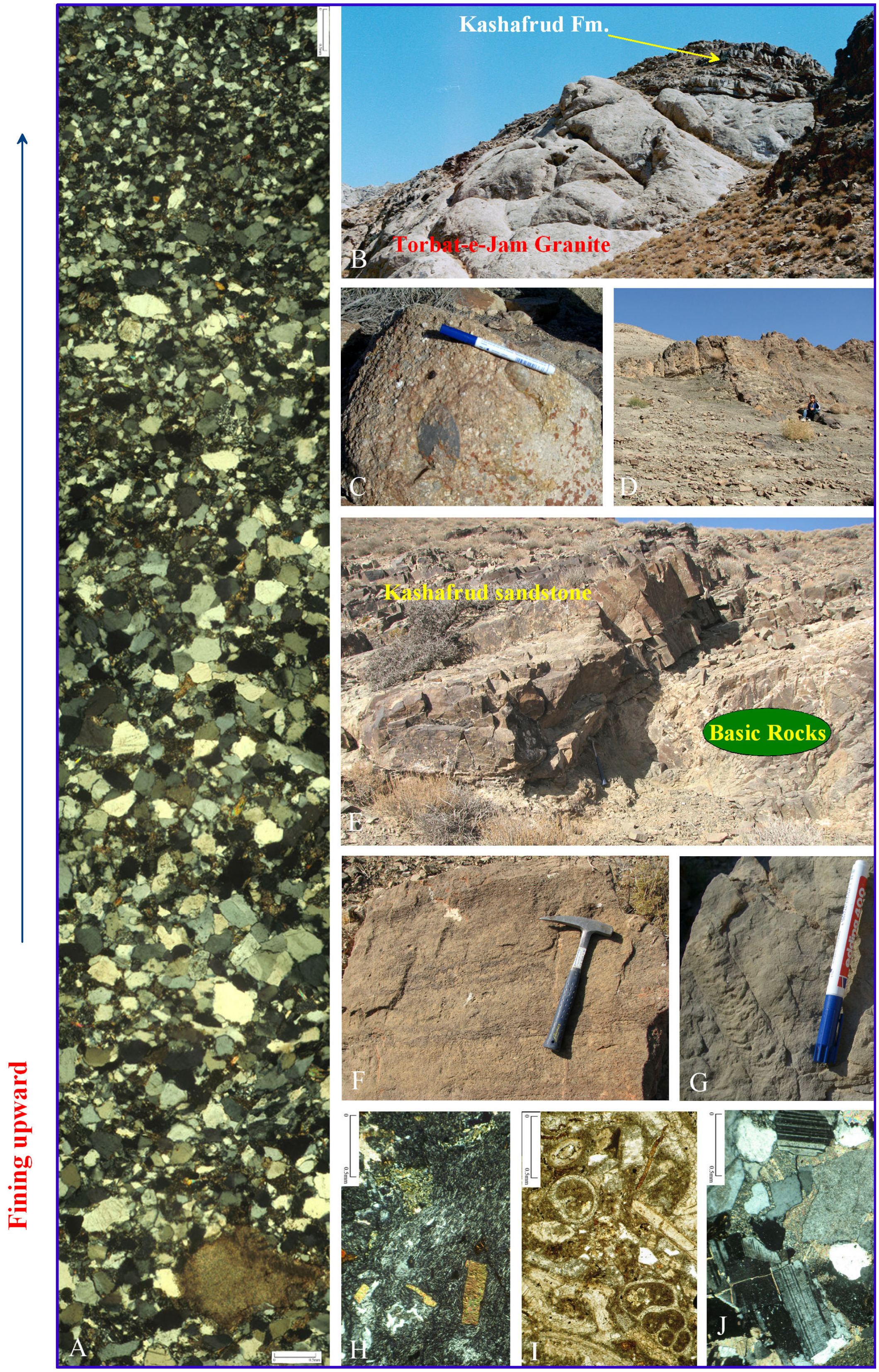



Fig. 3.48. Geological map of the Torbat-e-Jam area at the scale 1:250,000 (part of the Torbat-e-Jam sheet; EFTEKHARNEZHAD & BEHROOZI, 1993).

Trace fossils such as *Ophiomorpha, Thalassinoides, Gyrochorte, Planolites,* and *Diplocraterion* are seen in the shallow marine succession, whereas *Neonereites* occurs in the turbiditic upper part.

Fig. 3.49. Features of the Kashafrud Formation at Torbat-e-Jam. **A**. Thin-section of graded sandstone at 255 m. **B**. Basal micro-conglomerate and pebbly sandstone overlying Torbat-e-Jam Granite. **C**. Pebbly sandstone with bivalve *Fimbria* in the lower part of the section. **D**. Diabasic dyke with lateral outflow. **E**. Sandstone overlying mafic rocks; hammer as scale. **F**. Sandy fossiliferous limestone above the volcanic rocks. **G**. *Ophiomorpha*; length of marker pen 14.5 cm. **H**. Thin-section of trachy-andesite; at around 165 m. **I**. Sandy bio-oo-sparite at 48.5 m. **J**. Thin-section through medium- to coarse-grained calcareous litharenite at 248 m. →


Fining upward
A
Kashafrud Fm.
Torbat-e-Jam Granite
B
C
D
Kashafrud sandstone
Basic Rocks
E
F
G
H
I
J

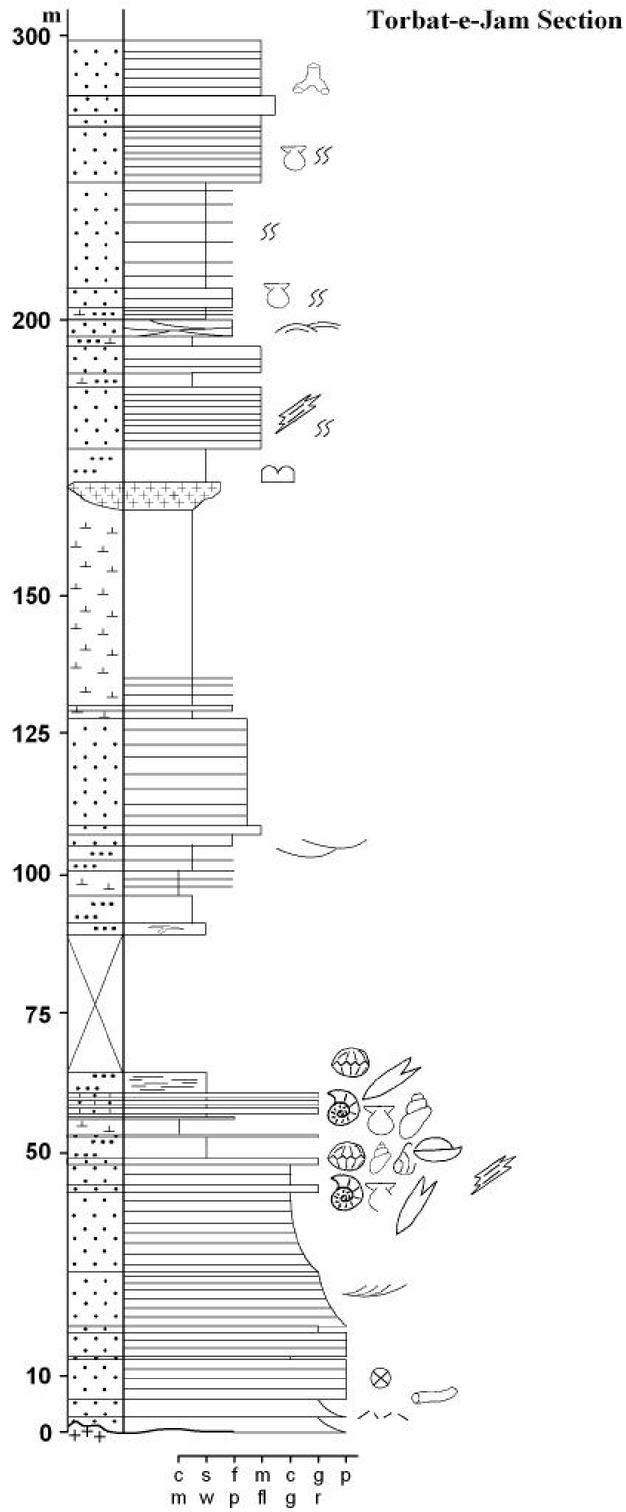



Fig. 3.50. Lithology of basal Kashafrud Formation in the Torbat-e-Jam area. For key of symbols see Fig. 3.51.

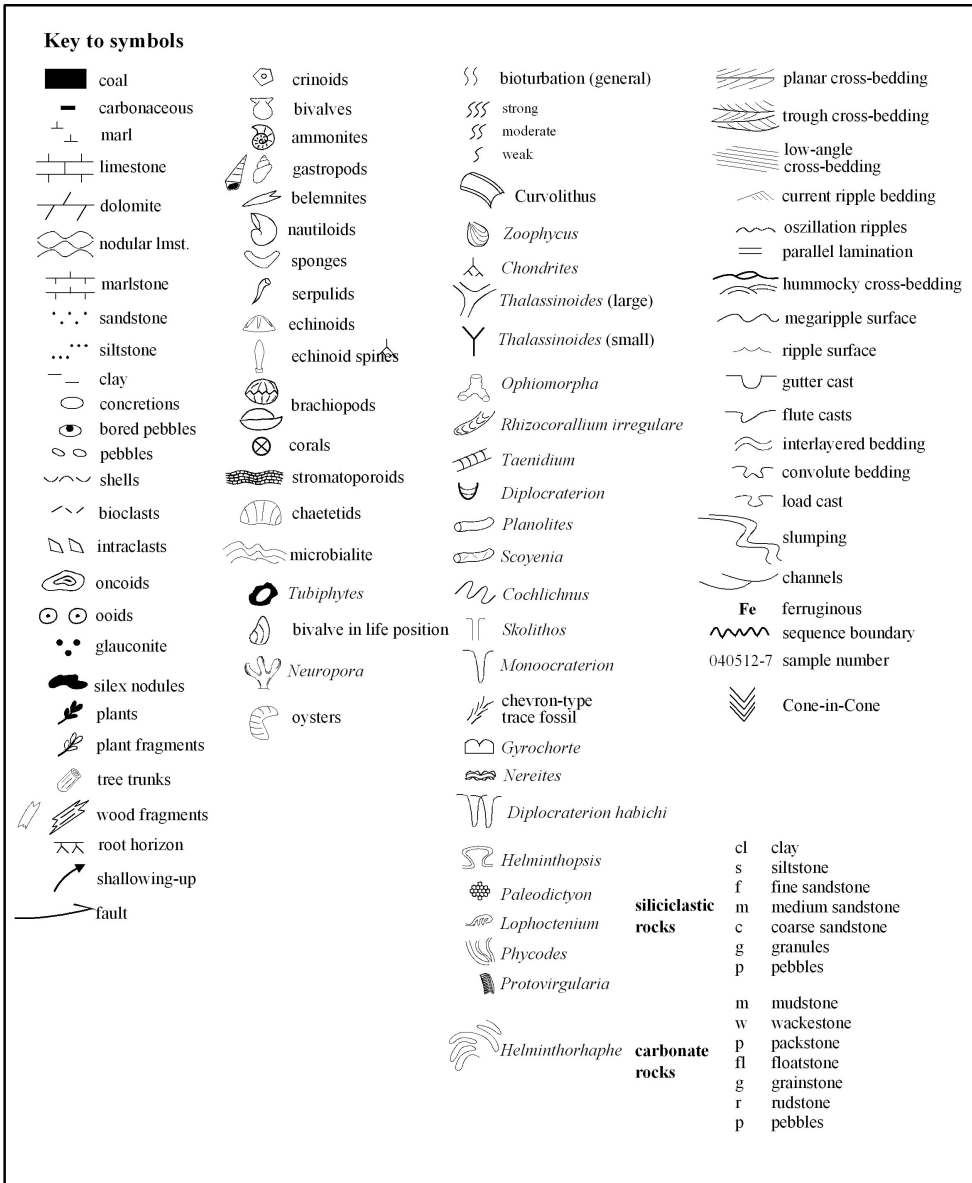



**Fig. 3.51. Symbols**

**4. Biostratigraphy**

Several studies, most of them master thesis dealt with the biostratigraphy of the Kashafrud Formation (SEYED-EMAMI et al., 1994, 1996; HOSAINIUN 1996; FRAIZI KERMANI 2001; SANAIE 2001; DEH BOZORGI 2004; HADDAD TAVAKOLI 2005).

Before discussing the biostratigraphy of the Kashafrud Formation in detail, the biostratigraphy of the remaining Upper Triassic-Lower-Middle Jurassic rock succession is reviewed as it provides a key for the geodynamic interpretation of the study area. These rock units are:

1) Mashhad Phyllite;
2) non-marine, non-metamorphosed Lower-Middle Jurassic siliciclastic rocks;
3) the Late Bajocian-Late Bathonian Kashafrud Formation.

**Mashhad Phyllite**

The Binalud Mountains comprise mostly thick, folded, and faulted, low-grade metamorphic rocks (phyllite and slate) which crop out in a vast region between Mashhad and Neyshabour. They have been tentatively placed in the Upper Triassic to Lower Jurassic (AGHANABATI 1986).

WENDT et al. (2005) discovered in the basal shales of the Mashhad Phyllite (as he mentioned), a flora of abundant *Clathropteris menisciodes* and *Anthrophyopsis crassinervis* (determined by H. T. SCHWEITZER, Bonn), which indicate a late Rhaetian age for the base of the unit. The same taxa as well as *Dictyophyllum* sp., *Nilssonia brongniarti*, *Phlebopteris* cf. *polypodioides*, *Podozamites* sp., and *Clathropteris* cf. *meniscoides* were recently reported from the Mashhad Phyllite by AKRAMI, & NAIMI (in press). Based on these finds, at least a Late Rhaetian age for a part of the Mashhad Phyllite and a Late Triassic-Early Jurassic, probably Liassic, in age for the whole lithostratigraphic unit seem likely.

**4.2 Non-marine and non-metamorphosed Lower-Middle Jurassic siliciclastic rocks**

This unit is composed of an alteration of carbonaceous shales, medium- to coarse-grained arkosic sandstones with occasionally coal lenses at (Derakht toot area, south Mashhad), and quartz conglomerates (Aghonj conglomerate). For these lithostratigraphic units, which crop out mostly in the northern domain of the Binalud Mountains and overlie the Mashhad Phyllite and some older rock units with unconformable contact (Figs. 3.45E and4.1 respectively), clearly more precise biostratigraphic data are needed. However, the above mentioned biostratigraphic evidence shows that they are not as young as the Kashafrud Formation but younger than the Mashhad Phyllite and should be part of the Shemshak Group.

The palynological analysis of spot samples yielded pollen and spores that range from the uppermost Triassic to the Middle Jurassic (Table 4.1).

Table 4.1. Microfloral composition of some selected samples from the non-metamorphosed Lower-Middle Jurassic strata at the south of Mashhad area.

| **Sample No.** | **Pollen/Spores/Dinoflagellates** | **Age** |
|---|---|---|
| **06.10.04-5** | **Spore**: *Dictyophylidites harrisii* | Rhaetian-Middle Jurassic |
| **06.10.04-6** | **Spores**: *Cyathidites mesozoicus, Dictyophylidites* sp.<br>**Pollen**: *Cycadipites follicularis* | Lower-Middle Jurassic |
| **06.10.06Ni** | **Dinoflagellates**: *Scriniocassis weberi, Nannoceratopsis* cf. *ambonis*<br>**Spore**: *Cyathidites mesozoicus*<br>**Pollen**: *Cycadopites follicularis* | Middle Jurassic |

All specimens in Table 4.1 were collected during 2006. New samples, taken in the summer of 2008, yielded the following spores and pollens (determined in GSI by B. FARAHANI):

Spores:

*Cyathidites mesozoicus*

*Concavisporites kaiseri*

*Dictyophyllidites mortonii*

*Leiotriletes mesozoicus*

*Biretisporites* sp.

*Concavissimisporites* sp.

*Concavisporites* sp.

*Deltoidospora* sp.

Pollen :

*Cycadopites follicularis.*

Based on these data the non-marine non-metamorphosed rock units in this area are dated as Early Jurassic.

AKRAMI (2008) recorded the following spores recovered from the Paye geological sheet at scale of 1:25000 (determined by B. FARAHANI & SABOURI, GSI) and assumed an Early-Middle Jurassic age for the rock unit:

*Tsugaepollenites dampleri*, *Cyathidites mesozoicus*, *Cyathidites concavus*, *Ischyosporites variegates, Dictyophyllidites* sp., *Alisporites thomasii, Cycadopites* sp., *Duplexisporites problematicus*, *Dictyphyllidites* sp., *Leptolepidites major*, *Contignisporites* sp.. Similar spores were also found in the Shandiz area.

In addition to the above mentioned spores, some megaplant fossils have been determined by TAVAKKOLI (2006, after NAIMI; in press), such as *Phoenicopsis* sp., *Pachypteris* sp., *Conipteris* sp., *Taeniopteris* sp., *Osmundopsis* sp., *Pityophyllum* sp., *Coniopteris* cf. *hymenophylloides, Podozamites lanceolatus,* and *Frizianopteris undula.* He assigned the flora to the Late Triassic-Early Jurassic.

Evaluation of these data and especially consideration of the fact that this rock unit overlies the Mashhad Phyllite with angular unconformity suggests that this non-marine siliciclastic succession most likely corresponds to the time interval Early to early Middle Jurassic and thus to the middle and upper Shemshak Group, the coaly sequence being equivalent of the Hojedk Formation of central Iran, the plants and spores/pollen are from the Bazehowz Formation, the Arefi Formation will range into the early Lias; of Wilmsen et al., 2009a.


Fig. 4.1. Unconformity between Mashhad Phyllite and the non-metamorphosed Lower Jurassic succession in the Cortayoon area.

Recently WILMSEN et al. (2009) in their geodynamic interpretation of the sedimentary succession attributed the siliciclastic succession to the Lower-Middle Jurassic. They classified the whole succession into three formations: Arefi, Baze Hose, and Aghonj.

### 4.3 Biostratigraphy of the Kashafrud Formation

As mentioned previously, the lower part of the Kashafrud Formation contains Upper Bajocian ammonites at several localities (i.e. at Tappenader, Ghal-e-Sangi, Senjedak; HOSAINIUN, 1996; SEYED-EMAMI et al., 1994, 1996; at Baghbaghu; MADANI, 1977).

The upper part of the Kashafrud Formation has never been dated before. In the context of this study, macroinvertebrate fossils have also been collected from the lower part of the Kashafrud Formation at some other localities such as Torbat-e-Jam, Kuh-e-Radar, Fraizi, and Maiamay. The lower part of the Kashafrud Formation north of Torbat-e-Jam contains rare gastropods, and occasional bivalves (*Fimbria*), brachiopods, belemnites, corals, and also ammonites.

In the lowermost marly part of Kuh-e-Radar section the following ammonites were found: *Parkinsonia rarecostata* (BUCKMAN), *Parkinsonia acris* (WETZEL), *Adabofoloceras subobtusum,* (KUDERNATSCH), *Phylloceras* sp., *Cadomites* sp., *Holcophyloceras* sp., and *Garantiana* sp.. This fauna again confirms a Late Bajocian age for the lower part of the Kashafrud Formation. Late Bajocian ammonites were also found in the lower marine part of the Fraizi section (*Cadomites* sp.) and in member 2 of the Maiamay section.

All these data indicate a Late Bajocian age for base of the Kashafrud Formation. The top of the Kashafrud Formation has been dated at several localities such as Jizabad and the Gas-pipeline section, where a sandy brownish limestone yielded *Prohecticoceras haugi* (PROVICI-HATZEG), *Cadomites claramontanus* (KOPIK), *Procerites* sp., and *Homoeoplanulites* sp.. In the Fraizi and Kuh-e-Radar sections, the beds immediately overlying the Kashafrud formation contain the Lower Callovian ammonite *Macrocephalites*. Therefore, the upper boundary of the Kashafrud Formation can be placed in the Late Bathonian. Additional ammonites, have also been collected from within the Kashafrud Formation, and their biostratigraphic significance data are shown in Table 4.2. photographs are presented in the plates.4.1 and 4.2.

Corals occur in the lower part of the Kashafrud Formation at some localities, e.g. in the Ghal-e-Sangi and Torbat-e-Jam sections. They include *Isastrea browni* DUNCAN, 1972, *Isastrea bernardiana* D'ORBIGNY, 1850, and *Actinastrea pentagonalis* GOLDFUSS, 1829 (determination by D. K. PANDEY, Jaipur).

Table 4.2. Ammonites from the Kashafrud Formation and their biostratigraphic significance.

| **Field No:** | **Name:** | **Age:** | **identified by:** |
|---|---|---|---|
| 04, Gh, 160 | *Garantiana* sp. | Late Bajocian | M. R. Majidifard |
| 04, Gh, 215-221 | *Strenoceras* sp. | Late Bajocian | M. R. Majidifard |
| 05, To, 49 | *Microbajocisphinctes* sp. | Late Bajocian | M. R. Majidifard |
| 05, To, 61-68 | *Phylloceras* sp. | | M. R. Majidifard |
| 05, M, 1028 | ?*Garantiana* sp. | Late Bajocian | M. R. Majidifard |
| 05, M, 1145 | *Phylloceratidae* sp. | | M. R. Majidifard |
| 05, M, 1240 | *Parkinsonia* sp. | Late Bajocian | M. R. Majidifard |
| 05, M, 1738 | *Calliphylloceras* sp. | | M. R. Majidifard |
| 05, M, 1774A | *Phylloceras* sp. | | M. R. Majidifard |
| 05, M, 1774B | ? *Procerites* sp. | Bathonian | M. R. Majidifard |
| 04, west Khij,A | *Macrocephalites* sp. | Early Callovian | M. R. Majidifard |
| 04, west Khij, B | *Homeoplanulites* sp. | Late Bathonian-Early Callovian | M. R. Majidifard |
| 04, F, 1790-1800 | *Cadomites* sp. | Bathonian | M. R. Majidifard |
| 05, R, 175 | *Cadomites* sp. | Bathonian | M. R. Majidifard |
| 04, west Khij, 14 | *Bullatimorphites* sp. | Late Bathonian | M. R. Majidifard |
| 04, F, west Khushab | ?*Choffatia* sp. | Late Bathonian | M. R. Majidifard |
| 04, Kh, 7 | *Macrocephalites* sp. | Early Callovian | M. R. Majidifard |
| 04, Kh, 13 | *Choffatia* sp. | Callovian | M. R. Majidifard |
| 04, west Khij, D | *Macrocephalites* sp. | Early Callovian | M. R. Majidifard |
| 04, west Khij, E | *Phylloceras* sp. | | M. R. Majidifard |
| 04, T, Jiz,2 | *Cadomites claramontanus* | Late Bathonian- | K. Seyed-Emami |
| 04, T, Jiz | *Homeoplanulites* sp. | Bathonian | K. Seyed-Emami |
| 05, T,S3,5A | *Prohecticoceras* sp., *Procerites* sp. | Middle-Late. Bathonian | K. Seyed-Emami |
| 05,S3,GPL,2 C, D | *Oxycerites yeovilensis* | Early Bathonian | K. Seyed-Emami |
| 05,S3,GPL,2 b | *Homeoplanulites* sp. | Bathonian | K. Seyed-Emami |
| 04, M, C1 A , B | *Prohecticoceras haugi* | Middle-Late. Bathonian | K. Seyed-Emami |

**Explanation of Plate 4.1**

Fig. 1-2. *Microbajocisphinctes* sp., at horizon 49 m of the Torbat-e-Jam section.

Fig. 3. ?*Phylloceras* sp., from lower part of the Torbat-e-jam section.

Fig. 4. *Prohecticoceras haugi*, HAUG, 1890, from the upper part of the Gaspipe-line section.

Fig. 5. ?*Garantiana* sp., Is found at horizon 1028 of the Maiamay section.

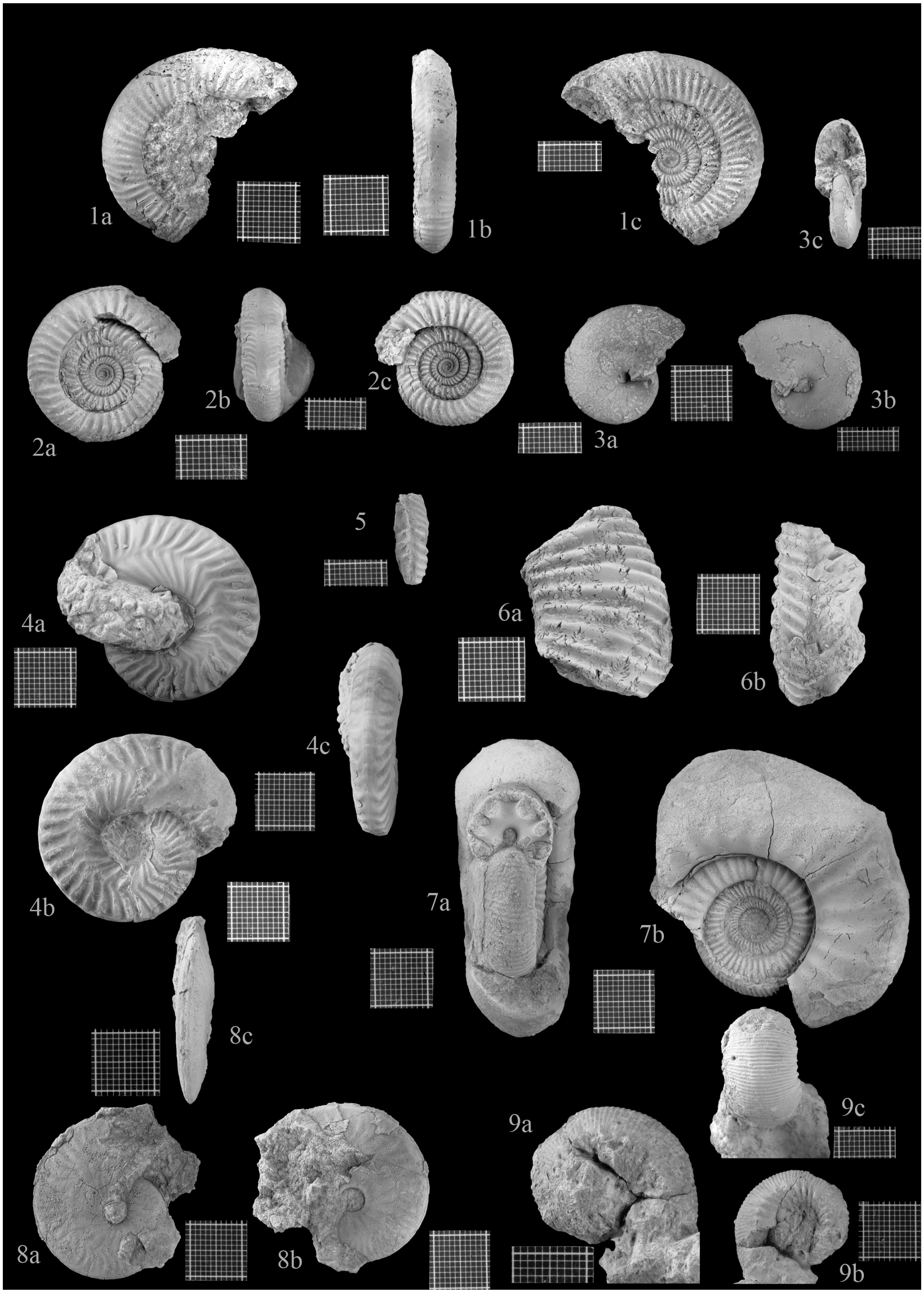
Fig. 6. *Parkinsonia* sp., from 1240 m of the Maiamay section.

Fig. 7. *Homoeoplanulites* sp., upper part of the Gas-pipe line section

Fig. 8. *Oxycerites yeovilensis*, ROLLIER 1909 from the upper part of the Gaspipe-line section.

Fig. 9. *Cadomites claramontanus*, upper part of the Jizabad section, near Tappenader scale: 1 cm.

**Plate 4.1**



**Explanation of Plate 4.2**

Fig.1. *Strenoceras* sp. FROM THE Kuh-e-Radar section at 175 m.

Fig. 2. *Garatina* sp., lower part of the Kuh-e-Radar section.

Fig.3. *Cadomites* sp., from the Kuh-e-Radar section at 175 m.

Fig. 4. *Prohecticoceras acris* HAUG, 1890 from the upper part of the Gas-pipeline section.

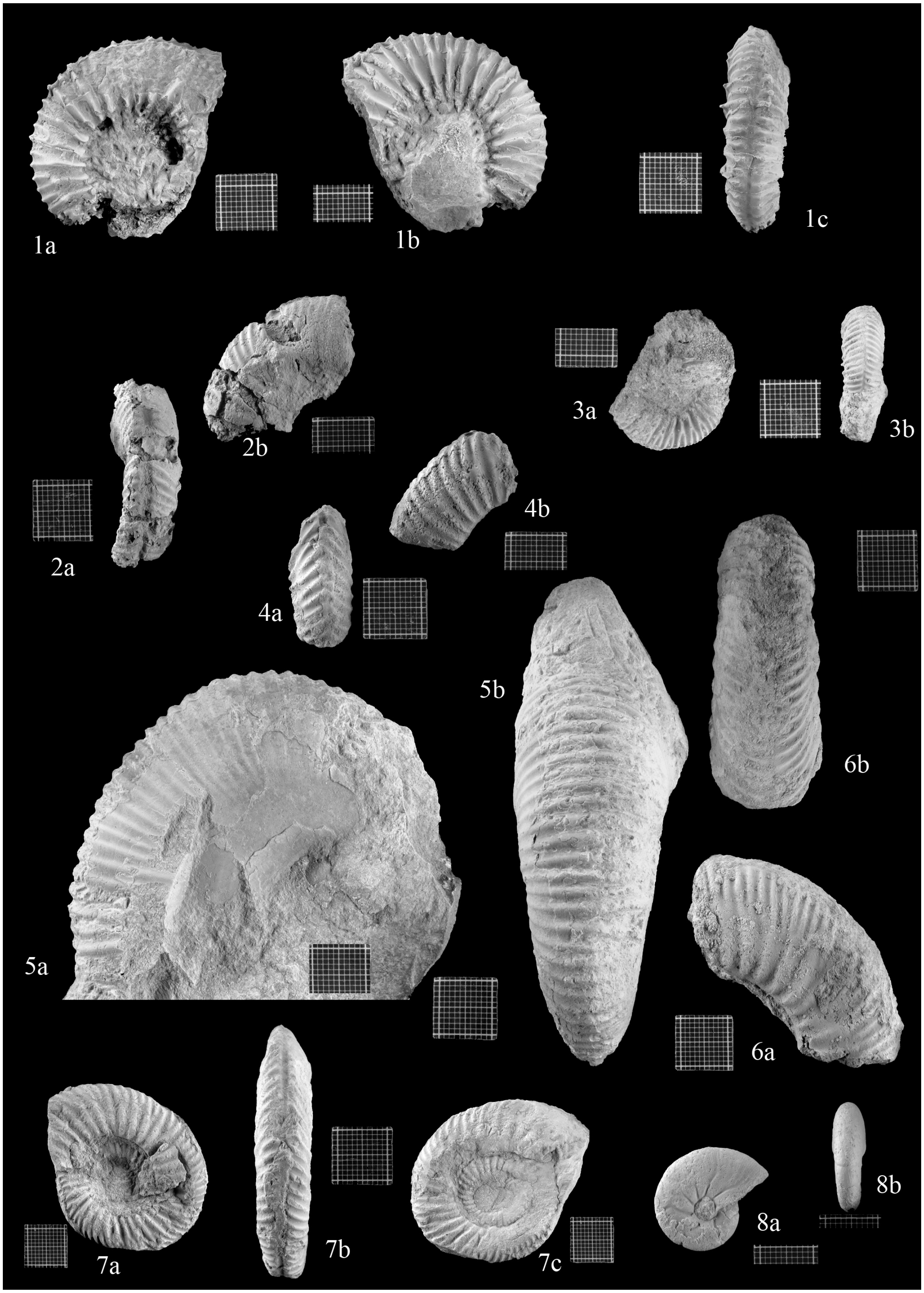
Fig. 5. *Adabofoloceras subobtusum* KUDERNATSCH, 1851 lower part of Kuh-e-Radar section.

Fig. 6. *Parkinsonia rarecostata* BUCKMAN 1881, from the lower part of Kuh-e-Radar section.

Fig. 7. *Parkinsonia parkinsoniy* SOWERBY, 1821, from the lower part of the Kuh-e-Radar section

Fig. 8. *Holcophylloceras* sp., from the lower part of the Kuh-e-Radar section.

**Plate 4.2**



**5. Facies association & Sedimentary Environment**

5.1 Preface

The Kashafrud Basin represents several sub-environments, which replace each other in two directions (S-N and W-E), whereby the general deepening trend is towards north. Field observations showed that the basin extended from the study area in a westerly direction for at least 300 km to Robat-e-Gharabill, and south to south-westwards towards the Bojnord area. In the present study only the sedimentary succession that crops out SW of Mashhad (Fraizi area) to the area north of Torbat-e-Jam, near the Afghanistan border, is discussed. The regional extension of the basin will be discussed briefly at the end of this chapter.

Environments represented by the Kashafrud Formation range from alluvial fans and braided rivers in the lowermost part of the Fraizi area to deltas, a narrow, storm-dominated shelf, slope, and a deep-marine basin. In the latter, turbidites, monotonous siltstones, and mudstones prevail. Among the turbiditic units proximality trends could be differentiated based on locality and distance from the shelf-break. Thickness and facies of the Kashafrud Formation vary strongly between localities and reflect basin morphology and submarine topography, and finally the effect of tectonic movements. In addition, sea-level fluctuations appear to have shaped the lithofacies of the Kashafrud Formation.

In the following, the various sedimentary environments represented by the Kashafrud Formation and diagrammatically shown in Fig. 5.1 will be reviewed.

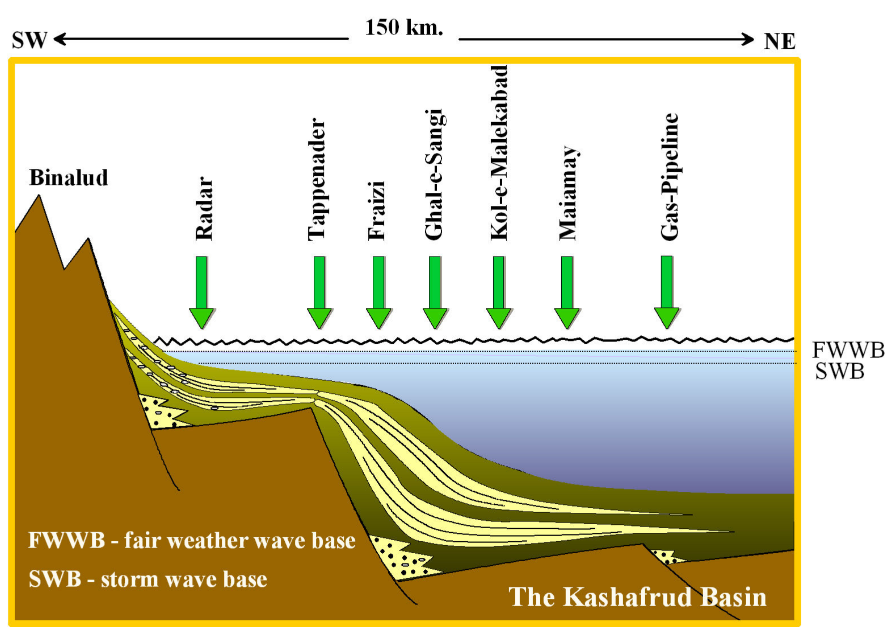



Fig. 5.1 General model for the Kashafrud Basin (modified after Taheri et al., 2009).

**5.2 Alluvial fan and braided river**

A relatively thick succession of alluvial fan and braided river sediments crops out in the area between Golmakan towards Fraizi. Although these rocks are not completely in the frame of our study (Kashafrud Basin), I shall briefly discus their characters for the following reasons:

- The non-metamorphosed Jurassic succession, which is exposed in the Fraizi area, starts with an unconformable basal conglomerate (alluvial fan deposits) that overlies the Mashhad Phyllite with angular unconformity and is followed by a considerable thickness of braided river sediments before the Upper Bajocian marine silicicalastic sequence starts. At this locality no angular unconformity could be recognized between this marine Upper Bajocian-Upper Bathonian unit and the underlying non-marine deposits.
- Regardless of the stratigraphic setting, the alluvial sediments unconformably overlying older rocks represent either the Early-Cimmerian or the Mid-Cimmerian tectonic event, both of which play an important role in the reconstruction of the geodynamic setting of the study area. For this reason, it is important to pay attention to the sedimentary characters of the unit.
- It seems that the succession as seen today is sandwiched between the Binalud Mountains and the Palaeothetys remnants and also the Mashhad Granite (Fig. 5.2). It is mostly folded and occasionally faulted in the south-eastern part, but in the Fraizi area the tectonic disruption of the succession decreases. Another major feature of this area is a sequence of typical braided river sediments that crop out across a large area, from east of Fraizi towards the village Golmakan.

A possible interpretation of these non-marine strata is that they are post Mid-Cimmerian sedimentary rock unit, which formed a fluvial system in the southwestern part of the Kashafrud Basin. Evidence in support of this view are somewhat doubtful Middle Jurassic plant fossils (*Klukia* sp.) that are determined by I.A DABRUSKINA (AGHANABATI, 1998). However, more trustable biostratigraphic data are needed in order to solve the age of this rock unit.

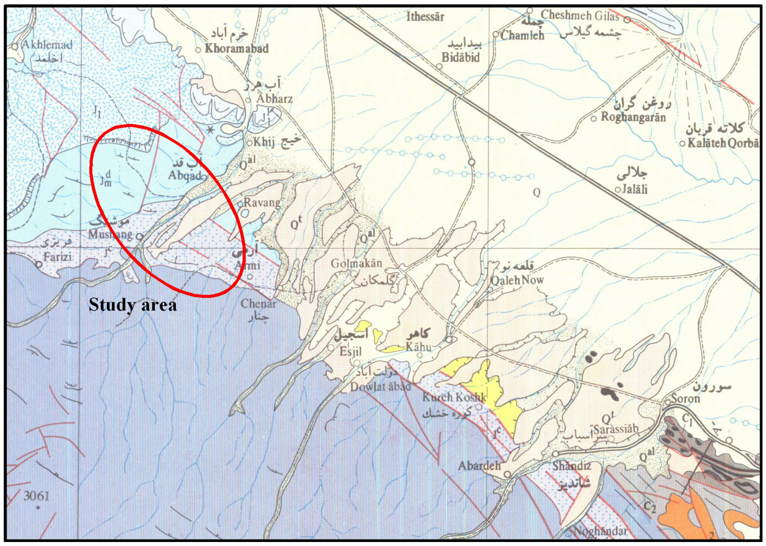



Fig. 5.2. The study area west of Mashhad (part of the Mashhad geological sheet at the scale of 1:250.000; AGHANABATI 1986).

### 5.2.1 Alluvial fan deposits

Rocks of this facies association occur in the lower part of the Fraizi section and include boulder beds, conglomerates and largely coarse-grained, arkosic sandstones. The composition of pebbles, cobbles and boulder-sized components varies according to source rocks (Fig. 5.4A).

The conglomerates are poorly sorted and have an arkosic sandstone matrix. At the west of Fraizi, 40 m of light-grey pebbly kaolinitic sandstones and conglomerates (components: milk quartz, metamorphic rocks, greywacke) overlie a 0-50 m thick reddish, mostly metsandstones, boulder bed and conglomerates. At the same time, an about 300 m thick boulder bed and conglomerate overlies the Mashhad Phyllite SE of Fraizi, which probably also belongs to the basal Kashafrud Formation.

The boulder beds, conglomerates, and pebbly sandstones are interpreted as debris flows and mudflows of proximal alluvial fans (Fig. 5.3). Their rapid lateral and vertical changes in facies and thickness suggest that deposition was largely fault-controlled. The thick stack of poorly sorted arkoses and conglomerates near Fraizi represent the distal equivalents of the proximal alluvial fans, which grade into braided river systems basinward.

Fig. 5.3 Alluvial fan conglomerate in south of the Hasan Aghe area.

Although the relationship of the thick conglomerate unit and the overlying packages of coarse-grained arkosic sandstone unit (Fig. 5.4C-D) with the Kashafrud Formation is not documented by index fossils (plant fossils occurring in the lower part of the arkosic sandstones were not diagnostic enough to yield a precise age - Fig. 5.4B), I tentatively place this unit at the base of the Kashafrud Formation because there is no sign of any unconformity or any other distinct change between the non-marine and the marine Bajocian-Bathonian part of the succession in the Fraizi area. It may well be that a large fluvial system entered the basin in the area and that the supply of sediment kept pace with the high subsidence level.

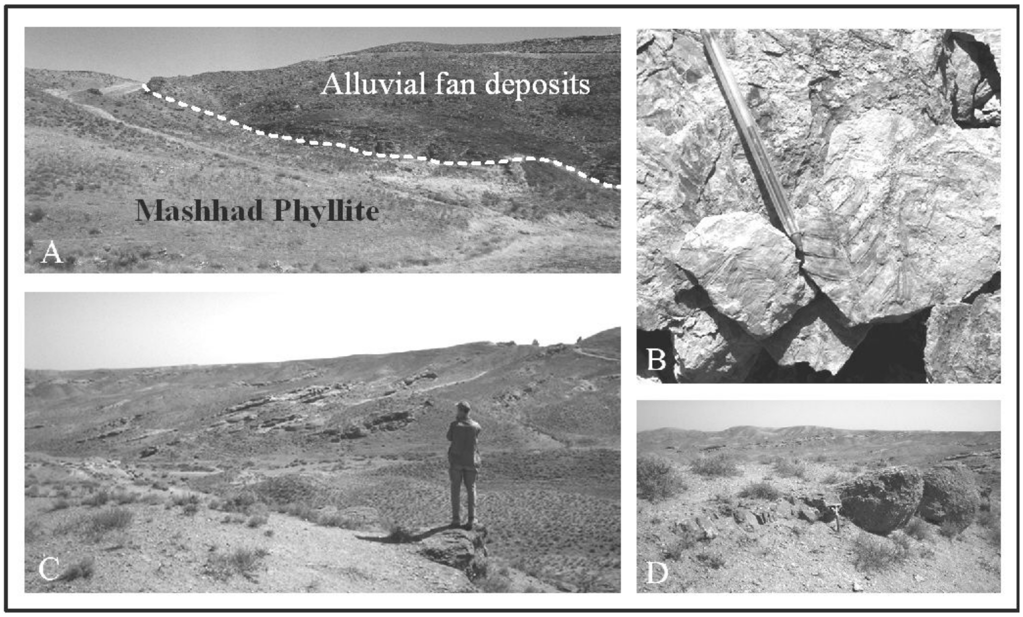



Fig. 5.4. Features of non-marine Jurassic succession in the Fraizi area. **A**. Basal conglomerate overlying the Mashhad Phyllite with angular unconformity. **B**. Plant fossils at 526 m, in fine-grained argillaceous silty sandstones. **C**. General view of braided river succession. **D**. Pebbly sandstone and micro-conglomerate with small channel structures at 162 m.

### 5.2.2 Braided River deposits

#### Lithofacies

This part of the Fraizi section is about 541 m thick and overlies the alluvial fan deposits and underlies the delta sediments with conformable contact. In general, this sequence includes of 25 minor cycles which range in thickness from 10.2 to 60.8 m, but most of them are around 30 m thick (see lithology, Fig. 5.6).

The lithofacies of these different units are mainly composed of three major lithofacies including conglomerate-dominated facies (Gm, Gt, Gp), sandstone (St, Sl, Se) and fine-grained siliciclastic rocks (mudstone, siltstone, and fine-grained sandstone).

<u>Conglomerate-dominated facies (Gm, Gt, Gh)</u>

Massive or crudely bedded conglomerates (Gm), occasionally more than 10 m in diameters. The components are mostly 1-2 cm in diameter but pebbles with a diameter of 3-5 cm were rarely observed. Horizontal bedding (Gh) and large-scale cross-bedding (Gt) also occur. Bed thickness ranges from 1 to 13.5 m, but occasionally thicker beds occur in the lower part of the section.

Thickness, grain size, and also the scale of the geometry decrease up-section, but locally coarser-grained or thicker beds are intercalated between finer- and thinner-bedded conglomerate units.

The only biostratigraphic evidence in this part of the Fraizi section are plant fossils, which are best preserved in greenish-grey mudstone, at 526-530 m, near the Golmakan-Fraizi road. As previously mentioned, attempts to use them for determining the age of the succession were not successful, because of their low diversity.

At 586-589 m and 640-643 m the micro-conglomerates exhibit a carbonate cement (Fig. 5.5). Petrographic analysis of a sample from the lower of the two units showed both diagenetic and also primariy sources for the carbonate.

Quartz and feldspar grains which are floating in a carbonate matrix, cracks filled by sparite in the in-situ fragmented quartz grains, dissolution of plagioclase grains rims altogether are evidence of diagenetic processes leading to deposition of carbonate in the rock, whereas fine-grained carbonate clasts in adjacent grains, circular carbonate grains with radial structures of fine- to coarse crystals of calcite and questionable bioturbated structures are evidences of a primary origin for the carbonate components.

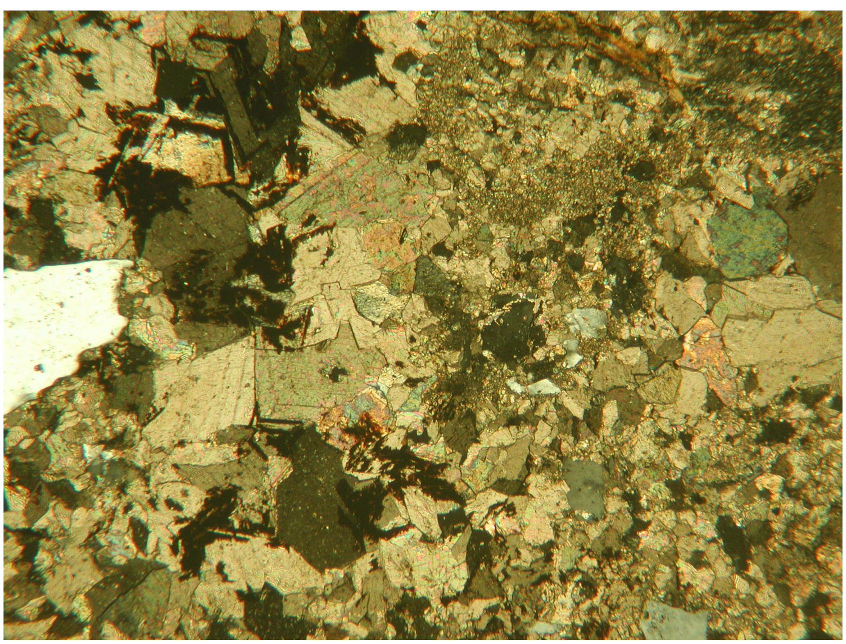


Fig. 5.5. Thin-section of specimen; shows carbonate cement and iron enrichment; Fraizi section at 586 m, S of Khoshab.

Discussion. Fluvial sediments constitute a significant part of the depositional record of the Earth's history (EINSELE, 2000). It is therefore important to study modern and also ancient fluvial sedimentary environments to understand phenomena that affected the Earth surface. Additionally, such environments are important reservoirs for hydrocarbon and ground water.

Fining- and also coarsening-upward cycles and parasequences, channel fills, bar structures, and the predominance of coarse-grained sediments are more compatible with braided river environments. At least 25 minor cycles have been distinguished in this part of the Fraizi section (Fig. 5.6).

In general, the succession is fining-upward and the amount of conglomerates and pebbly sandstones decrease up-section, although in one case (at 497 m) abruptly a conglomerate with pebbles of about 20 cm in diameter is intercalated. This can be related to a sudden increase in river discharge. However, the structureless and relatively thick unit (about 38 m), does not represent a single event but either a shift to a more humid climate or a rejuveneuation of the source area by tectonic uplift.

Except the above mentioned scenario, the general fining-upward trend most likely reflects the evolutiona of the fluvial system from a high gradient, and/or high discharge, coarse-grained bedload, and high-energy braided river system to a more stabilized, relatively low-gradient, sandy bedload river (MIALL, 1977) with occasionally high discharge.

The plant fossils show either vegetation that grew on the floodplain or on island (bars) within the braided river system. They also indicate a relatively semi-humid to humid climate in the area. Isolated, very small and localized coal veins (2-3 cm thick and less than 30 cm long) occur in several fine-grained beds within the section.

The relatively wide area within which channels shifted laterally combined with cut-and-fill structures shows that the river probably flowed in a vast valley. The relatively thick package of fluvial sediments is evidence of a high rate of subsidence and consequently ample accommodation space for a high discharge river.

The carbonate cement within microconglomerates probably is a result of pedogenic processes which are quite common in this type of environment. For instance the interweaving of ferruginous components and sparite in a chevron structure (Fig. 5.5) could represent different stages of diagenetic mineral precipitation or carbonate cement may have started as replacement rims of calcite around feldspar grains. The primary carbonate lithoclasts can attributed to a change in source area.

One should remember that tectonic activities and climatic fluctuations most likely affected the sedimentary basin.

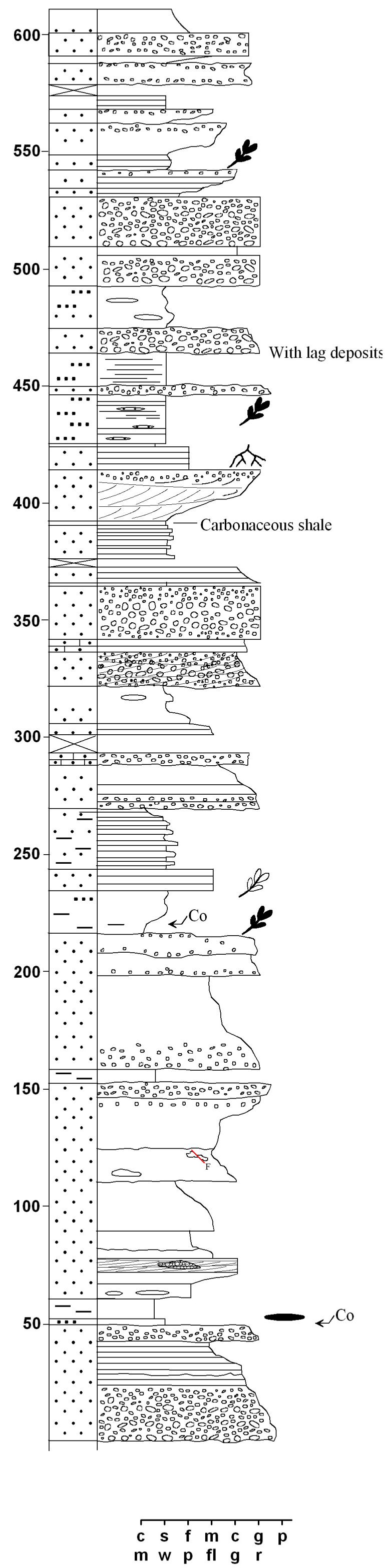



Fig. 5.6 Lithology of the braided river succession at Fraizi. Key of symbols in Fig. 3.51.

## 5.3 Deltaic deposits

Deltaic sedimentary successions were distinguished and classified based particularly on the various sedimentary processes involved, the geometry of the deposits, grain size, and the basin gradient. Based on field observations, fossil delta systems were recognized at least at two localities, one in the southwestern part of the outcrop belt at Fraizi and the other one in the central part of the southern margin of the basin at Kuh-e-Radar. These two delta systems differ in sedimentological features, time duration, and delta type, but both are very important for interpreting the facies pattern in the Kashafrud Basin and for reconstructing the palaeogeography of the area during the Middle Jurassic. The distance between the two outcrops is about 70 km (Fig. 5.7a).

In the Kuh-e-Radar area, the Kashafrud Formation is developed as an obvious fan-delta succession. Up-section it grades into the carbonate rocks of the Chamanbid Formation. The ammonite *Macrocephalites* was found in the transition zone and documents an Early Callovian age for the top of the formation.

Delta-type sediments were also recognized in the Fraizi area in the lowermost marine part of the succession. The sedimentation pattern consists of obvious coarsening- and thickening-upward packages with sedimentary structures that are characteristic of rapid sedimentation. More information on the lithofacies of these two delta-types will be found in the following.

### Fan-delta facies association (Kuh-e-Radar)

About 300 m of coarse-grained siliciclastic sediments (Fig. 3.34), mostly shallow-marine conglomerates, coarse-grained sandstones with interbeds of marl and marly silt, and occasional lenses of fossiliferous carbonate crop out on the southwestern slope of Kuh-e-Radar (Fig. 5.7B). Lithologically, this succession can be divided into at least four main lithofacies.

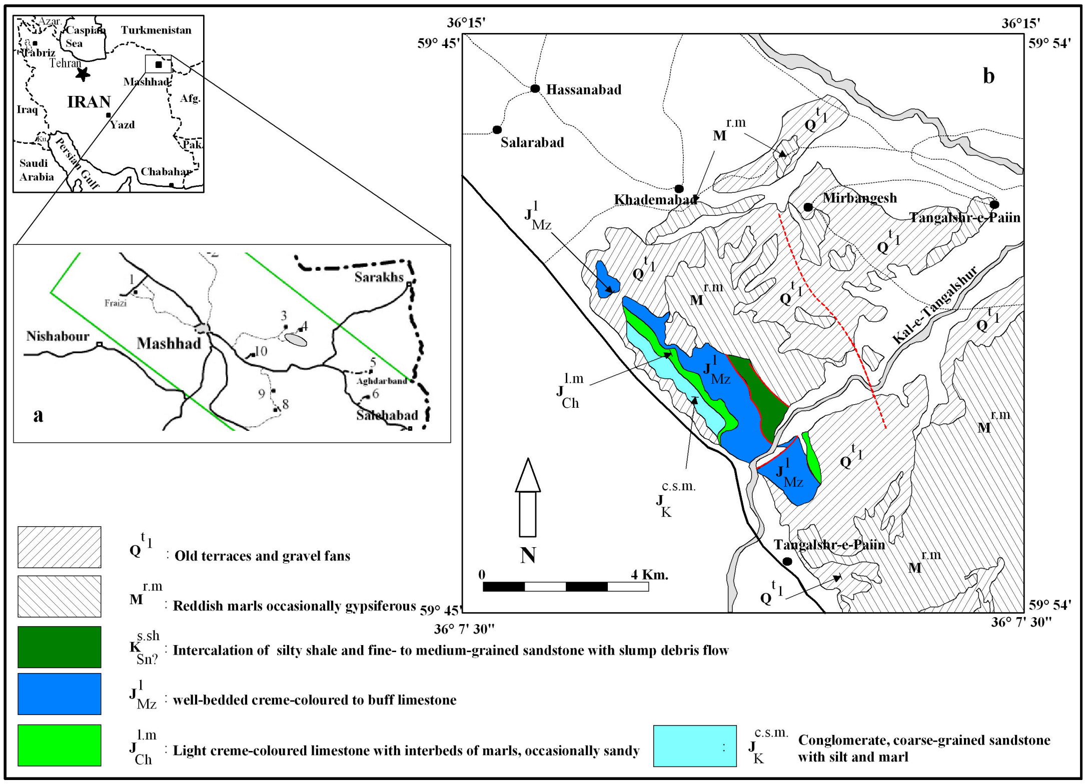



Fig. 5.7: **a**. Delta successions at localities (1) and (10). **b**. Schematic geological map of the Kuh-e-Radar area (modified after TAHERI & GHAEMI, 1994).

Lithofacies m.- This unit, about 65 m thick, forms the lowermost part of the section and consists of grey to greenish-grey marl with calcareous nodules and lenses and also coarse-grained sandstone beds (Fig. 5.9B). The ammonites *Garantiana* sp., *Parkinsonia parkinsoni* SOWERBY; *P. rarecostata* BUCKMAN, *P. acris* WETZEL and *Holcophylloceras* sp. (Chapter 4, Pls. 4.1-2) indicate a Late Bajocian age for this part of the succession.

Lithfacies Gm: This lithofacies consists of more than 1 m of thick- massive, matrix-supported, immature to sub-mature conglomerates (Fig. 5.8, Fig. 5.9G). Pebbles and cobbles composed of milky quartz, granite, aplite, pegmatite, and meta-sandstone range from about 1 cm to several dm, although boulders with a diameter of more than 1 m also exist. Wood fragments and shell fragments are also visible (Fig. 5.9E-F). The conglomerates are sharp-based and coarsen or fine upwards. Most units are related to channel structures (Fig. 5.9A).

Lithofacies Sc: This lithofacies comprises of coarse-grained, poorly sorted, subangular, pebbly sandstones, which are thick-bedded (0.5-2 m), sharp-based and rarely low-angle cross-stratified. Pebbles are mostly angular milky quartz, granitoids rocks, and sandstones. This lithofacies contains also shell fragments and wood debris.

Lithofacies S-m: This lithofacies is composed of intercalations of marl and coarse-grained sandstones, which appear from level 85 m of the section onwards (Fig. 5.9H). The sandstones coarsen upward and are more or less cemented by carbonate. Bioturbation is common. Some medium-sized to large carbonate concretions occur, which formed around wood fragments (Fig. 5.9C). The ammonites found in this unit (Fig. 5.9D) indicate a somewhat deeper condition than what one would expect for a delta front.


Fig. 5.8. Coarse-grained conglomerate at Kuh-e-Radar section. A. General view. B. Close-up view

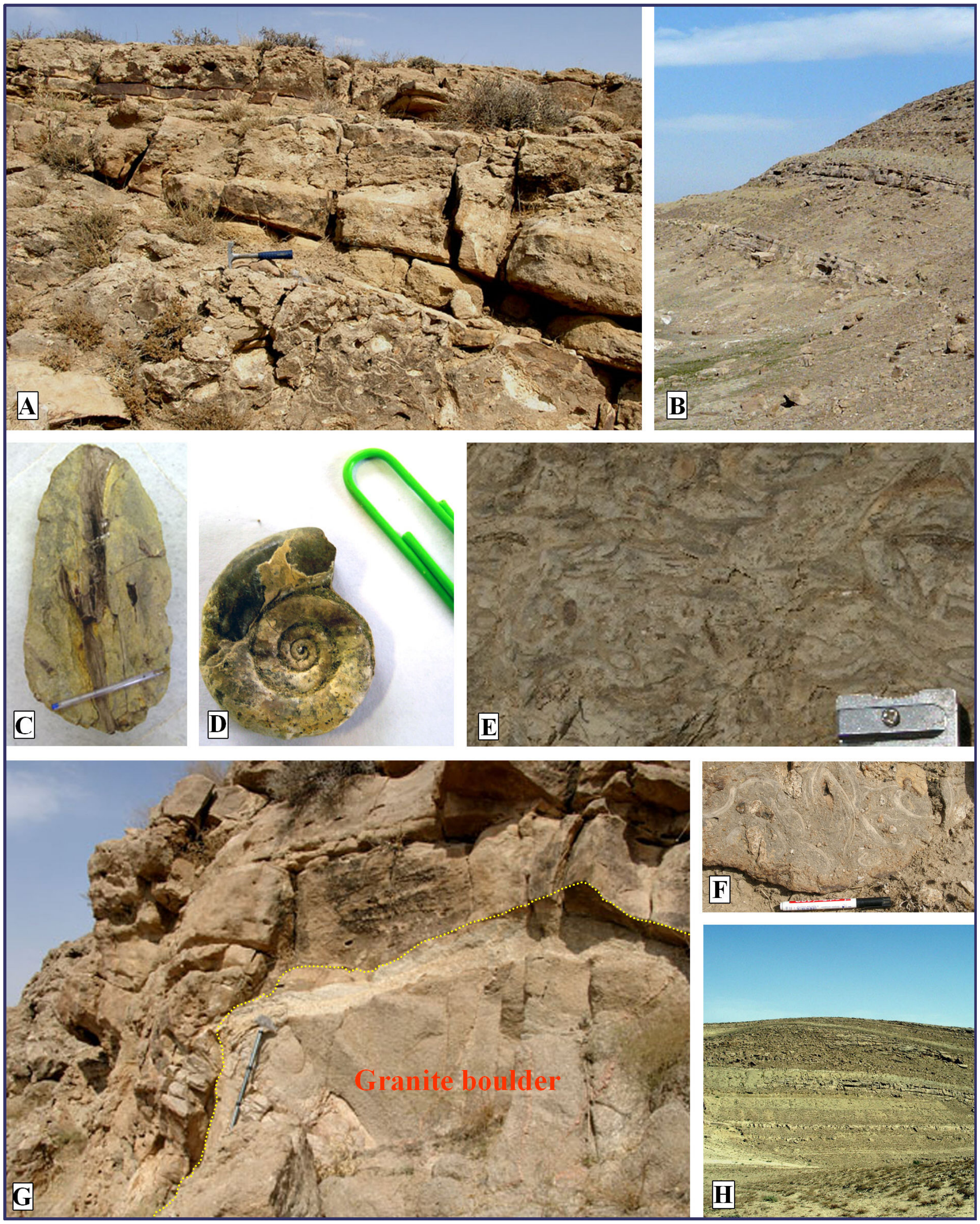



Fig 5.9. Features of the delta-related lithofacies at Kuh-e-Radar section **A**. Distributary channel deposits. **B**. Intercalation of marl and pebbly sandstones (lithofacies m), most likely representing deltafront deposits. **C**. Concretion with wood fragment at its core. **D**. Ammonite *Nannolytoceras tripartitum* in delta front sediments, lithofacies m. **E-F**. Oyster shells. **G**. Large boulder of granite, several metres in diameter, in the upper part of the deltaic unit at Kuh-e-Radar, the Jacobstaff is 150 cm long. **H**. Lobe structure in delta succession.

**Delta facies association (Fraizi area)**

East of Fraizi (Fig. 5.10), the Middle Jurassic? braided river sediments are gradually replaced by an about 300 m thick package of sandstones and micro-conglomerates. It shows a general coarsening- and thickening-upward pattern (Fig. 5.13).

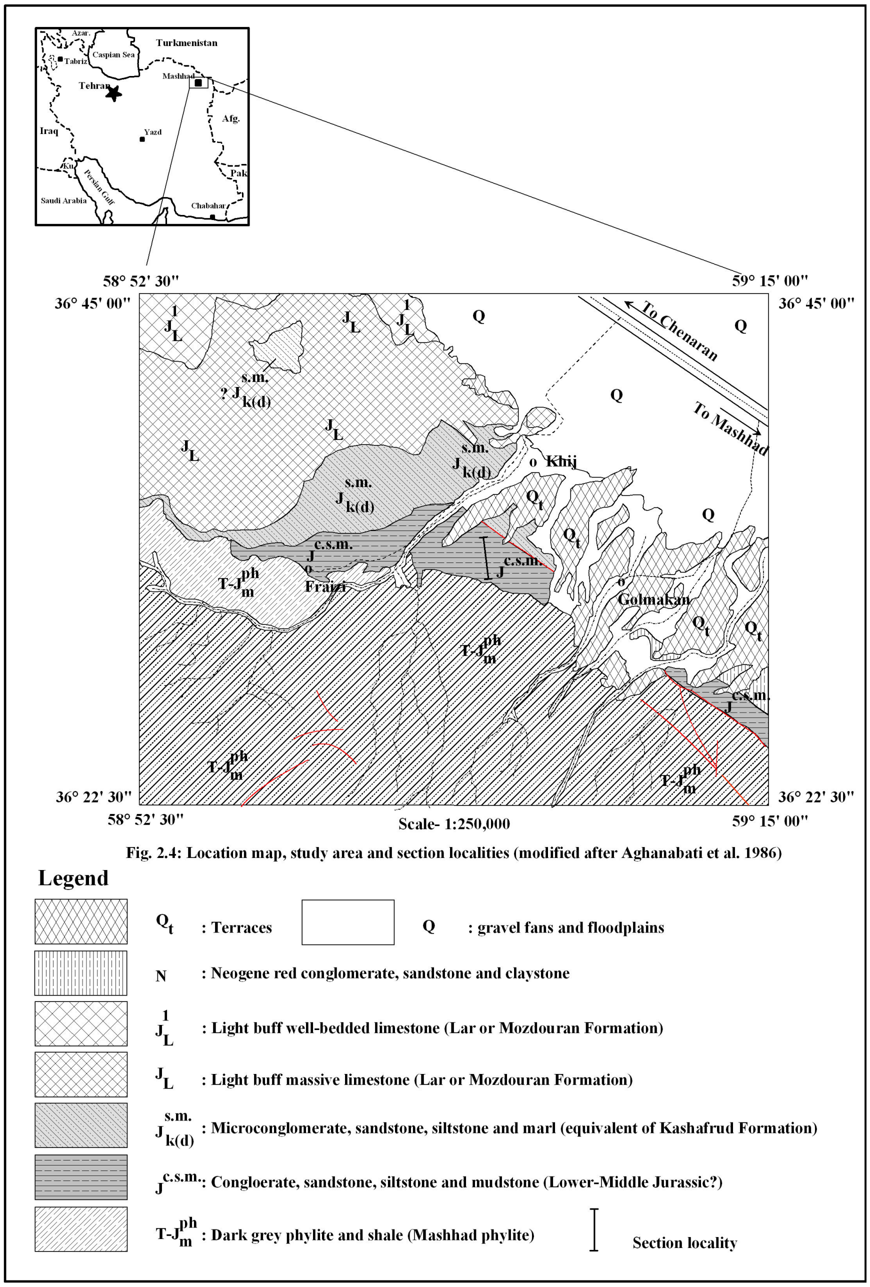



Fig. 2.4: Location map, study area and section localities (modified after Aghanabati et al. 1986)

Fig. 5.10 Schematic geological map of the Fraizi area.

The strata comprise at least 23 coarsening-upward paracycles. The cycles start with a conglomerate but in their middle and upper parts they are composed of coarse-grained pebbly sandstone and micro-conglomerate (Fig. 5.13). Wood fragments are visible in most parts of the section, but plant debris and indeterminable plant fossils are restricted to fine-grained sandstones and sandy silts.

Fig. 5.11 Pebbly sandstones and micro-conglomerates in the lower part of the delta succession in the Fraizi area.

Around 80-100 m above the base of the section, a coarsening- and thickening-upward unit exhibits huge convolute bedding, mud injections, and large-scale trough cross-stratification. These features are interpreted as having been caused by rapid sedimentation in a deltaic environment. Together with some trace fossils and bivalves they are the first evidence of marine conditions (Fig. 5.12a-d).

In the upper part of the section the succession grades into very fine-grained sandstone and then into sandy siltstone and marly silt to finally light-grey marl. Only at three levels, between horizons 87 and 135 m, intercalations of fine-grained sandstone and siltstone occur. This indicates that the condition of sedimentation remained relatively uniform at that time.

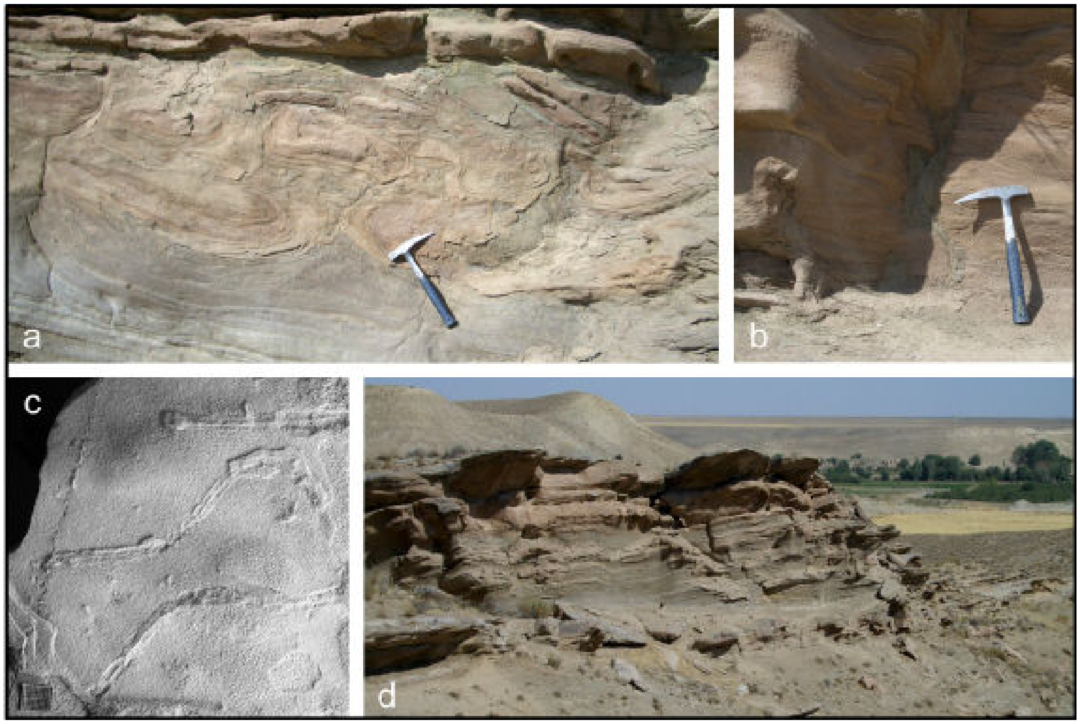



Fig. 5.12 **a**. Huge convolution bedding in delta front sandstone, Fraizi deltaic section at 80 m. **b**. Flame structure at the same level **c**. The trace fossil *Gyrochorte comosa*. Fraizi deltaic section, about 100 m above base. **d**. Delta front sandstones in the Fraizi section.

Large-scale cross-stratification occurs in some strata. In general, the lithofacies is composed of structureless conglomerates and micro-conglomerates (Gm), coarsening- and thickening-upward, fine- to medium-grained, cross-bedded sandstones with common wood fragments (Sh), medium- to thick-bedded, sharp-based, coarse-grained to pebbly sandstones (St), and sandy silt, marly silt, marl with iron concretions, and rare lenses of sandy intraclastic limestones (S-m).

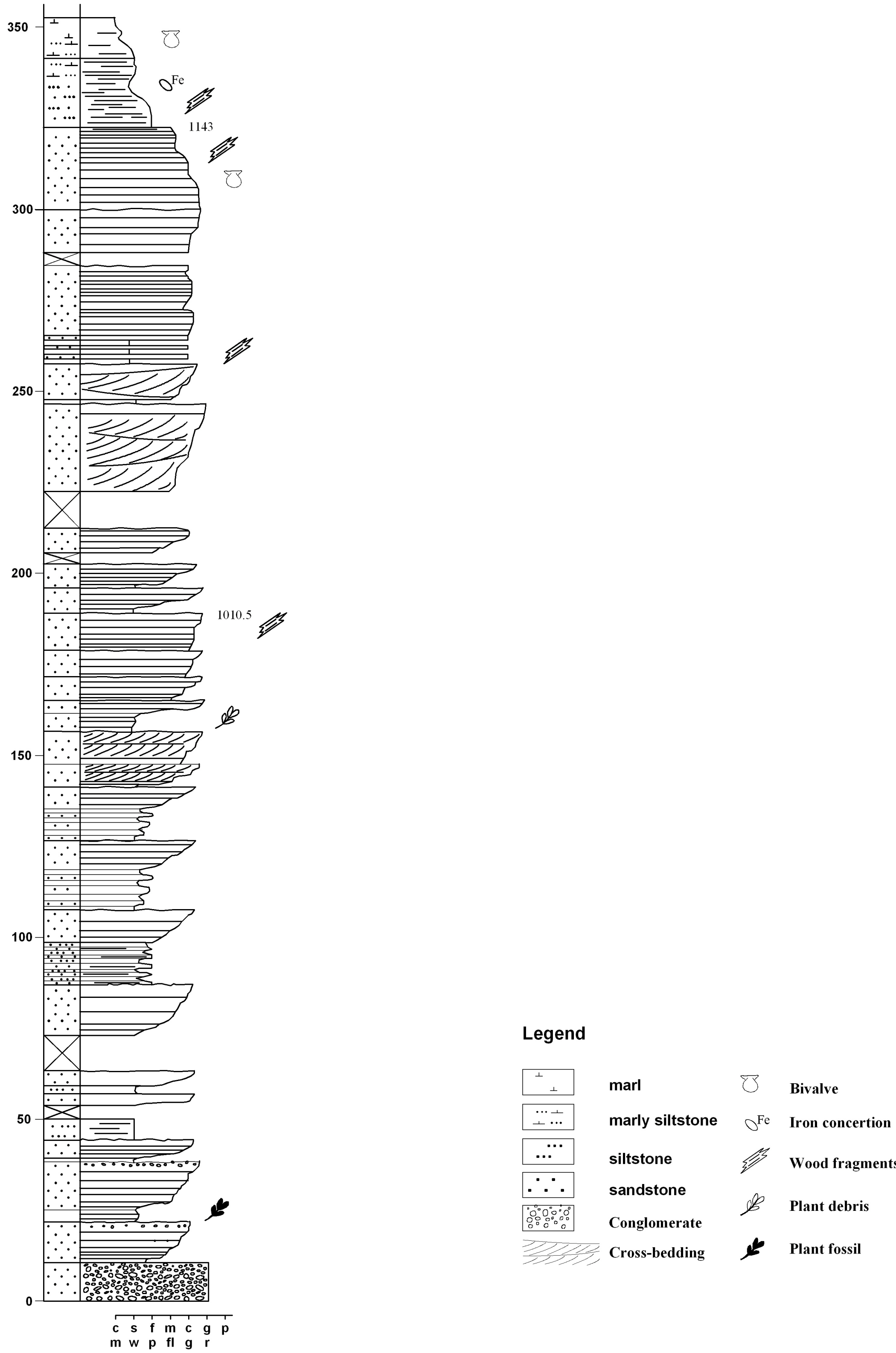



Fig. 5.13 Lithology of the lower marine part of the Fraizi section (delta facies association).

**Depositional environment**

At Kuh-e-Radar, the coarse-grained, immature sediment, the matrix-supported, marine conglomerates with channel structures, big cobbles and boulders of granitic rocks co-occurring with oyster shells (Fig. 5.9 E-F), the lobe shape of some packages (Fig. 5.9G), and the general coarsening- and thickening-upward trend all point to a fan-delta environment. Angular granitic rock fragments in a size-range from pebbles to very big boulders (Fig. 5.9G) in different lithofacies suggest the presence of a fault escarpment located just in front of a rocky shoreline with granitoid composition (Mashhad granite) in the Kuh-e-Radar area. The conglomerates most likely originated from an alluvial fan, which extended into the coastal zone and became successively eroded and reworked by marine processes.

It seems this fan-delta formed at a high-gradient shoreline. Associated large and thick-shelled bivalves and some corals were also of shallow-water origin. The size of shells (length: 15-20 cm) reflects suitable growth conditions, particularly a rich nutrient supply, for the benthic macrofauna, although the species diversity is low.

BOURGEOIS & LEITHOLD (1984) attributed accumulations of such large shells to reworking and concentration by high-energy events, pointing out that the species diversity is generally low in high-energy, nearshore environments where conglomerates may accumulate. Although the low diversity and thick shells in the Kuh-e-Radar area are comparable, the matrix-supported conglomerate and more or less complete shells show that the wave energy was not high enough to dissipate fine-grained sediments and/or breaking shell fragments. Alternatively, the rate of sedimentation exceeded winnowing and reworking processes.

Architecture and lithofacies of the fan delta succession, with a thickness of about 300 m, reveal important information about the tectono-sedimentary conditions of this part of the basin. Approximately 65 m of the lower part of the Kuh-e-Radar section are fining-upward, probably as a result of a high rate of subsidence and/or of a relative sea-level rise. Ammonites characteristic of deeper water are restricted to this part of the section. From 65 to around 100 m the area was in a relative equilibrium state between the rate of sedimentation and accommodation space.

From 100 to about 165 m, thickening- and coarsening-upward packages reflecting progradational cycles prevailed. This means that subsidence was slower than the rate of sedimentation so that the accommodation space decreased. This phase ended with channel structures cutting each other (Fig. 5.14). After that an aggradation phase prevailed again and continued for two-thirds of the succession at Kuh-e-Radar. From about 165 to around 205 m, beds with a thickness of 0.5-1.5 m consisting of coarse-grained or pebbly sandstones are intercalated between background sedimentation of normal siltstone and marly silt.

Fig. 5.14 Channel sandstone in the upper part of the succession at Kuh-e-Radar.

Bioturbation becomes more common in the upper part of these horizons. It seems that during the third step of basin evolution, marly silt and marl had begun to spread. From 205 m onwards, approximately every 15-16 m three thick, coarse-grained to pebbly sandstone and conglomerate beds with channel structure occur. They might be the result of episodic or, less likely, of intense seasonal precipitation.

Finally, from 270 m onwards, terrigenous sedimentation decreased and a carbonate shelf became established (Chamanbid Formation). Biostratigraphically, this facies change can be dated with the help of the ammonite *Macrocephalites*. As the Kuh-e-Radar area shows a nearly complete succession of the Kashafrud Formation in a delta facies the section is important for reconstructing the palaeogeography of the basin during the Middle Jurassic.

In contrast, in the Fraizi area deltaic facies is limited to the lowermost part of the marine succession and, with a rising sea-level, was replaced by open-marine, deeper water sediments. As the deltaic succession of the Fraizi area does not exhibit any distinct vertical and lateral variation in lithofacies and is directly connected to braided river sediments (the sub-aerial component of the braid plain-delta sequence), it is more compatible with the braidplain-delta model (MCPHERSON et al. 1988; ELLIOTT 1989).

**5.4 Shelf deposits**

In general, the Kashafrud Basin had no mature continental shelf environment. Only a narrow shelfal setting can be deduced at some localities and also for a restricted time span, during evolution of the basin. This is quite common in active tectonic settings. As BOUMA et al. (1982) stated, narrow shelves are usually found on active margins, such as along the Pacific coast, whereas broader shelves are more typical for passive margins.

Although in most parts of the Kashafrud Basin shallow marine condition dominated after the Late Bajocian transgression, it is only in the Tappenader area that a carbonate evolved, represented by several tens of meters. Nearshore to offshore sediments were deposited at the marine of different succession at Torbat-e-Jam, Ghal-e-Sangi, Kuh-e-Radar and Fraizi. After these, the lowermost shallow marine sedimentary rocks are the third member of the Ghal-e-Sangi section, from horizon 448 to about 750 m. Within this interval storm bed were recorded at least five horizons.

Except for the storm layers, the lithofacies in this part is an alternation of dark-grey to black muddy silt, and thin ripple-bedded, brownish, fine-grained sandstones. Occasionally, also ripple-bedded, poorly cemented sandstone beds that range in thickness from 0.5 to 1.5 m occur. In the lower part of these shelfal sediments iron-rich concretion were seen. Flaser-bedded sandstone and black muddy shales are also main features in this part of the Ghal-e-Sangi section (Fig. 5.15). The absence of ichnofossils, characteristic of deep marine environments, in the Ghal-e-Sangi section especially in this part also support this conclusion. It seems that this mud-dominated succession was precipated in a low energy setting. Macrofauna is rare and of low diversity, which may be related to dysoxic conditions and/or a low nutrient supply in the basin.

Muddy parts of ancient shelves are generally poorly exposed in outcrops and rarely studied in the subsurface (BOUMA et al. 1984). As a result, little is known about sequences of textures and structures. From this point of view, the middle to upper part of mud-dominated section at Ghal-e-Sangi should be a nice case study, especially considering that the more silty and deeper related Kol-e-Malekabad succession crops out in the adjacent area.

After this relatively shallow marine unit condition, documented from about 750-1000 m the relative sea-level rose again in the Ghal-e-Sangi area and deeper marine condition became established.

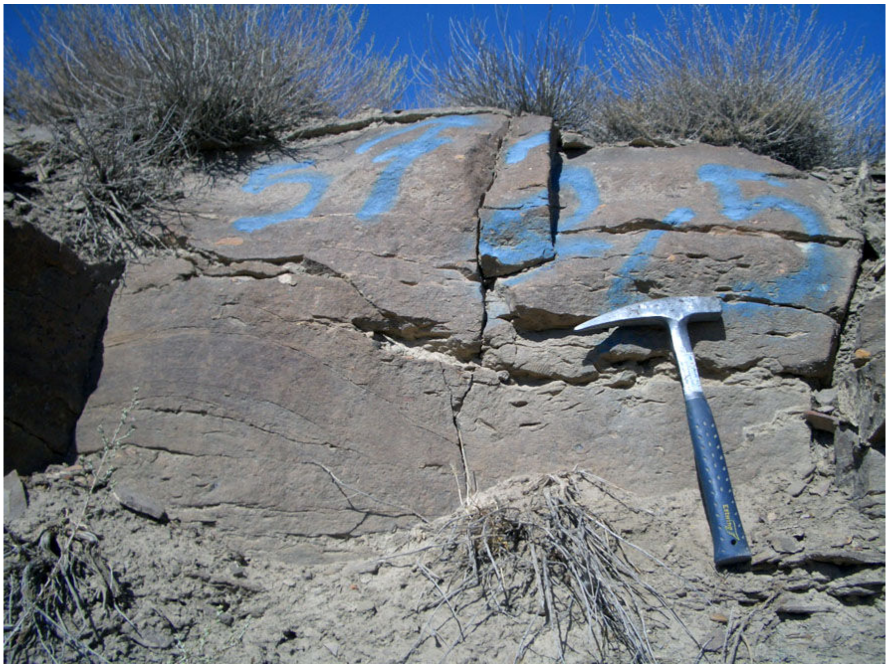


Fig. 5.15. ?Hummocky cross-stratified sandstone in the middle part of Ghal-e-Sangi section.

Storm beds are also visible in the upper part of the Fraizi section at horizon 1800-2100 m, where at least five such beds have been encountered. After these mostly middle to outer shelf sequences, the upper part of the Kashafrud succession, represents again shallow marine environments, which are more compatible with near-shore to inner shelf setting at different localities.

One of the best successions (about 150 m thick) is seen in the upper part of the Danesh section. It consists of thin- to medium-bedded, calcareous, hummocky cross-stratified litharenite to sandy limestone which has been deposited under relatively high energy conditions. Similar, but less pronounced shallowing-upward successions are found in the upper part of other sections including Maiamay, Fraizi, Gas-pipeline, Kol-e-Malekabad, and Ghal-e-Sangi.

**5.5 Deep-Sea deposits**

As the Kashafrud Basin was a strongly subsiding rift-related basin (WILMSEN et al. 2006; TAHERI et al. 2006; BRUNET et al. 2006, 2007), a thick succession of siliciclastic rocks, mostly developed as flysch sediments, was deposited under deep-sea conditions. This succession is composed of different lithofacies and rock units. The bulk of the sediments consist of turbidites, slope deposits, slump units and debris flows, monotonous mudstones, and conglomerates composed of rip-up clasts.

The sedimentary strata will be discussed in the framework of the depositional system, which according to the definition of FISHER & MCGOWEN (1967) is "a depositional system is a three-dimensional body of sediment deposited in a contiguous suite of process-related sedimentary environments".

The deep-sea succession of the Kashafrud-Basin is one of the most prominent features of the basin fill. Slope and base-of-slope or toe-of-slope deposits are particularly widespread in the Kashafrud Basin. Of the seven basic facies building blocks which have been described by GALLOWAY (1998) from such environments, at least five are easily distinguishable in the Kashafrud Basin :

(1) turbidite channel fills;

(2) turbidite lobes;

(3) sheet turbidites;

(4) slumps and debris-flow sheets, lobes, and tongues; and

(5) fine-grained turbidite fills and sheets.

**5.5.1 Turbidite channel fills**

The best outcrop of this system is found in the Maiamay area (Figs. 5.16-18), although similar successions were observed also at other localities. The second member (from horizon 158-570 m) and partly the fourth member (roughly between horizon 1146 and 1499 m) of the Maiamay section are attributed to this facies association. It comprises medium- to relatively thick-bedded, fine- to medium-grained sandstone beds in complex channel structures. The thickness of this succession in the second member is about 412 m. It is sandwiched between units that are composed of alternations of fine-grained turbiditic sandstones, dark-green to black siltstone and shales that probably were deposited in greater water depth.

Fig. 5.16 Member 2 (red bar) of the Kashafrud Formation at the Maiamay section.

According to READING & RICHARDS (1994) such channel deposits are characteristic of sand-rich submarine fans. The depositional system forms in lower slope and slope-base settings (GALLOWAY, 1998). The base of these channels is convex to flat (Fig. 5.17a-b). At about 570 m (top of this unit in the Maiamay section) there is an abroupt change to a dark-green to black fine-grained turbiditic unit (Fig. 5.17c). It seems that this sharp contact is related to a sea-level rise and/or increase in the subsidence rate.


Fig. 5.17 Turbidite channel fills. **a, b, e**. Upper and lower parts of channel fills in the Maiamay section. **c**. Contact between fine- to medium-grained sandstone of member 2 and black siltstone of member 3 of the Kashafrud Formation at Maiamay section. **d**. Erosional channel fill, Kol-e-Malekabad section.

Erosional channel types are rarely seen, except for the channel in the Kol-e-Malekabad section (Fig.5.17d). Other erosional channels exhibit locally some V-shaped profiles that have been filled with deposits such as mud clasts and occasionally fossil debris, e.g. NE of Maiamay at 2098 m in that section. Channels cutting each other reflect rapid migration (Fig.5.17e).

In addition to the channel sandstones in the second member of the Maiamay section, there are some fine-grained intervals which may represent sedimentation in inter-channel areas and/or a decrease in sediment supply. The facies association occurs in the Maiamay area and, to a lesser extent, at Kol-e-Malekabad, Ghal-e-Sangi, and north of the Radar section (along the road to Maiamay village; co-ordinates 36˚ 13′ 32″ N 59˚ 58′ 29″ E).

In member 2 the sediments are mostly turbiditic with a smaller amount of background sediments. Sandstone beds are sharp-based with sedimentary structures such as flute casts, groove casts, load casts, and ripple lamination. Graded bedding is also common as is plant debris.

The sand/silt ratio in member 2 is about 68:32. In member 4 of the Maiamay section, this parameter is 46:54, which reflects an obvious decrease in sand delivered to the basin (for more information see the stratigraphic columns of the two members; Fig. 5.18). Bioturbation in member 2 is rare, which may be related to the higher rate of sedimentation, than in member 4. The general trend of these two units is fining- and thinning-upwards. Obvious channel structures that dominated in the lower and middle parts of the succession are rare.

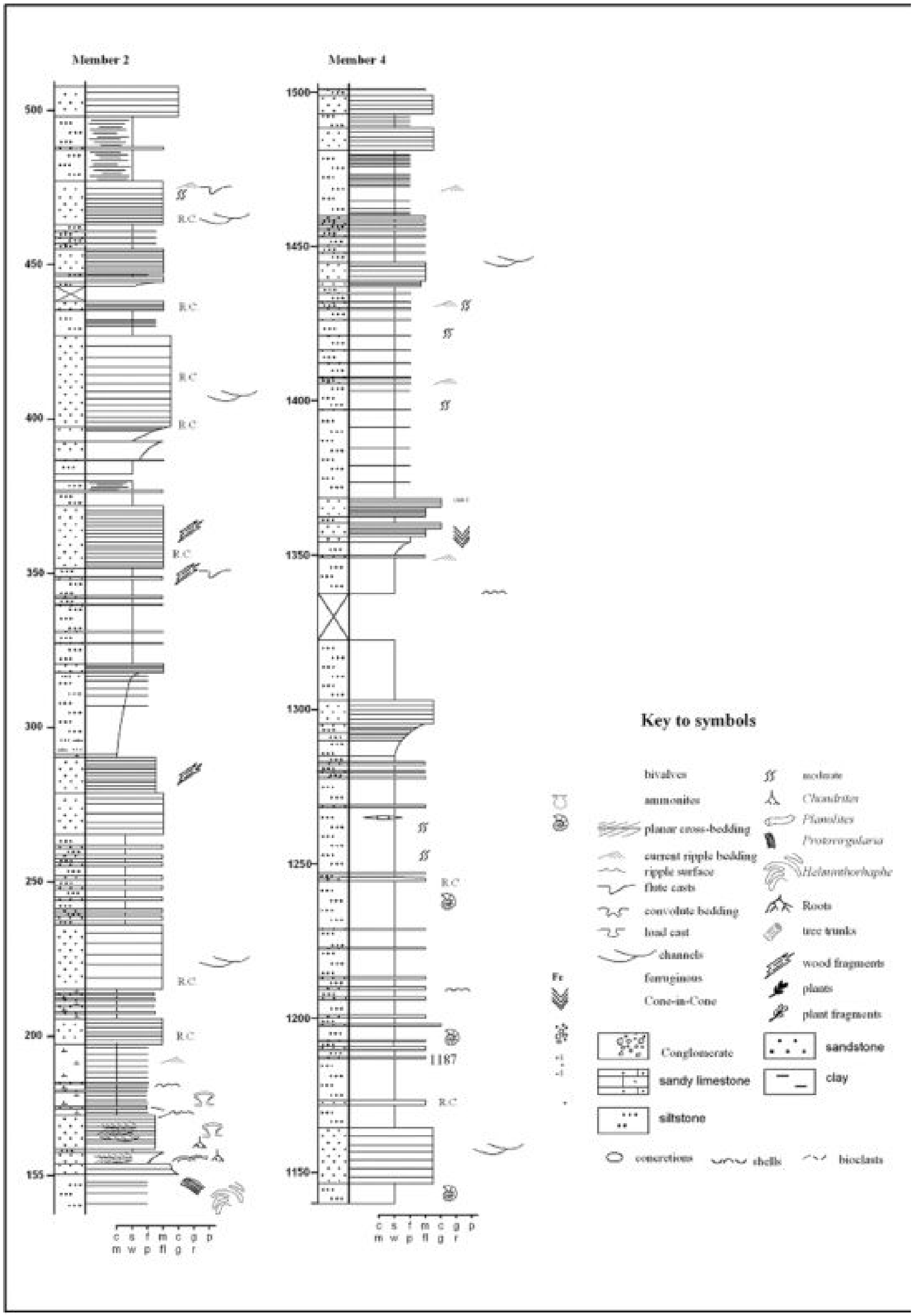



Fig. 5.18. Segments of the Maiamay section (member 2 and member 4) with channel structures.

### 5.5.2. Turbidite lobes

At Ghal-e-Sangi a mud-rich submarine fan deposit seems to have existed. In it, there are some medium- to coarse-grained sandstone beds, several kilometers wide and between 1 and

10 m thick. These stratigraphically repetitive sandstone units are probably turbiditic lobes. They occur between 750 and 1000 m in the section (Fig. 5.19).

GALLOWAY (1998) distinguished two types of turbidite lobes: sheeted lobes and mounded lobe, the latter being laterally more restricted than the former. The Ghal-e-Sangi sandstone units with a lateral extend of several km, more closely correspond to mounded lobes, because sheeted lobes commonly extend for several tens of kilometers.

Fig. 5.19. Turbiditic sheet sandstone lobes in the Ghal-e-Sangi section.

### 5.5.3. Sheet Turbidites

Alternations of turbiditic sandstones and shales are widespread in the Kashafrud Basin and exhibit considerable lateral continuation. Successions classified in this category were deposited by currents with high sediment load and resulted from failure of the shelf margin and upper slope that fed the basin. Consequently they resulted in vast classic turbidites.

Depositional settings of these types of turbiditic sequences range from base-of-slope, basin plain, intra-slope basin to inter-channel areas (GALLOWAY, 1998). In the study area this kind of turbidite system is widespread, although the grain size and consequently the proximality or distality differs from one locality to the next one.

In general, proximal sheet turbidites occur in the middle and upper part of the Fraizi section, in the lower part of the Maiamay section (Fig. 5.20i), and in the Danesh section (Fig. 5.20g-h) whereas the classic turbidites with relative thin and fine-grained sandstone beds of other localities are classified as distal turbidites (Fig. 5.20a-f). In the case of the Fraizi area apparentlya muddy slope system with highly fluid flows existed, which produced a coalescing sheet rather than focused lobes. When the rates of sediment failure or fluid flows have been decreased, then the abundance and thickness of turbidite sheets in the succession tended to decrease. Successive lobe turbidites are generated during periodic avulsion of up-dip middle and lower fan channels. An increase in sand content within the fan leads to a decrease in levee stability, increased channel switching, and greater potential for lobe connectivity (READING & RICHARDS, 1994).

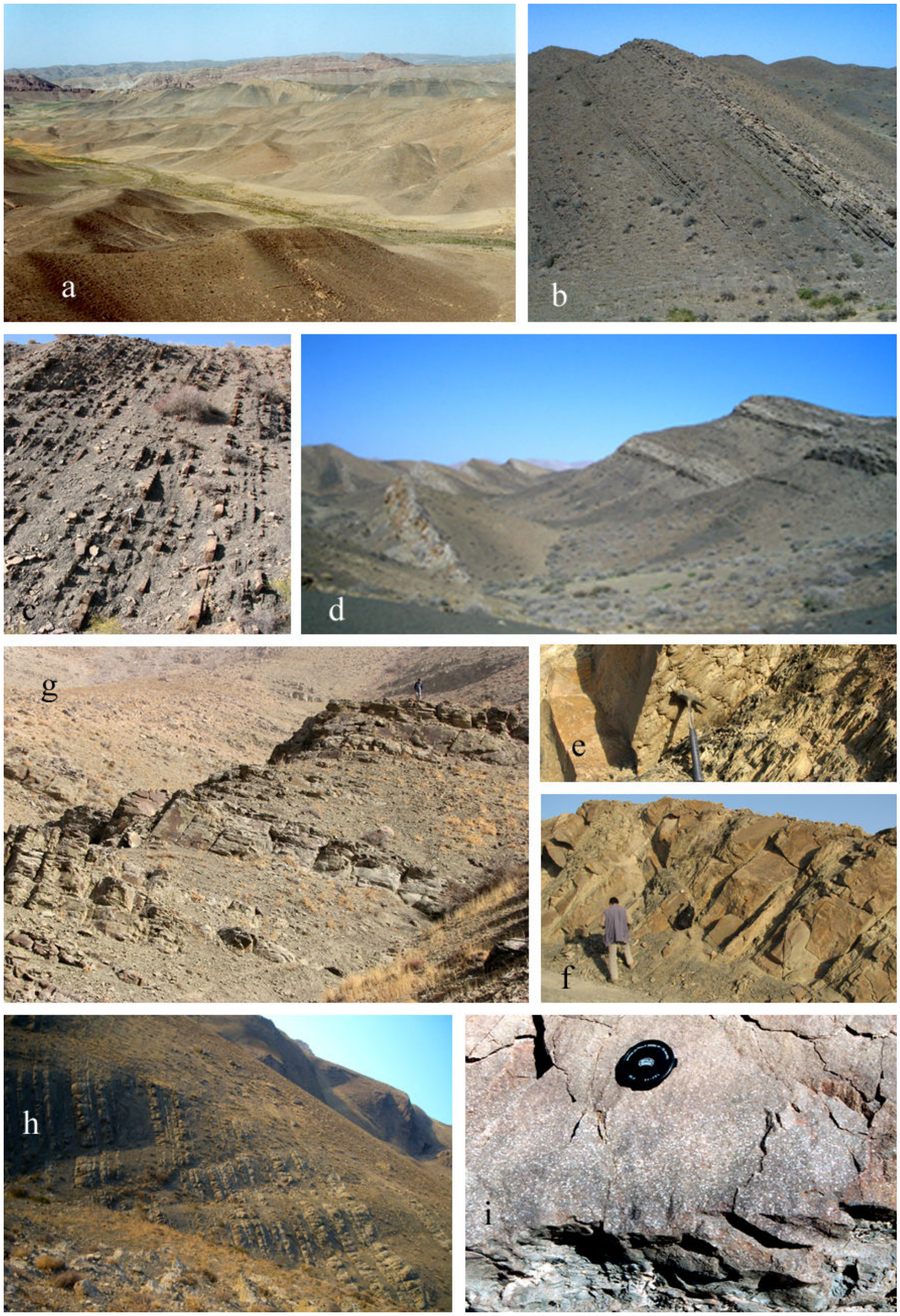



Fig. 5.20. Features of distal and proximal turbidites in the Kashafrud Basin. **a-f**. Distal turbidites, Senjedak section (a), Ghal-e-Sangi section (b). Classic turbidites at Kol-e-Malekabad section (c) and Maiamay section (d). Turbidites in the area between Gas pipe-line (e) and Maiamay sections (f). **g-i**. Relatively proximal turbidites; Danesh section (g), upper part of the Kol-e-Malekabad section (h), and lower part of the Maiamay section at about 155-175 m (i).

### 5.5.4 Slump and debris flow sheets

Apart from the slump units, which are more obvious in the field, there are some units in the study area that are characterized by relatively thick and structureless beds and for the most part contain matrix-supported clasts. This facies type is interpreted here as debris flow deposits (Fig. 5.21A-B).


Fig. 5.21. Debris flow units. **A**. North of Maiamay. **B**. Fraizi section. **C**. Close-up view of floating mud clasts.

The mechanism of sedimentation of this facies is completely different from that of turbidites and has been extensively studied during the last decade (PRIOR et al., 1984; POSTMA et al., 1988; SHANMUGAM, 2000, 2002). According to SHANMUGAM (1996, 2000), a debris flow is a sediment-gravity flow with plastic rheology and laminar state from which deposition occurs through freezing.

I identified sandstone beds as debris flow sheets if there were no features of turbidites and if they were thick and structureless, occurred within a deep-sea succession, and contained clasts floating in the matrix (Fig. 5.21B). MIDDLETON & SOUTHARD (after MIDDLETON, 1993) interpreted such grain-flows as associated with unstable, relatively steep slopes.

POSTMA et al. (1988) explained the mechanism of occurrences of large floating clasts in some turbiditic units by “the development of highly concentrated basal layer gave rise to flow bipartition, between the more viscose, turbulent upper layer, with a visually well-defined boundary between two layers” (POSTMA et al., 1988; p. 52). Additionally they wrote (p. 53) “the inertia-flow layer would thus display a quasi-plastic rheological behavior, with essentially non-Newtonian, pseudo-plastic viscometry”. This does not correspond to a turbidity current, and debris flow sheets should therefore be separated from turbidites. Accordingly, I have classified some sandstone beds in the Kashafrud Formation as debris flows.

Debris flow sheets in the study area range in thickness from less than 1 m to several metres and may be kilometre long with a lenticular geometry (Fig. 5.21A). Although some debris flows can develop turbulence (ENOS, 1977), in general such flows are not diagnostic of most debris flows which are laminar (POSTMA et al. 1988; SHANMUGAM, 2000). At some localities, probable sandy debris flow beds appear to be related to turbiditic units, whereby the former grades into turbiditic sandstone and siltstone beds. This supports the idea of EINSELE (1999) that "the top of the bed is either sharp or grades into an overlying turbidite, forming a compound debrite-turbidite couplet".

Another feature of the slope depositional system is slump units. They are distributed mostly in the upper parts of the Maiamay, Ghal-e-Sangi, Kol-e-Malekabad, and Danesh sections (Fig. 5.22A-F). The scale of slump beds ranges from several decimetres to more than one metre, In terms of depositional environments, slump units and debris flow deposits are more common in the upper and middle parts of slope, although some intense debris flows may have extended to the basin plain.

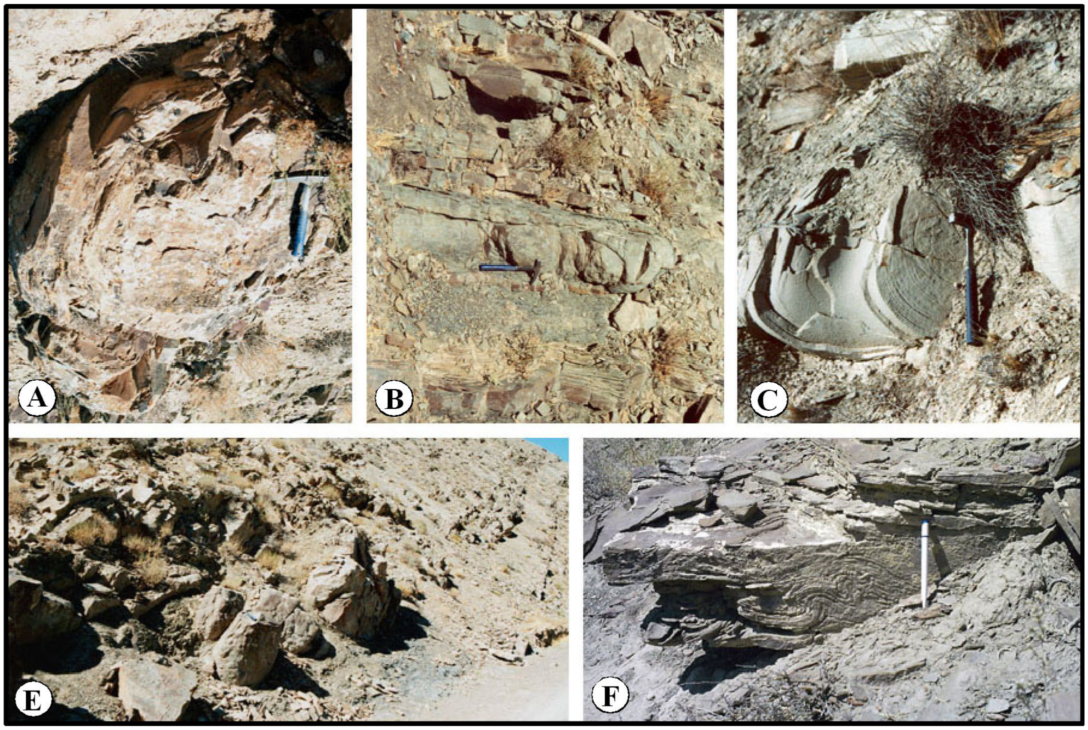



Fig. 5.22. Slumping features at Kol-e-Malekabad (A-B, E), Ghal-e-Sangi (C), and Maiamay (F) sections.

### 5.5.5 Fine-grained turbidite fills and sheets

Muddy turbidity flows tend to infill the lowest areas of the basin plain, intraslope depressions, and inter-channel areas of the slope itself (STOW & PIPER, 1984). In the Kashafrud Basin, this facies consists of widespread, thin to medium (≤1 m) turbidite beds. It is comparatively common in the Gas-pipeline, Senjedak, middle part of the Kol-e-Malekabad and lower units of the Maiamay sections, but it is the Gaspipeline section, where the succession displays the suite of basin floor depositional environments best. The last mentioned locality contains fine-grained turbidites which were deposited in interchannel areas. The bioturbation in these units is higher than in other parts of the depositional system and characterized by graphoglyptid trace fossils such as *Helminthorhaphe crassa, H. japonica, Nereites* cf. *macleayi, N. missouriensis, N. irregularis,* and *Neonereites multiserialis.*

## 5.6 Discussion

The assemblage of some depositional systems in the area from Kuh-e-Radar to north of Maiamay reveals sedimentary environments which show a distinct deepening trend. These environments range from deltaic to toe-of-slope and basin plain.

The relatively thick sedimentary succession, especially in the channel fills, and the obvious transport direction suggest that the feeder system may be a point-source submarine fan. The several hundred metres thick, sand-rich succession with a sand-silt ratio of about 68:32 (for the member two of the Maiamay section) and the lack of carbonate rocks in the area is the result of a narrow shelf and/or high gradient slope conditions (Fig. 5.23).

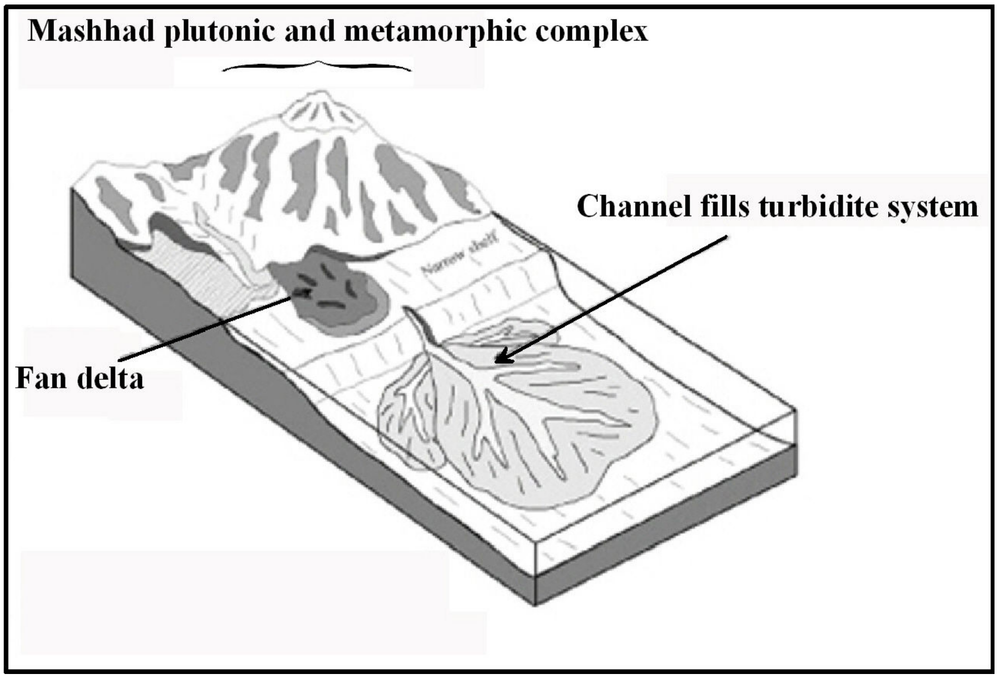



Fig. 5.23 Point source submarine fan model for the Kashafrud succession between Kuh-e-Radar and north of Maiamay village.

The lower and middle parts of the Kol-e-Malekabad section are composed of monotonous dark-green siltstones and shales which show comparatively deep-water conditions. The occurrence of the bivalve *Bositra* in some siltstone concretions, the presence of slump units and channel structures, and the presence of carbonate in the rock matrix in the upper part of the Kol-e-Malekabad section is compatible with an upper and probably middle slope setting.

The coarsening- and thickening-upward packages in the upper part of the Kol-e-Malekabad section reflect progradational trends in this part of the basin. In general, the Kol-e-Malekabad section represents a mud/sand-rich submarine fan, but it is difficult to say whether it corresponds to the point-source type or to the ramp-type depositional system.

The sand-silt ratio in the Ghal-e-Sangi section is about 46:54, and the sedimentary succession can therefore be interpreted as a mud-rich submarine fan. It may have formed due to the long transport distance of the sediment load or due to relatively mild tectonic movements that affected this part of the basin (Fig. 5.24). In this way, the Kol-e-Malekabad section lies in a transitional zone between Maiamay and Ghal-e- Sangi areas.

One should also keep in mind that the source rock is one of the most important factors governing sediment supply. In the plutonic domains in the eastern and western parts of the study area siliciclastic components were therefore more abundant, whereas in the central area such as at Kol-e-Malekabad and Ghal-e-Sangi, due to the pelitic metamorphosed source rocks, probably the amount of siliciclastic components was less than at other localities and consequently the percentage of mud increased.

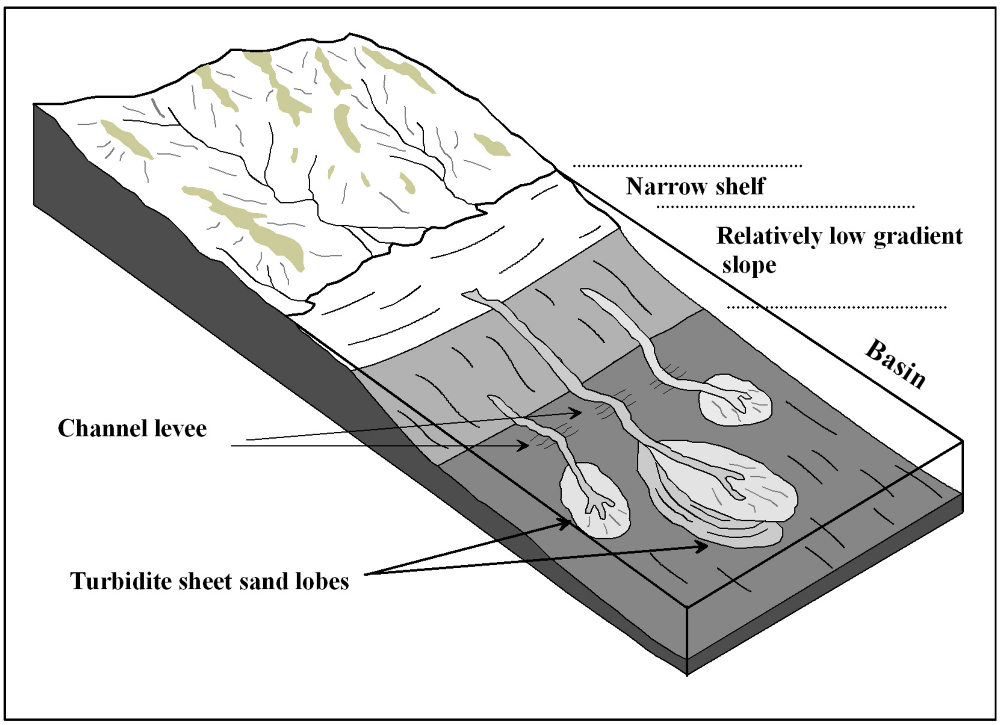



Fig. 5.24. Schematic model of the mud-rich turbidite system at Ghal-e-Sangi.

A sudden deepening event can be recognised in the lower part of the Kashafrud sections, particularly in the Senjedak, Ghal-e-Sangi, and Kol-e-Malekabad areas. It could be the result of a rift-related extensional pulse affecting the basin (Fig. 5.25).

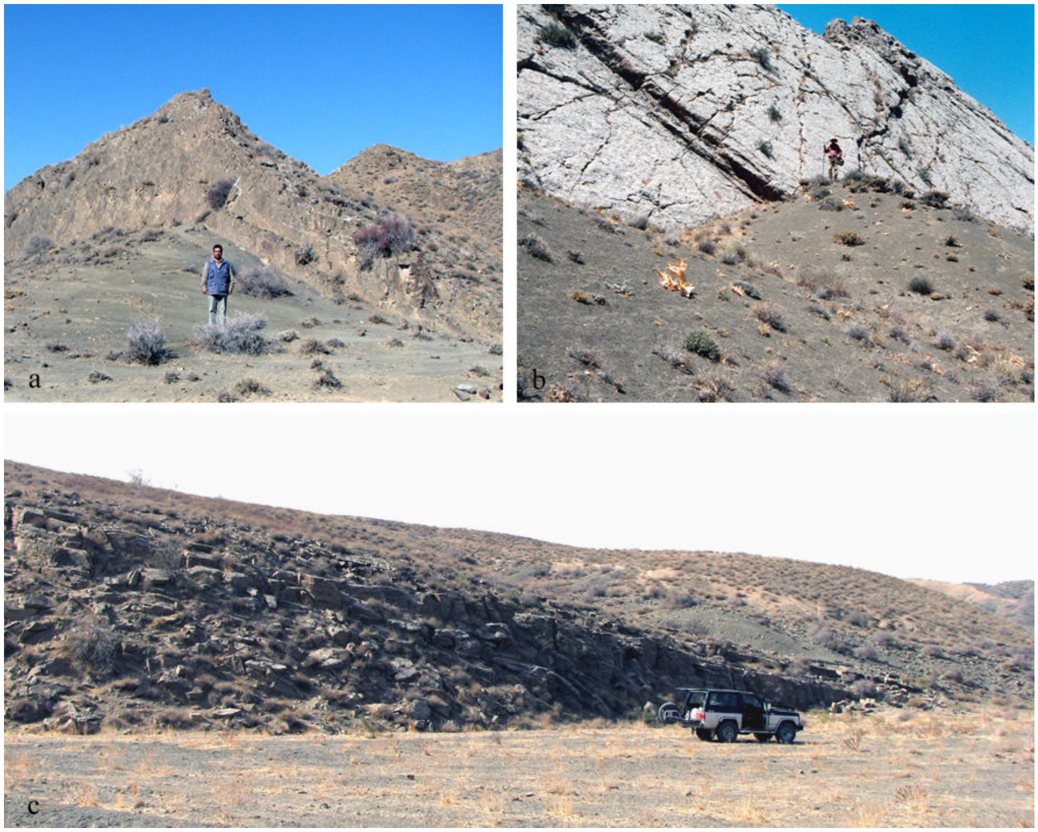



Fig. 5.25. Sharp upper contact of shallowing- and coarsening-upward packages documenting sudden deepening. **a**. Kol-e-Malekabad section. **b**. Senjedak section. **c**. Ghal-e-Sangi section at horizons 50, 4.75, and 96 m respectively.

Proximal turbidites are more common in the Fraizi, Danesh, and lower parts of the Maiamay sections. It seems that in the Fraizi area the high amounts of medium- to coarse-grained sediments have resulted from sediment failure at the outer shelf margin or upper steep slope and produced intercalations of sand-sheet turbiditic units between the marly background sediment. Accumulations of a large volume of terrigenous sediment under such unstable conditions have also been recorded from some other localities e.g., in the Gulf of Benin where a million cubic metres of sediment accumulate every year at the heads of both the Avon and the Calaber submarine canyons (BURKE, 1972). Such a huge amount of sediment is enough to produce a 1 m thick layer across a vast area in the short time span of about 1000 years.

BOUMA (2000) classified turbidite systems into two end members, coarse and fine and listed several main characteristics of the two types (Table 5.1).

Table 5.1. Some differences in transport-depositional characteristics between coarse-grained and fine-grained turbidite systems, After Bouma (2000).

| Parameter | Coarse-grained | Fine-grained |
|---|---|---|
| Type of margin | Typical for active margin | Typical for passive margin |
| Relative distance: source to coast | Rather short | Rather long |
| Gradient of fluvial system | Rather steep | Rather low |
| Size of fluvial system | Rather small | Commonly long |
| Degree of possible continental diagenesis | Rather small | Can be major |
| Width of coastal plain | Commonly narrow | Commonly wide |
| Size of deltaic system | Commonly small | Often large |
| Presence of incised valleys | Not common | Common |
| Shelf width | Often narrow | Commonly wide |
| Basin size | Small to medium | Medium - large |
| Type of fan sediment feeding | Canyon-fed | Delta-fed |
| Influence of relative sea-level lowering | Rather small | Very important |
| Characteristics of marine transport | Non-efficient | Efficient |
| General construction of fan | Prograding | Bypassing |
| Turbidite complex: sand/shale ratio | High | Low |
| Turbidite system: sand/shale ratio | High | High, except for overbank |

According to the characters listed in Table 5.1, the vertical sequence in proximal turbidite units of the Kashafrud Basin, especially in the Danesh area, is most compatible with the coarse-grained turbidite type.

## 6. Sequence stratigraphy

Sequence stratigraphy is used to interpret the development of sedimentary environments in time and space and therefore, it is an important tool in sedimentary basin analysis (COE, 2003; CATUNEANU, 2006). Furthermore, it allows to construct a chronostratigraphic framework for the fill of individual basins which, in the following, can be compared to other regional or global charts in order to elucidate tectonic and/or eustatic controls on the stratigraphic architectures. The basic definitions of sequence stratigraphic terminology are given by MITCHUM in VAIL et al., (1977) and HAQ et al., (1987, 1988) with modifications for carbonate systems by SCHLAGER (1992). Useful overviews are given by COE (2003) and CATUNEANU (2006).

Understanding the sequence stratigraphic dynamics of the Kashafrud Basin, especially the reconstruction of sequence boundaries, is of utmost importance for the interpretation of the basin evolution. The Kashafrud Basin represents a siliciclastic depositional system with a kind of shelf-break and a comparably steep slope system (abundant redepositional sediments) and thus can be interpreted in the sense of classic sequence stratigraphic model (cf. COE, 2003). Regional sequence stratigraphic studies are rare and related to the carbonate system of the Upper Jurassic Mozduran Formation (LASEMI, 1995).

According to the definition of sequence stratigraphy (MITCHUM et al., 1977a, b), a sequence is “a stratigraphic unit composed of a relatively conformable succession of genetically related strata bounded at its top and base by unconformities or their correlative conformities”. This means that the unconformities which form the lower and upper limits of a sequence are the most important surfaces which, at the same time, define the order of a sequence, depending on time duration of the embraced strata: $1^{st}$-order sequences are of more than 50 mys duration, $2^{nd}$-order sequences comprises 5-50 mys, $3^{nd}$-order sequences last between 500 kys and 5 mys (VAIL et al., 1991).

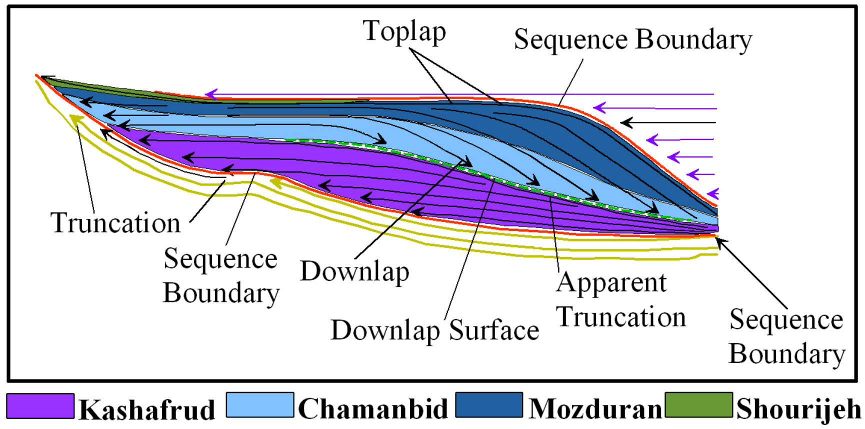



Fig. 6.1. Sequence stratigraphic development showing the main sequence boundaries (SB) and different rock units in between, from the Upper Bajocian to the Early Barremian in northeast Iran.

*2nd-order cycle*

Concerning the Koppeh Dagh Basin, it appears that the basin fill, including the Kashafrud, Chamanbid, Mozduran, and Shourijeh formations, represents a second order sequence of about 30 my. This 2nd-order sequence starts with an Upper Bajocian-Bathonian TST (Transgressive Systems Tract) and a Callovian-Upper Jurassic HST (Highstand Systems Tract) to be terminated by a Berriasian FSST (Falling Stage Systems Tract), represented by the non-marine Shourijeh Formation, and by its equivalent, the Zard Formation in the western Koppe Dagh, the latter with a correlative conformity at its base.

With respect to the position of the unconformities which bound this 2nd-order sequence, the first option of COE et al. (2003: 86) is followed, which emphasizes that the lowermost limit of the FSST package, regardless of the locality, represents the sequence boundary (SB), and that this boundary is commonly diachronous.

The unconformity between the basal conglomerate of the Kashafrud Formation and older rocks (or the onlap) has been dated as Late Bajocian based on ammonite occurrences at different outcrops, including Senjedak, Torbat-e-Jam, Kuh-e-Radar, and Tappenader (see for details Chapter 4). This unit overlies mostly Permo-Triassic rocks. The upper boundary (or offlap) is equivalent to the base of the non-marine, reddish, conglomerates and pebbly sandstones of the Shourijeh Formation and its equivalent (Zard Formation) in the western Koppeh-Dagh. These formations are Berriasian-Early Barremian and Hauterivian-Barremian in age, respectively (AFSHAR-HARB, 1994).

Although the magnitude of the upper sequence boundary (contemporaneous with the Late-Cimmerian orogenic event) varies from west to east within the Koppeh Dagh, it probably represents a diachronous unconformity. Regression and the deposition of a lowstand systems tract (LST) from SE toward N and NE observed.

The shallowing-upward trend in the topmost strata of the Kashafrud sections and the shift from deep-water siliciclastic flysch deposits to sandy bio-oo-sparite (see Chapter 3 for details) probably record a downlap surface on which the Chamanbid and Mozduran formations aggraded and prograded in clinoform structures (HST). During the final stages, the non-marine Shourijeh strata formed a FSST. Accordingly, the uppermost Kashafrud strata contain an important $2^{nd}$-order downlap surface (Fig. 6.1).

Among the different parameters (eustasy, subsidence, and sediment supply) which affect a sequence, it seems that in the case of the Kashafrud Basin, high subsidence rates played the most important role, although the global sea-level rise in the Middle Jurassic (HALLAM, 1992, 2001) should always be kept in mind. High Middle Jurassic subsidence rates have also been documented for adjacent areas in the north (SLOSS, 1979; BRUNET et al., 2003; SHAHIDI, 2008).

Although tilting of the older units below the upper SB was not as intense as at the sequence boundary at the base, it obviously initiated deposition of non-marine, reddish conglomerates and pebbly sandstones, and probably prolonged phases of erosion during the Tithonian to early Barremian. It seems that this SB changes to a correlative conformity toward the west of the Koppe Dagh (e.g., in the Arkan area south of Bojnord, about 250 km west of the study area). Fig. 6.2 provides a general overview of this scenario.

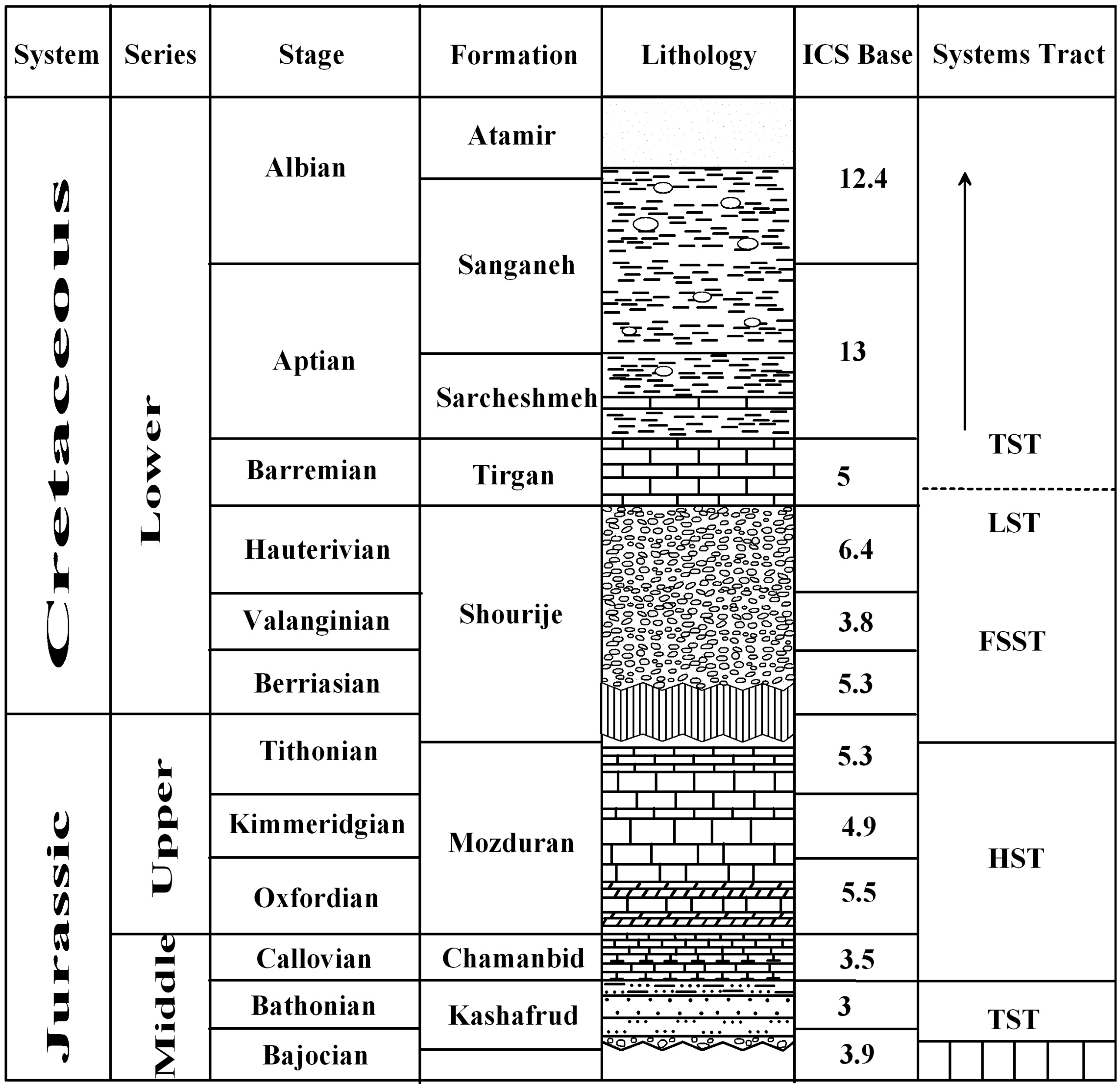



Fig. 6.2. Middle Jurassic-Lower Cretaceous stratigraphic units and their relationship to sequence stratigraphy, ICS: time duration based on the International Commission on Stratigraphy (2004).

The above mentioned sedimentary formations, which correspond to specific depositional systems, reflect the geodynamic and geological processes that prevailed in the area during these times. Concerning the Kashafrud Basin, section data, field observations, and the fact that more than 2,500 m of siliciclastic sediments accumulated in a relatively short time span (less than 5 my) confirm the importance of high subsidence rates and extentional tectonic movements rather than that of other factors such as eustatic sea-level changes and sediment input (TAHERI et al. 2009). Towards the top of the Kashafrud Formation, rapid subsidence ceased and other processes such as carbonate production and eustasy replaced the tectonic movements as governing the basin evolution (see also LASEMI, 1995).

The regional information on the Mozduran and Shourijeh formations (AFSHAR-HARB, 1994; LASEMI 1995) show that erosion and sediment by-passing played an important role in re-distributing the sediments at this stage (FSST). Most likely, part of the upper Mozduran beds were eroded and transported to deeper parts of the basin. A comparison of the Mozduran thickness along a S-N transect confirms this conclusion. For example, at Kol-e-Malekabad, this rock unit consists of only a few tens of meters of mostly dolomitised limestone, while its thickness at the type-section (Mozduran area) is 420 m, and about 50 km further to the north in well no. 2 of the Gonbadly area it is 900 m (AFSHAR-HARB, 1994). The 54 m thick Mozduran Formation at the Gharaghaitan locality (east Kol-e-Malekabad) changes to 1380 m in well no. 31 of the Khangiran area, about 54 km further north.

In contrast, the thickness of the Shourijeh Formation increases from 80 m at Khour (about 70 km north of Mashhad) to 778 m in the east. This fact is also explained by the more proximal position, in which thick deposits of the FSST accumulated in the eastern and southeastern Koppe-Dagh.

*3rd-order cycles:*

Third-order cycles are well developed in the study area, especially in the middle part of the Maiamay section, but are also common in the Kol-e-Malekabad and Danesh sections. They range from several tens of meters, for instance at Ghal-e-Sangi, Kol-e-Malekabad, and Danesh to a few hundred meteres up to more than 1 km in thickness in the Maiamay and Senjedak sections.

As the Maiamay area contains the most expanded record of the Kashafrud Basin fill and reflects more details of the sequence stratigraphy (i.e., 3rd–order cycles), I refer first to this area, and then extend the conclusions (wherever possible) to other parts of the basin.

In total, four depositional sequences (K1 to K4) are recognized in the Kashafrud Formation at Maiamay section which correspond to 3rd–order cycles based on the absolute age constrains (approximately more than 1 m. y. per cycle). These four sequences are characterized by a sharp base and/or fining- or coarsening-upward (K1-K4). They are described in detail below.

Sequence K1: The Kashafrud Formation starts with a basal conglomerate and TS (Transgressive Surface). The thickness of the basal conglomerate ranges from a few meters (Senjedak section) to more than twenty meters (Ghal-e-Sangi section), although in some localities it is less than one meter thick, representing only a transgressive lag (for instance at Mikh Khar small farm, north of Sefid Sang area). The basal conglomerate is rapidly replaced by a fining- and deepening-upward succession, and forming the first transgressive deposits of third-order sequence K1 (Fig. 6.5).

In the study area, the first distinct signs of extension after the transgressive conglomerate (TS) appear at the base of member 2 in most sections (which are discussed in Chapters 3 and 8), except in the Tappenader area, where a carbonate package accumulated (see stratigraphic sections in Chapter 3). The onlap surface is placed at the base of shallow marine, fossiliferous sediments with wood fragments at some localities (e.g., Torbat-e-Jam, Ghal-e-Sangi, and Tappenader). These early transgressive sediments were deposited during a relatively short time span in the Late Bajocian. Such facies is quite common due to the relative sea-level rise during the TST because organic productivity increased as more nutrients were available from the newly flooded areas (COE et al., 2003).

In the following, a sudden deepening event occurred, which is traceable in the Senjedak, Ghal-e-Sangi, Fraizi, and Kol-e-Malekabad regions. Consequently, a relatively thick package of deep marine, siliciclastic sediments was deposited during the TST, suggesting high sediment input into the basin. Classic turbidites (Kol-e-Malekabad) containing deep-marine ichnofossils, dark green siltstone (Senjedak, and Ghal-e-Sangi) and a thick marl unit (Fraizi area) are the main lithofacies in this part of the succession (Fig. 6.5; K1).

Sequence K2: After several hundred meters of fine-grained sediments (HST), either the accommodation space was outpaced by sediment input, and/or a significant relative sea-level fall occurred. Consequently, channel-fill deposits and proximal, coarse-grained turbidites of the FSST (Fig. 6.5; K2) entered the basin (Maiamay area, member 2) overlying sequence K1. A similar development occurred at Kol-e-Malekabad (member 3), Ghal-e-Sangi (member 3), Danesh (member 1), and Tapenader-Jizabad (unit 4). The second third-order sequence in most areas shows, more or less, a coarsening-upward trend, which depends on the locality and basin setting is reflected in the lithofacies and sedimentary characters (HSST).Up-section, due to tectonic movements (most likely extensional) and/or eustasy, the relative sea-level rose and accommodation space increased again. However, the sharp contact of black siltstone overlying medium-grained sandstone at the top of the last sequence (Maiamay area) is more related to a second tectonic extensional event in the basin than to a eustatic sea level change.

In the Maiamay area, classic turbidites and deep water trace fossils, such as *Nereites* isp. are quite common, although also some debris flows are deserved.

Sequence K3: A general trend of increasing sandstone beds is visible in the middle part of the Maiamay section which is also traceable in the other areas, especially in the Ghal-e-Sangi that reflect coarsening- and shallowing-upwards condition. This sequence is distinguished as third-order sequence that at the same time includes a parasequence-set of fourth order high frequency cycles.

In member 4 of the Maiamay section, equivalent to sequence K3, after several parasequences with progradational stacking patterns (Fig. 6.3), appearently relatively stable conditions occurred in the basin, and thin-bedded, fine-grained sandstones alternating with green to olive siltstones were deposited in the sequence 4.

Fig. 6.3. Parasequences in member 3 of the Maiamay section between 1140-1200 m.

Sequence K4: In this sequence the amount of marl characteristically decreases. This sequence shows falling stage systems tract characters (Fig. 6.5, K4). The basin converts from a high subsidence, deep basinal environment to a shelfal setting and with higher energy in general. After this sea-level fall, oolitic, calcareous litharenites were deposited.

During the Late Bathonian, the rate of subsidence and/or adjacent uplift was lower than before and the basin returned to shallower sedimentary conditions.

In terms of $2^{nd}$-order sequences, these uppermost beds of the Kashafrud Formation correspond to the maximum flooding surface (mfs). The aggradational and progradational successions of the Chamanbid and Mozduran formations were deposited during the *$2^{nd}$-order* HST until the falling stage systems tract (FSST), represented by the Shourijeh Formation, which terminated the $2^{nd}$-order cycle.

*Sequences of high frequency*

Parasequence sets PSK1-PSK9: High-frequency cycles are quite common in the study area, and range in thickness from several meters to more than one hundred meters. Lithofacies and field observations revealed that in the middle part of the section (Fig. 6.5) and generally third-order HST conditions, sets of parasequences formed in the basin, which in the Maiamay area is documented by at least nine parasequences. They represent the coarsening- and thickening-upward unit (Fig. 6.5, high-frequency cycles). The subsidence during the deposition of these parasequences still remained high, and more than one thousand m of sandstone and silty shale were deposited. One of the key features in this parasequence-set (in the Maiamay area) is the occurrence of several pulses of thick to massive, medium-grained, occasionally coarse-grained sandstones with convolute bedding (Fig. 6.4F). Some of these sandstones are structureless and probably originated from accelerated uplift of the basin margins, which caused a high amount of sediment input into slope and basin-floor areas. Thinner parasequences are common in upper parts of the Kol-e-Malekabad, Ghal-e-Sangi, and Danesh sections (Fig. 6.4).

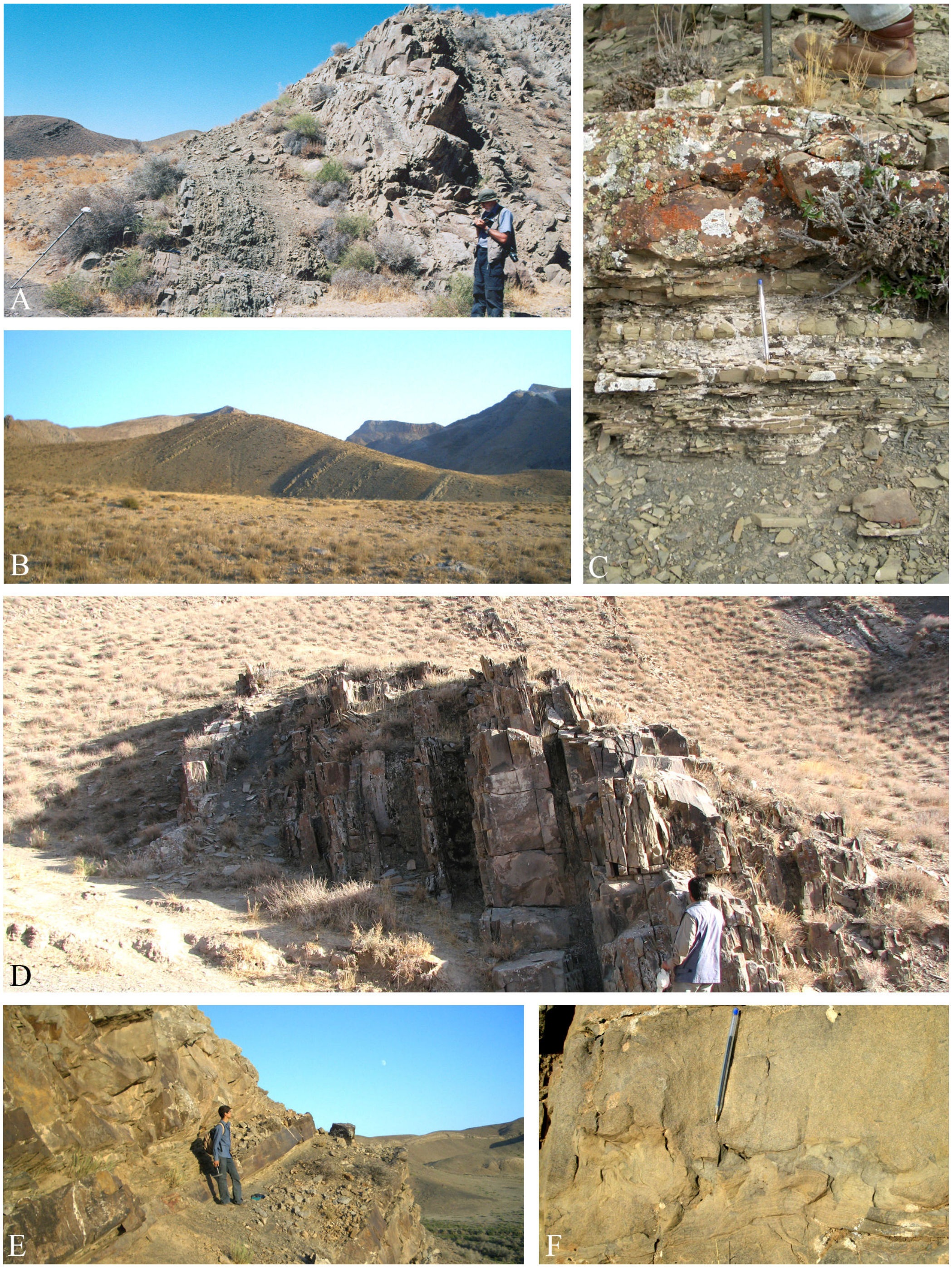



Fig. 6.4. A-D. Parasequences at different scales. A, D. Kol-e-Malekabad section. B-C. Danesh section. E, F. Member 3, Maiamay section: Thick sandy unit (E) and convolute bedding at horizon 1296 (F).

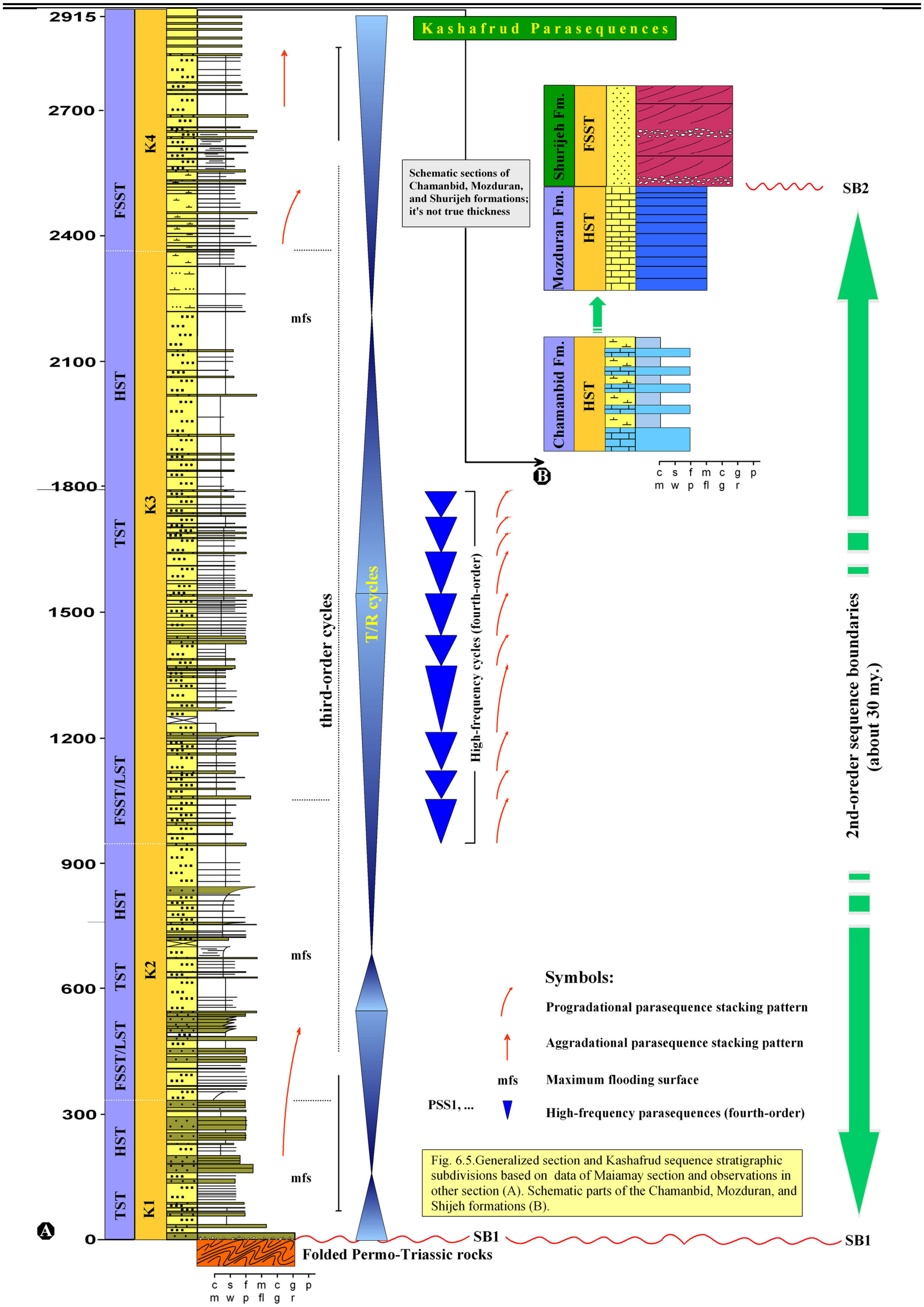



Fig. 6.5. Schematic section of the Kashafrud Formation and the sequence stratigraphic interpretation in the Maiamay area.

# Chapter 7

# Ichnology

## 7. Trace fossils

### 7.1 Preface

Trace fossils are one of the characteristic features of the Kashafrud Formation. Deep marine trace fossils from the Jurassic are comparatively poorly known. Here, a moderately diverse ichofauna from the Middle Jurassic of NE Iran is recorded for the first time.

Although ichnofauna is only of low to moderate diversing when individual horizons are considered, in the 10 sections which were logged bed by bed, 32 ichnospacies belonging to 19 ichnogenera could be identified. The preservation potential in different parts of the basin is not of the same level. Applying OLIVERO's (1994) index of trace fossil abundance only few levels of the sections and localities correspond to the classes 4 and 5 (abundant to very abundant), the remaining parts belong to similar classes 2 to 3 (rare to common).

Localities with abundant to very abundant trace forms (at least 1 trace per square meter to beds which are totally covered with traces) are the uppermost part of the Fraizi section west of Khij village, member one of the Maiamay and Kol-e-Malekabad sections, and some thin sandstone beds in the lower to middle parts of the Fraizi section.

In the following, the trace forms are described and interpreted. Susequently, they are evaluated in terms of ichnofacies and use in palaeoenvironmental reconstruction.

### 7.2. Ichnotaxonomy

**Ichnogenus *Biformites* LINCK, 1949**

Diagnosis. Bimorphous form, consisting of narrow section, partly divided by longitudinal furrows, continuing into wider section with prominent transverse ribs; resembling shafted hand grenade; preserved as positive hyporelief (modified from HÄNTZSCHEL, 1975).

Remarks. The type ichnospecies *B. insolitus* LINCK, 1949 occurs in the Middle Upper Triassic Schilfsandstein of Germany. A small form from the Atoka Formation of the frontal Ouachita Mountains has also been tentatively referred to *Biformites* (CHAMBERLAIN, 1971).

MILLER and KNOX (1985) reported similar trace fossils, probably as negative epireliefs. SEILACHER (1955) considered *Biformites* as a dwelling burrow. BOYER (1979) suggested that it represents both, resting and crawling behaviour of an ?arthropod, while according to CHAMBERLAIN (1971) it is a feeding burrow.

*Biformites* has been reported from different sedimentary environments. LINCK (1949) and SEILACHER (1955) reported *Biformites* from non-marine environments, while MILLER and KNOX (1985) found it in thin-bedded flysch sandstones.

**_Biformites_ isp.**

Pl. 1, Fig. 6

Material. One specimen (05 M 43b), from the middle part of the Maiamay section.

Description. Horizontal positive hyporelief, consisting of segments which have two parts: (1) a smooth narrow part 3-4 mm in diameter and 5-8 mm long, and (2) a relatively wide section with transverse ribs and median furrow. The width of this part is 7.5-9 mm and the rib diameter about 2 mm.

The length of the curved specimen is about 76 mm, which is divided into four segments, the length of which vary from 15.5 to 19.5 mm. It occurs in thin-bedded, fine-grained greenish sandstone.

Interpretation. Although the trace has been interpreted to present dwelling and also resting behaviour, a resting behaviour is more compatible with our specimen, because of the arrangement of segments along a curved line. The specimen was found in part of the succession which was deposited in water depth of about several 100 m.

**Ichnogenus _Chondrites_ STERNBERG 1833**

Remarks. *Chondrites* STERNBERG is one of the most easily determinable ichnogenera and also quite common trace fossils. Based on the obvious ramifying and dendritic pattern, the branching tunnel systems are more or less regular with master-shafts connected to the sediment surface (e.g., OSGOOD, 1970; FÜRSICH, 1974; UCHMAN, 1999).

SIMPSON (1957) reviewed this ichnofossil and suggested that it was produced by a member of the Sipunculoidea (a group of un-segmented worms). However, he also mentioned that the majority of modern sipunculoids have introverts much shorter and thicker than the tunnels of *Chondrites*; only the genus *Onchnesoma* has comparable dimensions.

SEILACHER (2007) explained its similarity to seaweed as phobotactic behaviour and argued that the branches were reconstructed in a backward succession.

*Chondrites* was recorded to range from the Ordovician to the Tertiary and to modern deep sea muds (SEILACHER, 2007). Although this ichnofossil is common in different rock types such as sandstone, shale and limestone, one of its most important aspects is that it typically represents systems that were produced deep within the sediment in anaerobic zones below the surficial oxidized zone (BROMLEY & EKDALE 1984).

In anoxic sediment such as black, laminated, carbonaceous clay, and dysoxic bottom waters commonly the only burrow system encountered is *Chondrites*.

BROMLEY & EKDALE (1984) showed that *Chondrites* is the last ichnofossil that remains when the oxygen content of bottom water decreases (Fig. 7.1) and made the following statements:

(1) *Chondrites* was produced at a greater depth within the sediment than any other associated trace fossil.

(2) Among *Chondrites* of different sizes, the smallest ones are the last ones to disappear.

(3) The observation that the smallest organisms reached the deepest tier demonstrates that small organisms generally have a greater tolerance of anoxia.

(4) *Chondrites* is a facies-crossing trace fossils, because it occurs both in sediments with a gradual redox boundary and in sediments which are rich in organic material.

(5) The occurrence of *Chondrites* is related to chemically reducing conditions deep within the sediment and only indirectly to conditions on the sea-floor.

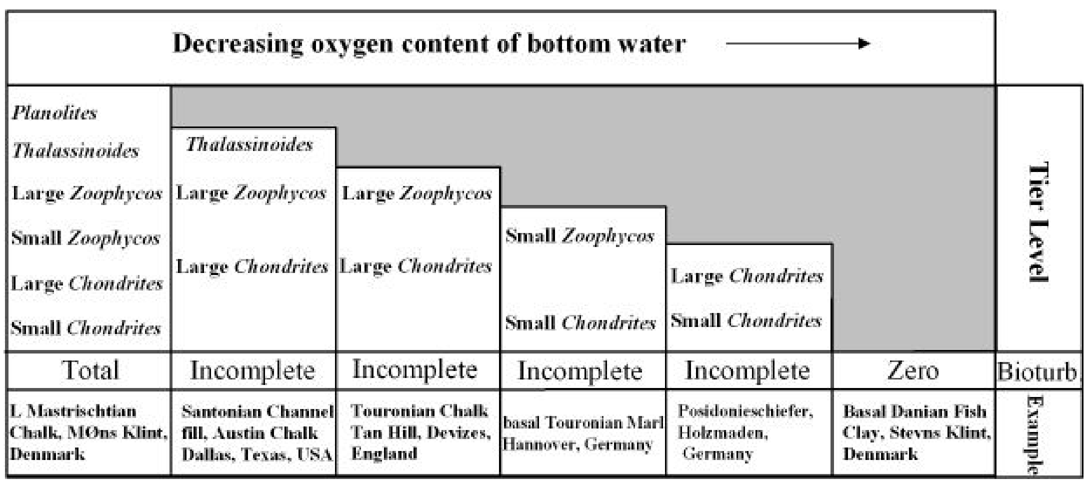



Fig. 7.1. Relationship between tier levels and diversity of trace fossils and the oxygen content of bottom water (redrawn from BROMLEY & EKDALE 1984).

FU (1991), reduced more than 150 ichnospecies of *Chondrites* to four, but Uchman (1999) doubted that all these ichnospecies should be synonymized with the four recognized by FU (1991). It is, however, clear that the diversity of *Chondrites* is grossly inflated.

As the tunnels are usually filled with soft sediment differing from the host rock they must have remained open and subsequently were filled passively with sediment.

**_Chondrites_ isp.**

Pl. 1, Fig. 2

Material. 6 specimens and numerous field observations, especially in the Fraizi section. 3 specimens from N: 36°, 30′, 09″ E: 59°, 04′, 01″ the remaining ones from the part of the section west of the small village of Abghad (N: 36°, 31′, 56″ E: 59°, 01′, 41″).

Description. Ramifying pattern, angles of branching between 37°-44°, preserved as full relief. Diameter of tubes 0.5 to 3.0 mm, fill consisting of lighter or darker soft sediment.

**_Chondrites intricatus_ BRONGNIART, 1823**

Pl. 1, Figs. 1, 4, 5

Material. 3 specimens, 1 from Fraizi (04, F, 14a), and 2 from the lower part of the Maiamay section (04, M, 5, 04, M, 6), which have been collected from thin-bedded, fine-grained sandstone.

Diagnosis. A plant- or tree-like branching, full relief burrow. Branches forming acute angles. In cross-section the burrows appear as patches of small circular or elliptical spots (after TUNIS & UCHMAN, 1996; UCHMAN, 1999; UCHMAN et al., 2004).

Description. Densely ramifying trace fossil, preservation in full relief, width of tunnels 1- 2 mm, angles of branching ranging from 30°to 44° (mean: 37°) and filled with lighter, finer-grained material than host rock.

In sample 04, F, 14a the tunnels seem to cut each other, but this is probably due to compaction.

**_Chondrites targionii_ BRONGNIART, 1828**

Pl. 1, Fig. 3

Material. One sample (04 F 20a) from Fraizi at horizons 1836-1841 m in thin interbedded sandstone with marl.

Diagnosis. Plant-like, ramifying system of more or less widely curved tubes. The angle of tunnels with the main shaft is sharp.

Description. Stem-like, horizontal to sub-horizontal flattened burrows with lateral branches connected to the first order branch with an angle smaller than 44°, width of tunnels 4-6 mm and filled with argillaceous sediments which is lighter than the host rock. Some tubes are curved.

The specimen measures about 78 mm. It was found in greenish-grey, thin-bedded, fine-grained sandstone in the upper part of the Fraizi section.

Discussion. UCHMAN & WETZEL (1999) interpreted curved tunnels either to the fill of a former helicoidal burrow that is not preserved, and this mimicry led to an aberrant geometry that is atypical of Chondrites (UCHMAN & WETZEL, 1999: 167; see also NODA & YOON, 1982).

According to UCHMAN & WETZEL (1999) the helicoidal structure in the aberrant *Chondrites* indicates a chemotactic/thigmotactic behaviour of its producer.

EKDALE and LAMOND (2003) attributed regular trace fossil patterns to a more advanced evolutionary behavior of the trace maker. Accordingly, *C. intricatus* should represent a more advanced behaviour than *C. targionii.*

### Ichnogenus *Curvolithus* FRITSCH, 1908

Remarks. The ichnogenus *Curvolithus* Fritsch, 1908 was originally described from the Ordovician of the Prague Basin (BUATOIS et al., 1998). At least six ichnospecies were distinguished before the ichnogenus was revised by BUATOIS et al. (1998). Of theis six ichnospecies (C. *gregarious, C.?davidis, C. annulatus, C. aequus, C. manitouensis*, and *C. multiplex*) only *C. multiplex w*as regarded to be a valid ichnospecies the remaining five ichnotaxa being synonyms.( BUATOIS et al., 1998). Earlier on, CHAMBERLAIN (1971: 224) had regarded *C. multiplex* as the only valid ichnospecis. *C. multiplex* is characterized by a quadrilobate lower surface and a trilobite upper surface.

BUATOIS et al. (1998) created the new ichnospecies *C. simplex* with a trilobate upper surface and a unilobate to trilobate lower surface.

There is no over-all agreement about the trace-maker of this ichnogenus, but most ichnologists believe that the producer was probably a carnivore. HEINBERG & BIRKELUND (1984), assume a member of the order Cephalaspidea as possible trace producer, but FÜRSICH & HEINBERG (1983) attributed *Curvolithus* ichnocoenosis to trophically diverse fauna of carnivores, infaunal or epifaunal deposit-and suspension-feeders.

SEILACHER (1990), based on the tongue-like aspect and the mode of the trace, suggested a flatworm as producer.

For determination of the *Curvolithus* specimens from the Kashafrud Formation, the ichnospecies concept of BUATOIS et al. (1998) has been accepted resulting in the recognition of *C. simplex* in several samples.

**_Curvolithus simplex_ BUATOIS, MANGANO, MIKULAS & MAPLES, 1998**

Pl. 2, Figs. 5-7

Material. 4 specimens (04 K 10a, 04 Gh 6a, 05 M 35a; 04 F 45) from the upper part of the Kol-e-Malekabad section, the middle part of the Ghal-e-Sangi section, and the upper part of the Maiamay and uppermost part of the Fraizi sections.

Diagnosis. Trilobate convex upper surface with narrower lateral, ribbon-like structures.

Description. Upper surface trilobate, 11-13 mm wide, lower surface mostly unilobate, but not completely visible, forming a positive hyporelief. Most specimens were found in highly bioturbated, thin-bedded, fine-grained sandstone. Sample 04, Gh, 6a from the the Ghal-e-Sangi section has a median furrow which is comparable to *Curvolithus* type 2 of HEINBERG (1970, 1973) and also to *C. simplex* (BUATOIS et al., 1998).

The specimen from Kol-e-Malekabad is slightly curved, which didn't divide the specimen into two segments and more or less comparable with Fig. 1 of BUATOIS et al. (1998).

**?_Curvolithus_ isp.**

Pl. 2, Fig. 4

Material. One specimen (04 K 16a) from the upper part of the Kol-e-Malekabad section.

Description. Negative hyporelief, 11-17 mm wide, upper surface trilobite. Although at first glance the specimen resembles a sedimentary structure such as a groove cast but, the obvious trilobate structure and the change in direction of the trail proves its biogenic origin. As the lower surface cannot be observed it is impossible to determine the specimen at the ichnospecies level. It was found in micaceous, bioturbated, fine-grained sandstone.

Discussion. *Curvolithus* is a useful trace fossil for reconstructing the sedimentary environment. Accordingly, LOCKLEY et al. (1987), proposed a new ichnofacies, the *Curvolithus* ichnofacies based on a trace fossil assemblage consisting of *Curvolithus, ?Margaritichnus, Muensteria, Planolites* as well as *Ophthalmoides, Lockeia* and rarely *Micatuba.* The middle part of the Ghal-e-Sangi section (at about 700-750 m) may well correspond to the *Curvolithus* ichnofacies.

FÜRSICH & HEINBERG (1983) reported *Curvolithus* from an Upper Jurassic offshore sand bar complex of Milne Land (East Greenland). According to them the *Curvolithus* ichnocoenosis is found in more offshore fine-sandy mudstones to mudstones than ichnofossils such as *Gyrochorte* and *Planolites*. In Middle Jurassic shallow-water sediments of the Kachchh Basin *Curvolithus* did not play a major role (FÜRSICH, 1998).

In the Pennsylvanian Minturn Formation of Colorado the *Curvolithus* ichnofacies is geographically restricted to marginal-marine settings and was generally made in sandy substrate (LOCKLEY et al., 1987). However, the present specimens and the strata in which they occur in the eastern part of the Kashafrud Basin are more comparable to those from Milne Land and Jameson Land indicating offshore, relatively quiet environments.

The Maiamay area represents a deep part of the Kashafrud Basin, but the *Curvolithus* specimen was found in the upper part of the formation, in which the rocks indicate shallowing of the basin.

**Ichnogenus *Diplocraterion* TORELL, 1870**

***Diplocraterion parallelum* TORELL, 1870**

Pl. 13, Figs. 2-4

Material. Three specimens, one from Fraizi section (04 F 20h), one from Jizabad area (04 J 1a) and one from Maiamay section (05 M 43); all three were found in fine- to medium-grained, thin-bedded sandstone.

Diagnosis. *Diplocraterion* having parallel burrow walls and an unidirectional spreite (FÜRSICH, 1974).

Description. Pair of funnel-shaped structures, occasionally dumbbell-shaped (Pl. 13, Fig. 2), diameter of tubes 4 to 8 mm. The funnel diameter ranges from 7 to 10 mm. Distance between limbs 0.4 to 2 cm.

**Ichnogenus *Gyrochorte* HEER, 1865**

Remarks. *Gyrochorte* is a trace fossil well-known from Europeian Jurassic epicontinental seas (HALLAM, 1970), but has also been reported from numerous other localities such as the Cretaceous of Utah, (DE GILBERT & EKDALE, 2002; ZONNEVELD et al. 2001).

Usually preserved as a positive epi- and negative hyporelief on the same thin sandstone slab, *Gyrochorte* can be used as a way-up criterion. WEISS (1940) argued that *Gyrochorte* could have only been produced by a polychaete or worm-like animal moving obliquely through the sediment. HEINBERG (1973), based on very well preserved material from the Jurassic of East Greenland, in which mica flakes traced the internal structure of the trace fossil, documented that WEISS in fact was correct and that *Gyrochorte* has beeen produced by an elongated organism moving obliquely through the sediment in search of food.

**_Gyrochorte comosa_ HEER, 1865**

Pl. 2, Figs. 1-3

Material. Three specimens (04 Gh 5a - 04 Gh 15a, 04 Gh 16b) from the Ghal-e-Sangi section at 678 m, 1200 m, and 1225-1230 m, and one specimen (06 F 2a) from the lower part of the marine succession at Fraizi.

Diagnosis. Ridges on bedding planes with biserially obliquely aligned transverse pads, both series separated by median furrow (FÜRSICH, 1974).

Description. Both positive epirelief negative hyporelief are visible among the specimens. The biserial ridges and grooves exhibit a median furrow respectively ridge and follow a nearly straight to strongly winding horizontal course.

Pads obliquely arranged pads in a chevron-like manner, and a median furrow are well displayed. The angle between pads and median furrow is about 45˚ (measured in specimens

04 Gh 5a 16b). In some cases, the ridges end abruptly and on some slabs crossing over of *Gyrochorte* is common. The width of the trace fossil varies from 2 to 7 mm.

**Ichnogenus _Hillichnus_ BROMLEY, UCHMAN, GREGORY & MARTIN, 2003**

**_Hillichnus_ aff. _lobosensis_ BROMLEY, UCHMAN, GREGORY & MARTIN, 2003**

Pl. 3, Fig. 7

Material. One specimen (04 Gh 16c) from the upper part of the Ghal-e-Sangi section at about 1225 m.

Diagnosis: Complex trace fossil comprising several contrasting parts. Two concentric structures, a basal segmented structure and within this a basal tube, run axially along the base and give rise to lateral spreiten or feather-like structures. The individual spreiten or feather-like structures arise alternately on either side of the basal segmented structure. Arising by branching from the basal tube, a series of sand- and mud-lined tubes curve upward into a nearly vertical position (Beomley et al., 2003). These rising tubes may stand in a straight line, as a zigzag line, or in irregular groups. The general course of the trace fossil is horizontal, straight to curving or rarely looping.

Description. The rather complex trace fossil consists of a more or less horizontal, cylindrical burrow (diameter 6-16 mm, depending on the angle of the burrow with the bedding plane) with meniscate-backfill and a central tube (diameter less than one-third of the host burrow) with a structureless fill. In some parts lateral linear tubular appendices are present surrounded by a thick wall. Also associated are vertical structures seen in cross-sections. The walls are internally smooth and relatively thick in comparison to the total width of the burrow structure.

This full relief biogenic structure was found in medium-grained, thin-bedded sandstone.

Interpretation. The lateral linear appendices, which are visible in some parts of the specimen, may be related to the burrowing action of a pair of pulpous tentacles, the circular open structures may possibly be related to a siphon of the trace maker. The thick wall and the lateral appendices obviously are incompatible with a designation of the trace as *Taenidium* or *Protovirgularia*. It is not as complex as *Hillichnus lobosensis* to which it has been related here. As only a single specimen is available, no attempt is made to describe it as a separate ichnotaxon.

**Ichnogenus *Helminthopsis* HEER, 1877**

Remarks. *Helminthopsis* is a feeding burrow produced usually at shallow depth within nutrient-rich sediment. Differentiation of this ichnogenus is difficult for several reasons; one of the most important is that the type material of *Helminthopsis* HEER, 1877 has not been accepted to represent this ichnogenus (WETZEL & BROMLEY 1996).

WETZEL & BROMLEY (1996) revised the ichnogenus *Helminthopsis* and concluded that *H. magna* HEER, 1877 and *H. intermedia* HEER, 1877 belong to *Scolicia* and that *H. labyrinthica* is a senior synonym of *Spirocosmorhaphe helicoidea* SEILACHER, 1989.

Another problem is the similarity with other trace fossils especially in incompletely preserved specimens, which are commonly documented in the literature.

Disagreement on *Helminthopsis* continued after KSIAŻKIEWICZ (1977), who introduced the new ichnospecies *Helminthopsis abeli* (based on ABEL's (1935) illustration) and considered it as the type ichnospecies (WETZEL & BROMLEY, 1996; UCHMAN, 1998). In contrast, SEILACHER (1977) attributed ABEL's specimen to *Cosmorhaphe lobata* SEILACHER, 1977. UCHMAN (1998) was of the oponion that the specimen is too small and it is difficult to decide whether it belongs to *Helminthopsis* or to *Cosmorhaphe*.

HAN & PICKERILL (1995) concluded that separation of *H. abeli* and *H. tenuis* is difficult, and regarded them as synonyms.

WETZEL & BROMLEY (1996) regarded *H. abeli* KSIAŻKIEWICZ, 1977 as *Cosmorhaphe helmithopsoidea* SACCO, 1888 but UCHMAN (1998) rejected this conclusion and prefered to keep the ichnotaxon in *Helminthopsis* instead of *Cosmorhaph*e. WETZEL & BROMLEY (1996) used a geometric analysis based on height and width of small and large loops as a tool to differentiate ichnospecies of *Helminthopsis*, although this can not be applied to all ichnospecies. HAN & PICKERILL (1995) used a Fourier Transfer Analysis (FTA) to distinguish various ichnospecies of *Helminthopsis*, but WETZEL & BROMLEY (1996) believed that the FT analysis was used wrongly.

In conclusion, it seems better to focus on a detailed morphological description of the traces (meandering shape, bell, horseshoe or omega shape), for different ichnospecies. One should also be aware about uncompleted specimens, which may resemble other traces such as *Cosmorhaphe* and *Gordia*.

CRIMES (1973, fig. 11) recorded *Helminthopsis* from shelfal (offshore) to upper slope environments of the Zumaya flysch, north Spain, Paleocene-Eocene in age. The type locality of the ichnogenus in Ganei Slate (Eocene, Switzerland), has been re-sampled by WETZEL & UCHMAN (1997) and the sedimentary succession has been interpreted as deep-sea fan overbank deposits, with *Helminthopsis* more common in their trace fossil assemblage II. CRIMES et al. (1981), found this ichnotaxa in the same environment of the Cretaceous-Eocene Gurnigel and Schlieren flysch deposits of Switzerland.

**_Helminthopsis_ cf. _abeli_ KSIAŻKIEWICZ, 1977**

Pl. 3, Figs. 3, 5

Material. Three specimens, preserved as negative epireliefs, specimen 04 F 20c from the upper part of the Fraizi Section (at 1836-1841 m) in fine-grained, mica-bearing, greenish-grey sandstone. Specimen o4 K 3a from silty sandstone of the lower part of Kol-e-Malekabad. Specimen 05 M-G 38 from the Gas-pipline section in greenish, fine-grained sandstone.

Diagnosis. Simple, unbranched, cylindrical, winding tubes producing shallow and deep meanders (after WETZEL & BROMLEY, 1996; UCHMAN, 1998).

Description. Meandering trail with both shallow and deep loops, preserved as negative epirelief. Width of traces 3-5 mm, with structureless margins fill. Course of trace Ω-shaped and with convex and concave winding pattern.

Discussion. The winding pattern closely correspounds to *Helminthopsis abeli* KSIAŻKIEWICZ, 1977, especially the closely spaced loops. The marginal ridges do not show any pattern as is characteristic of *Nereites*.

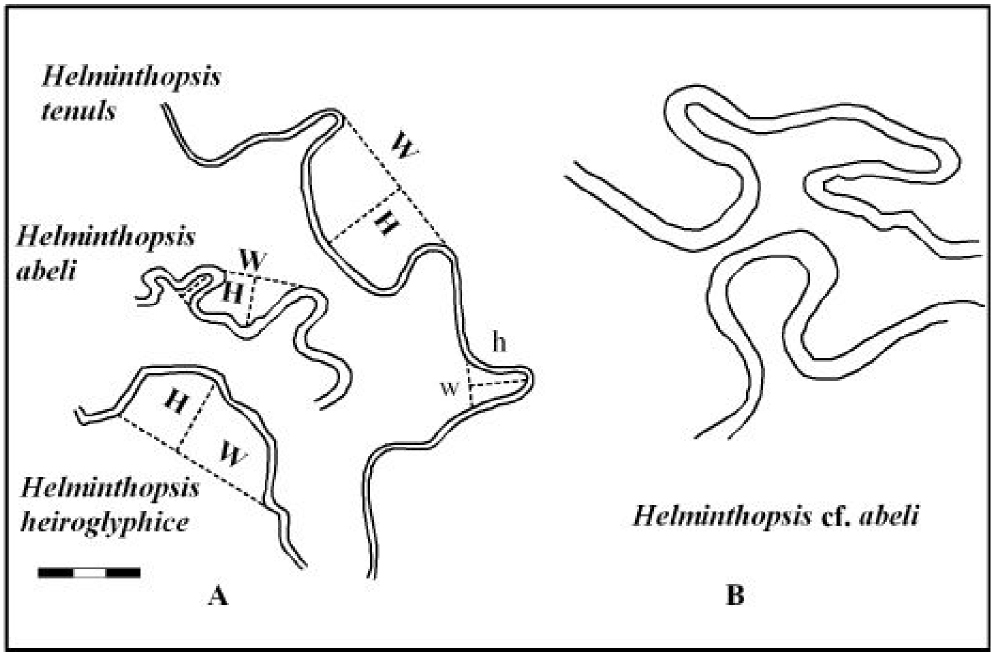



Fig. 7.2 A. Geometric pattern of three ichnospecies of *Helminthopsis* according to WETZEL & BROMLEY (1996: 14, text-fig. 7). B. Sketch of *Helminthopsis* cf. *abeli* from the Kashafrud Formation at Fraizi. The geometric pattern and also winding of the Kashafrud specimens is more compatible with *Helminthopsis abeli*.

REID & PEMBERTON (2004) reported *Helminthopsis* from the Cruziana ichnofacies of storm-influenced pro-delta to upper offshore environments.

BUATOIS et al. (2006) found *Helminthopsis* in normal-marine shelves to estuaries to lakes in Paganzo, Tarija and Paraná basins of Argentina and Brazil, which were affected by the Late Palaeozoic Gondwana deglaciation.

Our samples consist of only two specimens from the Fraizi and Kol-e-Malekabad areas and correspond to proximal turbidites at Fraizi and inner shelf to upper slope environments at Kol-e-Malekabad.

### Ichnogenus *Helminthorhaphe* SEILACHER, 1977

### *Helminthorhaphe crassa* SCHAFHÄUTL, 1851

Pl. 3, Figs. 1-2

Material. Four specimens, all from the lower part of the Maiamay section north of Maiamay village; two samples from horizons 76-113 m (04 M 1b, h), the third and fourth samples from horizon 170 m (04 M 7) and 180 m (04 M 8) respectively. They occur in very fine-grained sandstone to sandy siltstone.

Diagnosis. Meandering, cord-like ridges (0.5-0.8 mm across), lacking a regular meander pattern; cords are rather poorly guided and widely spaced relative to burrow diameter (LESZCZYŃNSKI & SEILACHER, 1991).

Description. Narrow, cord-like meandering structure with a tube diameter of 0.5-1.8 mm. In some parts the distance of neighboring tubes rarely exceeds 2.0 mm, except specimen 04 M 8, the tubes of all other samples are filled with lighter and finer sediment. It seems that the burrow fill contains less mica in comparison to the host sediment. In specimen 04 M 1h the cord forms a relatively continuous meandering pattern (although the contrast between the burrow and matrix is not so high), but in others cords are disconnected, which may be related to vertical undulation and/or subsequent bioturbation. As the meander pattern is not very regular the specimens are more compatible with *H. crassa,* than with other ichnospecies of *Helminthorhaphe*.

Remarks. Some discontinuities of cords and also intersections may be related to vertical undulation of the burrows.

**_Helminthorhaphe japonica_ TANAKA, 1970**

Pl. 3, Fig. 6

Material. One specimen (05 M-G 38) from the lower part of the Gas-pipeline section, found in very thinly laminated olive siltstone.

Diagnosis. Meanders of very high amplitude and densely guided, at least part of the ,eanders with rounded and often bulging turns (after SEILACHER, 1977).

Description. Very narrow (0.5 mm in diameter) horizontal meandering tube, preserved as negative epirelief. The diameter of the tube, which is filled with lighter sediment, varies to some extent, the width of the loops is about 8 mm, and the meanders are relatively regular. For this latter character the trace fossil is more compatible with *Helminthorhaphe japonica* than *H. crassa*.

**Ichnogenus _Lophoctenium_ RICHTER, 1850**

**_Lophoctenium_ cf. _richteri_ DELGADO, 1910**

Pl. 4, Figs. 2-5

Material. Two specimens (04 F 30a, 04 F 25a) from the Fraizi section at 1960 and 1972 m, two specimens (04 K 4e, 04 K 5a) from the Kol-e-Malekabad section (between 114-137m) and one specimen (04 Gh 11a) from the middle part of the Ghal-e-Sangi section (at 784 m).

Diagnosis. Curved, comb-like, elegant twig structures composed of alternating ridges and pits. General shape resembling bunches that connect to a main axis.

Description. Biogenic structure composed of closely spaced bunches of cylindrical burrows, without obvious walls, preservation as negative epirelief and hyporelief. Some of the twigs are inwardly bent resulting in typical comb-like structures. Width of bunches ranges between 5and 27 mm and diameter of burrows between 1 and 3 mm. The specimens were found in fine- to medium-grained sandstone. The traces closely resemble *L. richteri* as figured by CHAMBERLAIN (1971: pl. 32, fig. 2).

### ***Lophoctenium* isp.**

Pl. 4, Fig. 2

Material. Three specimens (04 F 20b, 04 F 22a, 04 F 24a) from the upper part of the Fraizi section at horizons: 1836.5, 1920, and 1910-1938 m, respectively, one specimen (04 K 6a) from the lower part of the Kol-e-Malekabad section at 137 m.

Description. Horizontal biogenic structure composed of bunches or twigs, which show a comb-like pattern preserved as epirelief and hyporelief. Width of burrows 1 to 2 mm. connected or disconnected. Width of bunches 10-15 mm. Specimen 04 F 20b shows a unidirectional feather-like structure (see also FU, 1991) and in another specimen (04 F 24a), the main stem shows a zigzag-like meandering pattern with narrow ridges and pits, about 1-2 mm wide, which rarely show a chevron-like pattern (see also CHAMBERLAIN, 1971).

In the lower part of the Kol-eMalekabad section, *Nereites* and *Lophoctenium* occur together as convex and concave epireliefs respectively.

Discussion. One of the diagnostic features of *Lophoctenium* is the presence of a spreite (CHAMBERLAIN, 1971) and for this reason it has been grouped as a spreiten biogenic form (WETZEL, 1984). The Kashafrud specimens are mostly preserved as horizontal epi- and hyporeliefs, produced at sedimentary interfaces.

One of the Fraizi samples (04 F 25a, Pl. 4, Fig. 6), shows a symmetrical array of bunches at both sides of the main axis and may represent a new ichnospecies, but in order to decide this more material is needed.

*Lophoctenium* specimens were found only at the southwestern and northeastern margins of the Kashafrud Basin (e.g. at Fraizi, Kol-e-Malekabad and Ghal-e-Sangi). They are absent in the deepest (Maiamay area) and shallowest part of the Danesh section.

ORR et al. (1996) reported *Lophoctenium* from deep-marine (Lower Carboniferous) rocks of Menorca, Balearic Islands. The ichnogenus was also reported in flysch deposits of Turkey (UCHMAN, 2004), Europe, and North America (e.g. HÄNTZSCHEL, 1975: W79; UCHMAN, 2001; CRIMES et al., 1981).

FÜRSICH (1998) described *Lophoctenium* from Upper Jurassic siltstones of western India, which represent an offshore, outer ramp environment. MANLEY & LEWIS (1998) reported helical *Lophoctenium* in vertical section from a Miocene submarine fan system in New Zealand. WETZEL, (1984) assumed a water depth of 2000-3500 m to the *Lophoctenium-Chondrites-Helminthopsis* ichnocoenosis of NW Africa. EAGAR et al. (1985) in contrast, documented *Lophoctenium* in Mid-Carboniferous deltaic sediments of the central Pennines, England.

It seems that the *Lophoctenium* specimens from the Kashafrud formation were not produced in very deep environments, but most likely represent a several 100 m deep setting.

**Ichnogenus *Monocraterion* TORELL, 1870**

***Monocraterion* isp.**

Pl. 13, Fig.1

Material. One specimen (04 K 14) between 1140-1160 m of the Kol-e-Malekabad section in fine-grained sandstone.

Description. Vertical hyporelief cylindrical structure perpendicular to the bedding plane, relatively thick wall. The external diameter is 7 mm and wall thickness is about 1.5 mm.

**Ichnogenus *Neonereites* SEILACHER, 1960**

Remarks. The ichnogenus *Neonereites* includes four ichnospecies: *N. uniserialis, N. biserialis, N. multiserialis,* and *N. renarius* (PICKERILL, 1991). The relationship of related ichnotaxa of the *Nereites* group is controversial. CHAMBERLAIN (1971) regarded *Nereites, Neonereites,* and *Scalarituba* as synonyms, but according to SEILACHER (1983, 1986) they are merely related. According to PICKERILL & HARLAND (1988), *Neonereites* occurs from the Late Silurian to the Eocene.

The relationship of *Neonereites* to several other ichnogenera, which at first glance show some similarities such as *Ophiomorpha, Granularia* and *Edaphichnium*, also needs to be discussed. The main difference between *Neonereites* and these ichnogenera is that in the former the pustulose or nodose burrow wall is only developed at the base of the burrow (for details see PICKERILL, 1991).

I am agree with MANGANO et al. (2000), who argued that the three ichnogenera of the *Nereites* group should be kept separate ("as in the case of compound specimens of *Thalassinoides, Ophiomorpha* and *Gyrolithes*, noting that these ichnogenera are nevertheless still retained as valid"; MANGANO et al. 2000: 152).

**_Neonereites multiserialis_ PICKERILL & HARLAND, 1988**

Pl. 5, Figs. 1-7

Material. Five specimens, 2 from the lower part of the Kol-e-Malekabad section (04 K 4a-b,f , and 04 K 5b-c) at 114-137 m; 1 specimen (04 Se 1a) from the lower part of the Senjedak section at the southern margin of the Kashafrud Basin and 1 specimen(04 M 30a) from the Maimay section at 2170-2190 m. All specimens are preserved as hyporeliefs.

Diagnosis. *Neonereites* with chains composed of more than two rows of pustules or pods when preserved in convex hyporelief or, conversely, dimples or pods in epirelief (PICKERILL & HARLAND, 1988).

Description. Curved to sinusoidal, horizontal burrow system, preserved as positive hyporelief. Width variable, from 0.6 to 1.2 cm, diameter of pustules varying between 1 and 3 mm, length of specimens 5-9 cm, restricted by slab size.

Although *Neonereites multiserialis* cuts *Nereites jacksoni* (Pl. 6, Fig. 3), both are post-depositional in origin. On the same slab there is the relict of a very thin pre-depositional trace fossil (*? Protopaleodictyon*).

**Ichnogenus _Nereites_ MAC LEAY, 1839**

**_Nereites missouriensis_ WELLER, 1899**

Pl. 6, Figs. 1-3

Material. Three specimens (04 K 3b; 04 K 5c; 04 K 4d), preserved as epichnia, from the lower part of the Kol-e-Malekabad section. The first two specimens are from level 114-123 m and the third one from level 123-137 m. The specimens were found in very thin-bedded (< 1.0 cm), brownish, fine-grained sandstone.

Diagnosis. Loosely meandering to winding trails. Wide central tunnel with menisci, and envelope zone of similar thickness (MARINTSCH & FINKS, 1982; UCHMAN, 1995).

Description. Curved to winding horizontal trails preserved as negative epirelief. Main tunnel with lateral bioturbated zones. Reworked sediments of lobate shape on both side of the gallery 4-9 mm wide. Depth of trails is less than 1 mm. Diameter of main trail and lateral bioturbated zones of more or less equal width.

Discussion. In the specimen (04 K 4d), was cut by *Neonereites multiserialis*, both traces being post-depositional in origin. There are also very fine relicts of another trace which could be? *Protopaleodictyon.*

The samples of this ichnospecies come from the lower part of the section, in which mudstones are interbedded with thin-bedded silt- and fine-grained sandstones. This part of the succession can be interpreted as distal turbidites.

**_Nereites irregularis_ SCHAFHÄUTL, 1851**

Pl. 6, Figs. 5, 8

Material.Three specimens (04 M 1a; 04 M 1c; 04 M 1d) from the lower part of the Maiamay section, and 1 specimen (05 M 30c) from the upper part of the same section.

Diagnosis. Closely spaced, meniscat meandering trace, preserved as epirelief and full relief, dimensions of meanders variable, envelop zone not as obvious as in other *Nereites* ichnospecies (UCHMAN, 1995; UCHMAN et al., 2004).

Description. Regular and irregular meandering epichnia, lateral zones along the main tunnel highly bioturbated and enriched with iron, main tunnel 2-3 mm wide, bioturbated envelop zones of variable thickness. Tunnels filled with finer and lighter sediments (olive- to dark grey). The specimens from the lower part of the section are multi-storey and show high bioturbated features. They are very close to specimen figured by UCHMAN (1995: pl. 9 figs. 3-4; 2004: fig. 56).

Remarks. UCHMAN (1995) revised *Helminthoida labyrinthica* HEER as *Nereites irregularis* which, according to him, has a highly variable morphology, and closely packed. Apparently a poorly preserved envelope zone of the main tunnel is one of the most characteristic feature of *N. irregularis*.

KSIĄŻKIEWICZ (1977) considered a worm-like organism such as a polychaete as producer of this ichnospecies. It ranges from the beginning of the Mesozoic (YANG, 1986) to the Miocene (UCHMAN, 1995), and possibly Quaternary (EKDALE & LEWIS, 1991).

### *Nereites* cf. *N. macleayi* MacLeay, 1839

Pl. 6, Fig. 6

Material. One specimen (04 Se 2a) from the southern margin of the Kashafrud Basin, at 55-65 m of the Senjedak section, preserved as epichnon in greenish fine-grained sandstone.

Description. Based on the criteria outlined by Uchman (1995), who presented schematic patterns of the different *Nereites* ichnospecies including envelope zone and dimensions of the main gallery, the specimen is most compatible with *N. macleayi*. The elongate lobes are connected with the main gallery by an angle of around 30°; the lobes are 1.0 mm wide and 1.5 mm long. The reworked envelope zone is not so sharply defined. The trace is curved to horse-shoe shaped and could be the segment of a meandering trail, lateral oblique lobes being preserved only in the curved part of the trail.

Remarks. McCann & Pickerill (1988) suggested that a systematic taxonomic re-examination of this ichnospecies should take into account lobe shape and size and overall morphology. It seems that Uchman's (1995: 27, text-fig. 8) schematic figures are a logical basis for classifying and determining ichnotaxa of the *Nereites* group. For more detailed characters see Benton, 1982.

This ichnospecies has been reported from the Upper Cambrian (Crimes & Germes, 1982) to the Eocene (Häntzschel, 1975).

### *Nereites*, isp.

Pl. 6, Fig. 9

Material. Two specimens (04 K 3b, 04 K 3d) preserved as epichnia from the lower part of the Kol-e-Malekabad section (at 101-113 m) in light-brown, thin-bedded, fine-grained sandstone, a third one (05 M 30c) from the upper part of the Maiamay section.

Description. Poorly preserved, horizontal winding to meandering trails, preserved as negative epirelief. Main tunnel 1-2 mm wide, reworked envelope zone variable, 1.5-3 mm wide. One of the specimens shows an obvious meniscate structure. As the specimens are poorly preserved identification is restricted to the ichnogeneric level.

**Ichnogenus *Scalarituba* WELLER, 1899**

***Scalarituba missouriensis* WELLER, 1899**

Pl. 6, Figs. 4, 7, 10

Material. Three specimens (04 K 1a, 04 K 2a, 04 K 2b) preserved as epichnia in very thin-bedded, light-brown to cream-coloured siltstone in the lower part of the Kol-e-Malekabad section (at 70-93 m).

Diagnosis. Scalariform, horizontal feeding burrow, curved to meandering, with asymmetric bioturbated zones along the main gallery.

Description. Negative epirelief; curved to winding and occasionally horse-shoe shaped trails. Width of the main gallery 2-8 mm. Diameter of reworked envelope zone variable (~1.5-8 mm) along the main tunnel. Distance of ladder-like ridges 1.5-4 mm. In a single slab rarely traces of different sizes occur. The width of the main tunnel increases in one direction and may indicate growth of the trace-maker.

The specimens on Pl. 6, Figs. 4, 7 are similar to those figured by CHAMBERLAIN (1971, pl. 31), DE GIBERT & EKDALE (1985), and RODRIGUEZ & GUTSCHICK (1970: pl. 6).

Discussion and occurrence. *Scalarituba* has been regarded as a eurybathic ichnofossil (CHAMBERLAIN, 1971). However, its occurrence with other deep-marine ichnotaxa such as *Nereites* and *Neonereites* in the Kashafrud Basin, in addition to lithological characters (thin-bedded distal turbidites), confirm at least on outer shelf to upper slope environment. *Scalarituba* differs from similar trace fossils, such as *Taenidium* by having a thick bioturbated envelope zone, whereas in *Taenidium* only a thin wall is developed.

The envelope zone in *Nereites* from the Kashafrud Formation is more pronounced and regular than in *Salarituba*, and the morphology of *Scalarituba* is completely different from that of *Neonereites*. Based on their close similarity *Nereites* and *Neonereites* possibly are synonyms, and these two ichnotaxa either reflects different styles of preservation and/or behaviour of the trace-maker.

*Scalarituba* has been recorded from a number of localities and stratigraphic levels, for instance the Mississippian-Pennsylvanian of the Ouachita Mountains (CHAMBERLAIN, 1971); the lower Pennsylvanian of the northern Cumberland plateau, Tennessee (MILLER & KNOX, 1985), the upper Pennsylvanian of Kansas (HAKES, 1985), the Miocene submarine fan system of the Taranaki Basin in New Zealand (MANLEY & LEVIS, 1998), Ordovician and Mississippian-Permian rocks of the North America (CONKIN & CONKIN, 1968), Pliocene rocks of the Var Basin, SE France (DE GIBERT & MARTINELL, 1998), and the Middle Jurassic of the Carmel Seaway Utah (De Gibert & Ekdale, 1999). RODRIGUEZ & GUTSCHICK (1970) reported it co-occurring with *Zoophycos*, but emphasized its shallower position.

According to CHAMBERLAIN (1971) *Scalarituba missouriensis*, S. *uniserialis,* and *Neonereites biserialis* probably are synonyms. SEILACHER & MEISCHER (1965) and SEILACHER (1983, 1986), argued that these ichnogenera are closely related (for details see LUDWIG, 1869; CHAMBERLAIN & CLARK, 1973; TURNER & BENTON, 1983). However, based on the Kashafrud specimens and considering the differences between the meniscate structure in *Nereites* and the ladder-like structure of *Scalarituba* these ichnogenera are best kept separate as has been done by FILLON & PICKERILL (1990) and PICKERILL (1991).

Another difference between these ichnotaxa lies in the envelope zone of *Scalarituba* which is not as nicely lobate as in *Nereites* and *Neonereites*.

### *Ichnogenus Ophiomorpha* LUNDGREN, 1891

Remarks. This trace fossil is one of the most famous and easily determinable biogenic structure. Numerous authors discussed the features of *Ophiomorpha* with respect to their ichnogeneric and ichnospecific significance (e.g. KENNEDY & SELLWOOD 1970; DIKE 1972; CHAMBERLAIN & BEAR 1973; FÜRSICH 1973, 1974; BROMLEY & FREY, 1974; FREY et al. 1978; FREY & HOWARD, 1990; POLLARD et al. 1993; GOLDRING, & POLLARD 1995; TCHOUMATCHENCO & UCHMAN 2001; DE GILBERT et al., 2006).

Although some overlap exists between *Ophiomorpha*, *Thalassinoides*, *Spongeliomorpha*, and *Gyrolithes* (FÜRSICH, 1973; FREY et al., 1978), the pelleted wall, which is more or less smooth interiorly (FREY et al., 1978), is the main diagnostic feature of *Ophiomorpha*.

In the siliciclastic strata of the Kashafrud Formation the trace fossil occurs at Fraizi, Kol-e-Malekabad, Maiamay, Ghal-e-Sangi and Danesh. The specimens from the Danesh and Maiamay sections could be identified at the ichnogeneric level only.

*Ophiomorpha* is most abundant in the middle and upper parts of the Fraizi section and is mostly preserved as relicts of horizontal mazes.

### *Ophiomorpha borneensis* KEIJ, 1965

Pl. 7, Figs. 3, 6, 8-9

Material. Four specimens from middle part of Fraizi section (04 F 14a-b, d, f), between 1318-1329 m.

Diagnosis. Burrow walls consisting predominantly of dense, regularly distributed bilobate pellets (FREY et al., 1978).

Description: Curved to bifurcating horizontal tunnel system, preserved as negative hyporelief, with distinct wall consisting of mostly bilobed or double-ovoid pellets. The tunnels are internally smooth, but show in some specimens, lines perpendicular to the long axis of the burrow (Pl. 7, Fig. 6). Occasionally, the horizontal tubes are connected to vertical or oblique shafts. Diameter of tubes 7-14 mm. Thickness of wall 1-3 mm .The trace fossils occur in thin-bedded, greenish-brown, mica-bearing, fine-grained sandstone with fine plant debris.

Remarks. This biogenic structure is obviously post-depositional in origin and cuts across load casts. According to RICCI LUCCHi (1995. 132). *O. borneensis* is common in turbidite sequences. The presence of belemnites, however, suggests that the basin was not very deep and could be proximal turbidite or storm sedimentation conditions in the shelfal environments.

**_Ophiomorpha nodosa_ LUNDGREN, 1891**

Pl. 7, Figs. 1, 4, 5, 7

Material. Four specimens, two from the Kol-e-Malekabad section (04 K 12a, 13a), at 1127 and 885 m the respectively. One from Maiamay section (05 M 16a), at 1200 m; and the last one from upper part of the Fraizi secion (04 F 31b), west of small village Khij.

Diagnosis. Ophiomorpha with burrow walls consisting predominantly of dense, regularly distributed discoid, ovoid, or irregular polygonal pellets (FREY et al., 1978).

Description. Curved to branching horizontal tunnel system, preserved as positive and negative hyporeliefs, with oblique and vertical shafts that show concentric layering (e.g. sample 04, F, 1318-29). Surface covered with dense ovoid to discoidal pellets. In some samples with transverse striations (Pl. 7, Fig. 4). Width of tubes 6-28 mm; walls in large tubes about 5-7 mm thick.

Discussion and remarks. Most samples of *Ophiomorpha* come from the Fraizi section. Based on sedimentological evidence the basin in this area was shallower than at other localities further to the east and south-east, such as at Kol-e-Malekabad, Ghal-e-Sangi, and especially, Maiamay.

It has long been recognized that *Ophiomorpha* is not restricted to shallow marine environments, but is also widespread in deep sea turbidite setting where it usually had been identified as Granularia (e.g. TUNIS & UCHMAN, 1996; TCHOUMATCHENCO & UCHMAN, 2001; UCHMAN et al., 2004).

Samples of *Ophiomorpha* from Kol-e-Malekabad and Ghal-e-Sangi, are from the upper part of the Kashafrud Formation, which is shallowing-upward. At the Maiamay section *Ophiomorpha* occurs at a horizon that is distinctly coarser-grained and shallower than the neighbouring deep marine basinal units.

**_Ophiomorpha irregulaire_ FREY, HOWARD & PRYOR, 1978**

Pl. 7, Fig. 10

Material. One specimen from the Ghal-e-Sangi section (04 Gh 7), at 722 m.

Diagnosis. *Ophiomorpha* with burrow walls consisting predominantly of sparse, irregularly distributed, ovoid to mastoid pellets or pelletal masses (FREY et al., 1978).

Description. Predominantly horizontal cylindrical burrows. Branching T- and/or Y-shaped, with smoothly curved internodal tunnels and obvious back filling structure, roof lining is pelleted with regularly spaced. Diameter of tube 3-8 mm. Pellets are variable in shape and size ranging from 2 to less than 7 mm. Their shape corresponds mostly to that of flame structures.

Remarks. Although no precise type locality or stratigraphic horizon has been indicated for *O. irregulaire*, BROMLEY & EKDALE (1998), based on published data (FREY, 1990; FREY & HOWARD, 1990) considered the unit 19 of the Spring Canyon Member of the Blackhawk Formation at Book Cliffs, Utah, as type locality and horizon of *O. irregulaire*.

In certain specimens the pellets are drown-out as “flame structures”, which according to FREY et al., (1978) reflect soft-sediment deformation of the muddy wall lining.

Most of the occurrences of the ichnospecies are from Upper Cretaceous. MARTIN & POLLARD (1996) reported *O. irregulaire* from the Upper Jurassic Fulmar Formation of the Central Graben of the North Sea. There is only a single occurrence from the Middle Jurassic (ETTER, 1996), but no details are given.

**Ichnogenus _Paleodictyon_ MENEGHINI, 1850**

Remarks. The ichnogenus *Paleodictyon* is one of the most obvious and distinctive trace fossils, because of its mostly hexagonal network morphology, which has been recorded from the Cambrian to the present day (SEILACHER, 2007).

EKDALE (1980) reported this trace fossil for the first time from modern deep-sea sediments, i.e. from the South Atlantic (one occurrence on the western flank of the Mid-Atlantic Ridge and another one on the northern flank of the Rio Grande Rise) at 3895 m and 1436 m, respectively. GAILLARD (1991) found *Paleodictyon* in 1680 m depth of water on the SW New Caledonia slope. Both authors compared their finds to *P. minimum* SACCO. According to SEILACHER (2007), *Paleodictyon* occurs in shallow marine environments in the Cambrian, and from the Ordovician to the present-day in deep-sea environments. Although in geological records *Paleodictyon* is commonly found in deep-water flysch successions (e.g., CHAMBERLAIN, 1971; CRIMES, 1973, 1977; SEILACHER, 1977;CRIMES et al., 1992; UCHMAN, 1995, 1999; TUNIS & UCHMAN, 1996; TCHOUMATCHENCO & UCHMAN, 2001), there is also evidences that occasionally it occurred in much shallower settings (UCHMAN &TCHOUMATCHENCO, 2003; UCHMAN et al., 2004; FÜRSICH et al., 2007).

CRIMES & CROSSLEY (1980) studied the orientation of *Paleodictyon* and *Squamodictyon* polygons and their probable relationship to the direction of bottom currents in the Aberystwyth Grit (Lower Silurian) of Wales. They concluded that the preferred orientation might reflect inter-turbidite bottom currents.

*Paleodictyon* is mostly preserved as positive hyporelief on the soles of siltstones and fine-grained sandstones, although in the Kashafrud Formation *P. maximum* occurs in medium- to coarse-grained sandstones. The burrow nets of *Paleodictyon* were excavated at shallow depth within mud and then sand-infilled (SEILACHER, 1977; CRIMES & CROSSLEY, 1980).

TUNIS & UCHMAN (1996) recognized in the flysch deposits of the Julian Prealps (Italy and Slovenia) that larger forms of *Paleodictyon* occupy deeper levels than smaller ones. On theoretical considerations there are different modes of fabrication for *Paleodictyon* (SEILACHER 1977, 2007: 157, pl. 55), i.e. meandering, radiating and spiral. According to SEILACHER (1977) the last modeis the only one realised.

Concerning the trace maker, the traces recovered from the deep sea did not contain the producer. SWINBURNE (1982) suggested that xenophyophores, giant infaunal protozoans, are possibly the producer of *Paleodictyon*, because he found polygonal fragments of xenophyophores about 1 cm in size, which is comparable to the diameter of many *Paleodictyon*. However, it is not clear whether these fragments are burrows or body fossils. Another problem is that xenophyophores are only known from modern environments (SWINBANKS, 1982).

The classification scheme of *Paleodictyon* used herein is that of UCHMAN (1995). It considers maximum mesh size and string diameter as characteristic features of *Paleodictyon* ichnospecies. Measurements resulted in three ichnospecieses of *Paleodictyon* in the Kashafrud Formation i.e., *P. maximum, P. strozzii*, and *P. miocenicum*.

Discussion. In general, the specimens from Kol-e-Malekabad and Maiamay are from deeper environments than those from Fraizi, but *Paleodictyon* is more abundant at Fraizi: six out of eight specimens come from there, and several additional specimens were observed in the field. Most of the Fraizi specimens come from outer shelf to upper slope environments (FÜRSICH et al., 2007) judging from their sedimentological context.

**_Paleodictyon maximum_ EICHWALD, 1868**

Pl. 8, Figs. 2, 4, 6, 7

Material. One specimen (05 M 37c) in sandy siltstone from the middle part of the Maiamay section, 3 specimens (04 F 12a, 04 F 31a, 04 F 33) from the middle part (at 1136 m and 1400 m) and the uppermost part of the Fraizi section, in fine- and medium-grained, thin-bedded.

Diagnosis. Medium-size with thick string, mesh-size up to 14 mm, string diameter 1.6-2.8 mm (after UCHMAN, 1995).

Description. Horizontal, coarse meshes with a diameter of 8-11 mm and relatively thick string diameter (1.8-2.2 mm). All specimens are post-depositional traces and preserved as positive hyporeliefs.

**_Paleodictyon strozzii_ MENEGHINI, 1850**

Pl. 8, Figs. 1, 3

Material. One specimen (04 K 4f) in very fine-grained sandstone of the lower part of the Kol-e-Malekabad section, 2 specimens (04 F 32, 04 F 34) in fine- to medium-grained sandstones of the upper part of the Fraizi section (west of Khij village).

Diagnosis. Small meshes and narrow string diameter, but mesh size larger than in *P. latum* and *P. minimum,* net 2-6 mm in size and 0.2-1.0 mm in string diameter (UCHMAN, 1995).

Description. Delicate nets, preserved as horizontal positive hyporeliefs. Mesh size 2-4 mm and string diameter 0.6-0.8 mm

### *Paleodictyon miocenicum* SACCO, 1886

Pl. 8, Fig. 5

Material. One specimen (04 F 28b) from the upper part of the Fraizi section, at 2090 m.

Diagnosis. Small Glennodictyum, mesh-size 2-6 mm, string diameter 1.0-1.6 mm (Uchman, 1995).

Description. Mesh size more or less similar to that of *P. strozzii*, but string thickness (about 1.1 mm) more compatible with *P. miocenicum*. This specimen also bears undeterminable vertical tubes, with an external diameter of 1.5-2.0 mm, and an internal filling of 1 mm in diameter. In one case the vertical shaft is about 2 cm long. The specimen occurs in fine-grained, thin-bedded sandstone.

### Ichnogenus *Palaeophycus* HALL, 1847

Diagnosis. Slightly irregular, cylindrical burrows of varying length which are oriented horizontal to obliquely to the bedding plane. Most forms are unbranched, although a few bifurcate infrequently in no apparent pattern. The genus is most commonly found as hemicylinders which are preserved either as convex hyporelief or concave epireliefs (modified from OSGOOD, 1970).

Remarks. OSGOOD (1970) provided a complete review on this ichnogenus, which is summarized in the following.

The type species is *Palaeophycus tubulare* HALL (1847) which was collected from the "calciferous sandstone" (Beekmantown; Lower Ordovician) of Mohawk valley of New York state. HALL had proposed six additional species: *P. rugosum, P. tortuosum, P. stratum, P. irregulare, P. simplex,* and *P. virgatum*). Subsequently, several other species were proposed by various authors from different localities.

HOWELL (1943) placed *Palaeophycus incipiens* BILLINGS, 1861 and *Palaeophycus congregatus* BILLINGS, 1861 in *Planolites*. JAMES (1885), discussed several species under *Palaeophycus*, but in 1892 he considered these and additional forms to belong to *Planolites*. Recognizing the confusion, HOWELL (1943) restricted *Planolites* to:

"All those usually more or less horizontal but sometimes diagonal or vertical burrows having diameters of approximately 8-12 mm that are not marked by such prominent cross ridges as are in *Arthrophycus*…" However, this diagnosis does not really serve to differentiate *Planolites* from *Palaeophycus*.

Possibly, NICHOLSON's (1873) original discussion of these traces as augmented by NICHOLSON & HINDE (1875) may provide the key. NICHOLSON (1873: 309-310) described *Planolites* as " burrows (which) run more or less horizontally as compared with the laminae of deposition, or they penetrate the strata obliquely and preserved not (as) the actual burrows themselves, but the burrows filled up with sand or mud which the worm has passed through its alimentary canal".

NICHOLSON & HINDE (1875: 3) expanded the definition, stating "…they appear usually in the form of cylindrical of flattened stem-like bodies, which are often more or less matted together and which may cross one another in every imaginable direction".

Neither NICHOLSON (1873) nor NICHOLSON & HINDE (1875) flatly stated that there is a difference between the lithology of the cylindrical tubes and that of the host rocks, but they implied it. Their definition has been followed by RICHTER (1937) and REINECK (1955). Thus, the key factor separating *Palaeophycus* and *Planolites* is the lithology of the burrow fill as compared to that of host rock. JAMES (1885) was one of the first to point out that *Palaeophycus* was a burrow and compared it to Recent annelid trails observed on the banks of the Little Miami River in Ohio. Most subsequent authors have accepted the burrow interpretation, although WILSON (1948) adhered to the "fucoid" hypothesis.

The animal moved within the sediment, pushing it aside, and stabilizing the burrow wall with mucus.

OSGOOD (1970) believed that *Palaeophycus* contained too wide a range of morphological characteristics and that the type specimens alone do not provide sufficient material to permit a meaningful restudy of the genus. He suggested that it will be necessary to recollect material from some of the original localities and to revise all the features which should result in a reduction of the number of species. For this reason, OSGOOD classified *Palaeophycus* only in three informal types A, B and C.

PEMBERTON & FREY (1982), based on an extensive literature survey, identified at least 54 different morphological types that have been described and named under *Palaeophycus*. Of them 85% (44 species) were erected during the years 1847-1883, when ichnology was in its infancy and, depending on the geographic or stratigraphic position, trace fossils received a new name (PEMBERTON & FREY, 1982). About one-third of the ichnospecies have not been rediscovered or redescribed after their original record. PEMBERTON & FREY (1982) after a detailed evaluation concluded that only 17 ichnospecies of the 54 (about 17%) truly represent *Palaeophycus,* which according to them may be grouped into three distinct ichnospecies; *P.*

*tubularis, P. striatus, P. heberti.* They also added two new ichnospecies: *P. sulcatus*, based on specimens originally described as *Trichophycus sulcatum* (MILLER & DYER, 1878), *Fucusopsis sulcatum* (OSGOOD, 1970), and *F. angulatus* (PABLIN in VOSSOEVICH, 1932), and *P. alternatus* based on specimens originally described as *Palaeophycus* type B by OSGOOD (1970).

**_Palaeophycus striatus_ HALL, 1852**

Pl. 9, Figs. 5, 9

Material. Two specimens (05 M 19b, 05 M 24b) from greenish, thin-bedded, fine-grained sandstone in the middle part of the Maiamay section at 1406 m and 1732 m.

Diagnosis. Thinly lined burrows, surface covered by fine, continuous, parallel, longitudinal striae (from PEMBERTON & FREY, 1982).

Description. Straight cylindrical burrows preserved either as full-relief or positive hyporelief. The diameter of the burrows, which cut each other ranges from of 5 to 8.5 mm. The diameter of individual burrows may also vary, rarely branched with poorly preserved striae along the main tunnel. Occasionally, due to compaction the cross section of the burrow may be oval. The longest specimen is about 10 cm. In specimen 05 M 19b the surface is faintly striate.

**Ichnogenus _Planolites_ NICHOLSON, 1873**

Diagnosis. Cylindrical to sub-cylindrical burrows, straight to gently curved, un-branched; usually more or less horizontal or oblique to bedding planes, penetrating the sediment in irregular course and direction, may cross one another (HÄNZTSCHEL, 1975).

Remarks. The ichnogenus *Planolites* was originally defined by NICHOLSON (1873) in an abstract of a paper that subsequently was never published, until that the missing manuscript was uncovered and published by the University of Aberdeen in 1978.

NICHOLSON's original concept of *Planolites* included three distinct ichnospecies: *P. vulgaris, P. granosus*, and *P. articulatus*. During last decades, at least 30 additional ichnospecies of *Planolites* have been named and described. PEMBERTON & FREY (1982) revised them and concluded that of 33 ichnospecies which have been assigned to *Planolites* only 13 ichnospecies truly represent *Planolites* and may be grouped into three distinct forms: *P. beverleyensis, P. annularis and P. montanus.*

With respect to differentiating between *Palaeophycus* and *Planolites*, ALPERT (1975: 512) stated that the presence or absence of branching may be used to recognize *Planolites* (unbranched) from *Palaeophycus* (branched). This criterion was widely accepted by ichnologists, but according to PEMBERTON & FREY (1982) the original description of both ichnogenera indicates that Alpert inadvertently misinterpreted this feature.

In fact, *Planolites* differs from *Palaeophycus* primarily by having unlined walls and a burrow fill differing in texture from that of the adjacent rock. Fills may differ also in fabric, composition, and colour (PEMBERTON & FREY, 1982). *Planolites* and *Palaeophycus* are also differentiated by the wall structure, which is found only in the latter one. *Planolites* is usually restricted to stuffed burrows and consequently interpreted as produced by deposit-feeders (e.g., FÜRSICH, 1974).

**_Planolites_ isp.**

Pl. 9, figs. 1-4, 6-8

Material. Ten specimens, one from Ghal-e-Sangi area (04 Gh 16), another from the Torbat-e-Jam section (05 To 1), and eight from the Kol-e-Malekabad section (04 K 7, 8, 11, and 14), and the Maiamay section (04 M 4, 10, 13b, and 24). In general, specimens are poorly preserved, except those from Kol-e-Malekabad.

Description. Horizontal, straight, unbranched, cylindrical to sub-cylindrical burrows, which occasionally cut each other. Burrow diameter ranges from 1.8 to 6 mm; rarely it reaches 6.5-7.5 mm. Preservation in full relief and positive hyporelief. The burrow fills and host rock are more or less identical, but occasionally the fill slightly differs from the matrix, which is mostly due to a slightly larger grain size and lighter colour.

**Ichnogenus _Protovirgularia_ MC COY, 1850**

Remarks. The ichnogenus *Protovirgularia* is a relatively simple, narrow, chevron-shaped trace (HAN & PICKERILL, 1994) with or without median furrow, and lateral appendages. It has been mostly reported as a straight pattern, but rarely occurs as slightly curved form.

MC COY (1850) regarded this biogenic structure as of octocoral origin, and several German authors, including RICHTER (1953), believed it to be a graptolite (HAN & PICKERILL, 1994). Finally, HÄNTZSCHEL (1958) recognized its trace fossil nature, a conclusion that was followed by VOLK (1961) and others later on.

Several trace-makers were proposed, for instance crabs (GÜMBEL, 1879), arthropods (RICHTER, 1941; VOLK, 1961), annelids (RICHTER, 1941) and, finally, burrowing bivalves (HAN & PICKERILL 1994; SEILACHER & SEILACHER, 1994). Subsequent authors discussed different mechanisms of bivalve locomotory activity and divided them into two main locomotion categories: (a) wedge-foot burrowing which produces *Lockeia* traces; and (b) flap-foot burrowing, which produces *Protovirgularia* structures. The two types are illustrated in Fig. 7.3

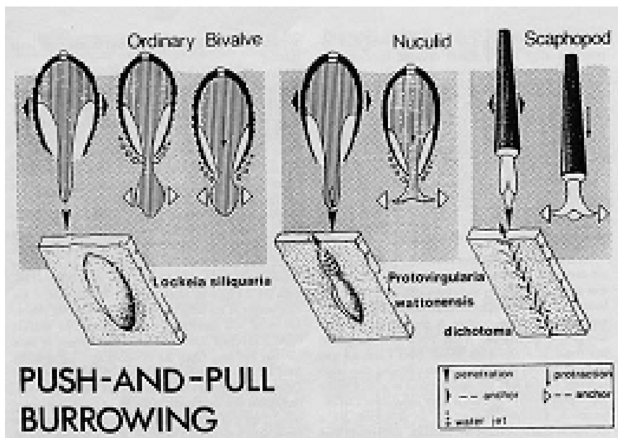



Fig. 7.3. Trace fossils produced by bivalves and scapleopods. (From SEILACHER & SEILACHER 1994).

<u>Discussion</u>. The different *Protovirgularia* ichnospecies, described in the following, were found only in the Maiamay area. Although the samples come from three parts of the section, they all belong to turbiditic sequences. Their occurrences are thus compatible with that recorded in some of the literature (SEILACHER & SEILACHER, 1994; UCHMAN, 1998; LUCAS & LERNER, 2004).

**_Protovirgularia dichotoma_ MC COY, 1850**

Pl. 10, Figs. 1, 3-4, 6-8

<u>Material</u>. Seven specimens, all from Maiamay area (04 M 2a- 04 M 3a- 04 M 14a- 04 M 14b- 04 M 19a- 04 M m4a- and 04 M m4b) in beds which cropp out along the main valley north of Maiamay village.

<u>Diagnosis</u>. Narrow, horizontal and longitudinal positive hyporelief, with straight, more or less symmetrical, chevron-shaped ridges.

Description. Horizontal, straight positive hyporeliefs, cross-section rounded-triangular. With obvious chevron pattern along the ridges. Aangles formed by chevrons varying from 93° to 142°. The maximum length of chevron ridges is about 4 mm, width of the individual pads 0.3-0.8 mm. There are up to 12 pads/cm, and usually around 7-10/cm. The longest trace is 14 cm, its width 0.4-0.7 cm. The specimens show a median furrow for part or all of the length.

Remarks. The specimens occur in fine-grained, thin-bedded, highly bioturbated, and brownish sandstones. Sample 04, M, 3a is associated with a *Lockeia*-type structure.

HAN & PICKERILL (1994), based on 25 samples from the Silurian and Devonian of New Brunswick (Eastern Canada), tabulated the dimensions of *Protovirgularia dichotoma*. Their mean values are compared here with those of the Kashafrud specimens (Table 7.1). The data are closely comparable and confirm the determination of the Kashafrud specimens as *Protovirgularia dichotoma*.

Table 7.1. Dimensions of *Protovirgularia dichotoma* from the Silurian-Devonian of New Brunswick and the Kashafrud Formation.

| **Characters** | **HAN & PICKERILL samples(25)** | **Kashafrud Formation samples** |
|---|---|---|
| Average width | 5.5 mm | 6.2 mm |
| V- shaped angle | 131.2° | 121.2° |
| Average appendage length | 3.1 mm | 3 mm |
| Average appendage width | 0.65 mm | 0.61 mm |
| Appendage per cm | 5.6 mm | 7.8 mm |
| Length of specimens (mean) | 68 mm | 72 mm |
| Median furrow | In more than 90% | In 100% |

### ***Protovirgularia* cf. *dzulynskii* KSIAŻKIEWICZ, 1977**

Pl. 10, Fig. 2

Material. One sample (04 M 21a) from the middle part of the Maiamay section at 1438 m.

Description. Horizontal string triangular in cross-section developed as surface covered with positive hypo-relief with dense, poorly preserved chevron markings. Diameter variable, 4-8 mm, length about 112 mm. Where the trace maker went into the sediment the resulting trace resembles *Lockeia* isp.

Occurring in fine-grained, bioturbated, thin-bedded sandstone in the lower part of the Maiamay section.

**_Protovirgularia rugosa_ MILLER & DYER, 1878**

Pl. 10, Fig. 5

Material. One specimen (04 M 22a) from the middle part of the Maiamay section.

Diagnosis. Commonly short *Protovirgularia* terminated by smooth *Lockeia*–like body. Chevron markings strong (after Uchman 1998).

Description. Straight, positive hyporelief with poorly preserved chevron-shaped ribs. Width about 10 mm. *P. rugosa* differs from the above mentioned ichnospecies by its flattened morphology pattern, and the lack of a median furrow. It seems that the trace was produced in a comparatively loose substrate because of several displacements occurring within the 10 cm long sample.

*P. rugosa* was found in highly bioturbated, iron-rich, brownish, thin-bedded sandstone at about 1458 m within the Maiamay section.

There is no general agreement on the environmental range of *Protovirgularia.* According to some authors, it is restricted to shallow marine environments (De GIBERT & EKDALE 1999), but according to MANGANO et al. (2002) it occurs from deep-marine to open, shallow marine environments, as well as on tidal flats. HAN & PICKERILL (1994) argued that there is a shift in environmental distribution of *Protovirgularia* isp. through time. In the Palaeozoic of Scotland it is found in deep-marine turbidites, whereas in Carboniferous and younger units it occurs in shallow water, open marine shelf sequences.

The occurrence of *Protovirgularia* in relatively deep-marine turbiditic beds of the Maiamay area shows that HAN & PICKERILL'S conclusion is not correct.

Based on lithofacies (dark green to black siltstone and thin-bedded turbiditic sandstones) and associated trace fossils such as *Helminthopsis*, the traces most likely were produced in a comparatively deep-marine environment (several hundred meters deep).

According to SEILACHER & SEILACHER (1994) and HAN & PICKERILL (1994), the trace maker was a burrowing bivalve. SEILACHER & SEILACHER (1994) suggested that *P. dichotoma* is the result of push-and-pull locomotory activity of a protobranch bivalve that possessed a cleft-foot.

**Ichnogenus *Rhizocorallium* ZENKER, 1836**

***Rhizocorallium* isp.**

Pl. 4, Fig. 1

Material. One specimen, collected from the upper part of Ghal-e-Sangi section, at 1230 m, in grayish, very fine-grained, thin-bedded sandstone.

Description. Two more or less parallel tubes filled with very fine-grained sandstone, between them 4-10 mm wide zones, convex, transversely striated. Striation is in one direction. The distance between u-formed tubes is 4-5 cm.

**Ichnogenus *Taenidium* HEER, 1877**

Remarks. The description with which HEER 1877 originally introduced the ichnogenus *Taenidium* is very similar to the original diagnosis of *Muensteria*, a plant fossil from the Tithonian Solnhofen lithographic limestone (D'ALESSANDRO & BROMLEY, 1987). This resulted in some ambiguities later on, until D'ALESSANDRO & BROMLEY (1987) discussed the problem in detail and recognized three valid ichnospecies (*T. serpentinum* HEER, 1877 as type ichnospecies, *T. cameronensis*, Bradly 1947, and *T. satanassi* nov.), in addition to four dubious ichnospecies (*Muensteria cretacea*, HEER, 1877; *T. carboniferum* SACCO, 1888; *T. ?maeanderiformis*, MÜLLER 1966; and *M. planicostata* KSIĄŻKIEWICZ 1977).

According to D'ALESSANDRO & BROMLEY (1987) the three ichnospecies of *Taenidium* are differentiated based mainly on the shape of the menisci (Fig. 7.4).

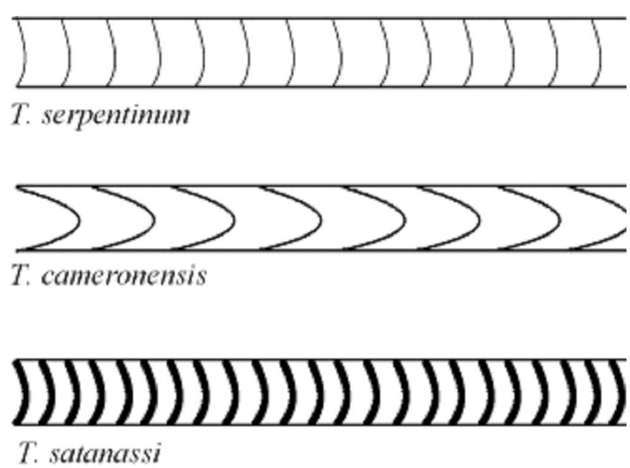



Fig. 7.4. Diagnostic features of the three valid ichnospecies of *Taenidium* (redrawn from D'ALSSANDRO & BROMLEY, 1987).

KEIGHLEY & PICKERILL (1994) considered the presence/absence of a wall or lining as criterion to distinguish between *Beaconites* and *Taenidium*, and proposed that *Taenidium* should be restricted to unlined burrows without wall. As a consequence, they included forms which previously were assigned to *B. barretti* in *Taenidium* as *T. barretti.*

Most samples of *Taenidium* have been recorded from Cretaceous to Eocene flysch deposits, but similar burrows have been described under different ichnogenera since the Lower Cambrian (CRIMES et al., 1992). The ichnogenus is also a common element of many shelf succession (e.g., Fürsich, 1998).

**_Taenidium satanassi_ D'ALESSANDRO & BROMLEY, 1987**

Pl. 11, Fig. 5

Material. One specimen (04 Gh 4a), from the middle part of the Ghal-e-Sangi section at 557 m in olive, very fine-grained, thin-bedded sandstone.

Diagnosis. Weakly sinuous to nearly straight *Taenidium*, the fill consisting of even alternations of meniscate-shaped packets of two types of sediment, of more or less equal thickness; Sediment packets considerably shorter than wide (D'ALESSANDRO & BROMLEY, 1987).

Description. Horizontal endichnial cylindrical burrow without wall structure, but with distinct meniscate backfill. The menisci are weakly arcuate, and relatively equal in size. The sediment fill is darker than the matrix around the structure. The course of the specimen is meandering to winding. The width of the menisci is about 3-4 mm and the diameter of the burrow 5-6 mm. The length of the specimen is about 19 cm.

**_Taenidium serpentinum_ HEER, 1877**

Pl. 11, Figs. 6-7

Material. Two specimens, one (04 Gh 18b) from the upper part of the Ghal-e-Sangi section, the other one (04 K 16b) from the uppermost part of the Kol-e-Malekabad section.

Diagnosis. Well-spaced, arcuate menisci, distance between menisci relatively equal or a little less than burrow width. Secondary subsequent branching and intersections occur. Boundary sharp, lining lacking or insignificant (D'ALESSANDRO & BROMLEY, 1987).

Description. The burrows are preserved as negative and positive hyporeliefs, the meniscate backfilling structure is obvious and a wall is absent, but the boundaries are sharp. The fill material and the surrounding sediment are identical. The width of the menisci is about 4 mm that of the burrow 3-6 mm. The trace fossils were found in very thin-bedded (less than 1 cm), fine-grained, green and brown sandstone.

**Ichnogenus *Teichichnus* SEILACHER, 1955**

***Teichichnus* isp.**

Pl. 11, Fig. 4

Material. One specimen (04 Gh 14a) in fine-grained greywacke from the upper part of the Ghal-e-Sangi section at about 1100 m.

Diagnosis. Long, wall-like spreiten burrows formed by vertical displacement of horizontal or oblique tubes (modified from FÜRSICH, 1974).

Description. The specimen is composed of progressively displaced tubes forming spreiten. It seems that the diameter of the tubes and at the same time the diameter of the spreiteu increases from one end to the other, which resulted in a truncated cone structure (Pl. 11, Fig. 4). As the specimen was collected loose sample it is not possible to infer the original orientation of the trace fossil.

The length of the specimen is 69 mm, the width of the relatively well preserved final tube ranges from 8.5 to 13.5 mm. The diameter ranges from 18.3 to 30 mm, the spreite from 18.5 to 31 mm (Pl. 11, Fig. 4).

**Ichnogenus *Thalassinoides* EHRENBERG, 1944**

Remarks. *Thalassinoides* is one the most common trace fossils in sedimentary rocks since the early Palaeozoic (EKDALE & BROMLEY, 2003).

In the 16 samples, which have been collected from Kashafrud sections in different areas, the burrow morphology is more Y-shaped than T-shaped. With respect to size of the samples they can be divided into two main range size: A. with a diameter of 2-6 mm and B. with 6-14 mm. The specimens are clearly enlarged at points of bifurcation and the burrows are horizontal cylinders, commonly somewhat flattened.

Of the different specimens 10 could be determined at the ichnogeneric level. They show the features described above. Six specimens could be determined at the ichnospecies level as *Thalassinoides suevicus*.

**_Thalassinoides suevicus_ RIETH, 1932**

Pl. 12, Figs. 2, 4, 6-8

Material. 7 specimens, collected from Maiamay section (05 M 12a, 25a, 29a), Fraizi section (04 F 12b, 29c), Kol-e-Malekabad section (04 K 1b), and Danesh section (05 D 13a).

Diagnosis. Predominantly horizontal, more or less regularly branched, essentially cylindrical components forming large burrow systems, dichotomous bifurcations more common than t-shaoed branches (FREY et al., 1985).

Description. Horizontal Y-shaped burrow systems, enlarged at bifurcation points of tunnels. T-shaped branching is rare; walls are internally and externally smooth. The burrows occur as positive and negative hyporeliefs in two size classes, the smaller one with a diameter of 2-4 mm and the larger one with a diameter of 8-14 mm.

Discussion. The specimens are mostly post-depositional in origin, especially in the Fraizi area. They occur in fine-grained, thin-bedded sandstone. *Thalassinoides* specimens from different localities of the study area occur more or less in environments which are characteristic of the trace fossil elsewhere.

*Thalassinoides* has been reported from nearshore to offshore marine environments (HOWARD & FREY, 1984; SPIEKER & REESIDE, 1925). According to lithofacies characters (an alternation of dark-green silt with fine-grained sandstone and thin, ripple-bedded sandstone), specimens from the Maiamay section are from the offshore transition zone to the outer offshore, whereas specimens from the sand-dominated Danesh section in the marginal part of the Kashafrud Basin occur in shallower environments (offshore transition zone and shallower).

In the most cases, *Thalassinoides* occurs in thin, ripple-bedded sandstone beds and none of them was found in deeper parts of the basin characterized by dark-green siltstones. In general, *Thalassinoides* occurs in lower and upper parts of the succession, which correspond to relatively shallow parts of the basin.

Specimens from the Maiamay area come from sandstones in the middle parts of the succession which exhibits a shallowing- upward trend. In the Fraizi area, *Thalassinoides* was observed mostly together with *Ophiomorpha.* This demonstrates that *Thalassinoides* and *Ophiomorpha* may form compound biogenic structures (FÜRSICH, 1973; MILLER, 2001).

For a more detailed environmental reconstruction, some segments of in the Fraizi and Kol-e-Malekabad sections should be sampled more closely.

**Ichnogenus *Tomaculum* GROOM, 1902**

Diagnosis. Faecal pellets of cylindrical outline that accumulated on the sediment surface in characteristic patches, strings and/or bands (after EISERHARDT et al., 2001).

Remarks. CHAMBERLAIN & CLARCK (1973) discussed *Tomaculum* from the Upper Carboniferous to Early Permian succession of the Oquirrh Basin in Utah and compared them to faecal material of ghost crabs. However, as crabs did not exist prior to the Mesozoic, they regarded *Tomaculum* as prototype of composite excavation animals most commonly found in brachyurids and therefore named them as "protobrachyurid" spoil.

According to EISERHARDT et al. (2001), an essential part of the definition of this trace fossil is the special mode of accumulation, which took place on the sediment surface in characteristic patches, strings and/or bands which originally were the excrements of an epibenthic animal. According to them *Tomaculum* is restricted to the Ordovician, but VIZCAÏNO et al. (2004) found this trace fossil also in the Early Cambrian. Their occurrence in Middle Jurassic strata extends their range at least until the Mesozoic.

***Tomaculum* isp.**

Pl. 11, Figs. 3, 8

Material. Two specimens (05 D 2, 05 M 36) the first from the lower part of the Danesh section at 50 m and the second one from the uppermost part of the Maiamay section at 2865 m.

Description. External cast of full-relief structures of small cylindrical pellets, which form patches and elongated bands, found on the lower surface of a sandstone bed. The Maiamay specimen (05 M 36) is about 9.5 cm long. The individual components are 0.5 mm wide and about 1-1.2 mm long. The pellets do not show a preferential direction. In the coarser specimen (05 D 2), which consists of about 25 pellets, individual casts are about 0.8 mm wide and 1.5 mm long. Both specimens were found in thin-bedded, fine-grained sandstone.

**Ichnogenus *Zoophycos* MASSALONGO, 1855**

Diagnosis. Tabular, protrusive spreiten structures, with helicoidal growth and presence of axial and marginal tubes. (Modified after FREY & HOWARD, 1970 and GAILLARD et al., 1999.)

Remarks. *Zoophycos* is a common and relatively complex trace fossil which has been studied by numerous ichnologists (e.g., FREY & HOWARD, 1970; HÄNTZSCHEL, 1970, 1975; KENNEDY,

1970; PLIČKA, 1970; SIMPSON, 1970; EKDALE, 1985, 1988; OLIVERO & GAILLARD, 1996; GAILLARD et al., 1999).

Well preserved *Zoophycos* exhibit a growth pattern with a marginal tube corresponding to the external border of a lamina, which is formed by numerous arched lamellae, the lamina is spirally coiled around a vertical axis, which is approximately perpendicular to bedding. Each whorl resembles a flattened cone, the apex of which points upwards. Diameter and degree of flattening of each successive whorl increase upwards (summarized and modified after GAILLARD et al., 1999).

*Zoophycos* occurs in a variety of shapes and sizes. Large specimens may measure up to 1 m in diameter. *Zoophycos* distribution patterns and the relationship of the trace fossil to sequence stratigraphy has been studied by OLIVERO (1996).

**_Zoophycos_ isp.**

Pl. 11, Figs. 1-2

Material. Two specimens (04 F 44, 04 F 46) from the uppermost part of the Kashafrud Formation of the Fraizi section. In addition, several field observations in the Danesh section.

Description. All *Zoophycos* specimens came from the uppermost parts of the Kashafrud Formation. They are moderately well preserved. In the Fraizi area, *Zoophycos* co-occurs with *Ophiomorpha nodosa* and *Thalassinoides suevicus* in thin-bedded sandstone beds.

The size of the Fraizi specimens of *Zoophycos* is smaller than that of Danesh samples which occasionally reach more than 15 cm in diameter. As the specimens cut each other exact size measurements are not possible, although well developed laminae 1 and 2 order are seen in Fig. 2, Pl 11; but these first and second order laminae are rarely ditingushable in Fig. 2 of Pl. 11.

Discussion. Well preserved *Zoophycos* occur also on bedding planes of the Chamanbid Formation at Kuh-e-Radar (Tangal Shour locality), which overlies the Kashafrud Formation and therefore is beyond the stratigraphic interval under consideration.

Although generalizations on the bathymetric significance of trace fossils should be avoided (HÄNTZSCHEL, 1970), it seems that during the early to Middle Mesozoic *Zoophycos* represents environments of shallow to medium depth in contrast to younger occurrences (FREY &

HOWARD, 1970; HÄNTZSCHEL, 1970; HECKER, 1970). This was explained by OLIVERO (1996) as a result of a shift in the bathymetric range of the producer in the course of the Jurassic.

In the study area, *Zoophycos* is restricted to a zone ranging from the transitional offshore to the deep shelf. According to MÜLLER & SUESS (1979) *Zoophycos* is absent in sediments with a high organic carbon content (>2%). As such conditions coincide with a high sedimentation rate, *Zoophycos* might be an indicator of lowered sedimentation rates. Their occurrence near the top of Kashafrud Formation, i.e. towards the end of terrigenous input into the basin supports this conclusion. Except for the age, the lithostratigraphic position of *Zoophycos* in the Kashafrud is very similar to that in the Nixon Gulch section of (Fig. 7.5).

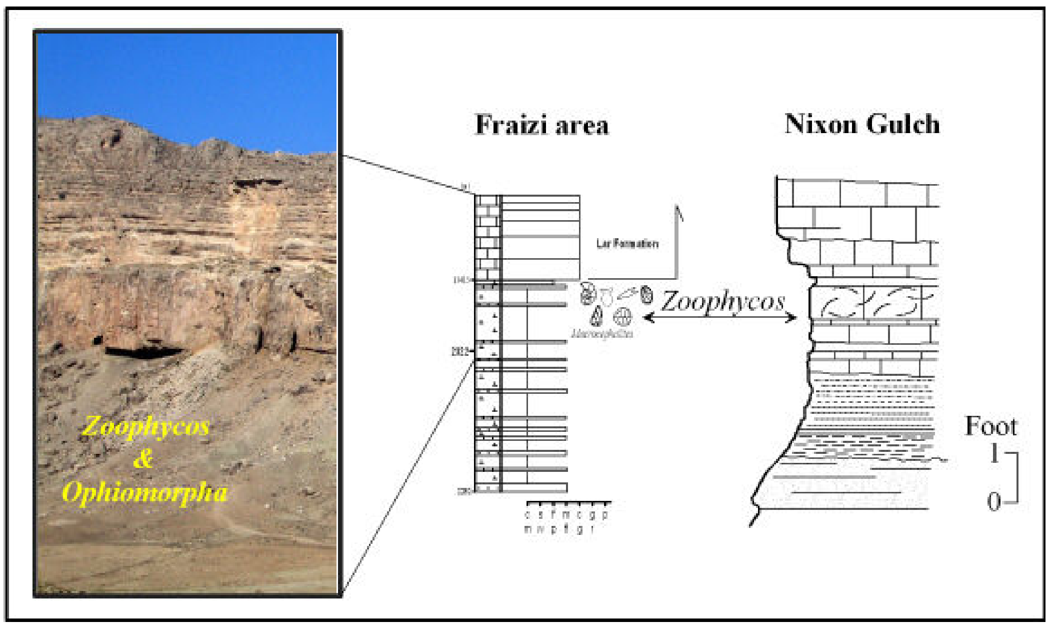



Fig. 7.5. Stratigraphic position of *Zoophycos* in the uppermost part of the Fraizi section and the Nixon Gulsh section (RODRIGUEZ & GUSCHICH, 1970).

In addition to the trace fossils described in this chapter, there are some specimens seen only in the field or well preserved material was so rare, that is was not possible to describe it in detail, such as *Phoebichonus* (at Fraizi section) or *Lockeia* (at Danesh section).

**Ichnofacies**

Altogether 29 ichnospecies belonging to 16 ichnogenera have been identified, as well as 10 ichnogenera, which were determined only at genus level. They can be grouped in the well-known Seilacherian ichnofacies. The Skolithos ichnofacies is rare and represented by low-diversity ichnocoenoses dominated by either *Diplocraterion* or vertical *Ophiomorpha*. This ichnofacies has been recognized in the lowermost part of unit 4 of the Tappenader-Jizabad composite section (see Chapter 3 for details), and in the lower parts of the Torbat-e-Jam and Kuh-e-Radar sections. Due to the high rate of sedimentation, which prevailed in these areas during the Late Bajocian, the short-lived shallow water conditions in the basin, and/or the development of narrow shelves a typical Skolithos ichnofacies characteristic of high energy conditions did not develop.

The Cruziana ichnofacies, characteristic of shelf environments, is also only poorly represented. This may be related to the high morphological gradients and narrow shelves of the Kashafrud Basin, but at some localities this ichnofacies has been identified, for instance, in the upper part of the Ghal-e-Sangi section (member 5). There, the common trace fossils include *Rhizocorallium, Teichichnus, Thalassinoides, Ophiomorpha, Gyrochorte, Planolites,* and *Hillichnus lobosensis*. For example, a relatively shallow development of the *Zoophycos* is found in the upper part of the Fraizi section, where storm beds and an abundant benthic fauna (brachiopods, and bivalves) are characteristic of the storm-dominated shelf.

In the study area, the Zoophycos ichnofacies is characteristic of outer shelf to upper slope environments. For the most part, this ichnofacies does not occur in its classical depth range in the Kashafrud Basin except for a lobed, questionable *Zoophycos* specimen in the slope sediments of the Maiamay area. Most occurrences of *Zoophycos* are related to shallower conditions (inner to middle shelf). This is not unusual because considering the assumed bathymetric shift of the trace fossil during the Mesozoic (Olivero, 1996).

The ichnocoenoses of the Zoophycos ichnofacies in the study area comprise *Ophiomorpha* (horizontal mazes), *Protovirgularia, Paleodictyon, Chondrites, Helminthopsis, Biformites,* and *Planolites*. The ichnofacies occurs in most parts of the Fraizi section except the upper part, the middle part of the Ghal-e-Sangi section (horizons 500-745 m), and the upper part of the Danesh, Maiamay and Gas-pipeline sections as well as in the Jizabad area.

The Nereites ichnofacies, characterized by graphoglyptids, is typical of the slope to basin plain. In the Kashafrud Basin, the ichnofacies is usually associated with turbidites, but less diverse than in typical flysch basins. The most important strata which represent this ichnofacies crop out in the lower part of the Maiamay section between 73-180 m. The ichnocoenosis consists mainly of *Nereites missouriensis, N. irregularis, N. macleayi, Helminthorhaphe* isp., and *Paleodictyon strozzii*. The second most important locality of this ichnofacies is the lower part of the Kol-e-Malekabad section, a classic distal turbidite succession. The ichnocoenosis which occurs there includes *Nereites missouriensis, Neonereites multiserialis, Scalarituba missouriensis,* and *Paleodictyon strozzii.*

The Nereites ichnofacies also occurs in the Senjedac area. The second member of the Ghal-e-Sangi and the middle part of the Kol-e-Malekabad section are deep basinal sequences, but trace fossils are rare so that it is difficult to extend the ichnofacies to these localities.

*Paleodictyon*, generally diagnostic of deep-sea environments, was found in the Kashafrud Basin also in comparatively shallow settings such as outer shelf and prodelta.

This has been attributed to the very high rates of sedimentation in the basin leading to enhanced preservation of traces such as graphoglyptids that are produced just below the sediment-water interface. Under normal conditions, they will be easily destroyed either by subsequent bioturbators or erosional processes, which are much more common in shelf environments than in the deep sea (FÜRSICH et al. 2007). Fig. 7.6 shows a summary of the Kashafrud ichnofossils and their bathymetric relationship.

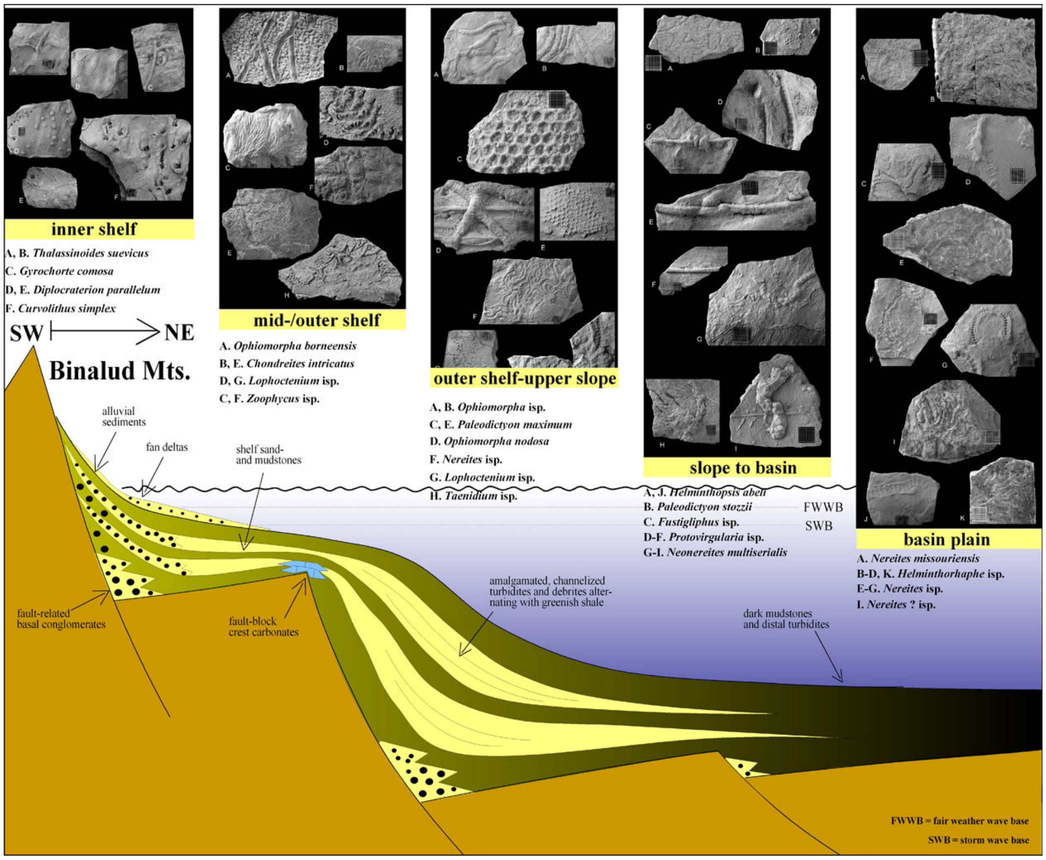



Fig. 7.6. Summary of the environmental distribution of the Kashafrud trace fossils. (modified from TAHERI et al., 2007).

**Explanation of Plate 1**

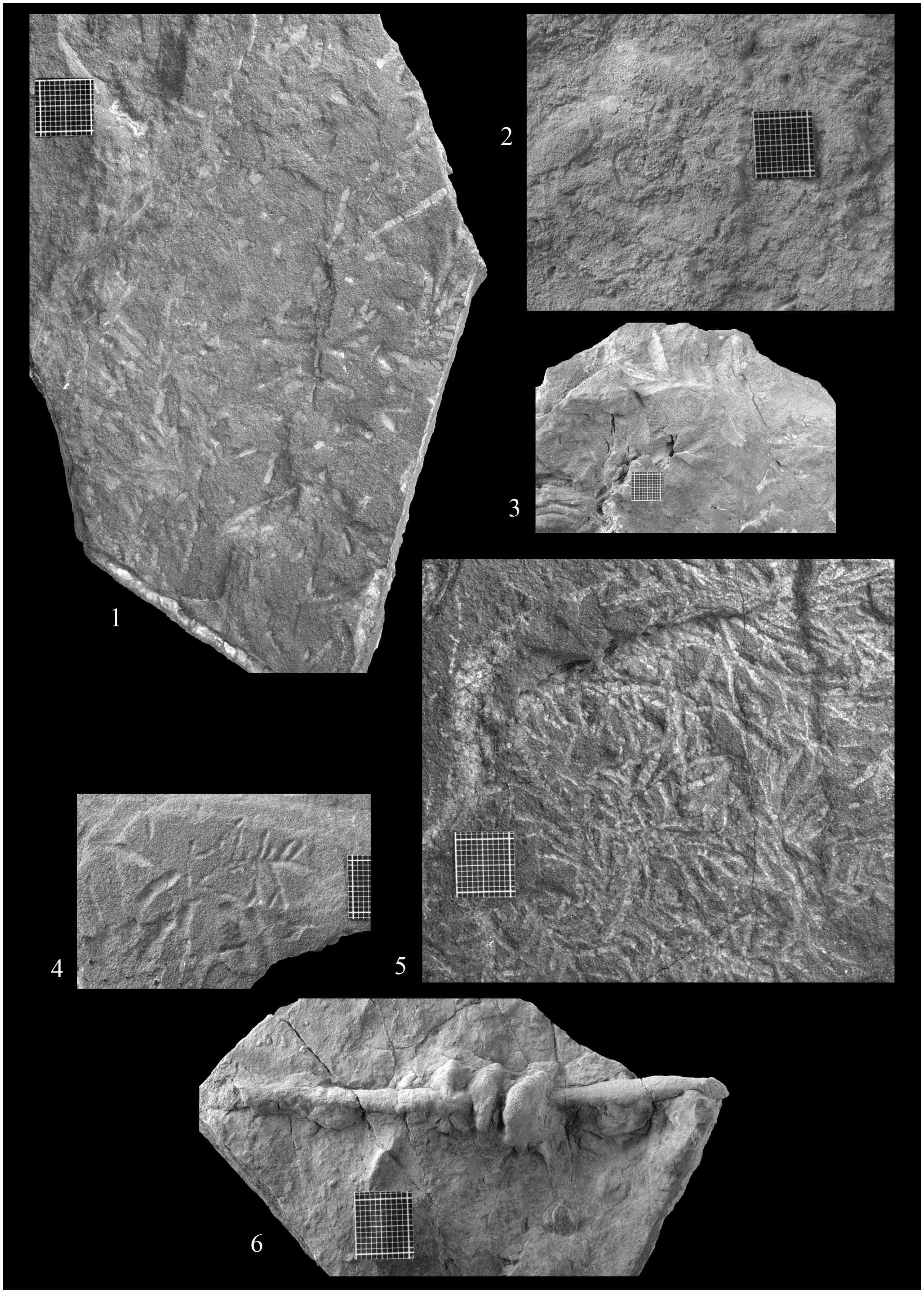
Figs. 1, 4, 5. *Chondrites intricatus* (BRONGNIART) in fine-grained sandstone. Scale in mm. 1, 4. Maiamay section. 5. Fraizi section.

Fig. 2. *Chondrites* isp. in medium-grained sandstone, middle part of the Fraizi section. Scale in mm.

Fig. 3. *Chondrites targionii* (BRONGNIART), full relief in fine- to medium-grained sandstone of the Fraizi section at 2014-2038 m. Scale in mm.

Fig. 6. *Biformites* isp. in fine-grained sandstone, Maiamay section (member 4). Scale in mm.

**Plate 1**



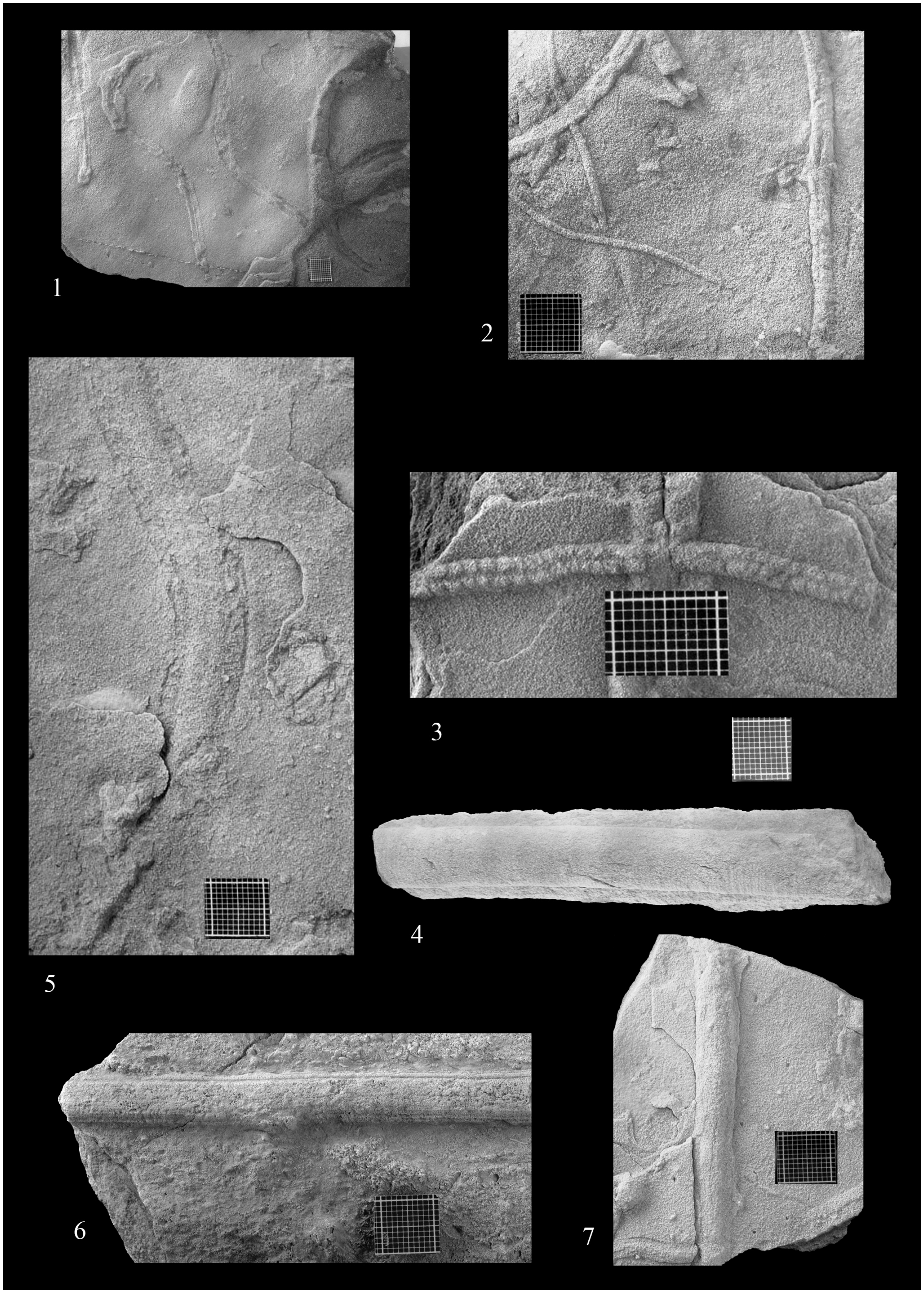
**Explanation of Plate 2**

Figs. 1-3. *Gyrochorte comosa* (HEER) in fine- to medium-grained sandstone Scale in mm. 1. Lower part of the marine part of the Fraizi section. 2, 3. Ghal-e-Sangi section, at 1200 and 687 m, respectively.

Figs. 4-6. *Curvolithus simplex* (BUATOIS, MANGANO, MIKULAS & MAPLES). 4. Fraizi section, west of small village Khij, in calcareous sandstone 5. Ghal-e-Sangi section at 721 m. 6. Kol-e-Malekabad section at 822 m. Scale in mm.

Fig. 7. *Curvolithus* isp. in fine-grained sandstone, Fraizi section at 1225 m. Scale in mm.

**Plate 2**



**Explanation of Plate 3**

Figs. 1, 2. *Helminthorhaphe crassa* (SCHAFHÄUTL) in very fine-grained sandstone, lower part of the Maiamay section. Scales in mm.

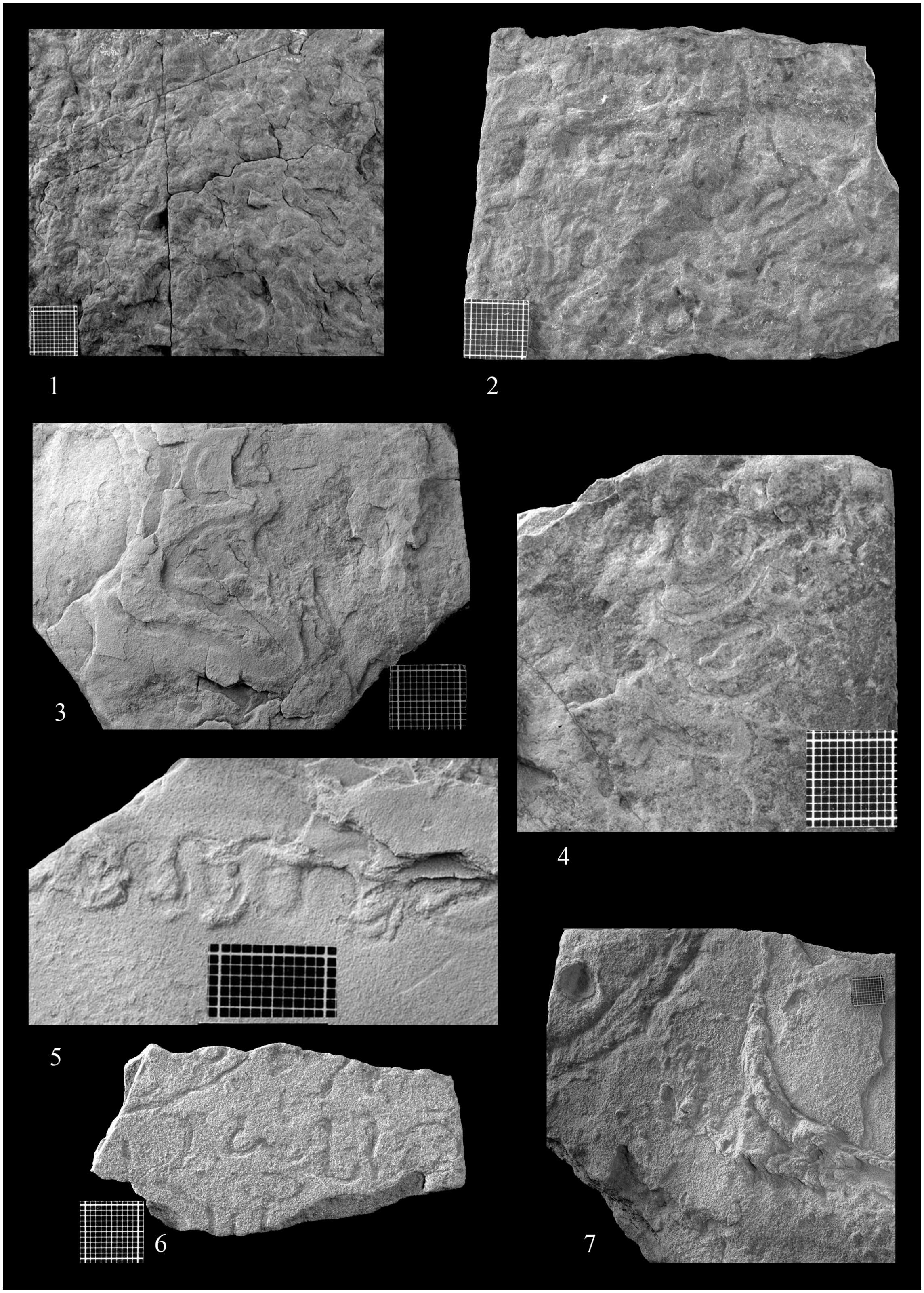
Figs. 3, 5. *Helminthopsis* isp. 3. In light-brown silty- to fine-grained greenish sandstone. Scale in mm. 3, 5. Kol-e-Malekabad section, at 101-113 m and 1117 m, respectively.

Fig. 4. *Helminthorhaphe* isp. in dark-grey fine-grained sandstone of the Maiamay section. Scale in mm.

Fig. 6. *Helminthorhaphe japonica* (TANAKA) in very fine-grained sandstone, lower part of the Maiamay section. Scale in mm.

Fig. 7. *Hillichnus* isp. in medium-grained sandstone of the upper part of the Ghal-e-Sangi section. Scale in mm.

**Plate 3**



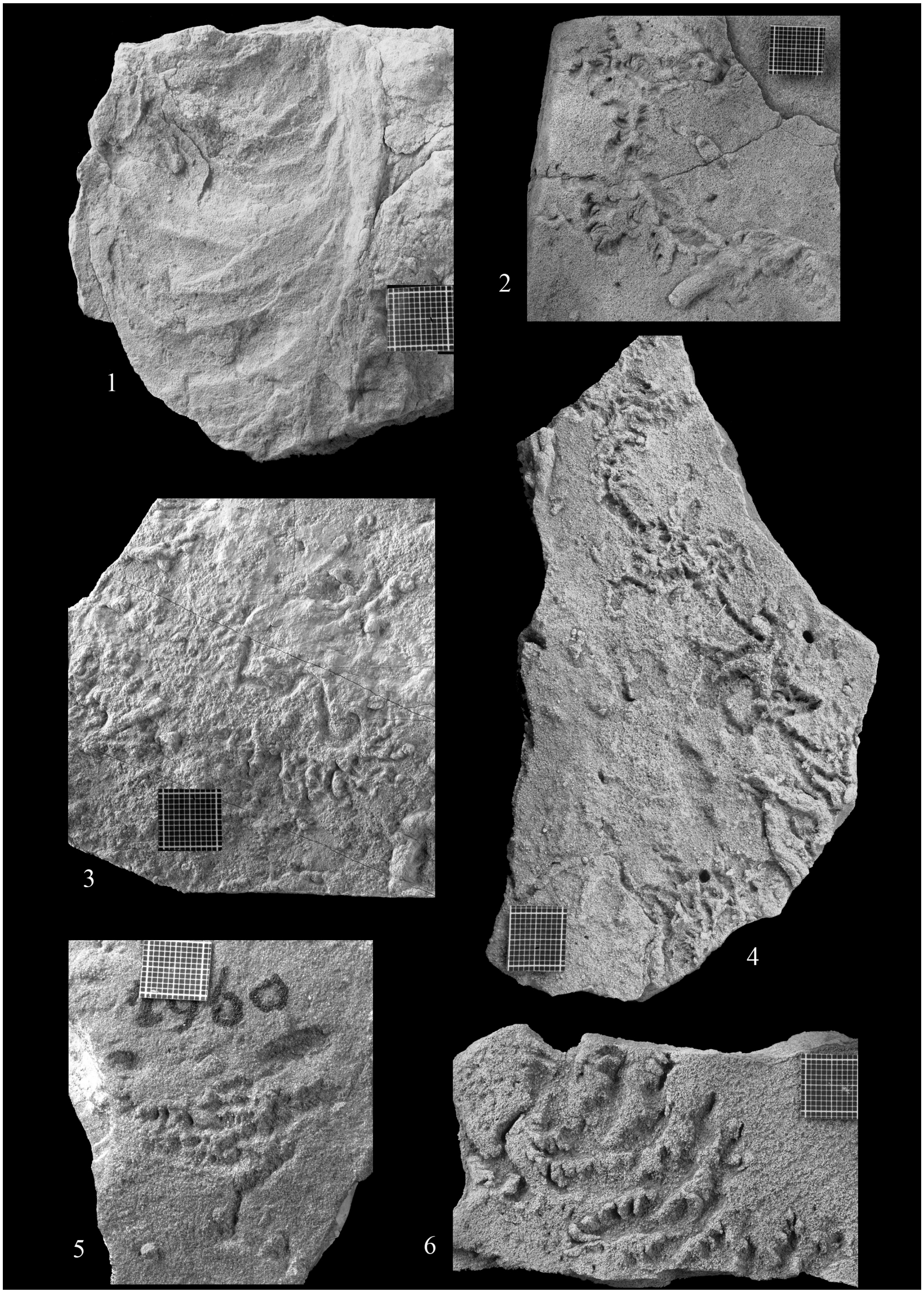
**Explanation of Plate 4**

Fig. 1 *Rhizocorallium* isp. in very fine-grained sandstone of the Ghal-e-Sangi section at 1230 m. Scale in mm.

Fig. 4. *Lophoctenium* isp. in medium-grained sandstone of the Fraizi section at 1910 m. Scale in mm.

Figs. 2-5. *Lophoctenium richteri* (DELGADO). 2. In fine-grained sandstone of the Kol-e-Malekabad section at 784 m. 3, 4. In fine- to medium-grained sandstone of 1960-1970 m of the Fraizi section. Scales in mm.

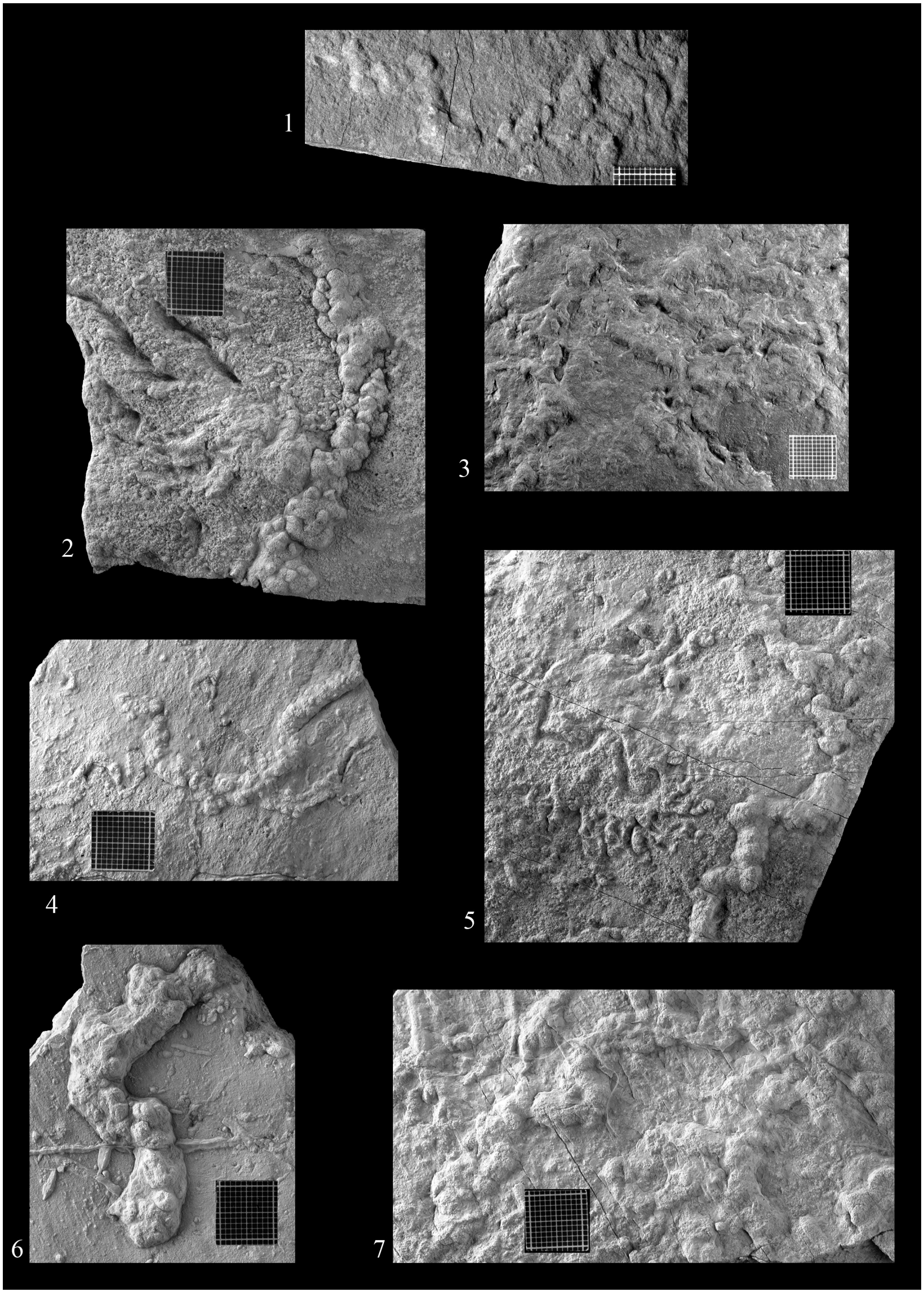
**Plate 4**



**Explanation of Plate 5**

Figs. 1-7. *Neonereites multiserialis* (PICKERILL & HARLAND) in fine-grained sandstone. Scale in mm. 1-5. From the Kol-e-Malekabad section. 6. Senjedak section. 7. Upper part of the Maiamay section.

**Plate 5**



**Explanation of Plate 6**

Figs. 1-2. *Nereites missouriensis* (WELLER) in fine-grained light-brown sandstone, lower part of the Kol-e-Malekabad section between 100-120 m. Scale in mm.

Fig. 3. *Nereites jacksoni* (EMMONS) in fine-grained brownish thin-beded sandstone, lower part of Kol-e-Maelkabad section between 114-122 m. scale in mm.

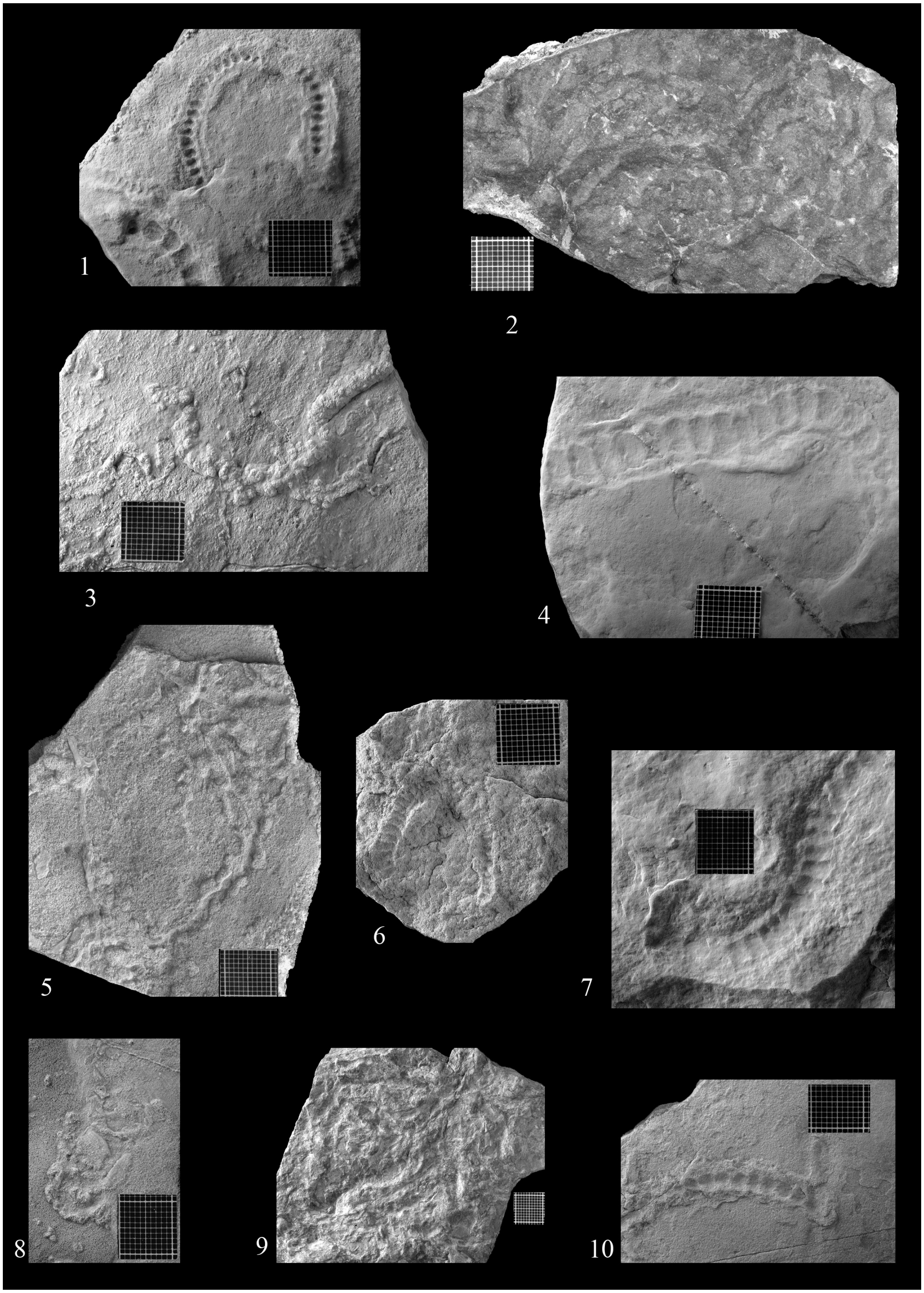
Figs. 4, 7, 10. *Scalarituba missouriensis* (WELLER) in sandy siltstone, lower part of the Kol-e-Malekabad section between 70-90 m. Scale in mm.

Fig. 6. *Nereites* cf. *macleayi* (MACLEAY) in fine-grained greenish sandstone, lower part of Senjedak section. Scale in mm.

Figs. 5, 8. *Nereites irregularis* (SCHAFHÄUTL) in very fine-grained sandstone of the lower part of the Maiamay section at horizonz 76-113 m. Scale in mm.

Fig. 9. *Nereites* isp. in fine-grained sandstone, lower part of the Kol-e-Malekabad section. Scale in mm.

**Plate 6**



**Explanation of Plate 7**

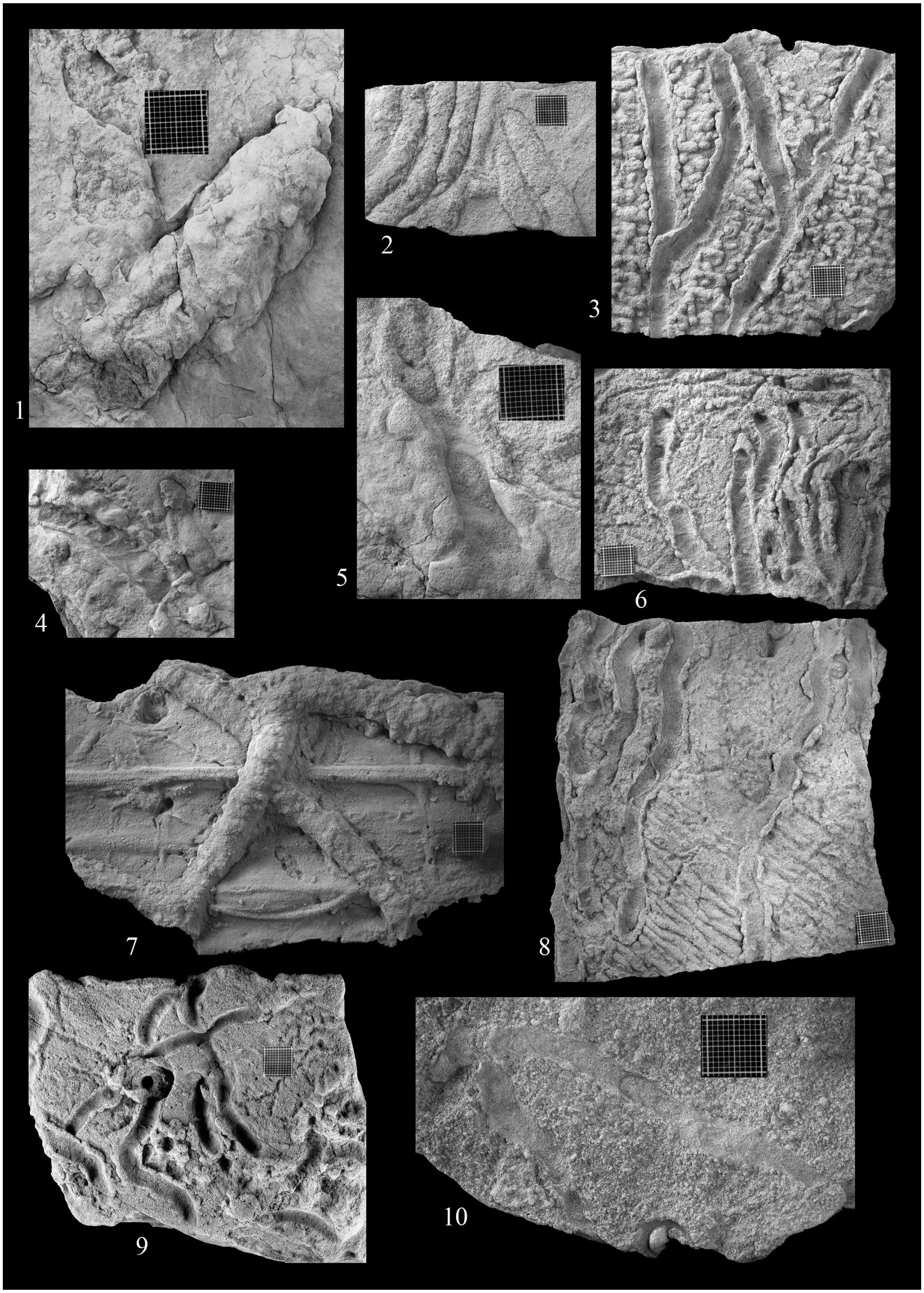
Figs. 1, 4, 5, 7. *Ophiomorpha nodosa* (LUNDGREN) 1. Fine- to medium-grained sandstone of the middle part of the Maiamay section. 4-5. Upper part of the Kol-e-Malekabad section. 6. Medium-grained sandstone of the upper part of the Fraizi section, west of the small village Khij. Scale in mm.

Fig. 2. *Ophiomorpha* isp. in medium-grained sandstone, middle part of the Ghal-e-Sangi section at 734 m. Scale in mm.

Figs. 3, 6, 8-9 *Ophiomorpha borneensis* (KEIJ) in medium-grained sandstone of the middle part of the Fraizi section. Scale in mm.

Fig. 10. *Ophiomorpha irregulaire* (FREY, HOWARD & PRYOR, 1978) in fine- to medium-grained sandstone at 722 m of the Ghal-e-Sangi section. Scale in mm.

**Plate 7**



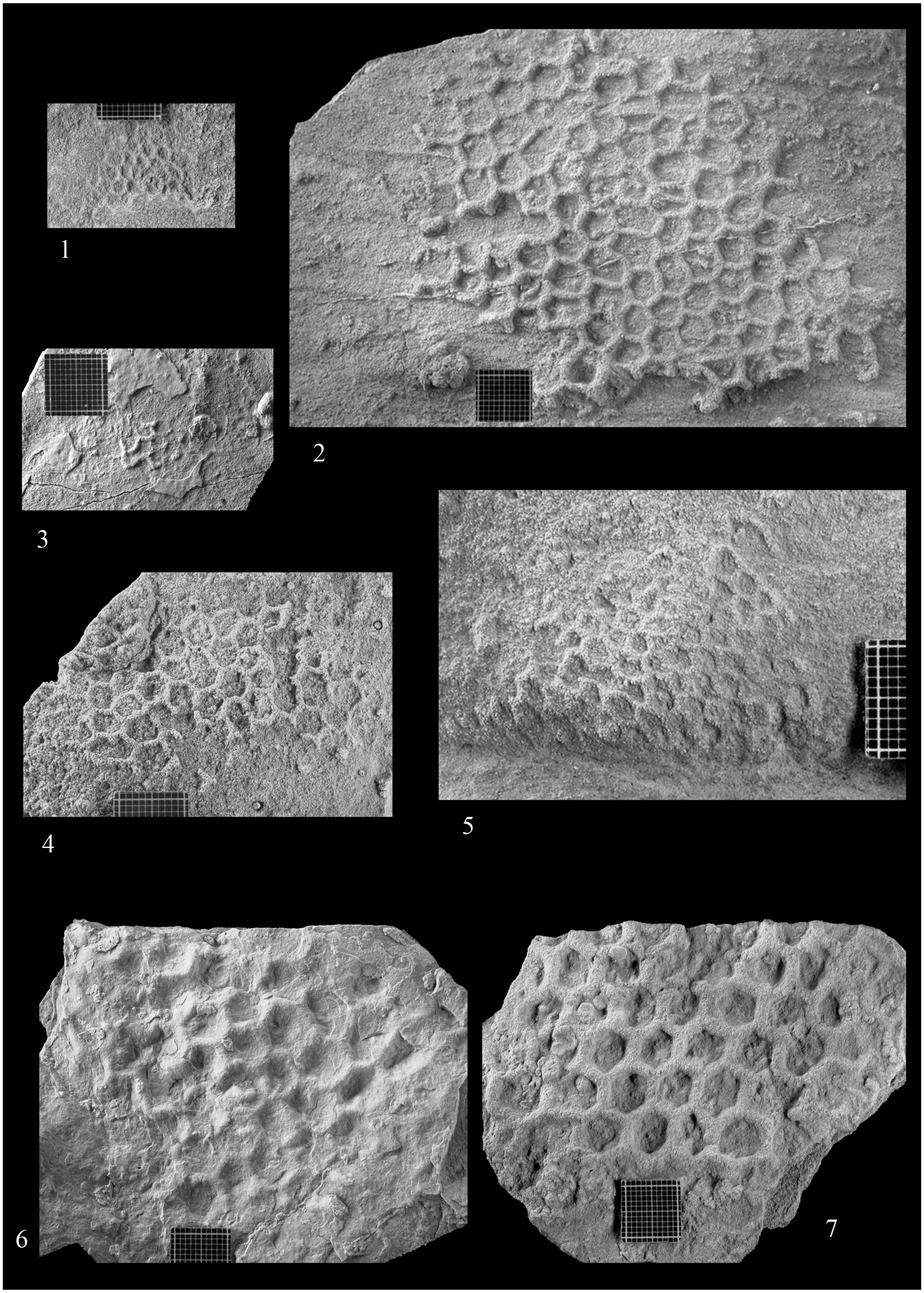
**Explanation of Plate 8**

Figs. 1, 3. *Paleodictyon strozzii* (MENEGHINI) in fine-grained sandstone of the upper part of the Fraizi section. Scale in mm.

Figs. 2, 4, 6, 7. *Paleodictyon maximum* (EICHWALD) in fine- to medium-grained sandstone. Scale in mm. 2, 4, 7. Fraizi section. 6. Maiamay area.

Fig. 5. *Paleodictyon miocenicum* (SACCO) in fine- to medium-grained sandstone of the Fraizi section at 2090 m. Scale in mm.

**Plate 8**

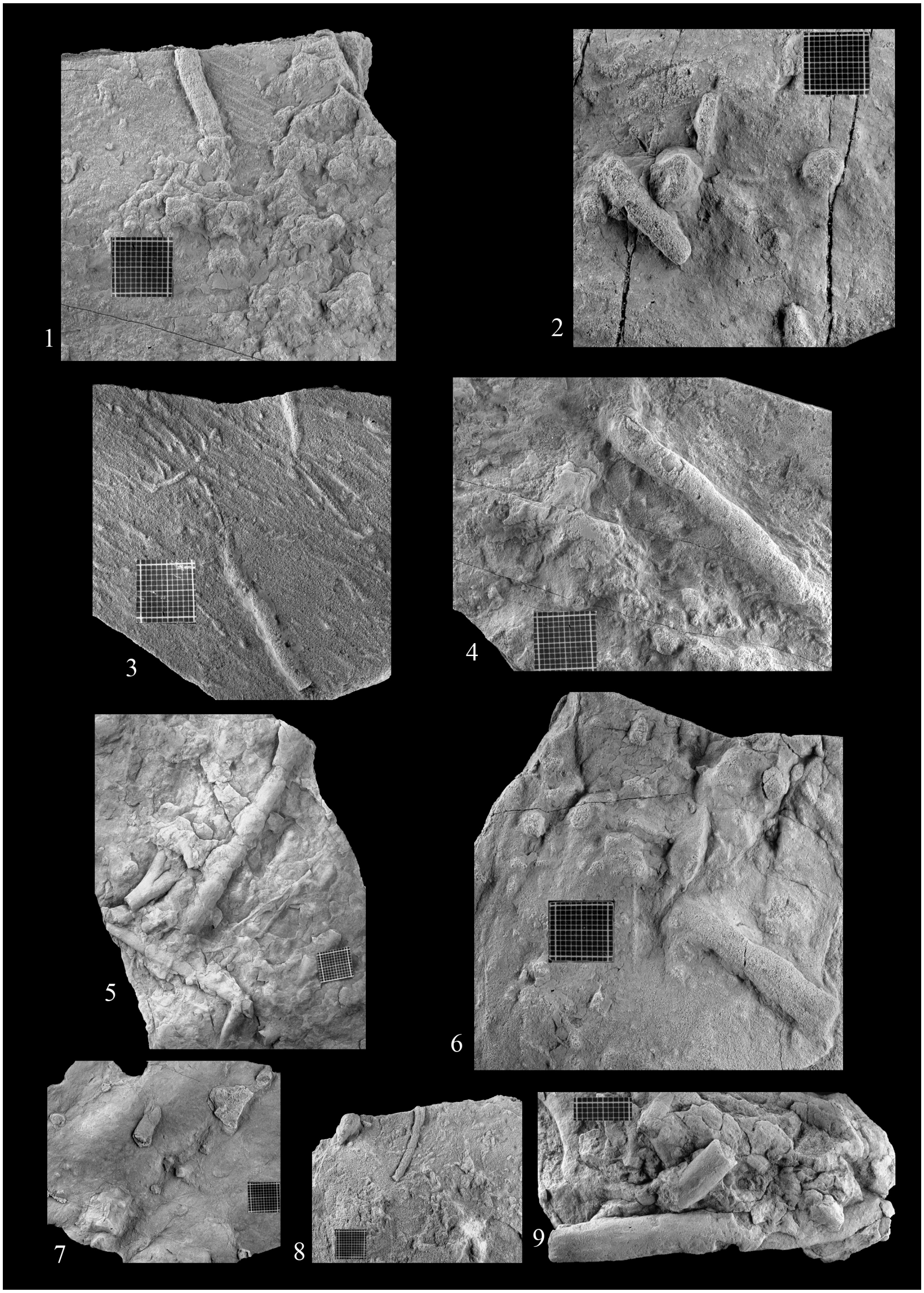


**Explanation of Plate 9**

Figs. 1-4, 6-8. *Planolites* isp. in fine-grained sandstone. Scale in mm. 1, 4, 8. Kol-e-Malekabad section at 316, 187, and 860 m, respectively. 2,-3, 6-7. Maiamay section at 1732, 158, 834, and 690 m, respectively.

Figs. 5, 9. *Palaeophycus striatus* (HALL) in fine- to medium-grained sandstone from the Maiamay section at 1406 and 1732 m, repectively. Sacle in mm.

**Plate 9**



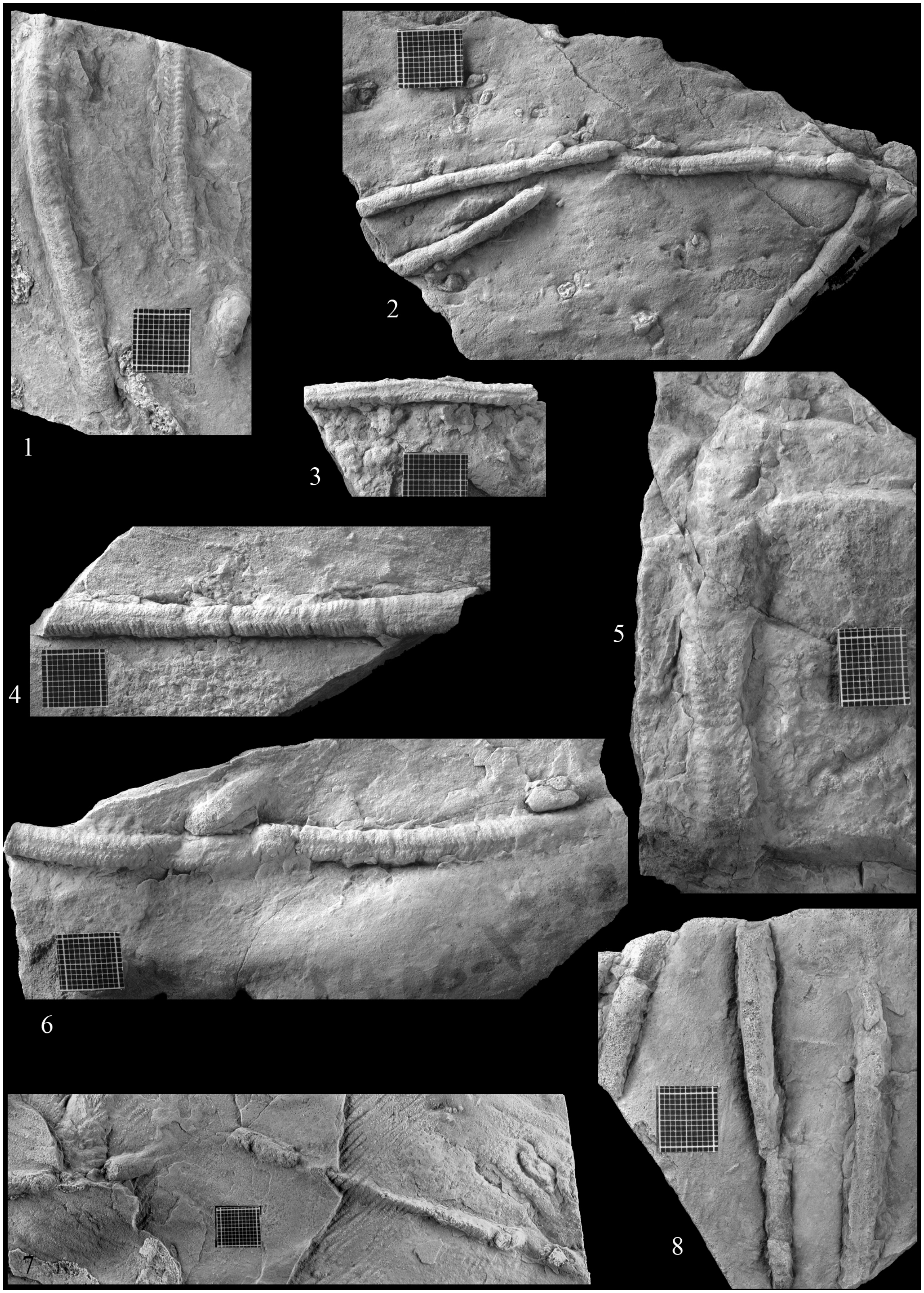
**Explanation of Plate 10**

Figs. 1, 3, 4, 6-8. *Protovirgularia dichotoma* (MC COY) in fine-grained sandstone from lower and middle parts of the Maiamay section. Scale in mm.

Fig. 2. *Protovirgularia* cf. *dzulynskii* (KSIAZKIEWICZ) in fine-grained sandstone of the Maiamay section at 1435 m. Scale in mm.

Fig. 5. *Protovirgularia rugosa* (MILLER & DYER) in fine-grained, turbiditic sandstone of the Maiamay section at 1458 m. Scale in mm.

**Plate 10**



**Explanation of Plate 11**

Figs. 1, 2. *Zoophycos* isp. in medium-grained calcareous sandstone, upper part of the Fraizi section. Scale in mm.

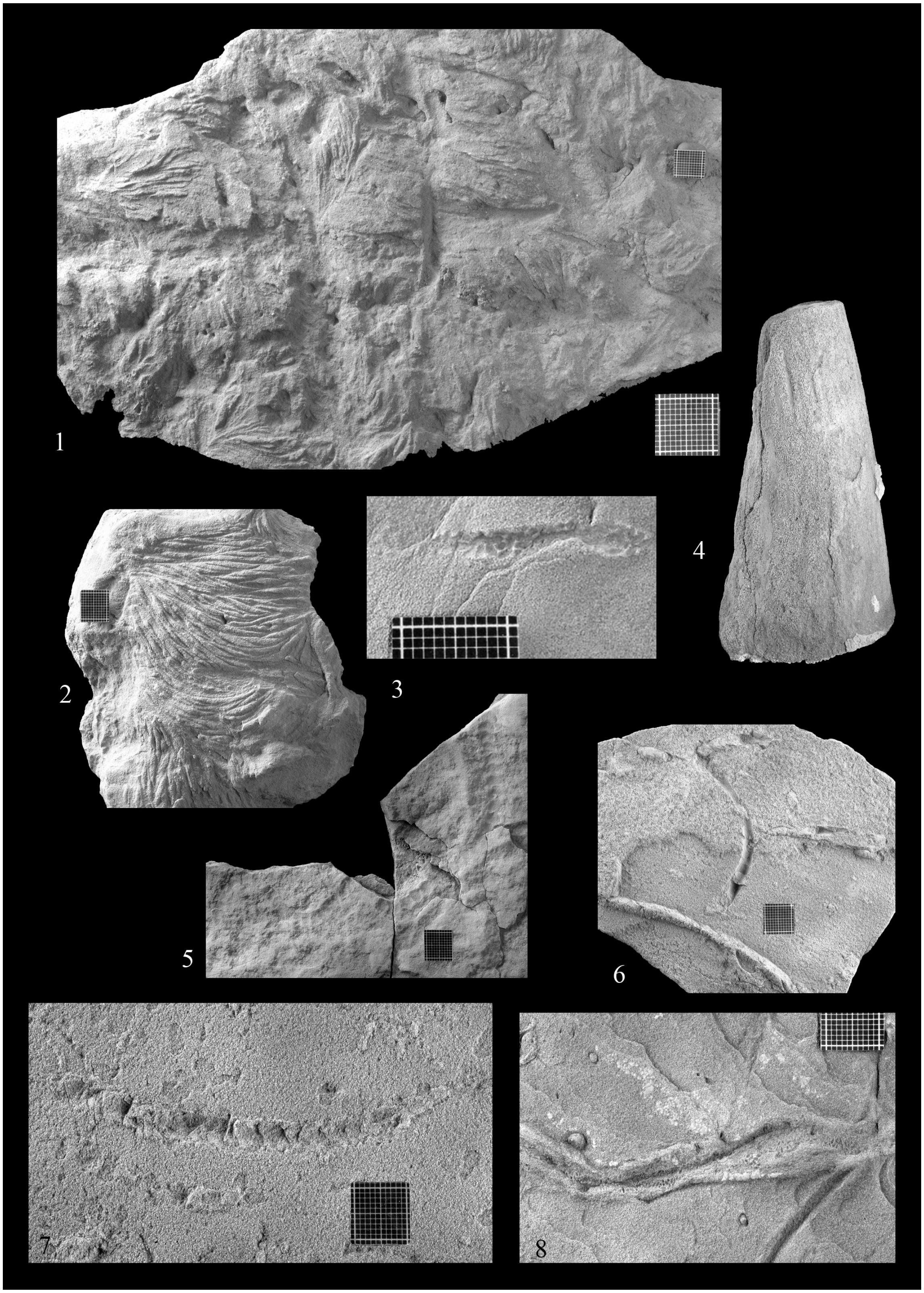
Figs. 3, 8. *Tomaculum* isp. in fine-grained sandstone. Scale in mm. 3. Danesh section. 8. from uppermost part of the Maiamay section at 2865 m.

Fig 4. *Teichichnus* isp., loose specimen from the upper part of the Ghal-e-Sangi section. Scale in mm.

Fig. 5. *Taenidium satanassi* (D'ALESSANDRO & BROMELY) in fine-grained sandstone of Ghal-e-Sangi at 557 m. Scale in mm.

Fig. 6-7. *Taenidium serpentinum* (HEER), in fine-grained sandstone of the Kol-e-Malekabad and Ghal-e-Sangi sections, respectively. Scale in mm.

**Plate 11**

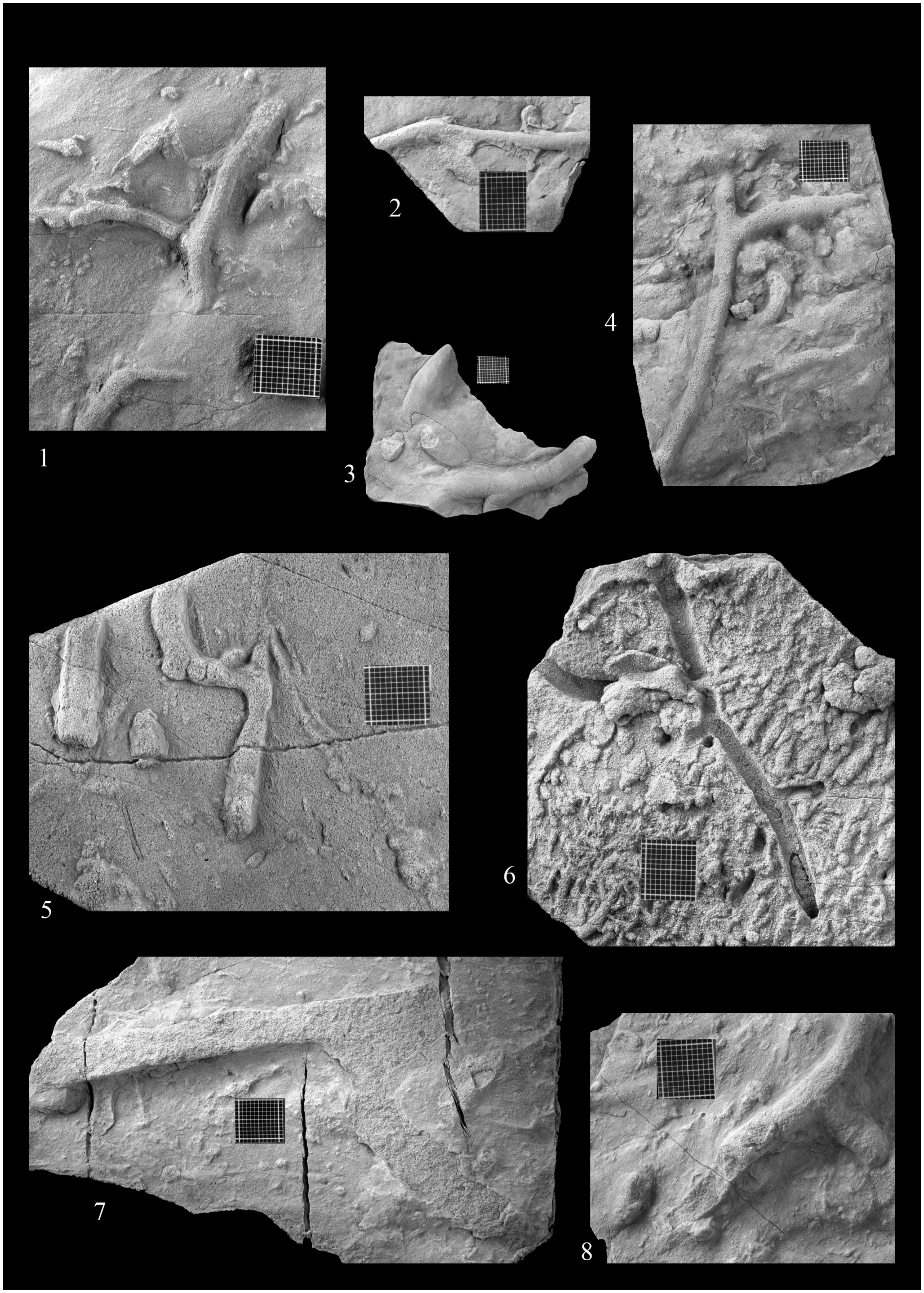


**Explanation of Plate 12**

Figs. 1, 3, 5. *Thalassinoides* isp. in fine-grained sandstone of the Danesh, Maiamay, and Kol-e-Malekabad sections, respectively. Scale in mm.

Figs. 2, 4, 6-8. *Thalassinoides suevicus* (RIETH) in fine- to medium-grained sandstone. Scale in mm. 2, 7, 8. Maiamay section at 745, 2160 and 1915 respectively. 4, 6. Fraizi section at 1836 and 1318 m.

**Plate 12**

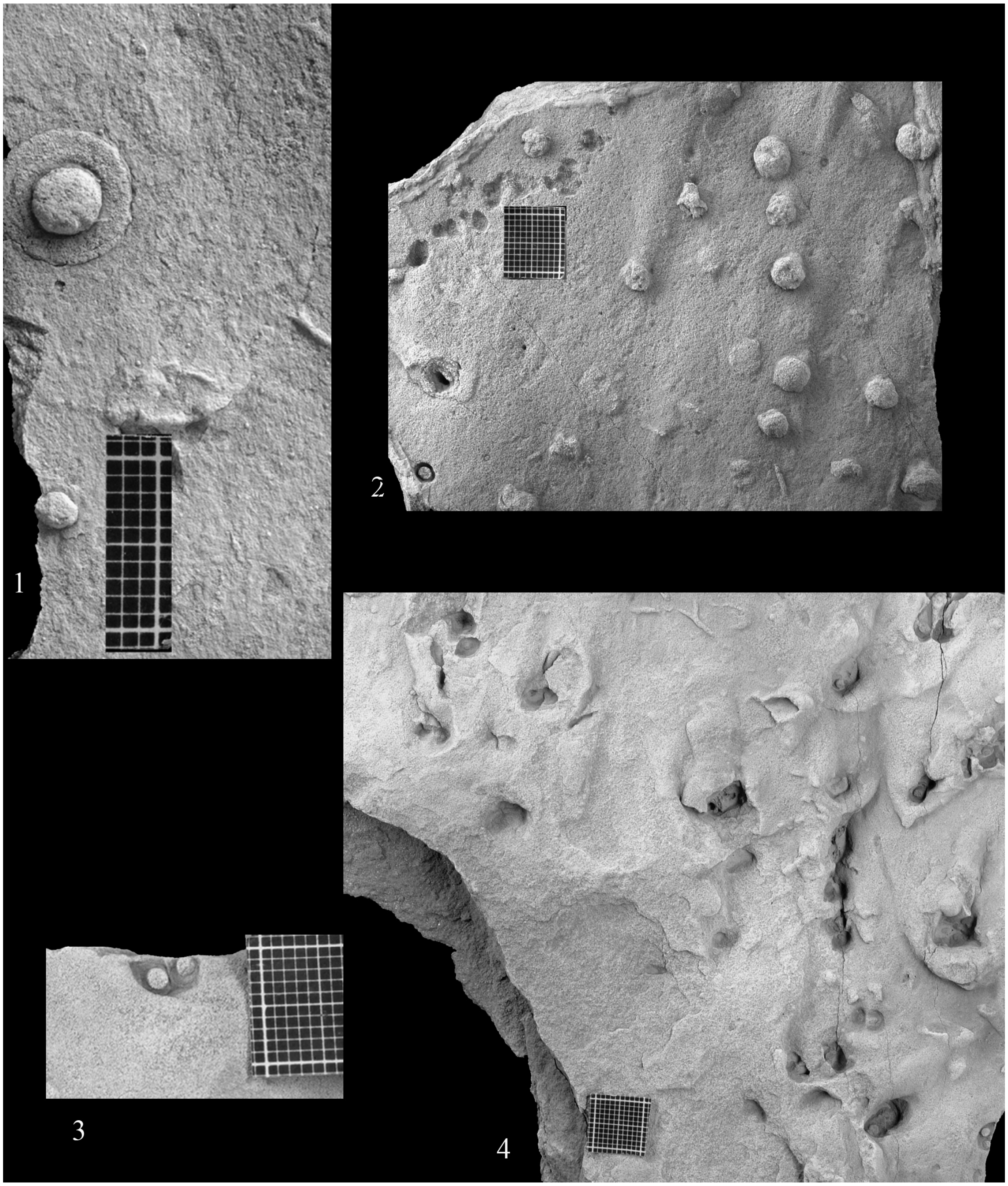


**Explanation of Plate 13**

Fig.1. *Monocraterion* isp. In fine-grained sandstone, from the Kol-e-Malekabad section. Scale in mm.

Figs.2-4. *Diplocraterion parallelum* (TORELL), 2 from Fraizi section, between1836.5-1841; 3 from lower part of the Jizabad section, and 3 from Maiamay section at 2431 m. They were found in fine- to medium-grained sandstone beds. Scale in mm.

**Plate 13**



## 8. Basin Evolution

After detachment of the Iran Plate (TAKIN, 1972; DAVOUDZADEH et al., 1981) from Gondwana in the late Permian (STAMPFLI et al., 1991) and its NNE migration, it collided with the Turan Plate (the southern margin of Eurasia). This collision took place in the Middle Triassic (SAIDI et al., 1997) or early Late Triassic (SEYED-EMAMI, 1971; SENGÖR, 1990; ALAVI et al., 1997) and is documented as the Early Cimmerian orogenic event (see Wilmsen et al., 2009b for a synopsis). As a result, the Palaeo-Tethys has been closed and, at the same time the Neo-tethys opened south of the Iran Plate.

The Early Cimmerian orogeny mostly involved compressional movements and was accompanied by an erosional megacycle, which resulted in deposition of the siliciclastic-type molasse succession of the Shemshak Group ranging in age from the Late Triassic to the Middle Jurassic. The biostratigraphy of this lithostratigraphic unit is still poorly known (FÜRSICH et al., 2009; WILMSEN et al., 2009a), but advances in recent years (for details see Chapter 4 and WENDT et al., 2005), especially in connection with the mapping surveys in the Mashhad area at a scale of 1:25000 (GSI), yielded new results.

Based on these new data the relationship between the main Triassic-Cretaceous lithostratigraphic units is presented in Fig 8.1. When reconstructing the basin evolution of the study area, especially the Mashhad area, identifying the stratigraphic positions of basal conglomerates is difficult. From the Early Cimmerian to the Mid-Cimmerian tectonic event, at least three basal conglomerates and regional metamorphic events occurred. Based on palynomorphs (see Chapter 4), at least a part of the Mashhad Phyllite was deposited during the Rhaetian, and can be attributed to the cycle of synorogenic Early Cimmerian event.

The low-grade metamorphism of the Mashhad Phyllite can be related to the geodynamic forces which governed the area after collision of the Iran and Turan plates. It may connect with the slab-breakoff event suggested by WILMSEN et al. (2009b) around the T/J boundary.

This phenomen took place before deposition of siliciclastic, coal-bearing sandstone and conglomerate units (Shemshak Group of the Binalud), which have been determined as Liasic in age. In this scenario, the metamorphism is younger than Rhaetian and older than Lias (Fig. 8.1), thus being clearly related to the T/J boundary, or Main-Cimmerian Event of WILMSEN et al. (2009b).

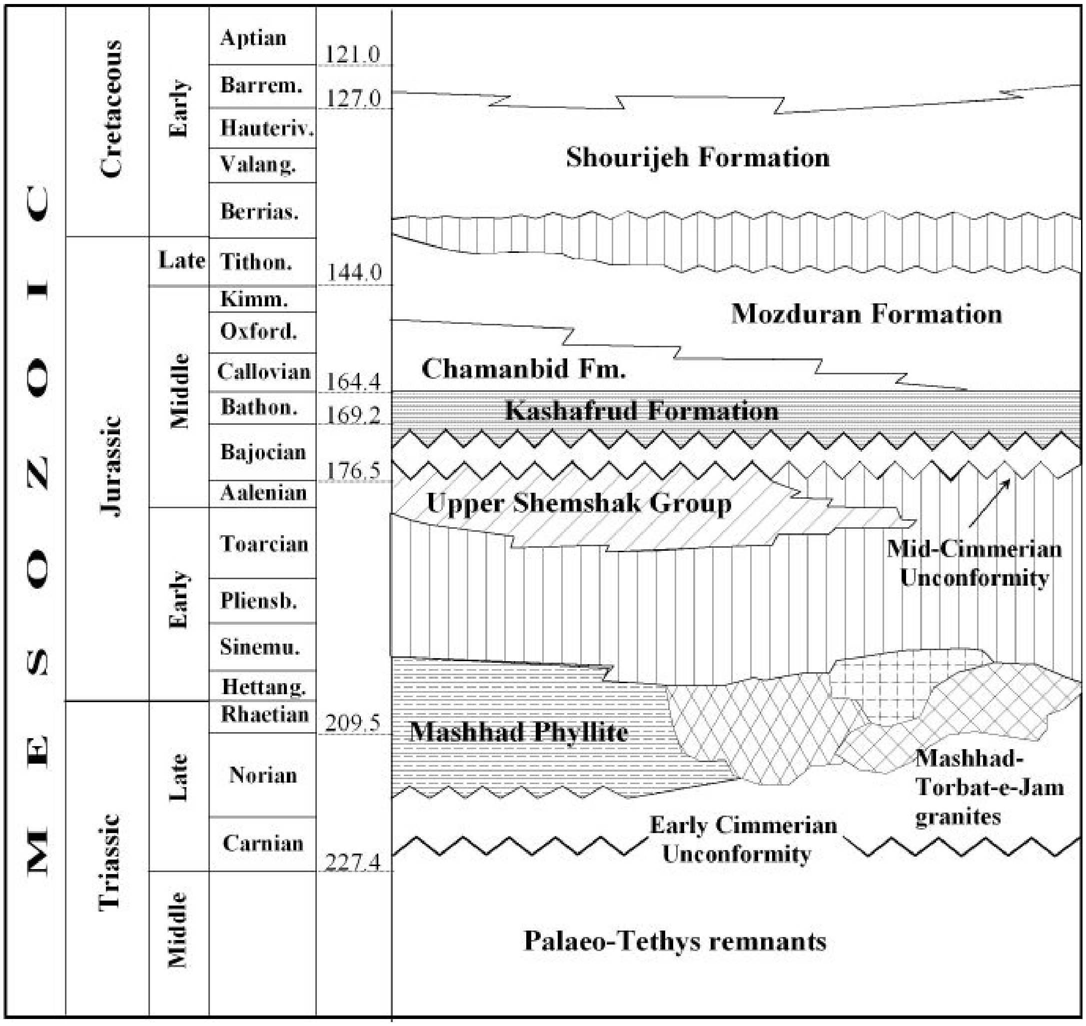


Fig. 8.1. Schematic relationship of the main lithostratigraphic units in the study area.

The basal conglomerate of the early Middle Jurassic, non-marine units (Arefi Formation, WILMSEN et al., 2009a) could be attributed to the main Cimmerian tectonic movement. In this scenario, the basal conglomerate of the Kashafrud Formation is a transgressive conglomerates and correspond to the Mid-Cimmerian extentional event of Wilmsen et al. (2009b).
According to SENGÖR (1992), in areas undergoing active convergence such as foreland-thrust belts and subduction–accretion complexes, the rates of tectonic progradation and aggradation are rapid and can lead to the development of numerous localized unconformities of short duration.

The Late Cimmerian orogenic movements in central and, north Iran as well as in the Koppeh Dagh resulted in uplift and regression (AGHANABATI, 1998, 2004; FÜRSICH et al., 2003, 2005; SEYED-EMAMI et al. 2005). The later does not correspond to the global eustatic see-level movements of that time (HALLAM, 1992) and therefore are more likely a result of regional tectonic movements (SEYED-EMAMI, 2005; Wilmsen et al., 2003, 2009c).

*Regional setting.* The stratigraphic characteristics, geological setting, deposition of huge amounts of siliciclastic sediments in a relatively short time span (less than 5 my.) and consequently a high subsidence rate all suggest extensional movements and formation of a rift-related basin in NNE Iran during the early Middle Jurassic (TAHERI et al., 2009; Fig. 8.2). Such extensional basins were assumed also for central and north Iran (SEYED-EMAMI, 2005; FÜRSICH et al., 2009) in the early Middle Jurassic.

Among different rift-related basin models (INGERSOLL & BUSBY, 1995; SENGÖR, 1995), a post-collisional extensional basin model is most compatible with the observed features in the study area, which could be accelerated by sediment loading. In addition to evidence of syn-tectonic activity, field observations including lateral lithofacies changes from shallow-marine to deep-sea across relatively short distances (e.g., from Tappenader to Senjedak area) and sudden deepening-upward from basal conglomerate to deep-marine sediments (discussed in the previous chapters) confirm that the study area was a fault-controlled basin.

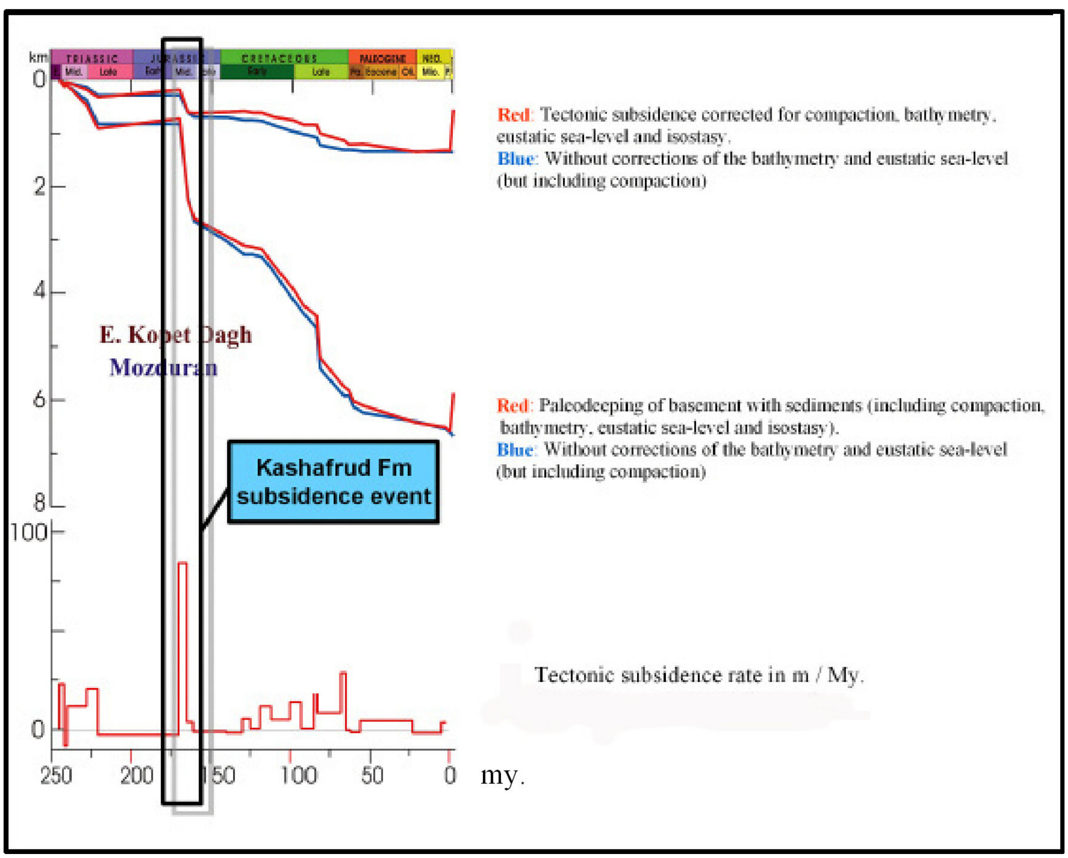



Fig. 8.2. Subsidence curve, which shows high tectonic subsidence rates of the Kashafrud Basin (from BRUNET & SHAHIDI, 2006).

Until now, no reliable data about syn-sedimentary volcanism exist, which one would expect during the first stages of rifting, exist. Such evidence has been reported from lower Middle Jurassic strata, including from the Bajocian, in north Iran (AGHANABATI, 1998). Evaporates may also form during initiation of rift basins. For example, SW Anzali in north Iran Toarcian-? Bajocian strata are composed of sandstone, siltstone, and shaly silt with evaporate components. As a result, springs there are completely salty (AGHANABATI, 1998). There are also xeno-blocks there. These aspects clearly require more field work and are presented here only as preliminary data.

*Basin Fill*. The Kashafrud Formation starts with a basal transgressive conglomerate whose thickness varies from less than 1 m (Mikh Khar small farm NE of the Sefid Sang area) to more than 20 m (Ghal-e-Sangi section). The components mostly originated from the local substrate and from source rocks which crop out in the neighbourhood. For instance, at Ghal-e-Sangi the basal conglomerate consists of Triassic rock units of the Aghdarband Groip. At Kol-e-Malekabad, pebbles are mostly ophiolites, and N of Torbat-e-Jam granitic components are the main components of the basal conglomerate.

Except for the Fraizi section where no obvious basal conglomerate is developed (probably because of a thick braided river conglomerate and sandstone intercalation), the thickness of basal conglomerate is 24 m at Ghal-e-Sangi, less than 10 m at Kol-e-Malekabad, about 5 m at Tappenader, 4.5 m at Senjedak, and about 15 m in the Torbat-e-Jam area.

In the Tappenader-Jizabad composite section, the only shallow marine carbonate succession occurs in the basin fill. In the Jizabad area the basin fill represents a pro-delta to outer shelf environment. In the Torbat-e-Jam region, about 60 m of the lower part of the section represent shoreface deposits and offshore sub-environments. Up-section, turbiditic shales and sandstones are more characteristic features. Both shallow- and deep-water sediments there are cut by dykes and sills of intermediate to mafic composition. As the upper strata of the Kashafrud Formation are folded and faulted, it is difficult to measure a complete section, but the basin passed from shallow marine to deep-marine slope, possibly even basinal conditions at this locality.

At Ghal-e-Sangi, about 86 m of the lower part represent shallow marine environments, especially the coral-bearing horizon at 86 m.

The second member in this area is a highly bioturbated, dark, greenish monotonous silty shale and fine-grained sandstone unit that was deposited in a deep basinal environment. In this area the third member indicates shallower conditions. Storm beds occasionally are visible in this part of the basin fill. The remaining parts of the Ghal-e-Sangi section are characterized by mud-dominated, low-energy conditions of moderate depth.

At Kol-e-Malekabad, the Kashafrud Formation overlies the Darre Anjir Ophiolitic complex and Triassic meta-sandstones. About 50 m of basal conglomerate and pebbly sandstone beds are followed by a succession of slope to basinal sediments characterized by the Nereites ichnofacies. After a classic distal turbiditic unit, green to olive, monotonous siltstone is the main lithofacies, which in turn is replaced by upper slope to outer shelf parasequences and finally dolomitic limestones of the Mozduran Fomation. In general, the Kol-e-Malekabad area is more silty and had deeper condition than Ghal-e-Sangi in the east.

The Kuh-e-Radar area characterizes the basin margin. The Kashafrud Formation forms a fan delta sedimentary succession in front of uplifted regions of the Mashhad Granite south of the basin. Marly, fossil-bearing sediments probably formed in a prodelta sub-environment, and conglomeratic horizons with granitic cobbles several meters in diameter imply a steep, cliff-rimmed coastline.

In the Danesh section, further to the northwest, the Kashafrud Basin was sand-dominated with proximal turbiditic elements, while structureless medium- to thick-bedded debris flows feeding the basin are another important sedimentary feature. The uppermost part of the sedimentary succession at this locality is characterized by calcareous litharenites, which were deposited under relatively high-energy conditions representing shoreface to storm-dominated, transitional offshore environments. In the northern domain of the Binalud Mountains, at Fraizi, in comparison to other localities at the southern margin of the basin a relatively thick (about 1300-1400 m) transitional facies is developed, consisting of marly silt with sandstone intercalations. These strata, which have been mapped as Dalichai Formation on the 1:250,000 and 1:100,000 geological maps are thought here to correspond more closely to the lithology of the Kashafrud Formation than the Dalichai Formation.

It seems that the depth of this part of the basin was less than several hundred meters, with deeper lithofacies possibly related to sea-level fluctuations. An ichnocoenosis including *Paleodictyon, Ophiomorpha, Zoophycos, Thalassinoides, Planolites* and *Curvolithus* is dominating in the middle to upper part of the succession and no other graphoglyptids or elements of the Nereites ichnofacies are found (FÜRSICH et al., 2007). No slump units were seen, but debris flows and storm beds are quite common in this part of the basin.

Field observations showed that the deepest parts of the Kashafrud Basin in NE Iran, possibly corresponding to the basin axis, run NW-SE corresponding to the Senjedak, Maiamay, and Gas-pipeline sections. This direction forms a high angle with the Palaeotethys suture zone. In the Senjedak area, a truncated section, cut by a thrust fault and covered by Cretaceous rocks, measures about 1700 m (HOSAINYOON, 1996). The lithofacies is mostly basinal greenish-grey silt with intercalated fine-grained sandstones of the Nereites ichnofacies. In the Maiamay area, the Kashafrud Formation comprises more than 2,500 m of slope to basinal fan deposits. The lithofacies here and variations in the sand/silt ratio, coarsening- and fining-upward sequences as well as turbiditic sandstones and shales are a function of different factors such as subsidence and accommodation space, eustatic sea-level fluctuations, and probably repeated fault activity which controlled the basin architecture. The Gas-pipeline section represents the deepest part of the basin in the study area. It is dominated by dark, greenish, highly bioturbated, monotonous silts with intercalations of very thin to thin, fine-grained sandstone beds.

In general, the Kashafrud Basin was a high-subsidence; fault-controlled, rift-related basin which was filled with flysch deposits (Fig. 8.2). Field observations indicate that the Kashafrud Basin extended further towards the west for more than 250 km, between Bojnord and Gorgan and probably was connected to the South Caspian Basin. More investigations are needed for a more precise reconstruction of Late Bajocian-Late Bathonian E-W extending basins of the area.

In an eastern direction, in west Afganistan (eastern extension of the study area), a non-marine succession named the Išpušta Formation is probably the equivalent of the Kashafrud Formation. This unit starts with a basal conglomerate (25-200 m thick) and is followed by sandstone and claystone with plant fossils remnants (WOLFART & WITTEKINDT, 1980).

**Evolution of the Kashafrud Basin evolution and probable syn-sedimentary volcanism**

One of the most important characters of rifting processes is volcanism. A rift zone may fail at any time (INGERSOLL & BUSBY, 1995; SENGÖR, 1995) and, consequently, oceanic crust is not created. To approach this problem in the Kashafrud Basin, most of the igneous rock units which are mapped on the 1:250,000 and 1:100,000 geological maps of the study area, have been checked. For this purpose several transects have been surveyed:

1. Southeastern part of the Sefid Sang geological map in scale of 1:100,000.
2. Dykes and sills in the Senjedak area.
3. Dykes and sills in the Torbat-e-Jam section.

Volcanic rocks were found in the first area close to the Sefid Sang-Senjedak-Sarcheshmeh main road, turning south at the small farm Alghour. The igneous rock unit crops out in the Kaki Mountain (Kuh-e-Kaki). This plutonic unit is composed of dacite to monzonite which cut the Kashafrud strata and metamorphosed and silicified it (Fig. 8.3A). Thus obviously this igneous unit must be younger than the Kashafrud Formation.

Dykes and sills near the small village of Senjedak (co-ordinates N 35 ˚ 44′ 49″, E 60˚ 14′ 38″) were also checked. They are also younger than Kashafrud strata, since both upper and lower contacts of the sills have been affected by these highly altered diabasic rocks (Fig. 8.3B).

In the Torbat-e-Jam section, the first unit of more extensive volcanic rocks occurs about 160 m above the base of the Kashafrud Formation. The sedimentary rocks at the base of the volcanic unit seem to have been affected at the contact, but the sedimentary rocks follow the morphology of the volcanics at the upper contact. This observation needs to be substantiated by additional fieldwork, because of probable folding in this part (Fig. 8.4B). In the turbiditic succession, dykes are also visible and appear to represent feeder dykes. No interaction with the sediments overlying the sill has been observed (Fig. 8.4A).

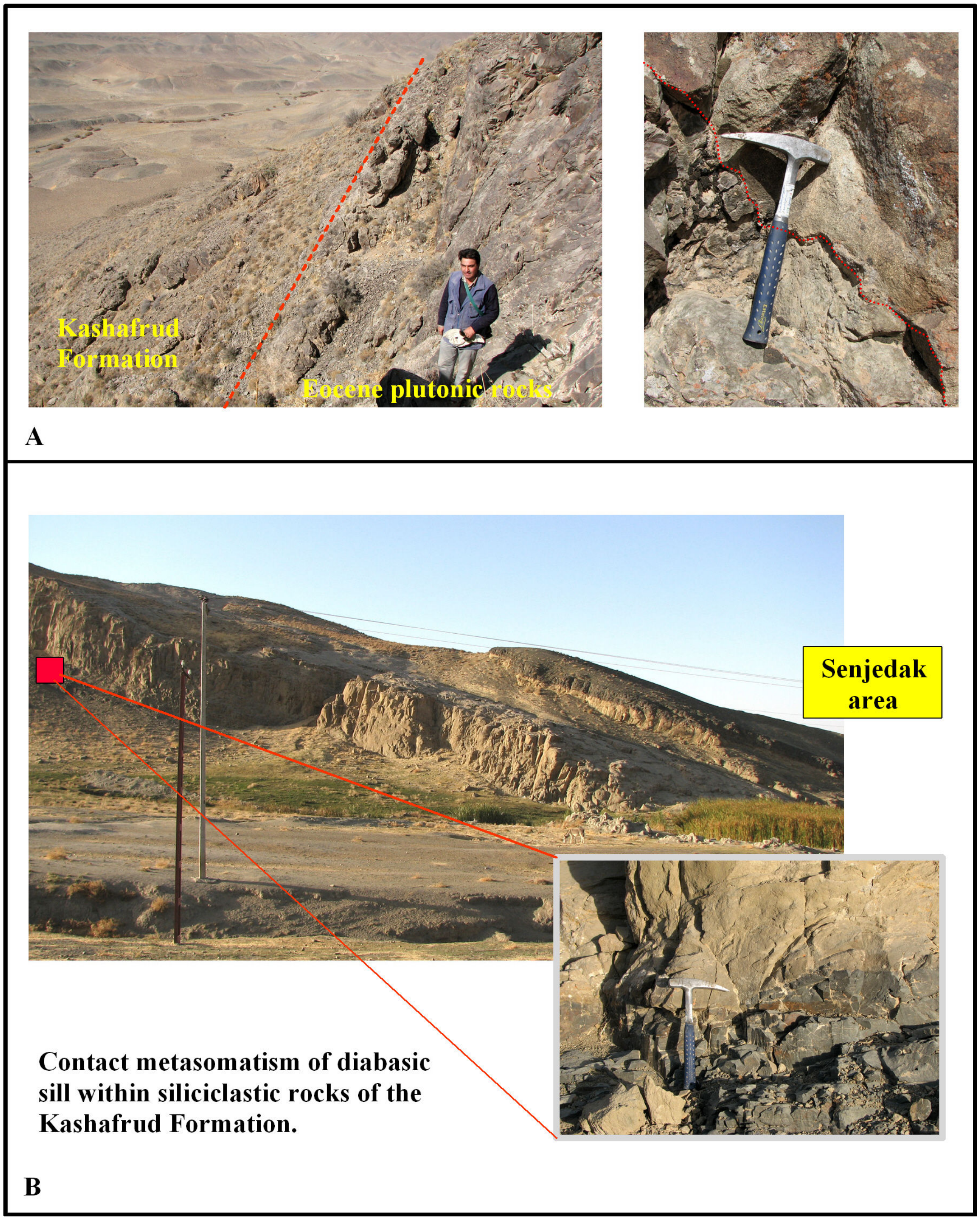



Fig. 8.3. Relationship between igneous rocks and the Kashafrud Formation. A. Eocene plutonic rocks which intruded the Kashafrud Formation at Kuh-e-Kahie area (SE Sefidsang). B. Altered basic dykes and sills near the Senjedak area.

It seems that the volcanic rocks of the Torbat-e-Jam section deserve more detailed investigations with respect to their chemical composition and, consequently, tectono-magmatic setting.

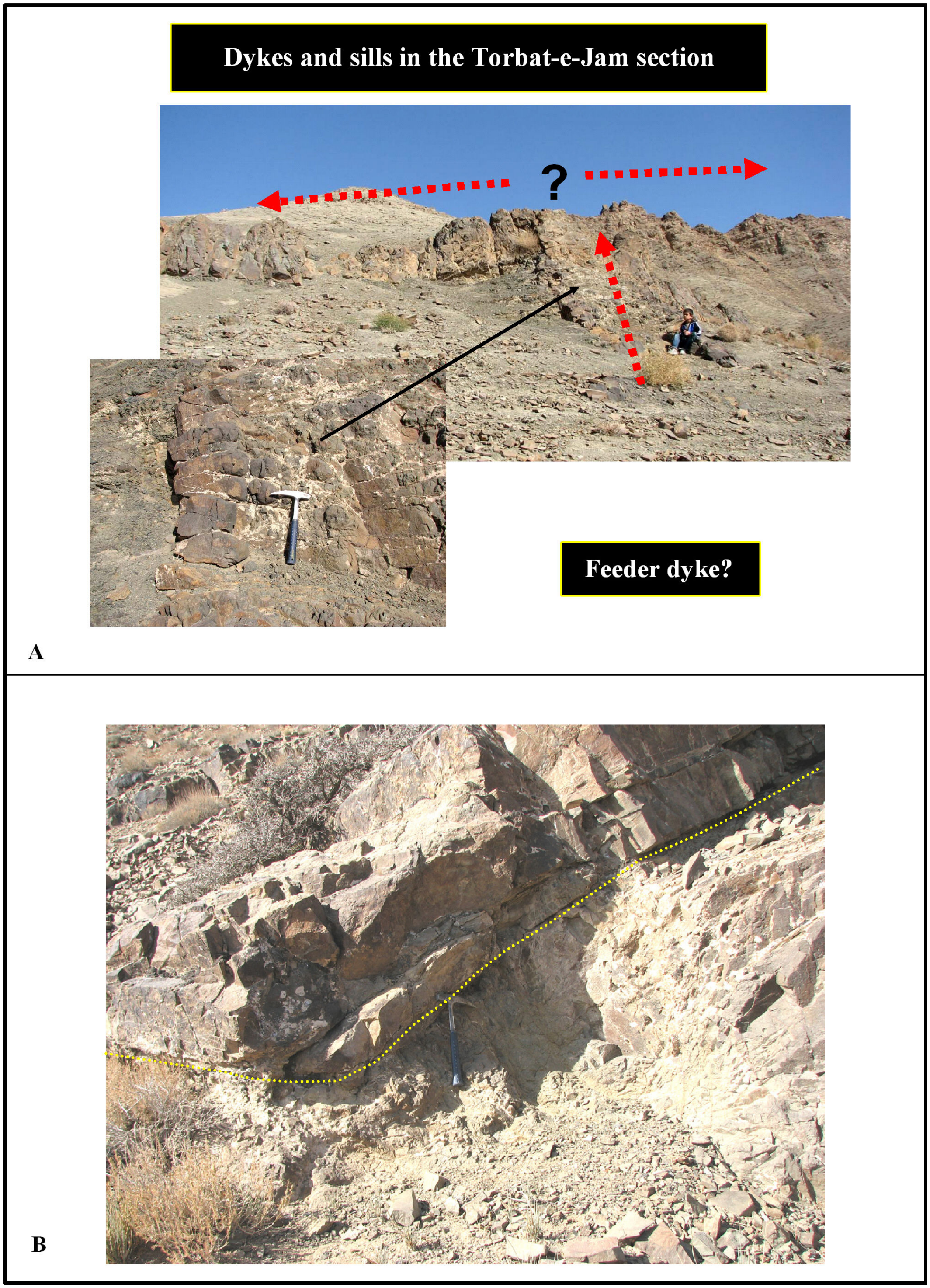



Fig. 8.4. Features of diabasic dykes and sills in the Torbat-e-Jam section. A. Probable feeder dyke in the upper part of the section. B. Synsedimentary diabasic sills in the lower part of the section. Red arrows indicate direction of lava flow.

**Western extention of the Kashafrud Basin**

In addition to the units, which have been mapped as Kashafrud Formation west of Robat-e-Gharabil and in adjacent areas, there are some other outcrops that more probably belong to the Kashafrud Formation, but have been mapped as Shemshak Formation. This includes the siliciclastic succession north of Shirouye (south of Bojnord, along the Esfarayen road), and in the Navia district (Fig. 8.5). At the latter locality, a monotonous basinal sequence of olive silts with intercalation of sandstones crops out; undeterminable fragments of ammonites were seen during a short field trip (Figs. 8.5 A, B).

At present, there is no evidence that this large area of Middle Jurassic rocks in the west and the study area were connected, and sub-surface data from the northern area are very rare. As the Kashafrud Formation is a potential hydrocarbon source rock, it is very important to continue prospecting at a regional scale. The area will also play a key role for revealing the connection with the South Caspian Basin and the rift-related Kashafrud Basin in the northeast Iran.

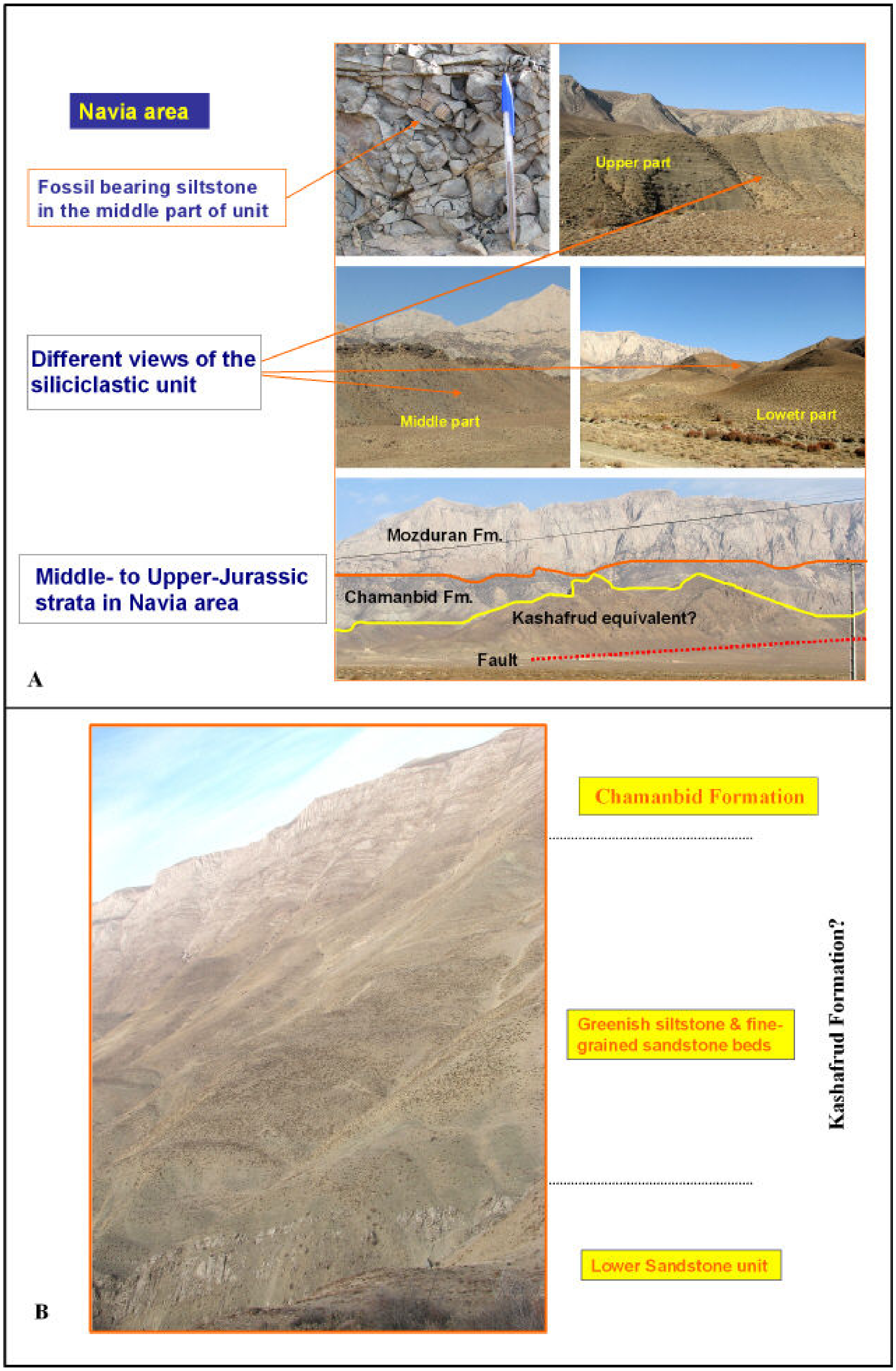



Fig. 8.5. Features of probable Kashafrud equivalents in western Koppeh Dagh. A. Navia area, south of Robat-e-Gharabil. B. Another outcrop of such a unit in south of Bojnrod along the Bojnord-Esfarayen road.

**The Kashafrud Basin: an impactogen structure**

The Kashafrud Basin is a fault-controlled basin which had its depocenter in the Senjedak-Gas pipeline direction. The basin narrowed towards the east. In the inner parts of Afganistan, WOHLFART & WITTEKINDT (1980) reported non-marine Middle Jurassic rocks (Išpušta Formation), including of 25-200 m basal conglomerate, which overlie other older rock units, the remaining parts being non-marine sandstones and claystones with plant debris.

The absence of the Kashafrud Formation, at least at the southern margin of the basin, from west of Mashhad to southeast of Bojnord may indicate a positive palaeo-relief there. Together with equivalents of the Kashafrud Formation further west it seems that a set of rifting zones existed which were oriented at high angle to the Palaeo-Tethys suture-zone. These post-collision, rift-related, extensional basin(s) can be interpreted in the light of the impactogen geodynamic model. In fact, impactogens are thought to be secondary tension stresses set up at high angle to a zone of compression (SENGÖR, 1995). According to him the characteristic features of this type of rift-related basin are as follows:

- No stratigraphic relationship exists between oceanic remnants of the last orogenic belt and impactogen basins.
- The pre-rift basement of collision is made up of the rocks of the orogenic fore- or hinterland, and their rift-fill is clearly post-collisional.
- Impactogens normally do not have associated pre-rift doming, and strike-slip deformation along the graben axis commonly begins late in their history.

These features are more or less compatible with the Kashafrud Basin. Concerning the creation of oceanic crust, extension in the basin was possibly less than the average for most rifts, and consequently the rift did not evolve to the oceanic crust stage. In contrast, in the South Caspian Basin the rate of the extension was high enough to form oceanic crust.

**Conclusion**

Several decades ago, due to the lack of precise precise data, the Kashafrud Formation was regarded as the equivalent of the Upper Triassic-Lower Jurassic Shemshak Formation (BAUD et al., 1991; DAVOUDZADEH 1984; SHAHRABI, 1999). Subsequent field studies, especially biostratigraphic investigations based on macrofauna, particularly on ammonites (SEYED-EMAMI et al. 1994; HOSAINIUN 1996) and geological mapping of the area, demonstrated a Late Bajocian - ?Late Bathonian age of this formation.

Prior to this study, little information existed about the sedimentary environments and other characters, especially the geometry of the basin. Exact biostratigraphic data from the top of the Kashafrud Formation were rare. Based on the macrofauna from the lower part of the overlying Chamanbid Formation the upper bounary of the Kashafrud Formation had been attributed to the ?Upper Bathonian and/or Early Callovian.

The present study is the first overview on the Kashafrud Basin covering the vast outcrops of the succession from the southeast, near the Afghanistan border, to north- northwestern areas around the city of Mashhad. In order to reconstruct the geometry of the basin and the facies architecture, a number of sections have been logged in detail. The facies analysis based on field data, resulted in the definition of facies associations.

Relative changes in sea level were reconstructed on the basis of deepening- and shallowing-upward trends (for detail see Chapter 3-5). The only continuous carbonate unit (~30 m) locally formed at Tappenader. Other localities in which thin fossil-bearing carbonate strata occur are Torbat-e-Jam (benthic fauna) and, to a lesser extent Ghal-e-Sangi.These rare shallow-water carbonates, which also contain corals, represent only short intervals.

In most areas, the basin rapidly evolved from a shallow marine, transgressive succession to a deep-marine, basinal succession. The only area where shallow conditions persisted from the Late Bajocian to the Late Bathonian and even into the Early Callovian is the Kuh-e-Radar area which corresponds to a fan-delta setting. The locality is very important for reconstructing of the palaeogeographic situation of the study area. It demonstrates that the present-day relationship the Binalud Mountains and Koppeh Dagh areas has not experienced extensive tectonic displacement since the Middle Jurassic times. In the Kuh-e-Radar area, pebbles and boulders (>1 m in diameter) of Mashhad granitoids rocks have fallen into the basin during the Late Bajocian to Late Bathonian without considerable lateral transport (Fig. 3.33). Such conditions point to a fault-controlled marginal setting and existence of a steep relief. At present, the nearest outcrop of the Mashhad Granite is 10-15 km further south (Fig. 9.1). This implies a rate of erosion of about 60-90 m/my, for the last 165 my ago, which is a reasonable assumption.

This means that since the Middle Jurassic, no major lateral movements could have taken place at least in the study area. Consequently, the boundary, along which rotation of the CEIM (Central East Iranian Microcontinent) has taken place, must be located further south, for instance, along the Great Kavir/Dorouneh Fault.

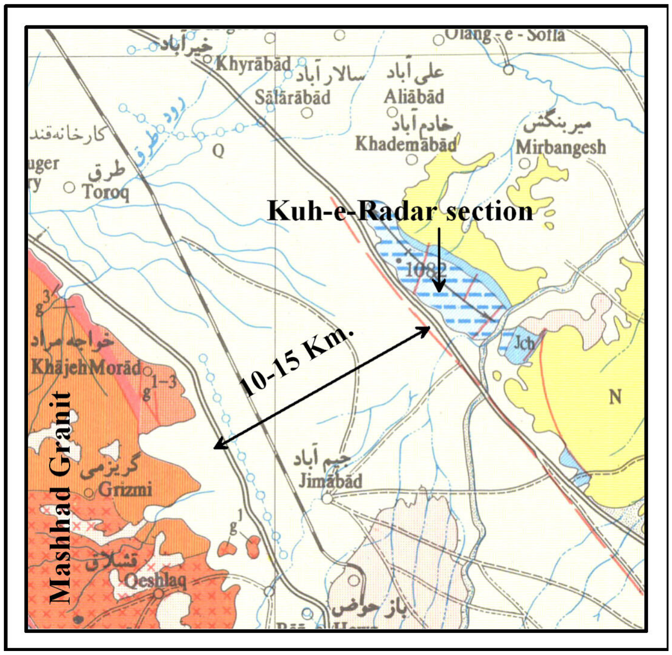



Fig. 9.1 Kuh-e-Radar section locality and outcrops of Mashhad Granite on the geological map of the area at the scale of 1:250,000.

In the Fraizi area, the basin evolved, through a short-lived delta succession, into deeper marine setting. The depth of the basin is estimated to have been several hundred meters, as debris flows are one of the main sedimentary features.

Toward NW, in the Danesh district, proximal turbidits are common, based on the dominance of sandstones and the scarcity of fine-grained background sediments.

The Maiamay area represents a typical toe-off-slope setting characterized by channel fills which cut each other in response to channel switching. Also, proximal turbidites with well developed graded bedding are present at the base of member 2. Both classic turbidites and debris flows occur in member 3 of the Maiamay section.

Basinal, fine-grained, bioturbated, dark green to black silts and greenish fine-grained sandstones, crop out in the Gas-pipline section, and also are traceable in the Kol-e-Malekabad toward the Senjedak region. Although deep-marine sediments were deposited also in the

Ghal-e-Sangi area, they are not as deep as the above mentioned localities. Storm beds are occasionally common in the middle part of Ghal-e-Sangi and the upper part of the Fraizi sections. In contrast to the Danesh section, the main character of the Ghal-e-Sangi area is a mud-dominated succesion (Fig. 9.2).

In several sections, the uppermost Kashafrud strata grade into shallow-marine, marly or carbonate rocks, belonging either to the Chamanbid or to the Mozduran Formation. Exceptions are the Jizabad and Fraizi sections, where the Kashafrud Formation is sharply overlain by limestones. Fig. 9.3 shows some of the main sections of the study area, which illustrate the lithofacies pattern and provide a raugh correlation of the strata.

The absence of mature continental shelf sediments in the study area suggests that the Kashafrud Basin had a narrow shelf which was bordered by uplifted regions in the south and east. At the same time, open-marine conbditions existed towards the north and northwest.
Thus, the Kashafrud Basin can be viewed as the eastern prolongation of the South Caspian-rift related basin further in the west (BRUNET et al., 2003; FÜRSICH et al., 2009; TAHERI et al., 2009).

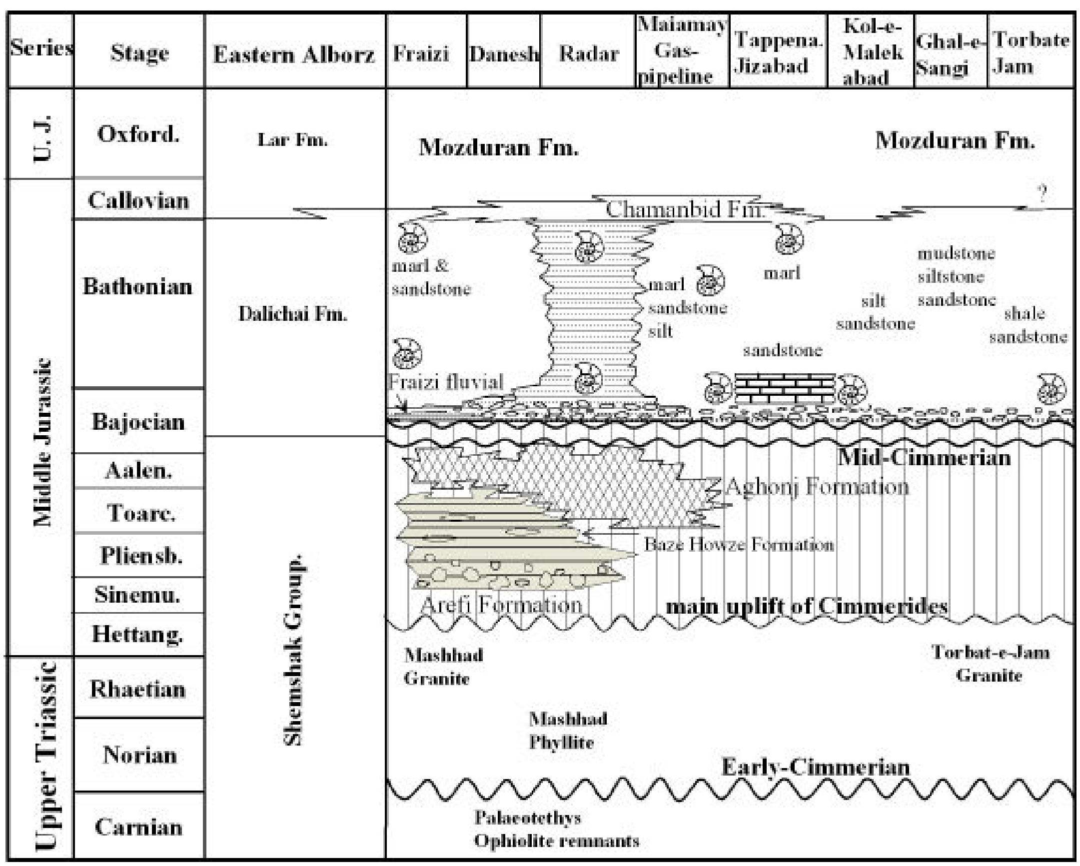



Fig. 9.2. Lithostratigraphic framework of the Kashafrud Formation based on field observations and section logging.

In view of the geographic extent of the Kashafrud Basin it seems that the NW-SE oriented basin became restricted towards the east. Age-equivalent rocks in present-day Afghanistan are represented by the non-marine, coal-bearing, siliciclastic Išpušta Formation (WOLFART & WITTEKINDT, 1980).

The marine part of the basin in Iran can be sub-divided into an eastern part (the study area) and western domains. Field observations and the absence of Kashafrud strata between SE Bojnord and West Fraizi support the idea that a palaeorelief existed along the southern margin of the basin, between the eastern and western parts, at least in southern margin of the basin.

A trace fossil analysis has been carried out to obtain additional evidence on the bathymetry of the basin. Altogether 32 ichnospecies belonging to 19 ichnogenera have been indentified. They can be grouped in the well-known Seilacherian ichnofacies. The Skolithos ichnofacies is rare and represented by low-diversity ichnocoenoses dominated by either *Diplocraterion* or vertical *Ophiomorpha*. The Cruziana ichnofacies occurs in inner to middle shelf environments and the Zoophycos ichnofacies characteristically on the slope. The Cruziana ichnofacies is also only poorly represented which may be related to the high morphological gradients and narrow shelves of the Kashafrud Basin, but at some localities this ichnofacies has been identified, for instance, in the upper part of the Ghal-e-Sangi section (member 5). There, the common trace fossils include *Rhizocorallium, Teichichnus, Thalassinoides, Ophiomorpha, Gyrochorte, Planolites,* and *Hillichnus lobosensis*.

The Nereites ichnofacies, characterized by graphoglyptids, has been found in slope to basin plain deposits. This ichnofacies is usually associated with turbidites, but is less diverse than in typical flysch basins. It consists mainly of *Nereites missouriensis, N. irregularis, N. macleayi, Helminthorhaphe* isp., and *Paleodictyon strozzii*. *Paleodictyon*, generally diagnostic of deep-sea environments, was found in the Kashafrud Basin also in comparatively shallow settings such as outer shelf and prodelta (FÜRSICH et al., 2007). This is attributed to the very high rates of sedimentation in the basin leading to enhanced preservation of traces such as graphglyptids that are produced just below the sediment-water interface. Under normal conditions, they will be easily destroyed either by subsequent bioturbation or erosional processes, which are much more common in shelf environments than in the deep sea (FÜRSICH et al., 2007).

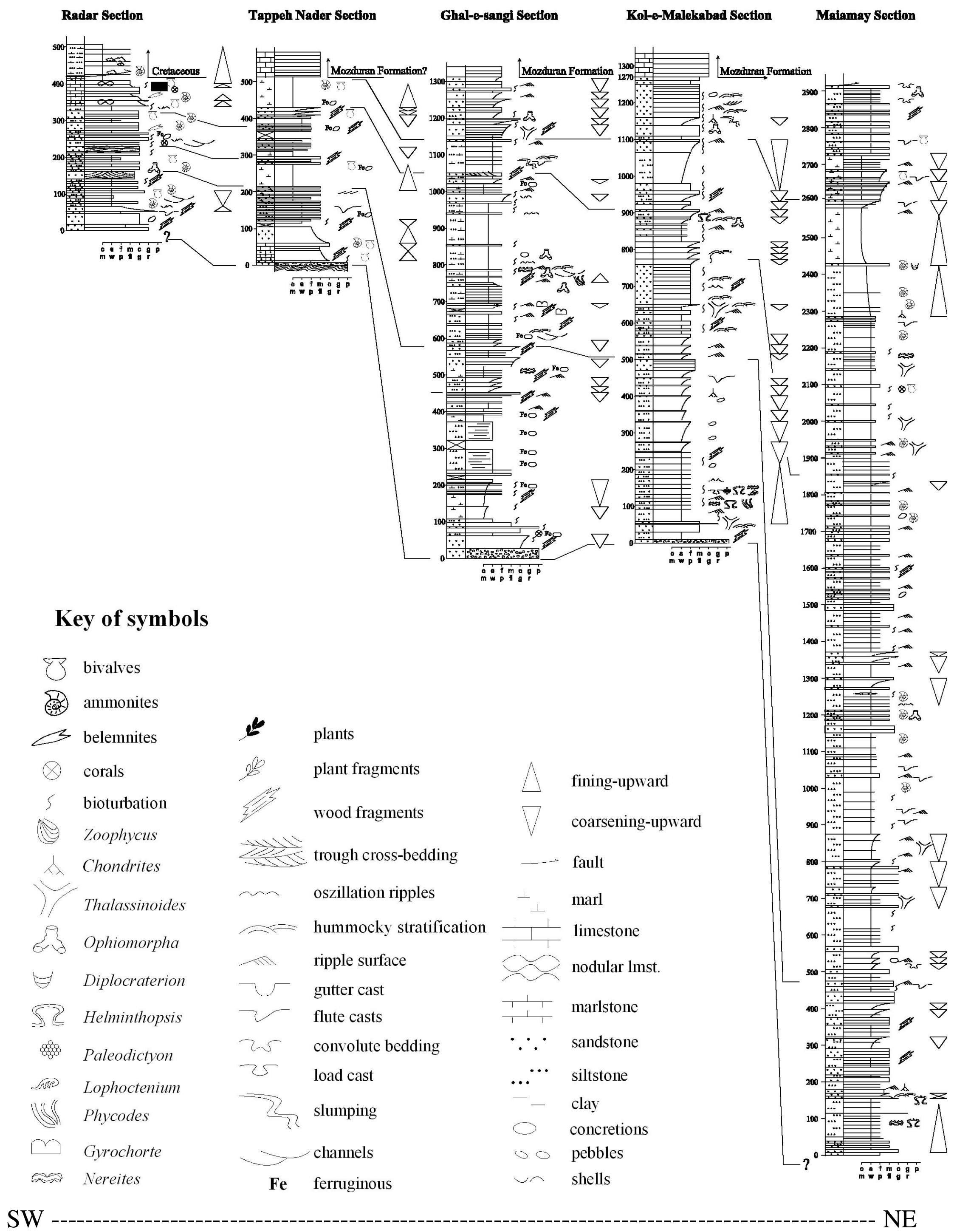



Fig. 9.3. Five sections through the Kashafrud Formation, roughly corresponding to a S-N cross-section through the basin (after Taheri et al., 2000).

For the reconstruction of the tectono-stratigraphic framework of the study area, one should recall that four separate tectonic episodes played a major role: the Early-Cimmerian, the Main Cimmerian, the Mid-Cimmerian, and the Late-Cimmerian orogenic movements. The Early

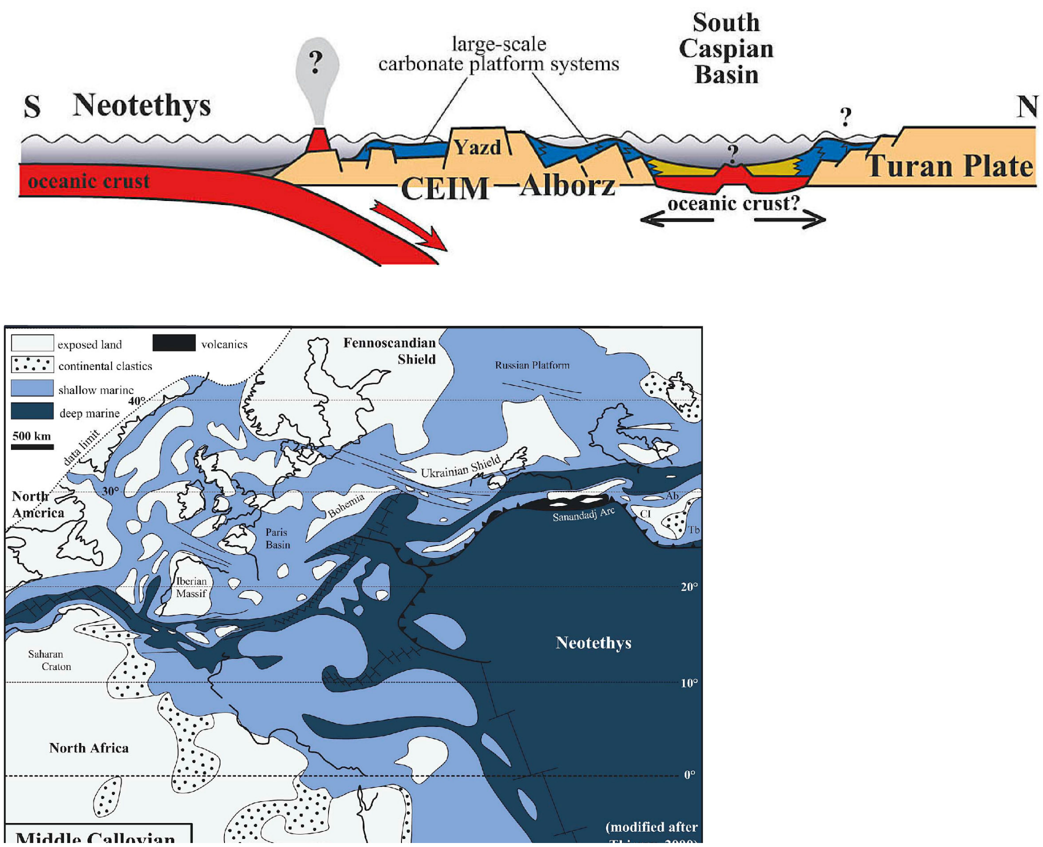
Cimmerian phase occurred during the Middle to Late Triassic (DAVOUDZADEH et al., 1981; STAMPFLI et al., 1991 SAIDI et al., 1997; WILMSEN et al., 2005) and corresponds to the collision of the Iran and Turan plates. Metamorphosis of the Mashhad Phyllite took plce during the Main Cimmerian event.

FÜRSICH et al. (2009) documented the Mid-Cimmerian tectonic event in the Alborz Mountains, and also in central Iran (FÜRSICH et al., 2003; WILMSEN et al., 2003; SEYED-EMAMI et al., 2009). They attributed the onset of sea-floor spreading within the South Caspian Basin to post Mid-Cimmerian extensional phases. In the study area, an angular unconformity is visible between the Kashafrud Formation and older rocks, mostly Permo-Triassic, or the formation overlies the Torbat-e-Jam plutone. An expression of the Late Cimmerian event around the Jurassic – Cretaceous boundary is reflected by the Shourijeh Formation (Berriasian-Barremian). This orogenic movement, which has not been as intense as the previous phases, is characterized by relatively strong vertical movements which led to widespread uplift and erosion that diminish towards the western Koppe Dagh.

All observations can be integrated into a rift basin model for the Kashafrud Basin. The basin axis ran roughly NW-SE. The stratigraphic and sedimentologic data indicate rapid subsidence and a main sediment input from the southwestern basin margin (Binalud Mountains). The northeastern basin margin is inferred to lie below the Koppe Dagh.

As mentioned before, the Kashafrud Basin developed between the Iran Plate and the southern margin of Eurasia (Turan Plate), which had been welded together during the Eo-and Main Cimmerian tectonic events. In response to the Late Bajocian-Late Bathonian crustal extension following the Mid-Cimmerian tectonic movements, the basin originated as the southeastern prolongation of the South Caspian Basin (SCB, Fig. 9.4-5), more or less opening along the Late Triassic Palaeotethys suture.

According to GOLONKA (2000), most of the former rift systems that had developed during Permian-Triassic times in the area were reactivated and new rift systems originated during the Toarcian-Aalenian (FÜRSICH et al., 2009). Although there is no consensus on the time of initiation of the South Caspian Basin, most authors believe that the rifting occurred in Jurassic time (BRUNET et al. 2003; FÜRSICH et al., 2005; 2009b). BERBERIAN (1983) even believed that the SCB could be a remnant of the Palaeotethys Ocean. GOLONKA (2000, 2004) proposed that the opening of the SCB occurred in several stages, from the Jurassic to the Eocene. For the southern part of the basin it may be as young as Miocene (EGAN et al., 2009).




b

Fig. 9.4. A. Schematic cross-section from the subduction zone of the Neotethys to the Turan Plate during the (from WILMSEN et al. 2009). B. Paleogeographic sketch of the western Neo-tethys and adjacent areas (b). From WILMSEN et al., 2009b.

KAZMIN (1991), based on data from the Talesh area, argued that the main phase of opening of the SCB occurred during the Eocene. While there is controversy regarding the timing of the opening of the basin, onshore drilling in Azerbaijan, and Turkmenistan showed a Late Jurassic to Pleistocene age of the basin fill (SHIKALIBEILY et al., 1988).

Considering that the lower 5 km of the SCB sedimentary fill is attributed to the Mesozoic, do not support the idea that this geodynamic event is younger than Jurassic, especially when we have clear evidence of a strong subsidence during the Late Bajocian to the Late Bathonian in the surrounding regions. Thus, it makes more sense to assume a multi-stage opening history of the SCB, which accelerated in stratigraphically youngerstages.

Concerning the creation of oceanic crust, ZONENSHAIN & LE PICHON (1986) studied the Black Sea and the South Caspian Basin. Based on seismic evidence and subsidence history, they concluded that the South Caspian Basin has an oceanic crust. KNAPP et al. (2000, 2004) argued that the apparent ~8-10 km thickness of the crystalline crust is consistent with an oceanic affinity for part of the SCB. Based on active seismicity down to mantle depths (80 km), and gentle deepening of that crust from the south to the north, they concluded northward subduction of the SCB lithosphere beneath the continental lithosphere of the central Caspian Basin.

With respect to probable syn-sedimentary magmatic activity in the Kashafrud Basin, geological maps of the study area at the scale of 1:250,000 and 1:100,000 have been analysed and special attention has been paid to this aspect in the field (for details see Chapter 8). A potential area is the Torbat-e-Jam, but additional studies are needed befor conclusions can be drawn. However, extention in the Kashafrud Basin was probably insufficient to lead to oceanic crust production.

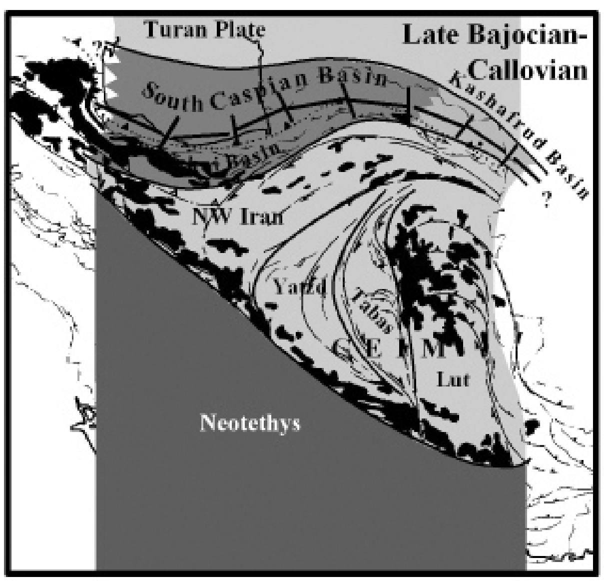



Fig. 9.5. Palaeogeographic and plate tectonic framework of the Kashafrud Basin (from TAHERI et al., 2006;).

### Suggestions for further research

1. Field observations and data analysis suggest that the Kashafrud Basin continued in a westerly direction. Outcrops exist at several localities, such as south of Bojnord and

southeast of Robate Gharabil. As the Kashafrud Formation is the source rock of a hydrocarbon reservoir, it is very important to evaluate and study these areas in detail in the future.

2. The dykes and sills north of Torbat-e-Jam deserve to be studied to reveal their tectono-magmatic setting.
3. A more detailed study of the sequence stratigraphy will help to throw further light on the basin evolution and of sea-level changes during the Late Bajocian to Late Bathonian.
4. This study provides evidence that no major lateral movements occurred between the Turan and Iran plates since the Middle Jurassic. Detailed palaeomagnetic investigations should be carried out to support this idea.

**References:**

ABEL, O. 1935. Vorzeitliche Lebensspuren. - FISCHER, J. 644pp.

AFSHAR-HARB, A. 1970. Geology of Sarakhs area and Khangiran Gas Field. - Geological Division, National Iranian Oil Co., Tehran.

AFSHAR-HARB, A. 1979. The stratigraphy and petroleum geology of Kopeh Dagh region, northern Iran. - 316 pp., Petroleum Geology Section. Royal School of Mines, Imperial College, London.

AFSHAR-HARB, A. 1983. Sarakhs geological sheet, in scale of 1:250,000. - National Iranian Oil Company, Tehran, Iran.

AFSHAR-HARB, A. 1994. The Geology of the Koppe-Dagh. - 275 pp. Geological Survey of Iran (in Farsi).

AGHANABATI, A. 1986. Geological map of Mashhad in scale of 1:250,000. - Geological Survey of Iran, Tehran.

AGHANABATI, A. 1998. Jurassic stratigraphy of Iran. Vls. 1-2: 746 pp., Tehran (Geological Survey of Iran.) (in Farsi).

AGHANABATI, A. 2004. Geology of Iran. - 586 pp., Tehran (Geological Survey of Iran.) (In Farsi).

AKRAMI, M. A. 2008. Geological map of Paye sheet, in scale of 1: 25,000, Geological Survey of Iran, NE Territory, Mashhad.

ALAVI, M. 1979. The Virani ophiolite complex and surrounding rocks. - Geologische Rundschau **68**: 334-341.

ALAVI, M. 1991. Sedimentary and structural characteristics of the Paleo-Tethys remnants in northeastern Iran. – Geological Society of America Bulletin **103**: 983-992.

ALAVI, M., VAZIRI, H., SEYED EMAMI, K. & LASEMI, Y. 1997. The Triassic and associated rocks of the Nakhlak and Aghdarbabd areas in central and northeastern Iran as remnants of the southern Turanian active continental margin. - Geological Society of America Bulletin **109:** 1563-1575.

ALBERTI, A., NICOLETTI, M. & PETRUCCIAN, C. 1973. K/Ar ages of micas of Mashhad granites (Khorasan, north-east Iran). – Priodico di Mineralogia **42**: 483-493.

ALBERTI, M. & MOAZEZ-LESCO, Z. 1974. Plutonic and metamorphic rocks of the Mashhad area (Khorasan, north-eastern Iran). – Bullettino Della Societa. Geologica **93**: 1157-1196.

ALPERT, S. P. 1975. Planolites and Skolithos from the Upper Precambrian-lower Cambrian, White-Inyo Mountains, California. - Journal of Paleontology **49**: 508-521.

BAUD, A. & STAMPFLI, G. 1989. Tectonogenesis and evolution of a segment of the Cimmerides: the volcano-sedimentary Triassic of Aghdarban (Kopet-Dagh, North-East Iran). In: SENGÖR, A. M. C. (ed.) *Tectonic Evolution of the Tethyan region,* Kluwer, 265–275.

BAUD, A., STAMPFLI, G. & STEEN, D. 1991. The Triassic Aghdarband Group: volcanism and geological evolution. – In: RUTTNER, A.W. (Ed.). The Triassic of Aghdarband (Aqdarband), NE-Iran, and its pre-Triassic frame. Abhandlungen der Geologischen Bundes-Anstalt in Wien **38**: 111-123.

BENTON, M. J. 1982. Trace fossils from lower Palaeozoic ocean-floor sediments of the Southern Uplands of Scotland. – Transactions of the Royal Society of Edingburgh, Earth Sciences **73**: 67-87.

BERBERIAN, M. 1983. the Southern Caspian: a compressional depression floored by a trapped , modified oceanic crust. – Canadian Journal of Earth Sciences **20**: 163-183.

BOLURIAN, G. & JAFARI, M. 2008. Geological map of Deh Ghaibi, at scale of 1:25,000. – Geological Survey of Iran, NE territory, Mashhad.

BOUMA, A. H. 1985. Introduction to submarine fans and related turbidite systems, p. 3-5. – In:Bouma, A. H., Normark, W. R. & Barnes, N. E. Submarine fans and related turbidite systems. – 351 pp., Berlin (Springer).

BOUMA, A. H. 2000. Coarse-grained and fine-grained turbidite systems as end member models: applicability and dangers. - Marine and Petroleum Geology **17**: 137-143.

BOUMA, A. H. 2000. Fine-grainedm mud-rich turbidite systems: Model and comparison with coarse-grained, sand-rich systems, p. 9-21. In: Bouma, A. H. & Stone, C. G. (Eds.) Fine-grained turbidits systems, 342 pp. American Association of Petroleum Geologists, Memoir 72; Society for Sedimentary Geology, SEPM Special Publication 68.

BOURGEOIS, J. & LEITHOLD, E. L. 1984. Wave-worked conglomerates - Depositional processes and criteria for recognition. - In KOSTER, E. H. & STEEL, R. J. (Eds.) Sedimentology of gravels and conglomerates. - Canadian Society of Petroleum Geologists, Memoir **10**: 331-343.

BOYER, P. S. 1979. Trace fossils *Biformites* and *Fustiglyphus* from the Jurassic of New Jersey. – Bulletin, New Jersey Academy of Science **24**: 73-77.

BRADLY, L. F. 1947. Invertebrate tracks from the Coconino sandstone of Northern Arizona. – Journal of Paleontology 21: 466-472.

BROMLEY, R. G. & EKDALE, A. A. 1984. *Chondrites*: A trace fossil indicator of anoxia in sediments. - Science **224**: 872-874.

BROMLEY, R. G. & EKDALE, A. A. 1998. *Ophiomorpha irregulaire* (trace fossil): redescription from the Cretaceous of the Book Cliffs and Wasatch Plateau, Utah. – Journal of Paleontology **72**: 773-778.

BROMLEY, R. G. & FREY, R. W. 1974. Redescription of the trace fossil *Gyrolithes* and taxonomic evaluation of *Thalassinoides*, *Ophiomorpha* and *Spongeliomorpha.* Bulletin of the Geological Society of Denmark **23**: 311-335.

BROMLEY, R. G. UCHMAN, A. MURRAY R. GREGORY, M. R. & MARTIN, A. J. 2003. *Hillichnus lobosensis* igen. et isp. nov., a complex trace fossil produced by tellinacean bivalves, Paleocene, Monterey, California, USA. - Palaeogeography, Palaeoclimatology, Palaeoecology **192**: 157- 186.

BRONGNIART, A. T. 1823. Observations sur les Fucoids. – Sociéte d'Historie Naturlle de Paris, Mémoire **1**: 301-320.

BRONGNIART, A. T. 1828. Historie des végétaux fossiles: ou recherches botaniques et géologiques les végétaux renfermés dans les diverse couches du Globe. - 2 volums, Paris.

BRUNET M. F., KOROTAEV, M. V., ERSHOV, A. V. & NIKISHIN, A. M. 2003. The South Caspian Basin: a review of its evolution from subsidence modelling. – Sedimentary Geology **156**: 119-148.

BRUNET M .F., SHAHIDI A., BARRIER, E., MULLER, C. & SAIDI, A. 2006. Geodynamic evolution of northern Iran in connection with the South Caspian Basin origin. Contribution from subsidence analysis. – MEBE Colloquium **4.-5**: 53-54, Milano.

BRUNET M .F., SHAHIDI A., BARRIER, E., MULLER, C. & SAIDI, A. 2007. Geodynamics of the South Caspian Basin southern margin now inverted in Alborz and Koppet-Dagh (Northern Iran). - Geophysical Research Abstracts, European Geosciences Union, Vienna. **9**: 08080.

BUATOIS, L. A., MANGANO, M. G., MIKULAS, R. & MAPLES, C. G. 1998. The ichnogenus *Curvolithus* revisitd. - Journal of Paleontology **72**: 758-769.

BUATOIS, L. A., NETTO, R. G., MANGANO, M. G. & BALISTIERI, R. M. 2006. Extreme freshwater release during the late Paleozoic Gondwana deglaciation and its impact on coastal ecosystems. – Geology **34**: 1021-1024.

BURKE, K. 1972. Longshore drift, submarine canyons, and submarine fans in development of Niger Delta. - The American Association of Petroleum Geologists Bulletin 56: 1975-1983.

CATUNEANU, O., 2006, Principles of Sequence Stratigraphy: Elsevier Science Ltd., Amsterdam, 375 pp.

CHAMBERLAIN, C. K. 1971. Morphology and ethology of trace fossils from the Ouachita Mountains, southeast Oklahoma. - Journal of Paleontology **45**: 212-246.

CHAMBERLAIN, C. K. & CLARCK, D. L. 1973. Trace fossils and conodonts as evidence for deep-water deposits in the Oquirrh Basin of central Utah. - Journal of Paleontology **47**: 663-682.

CHAMBERLAIN C. K. & BAER, J. L. 1973. *Ophiomorpha* and a new thalassinoid burrow from the Permian of Utah.

COE, A. L. & CHURCH, K. D. 2003. Sequence stratigraphy and sea-level change. – IN: COE, A. L., BOSENCE, D. W. J., CHURCH, K. D., FLINT, S. S., HOWELL, J. A. & WILSON, R. C. L. (Eds.) 2003. The sedimentary record of sea-level change. - 288 pp., Cambridge (Cambridge University Press).

COLLINSON, J. D. 1996. Alluvial sediments. – In: Reading, H. J (Ed.) Sedimentary Environments: processes, facies and stratigraphy: 37-81, Oxford ( Blackwell Science), (3rd ed.)

CONKIN, J. E. & CONKIN, B. M. 1968. *Scalarituba missouriensis* and its stratigraphic distribution. - University of Kansas, Paleontological Contributions **79**: 221-248.

CRIMES, T. P. 1973. From limestone to distal turbidites: a facies and trace fossil analysis in the Zumaya flysch (Paleocene-Eocene), north Spain. - Sedimentology **20**: 105-131.

CRIMES, T. P. 1977. Trace fossils of an Eocene deep-sea fan, northern Spain. - In: CRIMES, T. P. & HARPER, J. C. (Eds.) Trace fossils 2. - Geological Journal, Special Issue **9**: 71-90.

CRIMES, T. P. & CROSSLEY, J. D. 1980. Inter-turbidite bottom current orientation from trace fossils with an example from the Silurian flysch of Wales. - Journal of Sedimentary Petrology **50**: 821-830.

CRIMES, T. P. & GERMES, G. J. B. 1982. Trace fossils from the Nama Group (Precambrian-Cambrian) of southwest Africa (Namibia). - Journal of Paleontology **56**: 890-907.

CRIMES, T. P., GOLDRING, R., HOMEWOOD, P., STUIJVENBERG, J. V. & WINKLER, W. 1981. Trace fossil assemblages of deep-sea fan deposites, Gurnigel and Schlieren flysch (Cretaceous-Eocene), Switzerland. - Eclogae Geologicae Helvetiae **74**: 953-995.

CRIMES, T. P., GARCIA, HIDAI, J. E. & POIRE, D. G. 1992. Trace fossils from Arenig flysch sediments of Eire and their bearing on the early colonisation of the deep seas. - Ichnos **2**: 61-77.

D'ALESSANDRO & BROMLEY, 1987. Meniscate trace fossils and the *Muensteria-Taenidium* problem. - Palaeontology **30**: 743-763.

DAVOUDZADEH, M., SOFFEL, H. C. & SCHMIDT, K. 1981. On the rotation of the Central-East-Iran Microplate. - Neues Jahrbuch für Geologie und Paläontologie, Monatshefte **1981**: 180-192.

DAVOUDZADEH, M. & SCHMIDT, K. 1984. Contribution to the palaeogeography and stratigraphy of the Middle and Upper Jurassic of Iran. - Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen **168**: 182-207.

DE GIBERT, J. M. & EKDALE, A. A. 1999. Trace fossil assemblages reflecting stressed environments in the middle Jurassic Carmel seaway of central Utah. - Journal of Paleontology **73**: 711-720.

DE' GIBERT, J. M. & EKDALE, A. A. 2002. Ichnology of a restricted epicontinental sea, Arapien Shale, Middle Jurassic, Utah, USA. - Palaeogeography, Palaeoclimatology, Palaeoecology **183**: 275- 283.

DE GIBERT, J. M. & MARTINELL, J. 1998. Ichnofabric analysis of the Pliocene marine sediments of the Var Basin (Nice, SE France). - Geobios **31**: 271-281.

DE GIBERT, J. M, NETTO, R. G., TOGNOLI, F. M. W., & GRANGEIRO, M. E. 2006. Commensal worm traces and possible juvenile thalassinoidean burrows associated with *Ophiomorpha nodosa*, Pleistocene, southern Brazil. - Palaeogeography, Palaeoclimatology, Palaeoecology **230**: 70-84.

DEH BOZORGI, A. 2004. Palinostratigraphy of Kashafrud Formation in Senjedak section, SE Mashhad (NE Iran). - Unpublished M.Sc thesis, University of Tehran (in Farsi).

DIKE, E. F. 1972. *Ophiomorpha nodosa* LUNDGREN: Environmental implications in the Lower Greensand of the Isle of Wight. - Proceedings of the Geologists Association **83**: 165-177.

DELGADO, J. F. N. 1910. Terrains paléozoiques du Portugal, Étude sur les fossils des schistes à néréites de San Domonogos et des schistes à néréites et à graptolites de Barrancos. – Comission du Service Géologique du Portugal 56: 1-68.

EAGAR, R. M. C., BAINES, J. G., COLLINSON, J. D., HARDY, P. G., OKOLO, S. A. & POLLARD, J. E. 1985. Trace fossil assemblages and their occurrence in Silesian (Mid-Carboniferous) deltaic sediments of the central Pennine Basin, England. - In: CURRAN, H. A (Ed.) Biogenic structures; their use in interpreting depositional environments. Society of Economic Paleontologists and Mineralogists, Special Publication **35**: 99-149.

EFTEKHAR-NEZHAD, J. & BEHROOZI, A. 1989. Geological map of Torbat-e-Jam sheet, at scale of 1:250,000. - Geological Survey of Iran, Tehran.

EFTEKHAR-NEZHAD, J. & BEHROOZI, A. 1991. Geodynamic significance of recent discoveries of ophiolites and Late Paleozoic rocks in NE-Iran (including Koppe Dagh). – In: RUTTNER, A.W. (Ed.). The Triassic of Aghdarband (Aqdarband), NE-Iran, and its pre-Triassic frame. Abhandlungen der Geologischen Bundes-Anstalt in Wien **38**: 89-100.

EFTEKHAR-NEZHAD & BEHROOZI, A. 1993. Geological Quadrangle map of Torbat-e-Jam (scale 1:250,000). - Geological Survey of Iran, Tehran.

EGAN, STUART S., MOSAR, J. & BRUNET, M. F. 2009. Subsidence and uplift mechanisms within the South Caspian Basin: insight from the onshore and offshore Azerbaijan region. - In: BRUNET, M. F., WILMSEN, M. & GRANATH, J. W. (Eds.) South Caspian to Central Iran basins. - Geological Society London, Special Publications **312**: 219-240.

EHRENBERG, K. 1944. Ergänzende Bemerkungen zu den seinerzeit aus dem Miozän von Burgschleinitz beschrieben Gangkernen und Bauten dekapoder Krebse. – Paläontologische Zeitschrift **23**: 345-359.

EICHWALD, E. 1868. Lethaea Rossica ou paleontologie de la Russie. – Décrite et figure, Vol. **1**.

EINSELE, G. 1999. Event Stratigraphy: Recognition and interpretation of sedimentary event horizobns. - In: DOYLE, P. & BENNETT M. R (Eds.) Unlocking the stratigraphical record: Advances in Modern Stratigraphy: 145-193, Chichester (John Wiley & Sons)

EINSELE, G. 2000. Sedimentary Basins: Evolution, facies, and sediment budget. – 628 pp., 2nd edition, Berlin (Springer).

EISERHARDT, K. H., KOCH, L. & EISERHARDT, W. L. 2001. Revision of the ichnotaxon *Tomaculum* GROOM, 1902. - Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen **221**: 325-358.

ELLIOTT, T. 1989. Deltaic systems and their contribution to an understanding of basin-fill successions. – In: WHATELEY, M. K. G. & PICKERING, K. T. (Eds.). Deltas: Sites and Traps for Fossil Fuels. - Geological Society London, Special Publications **41**: 3-10.

ENOS, P. 1977. Flow regimes in debris flow. - Sedimentology **24**: 133-142.

EKDALE, A. A. 1980. Graphoglyptid burrows in modern deep-sea sediments. – Science **207**: 304-306.

EKDALE, A. A. 1985. Trace fossils and Mid-Cretaceous anoxic events in the Atlantic Ocean. – In: CURRAN, H. A. (Ed.) Biogenic Structures: their use in interpreting depositional environments - Society of Economic Paleontologists and Mineralogists, Special Publication **35**: 333-342.

EKDALE, A. A. 1988. Pitfalls of paleobathymetric interpretations based on trace fossil assemblages. – Palaios **3:** 464-472.

EKDALE, A. A. & BROMLEY, R. G. 2001. A day and a night in the life of a cleft-foot clam: *Protovirgularia-Lockeia-Lophoctenium*.- Lethaia **34**: 119-124.

EKDALE, A. A. & BROMLEY R. G. 2003. Paleoethologic interpretation of complex *Thalassinoides* in shallow-marine limestone, Lower Ordovician, southern Sweden. Palaeogeography, Palaeoclimatology - Palaeoecology **192**: 221-227.

EKDALE, A. A. & LAMOND, R. E. 2003. Behavioral cladistics of trace fossils: evolution of derived trace-making skills. - Palaeogeography, Palaeoclimatology Palaeoecology **192**: 335-343.

EKDALE, A. A. & LEWIS, D. W. 1991. Trace fossils and paleoenvironmental control of ichnofacies in a late Quaternary gravel and loess fan delta complex, New Zealand. – Geology **16**: 720-723.

EMMONS, E. 1844. The Taconic System; based on observations in New York, Massachusetts, Maine, Vermont, and Rhode Island 68 pp., Caroll & Cook, printers (Albany).

ENOS, P. 1977. Flow regimes in debris flow. - Sedimentology **24**: 133-142.

ETTER, W. 1996. Pseudoplanktonic and benthic invertebrates in the Middle Jurassic Ppalinum Clay, northern Switzerland. - Palaeogeography, Palaeoclimatology, Palaeoecology **126**: 325-341.

FILLION, D. & PICKERILL, R. K. 1990. Ichnology of the Upper Cambrian? to Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland, Canada. – Palaeontolographica Canadiana **7**: 1-119.

FISHER W. L. & MCGOWAN J. H. 1969. Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: Gulf Coast - The American Association of Petroleum Geologists, Bulletin **53**: 30-54.

FRAIZI KERMANI, M. 2001. Palynostratigraphy of the Middle-Upper Jurassic strata in the Fraizi section, NW Mashhad, Unpublished M.Sc. thesis, Geosciences Research Institute, GSI, Tehran (in Farsi).

FREY, R. W. & HOWARD, J. D. 1970. Comparison of Upper Cretaceous ichnofaunas from siliceous sandstones and chalk, western Interior Region, U.S.A. - In: CRIMES, T. P. & HARPER, J. C. (Eds.), Trace fossils. - Geological Journal, Special Issue No. **3**: 141-166.

FREY, R. W., HOWARD, J. D. & Pryor, W. A. 1978**.** *Ophiomorpha*: its morphologic, taxonomic, and environmental significance. - Palaeogeography, Palaeoclimatology, Palaeoecology **23**: 199-229.

FREY, R. W. & PEMBERTON, S. G. 1985. Biogenic structures in outcrops and cores. I. Approaches to ichnology. – Bulletin of Canadian Petroleum Geology **33**: 72-115.

FREY, R. W. 1990. Trace fossils and hummockyc ross-stratification, Up-per Cretaceous of Utah. Palaios. - **5**: 203-218.

FREY, R. W. & HOWARD, J. D. 1990. Trace fossils and depositional sequences in a clastic shelf setting, Upper Cretaceous of Utah. - Journal of Paleontology **64**:803-820.

FRITSCH, A. 1908. Problematica Silurica. – In: Barrande, J. (Ed.), Systeme Silurien du Centre de la Boheme. - 28p. Prague.

FU, S. 1991. Funktion, Verhalten und Einteilung fucoider und lophocteniider Lebensspuren. - Courier Forschungsinstitut Senckenberg **135**: 1-79.

FÜRSICH, F. T. 1973. A revision of the trace fossils *Spongliomorpha, Ophiomorpha* and *Thalassinoides*. - Neues Jahrbuch für Geologie und Päleontologie Monatshelte 1973: 719-735.

FÜRSICH, F. T. 1973. *Thalassinoides* and the origin of nodular limestone in the Corallian Beds (Upper Jurassic) of southern England. - Neues Jahrbuch für Geologie und Paläontologie Abhandlungen **140**:136-156.

FÜRSICH, F. T. 1974. Corallian (Upper Jurassic) trace fossils from England and Normandy. – Stuttgarter Beiträge zur Naturkunde Serie. B, Nr. **13**: 1-52.

FÜRSICH, F. T. 1998. Environmental distribution of trace fossils in the Jurassic of Kachchh (western India). - Facies **39**: 243-272.

FÜRSICH, F. T. & HEINBERG, C. 1983. Sedimentology, biostratigraphy, and palaeoecology of an upper Jurassic offshore sand bar complex. - Bulletin of the Geological Society of Denmark **32**: 67-95.

FÜRSICH, F. T., WILMSEN, M., SEYED-EMAMI, K., SCHAIRER, G. & MAJIDIFARD, M. R. 2003. Platform-basin transect of a Middle to Late Jurassic large-scale carbonate platform system (Shotori Mountains, Tabas Area, East-Central Iran). – Facies **48**: 171-198.

FÜRSICH, F. T., WILMSEN, M., SEYED-EMAMI, K. & MAJIDIFARD, M. R. 2005. The Upper Shemshak Formation (Toarcian-Aalenian) of the eastern Alborz (Iran): Biota and palaeoenvironmens during a transgressive-regressive cycle. - Facies **51**: 365-384.

FÜRSICH, F. T., TAHERI, J. & WILMSEN, M. 2007. New occurrences of the trace fossil *Paleodictyon* in shallow marine environments: Examples from the Triassic-Jurassic of Iran. – Palaios **22**: 424-432.

FÜRSICH, F. T., WILMSEN, M., SEYED-EMAMI, K. & MAJIDIFARD, M. R. 2009. The Mid-Cimmerian tectonic event (Bajocian) in the Alborz Mountains, Northern Iran: evidence of the break-up unconformity of the South Caspian Basin. – In: BRUNET, M. F., WILMSEN, M. & GRANATH, J. W. (Eds.) South Caspian to Central Iran basins. - Geological Society London, Special Publications **312**: 189-203.

GAILLARD, C. 1991. Recent organism traces and ichnofacies on the deep-sea floor of New Caledonia, southwestern Pacific. – Palaios **6**: 302-315.

GAILLARD, C., HENNEBERT, M. & OLIVERO, D. 1999. Lower Carboniferous *Zoophycos* from the Tournai area (Belgium): Environmental and ethologic significance. – Geobios **32**: 513-524.

GALLOWAY, W. E., 1998. Depositional processes, regime variables, and development of siliciclastic stratigraphic sequences. – In: GRADSTEIN, F. M., SANDVIK, K, D., & MILTON, N. J. (EDS.) Sequence stratigraphy, concepts and applications. - Amsterdam, Elsevier Science B.V., Norwegian Petroleum Society (NPF), NPF Special Publication **8**: 117–140.

GHAEMI, F. 1999. Geological map of Sefid Sang in scale of 1: 100,000. - Gelogical Survey of Iran, NE Territory, Mashhad.

GHAZI, A., M., HASSANIPAK, A, M., TUCKER, P. J., MOBASHER, K. & DUNCAN, R. A. 2001. Geochemistry and 40Ar-39Ar ages of the Mashhad Ophiolite, NE Iran: A rare occurrence of a 300 Ma (Paleo-Tethys) Oceanic Crust. – American Geophysical Union, Fall Meeting, abstract. #V12C-0993.

GHAZI, M., HASSANIPAK, A. & BABAIE, H. 2003. Paleo- and Neo-Tethyan ophiolites of Iran: a progress report. - EGS –AGU - EUG Joint Assembly, Abstracts from the meeting held in Nice, France 6-11.

GOLDSCHMID, K.T. 1956. Report on the coal deposit of Aghdarband. – National Iranian Oil Company (unpublished).

GOLDRING, R. & POLLARD, J.E. 1995. A re-evaluation of *Ophiomorpha* burrows in the Western Group (Lower Cretaceous) of southern England. Cretaceous Research **16**: 665-680.

GOLONKA, J. 2000. Pangean (Late Carboniferous-Middle Jurassic) paleoenvironment and lithofacies. - Palaeogeography, Palaeoclimatology, Palaeoecology **161**: 49-69.

GOLONKA, J. 2004. Plate tectonic of the southern margin of Eurasia in the Mesozoic and Cenozoic. – Tectonophysics **381**: 235-273.

GROOM, T. 1902. The sequence of the Cambrian and associated beds of the Malvern Hills. – Geological Society London Quart. Journal **17**: 8-10.

Gümbel, C. W. 1879. Geognostische Beschreibung des Fichtelgebriges mit dem Frankenwalde und dem westlichen Vorlande. – **3**: 698 p.

HADDAD-TAVAKOLI, E. 2005. Palynostratigraphy of Kashafrud Formation in Ghal-e-Sangi section, east Mashhad (NE Iran). - Unpublished M.Sc. thesis, University of Tehran (in Farsi).

HAKES, W. G. 1985. Trace fossils from brackish-marine shales, upper Pennsylvanian of Kansas,U.S.A. - In: Curran, H. A. (Ed.) Biogenic Structures: their use in interpreting depositional environments. - Society of Economic Paleontologists and Mineralogists, Special Publication **35**: 21-36.

HALL, J. 1847. Paleontology of New York. Vol. 1: 362 pp., C. Albany (Van Benthuysen).

HALL, J. 1852. Containing descriptions and figures of the organic remains of the lower Helderberg Group and the Oriskany sandstone. – New York geological Survey, Natural History. Memorial **16**: 670 pp.

HALLAM, H. 1970. *Gyrochorte* and other trace fossils in the Forest Marble (Bathonian) of Dorset, England. – In: CRIMES, T. P. & HARPER, J. C. Trace fossils (Eds.). Geological Journal, Special Issue **3**: 189-200.

HALLAM, A. 1978. Eustatic cycles in the Jurassic Palaeogeography, Palaeoclimatology, Palaeoecology. **23**: 1-32.

HALLAM, A. 1992. Phanerozoic sea-level changes. - 266 pp., NewYork (Columbia University Press).

HALLAM, A. 2001. A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of current knowledge. - Palaeogeography, Palaeoclimatology, Palaeoecology. **167**: 23-37.

HAN, Y. & PICKERILL, R. K. 1994. Taxonomic reassessment of *Protovirgularia* M'COY 1850 with new examples from the Paleozoic of New Brunswick, eastern Canada. - Ichnos **3**: 203-212.

HAN, Y. & PICKERILL, R. K. 1995. Taxonomic review of the ichnogenus *Helminthopsis* HEER 1877 with a statistic analysis of selected ichnospecies. - Ichnos **4**: 83-118.

HÄNTZSCHEL, W. 1958. Oktokoralle oder Lebensspur ? - Geologisches Staatsinstitut in Hamburg, Mitteilungen **27**: 77-87.

HÄNTZSCHEL, W. 1970. Star-like trace fossils. In: CRIMES, T. P. & HARPER, J. C. (Eds.) Trace fossils Geological Journal, Special Issues **3**: 201-214.

HÄNTZSCHEL, W. 1975. Trace fossils and problematica. – In: Teichert, C. Treatise on Invertebrate Paleontology. Part W, Miscellanea, Supplement 1 Trace fossils and problematica (second edition). – Geological Society of America, Inc. and the University of Kansas.

HAQ, B., HARDENBOL, U. J. &. VAIL, P.R. 1987. Chronology of Fluctuating Sea Levels since the Triassic (250 m ys. ago to presnt). - Science **235**: 1156-1167.

HAQ, B.; HARDENBOL, J. & VAIL, P.R. 1988. Mesozoic and Cenozoic Chronostratigraphy and Eustatic Cycles. - In: WILGUS, et al, (Eds.) Sea-Level changes: an integrated approach. - SEPM, Special Publication **42**: 71-108.

HECKER, R. T. 1970. Palaeoichnological research in the Palaeontological Institute of the Academy of Sciences of the USSR. In: CRIMES, T. P. & HARPER, J. C. (Eds.) Trace fossils. - Geological Journal, Special Issue No. **3:** 215-226.

HEER, O. 1865. Die Urwelt der Schweiz. - 622 pp., F. Schulthess (Zürich).

HEER, O. 1865. Flora fossils Helvetiae. – Die vorweltliche flora der Schweiz 182: p. 70, J. Würster & Co. (Zürich).

HEER, O. 1877. Flora fossils Helvetiae. – Vorweltliche Flora der Schweiz 182 pp., Zürich (J. Wurster & Comp.).

HEINBERG, C. 1970. Some Jurassic trace fossils from Jameson Land. - Geological Journal, Special Issue **3**: 227-234.

HEINBERG, C. 1973. The internal structure of the trace fossils *Gyrochorte* and *Curvolithus*. - Lethaia **6**: 227-238.

HEINBERG, C. & BIRKELUND, T. 1984. Trace-fossil assemblage and basin evolution of the Vardekloft Formation (Middle Jurassic, central east Greenland). - Journal of Paleontology **58**: 362-397.

HOSAINIUN, M. 1996. Biostratigraphy and sedimentology of Kashafrud Formation in east and southeast Koppe-Dagh regions, Unpublished M.Sc. thesis, University of Tehran (in Farsi).

HOWARD, J. D. & FREY, R. W. 1984. Characteristic trace fossils in nearshore to offshore sequence, Upper Cretaceous of east-central Utah. - Canadian Journal of Earth Sciences **21**: 200-219.

HOWELL, B. F. 1943. Burrows of Skolithos and Planolites in the Cambrian Hardyston sandstone at Reading, Pennsylvania. - Bulletin of the Wagner Free Institute of Sciences of Philadelphia.3: 3-33.

HUBER, H. 1968. Tectonic map of the Kopet Dagh and surrounding areas, !: 1,000,000. – internation Tectonic Maps of Europe, the Near and Middle East, Baku, 1968.

HUBER, H. (Compiler) 1976. Geological map and section of Iran (Sheet No. 3).Geological map of north-east of Iran. Exploration and Production, National Iranian Oil Company (NIOC), Tehran.

INGERSOLL, R. V. & BUSBY, C. J. 1995. Tectonics of sedimentary basins, p.1-51. - In: BUSBY, C. J. & INGERSOLL, R. V. (Eds.) Tectonics of Sedimentary Basins: 1-51, Berlin (Blackwell Science).

IRANMANESH J. & SETHNA S.F. 1998. Petrography and geochemistry of the Mesozoic granite at Mashhad, Khorasan Province, northeastern part of Iran. - Journal of the Geological Society of India, 52: 87-94.

JAMES, J. F. 1885. The Fucoids of the Cincinnatian Group. – Journal of Cincinnati Society of Natural History **7**: 124-132.

JENNY, J. 1981. Geologie et stratigraphie de l'Elbourz oriental entre Aliabad et Shahrud, Iran. Geology and stratigraphy of the eastern Elburz between Aliabad and Shahrud, Iran. - Universite de Geneve, Geneva, Switzerland.

KALANTARI, A. 1969. Foraminifera from the Middle Jurassic-Cretaceous successions of Kopet-Dagh region (NE Iran). - Publication of the NIOC Geological Laboratories **3**: 1-298.

KARIMPOUR, M. H., FARMER, L., ASHOURI, A. & SAADAT, S. 2006. Major, trace and REE geochemistry of Paleo-Tethys collision-related granitoids from Mashhad, Iran. – Journal of Sciences, Islamic Republic of Iran. **17**: 127-145.

KAZMIN, V. G. 1991. Collision and rifting history of the Tethys Ocean. - Geotectonics **23**: 391-399.

KEIGHLEY, D. G. & PICKERILL, R. K. 1994. The ichnogenus *Beaconites* and its distinction from *Ancoriconus* and *Taenidium*. - Palaeontology **37**: 305-337.

KEIJ, A. J. 1965. Miocene trace fossils from Borneo. - Palaontologische Zeitschrift **39**:220-228.

KENNEDY, W.J. & SELLWOOD, B.W. 1970. *Ophiomorpha nodosa* LUNDGREN, a marine indicator from the Sparnacian of south-east England. - Proceeding of the Geologists' Association **81**: 99-11.

KENNEDY, W. J. 1970. Trace fossils in the Chalk environment. In: CRIMES, T. P. & HARPER, J. C (Eds.) Trace fossils. - Geological Journal, Special Issues No. **3**: 263-282.

KERN, J. P. 1977. Trails from the Vienna Woods: paleoenvironments and trace fossils of Cretaceous to Eocene flysch, Vienna, Austria. - Palaeogeography, Palaeoclimatology, Palaeoecology **23**: 231-262.

KHATOONI MOLLAYOUSEFI, M. 2000. Study of plant fossil and stratigraphy of the Shemshak Formation at Shandiz area (NW Mashhad). Unpublished M.Sc. thesis, Mashhad Ferdowsi University (in Farsi).

KNAPP, J. H., DIACONESCU, C. C., MCBRIDE, J. A. & SIMMONS, M. D. 2000. Deep seismic exploration of the South Caspian Basin: lithosphere-scale imaging of the world's deepest basin. - AAPG's Inaugural Regional International Conference July 9-12 Istanbul, Turkey. Official Program book: 35-37, Tulsa, Ok.

KNAPP, C. C., KNAPP, J. H. & CONNOR, J. A. 2004. Crustal-scale of the South Caspian revealed by deep seismic reflection profiling. - Marine and Petroleum Geology **21:** 1073-1081.

KSIAŻKIEWICZ, M. 1970. Observations on the ichnofauna of the Polish Carpathians. - In: CRIMES, T. P. & HARPER, J. C. (Eds.) Trace fossils. - Geological Journal, Special Issue No. **3**: 283-322.

KSIAŻKIEWICZ, M. 1977. Trace fossils in the Flysch of the Polish Carpathians. – Palaeontologica Polonica **36**: 3-17.

LASEMI, Y. 1995. Platform carbonate of the Upper Jurassic Mozduran Formation in the Kopet Dagh Basin, NE Iran-Facies, Palaeoenvironments and sequences. – Sedimentary Geology **99**: 151-164.

LESZCZYŃSKI, S. & SEILACHER, A. 1991. Ichnocoenoses of a turbidite sole. - Ichnos **1**: 293-303.

LESZCZYNSKI, S. 2004. Bioturbation structures of the Kropivnik Fucoid Marls (Campanian-Lower Maastrichtian) of the Huwniki-Rybotycze area (Polish Carpathians). - Geological Quaternary **48**: 35-60.

LINK, O. 1949. Lebens-Spuren aus dem Schilfsandstein (mittle Keuper km 2) NW-Württembergs und ihre Bedeutung für die bildungsgeschichte der stufe. – Naturkd. Württemberg, Jahresh 97-101: 100pp.

LOCKLEY, M. G., RINDSBERG, A. K. & ZEILER, R. M. 1987. The paleoenvironmental significance of the nearshore *Curvolithus* ichnofacies. - Palaios **2**: 255-262.

LUCAS, S. G. & LERNER, A. J. 2004. Extensive ichnofossil assemblage at the base of the Permian Abo Formation, Carrizo Arroyo, New Mexico. - Museum of Natural History and Science Bulletin **25**: 285-289.

LUDWIG, R. 1869. Fossile Pflanzenreste aus den paläolithischen Formationen der Umgebung von Dillenburg, Biedenkopf und Freidberg und aus dem Saalfeldischen. – Palaentographica **17**: 105-128.

LUNDGREN, B. 1891.Studier öfver fossilförande lösa block. – Gologiska Föreningen i Stockholm Förhandlinger **13**: 111-121.

LYBERIS, N. & MANBY, G. 1999. Oblique to orthogonal convergence across the Turan Block in the Post-Miocene. - American Association of Petroleum Geologists Bulletin **83**: 1135–1160.

MAJIDI, B. 1978. Etude petrostructural de la region de Mashhad (Iran). Les problems des metamorphites, serpentinites et granitoides hercyniens. - France, Thease universite Scientifique Granoble, 277 pp.

MAJIDI, B. 1981. The ultrabasic lava flows of Mashhad, North East Iran. – Geological Magazine **118**: 49-58.

MACLEAY, W. S. 1839. Note on the Annelida. – In: MURCHISON, R. I. The Silurian system, part II, organic remains. 699 pp., London (J. Murray).

MADANI, M. 1977. A study of the sedimentology, stratigraphy and regional geology of the Jurassic rocks of eastern Kopet-Dagh (NE-Iran). - Unpublished PhD Thesis, Royal School of Mines, Imperial College London: 1-246.

MANGANO, G. S., BUATOIS, L. A., WEST, R. W. & MAPLES, C. G. 2002. Ichnology of a Pennsylvanian equatorial tidal flat - the Stull Shale Member at Waverly, eastern Kansas. - Kansas Geological Survey Bulletin **245**: 133pp.

MANGANO, M. G., BUATOIS, L. A., MAPLES, C. G. & WEST, R. R. 2000. A new ichnospecies of *Nereites* from Carboniferous tidal-flat facies of eastern Kansas, USA: implications for the *Nereites-Neonereites* debate. – Journal of Paleontology **74**: 149-157.

MANLEY, R. & LEWIS, D. W. 1998. Ichnocoenoses of the Mount Messenger Formation, a Miocene submarine fan system, Taranaki Basin, New Zealand. - New Zealand Journal of Geology and Geophysics **41**: 15-33.

MAPLES, C. G. & SUTTNER, L. J. 1990. Trace fossils and marine-nonmarine cyclicity in the Fountain Formation (Pennsylvanian: Morrowan/Atokan) near Manitou Springs, Colorado. - Journal of Paleontology **64**: 859-880.

MARINTSCH, E. J. & FINKS, R. M. 1982. Lower Devonian ichnofacies at Highland Mills, New York and their gradual replacement across environmental gradients. - Journal of Paleontology **56**: 1050-1078.

MARTIN, M. A. & POLLARD, J. E. 1996. The role of trace fossil (ichnofabric) analysis in the development of depositional models for the Upper Jurassic Flumar Formation of the Kittiwake Field (Quadrat 21 UKCS). – In: HURST, A., JOHNSON, H. D., BURLEY, S. D., CANHAM, A. C. & MACKERTICH, D. S. (EDS.) The sedimentology and sequence stratigraphy of the Upper Jurassic (Upper Oxfordian-Middle Kimmeridgian) Fulmar Formation of the Kittiwake Field, Western Platform of the north Central Graben are investigated through an integrated study of core. - Geological Society London, Special Publications **114**: 163-183.

MASSALONGO, A. 1855. Monographia delle nereidi fossili del M. Bolca. – 35 pp., Verona (Antonelli).

MCCANN, T. & PICKERILL, R. K. 1988. Flysch trace fossils from the Cretaceous Kodiak Formation of Alaska. - Journal of Paleontology **62**: 330-348.

MC COY, F. 1850. On some genera and species of Silurian Radiata in the collection of the University of Cambridge. – Annual Magazine Natural History **7**: 270-290.

MCPHERSON, J.G., SHANMUGAN, G. & MOILA, R.J. 1988. Fan deltas and braid deltas: conceptual problems. - In: NEMEC, W.M. & STEEL R.J. (Eds.) Fan deltas: sedimentology and tectonic settings. Blackie and Son, Glasgow & London, pp. 14-22.

MENEGHINI, G. G. 1850. In: Savi, P., MENGHINI, G. G. (Eds.) Osservazioni stratigrafische e paleontologische concernati la geologia della Toscana e die paesi limitrofi. – In: MURCHISON, R. I. (Ed.), Memoria sulla struttura geologica della Alpi degli Apennini e die Carpazi. Stemparia granucale, Firenze 246-528.

MIALL, A. D. 1977. A review of the braided-river depositional environment. - Earth-Science Review **13**: 1-62.

MIALL, A. D. 1985. Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. - Earth-Science Review **22**: 261-308.

MIALL, A. D. 1996. The geology of fluvial deposits. Sedimentary facies, basin analysis, and petroleum geology. - 582 pp., Berlin (Springer).

MIDDLETON, G. V. 1993. Sediment deposition from turbidity currents. - Annual Reviews, Earth Planetary Sciences **21**: 89-114.

MILLER, S. A. & DYER, C. B. 1878. Contributions to paleontology. – 2: 11 pp., Cincinnati (privately published).

MILLER, M. F. & KNOX, L. W. 1985. Biogenic structures and depositional environments of lower Pennsylvanian coal-bearing sequence, northern Cumberland Plateau, Tennessee, U.S.A. - In: Curran, H. A. (Ed.), Biogenic structures: their use in interpreting depositional environments. - Society of Economic Paleontologists and Mineralogists, Special Publication **35**: 67-97.

MILLER, M. 2001. *Thalassinoides-Phycodes* compound burrow system in Paleocene deep-water limestone, Southern Alps of Italy. - Palaeogeography, Palaeoclimatology, Palaeoecology **170**: 149-156.

MIRNAJAD, H. 1991. Petrology and geochemistry of Mashad region granites and pegmatiits. - Unpublished M.Sc. thesis, University of Tehran (in Farsi).

MITCHUM, RM. JR., VAIL, PR., THOMPSON, S. 1977. Seismic stratigraphy and global changes of sea level, part 2: the depositional sequence as a basic unit for stratigraphic analysis. In: PAYTON CE (Ed.) Seismic stratigraphy. – Applications to hydrocarbon exploration. American Association of Petroleum Geologists, Memoir **26:** 53-62.

MITCHUM, RM. JR., VAIL, PR., SANGREE, JB. 1977. Seismic stratigraphy and global changes of sea level, part 6: stratigrphic interpretation of seismic reflection patterns in depositional sequences. In: PAYTON CE (Ed.) Seismic stratigraphy. – Applications to hydrocarbon exploration. American Association of Petroleum Geologists, Mem **26**: 117-133.

MÜLLER, A. H. 1966. Neue Lebensspuren (vestigia invertebratorum) aus dem Karbon und der Trias Mittledeutschlands. – Geologie **15**: 712-725.

MÜLLER, P. J. & SUESS, E. 1979. Productivity, sedimentation rate and sedimentary organic matter in the oceanic carbon preservation. – Deep-Sea Research **26**: 1347-1362.

NABAVIEH, M. 1998. Geological map of Kalat-e-Naderi, in scale of 1:100,000. Geological Survey of Iran, Tehran.

NICHOLS, G. J. & FISHER, J. A. 2007. Processes, facies and architecture of fluvial distributary system deposits. - Sedimentary Geology **195**: 75-90.

NICHOLSON, H. A. 1873. Contributions to the study of the errant ennelids of the older Paleozoic rock. – Proceedings of the Royal Society of London **21**: 288-290.

NICHOLSON, H. A. & HINDE, G. J. 1875. Notes on the fossils of the Clinton, Niagara, and Guelph formations of Ontario, with descriptions of new species. - Canadian Journal **14**: 137-152.

NODA, H. & YOON, S. 1982. New occurrence and its geological significance of trace fossil *Chondrites maekawaaensis* from the Miocene Duho Formation in Korea. - Annual Report, Institute of Geosciences, University of Tsukuba **8**: 70-73.

OLIVERO, D. 1994. Le Trace fossil *Zoophycos* dans le sud-est de la France. Signification paleoenvironnementale. - Documents des Laboratoires de Geologie Lyon **129**: 1-329.

OLIVERO, D. 1996. *Zoophycos* distribution and sequence stratigraphy. Examples from the Jurassic and Cretaceous deposits of southeastern France. - Palaeogeography, Palaeoclimatology, Palaeoecology **123**: 273-287.

OLIVERO, D. & GAILLARD, C. 1996. Paleoecology of Jurassic *Zoophycos* from south-eastern France. - Ichnos **4**: 249-260.

ORR, P. J., BENTON, M. J. & TREWIN, N. H. 1996. Deep marine trace fossil assemblages from the Lower Carboniferous of Menorca, Balearic Islands, western Mediterranean. - Geological Journal **31**: 235-258.

OSGOOD, R.G., 1970. Trace fossils of the Cincinnati area. - Paleontographica Americana **6**: 281-444.

PEMBERTON, S. G. & FREY, R. W. 1982. Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. – Journal of Paleontology **56**: 843-881.

Pemberton, S. G. & Frey, R. W. 1984. Quantitative methods in ichnology; spatial distribution among populations. - Lethaia **17**: 33-49.

PICKERILL, R. K. 1991. The trace fossil *Neonereites multiserialis* Pickerill and Harland 1988 from the Devonian Wapske Formation, northwest New Brunswick. - Atlantic Geology **27**: 119-126.

PICKERILL, R. K. & HARLAND 1988. Trace fossils from Silurian slope deposits, North Greenland. - Grønlands Geologiske Undersøgelse, Rapport **137**: 119-133.

PLIČKA, M. 1970. *Zoophycos* and similar fossils. In: CRIMES, T. P. & HARPER, J. C. (Eds.) Trace fossils - Geological Journal, Special Issue, No. **3**: 361-370.

POIRE, D. G. 2001. *Gyrochorte* as trace fossil indicator of storm events in the Neuquén Basin, Argentina. - Annual Meeting, Expanded Abstracts, American Association of Petroleum Geologists, 2001: 159.

POLLARD, J.E., GOLDRING., R. G. & BUCK, S.G. 1993. Ichnofabrics containing *Ophiomorpha*: significance in shallow-water facies interpretation. - Journal of the Geological Society, London **150**: 149-164.

POSTMA, G., NEMEC, W. & KLEINSPEHN, K. L. 1988. Large floating clasts in turbidites: a mechanism for their emplacement.- Sedimentary Gelogy **58**: 47-61.

POURSOLTANI, M. R., MOUSSAVI-HARAMI, R. & GIBLING, M. R. 2007. Jurassic deep-water fans in the Neo-Tethys Ocean: The Kashafrud Formation of the Kopet-Dagh Basin, Iran. - Sedimentary geology **198**: 53-74.

PRIOR, D. B., BORNHOLD, B. D. & JOHNS, M. W. 1984. Depositional characteristics of a submarine debris flow. - Journal of Geology **92**: 707-727.

READING, H. G. & RICHARDS, M. 1994. Turbidite systems in deep-water basin margins classified by grain size and feeder system. - American Association of Petroleum Geologists Bulletin **78**: 792-822.

READING, H. G. & COLLINSON, J. D. 1996. Clastic coasts. - In: READING, H. G. (Ed.) Sedimentary environments. Processes, facies and stratigraphy, 688 pp.Oxford (Blackwell) (3rd ed.).

REID, S. A. & PEMBERTON, S. G. 2004. Ichnology of the Creek Member of the Kaskapau Formation: An example of the stark contrast of brackish and fully marine assemblages. - Annual Meeting, Expanded Abstracts, American Association of Petroleium Geologists **13**: 116.

REINECK, H. E. 1955. Marken und Spuren und Fährten in den Waderner Schichten (ro) bie Martinstein (Nahe). – Neues Jahrbuch Für Geologie, Paläontologie, Abhandlungen 101: 7-11.

RICCI LUCCHI, F, 1995. Sedimentographica: a photographic Atlas of sedimentary structures. - 2nd Ed. 255 pp. Columbia University Press, New York.

RICHTER, R. 1937. Marken und Spuren aus allen Zeiten. I-II Senckenbergiana **19**: 150-169.

RICHTER, R. 1941. Marken und Spuren im Hunsrückshiefer. 3. Fährten als Zeugnisse des Lebens auf dem Meeres-Grunde. – Senckenbergiana 23: 218-260.

RICHTER, R. 1850. Aus der thüringischen Grauwake. - Deutschland Geol. Gesell., Zeitschr. **2**: 198-206.

RICHTER, R 1853. ThüringischeGraptolithen. - Deutschland Geol. Gesell., Zeitschr. **5:** 439-464.

RIETH, A. 1932. Neue Funde spongeliomorpher Fucoiden aus dem Jura Schwabens. – Geologische und paläontologische Abhandlungen, Neue Folge **19**: 257-294.

RODRIGUEZ, J. & GUTSCHICK, R. C. 1970. Late Devonian- Early Mississippian ichnofossils from Western Montana and Northern Utah. - In: FREY, R. W. & HARPER, J. C. (Eds.) Trace fossils. - Geological Journal, Special Issue **3**: 407-438.

ROWSHANRAVAN, J. 2006. Geological map of Bazangan, in scale of 1:100,000. - Geological Survey of Iran.

RUTTNER, A.W. 1991. Geology of Aqdarband Area (Kopeh Dagh, NE-Iran). – In: RUTTNER, A.W. (Ed.). The Triassic of Aghdarband (Aqdarband), NE-Iran, and its pre-Triassic frame. - Abhandlungen der Geologischen band **38**: 7-79.

RUTTNER, A.W. 1993. Southern borderland of Triassic Laurasia in NE Iran. - Geologische Rundschau **82**: 110–120.

SACCO, F. 1888. Note di paleoichnologia Italina. – Atti della Societá Italiana di Scienze Naturali **31**: 151-192.

SAIDI, A., BRUNET, M.-F. & RICOU, L.-E. 1997. Continental accretion of the Iran Block to Eurasia as seen from Late Paleozoic to Early Cretaceous subsidence curves. - Geodinamica Acta **10:** 189-208.

SANAYE, N. 2001. Palynostratigraphy of the Lower-Middle Jurassic strata at the Fraizi section, NW Mashhad. - Unpublished M. Sc. Thesis, Geosciences Research Institute, GSI, Tehran (in Farsi).

SAVRDA, C. E. & BOTTJER, D. J. 1989 Trace-fossil model for reconstructing oxygenation histories of ancient marine bottom waters: Application to Upper Cretaceous Niobrara Formation, Colorado. - Palaeogeography, Palaeoclimatology, Palaeoecology **74**: 49-74.

SCHLAGER, W., 1992. Sedimentology and sequence stratigraphy of reefs and carbonate platforms: Tulsa, OK. American Association of Petroleum Geologists Continuing Education Course Note Series **34**: 71 p.

SCHAFHÄUTL, K. E. 1851. Geognostische Untersuchungen des südbayerischen Alpengebirges. – 208 pp., München (Literarischartistische Anstalt).

SEILACHER, A. 1955. Spuren und Fazies im Unterkambrium. – In: SCHINDEWOLF, O. H. & SEILACHER, A. (Eds.): Beiträge zur Kenntnis des Kambriums in der Salt Range (Pakistan). – Akademie der Wissenschaften und der Literatur, Mathematisch-Naturwissenschaftliche Klasse, Abhandlungen. Mainz **10**: 373-399.

SEILACHER, A. 1955. Spuren und Fazies im Unterkambrium. - In: SCHINDEWOLF, O. H. & SEILACHER, A. (Eds.) Beiträge zur Kenntnis des Kambrium in der Salt Range (Pakistan). Akademie der Wissenschaften und der Literature in Mainz, Abhandlungen der mathematisch-naturwissenschaftlichen Klasse **10**: 11-143.

SEILACHER, A. 1960. Lebensspuren als Leitfossilien. – Geologische Rundschau **49**: 41-50.

SEILACHER, A. 1977. Pattern analysis of *Paleodictyon* and related trace fossils. - In: Crimes, T. P. & Harper, J. C. (Eds.) Trace fossils 2. - Geological Journal, Special Issue **9**: 289-334.

SEILACHER, A. 1983. Upper Paleozoic trace fossils from the Gilf Kebir-Abu Ras area in southwestern Egypt. – Journal of Afrrican Earth Sciences **1**: 21-34.

SEILACHER, A. 1984. Constructional morphology of bivalves: evolutionary pathways in primary versus secondary soft-bottom dwellers. - Palaeontology 27: 207-237.

SEILACHER, A. 1986. Evolution of behavior as expressed by marine trace fossils. – In: NITECKI, M. H. & KITCHELL, J. A. (Eds.) Evolution of animal behavior: 62-87, New York (Oxford University Press).

SEILACHER, A. 1989. *Spirocosmorhaphe* a new glraphoglyptid trace fossil. – Journal of Paleontology **63**: 116-117.

SEILACHER, A. 1990. Paleozoic trace fossils. – In: SAID, R. (Ed.) The geology of Egypt: 649-670 Rotterdam (A. A. Balkema).

SEILACHER, A. 2007. Trace fossil analysis. - 226. pp., Berlin (Springer).

SEILACHER, A. & MEISCHER, D. 1965. Fazies-Analyse im Paläozoikum des Oslo-Gebietes. – Geologische Rundschau **54**: 596-619.

SEILACHER, A. & SEILACHER, E. 1994. Bivalvian trace fossils: a lesson from actuopaleontology. - Courier Forschungsinstitut Senckenberg **169**: 5-15.

SENGÖR, A.M.C. 1990. A new model for the late Palaeozoic-Mesozoic tectonic evolution of Iran and its implications for Oman. - In: ROBERTSON, A.H.F., SEARLE, M.P. & RIES, A.C. (Eds.) The geology and tectonics of the Oman region. - Geological Society of London, Special Publication **49:** 797-831.

SENGÖR, A. M. C. 1992. The Palaeo-Tethyan suture: a line of demarcation between two fundamentally different architectural styles in the structure of Asia. - The Island Arc **1:** 78-91.

SENGÖR, A. M. C. 1995. Sedimentation and tectonics of fossil rifts. - In: BUSBY, C. J. & INGERSOLL, R. V. (Eds.) Tectonics of sedimentary basins: 119-148, London (Blackwell).

SEYED-EMAMI, K. 1971. The Jurassic Badamu Formation in the Kerman region, with remarks on the Jurassic stratigraphy of Iran - Geological Survey of Iran. Report **19:** 5-79.

SEYED-EMAMI, K., FÜRSICH, F. T. & WILMSEN, M. 2005. New evidence on the lithostratigraphy of the Jurassic System in the Northern Tabas Block, East-Central Iran). - Earth Science **57:** 78-97 (in Farsi).

SEYED-EMAMI, K., SCHAIRER, G. & BEHROOZI, A. 1994. Einige Ammoniten aus der Kashafrud Formation (Mittlerer Jura) Eastern Mashad, Northeastern Iran. Mitteilungen der Bayerischen Staatssammlung für Paläontologie und Historische Geologie **34**: 145-158.

SEYED-EMAMI, K., SCHAIRER, G. & BEHROOZI, A. 1996. Ammoniten aus dem oberen Bajoc (Mittlerer Jura) des SE-Koppeh Dagh and SE-Alborz (NE-Iran). - Mitteilungen der Bayerischen Staatssammlung für Paläontologie und Historische Geologie **36:** 87-106.

SEYED-EMAMI, K., FÜRSICH, F.T. & SCHAIRER, G. 2001. Lithostratigraphy, ammonite faunas and palaeoenvironments of Middle Jurassic strata in North and Central Iran. - Newsletters on Stratigraphy **38**: 163-184.

SHAHIDI, A., 2008. Evolution tectonique du Nord de l'Iran (Alborz et Kopet-Dagh) depuis le Mesozoique. - Thèse, Université Paris 6: 500 pp.

SHAHRABI, M. 1999. Triassic in Iran. – 279 pp., (Geological Survey of Iran) Tehran (in Farsi).

SHANMUGAM, G. 1996. High-density turbidity currents: are they sandy debris flows? Journal of Sedimentary Research **66**: 2-10.

SHANMUGAM, G. 2000. 49 years of the turbidite paradigm (1950s-1990s): deep-water processes and facies models - a critical perspective. - Marine and Petroleum Geology **17**: 285-342.

SHANMUGAM, G. 2002. Ten turbidite myths. – Earth-Science Reviews **58**: 311-341.

SHIKALIBEILY, E. S., ABDULLAEV, R. N. & ALI-ZADE, A. 1988. Geological results of the super-deep well of Saatly. – Sovetskaya Geologiya 11: 61-66 (in Russian).

SIMPSON, S. 1957. On the trace-fossil *Chondrites*. – Quarterly Journal of the Geological Society of London **112**: 475-499.

SIMPSON, S. 1970. Notes on *Zoophycos* and *Spirophyton*. - In: CRIMES, T. P. & HARPER, J. C. (Eds.) Trace fossils. - Geological Journal London, Special, Issue No. **3:** 505-514.

SLOSS, L. L. 1979. Global sea level change; a view from the craton Memoir American Association of Petroleum Geologists **29**: 461-467.

SQNDERHOLM, M. & TIRSGAARD, H. 1998. Proterozoic fluvial styles: response to changes in accommodation space (Rivieradal sandstone, eastern North Greenland). - Sedimentary Geology **120**: 257-274.

SPIEKER, E. M. & REESIDE, J. B. 1925. Cretaceous and Tertiary formation of the Wasatch Plateau, Utah. - Geological Society of America bulletin **36**: 435-454.

STAMPFLI, G., 1978. Etude géologique generale de l'Elbourz oriental au sud de Gonbad-e-Qabus (Iran NE). - PhD. Thesis, Univ. Genève, 329 pp.

STAMPFLI, G., MARCOUX, J. & BAUD, A. 1991. tethyan margins in space and time. - Palaeogeography, Palaeoclimatology, Palaeoecology **87**: 373-409.

STANISTREET, I. G. & MCCARTHY, T. S. 1993. The Okavango Fan and the classification of subaerial fan systems. - Sedimentary Geology **85**: 115-133.

STEEL, R. J. & THOMPSON, D. B. 1983. Structures and textures in Triassic braided stream conglomerates (‘Bunter’ Pebble Beds) in the Sherwood Group, North Staffordshire, England. - Sedimentology **30**: 341-367.

STERNBERG, G. K. 1833. Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt. - **IV** Heft, 48pp., Regensburg (C. E. Brenck).

STÖCKLIN, J. 1974. Possible ancient continental margin in Iran. - In: BURK C. A. & DRAKE C. L. (Eds.) The geology of continental margins. - Springer, Berlin, Heidelberg, New York, 873–887.

STOW, D. A. V. & PIPER, D. J. W. 1984. Deep-water fine-grained sediments: facies models. – In: STOW, D. A. V. & PIPER, D. J. W. (Eds.) Fine-grained sediments: deep-water processes and facies. - The geological Society London, Special Publication **15**: 611-645.

SWINBANKS, D. D. 1982. *Paleodictyon*: The traces of infaunal xenophyophores?. - Science **218**: 47-49.

TAHERI, J., FÜRSICH, F.T. & WILMSEN, M. 2006. Stratigraphy and depositional environments of the Upper Bajocian–Bathonian Kashafrud Formation (NE Iran). – Volumina Jurassica **4**: 105-106; Warsaw.

TAHERI, J. FÜRSICH, T. F.; WILMSEN, M. (2006): The Kashafrud Basin (NE Iran): A key for understanding the Jurassic geodynamic evolution of the Iran Plate. – Volumina Jurassica, **4:** 69; Warsaw.

TAHERI, J., FÜRSICH, F.T. & WILMSEN, M. 2009. Stratigraphy, depositional environments and geodynamic significance of the Upper Bajocian–Bathonian Kashafrud Formation, NE Iran. – In: BRUNET, M. F., WILMSEN, M. & GRANATH, J. W. (Eds.) South Caspian to Central Iran basins. - Geological Society London, Special Publications **312**: 205-218.

TAHERI, J. & GHAEMI, F. 1994. Geological map of Mashhad, in scale of 1:100,000. Geological Survey of Iran.

TAKIN, M. 1972. Iranian geology and continental drift in the Middle East. - Nature **235:** 147-150.

TANAKA, L. 1970. Sedimentation of the Cretaceous flysch sequence in the Ikushumbetsu area, Hokkaido, Japan. – Geological survey of Japan, Report **242**: 1-31.

TAYLOR, B. J. 1967. Trace fossils from the Fossil Bluff Series of Alexander Island. - British Antarctic Survey, Bulletin **13**: 1-30.

TCHOUMATCHENCO, P. & UCHMAN, A. 2001. The oldest deep-sea *Ophiomorpha* and *Scolicia* and associated trace fossils from the Upper Jurassic-Lower Cretaceous deep-water turbidite deposits of SW Bulgaria. - Palaeogeography, Palaeoclimatology, Palaeoecology **169**: 85-99.

Torell, 0. 1870. Petrificata Suecana Formationis Cambricae. Lunds. Universitet Årsskrift 6:1-14.

TUNIS, G. & UCHMAN, A. 1996. Ichnology of Eocene flysch deposits of the Istria peninsula, Croatia and Slovenia. - Ichnos **5**: 1-22.

TURNER, B. R. & BENTON, M. J. 1983. Paleozoic trace fossils from the Kufra Basin, Libya. - Journal of Paleontology **57**: 447-460.

UCHMAN, A. 1995. Taxonomy and palaeoecology of flysch trace fossils: The Marnoso-arenacea Formation and associated facies (Miocene, Northern Italy). - Beringeria **15**: 1-115.

UCHMAN, A. 1998. Taxonomy and ethology of flysch trace fossils: Revision of the Marian Ksiazkiewicz collection and studies of complementary material. - Annales Societatis Poloniae **68:** 105-218.

UCHMAN, A. 1999. Ichnology of the Rhenodanubian flysch (Lower Cretaceous) in Austria and Germany. - Beringeria **25**: 67-173.

UCHMAN, A. 2001. Eocene flysch trace fossils from the Hecho Group of the Pyrenees, northern Spain. - Beringeria **28:** 3-41.

UCHMAN, A. 2002. Ichnological record of paleoenvironmental changes in the Lower Cretaceous of the Silesian unit, Polish Flysch Carpathians. - Geologica Carpathica **53:** 83-84.

UCHMAN, A. & DEMIRCAN, H. 1999. Trace fossils of Miocene deep-sea fan fringe deposits from the Cingöz Formation, southern Turkey. - Annales Societatis Geologorum Poloniae **69**: 125-135.

UCHMAN, A. & TCHOUMATCHENCO, P. 2003. A mixed assembelage of deep-sea and shelf trace fossils from the Lower Cretaceous (Valanginian) Kamchia Formation in the Troyan region, central Fore-Balkan, Bulgaria. - Annales Societatis Geologorum Poloniae **73**: 27-34.

UCHMAN, A. & WETZEL, A. 1999. An aberrant, helicoidal trace fossil *Chondrites* Sternberg. - Palaeogeography, Palaeoclimatology, Palaeoecology **146:** 165-169.

UCHMAN, A., JANBU, N. E. & NEMEC, W. 2004. Trace fossils in the Cretaceous-Eocene flysch of the Sinop-Boyabat Basin, central Pontides, Turkey. - Annales Societatis Geologorum Poloniae **74:** 197-235.

VAEZ JAVADI, F. & POURLATIFI, A. 2002. Geology and the age of the Mashhad Phyllites in Golmakan area in the Binalud Mountain. Geosciences **43-44**: 80-87.

VAIL, P.R., AUDEMARD, F., BOWMAN, S.A., EISNER, P.N. & PEREZ-CRUZ, C. (1991): The stratigraphic signatures of tectonics, eustasy and sedimentology - an overview. - In: EINSELE, G., RICKEN, W. & SEILACHER, A. (Eds.): Cycles and events in stratigraphy: 617-659; Berlin (Springer).

VAIL, P. R. & MITCHUM, R. M. 1977. Seismic stratigraphy and global changes of sea level. Part 1, Overview. - American Association of Petroleum Geologists, Memoir **26**: 51-52.

VAIL, P.R., MITCHUM, R.M. JR., TODD, R.G., WIDMIER, J.M., THOMPSON, S. III., SANGREE, J.B., BUBB, J.N., & HATLELID, W.G., 1977. Seismic stratigraphy and global changes of sea level. – In: PAYTON, C.E. (Ed.) Seismic Stratigraphy: Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir, **26**: 49–212.

VIZCAÏNO, D., ÁLVARO, J. J. & MONCERET, E. 2004. Trilobites and ichnofossils from a new fossil Lagerstätte in the Lower Cambrian Pardailhan Formation, southern Montagne Noire, France. - Geobios **37**: 277–286.

VASSOEVICH, N. B. 1932. Onekotorykh priznakakh pozvolyayushchikh otlicht óprokinutoe polo-zhenie flishevykh obrazovaniy ot normalynogo. - Akad. Nauk SSSR, Geological Institute., Trudy **2**:47-64.

VOLK, M. 1961. Protovirgularia nereitarum (Reinhard Richter), eine Lebesspura us dem Devon Thuiringen. – Senckenbergiana Lethaea **42**: 69-75.

WEISS, W. 1940. Beobachtungen an Zopfplatten. – Zeitschrift der Deutschen Geologischen Gesellschaft, Band **92**: 333-349.

WELLER, W. 1899. Kinderhook faunal studies. I. The fauna of the vermicular sandstone at Northview, Webster County, Missouri. – Transactions of the Academy of Science St. Louis **9**: 9-51.

WENDT, J., KAUFMANN, B., BELKA, Z., FARSAN, N. & KARIMI BAVANDPUR, A. 2005. Devonian/Lower Carboniferous stratigraphy, facies patterns and palaeogeography of Iran Part II. Northern and central Iran. - Acta Geologica Polonica **55:** 31-97.

WETZEL, A. 1984. Bioturbation in deep-sea fine-grained sediments: influence of sediment texture, turbidite frequency and rates of environmental change. – In: STOW, D.A.V. & PIPER, D.J.W. (Eds.) Fine-grained sediments: Deep-water processes and facies. - Geological Society London, Special Publication **15:** 595-608.

WETZEL, A. & BROMLEY, R. G. 1996. Re-evaluation of the ichnogenus *Helminthopsis* – A new look at the type material. - Palaeontology **39:** 1-19.

WETZEL, A. & UCHMAN, A. 1997. Ichnology of deep-sea fan overbank deposits of the Ganeo Slates (Eocene, Switzerland) - a classical flysch trace fossil locality studied first by Oswald Heer. - Ichnos **5:** 139-162.

WILMSEN, M., FÜRSICH, F.T., TAHERI, J. BRUNET, M.F.; SEYED-EMAMI, K. & MAJIDIFARD, M.R. 2006. The Kashafrud Basin (NE Iran): A key for understanding the Jurassic geodynamic evolution of the Iran Plate. Volumina Jurassica **4**: 69.

WILMSEN, M.; FÜRSICH, F.T.; TAHERI, J. 2009. The Shemshak Group (Lower Middle Jurassic) of the Binalud Mountain NE Iran: stratigraphy, depositional environments and geodynamic implications. – In: BRUNET, M. F., WILMSEN, M. & GRANATH, J. W. (Eds.) South Caspian to Central Iran basins. - Geological Society, London, Special Publications **312**: 175-188.

WILMSEN, M.; FÜRSICH, F.T.; SEYED-EMAMI, K. & MAJIDIFARD, M. R. 2009. An overview of the stratigraphy and facies development of the Jurassic Systam on the Tabas Block, east-central Iran. - In: BRUNET, M. F., WILMSEN, M. & GRANATH, J. W. (Eds.) South Caspian to Central Iran basins. - Geological Society, London, Special Publications **312**: 323-343.

WOHLFART, R. & WITTEKINDT, H. 1980. Geologie von Afghanistan. - Beiträge zur Regionalen Geologie der Erde **14:** 1-500, Stuttgart (Borntraeger).

YANG, S. P. 1986. Turbidite flysch trace fossils from China and their palaeoecology and paleoenvironment. – 13th & 14th Annual Conference of the Paleontological Society of China. Selected papers: 143-161; Bejing (Science Press). (in Chinese with English abstract).

ZENKER, J. C. 1836. Historisch-topographisches Taschenbuch von Jena und seiner Umgebung besonders in naturwissenschaftlicher und medicinischer Bezeihung. – In: ZENKER, J. C. (Ed.) 338pp., 1 map, Wackenhoder (Jena).

ZONNEVELD J.-P., GINGRAS, M. K. & PEMBERTON, S.G. 2001. Trace fossil assemblages in a Middle Triassic mixed siliciclastic-carbonate marginal marine depositional system, British Columbia. - Palaeogeography, Palaeoclimatology, Palaeoecology **166:** 249–276.

ZONENSHAIN, L. P. & LE PICHON, X. 1986. Deep basins of the Black Sea and Caspian Sea as remnants of Mesozoic back-arc basins. – Tectonophysics **123**: 181-211.