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Devonian/Lower Carboniferous stratigraphy, facies patterns and palaeogeography of Iran Part II. Northern and central Iran [1)]

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This work is dedicated to our friend and collaborator Noor Farsan (15. 9. 1940 – 23. 4. 2003) who passed away after a long period of illness. With tireless enthusiasm and a profound knowledge of brachiopods, tentaculitids and trilobites he formed the biostratigraphic fundamentals of our study, but unfortunately his work remained unaccomplished.

ABSTRACT:

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Apart from a few small remnants of the Turan Plate in the north, Iran during the Palaeozoic was part of the northern margin of Gondwana. On the basis of 65 sections, the majority of them covering the time-span from the Late Silurian into the Early Carboniferous, the stratigraphy and facies pattern of this area have been elucidated. Biostratigraphical calibration and correlation of the sections, mostly by means of conodonts and brachiopods, show the evolution from a shallow carbonate-dominated shelf in the Silurian which, by a drop of sea-level, was transformed into a siliciclastic shelf during the Early Devonian. Fully marine conditions were subsequently re-established in the Middle Devonian to early Frasnian and persisted into the early Late Carboniferous. A widespread uplift in the latest Carboniferous turned the entire area into a continental regime before the onset of a new marine cycle during the late Early Permian. With the exception of the northern zone (Talesh Range, Aghdarband), the Palaeozoic of Iran is characterized by continental to shallow marine deposits showing that enormous portions of the northern margin of this sector of Gondwana have been subducted during the convergence of the Turan and Iran Plates and the elimination of the Palaeotethys during the Late Triassic.

Key words: Iran, Silurian, Devonian, Carboniferous, Permian, Stratigraphy, Sedimentology, Palaeogeography, Plate tectonics.

INTRODUCTION

The existence of Devonian and Carboniferous rocks in Iran has long been known, but a comprehensive survey of this interval based on extensive field studies was lacking. After the examination of the biostratigraphically best documented Kerman area in southeastern Iran (WENDT & *al.* 2002), the present second part of

[1)] Part I (*Acta Geologica Polonica*, vol. **52**, 129-168) was devoted to southeastern Iran

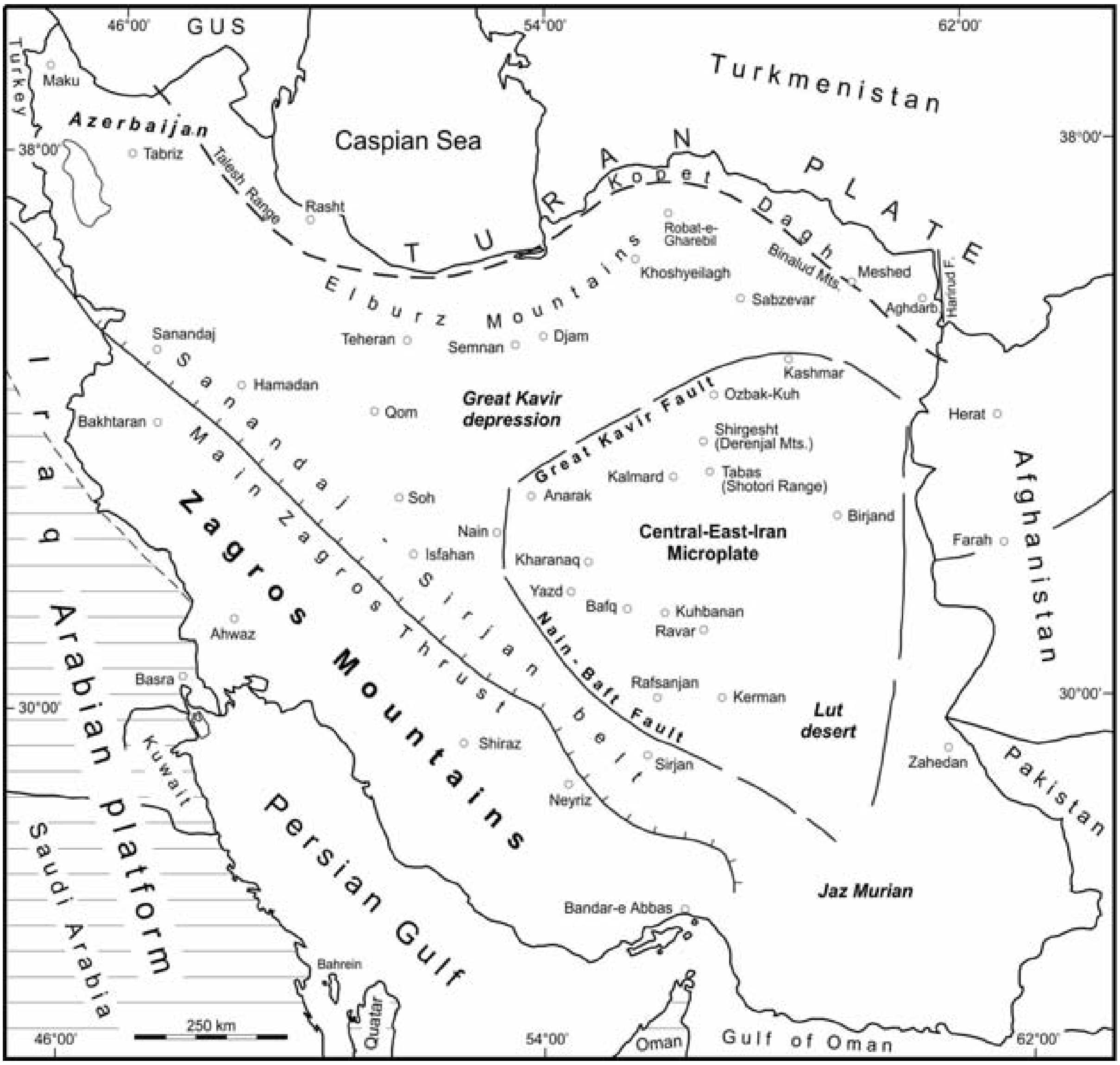


Fig. 1. Structural units of Iran (modified from WENDT & *al.* 2002)

our study is devoted to the remainder of the country, i. e. to northern and central Iran. Conveniently, Iran is structurally and palaeotectonically divided, from N to S, into the following units (Text-fig. 1):

(1) the northern zone which extends from eastern Azerbaijan across the Talesh Range (western Elburz), the Caspian depression into the Kopet Dagh and northwestern Afghanistan. Only a few remnants of Palaeozoic rocks are preserved in this zone, but they document that this narrow band is a fragment of Laurussia (Turan Plate). The position of its southern border and the width of the Palaeotethys which in Palaeozoic times separated Laurussia from Gondwana, are controversial (STÖCKLIN 1974, ALAVI 1991, STAMPFLI 2000, STAMPFLI & *al*. 2002, GOLONKA 2002, and others), in particular because vestiges of this ocean and the position of the suture zone (North Iran suture of LENSCH & *al*. 1984) are rarely preserved. The closure of the Palaeotethys between the Iran Plate as a part of Gondwana and the Turan Plate occurred in the early Late Triassic and were accomplished during the Early/earliest Middle Jurassic (GOLONKA 2002). At the same time granitic intrusions in central Iran began to disintegrate various blocks of zone (2) (RAMEZANI & TUCKER 2003)

(2) Central Iran south of the suture zone and comprising western Azerbaijan, the Elburz Mountains, the Binalud Mountains in the N and the mosaic of various Palaeozoic blocks farther S.

(3) The Central-East-Iran Microplate which is bound by major faults in the NW, SW and E. It is com-

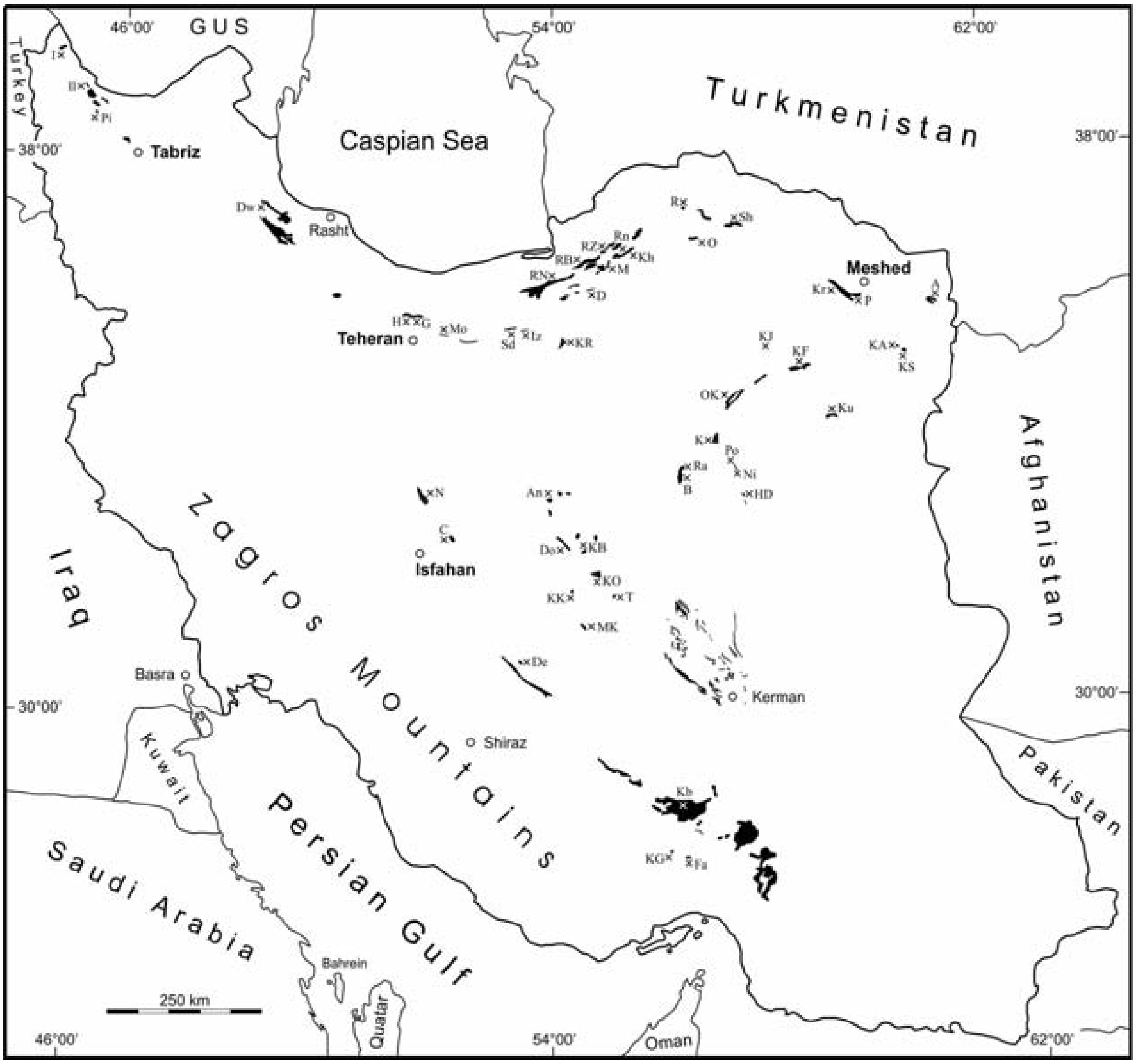


Fig. 2. Outcrops of Devonian in Iran (small occurrences are exaggerated) based on the geological map 1: 2 500 000 and own observations. For abbreviations of localities see Appendix 1

monly accepted that this microplate was subject to a 135° anticlockwise rotation since the Late Triassic (SOFFEL & *al*. 1996).

(4) The Sanandaj-Sirjan belt which extends over 1000 km from NW Iran to S Iran. This belt consists of imbricated sheets of Palaeozoic and Mesozoic rocks which, in connection with the closure of the Neotethys, were transported over tens to hundreds of kilometres to the SW.

(5) The Neotethys which opened during the latest Palaeozoic/Early Triassic thus splitting off zones (2) and (3) from the Arabian Platform. Its Iranian branch, the Zagros Ocean, was eliminated during the Early Tertiary. Allochthonous oceanic crust remnants are preserved along the Main Zagros Thrust and in the Zagros Mountains.

(6) The Zagros Mountains which consist of a few patchily preserved Palaeozoic rocks deposited on the Precambrian basement of the Arabian Platform, and Meso- and Cenozoic units partly derived from the Neotethys.

Compared to the vast surface of the country (1 648 165 km^2), Devonian/Carboniferous rocks cover only a tiny portion and are mostly exaggerated on Text-fig. 2. They are most widespread in the central and eastern Elburz (2) and in the western and central part of the Central-East-Iran Microplate (3) which constitute the main research areas of the present study. The allochthonous outcrops in the southeastern Sanandaj-Sirjan Belt (4) which often do not allow clear biostratigraphic attributions, have only cursorily been studied by us. The Devonian continental deposits of the Zagros Mountains (6) were excluded from our study.

A synoptic overview of the Silurian to Permian formations in these areas (Text-fig. 3) shows striking depositional and biostratigraphic contrasts between neighbouring zones. These contrasts are not only related to their position in the above sketched structural units, but also reflect different environmental regimes. Unfortunately, an exaggerated use of local formation names for similar lithologic units (in particular in the Middle/Upper Devonian) complicates comparisons between neighbouring areas. It has been the aim of our study to integrate all previous local studies into our own extensive field work covering the major part of Iran and to present a general view of the depositional-palaeogeographic history over a time-span of approximately a hundred million years.

PREVIOUS WORK

Apart from the books by KHOSROW-TEHRANI (1985) and ALAVI-NAINI (1993, in Farsi) and the short review by DASTANPOUR (1996), no attempt has been made so far to present a general survey of this period of the Devonian system in Iran. In the reference chapter of the present paper all available local studies have been listed, references to which are given in the equivalent paragraphs. Unpublished master theses and reports (by the Geological Survey of Iran and the National Iranian Oil Company) have only partly been accessible. References to geological maps are only made in areas of striking controversial interpretations compared with our work or where published reports are lacking. Papers omitted in our reference list may be found in DÜRKOOP & *al*. (1979) and in WRIGHT (1998).

REGIONAL STRATIGRAPHY AND SEDIMENTOLOGY

Northern zone

The palaeotectonic position and the boundaries of the northern zone (Talesh Range, northern Elburz, Kopet Dagh) is interpreted controversely. DAVOUDZADEH & SCHMIDT (1982, fig. 2) regard it as a "geosyncline" on the southern margin of the Turan Plate, i. e. as a fragment of Laurasia. This interpretation is accepted by SOFFEL & *al.* (1996), while ALAVI (1996, fig. 1) places the "Paleo-Tethyan continent-continent collisional suture zone" north of the Talesh Range and northern Elburz and considers only the Kopet Dagh area as part of the Turan Plate. Independent of both interpretations, it remains highly surprising that even in the northernmost parts of the north Iran mountain ranges (except Aghdarband, see below) the examined Palaeozoic successions consist exclusively of shallow water platform deposits. This fact indicates that enormous portions of the northern Gondwana margin in Iran must have been subducted during the continent-continent convergence and elimination of the Palaeotethys Ocean.

Because of the luxuriant vegetation on the southern shore of the Caspian Sea and the adjacent mountain slopes, outcrops are rather poor in that area. Structural complications are an additional obstacle to trace relatively undisturbed sections. Therefore only a few localities in this zone have been examined.

Talesh Range

In the southern Talesh Range, 3 km NE of the village of Derow, a 20-30 m thick intercalation of red limestones with orthoconic nautiloids (Pl. 5, Fig. 1) occurs at the base of a thick pile of Silurian to Permian deposits, thrust over Cretaceous volcanics. DAVIES & *al.* (1972) attributed these cephalopod limestones to the upper Llandovery/Wenlock. Subsequent studies of conodont samples from various levels of this member by HAMDI (1975) revealed that it comprises the major part of the Silurian (upper Llandovery to Ludlow). Unfortunately our four samples from the cephalopod limestones processed for conodonts were barren. Overlying levels of grey to black limestones are said to contain abundant conodont faunas of unspecified Early Devonian age (HAMDI 1975). This would be the first biostratigraphically well documented presence of Lower Devonian rocks in Iran. Elsewhere, this period is represented by a gap or by poorly dated siliciclastic rocks of the Padeha and Zarand Formations. Only in one place, NW of Zarand in eastern Iran, were we able to prove the presence of the Lochkovian in this lithology (WENDT & *al.* 2002, p. 153). The depositional area of these unique lithologies in the Silurian and Lower Devonian of the Talesh Range must be sought at an unknown distance farther north, i. e. they are remnants of the Turan Plate N of the Palaeo-Tethys suture zone. This view is also shared by ŞENGÖR (1990).

Northern Elburz

In some of the densely forested valleys SE and E of Gorgan (Rudhkaneh-e-Bakhshah, Rudhkaneh-e-Alastan),

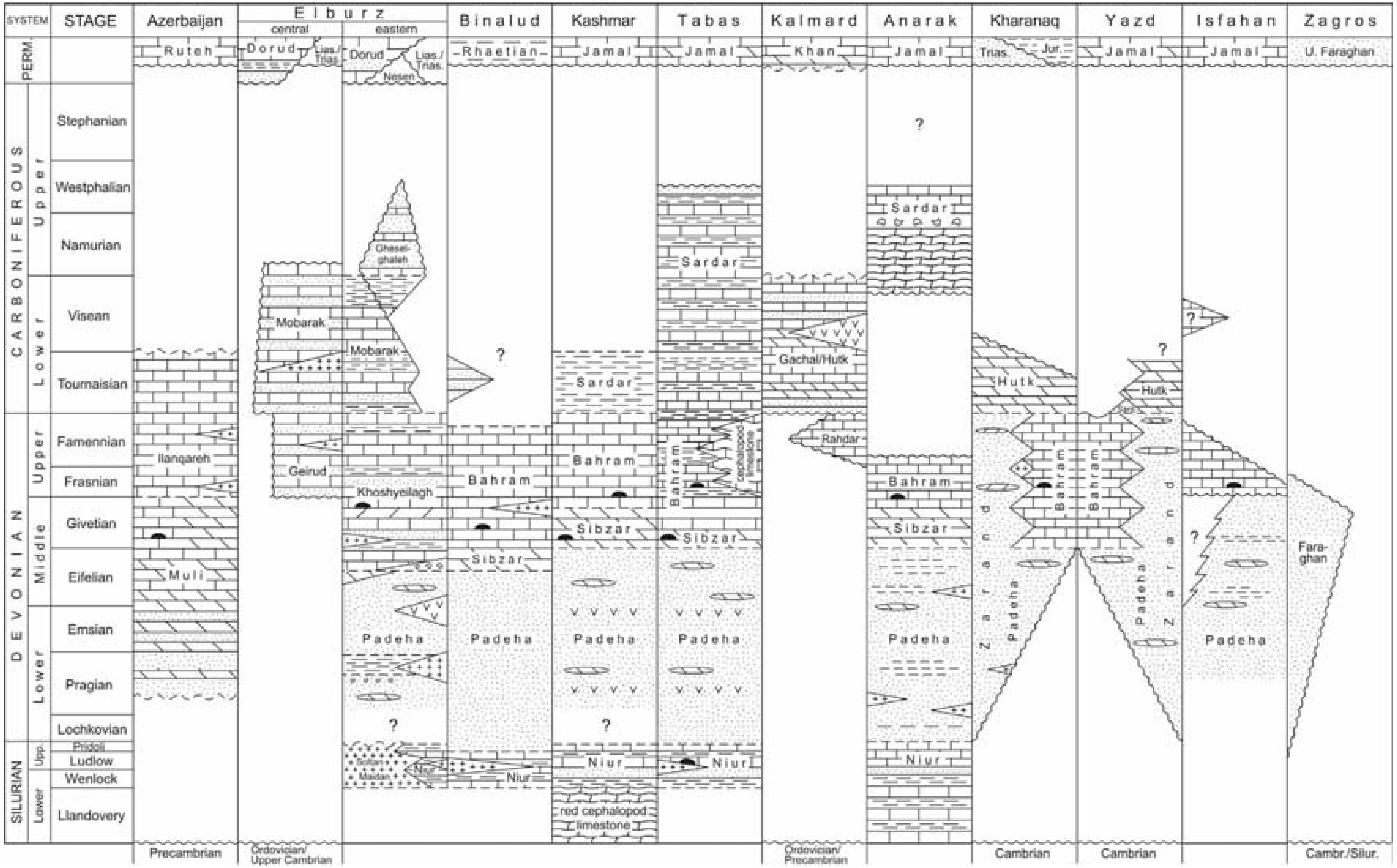


Fig. 3. Synoptic view of Silurian to Permian formations in Iran (modified from WENDT & *al.* 2002). Based on all available sources (publications, geological maps) and own data. For legend see Text-fig. 4. Black segments = biostromes. Broken lines indicate uncertain boundaries. Positions of lithologies (exept biostromes) within individual formations are generalized. For Kerman area see WENDT & *al.* 2002

tectonically strongly disturbed, black limestones and shales crop out which are mapped as Upper Devonian Khoshyeilagh Formation on sheet Gorgan 1 : 250 000 (1991). Both conodont samples from the limestones and palynomorph samples from the shales were barren. Only one sample from the headwaters of Rudhkaneh-e-Bakhshah (I 234) has yielded a fauna of foraminifera of Early Carboniferous (probably Visean) age (Pl. 8, Fig. 7), indicating that at least parts of this unit belong to the Lower Carboniferous Mobarak rather than to the Upper Devonian Khoshyeilagh Formation.

We could not find any outcrop of the band of "fossiliferous limestones and shales" of presumed Devonian-Carboniferous age mapped along the northern slope of the Kuh-e-Sorkhposhteh/Kuh-e-Chaharkal range 20-25 km E of Gorgan. This unit was already mentioned by STÖCKLIN (1959) and is mapped on sheet Gorgan (1 : 250 000, 1991) as transgressive on the ?Precambrian or Palaeozoic Gorgan Schist, and its existence and age would be of utmost importance for the understanding of the palaeotectonic position of the latter.

Aghdarband

In the 15 x 20 km large erosional window of Aghdarband, 120 km ESE of Meshed, an about 25 km long band of the Palaeozoic substrate of the Meso-/Cenozoic succession of the Kopet Dagh is exposed (RUTTNER 1980, 1984, 1991, 1993). Though biostratigraphic dating of the various rock units is poor and their boundaries are mostly tectonic, these outcrops provide an insight into a unique Devonian-Carboniferous sequence, unknown from other parts of Iran.

The remote position of the area and its vicinity to the Turkuman-Afghan border have permitted only two short visits and the examination of two sections, one along the gorge of the Aghdarband River (Aghdarband 1), the other in the Kashaf-Rud valley, 2.5 km NE of the small mining village of Aghdarband (Aghdarband 2), which are combined in Text-fig. 4.

In the Aghdarband 1 section we have distinguished (from S to N) the following five rock units the boundaries of which are all tectonic: (1) Anisian-Ladinian tuffaceous sandstones overthrust by (2) about 200 m of a poorly bedded, fine-grained marble whose age is controversial. RUTTNER (1984, 1991: 50) attributed it to a pre-Devonian (Precambrian or Caledonian) metamorphism, whereas HAMDI (in EFTEKHARNEZHAD & BEHROOZI 1991: 94) reported a Lower Carboniferous microfauna from limestone intercalations in the marble (which we were unable to find). These marbles have nothing in common with the Mobarak Formation (EFTEKHARNEZHAD & BEHROOZI 1991, fig. 2), a comparison which, from the palaeotectonic position of this unit alone, is very unlikely. The marbles are intersected by diabase dykes and followed by (3) 50-60 m of greenish phyllites and shales with intercalated black micritic limestones. Their lithological similarity to unit (5) and the organic content (acritarchs) suggest a Middle or Late Devonian age. The major part of the gorge is occupied by a thick pile of massive, coarse, partly conglomeratic sandstones (4), bound at the base and the top by vertical thrusts. RUTTNER (1984) mentioned Upper Devonian conodonts from calcareous intercalations near the base of this unit. It is followed by about 100 m of black mudstones alternating with sandstones and black shales. The presence of the chitinozoan *Ancyrochitina* (EISENACK 1931) in the basal part suggests a Middle Devonian age. SCHÖNLAUB (1991) described lower Famennian conodonts from the same locality which indicate a clearly pelagic environment. The limestone-shale unit passes gradually into turbiditic sandstones and shales of which only the lower portion is exposed along the southern border of the Kashaf Rud.

A more complete sequence of unit (5) is exposed in the Aghdarband 2 section. Here, green conglomeratic volcanic tuffs are conformably overlain by about 500 m of black shales with some intercalated calcareous mudstones which in turn pass into distal turbidites (Pl. 6, Fig. 2). As a probable consequence of the strong tectonic overprint of the Palaeozoic rocks, palynomorph samples from the shales have yielded only fine organic debris. Some mudstone layers near the base, however, are crowded with acritarchs (Pl. 8, Fig. 3, 4) among which the association of *Baltisphaeridium* cf. *hirsutoides* EISENACK 1951, *B. franconicum* SANNEMANN 1955, *B. longispinosoides* SANNEMANN 1955, *B. brevispinosum* EISENACK 1931, and *Multiplicisphaeridium robustum* SANNEMANN 1955 indicates a Givetian age of this unit. As already observed by RUTTNER (1993, fig. 35), the turbidite sequence is overlain, with an angular unconformity, by sandstones of the Jurassic Kashafrud Formation (unit 6 in Text-fig. 4; Pl. 1, Fig. 1).

Despite the poor biostratigraphic calibration of the rocks and their strong tectonic fragmentation, the Aghdarband section is extremely important because of its unique palaeogeographic and palaeotectonic setting. According to our present knowledge, it is the only area in Iran, in which Devonian deposits exhibit a distinct deep pelagic environment. For the first time STÖCKLIN (1974, p. 884; 1977, fig. 1) has recognized that the Aghdarband erosional window is part of the "northern domain" (Turan Plate). This region must thus be interpreted as a remnant of the passive continental margin

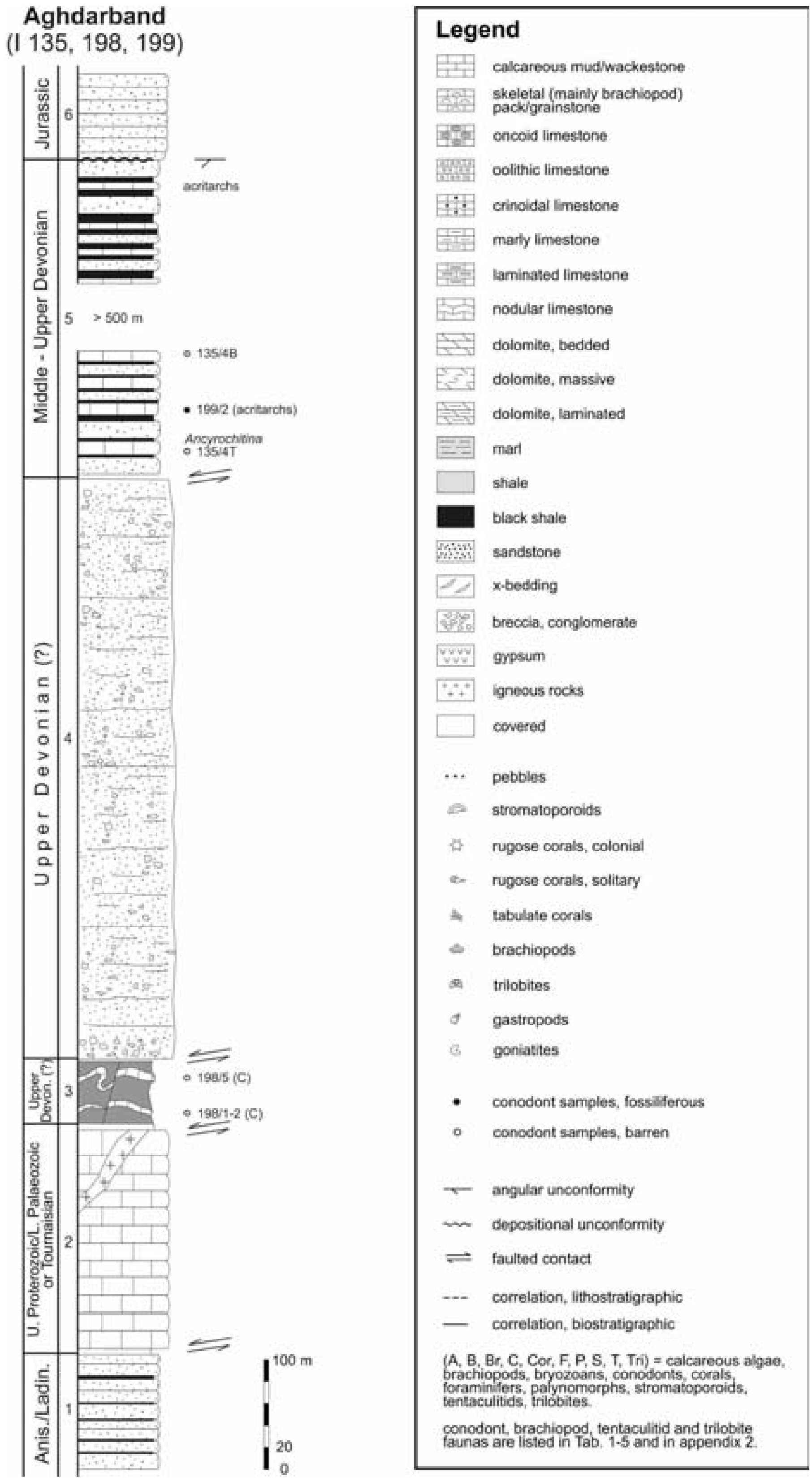


Fig. 4. Aghdarband section (with legend for all subsequent figures)

of Laurussia during the Devonian. The erosional upper boundary of the Devonian turbidites with the overlying Jurassic sandstones of the Kopet Dagh indicates a considerable uplift and a long continental interval during the late Palaeozoic and early Mesozoic.

Azerbaijan

The first observations on the occurrence of Palaeozoic rocks in northwestern Iran by GREWINGK (1853) are merely of historical interest; but he already recognized that sandstones, conglomerates and fossiliferous limestones of Devonian age transgress over a crystalline basement. A little more information can be found in FRECH & ARTHABER's (1900) report on the same region. The first to present some biostratigraphic data was RIEBEN (1935) in his dissertation about the geology of the Iran-Azerbaijan borderland. ALAVI & BOLOURCHI (1973) confirmed that in the area north of Tabriz deposits of presumed Early to Late Devonian age (Muli and Ilanqareh Formations) transgress on a Precambrian basement or on Lower Palaeozoic sandstones and dolomites of the Lalun and Mila Formations and are in turn overlain by Permian platform dolomites of the Ruteh Formation. The Devonian neritic deposits are the westward continuation of similar coeval lithologies in the central Elburz. The most continuous outcrops occur in a 25 km long SW-NE belt between Maku and the Araxes River, the border with the Republic of Azerbaijan. We examined the type sections of the Muli and Ilanqareh Formations close to the homonymous villages and realized that both localities, due to ubiquitous folding and faulting, are not suitable for establishing individual lithostratigraphic units (Pl. 1, Figs 2, 3).

The Muli Formation starts with some tens of metres of quartzitic sandstones which transgress over a deeply eroded surface of Precambrian metamorphics. The sandstones grade upwards into well-bedded, partly microbially laminated, dolomites with some intercalated black limestones (1-5). The latter contain tabulate corals (thamnoporids), stromatoporoids and some solitary rugose corals (4). In comparison with biostromal intercalations in other areas (Elburz, Binalud, Anarak, Kashmar, Kerman) a Givetian age is most feasible. Because of ubiquitous folding and faulting (Pl. 1, Fig. 3) the thickness of the Muli Formation can be only roughly estimated and probably does not exceed 300-400 m. It grades into a sequence of dark, medium- to thick-bedded skeletal limestones (Ilanqareh Formation) which contain several biostromal lenses composed of stromatoporoids, rugose and tabulate corals. The presence of favositids, thamnoporids, *Hexagonaria* and *Phillipsastraea* indicates they are not younger than Frasnian. The base of this

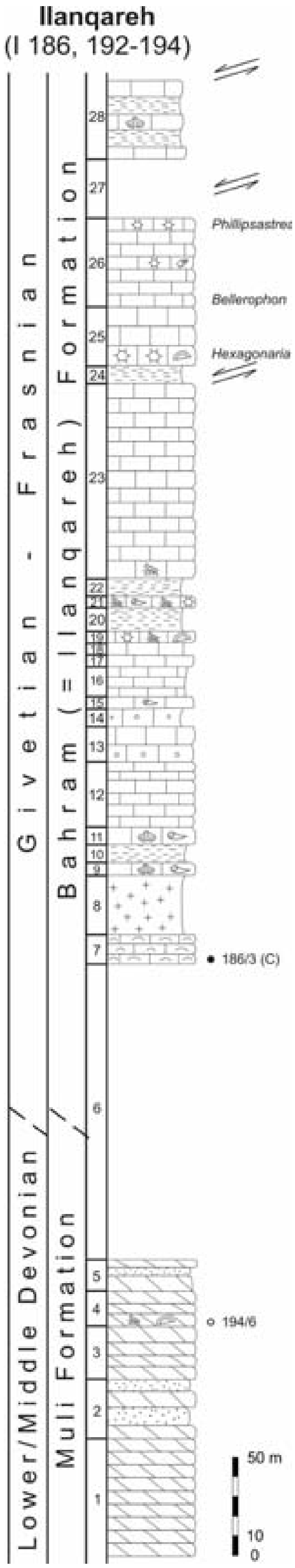


Fig. 5. Ilanqareh section

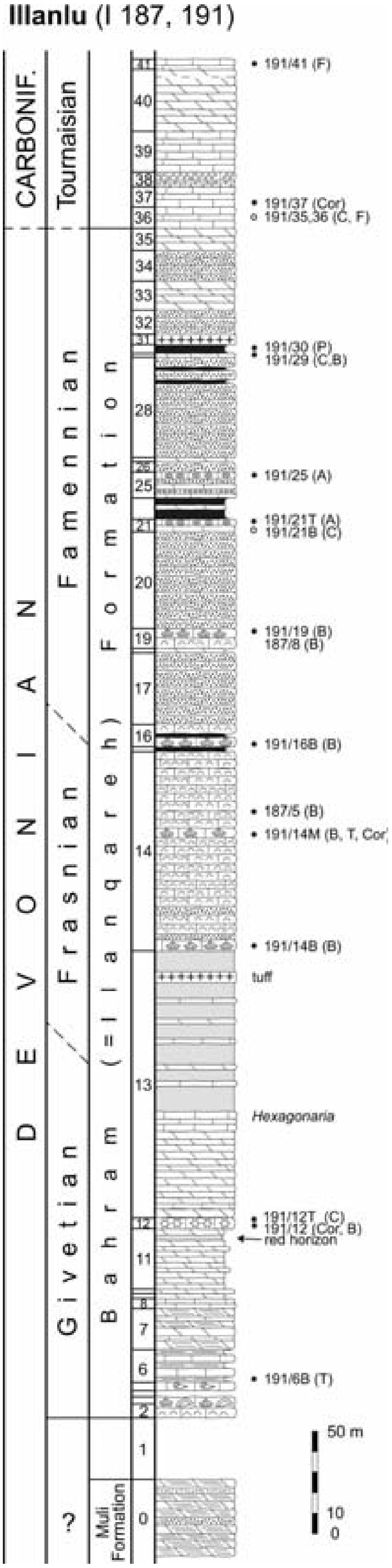


Fig. 6. Illanlu section

sequence (7) was dated as lower Givetian. This part (7-23) is only weakly folded in the type section where it is approximately 300 m thick (Text-fig. 5). Intense faulting higher up in the sequence (Pl. 1, Fig. 2), however, makes thickness calculations hazardous. Therefore we consider ALAVI & BOLOURCHI's (1973) measurement of 1308 m (sic!) for the entire Ilanqareh Formation as too high. In the uppermost, less disturbed, portion of the formation near the southern end of the valley east of Talom Khan (6.6 km SE of Ilanqareh) corals have not been observed. Brachiopods indicate a Tournaisian age (sample 184/7) for the uppermost part of the Ilanqareh Formation which is unconformably overlain by black limestones of the Permian Ruteh Formation.

A much better and almost undisturbed section through the upper part of the Muli and the entire Ilanqareh Formation is exposed near the village of Illanlu (sheet Poldasht 1 : 100 000). In this locality we examined a 745 m sequence of well-bedded skeletal limestones with some intercalated dolomite and sandstone intervals (Text-fig. 6). Brachiopods are very abundant and document the presence of Givetian to Famennian horizons. From the almost continuous occurrence of tentaculitids it is evident that the Frasnian portion of the sequence is about 150 m thick. Biostromal intercalations, each 0.5 to 1.5 m thick and crowded with stromatoporoids, tabulate and colonial as well as solitary rugose corals occur at three levels (3, 12, 13). Oncolithic limestones (Pl. 10, Fig. 3) indicate that shallow water conditions continued into the Famennian.Two intercalations of strongly weathered tuff breccias and basalts (13, 31) document weak volcanic activity during the Late Devonian. Poorly preserved solitary rugose corals (*Caninophyllum*) found near the top of the sequence (37) indicate a Tournaisian/early Visean age, but the Devonian-Carboniferous boundary could not be exactly established.

Another locality for examining the upper part of the Ilanqareh Formation is 1.5 km NW of Pireshag (sheet Julfa 1 : 100 000) where 185 m of brachiopod limestones, overlain by sandstones, are exposed. A brachiopod fauna from near the top of the limestones is latest Famennian (Strunian) age. A conodont sample from the top of the sequence indicates the presence of Lower Carboniferous (Visean). This sequence is overlain, with a tectonic contact, by about 500 m of volcanic rocks (rhyodacites, andesites) mapped as Devonian but possibly younger. On the neighbouring sheet Qara-Ziaaddin (1 :100 000) they are referred to as pre-Upper Permian. They are covered by grey mudstones with Permian bellerophontids

The overall facies evolution and the assemblages of brachiopods, tentaculitids and corals indicate that in

Devonian-Early Carboniferous times northwestern Iran was part of a wide, siliciclastically influenced shelf sea which extended from Afghanistan into the Azerbaijan-Turkey borderland (Gedik 1988).

Elburz Mountains

Central Elburz

The presence of Devonian-Lower Carboniferous rocks in the central part of the Elburz Mountains has been known for more than a century (Stahl 1897, 1911; Krumbeck 1922, Rivière 1934, Bailey & *al.* 1948, and others). This area has been mapped in great detail by Gansser and his students (Gansser & Huber 1962, Lorenz 1964, Dellenbach 1964, Glaus 1965, Allenbach 1966, Steiger 1966, Dedual 1967, Meyer 1967, Sieber 1970, Cartier 1971, Seger 1977, Isler 1977). Substantial stratigraphic research started in the 1960's (Assereto 1963, 1966; Gaetani 1965, 1967; Vatan & Yassini 1969; Stepanov 1971; Djafarian 1973). These authors recognized that deposits of Silurian to Middle Devonian age are totally lacking in the central Elburz and that the Upper Devonian Geirud Formation rests unconformably on the Cambrian Mila Formation. In the area E of the Kandevan Pass this gap is greater including the entire Upper Devonian (Glaus 1965, Dedual 1967, Cartier 1971, Rassekh & *al.* 1984, Vollmer 1987). The Devonian-Lower Carboniferous strata consist of skeletal limestones, shales, and quartzitic sandstones with, especially in the upper portion, up to 400 m of intercalated basalts. The total thickness of the Upper Devonian and Lower Carboniferous (Geirud and Mobarak Formations) attains up to 765 m (Assereto 1963). The biostratigraphic subdivision of this sequence has been based on brachiopods and therefore is still unsatisfactory.

Hassanakdar (Text-fig. 7)

This easily accessible section on the road from Karaj to Chalus has been studied by Kimyai (1980) and Ghavidel (1994b, 1995a). On the basis of palynomorphs the Devonian part (Geirud Formation) is said to be Middle Devonian to Frasnian (Kimyai 1980) or exclusively Frasnian in age (Ghavidel 1994b). With a faint erosional boundary the deposits of the Geirud Formation overlie Cambrian/Lower Ordovician (Mila Formation) limestones and shales with several intercalated basalt sills (5, 7). We could not find the limestone bed at the base of Ghavidel's (1994b, fig. 3) zone IV. The lower part of the Geirud Formation is poorly

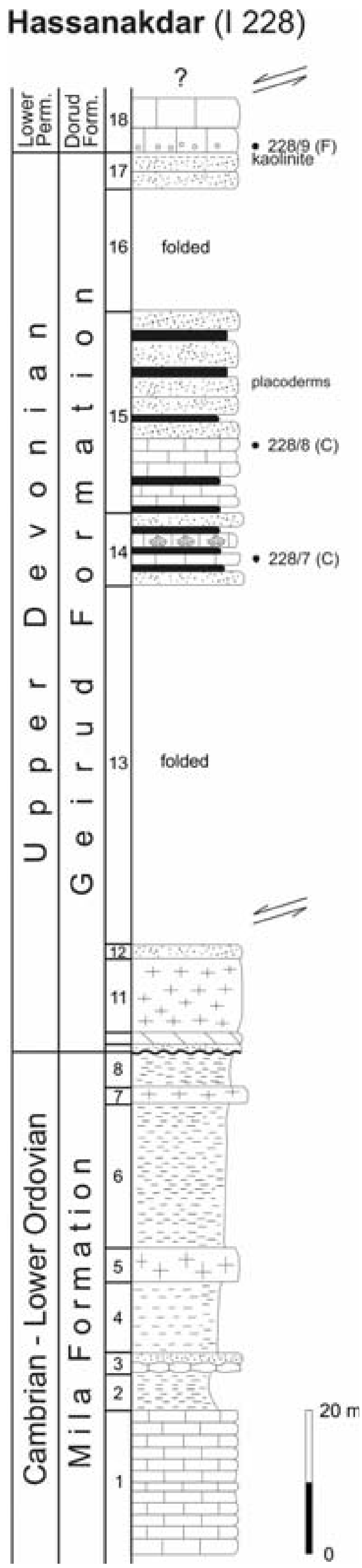


Fig. 7. Hassanakdar section

exposed and complicated by faulting. Several folds in the upper part suggest a much greater total thickness than in fact is present; we have calculated approximately 125 metres, i. e. about a third of GHAVIDEL's (1994b) measurement. Two samples from the upper part (14, 15) produced a few conodont fragments of late Famennian age. A thin kaolinite level at the top of the Geirud Formation (17) marks the boundary towards the Lower Permian fusulinid limestones of the Dorud Formation. The latter starts with a 0.5 m thick transgression conglomerate of reworked Devonian sandstones.

About 20 km to the N, the upper Tournaisian-Visean Mobarak Formation is again preserved (AHMADZADEH HERAVI 1971) showing that the transgression of the Lower Permian has cut down onto differing levels in the Upper Devonian/Lower Carboniferous.

Geirud

The type section near the village of Geirud examined by ASSERETO (1963, 1969), GAETANI (1965), AHMADZADEH HERAVI (1971), KIMYAI (1972), DJAFARIAN (1973) and WENSINK & *al.* (1978) is perfectly exposed along a trail leading to a mining adit for exploitation of Devonian phosphatic deposits. The intertidal dolomites of the Upper Cambrian Mila Formation contain two basaltic dykes and are overlain, without a visible sedimentary break, by sandstones with some intercalated unfossiliferous limestones. Abundant brachiopods higher in the sequence indicate a Frasnian age for these limestones. Tuffaceous sandstones near the top of this member contain poorly preserved plant remains attributed to the upper Famennian by SARTENAER (1964) and GAETANI (1965). A basalt flow, about 300 m thick and forming a prominent ridge, separates a lower from an upper marine member. The latter was originally included in the Geirud Formation by ASSERETO (1963), but later assigned to the Lower Carboniferous Mobarak Formation by STEPANOV (1971). Conodont discoveries by AHMADZADEH HERAVI (1971) confirm a late Tournaisian to late Visean age for the formation; it is unconformably overlain by the Lower Permian Dorud Formation. GAETANI (1965) studied additional sections farther west and east (Lalun, Zaigun Valley and others) but, apart from a reduced thickness of the basalt flow, they show little difference compared to the type section. The discovery of upper Famennian *Sporadoceras* (= *Maeneceras rotundolobatum*, T. BECKER, Münster, pers. comm.), *Prionoceras*, *Platyclymenia* and *Manticoceras* (the latter is probably a misidentification) from the Zaigun Valley by DASHTBAN (1995) is remarkable, as are the reports of Lower Carboniferous gonitatites by the same author and from the same section; but they are neither specified nor localized.

Mobarak

This section has been studied by ASSERETO (1963, 1966), ASSERETO & GAETANI (1964), DELLENBACH (1964) and AHMADZADEH HERAVI (1971). ASSERETO (1963) established the Lower Carboniferous Mobarak Formation on the upper part of the sequence. The Upper Devonian Geirud Formation is only about 140 m thick, but is faulted near the top. In contrast to other localities in the central Elburz, this unit is predominantly siliciclastic and contains only a few calcareous interbeds in which some Frasnian brachiopods and two species of upper Famennian clymenids (RIVIÈRE 1931, FURON 1941) have been found. In contrast to ASSERETO's (1963) type section, the lower 200 m of the Mobarak Formation are predominantly shaley, overlain by a thick pile of dark limestones with productid brachiopods and crinoids, which may be equivalent to ASSERETO's (1963) members 3 and 4 and in which AHMADZADEH HERAVI (1971) found upper Visean conodonts. Some tens of kilometres farther east, the presence of upper Devonian equivalents in the series overlying the Cambrian Mila Formation is not well established (ALLENBACH 1966); deposits of this age may be totally lacking. The thickness of the overlying Mobarak Formation is in the order of 150 to 200 m (STEIGER 1966).

Shahmirzad

The Shahmirzad section north of Semnan is important because of the unusually fossiliferous Cambrian Mila Formation (PENG & *al.* 1999) which, in the middle part (member 3) includes upper Middle Cambrian demosponge patch reefs (HAMDI & *al.* 1995). They are overlain by a 200 m sequence of limestones, sandstones and shales (upper part of member 3 and member 4-5 of the Mila Formation). HAMDI & *al.* (1995) reported shallow-water trace fossils and trilobites from these rocks, whereas LASEMI (2001, Fig. 4-8) inferred a deep marine, turbiditic environment for the same lithology. In the field we could not find any proof for the latter view and therefore differ over the construction of Ordovician-Silurian syn-rift systems in the Elburz Mountains based on this section (LASEMI 2001, p. 88). The upper part of the Mila Formation is of Early Ordovician (Tremadoc) age and is unconformably overlain by about 100 m of Upper Devonian skeletal lime-

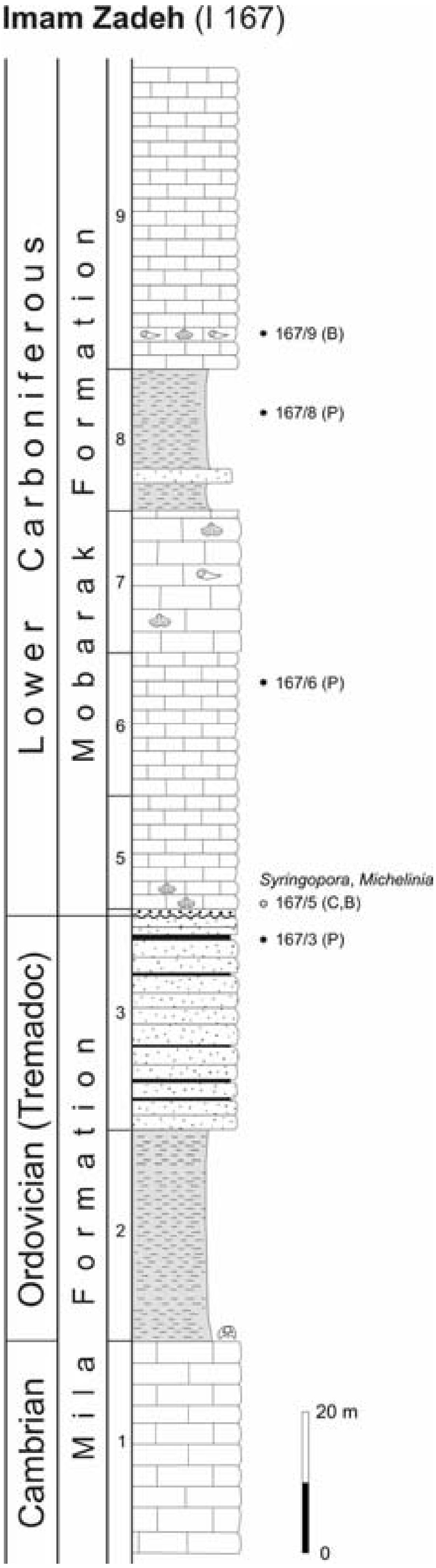


Fig. 8. Imam Zadeh section

stones with brachiopods (partly figured by KALANTARI 1981), crinoids and bellerophontids (Geirud Formation) which in turn grade into 150 m of black shales and limestones with productids and crinoids of the Lower Carboniferous Mobarak Formation. The latter is capped by a conspicuous laterite level reflecting a long continental interval before the onset of carbonate platform sedimentation of the Triassic Elika Formation.

Imam Zadeh

An even greater gap at the top of the Mila Formation is observed about 20 km SSE of the Shahmirzad section, near the mosque of Imam Zadeh (Text-fig. 8). At this locality, skeletal mudstones with brachiopods, crinoid remains, *Michelinia* and *Syringopora* of Early Carboniferous age transgress over black shales and sandstones (2, 3) which have produced trilobites and palynomorphs of Tremadocian age. The transgression is marked by a coarse sandstone layer with phosphatic pebbles (4). We found brachiopods of Visean age about 80 m above the base of the overlying dark limestones. Already ALAVI-NAINI (1972) has recognized that this northern zone (A) is sharply separated from the southern one (B; Kuh-e-Rezaabad section, see below) where the sequence is much more complete and includes Silurian to Upper Devonian deposits as well. The boundary between the two zones is marked by a steep, south-dipping thrust fault (Attarie Fault) which must have been active already in mid-Palaeozoic times and repeatedly reactivated until the Late Cretaceous.

Kuh-e-Rezaabad (Text-fig. 9)

We have re-examined the section of Kuh-e-Rezaabad studied by ALAVI-NAINI (1972). The lower part (1, Padeha Formation) consists of an alternation of cross-bedded white quartzites and red sand- and siltstones, with some intercalated laminated dolomites and two gypsum-layers. The base of this sequence is faulted; the contact with the underlying Silurian Niur Formation is not exposed. The sequence overlying the Padeha Formation is 245 m thick and can be divided into four units: (a) 45 m of dark skeletal limestones containing some colonial rugose corals (*Phillipsastrea),* with some intercalated microbial layers (3-6). Close to the top (5), brachiopods of Middle Devonian age have been found. (b) 50 m of gypsum with laminated dolomite layers (7). (c) 70 m of brachiopod limestones (Pl. 9, Figs 1-2), partly folded and faulted (8-12). Several brachiopod faunas indicate an early to late Frasnian age of this member. (d) 60 m of thin-bedded sandstones interbedded with marls (13), overlain by 20 m of laminated whitish quartzite (14). The latter is attributed to the Permian by ALAVI-NAINI (1972), but because of no visible break in sedimentation at the base, a Famennian age of this member appears more feasable.

The Permian Jamal Formation is calcareous at the base and dolomitic higher up and contains bellerophontids and colonial rugose corals (*Lithostrotion*). The Kuh-e-Rezaabad section is remarkable because it is, apart from Kuh-e-Ozom (see below), obviously the only place in Iran where an evaporitic facies occurs in the Upper Devonian. This phenomenon appears to be a rather local one because only 5 km to the north, coeval gypsum layers are absent.

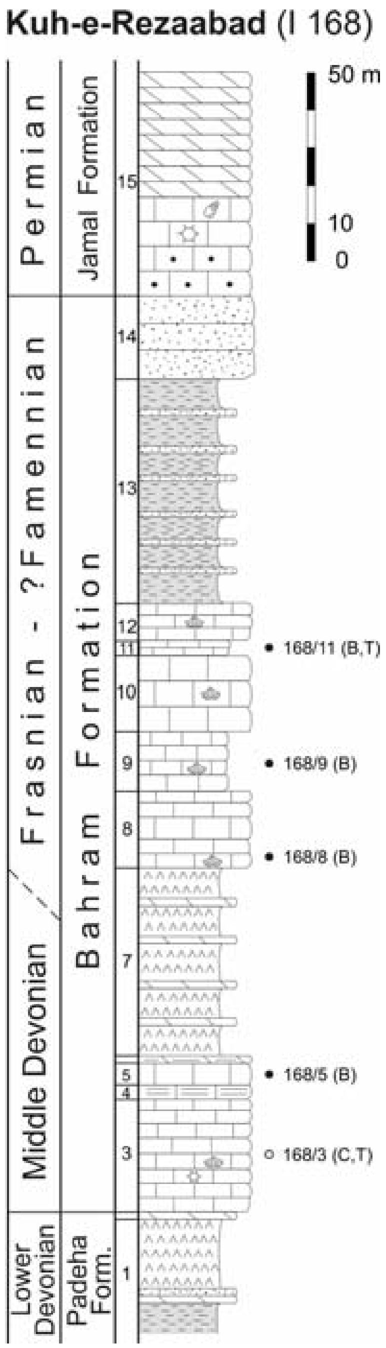


Fig. 9. Kuh-e-Rezaabad section

About 60 km farther SE, in the mountain ranges delimiting the Great Kavir in its north, are Palaeozoic rocks influenced by a low-grade metamorphism. A probable Silurian to Middle Devonian age has been obtained from poorly preserved corals from a phyllite-marble sequence (THIELE 1970).

Rud-e-Namakeh

In the mountain ranges NNW of Damghan (Kuh-e-Siakhany, Kuh-e-Charhalat) an Upper Devonian to Permian sequence is thrust to the S over Neogene or Jurassic strata. In the deeply incised valley of Rud-e-Namakeh the basal part of the exposed Palaeozoic consists of strongly folded and faulted skeletal wackestones with numerous brachiopods and tentaculitids indicating a Frasnian age passing upwards into similar dark limestones with brachiopods, crinoids and ostracods (Geirud Formation). The Mobarak Formation shows a subdivision into two members similar to the eastern Elburz: (1) grey and black shales with a prominent quartzite ridge in the middle part passing into (2) well-bedded dark limestones with rare brachiopods, crinoids, gastropods and entomozoans. A conodont sample from the base of this member (I 24/7M) indicates an uppermost Tournaisian/lowermost Visean age. Because of ubiquitous folding and faulting, thickness estimates for the entire sequence are speculative and may be in the order of 1000 metres.

Eastern Elburz

Because of their relative completeness and high fossil content, several sections in the eastern Elburz have repeatedly been studied in the past and have contributed considerably to the knowledge of the sedimentary record of the Devonian/Lower Carboniferous in northern Iran (BOZORGNIA 1973, BRICE & *al.* 1974, AHMADZADEH HERAVI 1975, JENNY 1977a, COQUEL & *al.* 1977, STAMPFLI 1978, BRICE & *al.* 1978, HAMDI & JANVIER 1981, WEDDIGE 1984b, ASHOURI 1990, GHAVIDEL 1994b). In contrast to the central Elburz, this interval is represented by much thicker and more fossiliferous deposits and therefore has become a key region for study of the Devonian/Lower Carboniferous in Iran. For the present study we examined the following sections: Khoshyeilagh, Mighan, Deh Molla, Kuh-e-

Ozom, Robat-e-Gharebil and Shiroohyeh. One of us (A. K. B.) collected a great number of conodont samples from these sections, but the determination of the taxa by M. Yazdi (Isfahan) and his collaborators is still in process. The obtained data will be published in a forthcoming paper.

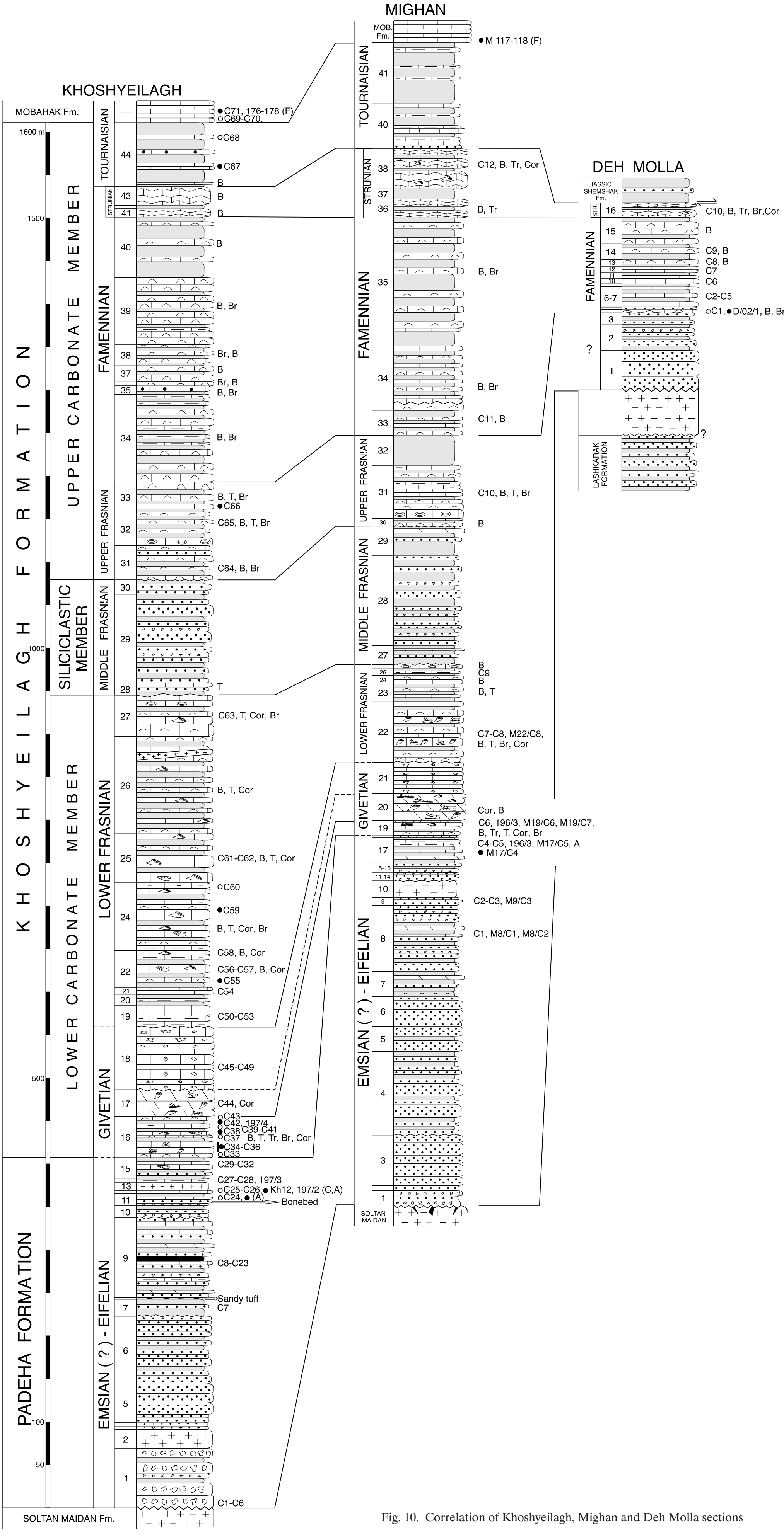
Khoshyeilagh (Text-fig. 10)

Because of its easy accessibility, the Devonian-Lower Carboniferous sequence exposed along the paved road from Shahrud to Gonabad has again and again attracted stratigraphers. It has first been measured and roughly dated by BOZORGNIA (1973) who established the formation name (Khoshyeilagh Formation) and divided it into 17 units extending from the Eifelian to Famennian with a total thickness of 1354 m. The lower part of the section was restudied and dated with brachiopod and conodont faunas by AHMADZADEH HERAVI (1975). The conodonts were revised by WEDDIGE (1984b) who demonstrated that the oldest fauna is earliest Givetian rather than late Emsian in age. HAMDI & JANVIER (1981) remeasured the section and dated the basal part by 11 conodont faunas which are said to range from the lower Emsian into the Eifelian. These contradictory age attributions of the basal part of the Khoshyeilagh Formation were discussed by ASHOURI (1990) who, in accordance with WEDDIGE (1984), BRICE & *al.* (1974, 1978) and STAMPFLI (1978), argued that the onset of a fully marine sedimentation is earliest Givetian (*hemiansatus* Zone). Biostratigraphic evidence of Eifelian to Upper Carboniferous levels in this section was mentioned by ASHOURI (2001).

In contrast to previous workers who subdivided the section into 7 or 8 members and 17 units or "beds", we found that the Devonian sequence can be split into only 4 clearly discernible members. Simultaneously with our research, ALAVI NAINI (2000) proposed the following names for these members (from base to top): Mighan (= Padeha Formation), Tilabad (= lower carbonate member), Shahvar (= siliciclastic member) and Sarcheshmeh (= upper carbonate member). The top of the andesitic lavas and tuffs of the Soltan Maidan Formation is a sharp, irregular boundary (Pl. 6, Fig. 1) indicating a long exposure of unknown duration (part of the Silurian and Early Devonian). The Padeha Formation (member 1) starts with a 70 m thick polymict and poorly sorted conglomerate (1) of Cambrian (?) sandstones and Silurian (?) limestones and basalts with interlayered red and grey shales. Interrupted by a conspicuous basaltic lava flow (2), the conglomerates grade into red and white, partly laminated, sandstones (3-6) passing in turn into a heterogeneous series of varicoloured shales, siltstones, sandstones, conglomerates and dolostones seamed by basalt dykes (7-15). In unit (11) BLIECK & *al.* (1980) found a fish bonebed which was dated as Eifelian. Conodont samples taken from calcareous intercalations in units (12) and (14) were barren, but they contain, apart from thin-shelled ostracods, numerous charophyte oogonia indicating a freshwater to brackish environment (Pl. 8, Figs 1-2). Among the species identified by M. FEIST (pers. comm.) are: *Trochiliscus panderi* (EHRENBERG) HINZ-SCHALLREUTER & SCHALLREUTER and *Sycidium minor* (KARPINSKY) HINZ-SCHALLREUTER & SCHALLREUTER, which indicate a late Eifelian age of these units. Unit (15), equivalent to BOZORGNIA's (1973) bed 4, contains numerous pelecypods and ostracods indicating a marginal marine environment.His report of "Couvinian" brachiopods from this level is thus problematic. Taken the overall lithology of this member which reflects a very rapid sedimentation, these scarce biostratigraphic data suggest that the Padeha Formation is Eifelian, but may include an unknown amount of Emsian. GHAVIDEL-SYOOKI's (1994) attribution of this formation to the Frasnian, based on palynomorphs, therefore cannot be accepted.

In 1977 the National Iranian Committee (unpubl. internal report) proposed to place the base of the Khoshyeilagh Formation in the type section at the lower limit of our unit (9). Because this boundary appears rather arbitrary, we consider the onset of a fully marine sedimentation in unit (16) as a much more consistent lower limit of the Khoshyeilagh Formation. The latter starts with skeletal wacke- to packstones which in many levels are crowded with brachiopods (partly figured by KALANTARI 1981) and, to a lesser degree, with tentaculitids, bryozoans, rugose corals, and trilobites. The formation can be divided into three lithologically characterized members: a lower carbonate (1), a siliciclastic (2) and an upper carbonate member (3).

The lower carbonate member is 540 m thick and consists of an alternation of skeletal and peloidal wacke- and packstones, shales and dolomites. Several brachiopod, tentaculitid and trilobite (MORZADEC 2002) faunas, as well as dates proposed by other workers, indicate that this member includes the entire Givetian and the lower Frasnian, but the exact boundary between these stages is not clear. Coral floatstones occur at various levels, but the abundant colonial Rugosa and Tabulata (some described by GHODS 1982) are mostly current-swept and only locally constitute small biostromes. The prominent massive dolomites (17) and the overlying brecciated


KHOSHYEILAGH
MIGHAN
DEH MOLLA
MOBARAK Fm.
SOLTAN MAIDAN Fm.
KHOSHYEILAGH FORMATION
PADEHA FORMATION
UPPER CARBONATE MEMBER
SILICICLASTIC MEMBER
LOWER CARBONATE MEMBER
TOURNAISIAN
STRUNIAN
FAMENNIAN
UPPER FRASNIAN
MIDDLE FRASNIAN
LOWER FRASNIAN
GIVETIAN
EMSIAN (?) - EIFELIAN
LIASSIC SHEMSHAK Fm.
LASHKARAK FORMATION
Bonebed
Sandy tuff
Fig. 10. Correlation of Khoshyeilagh, Mighan and Deh Molla sections

limestones (18) may be tentatively correlated with lithologically similar levels (20) and (21) of the Mighan section, but precise biostratigraphic control is lacking. .

The siliciclastic member (28-30), bed 13 of BOZORGNIA (1973), consists of mostly reddish, rarely greenish sandstones, siltstones and shales. The sandstones show cross lamination and current ripples indicating a nearshore to possibly fluvial environment. Skeletal remains have not been found in this member but, inferred from the age of the under- and overlying brachiopod and tentaculitid limestones, it is of middle Frasnian age.

The upper carbonate member (31-44) consists of an alternation of skeletal limestones and shales and is exeptionally rich in brachiopods. The Frasnian-Famennian boundary must be placed at the top of (33), i. e. somewhat above the last occurrence of tentatulitids. The nodular limestones of (41) to (43) contain brachiopods and trilobites of uppermost Famennian (Strunian) age and represent a typical lithology which can be also found in the Mighan and Deh Molla sections (see below). ASHOURI (1990, 1994) reported conodont faunas from these units indicating a latest Famennian to late Tournaisian age (*anchoralis* Zone) for the upper part of the Khoshyeilagh Formation.

The uppermost Tournaisian/Visean Mobarak Formation (not shown on Text-fig. 10) consists of a lower calcareous and an upper, predominantly argillaceous member, each about 200 m thick. The lower member forms a prominent escarpment, the upper member is capped by fusulinid limestones of the Lower Permian Dorud Formation.

Mighan (Text-fig. 10)

The section 40 km SW of Khoshyeilagh is situated on both sides of a narrow valley about 6 km NW of the village of Mighan and 24 km north of the town of Shahrud. It has been studied by JENNY (1977a, under the name of Kalate Hadji Abdul Hossein), BIROUNROU (2000) and KARIMI (2001) and shows a perfectly exposed sequence from the Silurian (?) into the Permian. The lower part consists of a several hundred metres complex of basaltic rocks (Soltan-Maidan-Formation) of presumed Silurian age. The top of the basalt is an irregularly eroded surface from which dolomite-filled veins penetrate into the uppermost 10-20 m of the deeply weathered rock. This phenomenon indicates a major hiatus equating with part (or all?) of the Silurian and the Lower Devonian. The Padeha Formation and the three members of the Khoshyeilagh Formation have a similar overall appearance compared to the Khoshyeilagh section and can be lithostratigraphycally correlated to the latter with some confidence.The Padeha Formation consists of 430 m of thick, red, white and grey, partly cross-bedded and/or conglomeratic sand- and siltstones, into which some intertidal mud- and dolostones are intercalated. Apart from ostracods and some recrystallized mollusc shells they do not contain any diagnostic organic remains. In sandstones above a conspicuous 20 m basalt sill (10), JENNY (1977a) has found plant remains to which he attributed a probable Eifelian age. We obtained a more precise Eifelian age from charophyte oogonia found in the upper part of unit (17); it can thus be correlated with unit (12) of the Khoshyeilagh section. JENNY (1977a) restricted the term Padeha Formation to the lower 191 m of the sequence, but we propose to extend it until the onset of fully marine sedimentation in (19) which provides a less arbitrary boundary between the two formations. BIROUNROU (2000) figured several upper Emsian and Eifelian conodonts from limestone intercalations in the Upper Padeha Formation, but some of her determinations are misidentifications leaving no doubt that the onset of a fully marine environment, as in the Khoshyeilagh section, is not older than earliest Givetian. In addition to brachiopods, the lower skeletal limestones (19, 20) contain transported thamnoporids and solitary rugose corals (Pl. 7, Figs 2, 3). The brachiopod fauna in (19) is very similar to that of unit (16) in Khoshyeilagh and indicates a probable early Givetian age.

The Khoshyeilagh Formation is a very heterogeneous sequence of dark skeletal limestones, shales, sandstones and a few dolomitic intercalations and has a total thickness of 925 m. The limestones contain numerous brachiopods, crinoid debris, tentaculitids (Pl. 7, Fig. 5), some rugose and tabulate corals, gastropods and, in the uppermost part (36, 38), scattered trilobites. Brachiopods and tentaculitids indicate a Givetian-Frasnian age for the lower 470 m of the sequence. The Famennian is 330 m thick, the Tournaisian part of the Khoshyeilagh Formation 120 m. The Devonian-Carboniferous boundary could not be exactly established and must be searched somewhat above level (38) with uppermost Famannian brachiopods previously reported by JENNY (1977a). The overlying shale unit (41) contains some dark wackestone layers with typical foraminifera (*Earlandia*, *Endothyra*, *Palaeotextularia*) of Tournaisian age.

The Lower Carboniferous Mobarak Formation (not shown on Fig. 10) consists of two lithologic members, each about 300 m thick, a lower calcareous sequence forming a conspicuous escarpment, and an upper shale member with thin limestone intercalations. The latter is followed by 150 m of sandstones attributed to the upper

Visean/Namurian Gheselghaleh Formation by JENNY (1977a). The base of the Lower Permian Dorud Formation is a distinct hiatus indicated by an erosional unconformity. The lowermost 0.5 m of the Dorud limestones is distinguished by a high amount of detrital quartz and contains numerous corals, oncolites and fusulinids of late Early Permian age.

Deh Molla (Text-fig. 10)

STAHL (1911) reported the first evidence of brachiopod-bearing Upper Devonian rocks in this part of the eastern Elburz. Though only 37 km SW of Mighan, the Deh Molla section shows a considerable reduction in thickness (220 m vs. 1350 m for the Middle and Upper Devonian) making lithostratigraphic correlations between the two sections impossible. According to the 100,000 map (sheet Shahrud, 2001) the Upper Devonian Geirud Formation is underlain by sandstones, shales and limestones of the Ordovician (?) Lashkarak Formation. In this map the 50 m basalt of our section is included in the Geirud Formation, but may be considerably older. With an erosional contact, it is overlain by 85 m of sandstones and shales (1-3) of uncertain age. KEBRIAIEZADEH & GHOLAMALIAN (2004) studied the brachiopod fauna of the overlying skeletal limestones (4-15) and found they are of Famennian age. They pass into typical uppermost Famennian (Strunian) nodular limestones (16) crowded with brachiopods, bryozoans and solitary rugose corals. The section is truncated by an overthrust against shales of the Jurassic Shemshak Formation. Because of its reduced thickness and the incomplete Devonian sequence, the Deh Molla section is much more similar to the central Elburz (Geirud area) than to the Mighan-Khoshyeilagh area. A palaeofault can be assumed to explain the striking contrast between the two sections of Imam Zadeh and Kuh-e-Rezaabad (see above)

Robat-e-Gharabil

The mountain ranges of the Kuh-e-Aladag and Kuh-e-Kurkhud S and W of Bojnurd are the eastern prolongation of the Elburz Mountains S of the Kopet Dagh from which they are separated by the (concealed) suture zone of the Palaeotethys. Three localities in this area have been examined for the present study: Robat-e-Gharabil, Kuh-e-Ozom and Shirooyeh (Text-fig. 11).

The section 4 km NNE of the village of Robat-e-Gharabil was first mentioned by BRICE & *al.* (1974) who figured a very generalized stratigraphic column and described several Silurian, Middle Devonian and Frasnian brachiopods. More precise stratigraphic information can be gathered from AFSHAR HARB's (1979) dissertation on the Kopet Dagh region. He recognized a very thick (660 m) Niur Formation composed of three members: a lower shale member with an intercalation of basic volcanics, a middle carbonate and an upper sandstone member. Tabulate corals and brachiopods from the carbonate member indicate a Llandovery-Wenlock age (BRICE & *al.* 1974, AFSHAR HARB 1979, COCKS 1979). The upper sandstone member (3-4 in Text-fig. 11) is overlain by a dolomitic member (5) whose upper boundary is regarded as the Niur/Padeha boundary by AFSHAR HARB (1979), whereas BOZORGNIA (1973) places this boundary at the base of the dolomite. Due to the total lack of organic remains both attributions remain doubtful. At various levels (2 and older) basic igneous rocks are intruded into the Silurian sequence, but it cannot be decided if they are an equivalent of the Soltan Maidan volcanics farther west. The Padeha Formation consists of a lower siliciclastic (6-9) a middle evaporite (10) and an upper dolomitic member with gypsum intercalations (11-14) indicating a sebkha environment with clastic influx.

The basal 100 m of the Khoshyeilagh Formation (15-18) have yielded only poorly preserved brachiopods of Eifelian-Givetian age (levels 13-14 in BRICE & *al*. 1974). An abundant Givetian fauna of brachiopods, tentaculitids, rugose corals and trilobites was collected from two levels of (19). The age of the cliff-forming massive dolomites with *Syringopora* (20) and brecciated limestones (21-22) remains doubtful. AFSHAR HARB (1979) assigns it to the Tournaisian Mobarak Formation, assuming a considerable depositional gap at its base, but a Givetian age (corresponding to units 17-18 of the Khoshyeilagh section) cannot be excluded. After a concealed (faulted?) zone at its top, a sequence of thin-bedded limestones (23-29) is exposed, crowded with Frasnian brachiopods and rugose corals (Pl. 1, Fig. 1) is exposed described by BRICE & *al*. (1974). Famennian equivalents of the Khoshyeilagh Formation seem to be absent from the Robat-e-Gharabil area. In the described section the Frasnian skeletal limestones are faulted against marls of the Middle Jurassic Chamanbid Formation.

Kuh-e-Ozom (Text-fig. 11)

The section is situated on the southern flank of a south-vergent syncline (Kuh-e Tagh gahi) and was first described by AFSHAR HARB (1979) who discriminated 4 Devonian members: lower evaporite (= Padeha Formation), lower carbonate, upper evaporite and upper carbonate members, the last three equating with the Khoshyeilagh Formation. Despite the short dis-

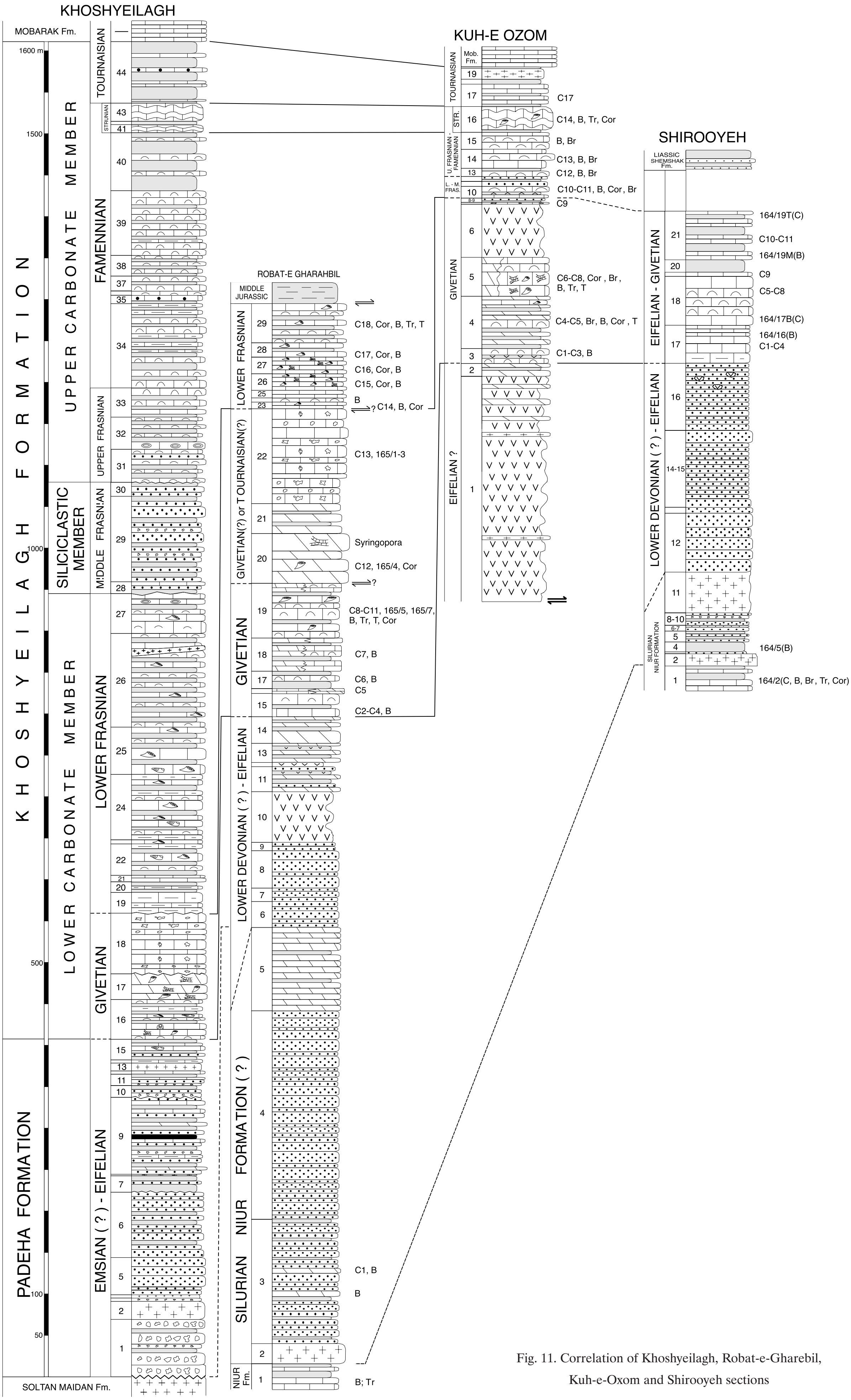


Fig. 11. Correlation of Khoshyeilagh, Robat-e-Gharebil, Kuh-e-Oxom and Shirooyeh sections

tance from Robat-e-Gharabil (40 km), the lithologic composition of these formations is significantly diverse, precluding any attempt at lithostratigraphic correlation between the two sections. The Padeha Formation (1, 2) is incomplete due to an overthrust at the base; it consists of >400 m of gypsum and shale with some intertidal dolomitic interlayers and two diabase sills. GHAVIDEL-SYOOKI (1994, 1998b) studied the palynomorphs of the Padeha Formation to which he assigned a Frasnian age; this is incompatible with the age of the base of the overlying Khoshyeilagh Formation. This and other age attributions of the Padeha Formation to the Frasnian are probably a result of unreliable biostratigraphic resolution of palynomorphs; they are disproved by our data. The first bed of skeletal limestones (3) at the base of the Khoshyeilagh Formation has yielded a brachiopod fauna of Givetian age. Units (3-5) correspond to AFSHAR HARB's (1979) lower carbonate member to which he erroneously assigned an Early Devonian age. Unit 5 contains numerous rugose and tabulate corals locally forming small biostromes (Pl. 7, Fig. 4). The intercalation of another evaporite member (6) has been observed by us only at Kuh-e-Rezaabad (see above) and shows the existence of local sebkha environments in the eastern Elburz in the upper Givetian or about the Givetian-Frasnian transition. Five brachiopod faunas obtained from units (10-16) indicate that the Frasnian-Famennian portion of the Khoshyeilagh Formation is considerably reduced in thickness compared to the type section (~100 m vs. ~1000 m). The uppermost Famennian (Strunian) nodular limestones (16), however, have a similar appearance and thickness in both sections. A local phenomenon is a 15 m basalt sill (19) at the base of the Mobarak Formation. The latter formation (not shown on Text-fig. 11) is approximately 350 m thick and predominantly calcareous-dolomitic. It is capped by ferrugineous sandstones of presumed Permian age (AFSHAR HARB 1979).

Shirooyeh

The section about 30 km S of Bojnurd (Text-fig. 11) is located on the southern flank of a monocline in which Cambrian to Lower Jurassic strata are thrust on Upper Jurassic. It has been described and roughly dated by AHMADZADEH HERAVI (1983), JAFARIAN & TAHERI (1995) and GHAVIDEL-SYOOKI (2001a). An 80 m limestone unit in the Niur Formation (1) contains numerous brachiopods, bryozoans, rugose and tabulate corals, orthoconic nautiloids and trilobites of probable Wenlock age (D. BRICE, Lille, pers. comm.). Separated by a 25 m thick basalt sill (2), the limestones are overlain by grey-reddish marls and siltstones with brachiopod coquinas (3-10; Pl. 7, Fig. 6) also probably Wenlock in age (D. BRICE, Lille, pers. comm.). They grade into red sandstones and shales with another intercalation of basalt and volcanic tuffs at the base (11). The Padeha Formation (12-16) not clearly separated from the Niur Formation, consists mostly of red sandstones with wave ripples, with some shale and intertidal dolomite interlayers and with dispersed gypsum nodules near the top. Conodont samples from the Khoshyeilagh Formation (17-21) were barren; brachiopod faunas have yielded only imprecise Eifelian to Givetian ages. Nevertheless we assume that the onset of fully marine sedimentation, as at Khoshyeilagh and Mighan, is early Givetian. The boundary with the overlying shales of the Shemshak Formation is concealed but may be depositional.

Binalud Mountains

The Binalud Mountains are the eastern prolongation of the Elburz and, for their major part, consist of several imbricated wedges of Jurassic strata thrust in a southwestern direction over Cenozoic sedimentary and igneous rocks. The northeastern margin of the mountain range and the adjacent depression correspond to the suture zone between the Iran and Turan Plates cropping out in the vicinity of Meshed as a complex of Triassic ultramafic rocks and metasediments (MAJIDI 1978, ALAVI 1991). Along the southwestern margin of the range, a 70 km band of Devonian rocks is tectonically emplaced between two wedges of uppermost Triassic to Middle Jurassic Shemshak shale and additionally fragmented by several overthrusts. Several, up to 200 m thick, basic lava flows and volcanic sills of presumed Devonian age are intercalated in this sequence. It is well exposed in the valleys of Pivehjan, Dizbad, Garineh, Darrud and Karv-e-Bala (Text-fig. 12), but the sequence is much more intensely faulted than shown in the very simplified section by LAMMERER & *al.* (1983, 1984). WEDDIGE (1984) presented the first biostratigraphic data on the age of the Devonian rocks and showed that their lower part comprises the interval between the lower Emsian and the lower Givetian. Additional data on the distribution, lithology and stratigraphy were published by WAUSCHKUHN & *al.* (1984) and WENDT & *al.* (1997).

We examined several sections in the above-mentioned valleys, but only the sequence exposed on the southern slope of the mountain range 6-8 km NNW of the village of Pivehjan turned out to be relatively undisturbed (Text-fig. 13). We cannot exclude that the enormous thickness of the Bahram Formation of about 1100 metres is exaggerated by minor tectonic repetitions. An

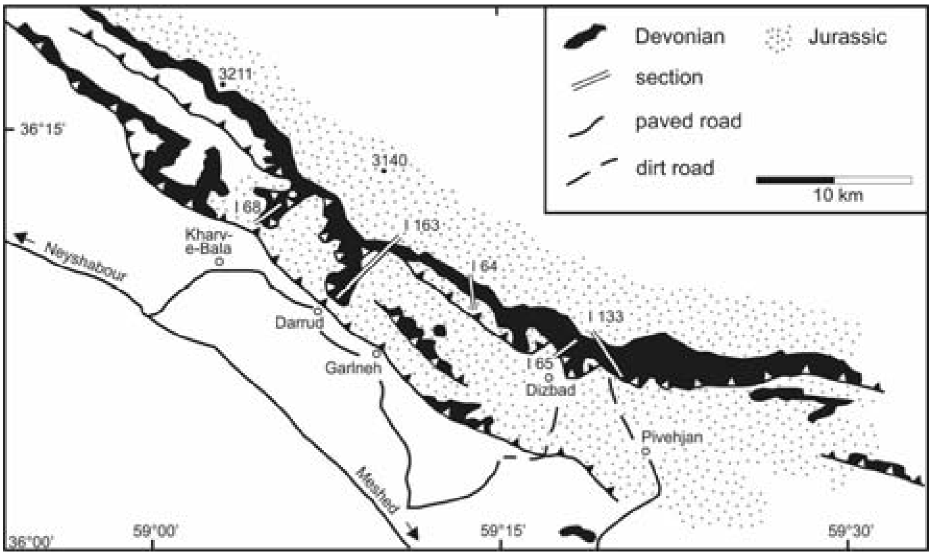


Fig. 12. Location of sections in the Binalud Mountains (after the geological map 1 : 250.000, sheet Mashhad, simplified)

early Emsian age (*dehiscens* Zone) was obtained by WEDDIGE (1984) from the top of "Niur" limestones underlying the Padeha sandstones. We agree with HAMEDI & *al.* (1997) that this level must be considered as a calcareous intercalation in the Padeha Formation rather than evidence for an unusually young upper boundary of the Niur Formation. The laminated and cross-bedded quartzitic Padeha sandstones (1) pass gradually into well-bedded dolomites (2) possibly equivalent to the Sibzar Dolomite of the Ozbakh-Kuh (see below). They are overlain by sandstones lithologically similar to the Padeha Formation but containing 1-2 m dolomitic intercalations (3). The Bahram Formation consists of a monotonous sequence of finely laminated and weakly metamorphosed limestones (Pl. 5, Fig. 2; Pl. 8, Fig. 6) which, apart from some undeterminable shell debris, are virtually unfossiliferous. In the lower 120 m, four conspicuous, strata-bound hematitic iron ores are intercalated (7, 9, 11, 14); these were exploited in the past (WAUSCHKUHN & *al.* 1984). Below the uppermost level we discovered a thin band with solitary as well as colonial rugose corals and stromatoporoids (13). On the base of conodonts, WEDDIGE (1984) attributed the lower 350 m of the laminated limestones (4-19) to the lower Givetian. Additional conodont samples taken by us from the upper 400 metres of the sequence were almost barren and did not indicate precise ages. In these samples only one endemic species of *Icriodus* was found; it shows affinities to both *I. excavatus* WEDDIGE 1984 (*timorensis*- to *triangularis* Zone) and *I. iowaensis iowaensis* YOUNGQUIST & PETERSON 1947 (Middle *triangularis*- to Lower *rhomboidea* Zone). The same species was found in the Kuh-e-Tizi section (WENDT & *al.* 2002), where it is definitely of Givetian age. Therefore we suppose that the entire sequence of the Bahram Formation at Pivehjan is of Middle Devonian age, but may range into the lower Frasnian. It is overlain, possibly with a tectonic contact, by a 30 m member of sandstones and shales with unspecific trace fossils (*Rhizocorallium*) and spiriferids of probable Early Carboniferous age (46-47). The Palaeozoic sequence is followed by several thousand metres of black shales and greywackes (Shemshak Formation) which constitute the crest and northern slopes of the Binalud Mountains. In the basal shales (48) we discovered a flora of abundant *Clathropteris meniscioides* and *Anthrophyopsis crassinervis* (det. H.-J. SCHWEITZER, Bonn) which indicate a late Rhaetian age for the base of the Shemshak Formation.

Torbat-e-Jam

The metamorphosed substrate of the Mesozoic rocks in the Hezar Masjed Mountains NE of Torbat-e-Jam is considered an allochthonous remnant of upper Palaeozoic deep-water deposits of the Palaeo-Tethys (ALAVI 1996) which include some patches of volcanoclastics, limestones and shales of Permian and possibly Devonian age (KOZUR & MOSTLER 1991, and sheet Torbat-e-Jam 1 : 250 000, 1993; sheet Sefidsang 1 : 100 000, 1999). The latter may originally have been deposited in the vicinity of the Upper Devonian turbidites of the Aghdarband area (see above), but biostratigraphic data to support this suggestion are not available. In contrast, the Palaeozoic core of the mountain ranges SW of Torbat-e-Jam consists of unmeta-

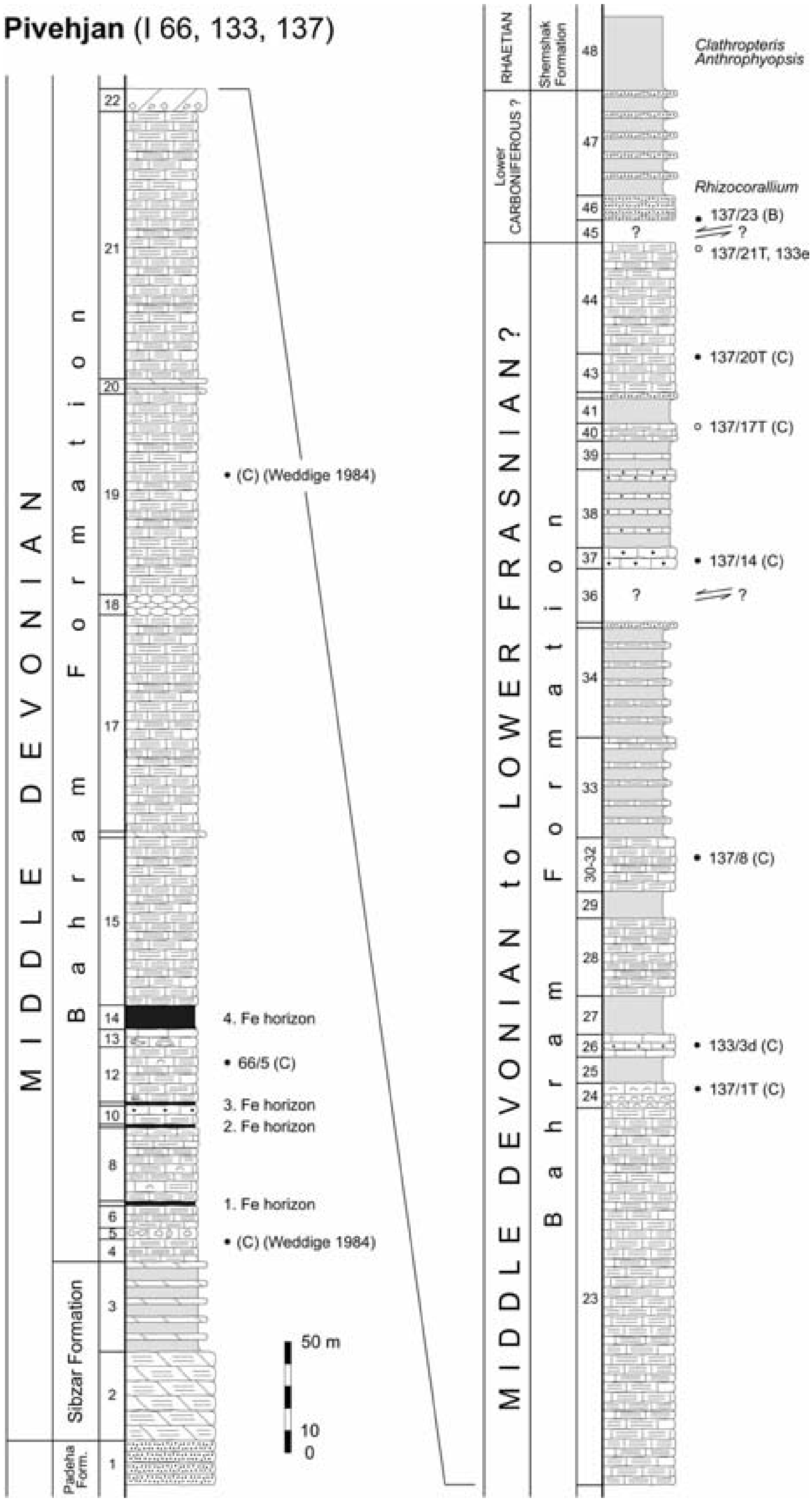


Fig. 13. Pivehjan section

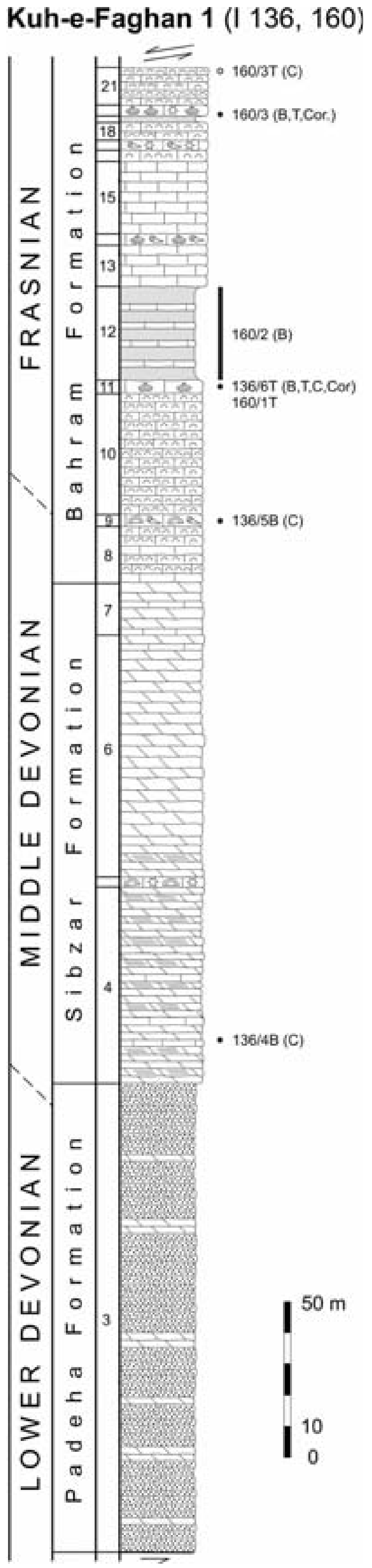


Fig. 14. Kuh-e-Faghan 1 section

morphosed rocks which constitute the northeastern margin of the platform deposits in Iran, outside the Central-East-Iran Microplate. We examined two sections in this area, Kuh-e-Shaftalu Ghaltan and south of Kuh-e-Ashti, but we could not confirm the existence of an undisturbed Devonian sequence as mapped on sheet Kariz Now 1 : 100 000 (1984). Kuh-e-Shaftalu Ghaltan shows an over 500 m thick sequence of unfossiliferous variegated sandstones, quartzites, shales and dolomites which we consider equivalent to the Padeha Formation. This pile is thrust over Neogene sediments, with a thin wedge of Upper Devonian (Bahram Formation) skeletal limestones at the base of the thrust plane. The Padeha siliciclastics are overlain by well-bedded carbonates of the Permian Jamal Formation. BOZORGNIA (1964, pl. 4) reported also Givetian or Frasnian tentaculitid limestones from approximately the same area.

The alleged conformable Devonian sequence exposed in a valley south of Kuh-e-Ashti proved to be a several hundred metres wide thrust zone in which tectonically imbricated wedges of ?Triassic dolomites, Permian fusulinid limestones and Devonian skeletal limestones occur. A conodont sample from the last has yielded an early Eifelian (*costatus* Zone) age. Despite these unsatisfactory data, the occurrence of typical Devonian platform deposits in this area, similar to those on the Central-East-Iran Microplate, is noteworthy.

Kashmar area

South of the Great Kavir Fault which marks the northern boundary of the Central-East-Iran Microplate, an arch of Palaeozoic outcrops extends from Kashmar towards the SW across Ozbakh Kuh to the Derenjal Mountains. On the northern slope of Kuh-e-Faghan east of Kashmar, a hitherto undescribed sequence of Devonian rocks is exposed (Kuh-e-Faghan 1, Text-fig. 14). It consists of a sandstone-dolomite alternation at the base (3, Padeha Formation) passing into cyclically deposited dolomites (4-7, Sibzar Formation) which contain, 70 m above the base, a 0.5 m thick biostrome (5) crowded with stromatoporoids, rugose (*Hexagonaria*) and tabulate corals (*Thamnopora*). They pass into skeletal limestones of the Bahram Formation which contain another 1 m-thick coral-stromatoporoid biostrome (9; Pl. 9, Fig. 5). Conodont recovery from this interval was poor indicating only a general Middle Devonian age. Overlying levels (10-21) contain abundant brachiopods and tentaculitids of Frasnian age. This formation is about 160 m thick but incomplete due to a fault at the top. Another major reverse fault, running along the median valley of the mountain range, thrusts a several hundred metres thick

Ordovician-Silurian sequence (Kuh-e-Faghan 2) against the Devonian one described above. In the lower portion of the former, a conspicuous dark-red, 13 m limestone intercalation with orthoconic nautiloids has yielded a conodont fauna of Llandovery age. In the western part of the entire mountain range (Kuh-e-Bogho) GHAVIDEL-SYOOKI (1995) mentioned a 993.5 m (sic!) Lower to Middle Silurian sequence for which he proposed the term Aliabad Formation.

RAZZAGHMANESCH (1968) and MÜLLER & WALTER (1984) have described a similar Devonian sequence N of the Great Kavir Fault in the so-called Taknar inlier 60 km W of Kashmar. This structural unit is a wedge-shaped block delineated by the Rivash Fault in the N and the Great Kavir (=Doruneh) Fault in the S and is regarded as a fragment of the Lut Block which was split off during the presumed rotation of the Central-East-Iran Microplate (LINDENBERG & *al*. 1984). In the mountain range between the villages of Kalateh Jomeh and Borjak, strongly faulted Lower Carboniferous Sardar(?) shales are thrust against Permian fusulinid limestones. We could not find any trace of Devonian limestones mentioned by MÜLLER & WALTER (1984). Nevertheless, the occurrence of unmetamorphosed Upper Palaeozoic rocks similar to those immediately south of the supposed plate boundary is noteworthy.

In the Kuh-e-Kalateh-Ali range E of Gonabad, 100 km SSE of Kashmar, FAUVELET & EFTEKHAR-NEZHAD (1992) described a 1200 m sequence of sandstones with some intercalated nodular and crinoidal limestones which they ascribed to the Padeha Formation. It is overlain by about 1000 m of limestones and shales of the supposed Bahram and Shishtu Formations, followed by 900 m of siliciclastics of the Sardar Formation. Because biostratigraphic data are totally lacking and the sequence is strongly faulted, these age attributions remain doubtful, but it can be assumed that rocks of Devonian and Carboniferous age are present in this area.

Ozbakh Kuh

Because the type localities of the Niur, Padeha, Sibzar, Bahram and Shishtu Formations were established in the Ozbakh-Kuh Mountains, this area is often quoted as a reference section for the Devonian in eastern Iran. Unfortunately the report by RUTTNER & *al.* which was intended to accompany the 1 : 100 000 map of this area was never published, and stratigraphic data on these formations must be assembled from subsequent publications by RUTTNER & *al.* (1968), STÖCKLIN (1972), WEDDIGE (1984), STÖCKLIN & SETUDEHNIA (1991), ASHOURI (1990) and others. Our examination

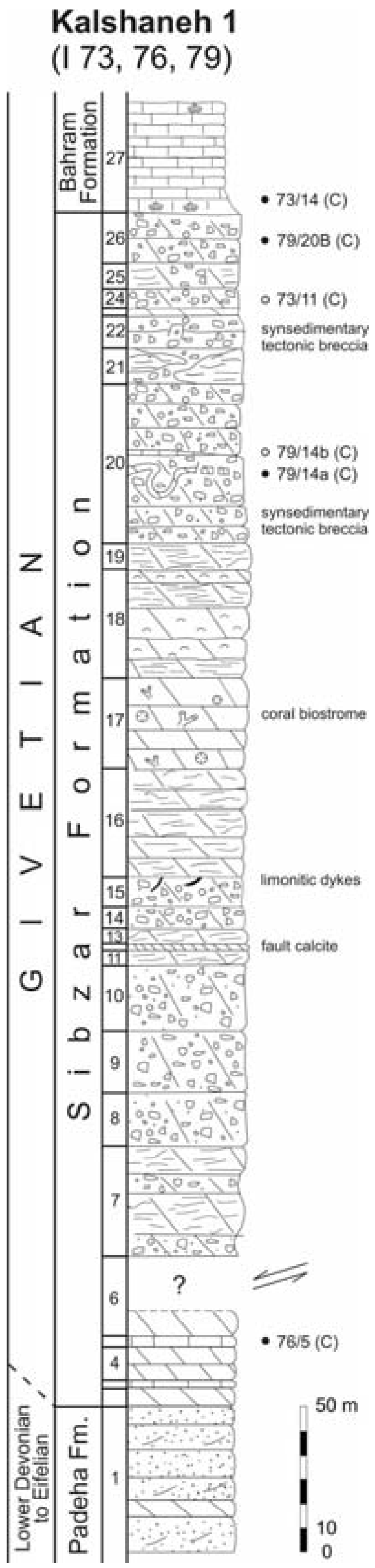


Fig. 15. Kalshaneh 1 section

of several areas in this mountain range, based on the unpublished 1 : 50 000 geological map of Ruttner, has revealed that there are no undisturbed sections of the entire Devonian in the Ozbakh-Kuh, and that previous thickness measurements must be considered with some reserve. Significantly, WEDDIGE's (1984) and ASHOURI's (1990) well dated sections of the Bahram (including Shishtu) Formations are only some tens of metres in thickness.

In the type section near Gushkamar, the Padeha Formation is said to be 492 m thick (RUTTNER & *al.* 1968), a rather arbitrary value because of folding and faulting. It consists of an alternation of unfossiliferous red and whitish sandstones, siltstones, clays, intertidal dolomites and up to 50 m thick gypsum levels. The boundary towards the overlying Sibzar Dolomite is gradual and does not show any depositional evidence of the so-called "Eifelian hiatus" (WENDT & *al.* 1997). Up to 10 m intercalations of sedimentary breccias in these thick-bedded dolomites document tectonic activity which occurred probably during the early Givetian. According to WEDDIGE's (1984b) conodont data, the base of the Bahram Formation is of mid-Givetian (*ansatus* Zone) age. In younger levels the presence of Frasnian (SARTENAER 1966) and Famennian equivalents is documented, the latter being labelled as Shishtu Formation. In ASHOURI's (1990) section at Qa'leh, upper Famennian limestones are directly overlain by uppermost Tournaisian (*anchoralis* Zone) limestones indicating a major gap. Near Anarak we observed a similar gap at the Devonian/Carboniferous boundary (see below).

Derenjal Mountains

This outcrop of upper Precambrian to Middle Devonian rocks is the southwestern prolongation of the Ozbakh Kuh; it is delineated towards the NW by the same strike-slip fault (Kalmard Fault). The stratigraphy and tectonics of the area are well known from the detailed work of RUTTNER & *al.* (1968). We examined several sections on the southern termination of the mountain some kilometres SE of the village of Kalshaneh where the Silurian to Middle Devonian sequence is exposed in a recumbant syncline (Kalshaneh 1). The 600 m thick Niur Formation is Middle to Late Silurian in age (WALLISER in RUTTNER & *al.* 1968) and consists of brownish, partly cross-bedded sandstones, coarse breccias and limestones, the latter often crowded with brachiopods and rugose and tabulate corals. They grade upwards into about 700 m of alternating cross-bedded sandstones and dolomites of the Padeha Formation. Higher up, intercalations of intertidal to shallow subtidal dolomites become more frequent and indicate a gradual transition into the Sibzar Formation which is much thicker in the southern Derenjal Mountains than mentioned by RUTTNER & *al.* (1968). The thickness of 300 m shown in Text-fig. 15 is a minimum value because the basal part is faulted. The Sibzar Dolomite of the Derenjal Mountains is distinguished from the same interval in other areas by the occurrence of thick breccia layers (Pl. 5, Fig. 3) of synsedimentary-tectonic origin (WENDT & *al.* 1997). In addition, a 25 m thick biostrome constructed of rugose and tabulate corals and a pronounced cyclicity of the upper- and underlying beds are remarkable. Two conodont samples, one from 15 m above the Padeha-Sibzar transition (*hemiansatus* to *timorensis*-Zone) in a nearby section (I 76), the other from 68 m below the Sibzar-Bahram boundary (*timorensis* Zone), have yielded for the first time precise dates for the age of the Sibzar Formation. They show that the >300 m thick sequence was deposited during a relatively short interval of the early Givetian. This age is in accordance with that of the base of the Bahram limestones (*timorensis*- to *ansatus*- Zone) of which the major part has been eroded in the Derenjal Mountains.

Two tectonically isolated remnants of younger levels of the Bahram (= Shishtu) Formation were discovered by RUTTNER & *al.* (1968) 14 km farther south in the hills S of Shirgesht (Kalshaneh 2). Here, a red quartziferous iron-oolitic "cephalopod" limestone contains rare *Platyclymenia* (RUTTNER & *al.* 1968) and *Maeneceras* of middle (*marginifera* Zone) to late Famennian age. The contact with the overlying shales of the Lower Carboniferous Sardar Formation is faulted.

Southern end of the Shotori Range

The 70 km long mountain range east of Tabas, first mentioned and named by HEDIN (1918, pp. 42-43, pl. 5), consists of a sequence from the Lower (?) Devonian into the Paleogene. The stratigraphy is well known from the work of STÖCKLIN & *al.* (1965) and STÖCKLIN & NABAVI (1971) who introduced new lithostratigraphic units of the Permian (Jamal Formation) and the Triassic (Sorkh Formation, Shotori Formation) from here. More precise biostratigraphic data and a better subdivision of the Devonian and Carboniferous strata were achieved by ASHOURI (1990), YAZDI (1996, 1999), WENDT & *al.* (1997) and BRICE & *al.* (1999). SARTENAER (1966) described some Frasnian rhynchonellids from older collections; YAZDI & TURNER (2000) and HAIRAPETIAN & *al*. (2000) studied microvertebrate remains from the Upper Devonian and Lower Carboniferous from two of YAZDI's (1996, 1999) sections.

The only place in the entire range where a complete, but discontinuous sequence from the Devonian Padeha Formation into the Permian Jamal Formation is exposed, is near its southern termination south of Howz-e-Dorah (Text-fig. 16; Pl. 3, Fig. 2). The oldest rocks crop out near the foothills where reddish cross-bedded sandstones of the upper Padeha Formation (1) are thrust over Paleogene dacites. They grade into a thick-bedded dolomite-limestone member (2) forming a prominent escarpment intersected by a narrow gorge.

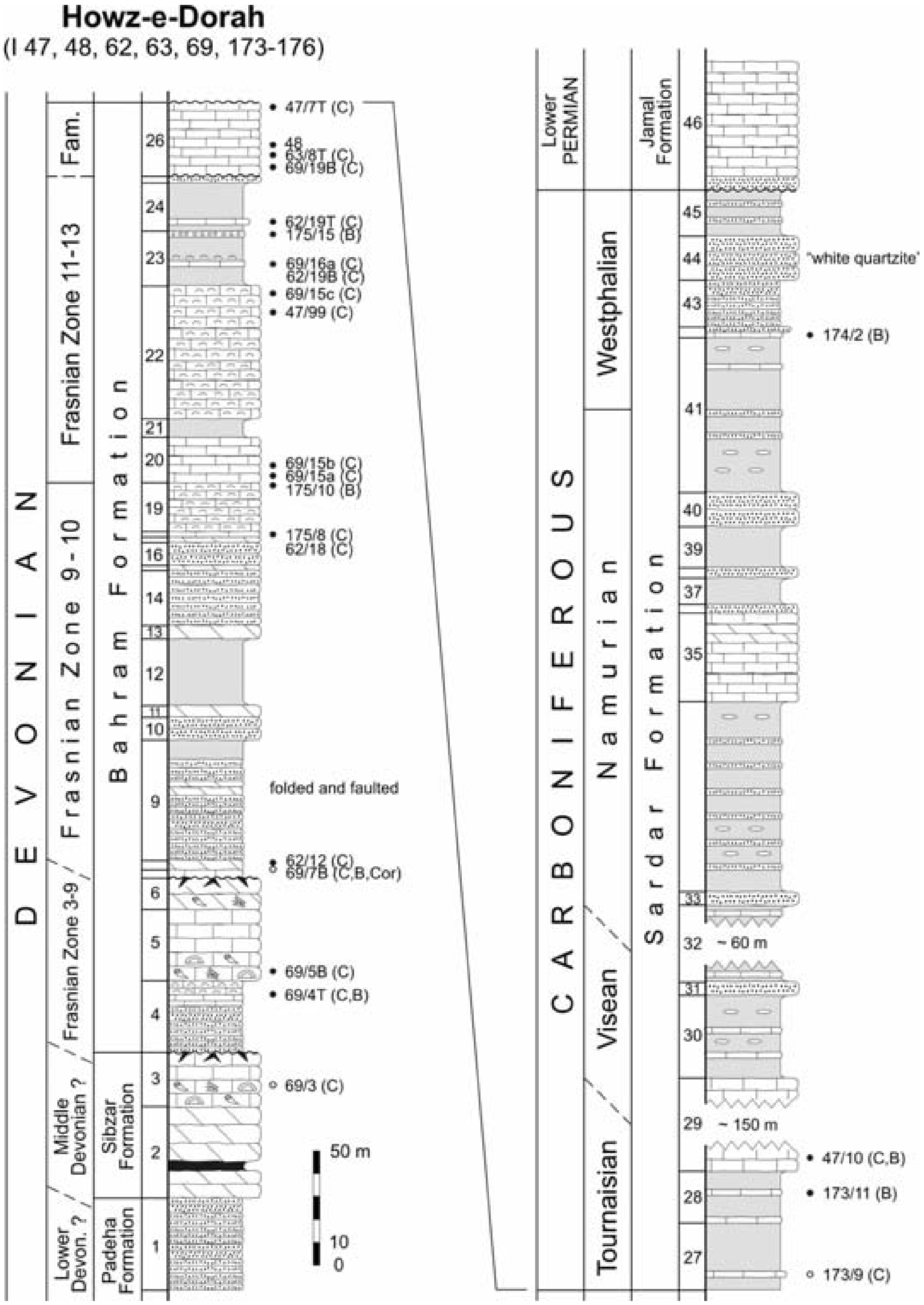


Fig. 16. Howz-e-Dorah section

The upper part of this member is a stromatoporoid-coral boundstone and floatstone (3) which has not been precisely dated yet but may be coeval with the biostrome in the Sibzar Formation of the Derenjal Mountains (see above). From its upper boundary, sandstone dykes penetrate downwards indicating a depositional unconformity and a gap of yet imprecisely known duration. The overlying Bahram Formation starts with sandy brachiopod limestones passing into a second biostromal limestone (5-6), dated as lower to middle Frasnian (Zone 6-9). Metre-scale synsedimentary faults and sandstone-filled veins at the top reveal another hiatus before the onset of a sandstone-shale-dolomite sequence (9-16) with common ball-and-pillow structures in the lower and skeletal limestones in the upper part (19). From several conodont samples it becomes evident, that this portion of the sequence (8-19) is of mid-Frasnian age (Zone 9-10). The upper part (20-24) consists of shales and skeletal limestones with abundant brachiopods and bryozoans (Pl. 10, Fig. 6) in which several productive conodont samples (Text-fig. 16 and YAZDI 1999) indicate a tightly-bracketed late Frasnian age (Zone 11-13). The Frasnian-Famennian boundary must be searched above the top of a member of grey shales (24) which, in contrast to YAZDI (2000), we cannot regard as an equivalent of the "Kellwasser event". We also could not find the "rolled allochthonous blocks" which YAZDI (2000) ascribed to a possible tsunami near the Frasnian/Famennian boundary. The latter is probably represented by the erosional top of the overlying quartzitic sandstone bed (25 in Text-fig. 16; Pl. 3, Fig. 3) not included in YAZDI's (1996, 1999) section. This gap may include the uppermost Frasnian and the lowermost Famennian. The subsequent member 26 is the "cephalopod beds" of STÖCKLIN & *al.* (1965) in which, however, apart from some orthoconic nautiloids, we found only a few specimens of *Cheiloceras* and *Sporadoceras*. A more abundant cephalopod fauna from this unit was described by WALLISER (1966). These beds comprise the interval from the *triangularis*/Lower *crepida* to the *trachytera* Zone, but contain several distinctive depositional gaps. A detailed section of the "cephalopod beds" in this locality has been figured by WENDT & *al.* (1997). A high quartz content, several erosional surfaces, reworked limestone clasts (Pl. 6, Fig. 4) and the predominance of brachiopods clearly indicate a neritic environment. The top of this unit is marked by another gap which includes the uppermost Famennian and the basal Tournaisian. The Sardar Formation starts with a member of grey shales and thin-bedded limestones with productid and spiriferid brachiopods (27, 28). It grades into a 190 m thick, cliff-forming unit of grey, well-bedded, partly bituminous limestones (29) with numerous brachiopods, corals and trace fossils (*Rhizocorallium* and others) in the lower part. According to the conodont data of YAZDI (1996, 1999), the remainder of the Sardar Formation comprises the Visean, the Namurian and a not yet well defined portion of the upper Westphalian or the lower Stephanian.

The exact position of the Carboniferous/Permian boundary is regarded controversially. In contrast to STÖCKLIN & *al.* (1965), HAMEDI (1989) and YAZDI (1996, 1999) place it below a conspicuous band of white, laminated and cross-bedded, sandstone (44) the so-called "white quartzite", though this level has gradational lower and upper boundaries. This massive white sandstone passes into a sandstone-clay alternation (45) with an erosional, iron-stained top which more reasonably represents the Sardar/Jamal unconformity. The Jamal Formation starts with fossiliferous (foraminifera, brachiopods, gastropods, crinoids) quartziferous limestones which mark the base of a new transgressive cycle. These observations favour the STÖCKLIN & *al*. (1965) interpretation and positioning of the Sardar/Jamal boundary.

Western flank of the Shotori Range

A 12 km band of patchy outcrops of the Upper Devonian "cephalopod beds" was found by STÖCKLIN & *al.* (1965) east of Tabas close to the western boundary thrust of the Shotori Range. Due to their location in the vicinity of a major overthrust (not an olistostrome as stated by BECKER 2000), they are a tectonic melange of chaotic blocks in which minor internal faults can sometimes only be detected by meticulous sampling and dating. This is shown by ASHOURI's (1990, figs 14-17) and YAZDI's (1996, 1999) precisely dated short sections which, by biostratigraphic correlation, might be combined to a more complete record of the Upper Devonian. Compared to the Howz-e-Dorah section, the "cephalopod beds" in this area are much more fossiliferous and contain numerous goniatites, clymenids, ahermatypic corals and *Receptaculites*. Intercalations of clays and sandstones have expanded the thickness with respect to the southern part of the Shotori Range (Text-fig. 16), but several omission surfaces, flat pebble conglomerates and frequent reworking show that the sequence is nevertheless incomplete. Some layers of fine-grained sandstones are covered with wave ripples and show that the depositional area during the Late Devonian was near a yet unknown shore. Temporary pronounced currents are indicated by aligned orthoconic nautiloids. SCHULTZE (1973) described Frasnian arthrodires from here. Discoveries of hermatypic

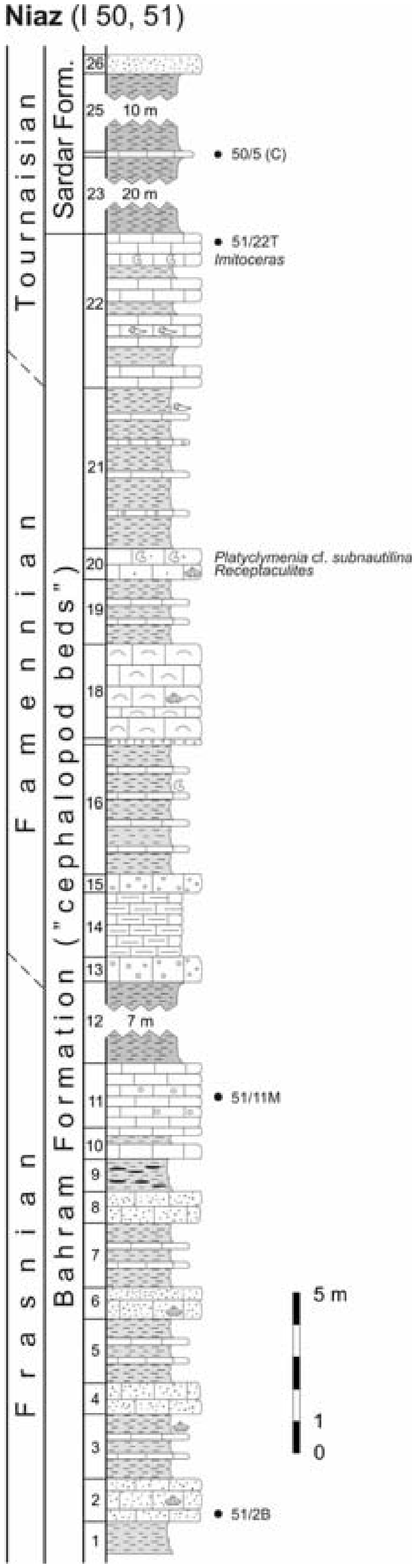


Fig. 17. Niaz section

rugose corals and stromatoporoids (MISTIAEN 2001) at Kal-e-Sadrar some km farther E, show that also Middle Devonian rocks were incorporated in the thrust zone along the western flank of the Shotori Range.

The most complete, rather undisturbed section (Text-fig. 17), located 800 metres NNW of the village of Niaz on the right bank of the Sardar River has been described by WENDT & *al.* (1997, fig. 9). FEIST & *al.*

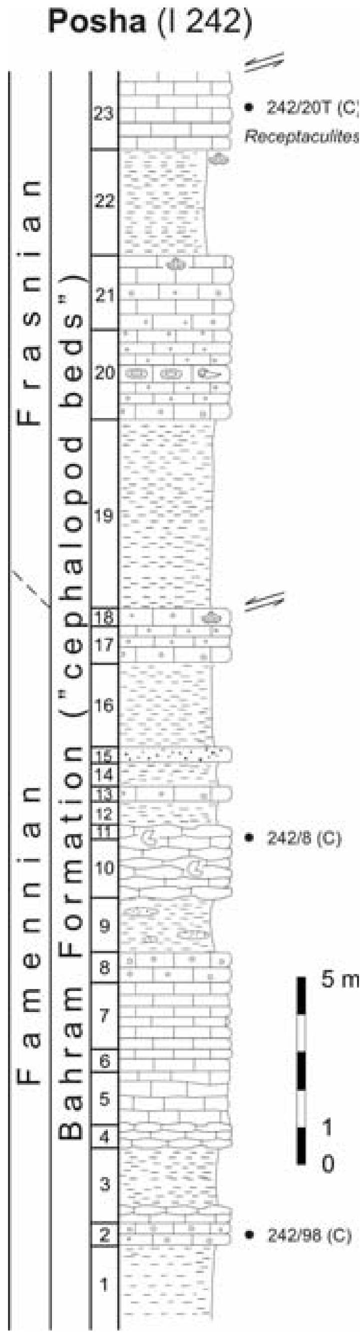


Fig. 18. Posha section

(1999) mentioned some Famennian trilobites from here; BECKER & *al.* (2004) sampled a small fraction of this section and located the position of the so-called *Annulata*-Event in the upper Famennian. MORZADEC (2002) described some Frasnian trilobites from here. *Beloceras tenuistriatum* (genus already mentioned by CLAPP 1940), *Manticoceras*, *Maeneceras*, *Prionoceras*, *Praeglyphioceras*, *Platyclymenia* and *Cyrtoclymenia* in minor outcrops in the vicinity document the presence of middle Frasnian to upper Famennian levels. The presence of Frasnian equivalents is also documented by brachiopods (LEGRAND-BLAIN 1999). We found *Platyclymenia* cf. *subnautilina* (Sandberger) from the Lower *postera* Zone in the upper part (20). The topmost limestone layer (22) which is sharply overlain by grey-greenish clays of the lower Sardar Formation, has yielded a few conodonts which indicate a middle Tournaisian age. Thus, in this locality there is no obvious break in sedimentation at the Famennian-Tournaisian boundary as occurs in the Howz-e-Dorah section (Text-fig. 17, YAZDI 1999). The presence of the upper Famennian in other allochthonous blocks of the area is also documented from ASHOURI's (1990, fig. 16) section C in the vicinity, and from unpublished material from nearby localities (pers. comm. T. BECKER, Münster).

Tectonically isolated blocks of "cephalopod limestone" found 8 km to the NW and 6 km E of Posha have yielded brachiopods, *Receptaculites* and abundant goniatites among which *Manticoceras* sp., *Phoenixites frechi* (WEDEKIND), *Maeneceras* sp., *Platyclymenia annulata* (MÜNSTER) and *Platyclymenia* sp. indicate the presence of upper Frasnian and lower, middle and upper Famennian levels. The red skeletal limestones contain crinoid debris, chamosite ooids, iron-stained oncolithic nodules and numerous limonitic crusts. Conodont samples from three levels of a supposed undisturbed section (Text-fig. 18) show that its upper part (which is not overturned!) is older than the lower part indicating a fault, probably between (16) and (19).

Kalmard area

The Kalmard Fault, an important pre-Devonian thrust fault which later developed into a dextral strike-slip fault, delimits the relatively thick Palaeozoic development of the Derenjal and Shotori Mountains (Tabas Block) to the west (Yazd Block). RAMEZANI & TUCKER (2003) have introduced the term "Kashmar-Kerman Tectonic Zone" for this boundary. In the Rahdar-Gachal Anticline, immediately west of thr Kalmard Fault and in the adjacent Kalmard Anticline, a reduced Upper Devonian and a more complete Lower Carboniferous sequence is exposed (AGHANABATI 1977). Preliminary biostratigraphic data from the three sections shown in Text-fig. 20 were presented by us in an earlier study (WENDT & *al*. 1997). The Rahdar and Bakshi sections are situated in the Rahdar-Gachal Anticline, the Madbeiki section in the Kalmard Anticline (Text-fig. 19).

The oldest exposed rocks are upper Precambrian (?) granodiorites intruded into intensely folded and faulted siltstones and shales (Kalmard Formation) and overlain by sandstones and dolomites of the Shirgesht Formation (Pl. 2, Fig. 1). In the north (Rahdar) the latter contain poorly preserved trilobites and brachiopods indicating an Ordovician age (AGHANABATI 1977). Their continuation towards the south (Bakshi) can be inferred from similar lithologies and stratigraphic position. We interpret the sudden onset, at Bakshi with a bauxite level at the base, of black skeletal, partly oolitic limestones as the beginning of the Bahram (= Rahdar) Formation to which AGHANABATI (1977) attributed a Late Devonian age. The majority of our conodont samples of this unit were barren; only two yielded a Famennian age for this sequence which attains a thickness of 80 m at Rahdar and 60 m at Bakshi, but is missing at Madbeiki.

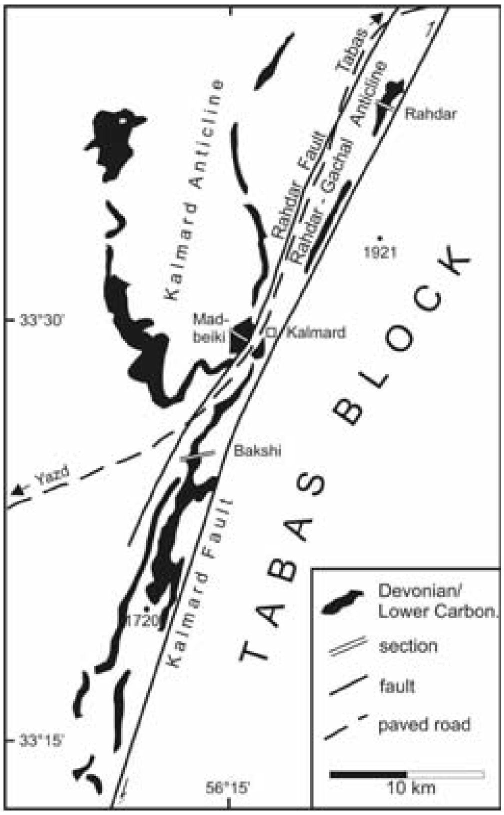


Fig. 19. Locations of sections in the Kalmard area (after the geological map 1 : 250 000, sheet Tabas, simplified)

The Lower Carboniferous succesion to which AGHANABATI (1977) assigned a proper formation name (Gachal Formation), has a thickness of 165 m at Madbeiki, 250 m at Rahdar and 315 m at Bakshi. These variations are predominantly the result of pre-Permian erosion which cut down to various levels of the Lower Carboniferous. Lithologically, this part of the sequence can be subdivided into three units: In the lower part

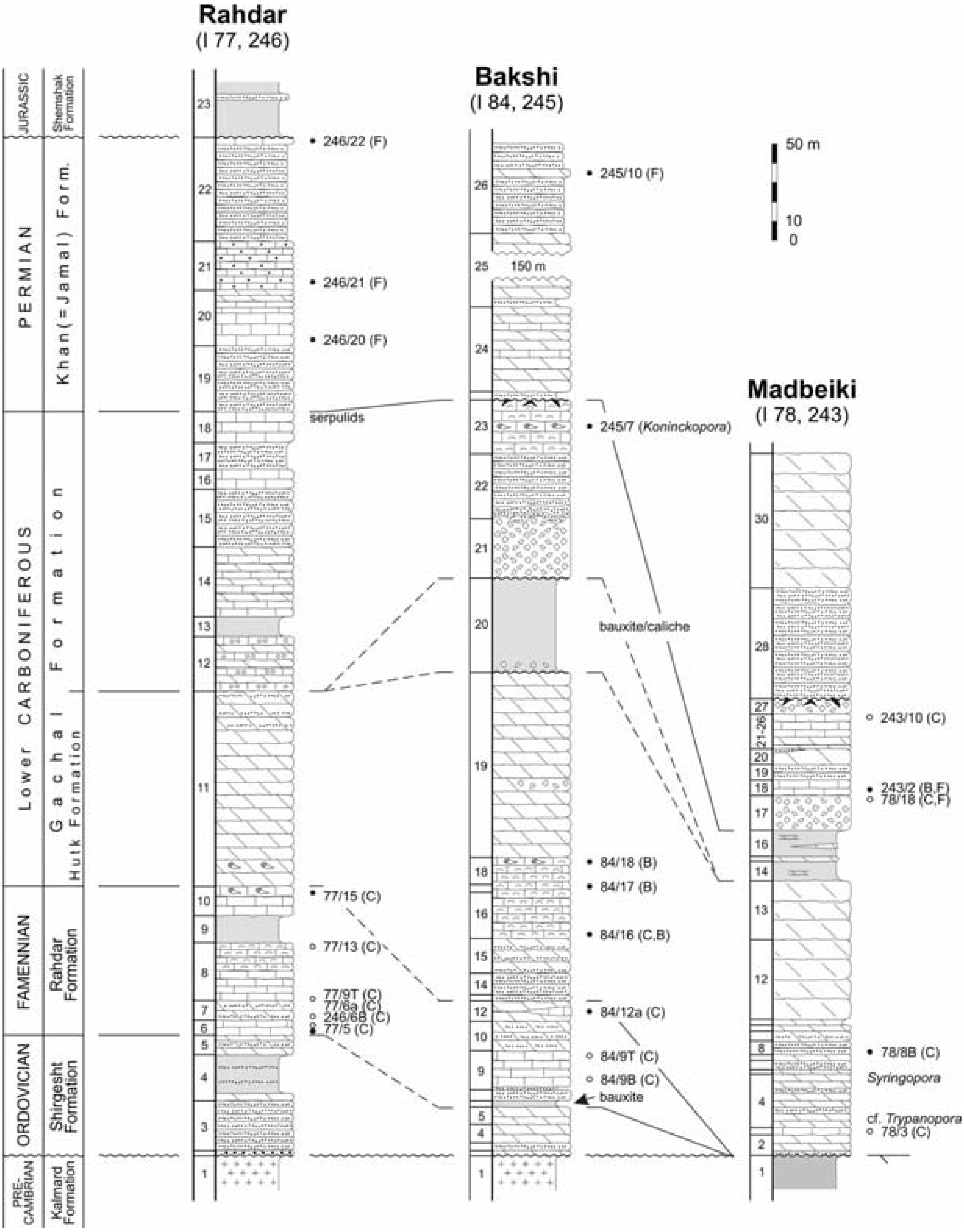


Fig. 20. Correlation of Rahdar, Bakshi and Madbeiki sections

(missing at Rahdar, 13-18 at Bakshi, uncertain at Madbeiki), skeletal limestones prevail, with at some levels crowded with brachiopods, solitary rugose corals and problematic serpulids (Pl. 10, Fig. 5). Sparse conodont faunas indicate a Tournaisian age (*delicatus* to *anchoralis* Zone) for this member. The middle part (11 at Rahdar, 19 at Bakshi, up to 13 at Madbeiki) consists of thick-bedded, cliff-forming dolomites (Pl. 2, Fig. 2) possibly equivalent of the Hutk Formation in the Kerman area (WENDT & *al.* 2002). They are capped, in the Bakshi area, by a very conspicuous, orange-weathering bauxite level (Pl. 2, Fig. 2) indicating a continental interval which may be more or less coeval with the gypsum-bearing regressive phase in the southernmost extremity of the Rahdar-Gachal Anticline reported by AGHANABATI (1977). The upper part (12-18 at Rahdar, 21-23 at Bakshi, 14-16 at Madbeiki) is a mixed carbonate-siliciclastic member containing brachiopods, large solitary rugose corals, calcareous algae (*Koninckopora*) and Problematica (Pl. 10, Fig. 7) of Visean age. A special feature in the Bakshi section is a 20-30 m thick polymict rockfall breccia (21) consisting of poorly sorted dolomite clasts derived from level 19. Some of the clasts show calcitic veins which do not continue into the matrix (Pl. 5, Fig. 4) indicating origination from considerable depths. They are interpreted as evidence for Early Carboniferous tensional movements. These subaerial talus cones are draped by sandstones (22) which leveled the irregular topography (Pl. 2, Fig. 3).

The transgression of the Permian Jamal (= Khan) carbonates and sandstones is barely visible in the Rahdar section, but well marked at Bakshi by an erosional unconformity from which sandstone dykes and veins penetrate into the underlying black Visean brachiopod-coral limestones. At Madbeiki the base of the Permian is marked by a 15-20 m thick, laterally discontinuous, marine breccia grading into fetid brachiopod-coral limestones with Permian foraminifera (miliolids, Endothyracea, *Globivalvulina vonderschmitti*). Another depositional unconformity is indicated some 50 m upsection by a 7 m limestone breccia in a sandy matrix (27) showing that the ridge position of the Madbeiki area persisted from the Early Carboniferous into the Permian, after a continental interval during the Late Carboniferous/earliest Permian. The striking depositional contrast of this area compared to the much thicker succession in the Rahdar-Gachal Anticline (Rahdar and Bakshi sections) must be explained by late Palaeozoic strike slip movements rejuvinated in post-Jurassic times.

Another example of similar tectonically controlled depositional contrasts can be observed on the eastern flank of the Rahdar-Gachal Anticline, 1 km opposite to the Rahdar section, where white oolitic limestones of the Middle Jurassic Badamu Formation transgress over sandstones of the Ordovician Shirgesht Formation. Such an enormous depositional gap cannot be explained solely by pre-Jurassic erosion.

Anarak

According to SOFFEL & *al.* (1996) the Anarak-Khur Block constitutes the northwestern margin of the Central-East-Iran Microplate and is "characterized by a thick (5000-8000 m) Palaeozoic metamorphic series consisting mainly of detrital sediments and volcanic rocks". This interpretation is based on the presumed Palaeozoic age of the Anarak metamorphics which have yielded K/Ar ages of 208-400 Ma (SHARKOVSKI & *al.* 1984, p. 23), but it is incompatible with the biostratigraphically well established Early Cambrian age of the Lakh marble, regarded as the uppermost unit of the Anarak metamorphics (SHARKOVSKI & *al.* 1984). These radiometric ages seem to be connected with late Hercynian and late Triassic greenshist metamorphism (ROMAN'KO & SHARKOVSKIY 1984), but they must not necessarily reflect the primary age of these rocks for which a Precambrian age (845 Ma) appears more conceivable (REYRE & MOHAFEZ 1970, p. 705; ROMAN'KO & MOROZOV 1983). A similar age was proposed by DAVOUDZADEH (1972, pp. 24-25) who found reworked pebbles of the Anarak metamorphics in the basal Ladinian Baqoroq Formation about 15-20 km farther north near Nakhlak. A later paper on this subject (DAVOUDZADEH & *al.* 1981, p. 182), however is contradictory about the provenance of these pebbles: either a derivation from the Anarak metamorphics or a very remote source (Herat-Hindukush area in Afghanistan?) is assumed. The latter interpretation would certainly better justify the presumed rotation of the Central-East-Iran Microplate. Thus, the Triassic Nakhlak Group was interpreted as a fragment of the Turan Plate (DAVOUDZADEH & SCHMIDT 1984, ALAVI & *al*. 1997).

Ten km southeast of the type locality Kuh-e Lakh and south of the Biabanak Fault, a marble-phyllite sequence (Doshakh metamorphics) resembling the Lakh marble, is depositionally overlain by unmetamorphosed Ordovician to Permian sediments. This juxtaposition of a Palaeozoic platform sequence and the above mentioned coeval "geosynclinal facies" (DAVOUDZADEH & WEBER-DIEFENBACH 1987) in the Anarak Mountains casts serious doubts on the presumed Devonian-Carboniferous ages of the Anarak metamorphics.

The sequence exposed on the northeastern slope of an unnamed 1625 m peak 22 km southeast of Anarak (Anarak 1, Text-fig. 21; Pl. 3, Fig. 1) was first mentioned

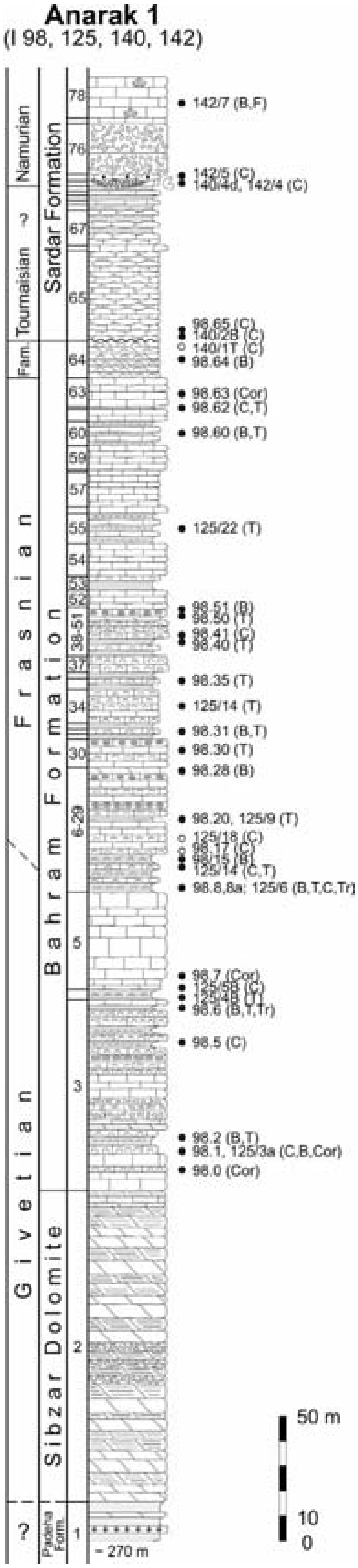


Fig. 21. Anarak 1 section

by REYRE & MOHAFEZ (1970: 702) and later examined in more detail by SHARKOVSKI & *al.* (1984, p. 27). It is one of the most fossiliferous Middle Devonian/Lower Carboniferous sections in Iran and was dated by us with 1 goniatite, 12 conodont, 13 brachiopod, 13 tentaculite, 3 trilobite and 2 foraminiferal faunas. The Padeha Formation is about 300 m thick and consists of an alternation of sandstones, shales and dolomites into which several up to 60 m thick basalt flows are intercalated. The contact towards the overlying Sibzar Dolomite (2) is sharp but deposition appears continuous. The Sibzar Dolomite is 120-200 m thick and composed of thick-bedded microbially laminated dolomites with a strongly brecciated member in the middle part. The boundary with the Bahram Formation is gradual and was drawn by us at the base of the first calcareous mud-/wackestone layer (3). The following alternation of skeletal limestones and marls is exceptionally fossiliferous (brachiopods, tentaculitids, rugose corals, stromatoporoids, bryozoans, trilobites; Pl. 9, Figs 3, 9). Solitary rugose corals outnumber colonial ones and form, associated with abundant globular stromatoporoids, rare amphiporids and tabulate corals, up to 5 m thick biostromes which appear intermittently over almost the entire thickness of the Bahram Formation. Current-aligned tentaculitids are extremely common on bedding planes and in marly interlayers. The lower 130 m of the Bahram Formation is upper Givetian, but the boundary with the Frasnian could not be exactly positioned. A lower Famennian brachiopod fauna collected from the uppermost 15 m (64) shows that the major part of the Bahram Formation is Frasnian and that Famennian equivalents have largely been removed by pre-upper Tournaisian erosion. The boundary with the overlying Sardar Formation is sharp and locally disturbed by minor faults. As shown by a conodont fauna from the base, this boundary is a major gap which comprises almost the entire Famennian and the bulk of the Tournaisian. The Sardar Formation consists of marly, red nodular limestones (65-75), a unique lithology of this age in Iran which recalls the coeval Alba Griotte of the Cantabrian Mountains in northern Spain (WENDT & AIGNER 1985). Close to the top we discovered a goniatite fauna of Namurian age with reworked Visean forms (KORN & *al.* 1999). The upper boundary of the nodular limestone member is another depositional unconformity marked by a coarse breccia of white limestone clasts embedded in a dolomitic matrix (76; Pl. 8, Fig. 5). It grades into dark thick-bedded skeletal limestones (78) with Namurian brachiopods and foraminifera. The thickness of the Sardar Formation is unknown because higher levels are eroded in this section. Tectonically isolated remnants of the Permian

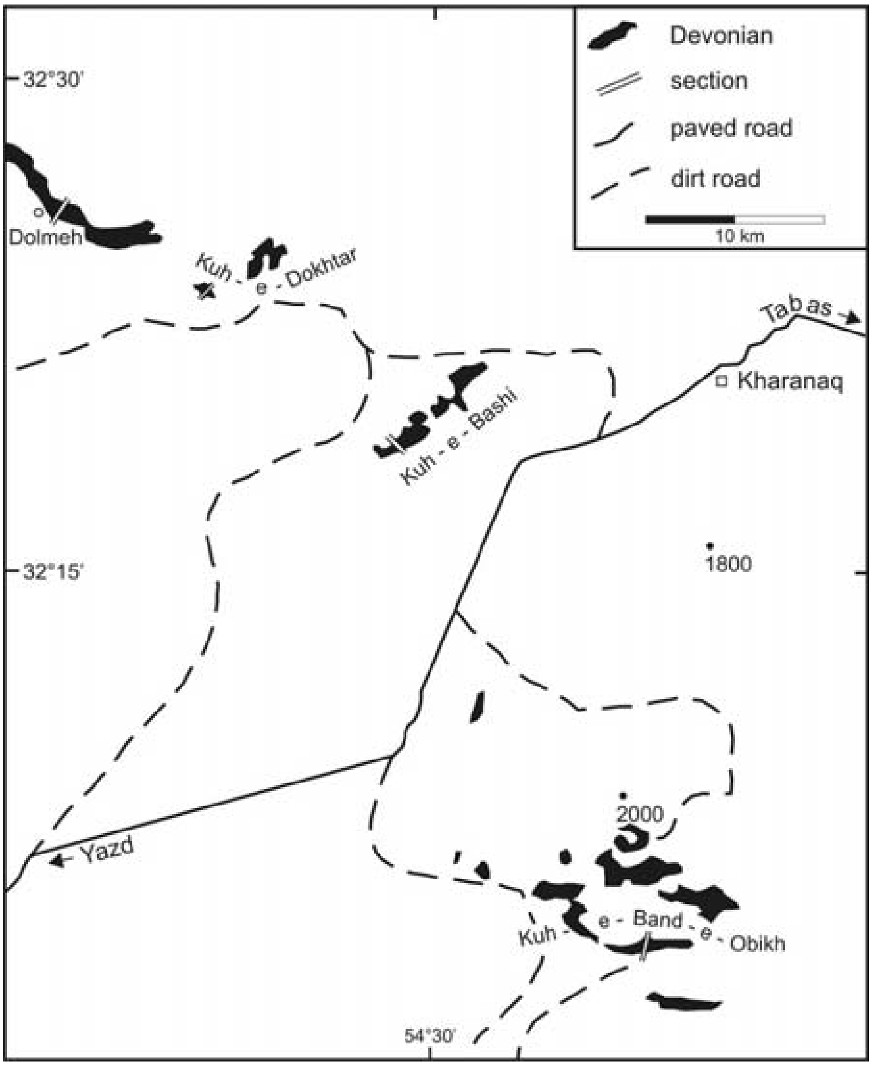


Fig. 22. Location of sections in the Kharanaq area (after the geological map 1 : 250.000, sheet Ardekan, simplified)

Jamal carbonates are widespread in the vicinity, but we could not find a depositional contact with the Sardar Formation.

Twelve km to the SSE a tectonically strongly disturbed section of Bahram, Sardar and Jamal carbonates and shales is exposed (Anarak 2). The skeletal limestones of the Bahram Formation occur only as imbricated wedges. The Sardar Formation is represented by a >150 m thick limestone-shale alternation the (tectonic) base of which was dated as lower Namurian. There is no trace of the coeval red nodular limestone facies as in the Anarak 1 section.

Kharanaq area

The stratigraphy of this area was studied by HAGHIPOUR & *al.* (1977).We examined four sections (Dolmeh, Kuh-e-Dokhtar, Kuh-e-Bashi and Kuh-e-Band-e-Obikh, Text-fig. 22) of these structurally very complex, about 100 km long mountain ranges which are crowned by impressive cliffs of Upper Cretaceous rudist limestones. These sections are distinguished by enormous gaps and allow only tentative correlations from one to another.

Dolmeh (Text-fig. 23)

Lower to Middle Devonian (or Cambrian?) cross-bedded sandstones of the Padeha Formation (?) pass gradually into a dolomite unit (2) which may be considered as an equivalent of the Sibzar Dolomite and is overlain in turn, with a slight depositional unconformity, by a biostrome (3). The latter consists of numerous tabulate corals (in particular thamnoporids and *Alveolites*),

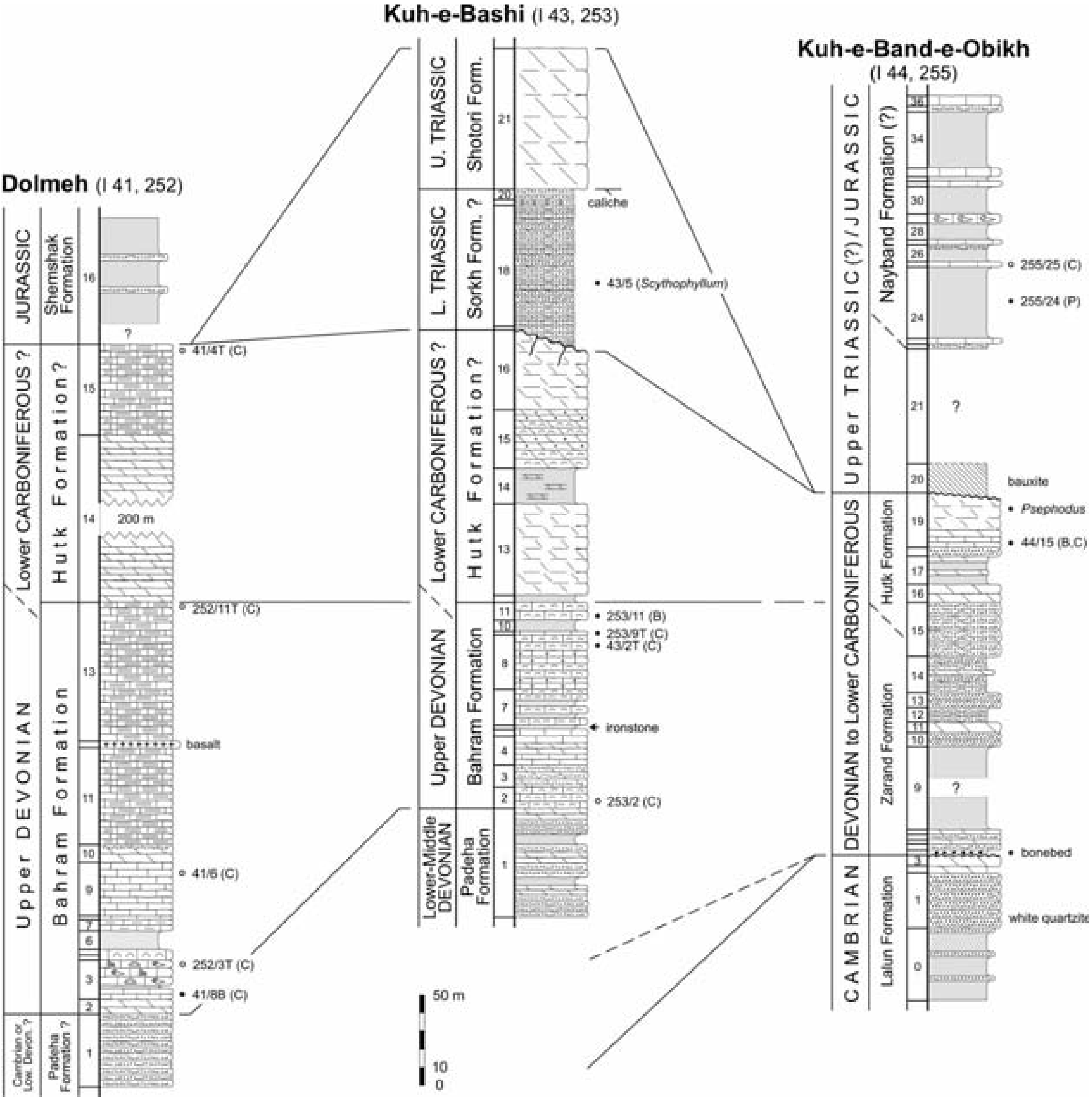


Fig. 23. Correlation of Dolmeh, Kuh-e-Bashi and Kuh-e-Band-e-Obikh sections

stromatoporoids, sparse solitary and abundant colonial rugose corals (*Phillipsastrea* and others), mostly in place. Though a conodont sample from the base of this unit has yielded only an approximate age (Middle to Upper Devonian), we assume, in comparison with the same lithology in the Kerman area (WENDT & *al.* 2002, p. 160), that this biostrome is of early to middle Frasnian age. The biostromal facies was again found at Kuh-e-Dokhtar, 10 km SE of Dolmeh, but not farther south. The main portion of the Bahram Formation consists of well-bedded laminated limestones and shales (11-13) similar to those in the Binalud Mountains (see above) with an intercalated basalt sill in the middle part. Both the limestones and the shales were subjected to a low-grade metamorphism and transformed into fine-grained marbles and phyllites. Though conodont samples from the base and top were barren, we consider the overlying 280 m thick dolomite member (14) as equivalent to the lower Tournaisian Hutk Formation, the upper part (15) of which lithologically resembles units 11-13. But a Permian age (Jamal Formation) cannot be excluded. The contact with the shales and sandstones of the Jurassic Shemshak Formation (16) is concealed but apparently depositional.

From an area 4 km to the NW ("Dalmeh") GINTER & *al.* (2002) and HAIRAPETIAN & YAZDI (2003) figured a similar, but less complete section of the upper part of the Bahram Formation (Shishtu Formation), in which the limestones are apparently less metamorphosed and therefore had a better conodont recovery. Obtained ages include *triangularis* to *praesulcata* Zone and show that our units 9-13 embrace virtually the entire Famennian. HAIRAPETIAN & *al*. (2000) mentioned upper Famennian vertebrate remains from this section.

Kuh-e-Bashi

In contrast to Dolmeh, the Bahram Formation at Kuh-e-Bashi (Text-fig. 23) consists predominantly of skeletal (brachiopods, crinoids) limestones without biostromal intercalations (2-11). They are overlain by a dolomitic member which forms two prominent cliffs (13, 16), separated by thin-bedded, partly argillaceous dolomites (14, 15). The age of the entire dolomitic member is unclear. According to the lithology we tend to correlate it with the lower Tournaisian Hutk Formation. This interpretation is supported by discoveries of sparse brachiopods by HAGHIPOUR & *al*. (1977) in the upper part (16) of this member. But K. RASHIDI (Payam-e Nour University Ardekan, pers. comm.) found Famennian brachiopods and conodonts in the upper, locally calcareous unit (16). The latter discoveries suggest referring the entire member to the Upper Devonian/lower Tournasian Bahram Formation. The top of the upper dolomitic cliff (16) is a major erosional unconformity with up to 30 m karstic relief, accentuated by cavities and dykes, which are filled with dark red sandstones from the overlying unit (18). The latter is a continental deposit, possibly a time-equivalent of the shallow marine Sorkh Formation of the Shotori Range (STÖCKLIN & *al.* 1965). Geologists from the GSI Meshed who mapped the area in 1995, found a specimen of *Scythophyllum persicum* (SCHENK) KILPPER (det. H.-J. SCHWEITZER, Bonn; Pl. 10, Fig. 4) in these fine-grained sandstones, a species which is known from the basal Shemshak Formation of the Kerman area, but in this place may be older (Lower Triassic?). The upper 20 m of this member contain several caliche levels (19-20) below the sharp contact with a thick-bedded dolomite unit (21) which we correlate with the Upper Triassic Shotori Formation. This boundary is locally accentuated by an angular unconformity of up to 15°.

Kuh-e-Band-e-Obikh (Text-fig. 23)

The core of the tectonically fragmented anticline N of the village of Neiouk is mapped as Cambrian Lalun Formation on the 250,000 map (1972) and as Lower Devonian on the 100,000 map (2002). We have adopted the former interpretation and consider the white quartzite (1) equivalent to the "Top Quartzite" of the Lower Cambrian Lalun Formation. The top of the overlying dolomite (2-3) shows a conspicuous relief with sandstone veins penetrating from above, thus indicating a major depositional gap. It is levelled by 20 cm brownish sandstone (4) crowded with fish remains, some of which are up to 10 cm long (Pl. 10, Figs 1, 2). This is probably the first record of a veritable Palaeozoic bonebed in Iran and indicates an unspecified Devonian age for the overlying, totally unfossiliferous sandstone-dolomite series (5-15), which we attribute to the Zarand Formation. The Upper Cambrian Mila Formation which is about 500 m thick only 8 km farther W (HAGHIPOUR & *al*. 1977) has been almost totally removed by pre-Devonian erosion in this section. A conodont sample from the base of a prominent dolomitic ledge (19) has yielded a Tournaisian age (older than *anchoralis* Zone). Two tiny bradyodont teeth of *Psephodus* (det. H.-P. SCHULTZE, Berlin) are an additional indication that the beds from 15 (or 16?) to 19 belong to the Hutk Formation. HAGHIPOUR & *al*. (1977) found Tournaisian brachiopods in this unit. The upper boundary of ledge 19 is another major erosional unconformity with an up to 20 m relief which is locally accentuated by syndepositional faults. This relief is levelled by a 30 m thick bauxite level (20) which has been exploited in the past (HAGHIPOUR & *al*. 1977, fig. 40). It precedes, after a concealed unit (21), a sequence of fully marine and very fossiliferous (colonial and solitary corals, stromatoporoids, calcareous sponges) deposits which resemble the Upper Triassic Nayband Formation but may be younger. They pass into white oolites typical of the Jurassic Badamu Formation. There is no reason to assume an overthrust at the base of the latter as shown on the 1 : 100 000 map (2002).

These three sections are another example of the considerable lateral facies changes which make lithostratigraphic correlations in the Palaeozoic very speculative. Fully marine Devonian deposits (Bahram Formation) occur only in the northern two sections, Dolmeh and Kuh-e-Dokhtar. Because of the tectonic complications in the entire mountain range, it cannot be decided yet if the boundary with the siliciclastic-dolomitic facies of the Devonian (Zarand Formation) in the south is due to synsedimentary strike-slip movements as in the Kerman area (WENDT & *al.* 2002, p. 160) and near Kalmard, or merely due to "normal" facies transitions. Repeated intense erosion prior to deposition of the Lower Triassic Sorkh Formation, the Upper Triassic Nayband Formation and the Lower

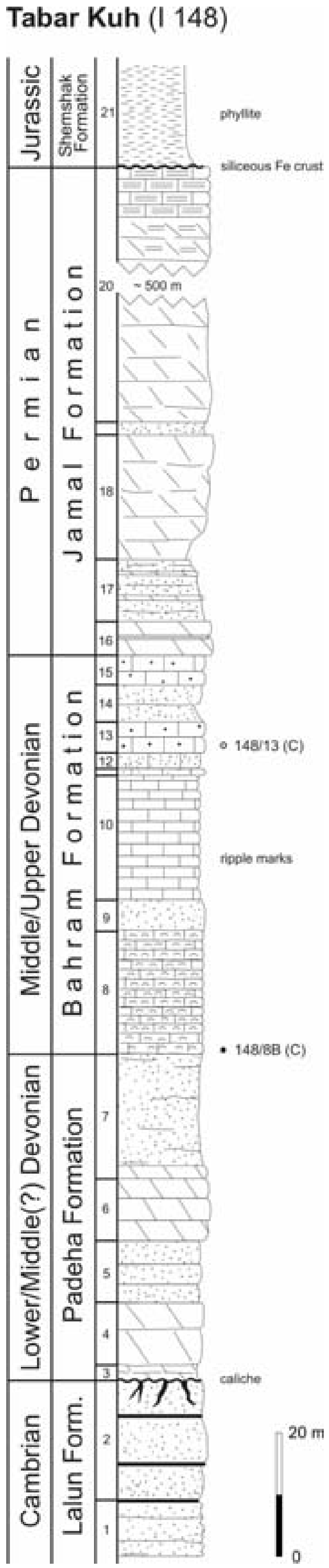


Fig 24. Tabar Kuh section

Jurassic Shemshak Formation has probably left no vestiges of the otherwise ubiquitous carbonate platform of the Upper Permian Jamal Formation in this area.

Yazd area

Tabar Kuh

This tectonically isolated monocline 40 km WNW of Bafq exposes a Cambrian to Permian sequence which differs markedly from those farther W and in the Ravar-Kuhbanan area (WENDT & *al*. 2002) in the SE (Text-fig. 24). The oldest rocks are unfossiliferous red quartzitic sandstones alternating with shales, siltstones

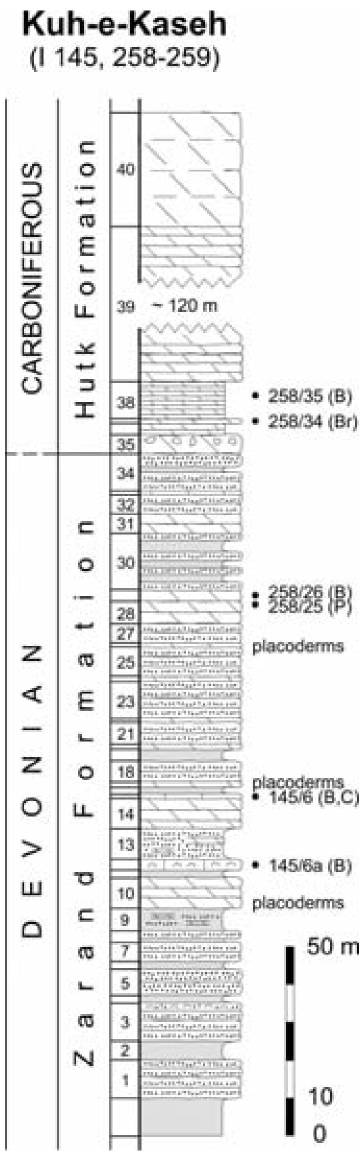


Fig. 25. Kuh-e-Kaseh section

and dolomites grading upwards into more massive sandstones (2). This sequence is usually labelled as Cambrian Lalun Formation. The top shows a pronounced relief levelled by a 1-3 m thick dolomitic caliche representing a continental interval of unknown duration (3). We tentatively attribute the overlying 50 m thick sandstone-dolomite sequence (4-7) to the Lower/early Middle Devonian Padeha Formation though biostratigraphic evidence for this age is lacking. The sudden onset of sandy skeletal limestones (8) marks a transgression which could be roughly dated as Givetian-Frasnian (*timorensis* to Frasnian Zone 10). Higher levels include platy limestones with occasional current ripples (10), quartzitic and calcareous sandstones, shelly and crinoidal limestones which, however, did not yield diagnostic organic remains. They represent a nearshore facies of the Upper Devonian Bahram Formation but could also include Lower Carboniferous equivalents. This sequence is abruptly overlain by thick-bedded dolomites of the Permian Jamal Formation (16-20) which form the peak and southern escarpment of the mountain. This 500-600 m thick pile is weakly metamorphosed in the upper part and truncated by another erosional hiatus predating the phyllitic shales of the Lower Jurassic Shemshak Formation (21).

Kuh-e-Kaseh

The monocline of Kuh-e-Kaseh 15 km SW of the city of Yazd (Text-fig. 25) exposes a hitherto unknown Palaeozoic sequence which yields new data on the depositional environment during the Devonian/Lower Carboniferous along the western margin of the Yazd Block. The foothills of the horseshoe-shaped crest consist of platy, white, quartzitic, passing into iron-stained brown sandstones which represent the Cambrian Lalun Formation but may include, after an undetected disconformity, parts of the lower Zarand Formation (Devonian). They are overlain by a 20 m thick unit of black dolostones and skeletal limestones (12-15) which, in the lower part (12), contain numerous *Cyrtospirifer* of Frasnian age. A conodont sample from the third limestone layer (15) of this unit has yielded a Frasnian age (Zone 8-10). The basal part of the cliff consists of an alternation of whitish to brownish, cross-bedded or laminated sandstones with intercalated dolomites (16-34). The latter show phenomena of deposition in the shallow sub- to supratidal realm, indicated by microbial laminations in the intertidal, and tepee structures in the supratidal members. The subtidal members have yielded some fragments of placoderms and poorly preserved cyrtospiriferids suggesting a Late Devonian age. This unit which we attribute to the upper part of the Zarand Formation is terminated by a breccia of reworked quartzitic sandstones in a dolomitic matrix (35) overlain by thin-bedded dolomites containing large crinoid columnals, bryozoans and cyrtospiriferids of probable Early Carboniferous age (36-38). These in turn pass into thick-bedded structureless dolomites of the Hutk Formation which form the crest of the 1570 m high mountain. They continue for several hundreds of metres, but their approximate thickness cannot be estimated because of several faults and overthrusts.

Mazraeh-e-Kheradmand

On the northern slope of the Kuh-e-Dosar range, about 60 km S of Yazd, a poorly exposed section (Text-fig. 26) of Upper Devonian to Upper Permian rocks shows red quartzitic sandstones (1-5) of the Zarand or

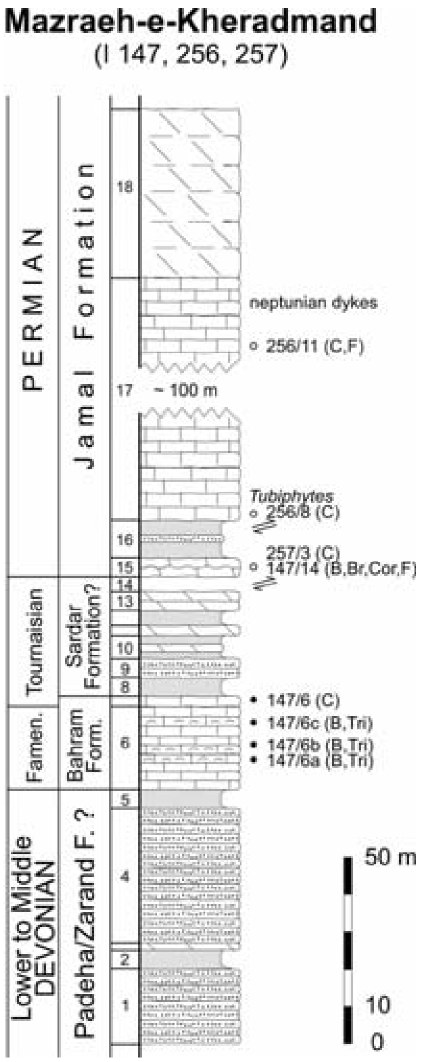


Fig. 26. Mazraeh-e-Kheradmand section

Padeha Formation in the foothills. They are overlain by black skeletal limestones (6) with abundant brachiopods and rare trilobites (Pl. 9, Fig. 7) which indicate a latest Famennian (Strunian) age for most of this unit. A conodont sample from (7) has yielded a Tournaisian age showing that the Devonian/Carboniferous boundary is close to the top of this limestone ridge. The following 40 metres of unfossiliferous sandstones, dolomites and shales (8-14) are probably also of Tournaisian age. The boundary with a band of nodular limestones (15) is faulted. The latter contain brachiopods, bryozoans, rugose corals and fusulinids of Early Permian age. Also the contact with the cliff-forming carbonates of the Jamal Formation (17) is locally faulted. The lower 150 m are calcareous and crowded with *Tubiphytes* near the base and Upper Permian fusulinids (?*Sichotonella*, *Baisalina pulchra*, *Stipulina*) higher up. The upper part of this steep cliff is crisscrossed by numerous neptunian dykes filled with red micrite indicating another break in sedimentation of still unknown age and duration.

Sanandaj-Sirjan Belt

This belt (the Rezaiye-Esfandagheh orogenic belt of TAKIN 1972) is a 100-250 km wide and over 1000 km long zone which extends in a NW-SE direction between the Zagros thrust front in the SW and the Urumieh-Dokhtar magmatic assemblage (Jurassic to Eocene) in the NE. It consists of several superimposed and imbricated wedges of unmetamorphosed or low-grade metamorphosed Phanerozoic rocks thrust from the NE over distances of tens to possibly hundreds of kilometres (ALAVI 1994). Tectonically isolated remnants of Palaeozoic rocks occur patchily over the entire length of the belt but were not studied in great detail by us. In the southern part of this belt, metasediments and basic to ultrabasic rocks of presumed Devonian-Carboniferous age occur, interpreted as a "geosynclinal" facies of Hercynian mobile zones (DAVOUDZADEH & WEBER-DIEFENBACH 1987).

Khabr Complex

This area is situated about 50 km SSW of Baft in the southeastern sector of the Sanandaj-Sirjan Belt. It consists of four superimposed complexes of (from bottom to top) (1) gneiss, amphibolite, marble, (2) micaschist, greenschist, marble, (3) limestone and marble and (4) micaschist, quartzite, marble, black schist. This sequence is interpreted as Cambrian to Lower Permian in age and is presumed to be structurally intact (sheet Khabr 1 : 100 000, 1997; M. SABZEHEI, pers. comm.). Guided by M. SABZEHEI (Teheran) we examined a sec-

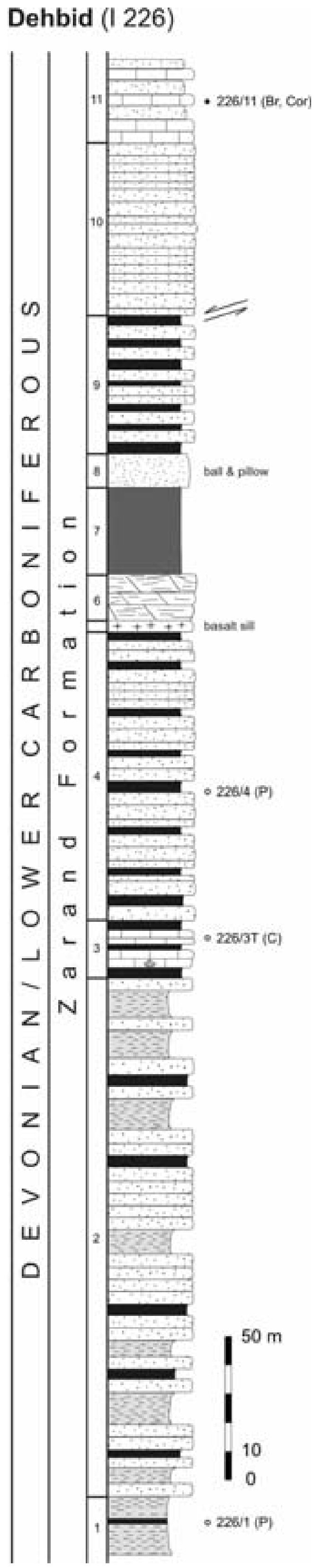


Fig. 27. Dehbid section

tion on the southern slope of Kuh-e-Khabre where complex 3, attributed to the Devonian-Carboniferous, consists of three units: (a) about 500 m of well-bedded, partly laminated (micro-stylolitized) limestone and calcschist containing some crinoids and undeterminable shell debris, followed by (b) a 200 m thick conspicuous band of white, thick-bedded to massive, partly dolomitic marble and (c) about 300 m of shale and calcschist which form the peak of the 3095 m high mountain. The boundary between (a) and (b) is a distinct, 10-30 m thick thrust zone. The overlying marble (b) shows cross-sections of thick-shelled bivalves which resemble rudists. As a result of a new mapping of the area by the GSI Kerman, our supposed Upper Cretaceous age of this member has recently been confirmed by findings of *Orbitolina* in this marble. These new discoveries require a structural and stratigraphical re-examination of the Khabr Complex in which the presence of Devonian-Carboniferous equivalents remains doubtful.

Near Esfandagheh, about 60 km east of Kuh-e-Khabre, the Khabr unit (here labelled as Upper Permian/Triassic) is said to overlie a 3000 m thick unit of schists, phyllites, marbles and basic metavolcanics (Sargaz-Abshur Complex) which are attributed to the Devonian-Carboniferous (DAVOUDZADEH & *al.* 1986, WEBER-DIEFENBACH & *al.* 1986). Such an age is inferred from alleged crinoid, brachiopod and pelecypod remains (SABZEHEI 1974) or merely adopted from K/Ar ages of biotite paragneises obtained from an area about 250 km farther NW (ADIB 1978, DAVOUDZADEH & WEBER-DIEFENBACH 1987, ŞENGÖR 1990) which reflect a Devonian (362-404 Ma) metamorphism. These far-fetched correlations and unsatisfactory data are an insufficient support for the presumed existence of a "geosynclinal" setting in the Sanandaj-Sirjan Belt during Devonian-Carboniferous times.

Dehbid area

One of the numerous thrust sheets of the central Sanandaj-Sirjan Belt, 30 km NE of Dehbid (Text-fig. 27), has a predominantly clastic assemblage of reddish clays, quartzites with some dolomitic and calcareous intercalations which, on the 100 000 sheet, is attributed to the Devonian. Our conodont and palynomorph samples from units (3) and (4) were barren. An imprecise Devonian age can be inferred only from poorly preserved cyrtospiriferids in a black mudstone layer (3). The overlying sandstones and dark shales (4-10) pass into a thick sequence of well-bedded dark limestones with reddish sandy seams (11) which contain crinoids, bryozoans, rugose corals and michelinids of Early Carboniferous age.

About 80 km to the NW, in the vicinity of Abadeh, YAZDI & *al*. (2000) found lower Famennian (*crepida* Zone) conodonts in an allochthonous, strongly disturbed limestone unit overlain by sandstones which pass into sandy carbonates of Carboniferous age. The latter may be equivalent to a 280 m thick limestone unit mentioned by TARAZ (1974) in the same area which could correspond to our unit (11). It passes into a 130 m thick sandstone unit overlain by Permian fusulinid limestones. The pre-Permian rocks are attributed to the Lower Carboniferous and are said to be thrust onto Upper Devonian quartzites.

Isfahan area

The presence of Devonian strata in the mountains NE of Isfahan (Isfahan Basin of CHERVEN 1986) was first documented by DJAFARIAN & BRICE (1973) who found upper Famennian brachiopods in the Kuh-e Kaftar and Kuh-e Zard ranges. Later, ZAHEDI (1976), HAMEDANI (1996), MISTIAEN & *al*. (2000), GHAVIDEL-SYOOKI (2001b), MORZADEC (2002), GHOLAMALIAN (2003) and KEBRIAIE (2003) examined two sections (Zefreh and Chariseh) in this area and dated several levels of the Devonian by means of conodonts, brachiopods and trilobites. HAMEDANI & *al*. (1998) mentioned gabbros and diorites intruded into Upper Devonian strata. HAIRAPETIAN & *al*. (2000) found microvertebrate remains in Frasnian to Upper Famennian strata. PLUSQUELLEC (2000) and PLUSQUELLEC & GOURVENNEC (2000) described two problematic organic remains from the Chariseh section. In recent years M. YAZDI (Geol. Dept Univ. Isfahan) performed stratigraphic investigations in this area and introduced us to the local geology.

The oldest exposed rocks are pale and reddish sandstones, shales and dolomites which may be coeval with the Padeha Formation of the Kerman area. The subsequent transgression of skeletal limestones was dated by HAMEDANI (1996) as Emsian/Eifelian boundary and by YAZDI (unpubl.) as late Frasnian. This up to 250 m thick sequence of limestones, shales, quartzitic sandstones and dolomites shows lithologies typical of the Bahram (including Shishtu) Formation and comprises the Givetian, Frasnian and, from place to place different, portions of the Famennian. The skeletal limestones contain a great variety of brachiopods (*Spinatrypa*, *Cyrtospirifer*, rhynchonellids and others), tentaculitids and rugose corals (*Hexagonaria*) which form local biostromes. YAZDI & *al.* (2000) and GHOLAMALIAN (2003) found upper Famennian conodonts in the topmost part of the Bahram Formation below the Permian transgression. HAMEDANI (1996) mentioned findings of

Clymenia and *Goniatites* which would also indicate the presence of upper Famennian and even Visean equivalents in the topmost part. The transgression of the Permian Jamal Formation onto different levels of the upper Frasnian to upper Famennian is a sharp boundary marked by a bauxitic palaeosol. The middle to upper Permian limestones are very fossiliferous and contain numerous foraminifera, brachiopods, bryozoans, solitary and colonial rugose corals, syringoporid tabulates, coralline sponges (chaetetids, *Amblysiphonella*), pelecypods, gastropods, orthoconic nautiloids and trace fossils.

Neqleh

The presence of Devonian rocks in the Kohrud Mountains about 50 km S of Kashan has long been known (FRECH 1900; DOUVILLÉ 1901, 1904; STAHL 1911). ZAHEDI (1973) mapped part of the mountain range NE of Soh and presented the first detailed sections of the Silurian to Triassic strata. Our section on the northwestern slope of the Neqleh valley (Text-fig. 28) is close to the one figured by him and shows only minor differences compared to his figure 16. The Sibzar Formation (3) is considerably thicker (110 m vs. 40 m) and does not contain any limestone intercalations. The sequence shows a pronounced cyclicity in which the sandstone layers represent the supratidal members. The Bahram Formation starts with a 20 m thick unit of black oolite (5) passing into dark mudstones and finally into skeletal limestones crowded with brachiopods. A conodont sample from the top of this unit has yielded only an unprecise Givetian/Frasnian (*timorensis* to Frasnian Zone 10) age. ZAHEDI (1973) reported brachiopods, tentaculitids and rugose corals from the Bahram Formation which were probably derived from this level. These faunas were partly revised by BRICE (1999) and ROHART (1999). The upper part of the Bahram Formation (7) consists of an alternation of shales with limestone intercalations with poorly preserved brachiopods which may include a part of the Upper Devonian. They are capped by a conspicuous level of greenish caliche with pisoids passing into a white kaolinite (8) which represents a long continental interval before the onset of the Middle Permian carbonate platform sedimentation (9).

LONG & ADHAMIAN (2000), HAIRAPETIAN & *al.* (2000) and ADHAMIAN (2003) studied a similar sequence in the vicinity and showed that Givetian limestones with microvertebrate remains of the Bahram Formation are directly overlain by dolomites of the Jamal Formation. It appears that, as a result of the pre-

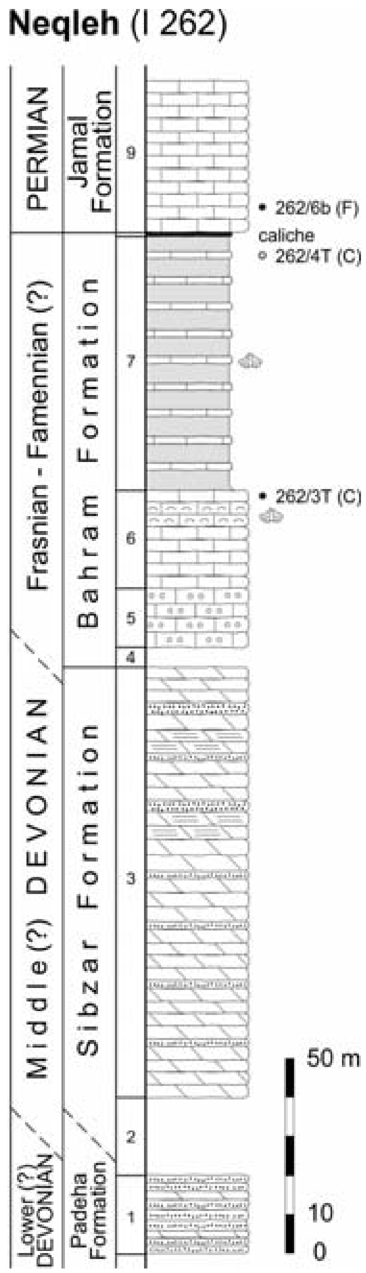


Fig. 28. Neqleh section

Permian erosion, the Upper Devonian (?) shale unit of the Neqleh area (7 in Text-fig. 28) is not preserved in this locality.

From these few and patchy occurrences of Devonian/Lower Carboniferous rocks it becomes evident that in Palaeozoic times the Sanandaj-Sirjan Belt was part of the central-Iranian shelf. The existence of pre-Mesozoic "mobile zones" (DAVOUDZADEH & WEBER-DIEFENBACH 1987, fig. 1) northeast of the emergent area of the Zagros Mountains is not confirmed by our observations.

Zagros Mountains

In the southern Zagros Mountains (Kuh-e-Faraghan, Kuh-e-Gakhum), Lower Silurian graptolite shales crop out (ALA & *al.* 1980, KALANTARI 1981, HUSSEINI 1991, KONERT & *al.* 2001) which are a time-equivalent of the lower Niur Formation and constitute important source rocks (hot shales). They are unconformably overlain by continental deposits of the Faraghan Formation subdivided and dated by GHAVIDEL-SYOOKI (1994b) as Lower Devonian to Frasnian. In the well Darang 1 on the southwestern foothills of the Zagros Mountains, 450 m of "Silurian-Devonian" shales have been cored, overlying 700 m of Ordovician shales (KALANTARI 1992). Farther N, in the areas of coastal and interior Fars, Cambrian sandstones and carbonates of the Lalun and Mila Formations are unconformably capped by the continental Faraghan Formation indicating considerable pre-Devonian uplift and erosion (GHAVIDEL-SYOOKI 1997, 1998a). In the northwestern Zagros Mountains and adjacent areas of Lurestan and Khuzestan, Devonian deposits are absent and Cambrian/Lower Silurian deposits are directly overlain by the Permian portion of the upper Faraghan Formation. It should be noted that the National Stratigraphic Committee of Iran (unpubl.) has proposed to restrict the usage of the term Faraghan Formation to its Lower Permian equivalents (M. Davoudzadeh, Munich, pers. comm.). From these data it becomes evident that a large land area persisted in western and southwestern Iran during the Devonian-Carboniferous, whose boundaries towards the marine shelf farther NE have been obscured by the enormous amounts of crustal shortening along the Zagros thrust belt.

Kerman area

The area between Kerman, Rafsanjan, Zarand and Ravar and the facies evolution from the Silurian into the Lower Carboniferous has been treated in WENDT & *al.* (2002). Recently, two more sections have been examined which provide new insights into palaeogeography of the Devonian in southeastern Iran.

Kuh-e-Kanseh (Text-fig. 29)

This locality at the southeastern termination of the Bidou syncline, 50 km N of Kerman, was first mentioned (under the name "Heruz") by DASTANPOUR (1996), but his figured section has little in common with the sequence observed in the field. This is the only place where we discovered a slight angular unconformity (10-15°) between the sandstones of the Cambrian Lalun

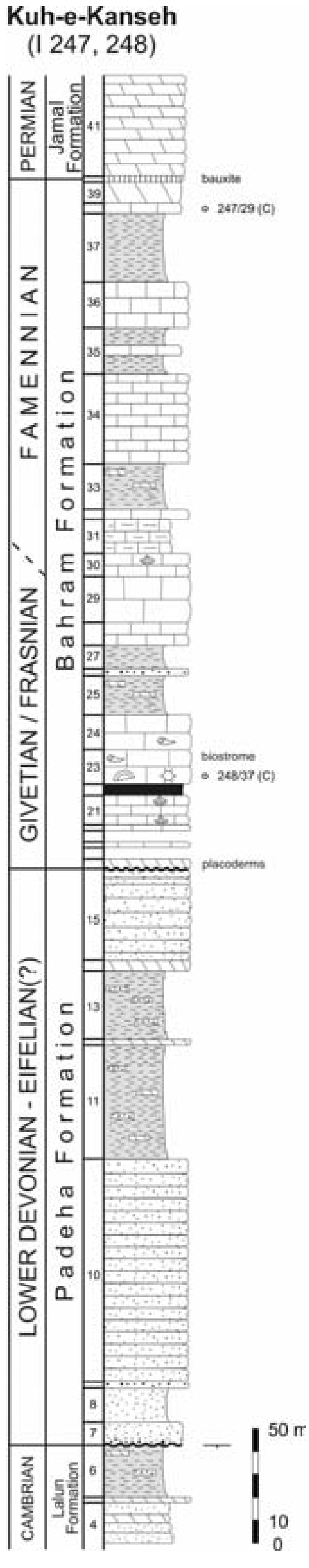


Fig. 29. Kuh-e-Kanseh section

Formation and similar ones of the Lower Devonian/ Eifelian Padeha Formation (Pl. 4, Fig. 2). In addition, this hiatus is marked by an erosional unconformity. The red sandstones of the Padeha Formation (7-15) start with a 0.1 m thick breccia of black cherts (Pl. 4, Fig. 3), a lithology which we did not find in the underlying strata. The top of the Formation is easily identified by another erosional unconformity and overlain by a dolomite layer (16) crowded with small gastropods and placoderm debris. Thirty metres above the base of the Bahram Formation, a 20 m thick biostrome (23), constructed of bulbous *Hexagonaria*, *Phillipsastrea*, alveolitid tabulate corals and stromatoporoids, is striking. Though a conodont sample from this level was barren, we regard it, in comparison with similar lithologies in the vicinity (WENDT & *al.* 2002), as early Frasnian in age. It grades upwards into skeletal limestones with reworked tabulate corals (24). The disappearance of tentaculitids after unit (30) probably indicates the Frasnian/Famennian transition. The remainder of the Bahram Formation consists of an alternation of skeletal (crinoids, brachiopods, bryozoans) limestones and shales. Because a conodont sample from the topmost limestone layer (38) was barren, it cannot be decided yet how much of the Upper Devonian has been eroded prior to the transgression of the Permian Jamal dolomites (41). As in other places, this boundary is very conspicuous and marked by a dark red sandstone/bauxite layer (40).

Rizu

The area NW of Zarand (zone B in WENDT & *al.* 2002, text-fig. 17) is distinguished from the fully marine sequence farther E and S, by a predominantly siliciclastic lithology in the Devonian (Zarand Formation), into which only sparse carbonate layers are intercalated. Widespread erosion prior to the Permian transgression has removed large portions of the calcareous Devonian in this area, leaving behind only the basal part of the Zarand Formation. In some places the Permian Jamal dolomites directly overlie Cambrian sandstones without or with an imperceivable angular unconformity (WENDT & *al.* 2002, pl. 4, fig. 3).

The gentle anticline 7 km S of Rizu and 5 km SE of Mohamed-Abad (Text-fig. 30) is the only place in this region where a considerable portion of the calcareous Devonian has escaped the pre-Permian erosion. The contact Padeha/Bahram Formation and the basal part of the latter are concealed and faulted. About 20 m above the base of the Bahram Formation a 4 m thick biostrome (6) constructed of stromatoporoids, *Alveolites* and *Hexagonaria* is obvious. Another coral-stromatoporoid biostrome, crowded also with ramose bryozans (13; Pl. 9,

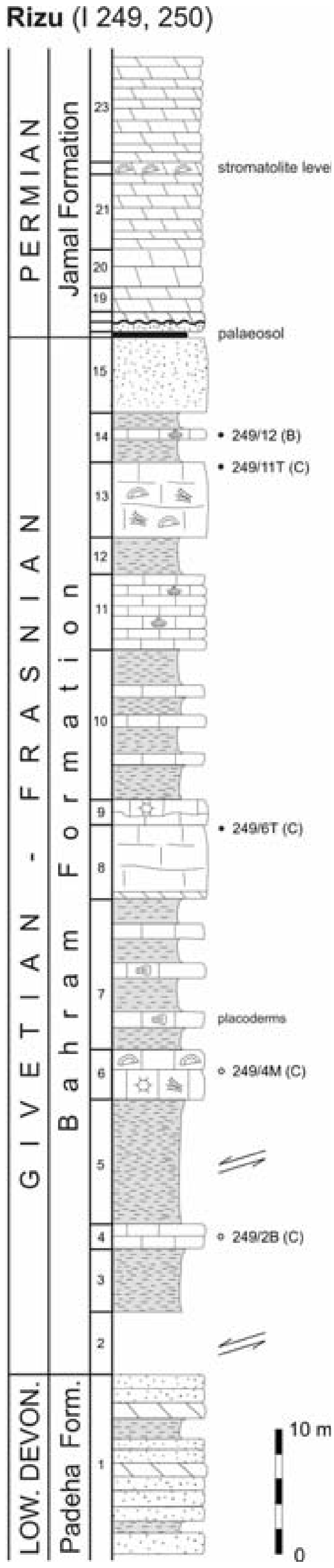


Fig. 30. Rizu section

Fig. 6) occurs 40 m higher up. The lower biostrome may be still Givetian, the upper one is Frasnian. A palaeosol (16) intercalated in the topmost part of a quartzitic structureless sandstone, and an erosional unconformity 1 m higher (Pl. 6, Fig. 3) mark the boundary with the Permian Jamal dolomite (18-23). A stromatolite level (22) 12 m above the base of the dolomite is a widespread and synchronous index level (WENDT & *al.* 1997, Figs 13-14, here misinterpreted as pertaining to the Bahram Formation). On the eastern flank of the anticline, opposite the section of Text-fig. 30, the erosional unconformity at the base of the Jamal Formation cuts down onto progressively older levels of the Bahram and finally onto the Padeha Formation (Pl. 4, Fig. 1).

FACIES PATTERN AND PALAEOGEOGRAPHY

The palaeogeographic maps of Figs 31-35 must be regarded as a first attempt to depict Devonian/Lower Carboniferous facies patterns on a wider regional scale and using much more data than were available before. The first palaeogeographic maps of the Devonian were presented by WOLFART (1967, 1981), STAMPFLI (1978, republished by BRICE & *al.* 1978), WEDDIGE (1984a, b) and WENSINK (1991). But these authors had relatively few data obtained from personal research and a smaller number of previous publications and maps. In comparison with these nevertheless very useful reconstructions, DASTANPOUR's (1996) simplified palaeogeographic map of the Iranian Upper Devonian is a step backwards. The idea of a "deep eusynclinal trough or megagraben" (Kerman-Kashmer Trough) in the Palaeozoic, proposed by BRATASH (1975), is not based on personal knowledge of the rock record and will therefore not be discussed here.

For the bulk of the included data, the palaeogeographic and facies maps of figures 31-35 are based on our own research. In addition, all available sources from the literature and from geological maps were incorporated. The considerable Cimmerian (Late Triassic) and Alpine (Late Cretaceous-Tertiary) shortening within individual areas, however, could not be taken into account. Also the alleged 135° anticlockwise rotation of the Central-East-Iran Microplate (SOFFEL & *al.* 1996) has not been considered in our maps (see below). Therefore these maps reproduce the actual distribution of facies patterns and their boundaries, but not necessarily their exact original setting.

Silurian (Niur Formation) (Text-fig. 31)

Despite excellent and continuous outcrops and a high fossil content, the base and top of the Niur Formation have never been precisely dated. Ages of casually collected faunas range from the Llandovery (GHAVIDEL-SYOOKI 2001) or early Wenlock into the late Ludlow, and possibly into the Lochkovian (RUTTNER & *al.* 1968, STÖCKLIN & SETUDEHNIA 1970, HUBMANN 1991, HAMEDI & *al.* 1997). An attempt of a palaeogeographic reconstruction of Iran during the Silurian/Lower Devonian was presented by DAVOUDZADEH & *al*. (1986).

As a consequence of the Late Ordovician glaciation and a lowstand of sea level, large areas of northern Gondwana including Azerbaijan, the western and central Elburz, parts of the Sanandaj-Sirjan Belt, the Zagros Mountains and eastern Iran were emergent since the Late Cambrian/Early Ordovician. After melting of the glaciers a rise of sea level occurred in the Early Silurian, concomitant with a transgression from the Palaeo-Tethys in the north which flooded parts of northeastern and central Iran. The stratigraphic record is most complete in the eastern Elburz (R, Sh) and in the mountain ranges between Kashmar and Kalshaneh (KF, OK, K). In both areas up to 700 m of limestones and shales were deposited, rich in shallow water organisms (brachiopods, rugose and tabulate corals, trilobites). Locally (OK, K), small biostromes, composed of corals and stromatoporoids, developed. Towards the margins of the depocenter (KR, N, An) sandstones and shales predominated. It should be noted that these deposits are exclusively of shallow water origin. Therefore the assumption of Ordovician-Silurian "syn-rift deposits" and the construction of of a N-S trending "Tabas Aulacogen" (LASEMI 2001) which is not based on field evidence, must be rejected. Also RAMEZANI & TUCKER (2003) could not find "firm evidence for the rift-drift transition, continental breakup or ocean basin formation in the lower Paleozoic sedimentary (or paleomagnetic) record of the unified Arabo-Iranian platform".

Three areas in Iran do not simply fit into this rather consistent palaeogeographic pattern. (1) NW of Kerman, up to 1000 m of carbonates and siliciclastics (partly labelled as Shabdjereh Formation by HAMEDI 1995) were deposited. This marginal marine shelf with an intermittent fluvial influx was separated from the above mentioned basin by a W-E trending continental area. One could be tempted to interprete the isolated position of the Kerman Silurian as a proof for the presumed 135° anticlockwise rotation of the Central-East-Iran Microplate (SOFFEL & *al.* 1996). But such a construction would imply also a rotation of the Kashmar-Kalshaneh area (KF, OK and K) and its contradictional separation from equivalent deposits farther north in the Binalud (P, Kv) and in the easternmost Elburz (R, O, Sh).

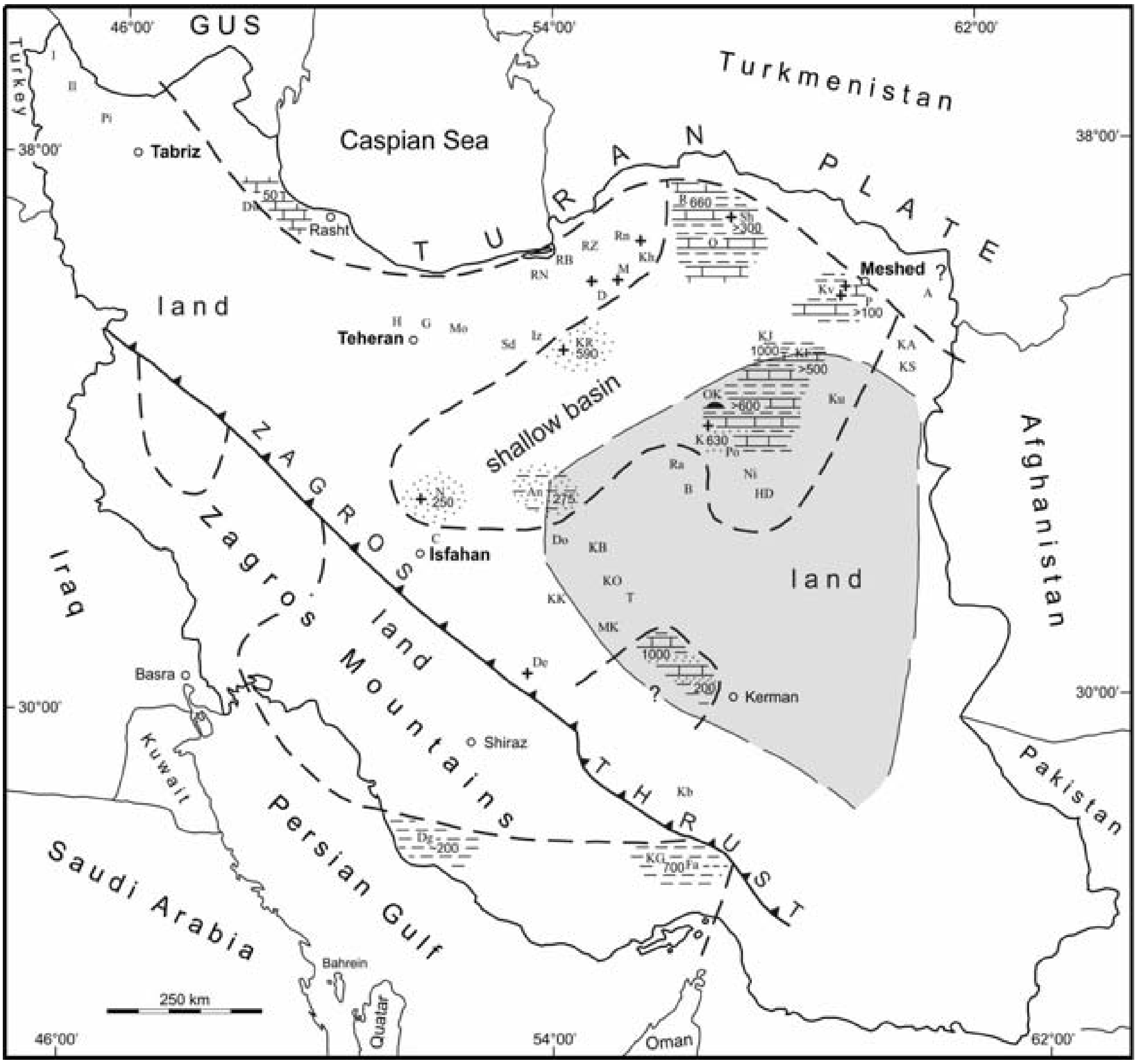


Fig. 31. Facies pattern and palaeogeography of the Silurian (Niur Formation). Boundaries of marine towards continental areas in the Zagros Mountains partly after KONERT & *al.* (2001). Shaded area is Central-East-Iran Microplate. For symbols of localities see Appendix 1, for lithologies see Text-fig. 4

(2) Still farther south, in the southern Zagros Mountains (KG), about 700 m of graptolite shales are recorded. Despite the allochthonous position of the area and the poor biostratigraphic and sedimentologic evidence (HUSSEINI 1991, GHAVIDEL-SYOOKI 1994b), the origin of this deep-marine Silurian and its possible connection with the Palaeo-Tethys remain enigmatic. In STAMPFLI's (2000) plate reconstruction the southern boundary of the Palaeotethys is situated north of the Sanandaj-Sirjan to Lut blocks, but in SCOTESE's (2002) reconstruction the submerged shelf of Gondwana is shown to extend into the area of the Zagros Mountains, northern Arabia and farther west. The latter configuration would not only explain the occurrence of the Zagros graptolite shales but also their extension into parts of Saudi Arabia.

(3) A small outcrop of 30 m of red *Orthoceras* limestone in the northwestern Talesh Range (Dw) has been dated by HAMDI (1975) as Wenlock to Ludlow in age. This lithology extends as far as 65 km to the SE where equivalents of Ordovician to Lower Devonian fossiliferous limestones have been discovered (CLARK & *al.* 1975). The unique lithologies and the isolated position of an open marine environment in the Silurian, surrounded by continental areas in the W, N and E, suggest that the Talesh Range must be positioned N of the Hercynian suture zone as a fragment of the Turan Plate (for a different interpretation see ALAVI 1996, fig. 1).

Lower (?) to early Middle Devonian (Padeha Formation)

Due to the lack of diagnostic organic remains, the stratigraphic range of the Padeha Formation is still poorly understood. In the most complete sections, Padeha deposits overlie marine Silurian shales and carbonates and are in turn overlain by well dated Lower Givetian sediments of the Bahram Formation. Therefore the age of the Padeha Formation is generally ascribed to the Early Devonian, but locally (eastern Elburz) it includes parts of the Eifelian. In other areas, Padeha siliciclastics conformably overlie lithologically very similar Cambrian/Lower Ordovician sediments of the Mila Formation, the separation of which is sometimes rather arbitrary. In central and eastern Iran, the same lithology continues into the Lower Carboniferous (Zarand Formation), the Lower Devonian portion of which is almost impossible to discern. Due to these uncertainties, the palaeogeography of the Lower Devonian/Eifelian shown on Text-fig. 32 must be considered as tentative.

A drop of sea level at the Silurian-Devonian transition caused a large-scale regression and establishment of a siliciclastic shelf with intermittent deltaic and fluvial influence. Subsidence rates remained high and led to deposition of up to 700 (1200?) metres of mostly red, more rarely grey or greenish, siltstones and sandstones with trough cross bedding, wave ripples, current ripple cross-lamination and other features of turbulent waters. Intertidal to shallow subtidal dolomites are often intercalated in this sequence. Sebkha conditions prevailed in

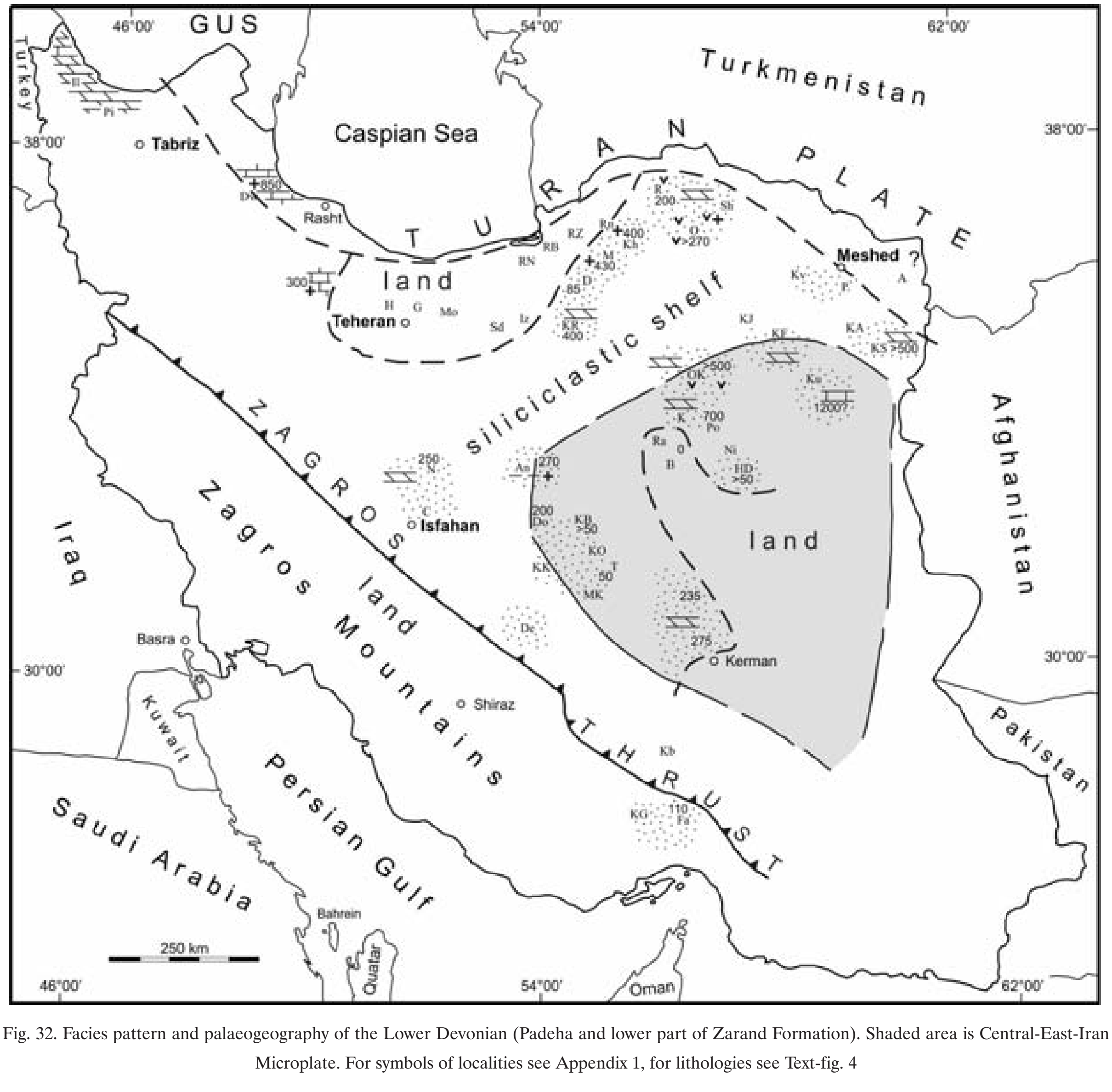


Fig. 32. Facies pattern and palaeogeography of the Lower Devonian (Padeha and lower part of Zarand Formation). Shaded area is Central-East-Iran Microplate. For symbols of localities see Appendix 1, for lithologies see Text-fig. 4

some areas of the eastern Elburz (O) where over 270 m of gypsum were deposited. They were repeatedly interrupted by siliciclastic influx farther N and S (R and OK). Volcanic activity is reflected by some diabase sills in the eastern Elburz (Kh, M, Sh) and in central Iran (An), which are believed to be also Early Devonian.

This shelf on which more open marine conditions are locally recorded by rare fish remains (e. g. KO and NW of Kerman) and in one locality in the Kerman area by conodonts (WENDT & *al.* 2002) passed into a land area farther SW in the Zagros Mountains. The continental Faraghan Formation which may include Carboniferous (and Permian?) equivalents is dated as Devonian by palynomorphs only in the far south (Fa) but is said to extend into the central Zagros. Northern (central and parts of the eastern Elburz) and eastern Iran (E of Kerman) remained uplifted and were deeply eroded, locally down to the Precambrian.

In Azerbaijan (I, Il) the lower part of a thick pile of unfossiliferous dolomites (Muli Formation) which overlies a metamorphic basement may include Lower Devonian equivalents and reflects intertidal to shallow subtidal conditions. The fully marine Lower Devonian of the Talesh Range (Dw) with intercalated spilites is an extraneous element which again supports the interpretation that this area is a remnant of the Turan Plate. In this reconstruction, the occurrence of marine carbonates of presumed Pragian/Emsian age in the North Qazvin Range S of Rasht (ANNELLS & *al.* 1975) remains enigmatic. In the Soltanieh Mountains farther NW, limestones of the Upper Cambrian Mila Formation are capped by quartzites of the Lower Permian Dorud

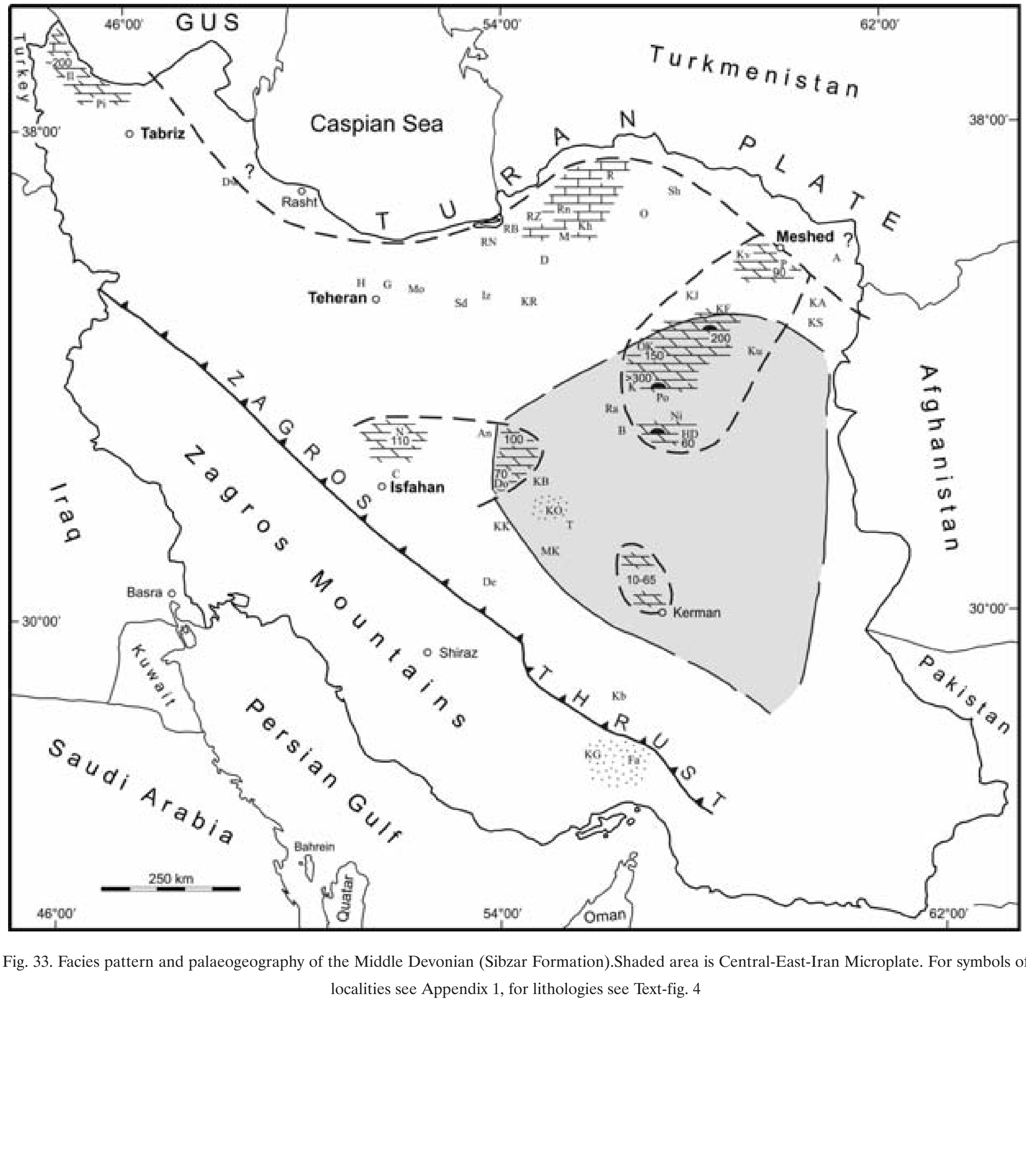


Fig. 33. Facies pattern and palaeogeography of the Middle Devonian (Sibzar Formation).Shaded area is Central-East-Iran Microplate. For symbols of localities see Appendix 1, for lithologies see Text-fig. 4

Formation indicating an extensive continental interval in the western Elburz (STÖCKLIN & *al.* 1965).

Givetian (Sibzar Formation)

The term "Sibzar Dolomite" was introduced by RUTTNER & *al.* (1968) for a dolomitic unit in the Ozbakh-Kuh intercalated between the Padeha and the Bahram Formations. In contrast to previous statements, not only the upper but also the lower boundary of the Sibzar Formation is gradational (WENDT & *al.* 1997), and the idea of an "Eifelian hiatus" (WEDDIGE 1984a, 1984b, and others) must be abandoned. Only in the Derenjal Mountains (K) could the age of the Sibzar Formation be determined as early Givetian. Elsewhere, due to the lack of diagnostic fossils, an approximate Givetian age of the Sibzar Formation can be deduced from the age of the overlying Bahram Formation. Overlapping ages of the Sibzar and the basal Bahram Formation indicate that the former is nothing else than a predominantly dolomitic time-equivalent of the latter.

The Sibzar Formation (Text-fig. 33) is represented by several isolated ephemeral carbonate platforms in which minor oscillations of sea level are recorded by sub-, inter- and supratidal members. Vestiges of such platforms are encountered in the areas between Meshed and the southern Shotori Range, in the Neqleh-Anarak area and NW of Kerman. In Azerbaijan, the upper part of the Muli Formation represents a similar environment. Locally (KF, K, HD), coral-stromatoporoid biostromes are developed which attain thicknesses of up to 25 metres in the Derenjal Mountains (K). In the eastern Elburz (M, Kh, R) some tens of metres of poorly dated limestones and dolomites may represent a time-equivalent of the Sibzar Formation. The central Elburz was still emergent in early Givetian times, as were the Zagros Mountains, where only in the far south (Fa) a continental environment is recorded by palynomorph-bearing shales and sandstones.

Givetian to Lowermost Carboniferous (Bahram Formation, Text-fig. 34)

A more pronounced rise of sea level in the Middle Devonian caused flooding of large parts of Iran and deposition of fully marine deposits which in the eastern Elburz reach 1200 m of thickness. They consist of a great variety of lithologies including skeletal limestones, shales, intertidal dolomites, and siliciclastics. Regardless of the overall similar lithology and the considerable lateral facies changes, this sequence has been labelled with different names derived from homonymous localities: Geirud Formation (ASSERETO 1963), Khoshyeilagh Formation (BOZORGNIA 1973), Ilanqareh Formation (ALAVI & BOLOURCHI 1973), Rahdar Formation (AGHANABATI 1977). We also include the Upper Devonian/lowermost Carboniferous Shishtu Formation (STÖCKLIN & *al.* 1965, RUTTNER & *al.* 1968) in the Bahram Formation, because it does not represent a mappable entity.

The lower boundary of the Bahram Formation appears diachronous. The oldest conodont dates indicate lowermost Eifelian near Torbat-e-Jam (KA) or broadly Eifelian in the southern Shotori Range (HD) and in the Kerman area (WENDT & *al.* 2002). In most places, the base of the Bahram Formation is earliest Givetian. The top of the Formation is lower Tournaisian, but the boundary with the overlying Sardar Formation (see below) appears somewhat arbitrary. The alleged sea level changes during the Late Devonian/Early Carboniferous stated by DASTANPOUR (1997) are not based on field evidence and must not be discussed here.

For the first time since the Late Cambrian/Early Ordovician, the central Elburz was flooded. Fully marine conditions were established from Azerbaijan in the NW to central and eastern Iran with the exception of the present Zagros Mountains and the region E of Kerman. It is not clear to which extent, areas of the present western Elburz were also submerged because biostratigraphic data are not available.

Upper Devonian equivalents might be present in the schists and phyllites in the mountain ranges S of the Talesh Range (CLARK & *al.* 1975, CRAWFORD 1977; not shown on Text-fig. 34). Farther SE, only Carboniferous deposits transgress over a peneplained Cambrian-Ordovician surface (GLAUS 1965, MEYER 1967, DEDUAL 1967). The intercalation of current-swept land plants in shallow marine limestones and shales of the Geirud Formation indicates the proximity of emergent areas during the Late Devonian in the western and central Elburz.

Locally during the late Givetian, and more widespread during the Frasnian, small biostromes, constructed of tabulate and rugose corals as well as stromatoporoids, flourished. They did not exceed 20 metres in thickness and a few tens of metres in lateral extent, and nowhere developed into fringing reefs. In two areas in the eastern Elburz (KR and O), gypsum deposits indicate local sebkha environments during the Givetian.

A totally different lithology occurs at Aghdarband E of Meshed. Here, >500 m of distal turbidites with intercalated mudstones overlie submarine volcanic tuffs of unknown age. As stated above, these pelagic deposits whose Middle to Late Devonian age has been established by our acritarch discoveries and by SCHÖNLAUB (1991), must be considered as a remnant of the Turan Plate.

Submarine volcanism was most active in the central Elburz (H, G, Mo) where up to 400 m of basaltic lavas and tuffs were deposited. In other areas sills of similar composition intruded into the marine sequence and are supposed to be of the same age.

Thicknesses of Upper Devonian strata are highest in the eastern Elburz (M, Kh) and in the Binalud Mountains (P) and seem to decrease towards the south. In this still very generalized facies pattern, submarine ridges with conspicuously reduced sedimentation can be recognized in the central Elburz (IZ), in the Kalmard region (Ra, B), east of Yazd (T) and west of Kerman. In the Saghand region between Kalmard and Kharanaq, deposits between the Cambrian and the Permian are totally lacking (HUCKRIEDE & *al*. 1962, HAGHIPOUR 1976, HAGHIPOUR & *al.* 1977, RAMEZANI & TUCKER 2003) indicating a considerable uplift and a continental area in central Iran. A predominantly siliciclastic facies is widespread in the Kerman-Zarand area (WENDT & *al.* 2002) and extends into parts of the Sanandaj-Sirjan Belt (De, KK, MK), but the exact stratigraphic range of this neritic lithology (Zarand Formation) is uncertain.

The Zagros Mountains remained emerged during the Late Devonian/Early Carboniferous and were only locally covered by some tens of metres of continental sandstones and shales. This land area may have been connected to that E of Kerman in the region of the present Lut Desert. In this area a gap between Precambrian (or Lower Palaeozoic?) metamorphics and Permian limestones has been observed (STÖCKLIN & *al.* 1972). Due to the considerable crustal shortening

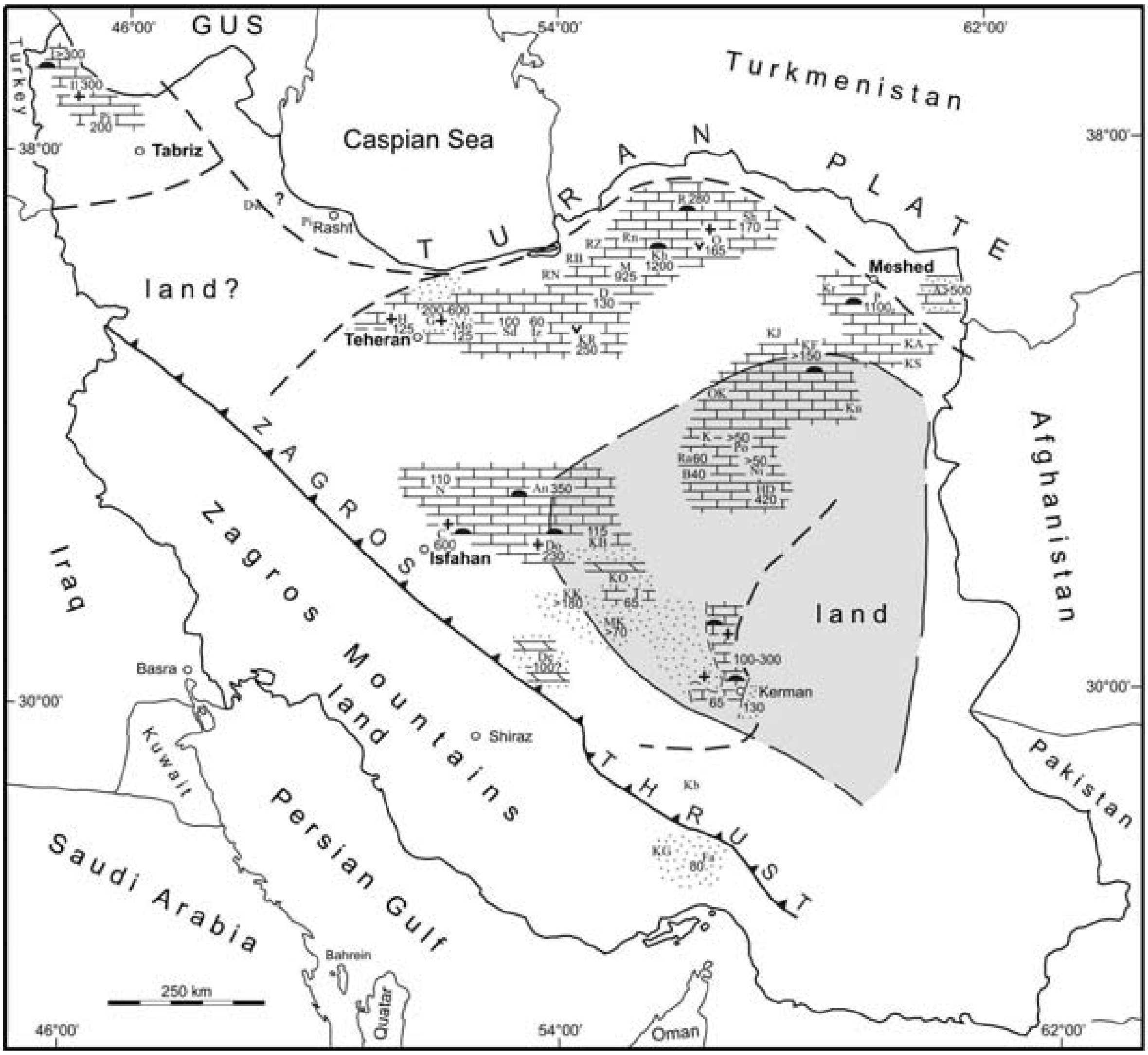


Fig. 34. Facies pattern and palaeogeography of the Upper Devonian (Bahram Formation). Shaded area is Central-East-Iran Microplate. For symbols of localities see Appendix 1, for lithologies see Text-fig. 4

between the two areas since the Mesozoic, such interpretations, however, remain highly speculative. The extensive outcrops of alleged Devonian rocks in the southeastern Sanandaj-Sirjan Belt (Kb and surroundings) shown on Text-fig. 2 probably do not include any Palaeozoic deposits and therefore have been ignored in our study.

Lower Carboniferous (Sardar and Mobarak Formations, Text-fig. 35)

The gradual transition and the lithologic similarity between the Upper Devonian and the Lower Carboniferous show that the depositional regime remained virtually unchanged during both stages. In the majority of the examined sections, the upper boundary of the Lower Carboniferous is marked by a hiatus with the overlying platform carbonates of the Permian Jamal Formation, more rarely by a transition into Namurian or younger deposits as in parts of the eastern Elburz (M) and in the Shotori Range (HD). Two main depositional areas can be distinguished: (1) Elburz Mountains and (2) central and eastern Iran.

(1) In the central and eastern Elburz a mixed carbonate-shale sedimentation with some siliciclastic input prevailed, with thicknesses up to 1000 metres. Frequent intercalations of bituminous limestones indicate temporary anoxic conditions. Minor thicknesses are mostly a result of the pre-Permian erosion which may be also the cause for the local absence of Carboniferous rocks. This is the case in the area between the southern Elburz and a line Isfahan - Meshed. On Text-fig. 35 these areas

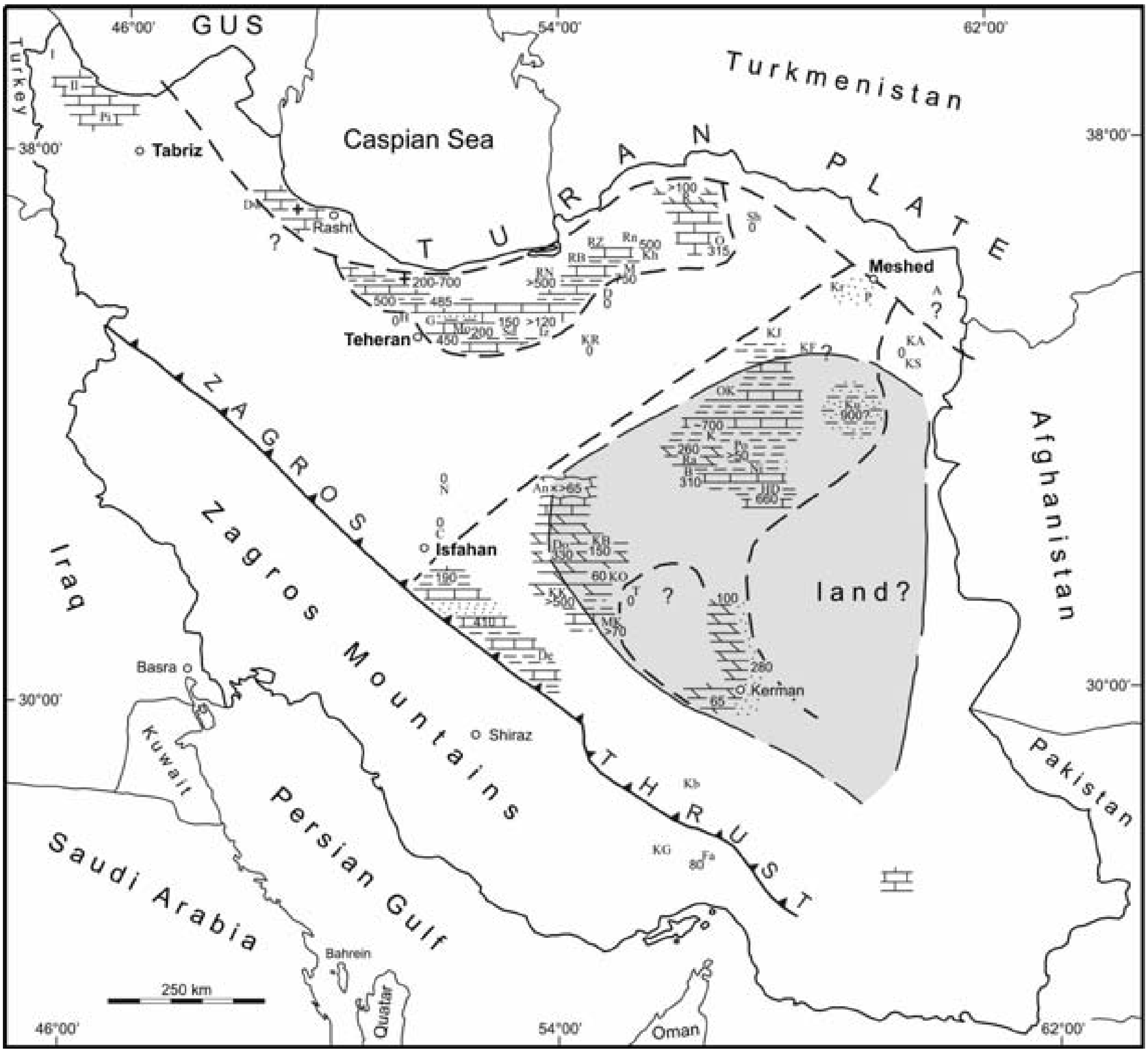


Fig. 35. Facies pattern and palaeogeography of the Lower Carboniferrous (Mobarak, Sardar and Hutk Formations). Shaded area is Central-East-Iran Microplate. For symbols of localities see Appendix 1, for lithologies see Text-fig. 4

are left blank, but this uncertainty does not necessarily imply the presence of land areas. Thus, in the central Elburz N of Teheran (H), Upper Devonian is directly covered by Permian. The same situation is found at Kuh-e-Rezaabad (KR) while farther NE (D, Sh), Upper Devonian deposits are capped by shales of the Lower Jurassic Shemshak Formation.

The upper Ilanqareh Formation of Azerbaijan includes parts of the Lower Carboniferous, but the connection of this area with the Elburz is not clear and it may have been interrupted by an emergent area as during the Late Devonian. This zone, characterized by pre-Permian erosion, extends from N of Isfahan (C, N) towards the NE and was connected to the extensive land area in the Zagros Mountains farther SW.

(2) A second, larger depocenter is situated in central and eastern Iran in the Kerman-Isfahan-Meshed triangle. It includes the "Central-East-Iran Microplate" as well as the northwestern part of the adjacent Sanandaj-Sirjan Belt and may extend into SE Iran (Baluchistan) where Carboniferous deposits were discovered by DOUGLAS (1950). A special feature of the area between Kerman and Yazd (KK, Do, KB, KO) is the establishment of isolated dolomitized carbonate platforms (Hutk Formation) during the late Tournaisian. A possible island on which Cambrian or remnants of Devonian sediments are capped by Permian platform carbonates, existed in the Kuhbanan-Baft area (T). A wide land area persisted in eastern Iran (Lut Block) and extended into western Afghanistan (Helmand Block). Its western boundary is exposed in the Lakkar Kuh (WENDT & *al.* 2002), but its continuation farther north is speculative. Volcanic activity was much weaker than during the Late Devonian and is reported only from the western Elburz (ANNELLS & *al.* 1975).

The only hint of Lower Carboniferous deposits north of the Hercynian suture zone (Turan Plate) is from the Talesh Range (Dw) where algal-foraminiferal limestones of Tournaisian-Visean age overlie Silurian cephalopod limestones with a tectonic contact (DAVIES & *al.* 1972). It cannot be excluded that the Middle/Upper Devonian turbidites in the Aghdarband area (A) continue into the Lower Carboniferous, but biostratigraphic data for this assumption are not available.

THE CENTRAL-EAST-IRAN MICROPLATE

WELLMANN (1966) was probably the first to envisage a palaeotectonic individuality of central Iran. His idea was adopted by TAKIN (1972) and SBORCHSHIKOV (1979) who considered this part of Iran as an individual block (Lut and Tabas Blocks of STÖCKLIN & *al*. 1965, STÖCKLIN 1968, 1977 and STÖCKLIN & *al*. 1972; Central-and-East Iranian Microcontinent of STÖCKLIN 1974). This block appears to have been rotated in an anticlockwise sense and is surrounded by Cretaceous ophiolites some of the latter were regarded as Palaeozoic (LENSCH & DAVOUDZADEH 1982). Later, DAVOUDZADEH & *al.* (1981) formulated the concept of the Central-East-Iran Microplate. This plate is bounded by the Great Kavir Fault in the N, the Nain-Baft Fault in the W and SW and the Harirud Fault in the E (Text-fig. 1). Palaeomagnetic data by WENSINK (1982, 1983), SCHMIDT & SOFFEL (1984) and by SOFFEL and his co-workers (summary in SOFFEL & *al.* 1996) seem to confirm the rotation of this plate which should have started with a 65º rotation in the Late Triassic (220 Ma), accompanied by a shift of the plate into an area south of the palaeo-equator. The plate motion was accomplished during the Early Tertiary with an additional rotation in the same sense attaining a total of 135º and a "return" of the plate into its original position. Consequently, WEDDIGE (1984a, b), in his palaeogeographic reconstructions of Iran during subsequent intervals from the Lower Devonian into the Upper Carboniferous, took into account these plate movements and rotated the microplate into its presumed pre-Triassic position.

This is not the place to examine the validity of the palaeomagnetic data which have been obtained from Devonian through Cretaceous rocks both inside and outside the plate. But it should be mentioned that some of WENSINK's (1983) data refer to Cambrian rather than Devonian rocks (e. g. in the Kerman area). Nonetheless, if the post-Triassic rotation of central Iran is accepted, then the facies pattern sketched in Text-figs 31-35 must be more realistic after a clockwise (re)rotation of 135°. We will therefore briefly examine if such constructions yield a better fit of palaeogeographic boundaries than their present one.

In the Silurian (Niur Formation), the isolated depocenter NW of Kerman (Text-fig. 31) could be interpreted, at first glance, as proof for an actual post-rotational position. But such a construction would also imply rotation of the Kashmar-Kalshaneh area (KF, OK, K) and its contradictory separation from similar deposits farther north in the Binalud (P, Kv) and in the easternmost Elburz (R, O, Sh).

Facies patterns of the Lower Devonian/Eifelian (Padeha Formation) are too uniform, and moreover too poorly established biostratigraphically, for showing significant inconsistencies comparing pre- (Text-fig. 32) with post-rotational reconstructions. The same is true for the Sibzar Formation (Text-fig. 33) the isolated carbonate platforms of which allow any sort of displacements if they were justified palaeomagnetically. Facies patterns of the Givetian through Lower Carboniferous

(Bahram and Sardar Formations, Text-figs 34-35), however, are much better established biostratigraphically and show more reliable palaeogeographic boundaries. A clockwise rotation of the microplate in this interval would completely separate the depositional area between Kashmar (KF) and the Shotori Range (HD) from similar environments in the north (KJ, KS, P) and shift them into a totally isolated position in the far south. The same inconsistency would arise for the Anarak-Yazd area farther west (An, Do). Still less acceptable would be the existence of land between the Kerman area and the Sanandaj-Sirjan Belt (N, C). As mentioned above, the Palaeozoic deposits of this belt are allochthonous and were transported over hundred(s) of kilometres from the NE. Nobody would assume that they are derived from a former continental area during the Late Devonian/Early Carboniferous.

It must be concluded that the facies patterns of the Silurian through Lower Carboniferous, as shown by their actual geometries, do not support the idea of an anticlockwise rotation of central-east Iran in post-Triassic times.

SYNSEDIMENTARY TECTONICS (Text-fig. 36)

Phenomena of synsedimentary tectonics have been observed in several sections of the study area and appear to be related to tensional and strike-slip movements which were active during various intervals of the Palaeozoic. Most conspicuous are sedimentary breccias intercalated in Middle Devonian carbonates and characterized by a good fitting of the clasts (*in-situ*-breccias), accompanied by small-scale folds and horst-and-graben structures. These phenomena are common in the Sibzar Formation of the Derenjal Mountains and Ozbakh-Kuh (WENDT & *al.* 1997). Normal faults with minor displacements (1-2 m) levelled by the overlying strata, occur also in upper Givetian/lower Frasnian strata of the Shotori Range (Text-fig. 16). The frequent depositional gaps in this section, in particular in the Famennian, are also related to repeated local uplifts and erosion.

Another type of sedimentary breccias was observed in the Kalmard area. We interpret the local accumulations of poorly-sorted and poorly-rounded clasts in the Lower Carboniferous of the Bakshi section (Text-fig. 20) as a submarine rockfall in the vicinity of (concealed) fault scarps. The fact, that calcitic veins of individual clasts do not continue into the matrix of the breccia (Pl. 5, Fig. 4) shows that the host rock of the clasts has been uplifted from considerable depths.

Synsedimentary movements of a much larger scale are exemplified by important strike-slip faults causing sharp facies boundaries in the Upper Devonian/Lower Carboniferous facies patterns. Some of these faults may have been inherited from the Lower Palaeozoic and remained active until the late Mesozoic/early Tertiary. Examples of such faults are obvious in the Kerman area (WENDT & *al.* 2002), in the Kalmard area (see above), in the Zeber Kuh range NE of Ozbakh-Kuh (SAHANDI & *al.* (1984), north of Djam (ALAVI-NAINI 1972) and possibly also in the Kharanaq area (see above); but they are probably more frequent than can be demonstrated.

The most important tectonic event was the uplift of the entire Iranian sector of Gondwana during the latest Carboniferous/earliest Permian and its transformation into a continental regime, accompanied by intense erosion. These movements are rarely expressed by angular unconformities (e. g. in the Kerman area). The peneplained surface was inundated during the late Early Permian with the growth of the vast carbonate platform of the Jamal Formation. The tectonic disintegration of this platform during the Late Permian is again expressed by *in-situ* breccias, neptunian dykes and synsedimentary faults. Impressive examples of these phenomena were observed by us in the Kerman area (WENDT & *al.* 2002) and south of Yazd (Text-fig. 26).

IGNEOUS ROCKS

Mid Palaeozoic mafic intrusions, sills, dykes, volcanic tuffs and lava flows are widespread in Iran. The most prominent volcanic activity is expressed by the up to 600 metres thick andesitic lavas and tuffs in the Soltan Maidan Formation in the eastern Elburz (Kh, M) which are ascribed to a breakup of the northern margin of Gondwana (JENNY 1977a, b; ALAVI 1996). The precise age of this volcanism is not known because K-Ar datings have yielded contradictory results ranging from 633 to 196 Ma of which the most recent ones are certainly rejuvenated (DELALOYE & *al*. 1981). Because the Soltan Maidan volcanics are unconformably overlain by conglomerates and sandstones of the Lower Devonian/Eifelian Padeha Formation, they are generally considered Silurian in age. But from the fact that in some places deposits of the Lower to Middle Ordovician Lashkarak Formation underlie these volcanics, an earlier age cannot be excluded. This assumption is supported by the observation in the Bojnurd and Robat-e-Gharabil area.

Apparently younger subvolcanic vestiges are reported from the eastern Elburz (KR, R, Sh), Djam, the Derenjal Mountains and parts of the Sanandaj-Sirjan Belt (De, N) where basaltic sills and dolerites intruded into limestones and shales of the Silurian Niur

Formation. The volcanic activity continued into the Early Devonian/Eifelian when up to 60 m thick basalt flows and sills are intercalated in the siliciclastic sequence of the Padeha Formation in the eastern Elburz, the Binalud Mountains and central Iran (e. g. Anarak). They are generally considered as contemporaneous with their host rocks, but from K-Ar datings (DELALOYE & *al.* 1981) it can be suspected that some of

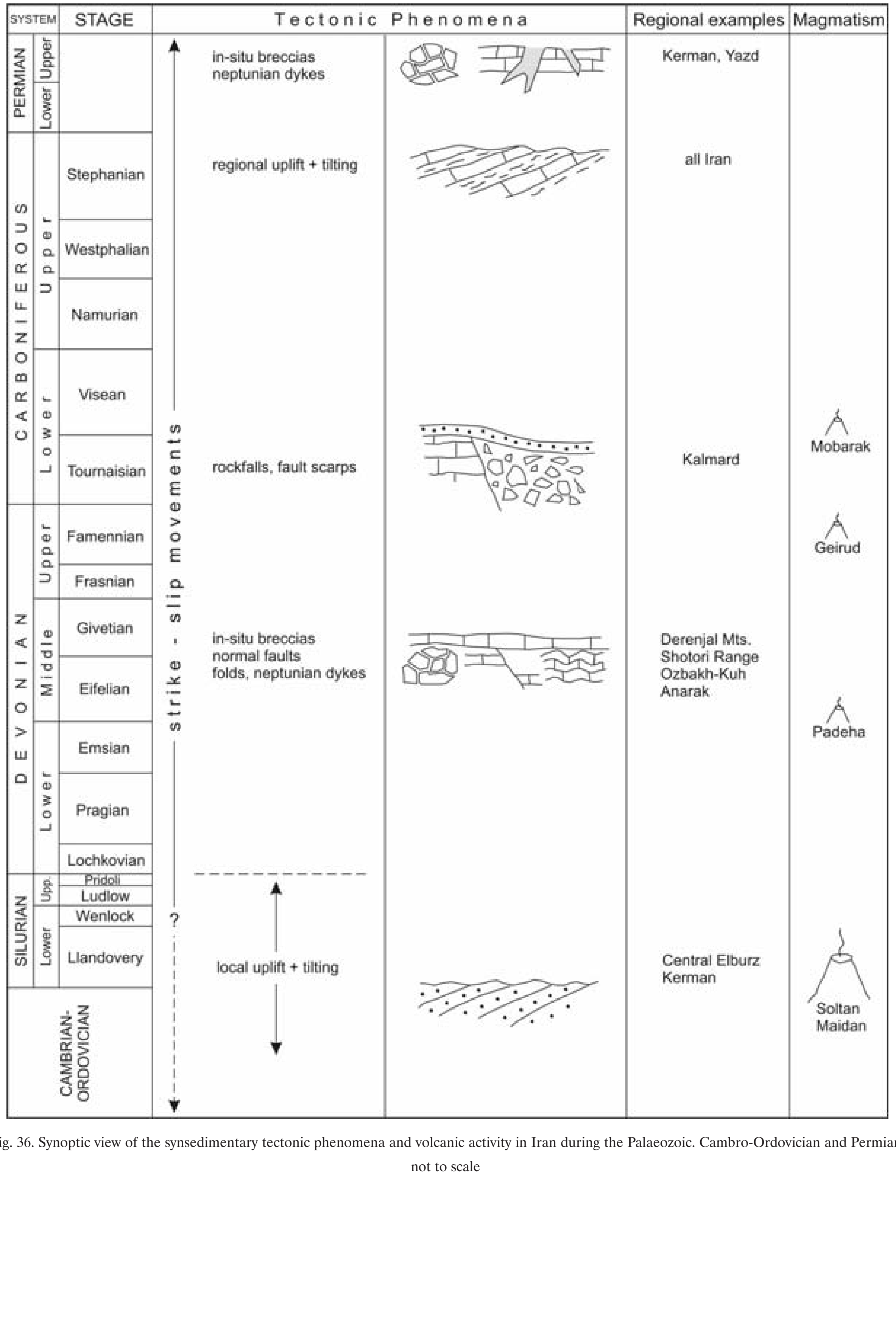


Fig. 36. Synoptic view of the synsedimentary tectonic phenomena and volcanic activity in Iran during the Palaeozoic. Cambro-Ordovician and Permian not to scale

them are considerably younger. Middle Devonian volcanic tuffs near Aghdarband and spilites in the Talesh Range (HAMDI 1975) document volcanic activity on the southern margin of the Turan Plate.

The central Elburz was a centre of submarine volcanism during the Late Devonian. From the Geirud area up to 400 m thick lava flows are recorded which, on the basis of still unsufficient biostratigraphic data, are attributed to the Famennian. In other areas of northern and central Iran, intrusives, volcanic sills and tuff intercalations in the Bahram Formation attain thicknesses of several tens of metres. Up to 200 m thick tuffs and diabase flows of imprecise age are tectonically intercalated in the Silurian-Devonian sequence of the Binalud Mountains. Volcanic activity in Iran decreased markedly in the Lower Carboniferous and is recorded only from the western (ANNELLS & *al*. 1975) and eastern Elburz (Kuh-e-Ozom).

The petrography and age of all these volcanics are still poorly understood precluding in most cases speculations about their palaeotectonic setting and interpretation. A synoptic summary of the tectonic events and volcanic activity is shown on Text-fig. 36.

CONCLUSIONS

The present study is the second (and final) part of a stratigraphic, sedimentologic and palaeogeographic examination of Devonian and Carboniferous deposits in Iran. It is the first attempt of a large-scale study and comprises the major part of the country except a few metamorphic zones possibly including coeval deposits, the Zagros Mountains in the SW and the extreme South (Sistan-o-Baluchestan, Makran), where deposits of this age are mostly unknown or continental. The study area (approximately 700,000 km^2) includes the northern zone (northern Elburz and remnants of the Turan Plate), Iranian Azerbaijan, the central and eastern Elburz, the Binalud Mountains, the puzzle of various blocks in central Iran, and selected parts of the Sanandaj-Sirjan Belt facing the Zagros Main Thrust. The following results have been obtained:

1. 65 sections, the majority of them never studied in the past and comprising the entire Devonian and the Lower Carboniferous, were logged and sampled.

2. Dating and correlation of the sections was mostly achieved biostratigraphically, i. e. by means of conodonts, brachiopods, tentatulitids and less common index fossils (foraminifera, trilobites, calcareous algae, acritarchs, palynomorphs and cephalopods). Due to rapid lateral facies changes, lithostratigraphic correlations must be used with utmost caution and can only tentatively be applied to some distinct levels in closely neighbouring sections. Due to the overall scarcity of index fossils, calibration and correlation of many sections is often incomplete and unsatisfactory. Nevertheless, the overall temporal and spatial facies evolution during a time span of approximately 100 Ma could be reconstructed.

3. The examined sequences comprise the following formations: Silurian Niur Formation (of which only the top was examined), Lower Devonian (and partly Eifelian) Padeha Formation, Givetian to lowermost Carboniferous Bahram Formation (and equivalents), Lower to early Upper Carboniferous Mobarak (and Sardar) Formation. The Middle Devonian Sibzar Formation can only locally be discriminated and is regarded as a time equivalent of the lower Bahram Formation. Maps of facies patterns and thickness variations have been sketched for these time intervals. They show the evolution of a fully marine carbonate platform in the Silurian into a siliciclastic, fluvial and deltaic shelf in the Early and early Middle Devonian delineated by land areas in the N (central and part of the eastern Elburz), SE (Lut) and SW (Zagros). This shelf was again flooded in the Givetian (locally earlier) when isolated carbonate platforms (Sibzar Formation) developed and former land areas became more restricted. Fully marine conditions persisted until the early Late Carboniferous, during which time some of the former land areas expanded. The entire area became emergent during the Late Carboniferous. A veneer of widespread continental deposits (caliche, bauxites) indicates an interval of subaerial erosion prior to establishment of another giant carbonate platform during the late Early Permian (Jamal Formation). Later continental/erosional intervals during the Early and Late Triassic have locally overprinted the upper boundary of the Devonian/Carboniferous sequences. As a result of the transgressions during the Permian (Jamal), Triassic (Sorkh, Shotori) and Jurassic (Shemshak) formations, the remaining thicknesses of the Devonian/Carboniferous deposits show highly contrasting amounts between 100 and 2000 metres.

4. The major part of the study area belongs to the stable northern margin of Gondwana. As shown by the general, larger-scale, uniform facies patterns, an early individualization and separation of major blocks within this segment (Sanandaj-Sirjan, Yazd, Tabas, Lut, southern Elburz) is not clearly evident during the Devonian-Carboniferous. Striking depositional constrasts between some neighbouring areas are interpreted as the result of Hercynian strike-slip movements (e. g. Kuhbanan Fault, Kalmard Fault, Attarie Fault) which may have been active already during Early and Middle

Palaeozoic times. Minor extensional movements are expressed by synsedimentary tectonic breccias, faults and contrasting subsidence patterns, some of them leading to local and temporal emergence and karstification (e. g. in the Kalmard area).

5. Parts of the western Elburz (Talesh Range) and eastern Kopet Dagh (Aghdarband) are characterized by a totally different facies pattern. Shallow pelagic limestones in the former and turbiditic deposits in the latter area, unknown from the rest of Iran, indicate that these areas are remnants of the Turan Plate north of the Palaeotethys. The latter was eliminated during the Late Triassic and can now be traced only from a few relics of ophiolites and oceanic deposits in the Talesh Range and north of the Binalud Mountains (Meshed). The fact that the Devonian/Carboniferous deposits which cover all Iran south of this suture zone, are exclusively of shallow marine origin, shows that enormous portions of the northern margin of Gondwana including the entire continental slope, must have been subducted during the Upper Triassic elimination of the Palaeotethys and the collision of Gondwana with the Turan Plate.

6. The existence of alleged Devonian mobile zones in central and southern Iran (at the western margin of the Central-East-Iran Microplate and in the southern Sanandaj-Sirjan belt) is hardly compatible with the above palaeotectonic scenario. Biostratigraphic proof for a Devonian age of these "geosynclinal" deposits is lacking, and available radiometric ages are contradictory. It should be examined if this magmatic arc and associated oceanic deposits are not considerably younger, i. e. related to the opening of the Neotethys.

7. Silurian to Lower Carboniferous facies patterns plotted on the present geographical map of Iran do not support the concept of a Central-East-Iran Microplate and its supposed 135° anticlockwise rotation since the Upper Triassic.

8. Volcanic activity is expressed by thick lava flows in the Soltan Maidan Formation (Silurian or older) and by minor intercalations of basaltic lavas in the lower Devonian (Padeha), Upper Devonian (Bahram) and Lower Carboniferous (Mobarak) sediments. Radiometric ages for these volcanics are not available and some might be substantially younger than their host rocks.

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APPENDIX 1: Coordinates of sections (B = Base, T = top)

Symbol on Figs 2,31-35	locality name	section number	coordinates
A	Aghdarband 1	(I 135, I 198)	
			B: N 35°59.060'; E 60°52.273'
			T: N 35°59.899'; E 60°51.502'
	Aghdarband 2	(I 199)	
			B: N 36°00.296'; E 60°52.218'
An	Anarak 1	(I 98, I 125, I 126, I 140)	
			B: N 33°11.327'; E 53°53.655'
			T: N 33°10.623'; E 53°52.278'
	Anarak 2	(I 143)	
			B: N 33°05.273'; E 53°56.633'
B	Bakshi	(I 84, I 244, I 245)	
			B: N 33°24.446'; E 56°13.674'
			T: N 33°25.203'; E 56°12.549'
C	Chariseh	(I 129, I 130)	
			B: N 32°59.776'; E 52°03.881
			T: N 32°59.145'; E 52°03.766'
D	Deh-Molla		
			B: N 36°21.420'; E 54°44.560'
			T: N 36°21.490'; E 54°44.530'
Da	Darrud	(I 63)	
			B: N 36°08.737'; E 59°07.745'
			T: N 36°11.179'; E 59°10.851'
De	Dehbid	(I 226)	
			B: N 30°47.588'; E 53°24.615'
Dg	Darang 1 well		
			N 28°06.962'; E 51°37.147'
Dh	Dhizbad	(I 65, see Text-fig. 12)	
			T: N 36°06.764'; E 59°17.634'
Do	Dolmeh	(I 41. I 251, I 252)	
			B: N 32°25.548'; E 54°16.974'
			T: N 32°25.204'; E 54°16.795'
Dw	Derow	(I 227)	
			N 37°26.095'; E 48°42.940'
Fa	Kuh-e-Faraghan		
		Not visited	
G	Geirud	(I 166)	
			B: N 35°58.736'; E 51°28.164'
Ga	Gerineh	(I 64, see Text-fig. 12)	
			T: N 36°08.884'; E 59°13.928'
H	Hassanakdar	(I 228)	
			B: N 36°04.052'; E 51°18.687'
			T: N 36°04.274'; E 51°18.574'
HD	Howz-e-Dorah	(I 47, I 62, I 63, I 69, I 173, I 174, I 175, I 176)	
			B: N 33°19.663'; E 57°21.171'
			T: N 33°23.077'; E 57°20.745'
I	Ilanqareh	(I 185, I 186, I 192, I 193, I 194, I 195)	
			B: N 39°27.675'; E 44°45.363'
Il	Illanlu	(I 187, I 190, I 191)	
			B: N 39°02.702'; E 45°17.313'
			T: N 39°02.918'; E 45°17.816'
IZ	Imam Zadeh	(I 167)	
			B: N 35°43.473'; E 53°31.490'
			T: N 35°43.443'; E 53°31.487'
K	Kalshaneh 1	(I 53-56, I 72-76, I 79)	
			B: N 34°06.545'; E 56°43.710'
	Kalshaneh 2	(I 57)	
			N 33°59.913'; E 56°44.682'
KA	Kuh-e-Ashti	(I 239)	
			N 35°16.024'; E 60°11.859'

KB Kuh-e-Bashi (I 43, I 253)
B: N 32°18.670'; E 54°28.419'
T: N 32°18.467'; E 54°28.558'

Kb Khabr (I 202-204)
N 28°47.114'; E 56°25.531'

KD Kuh-e-Dorbid (I 46)
N 32°05.256'; E 54°33.892'

Ke Kuh-e-Dokhtar (I 42)
N 32°18.698'; E 54°21.783'

KF Kuh-e-Faghan 1 (I 136, I 160-162, I 169, I 170)
B: N 35°06.994'; E 58°32.533'
T: N 35°06.861'; E 58°31.869'
Kuh-e-Faghan 2 (I 162, I 169)
B: N 35°05.449'; E 58°29.755'
T: N 35°05.128'; E 58°29.825'

KG Kuh-e-Gakhum
not visited

Kh Khoshyeilagh (I 21, I 197)
B: 36°49.948'; E 55°20.241'
T: 36°51.446'; E 55°19.890'

KJ Kalateh Jomeh (I 171, I 172)
B: N 35°20.202'; E 57°48.350'

KO Kuh-e-Band-e-Obikh (I 44-45, I 254-255)
B: N 32°03.327'; E 54°37.212'
T: N 32°02.936'; E 54°37.691'

Kv Karv-e-Bala (I 68, I 134, see Text-fig. 12)
B: N 36°11.738'; E 59°04.814'
T: N 36°12.220'; E 59°04.840'

Ku Kuh-e-Kalateh-Ali
not visited
Kuh-e-Kanseh (I 247, Kerman area)
B: N 30°43.480'; E 57°00.997'
T: N 30°43.604'; E 57°00.454'

KK Kuh-e-Kaseh (I 145, I 258)
B: N 31°49.148'; E 54°13.339'
T: N 31°48.914'; E 54°12.877'

O Kuh-e-Ozom
B: N 37°02.140'; E 56°32.190'
T: N 37°02.290'; E 56°32.290'

KR Kuh-e-Rezaabad (I 168)
B: N 35°48.330'; E 54°07.163'

KS Kuh-e-Shaftalu Ghaltan (I 238)
B: N 35°14.567'; E 60°15.857'
T: N 35°15.421'; E 60°16.873'

Ma Madbeiki (I 58, I 78, I 243)
B: N 33°30.313'; E 56°15.826'
T: N 33°30.446'; E 56°16.152'

MK Mazraeh-e-Kheradmand (I 147, I 256, I 257)
B: N 31°21.596'; E 54°24.660'
T: N 31°21.383'; E 54°24.687'

M Mighan (I 196)
B: N 36°38.210'; E 54°57.824'
T: N 36°38.661; E 54°56.448'

Mo Mobarak (I 139)
B: N 35°47.388'; E 51°58.289'

N Neqleh (I 262)
B: N 33°28.742'; E 51°35.781'
T: N 33°28.931'; E 51°35.768'

Ni Niaz (I 49-52)
T: N 33°39.512'; E 57°08.568'

OK Ozbakh Kuh (I 61, I 70, I 71, I 80-83, I 200)
B: N 34°42.277'; E 57°15.906'
T: N 34°42.736'; E 57°14.561'

P Pivehjan (I 66, I 67, I 131, I 132, I 137)
B: N 36°06.522'; E 59°19.669'
T: N 36°07.757'; E 59°19.038'
Karv-e-Bala (I 68, I 134, see Text-fig. 12)
T: N 36°12.220'; E 59°04.840'

Pi Pireshag (I 189)
B: N 38°43.762'; E 45°31.127'
T: N 38°44.179'; E 45°31.790'

Po Posha (I 242)
B: N 33°41.507'; E 57°04.693'

Ra Rahdar (I 59, I 60, I 77, I 85, I 246)
B: N 33°37.055'; E 56°21.612'
T: N 33°37.515'; E 56°20.865'

Rn Ramian (I 236)
B: N 36°55.223'; E 55°08.269'
T: N 36°54.371'; E 55°09.565'
Rizu (I 249, Kerman area)
B: N 31°01.784'; E 56°16.705'

R Robat-e-Gharabil (I 165)
B: N 37°22.617'; E 56°20.599'
T: N 37°22.859'; E 56°20.515'

RN Rud-e-Namakeh (I 24)
N: 36°28.056'; E: 54°06.012'

RB Rudkaneh-e-Bakhshah (I 231-235)
I 231: N 36°44.295'; E 54°34.068'
I 232: N 36°42.931'; E 54°35.083'
I 233: N 36°42.840'; E 54°35.199'
I 234: N 36°42.056'; E 54°35.250'
I 235: N 36°42.162'; E 54°34.653'

RZ Rudkaneh-e-Zaringol (I 237)
N 36°52.639'; E 54°57.200'

Sd Shahmirzad (I 138)
B: N 35°47.503'; E 53°18.937'

Sh Shirooyeh (I 164)
B: N 37°14.150'; E 57°20.190'
T: N 37°14.320'; E 57°20.240'

T Tabar Kuh (I 148)
B: N 31°43.863'; E 55°00.079'
T: N 31°42.993'; E 54°59.995'
Talom Khan (I 184, near Ilanqareh)
B: N 39°27.192'; E 44°48.274'
T: N 39°26.233'; E 44°49.193'

Z Zefreh (I 127)
B: N 32°56.017'; E 52°14.042'
T: N 32°56.421'; E 52°14.203'

APPENDIX 2: Ages of conodont samples listed in Tab. 1.

Section	Sample no.	Age
Ilanqareh	186/3	hemi*ansatus* - *timorensis*
Illanlu	191/12T	*costatus* - *ensensis*
	191/29	*rhomboidea-expansa*
Pireshag	189/2	Visean
Hassanakdar	228/7	Uppermost *marginifera* - Middle *expansa*
	228/8	Uppermost *marginifera* - Middle *expansa*
Rud-e-Namakeh	24/7M	*anchoralis* - *texanus*
Pivehjan	66/5	Middle Devonian
	133/3d	*timorensis* - Frasnian Zone 10
	137/1T	*timorensis* - Frasnian Zone 10
	137/8	*timorensis* - Frasnian Zone 10
	137/14	*timorensis* - Frasnian Zone 10
	137/20T	*timorensis* - Frasnian Zone 10
Karv-e-Bala	134a	*timorensis* - Frasnian Zone 10
	134b	Devonian
Kuh-e-Ashti	239/3	*costatus*
Kuh-e-Faghan 1	136/4B	Devonian
	136/5B	Middle Devonian
	136/6T	Lower/middle Frasnian
Kuh-e-Faghan 2	162/5T	Llandovery
	169/1	Upper Ordovician - Llandovery
Kalshaneh 1	76/5	*hemiansatus* - *timorensis*
	79/14a	*timorensis*
	79/20B	Devonian
	73/14	*timorensis* - *ansatus*
Kalshaneh 2	57	Uppermost *crepida* - Upper *marginifera*
Howz-e-Dorah	69/4T	Frasnian Zone 3 - 5
	69/5B	Frasnian Zone 6 - 9
	62/12	Frasnian Zone 9 - 10
	62/18	Frasnian Zone 10
	175/8	Frasnian Zone 10
	69/15a	Frasnian Zone 11
	69/15b	Frasnian Zone 11 - 12
	47/99	Frasnian Zone 12 - 13
	69/15c	Frasnian Zone 12 - 13
	69/16a	Frasnian Zone 12 - 13
	62/19T	Frasnian Zone 12 - 13
	69/19B	*triangularis* - Lower *crepida*
	48	Uppermost *marginifera* - Lower *trachytera*
	63/8T	Uppermost *marginifera* - *trachytera*
	47/7T	Uppermost *marginifera* - *trachytera*
	47/10	*anchoralis*
Niaz	51/2B	Frasnian
	51/11M	Frasnian Zone 11
	51/22T	Middle Tournaisian
	50/5	Tournaisian
Posha	242/98	Upper *triangularis*
	242/8	Uppermost *crepida* - Upper *marginifera*
	242/20T	Frasnian zone 13
Rahdar	77/5	Famennian?
	77/15	*postera* - *praesulcata*
Bakshi	84/12a	U. Famennian - L. Tournaisian
	84/16	*cuneiformis* - *anchoralis*
Madbeiki	78/8B	*duplicata* - *delicatus*

Anarak 1	125/3a	Givetian
	98/5	Givetian
	125/5B	Givetian
	125/6	Upper Givetian
	125/14	Upper Givetian
	98/41	Upper Givetian - Frasnian Zone 10
	98/62	Frasnian
	98/65	*cuneiformis*
	140/2B	*cuneiformis*
	140/4d	*noduliferus*
	142/4	*noduliferus*
	142/5	*noduliferus*
Anarak 2	143/2	lower Namurian
Tabar Kuh	148/8B	*timorensis* - Frasnian Zone 10
Kuh-e-Kaseh	145/6	Frasnian Zone 8 - 10
Mazraeh-e-Kheradmand	147/6	Tournaisian
Dolmeh	41/8B	M. - U. Devonian
Kuh-e-Bashi	43/2T	U. Devonian
	253/9T	*marginifera* - *trachytera*
Kuh-e-Band-e-obikh	44/15B	Tournaisian (older than *anchoralis*)
Neqleh	262/3T	*timorensis* - Frasnian Zone 10
Rizu	249/6T	*timorensis* - Frasnian Zone 10
	249/11T	Frasnian

Conodont taxa Sections	I	Il		P						Kv		KA	KF1		KF2		K1				T	KK	Do	KB		N	Ri	
Samples	186/3	191/12T	191/29	66/5	133/3d	137/1T	137/8	137/14	137/20T	134/a	134/b	239/3	136/5B	136/6T	162/5T	169/1	76/5	79/14a	79/20B	73/14	148/8B	145/6	41/8B	43/2	253/9	262/3T	249/6T	249/11T
Eognathodus bipennatus bipennatus	●																●											
Icriodus excavatus	●				●	●	●	●	●	●									●		●	●				●	●	
Icriodus regularicrescens		●																										
Polygnathus aff. *P. brevilaminus*			●																									
Icriodus liliputensis			●																									
Icriodus expansus											●	●	●	●									●	●				
Polygnathus sp.				●																			●	●	●			
Icriodus corniger corniger												●																
Polygnathus costatus partitus												●																
Polygnathus costatus patulus												●																
Polygnathus ling. linguiformis												●					●											
Polygnathus linguiformis pinguis												●																
Icriodella discreta															●													
Hamarodus europaeus															●													
Walliserodus sp.															●													
Gamachignathus sp.																●												
Icriodus brevis																	●			●								
Polygnathus pseudofoliatus																		●										
Polygnathus timorensis																				●								
Polygnathus aspelundi																						●						
Icriodus chojnicensis																									●			
Icriodus costatus																									●			
Polygnathus politus																												●

Tab. 1. Composition of conodont faunas marked in Text-figs 4-30. For symbols of sections see Appendix 1, for ages of faunas see Appendix 2 (part 1)

Conodont taxa Sections	H		RN	K2	HD															Ni				Ra	
Samples	228/7	228/8A	24/7M	57	69/4T	69/5B	62/12	62/18	175/8	69/15a	47/99	69/15c	69/16a	62/19T	69/19B	48	63/8T	47/7T	47/10B	51/2B	51/11M	51/22T	50/5	77/5	77/15
Icriodus costatus	●	●															●								
Icriodus sp.		●																						●	
Polygnathus sp.		●																		●				●	
Gnathodus pseudosemiglaber			●																●						
Palamtolepis glabra acuta				●																					
Palmatolepis schindewolfi				●												●									
Polygnathus nodocostatus				●																					
Ancyrodella rugosa					●																				
Icriodus subterminus					●	●																			
Polygnathus aequalis						●																			
Polygnathus alatus						●		●	●	●											●				
Ancyrodella nodosa							●																		
Icriodus alternatus								●	●	●		●		●	●						●				
Ancyrodella curvata (early form)									●												●				
Ancyrodella lobata									●												●				
Ancyrognathus coeni									●												●				
Icriodus excavatus									●																
Polygnathus planarius											●	●	●	●											
Ancyrodella curvata (late form)												●	●	●							●				
Polygnathus webbi												●	●								●				
Palmatolepis triangularis															●										
Polygnathus brevilaminus															●										
Icriodus cornutus																●									
Palmatolepis glabra pectinata																●									
Palmatolepis marg. marginifera																●									
Pandorinellina insita																	●								
Polygnathus semicostatus																●		●							
Polygnathus subirregularis																●									
Alternognathus regularis																	●								
Polygnathus perplexsus																	●								
Palmatolepis rugosa ssp.																		●							
Scaphignathus velifer																		●							
Gnathodus cuneiformis																			●						
Pseudopolygnathus multistriatus																			●						
Ancyrodella sp.																				●					
Palmatolepis jamiae																					●				
Polygnathus inornatus																						●			
Pseudopolygnathus sp.																						●			
Siphonodella sp.																						●			
Gnathodus sp.																							●		
Bispathodus stabilis																									●
Polygnathus aff. *P. symmetricus*																									●

Tab. 1. Composition of conodont faunas marked in Text-figs 4-30. For symbols of sections see Appendix 1, for ages of faunas see Appendix 2 (part 2)

Conodont taxa Sections	Po			B		Ma	An1												An2	MK	KO
Samples	242/98	242/8	242/20T	84/12a	84/16	78/8B	125/3a	98/5	125/5B	125/6	125/14	98/41	98/62	98/65	140/2B	140/4d	142/4	142/5	143/2	147/6	44/15B
Icriodus alternatus	●		●																		
Icriodus cornutus	●																				
Palmatolepis minuta minuta		●	●																		
Palmatolepis subperlobata	●																				
Palmatolepis tenuipunctata	●																				
Palmatolepis triangularis	●																				
Palmatolepis glabra acuta		●																			
Palmatolepis glabra prima		●																			
Palmatolepis schindewolfi		●																			
Polygnathus nodocostatus		●																			
Polygnathus semicostatus		●																			
Ancyrodella gigas			●																		
Palmatolepis bogartensis			●																		
Palmatolepis aff. *P. ultima*			●																		
Bispathodus sp.				●																	
Polygnathus inornatus				●											●						●
Gnathodus typicus					●									●	●						
Polygnathus communis communis					●																
Pseudopolygnathus multistriatus					●														●		
Siphonodella sp.						●															
Icriodus difficilis							●														
Icriodus arkonensis								●													
Icriodus brevis									●												
Polygnathus xylus xylus								●													
Polygnathus cf. *P. timorensis*								●													
Icriodus expansus									●												
Icriodus brevis										●											
Polygnathus aff. *P. aspelundi*										●											
Polygnathus sp.										●	●	●									
Icriodus excavatus											●	●									
Polygnathus ling. linguiformis											●										
Polygnathus cf. *P. zinaidae*											●										
Icriodus subterminus													●								
Gnathodus cuneiformis															●						
Pseudopolygnathus pinnatus															●						
Pseudopolygnathus oxypageus															●						
Scaliognathus fairchildi															●						
Scaliognathus praeanchoralis															●						
Declinognathodus nodiliferus																●	●	●			
Declinognathodus lateralis																●					
Declinognathodus sp.																●		●	●		
Adetognathus lautus																		●			
Cavusgnathus sp.																			●		
Clydagnathus sp.																					●

Tab. 1. Composition of conodont faunas marked in Text-figs 4-30. For symbols of sections see Appendix 1, for ages of faunas see Appendix 2 (part 3)

[redacted]

Tab. 3. Composition and age of brachiopod faunas marked in Text-figs 6, 8, 9, 14, 16, 21 and 26. For symbols of sections see Appendix 1

section	Anarak													Illanlu		KF	R	KO	Mighan			Khoshyeilagh					
genus, species / sample/unit	98/8	98/8a	98/20	98/31	98/35	98/40	98/50	98/60	98/62	125/4b	125/6	125/14	125/22	191/6B	191/14M	160/3	19, 165/5	5	19	22	31	16	24	25	25-28	28	33
Alekseites harundata					●								●								●						
Alekseites longiformis																●											
Bicingulites (Issites?) lunaris											●																
Chelmastanites grossicostatus																			●			●					
Chelmastanites tenuiannulatus														●			●	●	●			●					
Dicricoconus harundata									●												●						●
Dicricoconus gracilis																											●
Dicricoconus ghukensis								●																			●
Lonchidium aculeus											●																
Lonchidium levitckii																●											
Lonchidium profundum					●	●																					
Odessites sp.				●																							
Podolites lunaris		●									●																
Podolites lepidus																										●	
Pseudoporites tangangari												●															
Rossiites laciformis																					●						
Rossiites tichonirovi		●																									
Sektionites biordinis	●														●									●			
Sektionites triordinis																									●		
Sektionites uniordinis	●																										
Tripartites ferquensis			●																								
Turmalites arusensis																				●			●				
Turmalites dupliannulatus																●											
Turmalites gracilis				●		●	●																			●	
Turmalites lunaris										●	●				●								●				
Turmalites sinuosus										●	●									●							
Undacyclites humilis																										●	
Undacyclites n.sp. 1 & 2																										●	
Undacyclites undatus	●	●																									
Uniconocyclites n.sp.1																							●				
Uniconocyclites n.sp.2																				●							
Uniconus glaber											●																
Volynites alaformis n.sp.																				●							
Zendadjanites ordinis	●										●																
Age	*upper Givetian*	*upper Givetian*	*lower Frasnian*	*lower Frasnian*	*Frasnian*	*lower Frasnian*	*lower Frasnian*	*upper Frasnian*	*upper Frasnian*	*upper Givetian*	*upper Givetian*	*upper Givetian*	*upper Frasnian*	*upper Givetian*	*upper Frasnian*	*Frasnian*	*Givetian*	*Givetian*	*Givetian*	*lower Frasnian*	*upper Frasnian*	*Givetian*	*lower Frasnian*	*lower Frasnian*	*lower Frasnian*	*lower Frasnian*	*upper Frasnian*

Tab. 4. Composition and age of tentaculitid faunas marked in Text-figs 6, 10, 11, 14 and 21. For symbols of sections see Appendix 1

section	Khoshyeilagh							Mighan						Kuh-e Ozom					Robat-e Gharabil		Shirooyeh			
genus, species / unit/sample	16	22	24	25	26	34 - 39	41 & 43	19	22	33	35	36	38	3	5	10	14	16	19, 165/5	19, 165/7	1, 164/2	4, 164/5	18, 164/16	18, 164/19M
Athyris aria	●							●											●					
Athyris chitralensis											●	●	●					●						
Athyris chitralensis gentilis							●					●	●				●	●						
Athyris gurdoni													●											
Athyris tau							●					●	●											
Aulacella interlineata												●						●						
Camarotoechia baitalensis											●						●	●						
Camarotoechia livoniciformis										●	●													
Centrorhynchus deltidialis												●												
Chimaerothyris sp.																							●	
Cleiothyridina (?) *coloradensis*							●					●	●					●						
Cleiothyridina aff. *roissyi*													●											
Cleiothyridina reticulata							●				●	●	●				●	●						
Cleiothyridina transversa							●						●											
Cleiothyridina (?) *transversa*							●					●												
Composita sp.											●		●					●	●					
Crurithyris inflata		●																						
Cupularostrum recticostatum			●																					
Cupularostrum recticostatum lapparenti								●																
Cyphoterorhynchus arpaensis			●		●				●							●								
Cyphoterorhynchus baitalensis												●												
Cyphoterorhynchus koraghensis			●	●					●															
Cyphoterorhynchus koraghensis interpositus									●							●								
Cyphoterorhynchus letiensis												●												
Cyrtiopsis graciosa chakhaensis												●	●					●						
Cyrtiopsis lapparenti												●												
Cyrtospirifer chantaginicus						●																		
Cyrtospirifer crassiplicatus crassiplicatus												●	●											
Cyrtospirifer crassiplicatus cyrtinaeformis												●												
Cyrtospirifer kermanensis			●																					
Cyrtospirifer aff. *semisbugensis sphaeroidea*													●											
Cyrtospirifer aff. *subextensus*					●																			
Cyrtospirifer syringothyriformis	●								●															
Cyrtospirifer verneuili echinosus			●		●				●															
Dalejina sp.																					●			
Desquamatia sp.		●																						
Devonochonetes salemi		●																						
Devonochonetes sp.																			●					
Diazoma persanica														●	●									
Diazoma volhynica																			●					●
Diazoma volhynica volhynica	●							●						●	●									
Dichospirifer piriformis							●						●											
Dichospirifer thylakistoides							●					●												
Emanuella alveosimilis	●																		●					
Emanuella avagana	●																			●				
Enchondrospirifer ghorensis							●																	
Eobrachythyris strunianus alatus												●												
Eobrachythyris strunianus strunianus													●											
Eoplectodonta aff. *bidecorata*																					●			
"Eosyringothyris" trapesoidalis															●									
Evanescirostrum seversoni											●													
Gastrotedoechia dichotomians assimulata												●												
"Huanospirifer" ninghsiangensis										●		●												
Iridistrophia sp.																							●	
Ladogilina n.sp.1&2		●			●																			
Leioproductus varispinosus										●														
Leptaena sp.																					●			
Megalopterorhynchus chanakchiensis													●											
Mesodouvillina birmanica								●												●				
Nikoforovaena gr. *ferganensis*																					●			
Orthospirifer elburzensis elburzensis	●							●						●						●				
Orthospirifer elburzensis orthogonia	●							●											●					
Orthospirifer rhukensis									●															
Orthospirifer trapezoidalis	●																		●					
Paurogastroderynchus nalivkini												●												
Pentamerus aff. *subquadratus*																					●			
Platyspirifer minutus													●											
Productella subaculeata										●														
Ptychomaletoechia (?) *charakensis*											●		●											
Ptychomaletoechia (?) *turanica*													●											
Resserella sp.																					●			
(?) *Reticulariopsis* sp.																							●	
Rhipidiorhynchus elburzensis										●														
Rhipidiorhynchus (?) *Kotalensis*									●	●														
Rhynchotrema cf. *fringilla*																						●		
Schizophoria impressa							●																	
Schizophoria ivanovi													●											
Schizophoria schnuri blankenheimensis								●																
Schizophoria striatula								●																
Spinatrypina (*Exatrypa*) *explanata*		●																						
Spinocyrtia plicatula			●																					
Stegocornu aff. *procerum*																					●	●		
Sulcathyris gastra	●							●							●					●				
Sulcathyris periplicata	●							●												●				
Tornyfer cf. *pseudolineatus*	●																							
Toryniferella echinulata							●					●												
Uchtospirifer excelsus			●																					
Uchtospirifer multiplicatus minor					●																			
Xystostrophia umbraculum		●																		●				
Yunuanella uncinuloides subpentaplicata										●														
Age	*Givetian*	*lower Frasnian*	*lower Frasnian*	*lower Frasnian*	*lower Frasnian*	*Famennian*	*Strunian*	*Givetian*	*Frasnian*	*Famennian*	*Famennian*	*Strunian*	*Strunian*	*Givetian*	*Givetian*	*lower - middle Frasnian*	*u. Frasnian - l. Famennian*	*Strunian*	*Givetian*	*Givetian*	*Silurian (Wenlock ?)*	*Silurian (Wenlock ?)*	*Eifelian*	*Eifelian - Givetian*

Tab. 2. Composition and age of brachiopod faunas in the eastern Elburz (Text-figs 10, 11)

genus, species \ section / sample/unit	Anarak 98/2	Anarak 98/6	Anarak 98/8	MK 147/6a	MK 147/6b	MK 147/6c	IZ 167/2	Mighan 19 (lower part)	Mighan 19 (upper part)	Mighan 36	Mighan 38	R 19, 165/5
Bradocryphaeus sharudensis								●				
Neocalmonia (Heliopyge) afghanica		●							●			
Neocalmonia (Heliopyge) marianae			●						●			●
Neocalmonia (Radiopyge) bidouensis	●											
Neocalmonia (Radiopyge) heratensis	●											
Phacops (Omegops) accipitrinus accipitrinus						●				●	●	
Phacops (Omegops) accipitrinus maretiolensis										●	●	
Phacops (Omegops) cornelius											●	
Phacops (Omegops) paiensis				●	●							
Saukia rotunda							●				●	
Age	upper Givetian	upper Givetian	upper Givetian	uppermost Famennian	uppermost Famennian	uppermost Famennian	Tremadocian	Givetian	Givetian	uppermost Famennian	uppermost Famennian	Givetian

Tab. 5. Composition and age of trilobite faunas marked in Text-figs 8, 10, 11, 21 and 26. For symbols of sections see Appendix 1

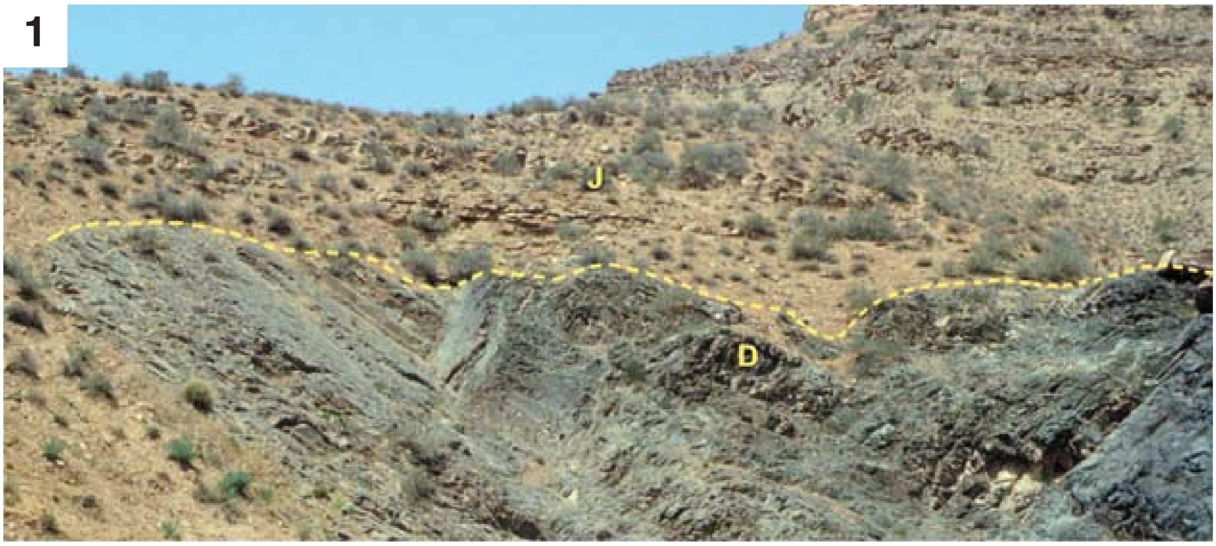
PLATE 1

1 – Aghdarband 2 section (I 199). Angular and erosional unconformity between Upper Devonian turbidites (D) and Jurassic Kashafrud Formation (J). Compare Text-fig. 4.

2 – Type section of the Upper Devonian Ilanqareh Formation (I 192). Note that the sequence is complicated by several reverse faults (arrows). Compare Text-fig. 5.

3 – Folded and faulted dolomites of the Middle Devonian Muli Formation. 3 km N of the type section of the Ilanqareh Formation (I 192).

1



2

3

PLATE 2

1 – Lower part of Bakshi section (I 245) with Precambrian granodiorite (G) at the base, overlain by Ordovician dolomites (O), followed by Famennian (F) and Tournaisian (C) carbonates. Compare Text-fig. 20.

2 – Upper part (Lower Carboniferous) of Bakshi section (I 245). Note red band of bauxites (B) in the lower part. Compare Text-fig. 20.

3 – Lower Carboniferous part of Bakshi section (I 245), opposite Pl. 2, Fig. 2, overlying bauxite in right centre (covered). Submarine rockfall (unit 21) on base of lower cliff is draped by wavy sandstone layer (unit 22, arrowed). Compare Text-fig. 20.

1

2

3

PLATE 3

1 – Anarak 1 section (I 98) showing sequence of Sibzar Dolomite (SD) on right margin, passing into Bahram Formation (B) and red nodular limestones of Sardar Formation (S) with goniatite level on top (asterisk). Arrow indicates minor fault near top of Bahram Formation. Compare Text-fig. 21.

2 – Upper part of Howz-e-Dorah section showing Bahram Formation (B), cephalopod limestone member (C, base arrowed, compare Pl. 3, Fig. 3) and lower Sardar Formation (S) consisting of shale member (27-28 in Text-fig. 16) at the base and a limestone member (29) forming the crest of the mountain.

3 – Close-up of Pl. 3, Fig. 2: Erosional unconformity (arrowed) at base of cephalopod limestone member (between units 25 and 26 in Text-fig. 16). This unconformity probably represents the Frasnian-Famennian boundary. Diameter of coin is 25 mm.


1
S
B
SD


2
S
C
B

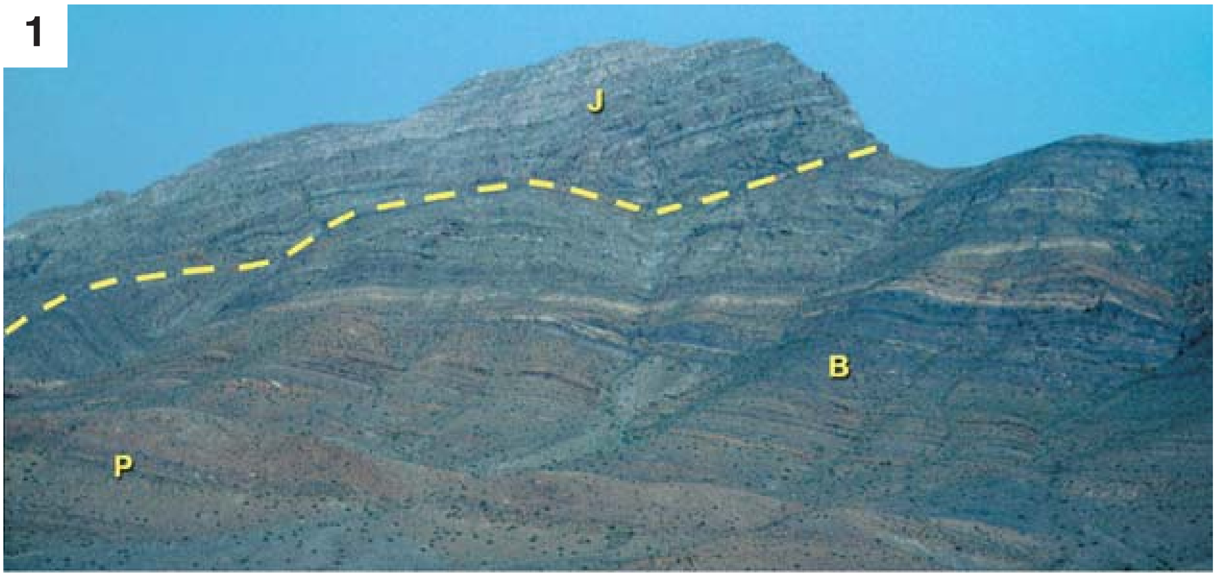

3

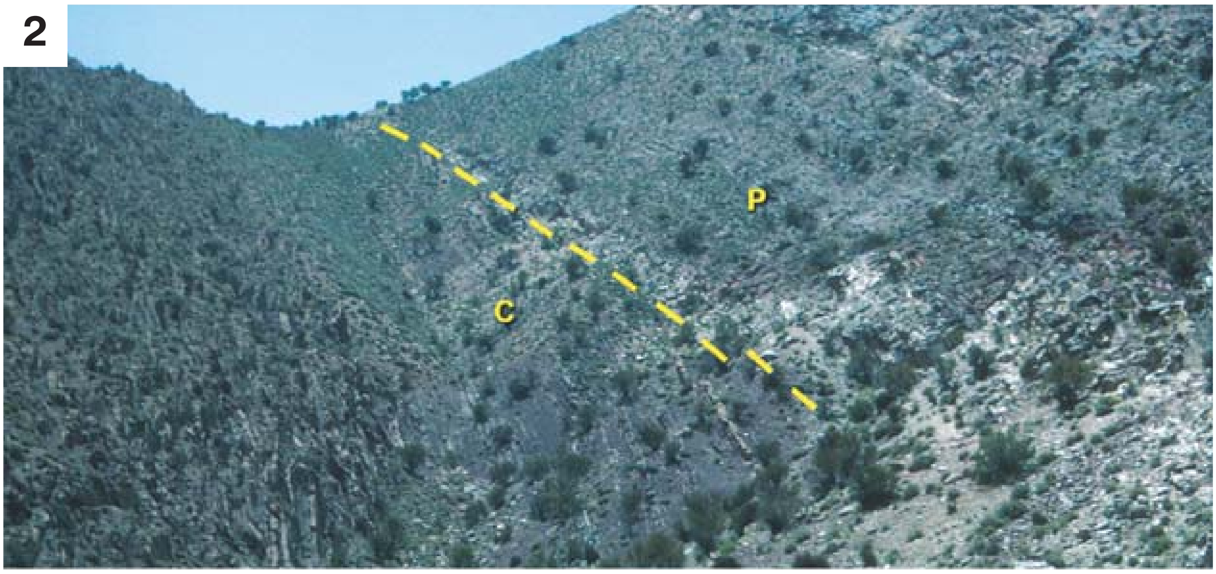
PLATE 4

1 – Mountain opposite Rizu section (Text-fig. 30) showing erosional and angular unconformity (broken line) between Devonian Padeha (P) and Bahram Formation (B) truncated by Permian Jamal dolomites (J).

2 – Kuh-e-Kanseh section. Broken line indicates angular unconformity between Cambrian Lalun Formation (C) and Lower Devonian Padeha Formation (P). Compare Text-fig. 29.

3 – Close-up of Pl. 4, Fig. 2. Erosional unconformity between deeply weathered red sandstone of Cambrian Lalun Formation (unit 6 of Text-fig. 29) and white quartzite (unit 7) with reworked black chert clasts at the base. Diameter of coin is 25 mm.


1
J
B
P


2
P
C

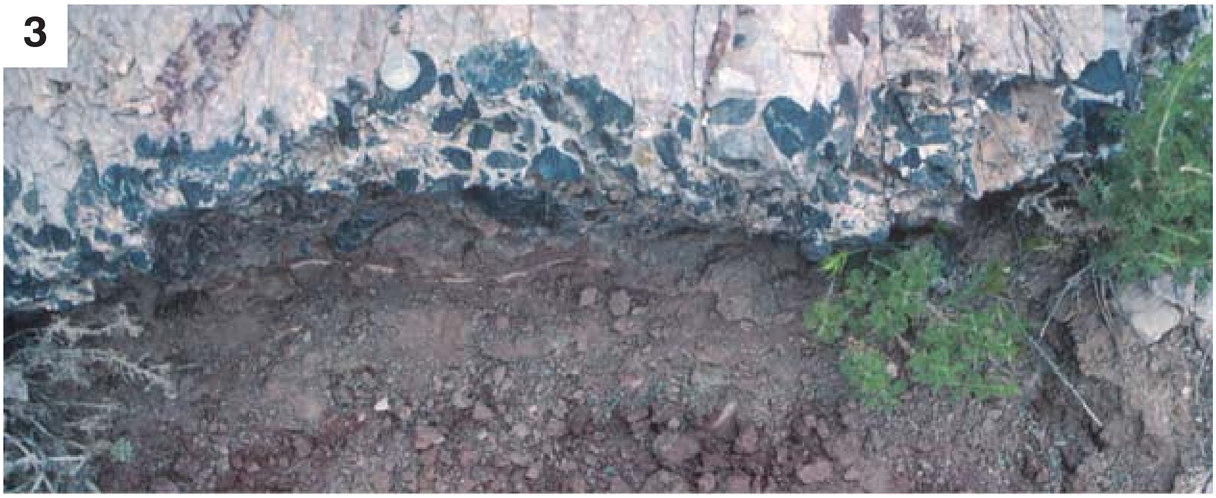

3

PLATE 5

1 – Red cephalopod limestone with cross sections of orthoconic nautiloids, NW of Derow. This exceptional lithology in the Silurian suggests that the Talesh Range is a fragment of the Turan Plate.

2 – Intertidal facies of lower Bahram Formation (Givetian) NW of Garineh (I 64) showing alternation of recrystallized grey limestone bands and brownish weathering marly interlayers. Length of pencil on right margin is 15 cm.

3 – *In-situ* breccia of grey and white intertidal dolomites with red dolomitic matrix. Note occasional good fitting of clasts (arrowed). Level 20 of Kalshaneh 1 section (Text-fig. 15). Diameter of coin is 25 mm.

4 – Close-up of submarine rockfall. Note that calcitic veins of individual clast do not continue into the matrix. Bakshi section (Text-fig. 20, I 245, level 21).

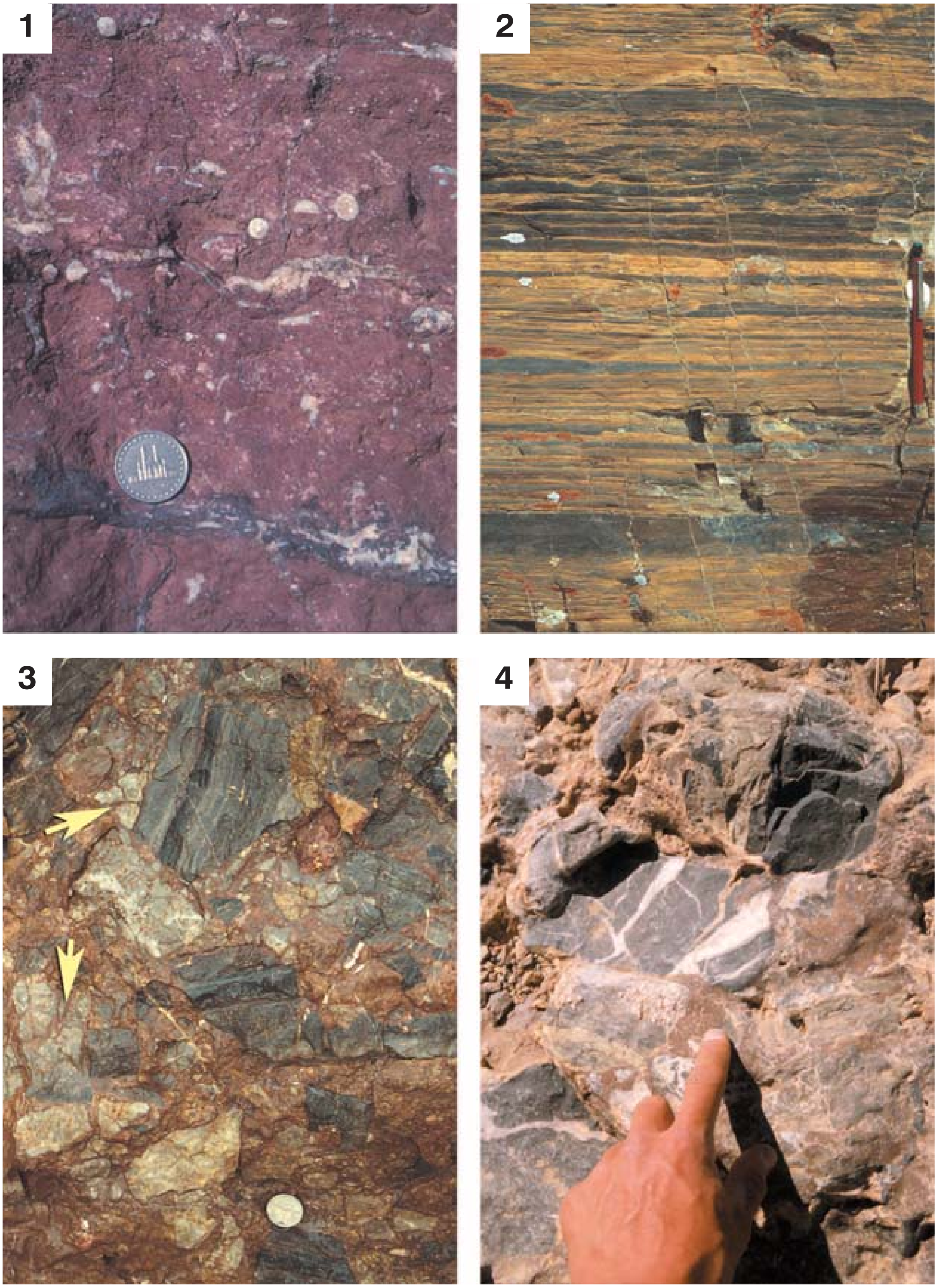

1
2
3
4

PLATE 6

1 – Contact (arrowed) between deeply eroded and weathered basalts of the Soltan Maidan Formation (Silurian or older) and the basal coarse conglomerate of the Padeha Formation (Lower Devonian?/Eifelian). Khoshyeilagh section (I 197). Compare Text-fig. 10. Diameter of coin is 25 mm.

2 – Middle/Upper Devonian distal turbidites in the topmost part of Aghdarband 2 section (I 199). Compare Text-fig. 4.

3 – Erosional boundary (arrowed) between Frasnian (17 in Text-fig. 30) sandstone and Permian Jamal dolomite (18) of Rizu section (I 249). Diameter of coin is 25 mm.

4 – Polymict breccia of reworked clasts in the middle part of the "cephalopod limestone" of Howz-e-Dorah section (26 in Text-fig. 16). Diameter of coin is 25 mm.

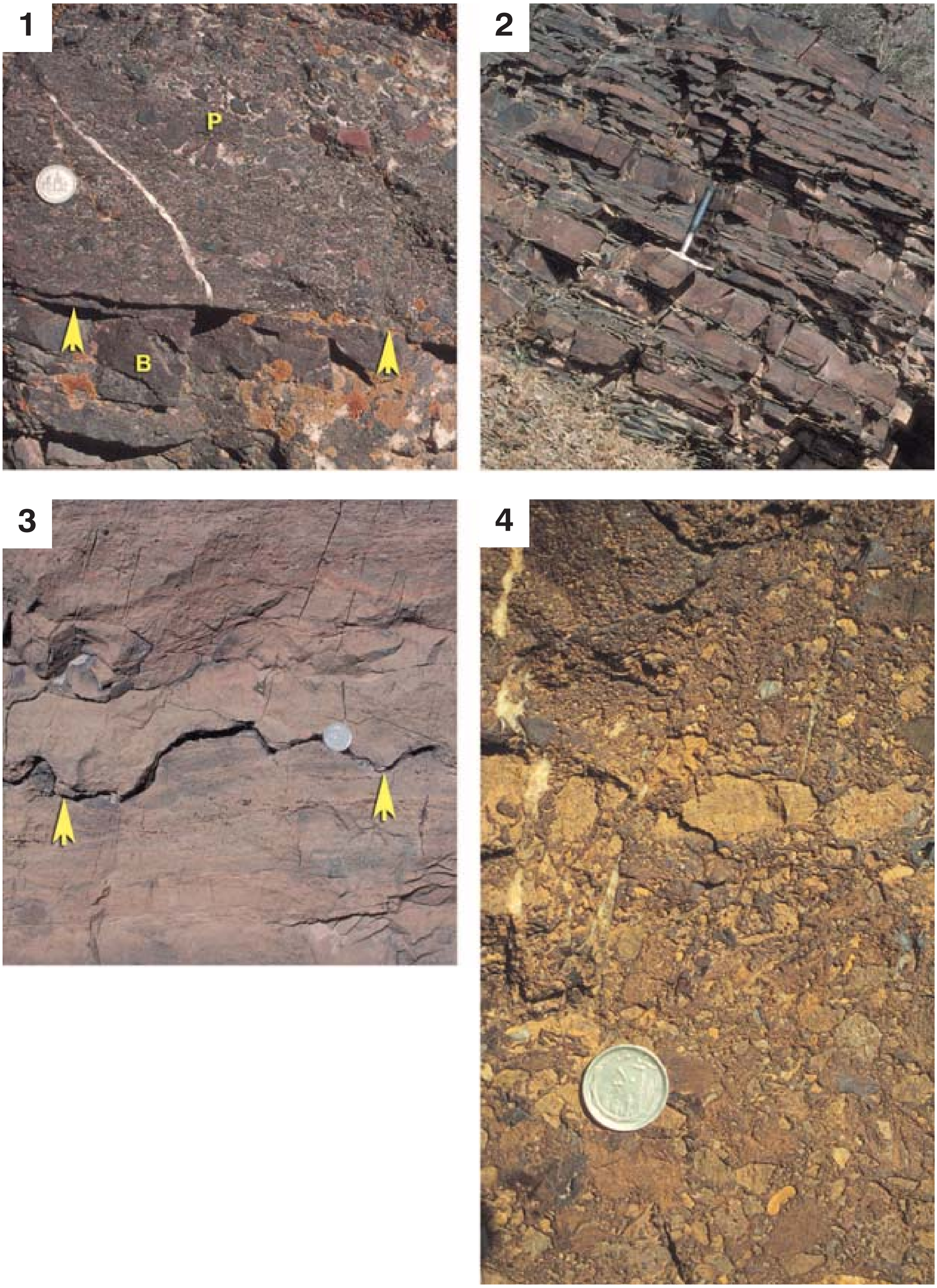

1
P
B
2
3
4

PLATE 7

1 – Coral floatstone with rolled specimens of solitary Rugosa. Frasnian of Robat-e-Gharabil section (unit 29 in Text-fig. 11).

2 – Coral floatstone with well preserved specimens of solitary Rugosa. Frasnian of Mighan section (unit 22 in Text-fig. 10).

3 – Floatstone with reworked clasts and fragments of solitary rugose corals. Frasnian of Mighan section (unit 22 in Text-fig. 10).

4 – Tabulate coral (cf. *Alveolites*) in growth position in Givetian biostrome of Kuh-e-Ozom section (unit 5 in Text-fig. 11).

5 – Bedding plane crowded with current-oriented tentaculitids. Frasnian of Mighan section (unit 22 in Text-fig. 10).

6 – Brachiopod coquina in upper Silurian marlstone of Shirooyeh section (unit 4 in Text-fig. 11).

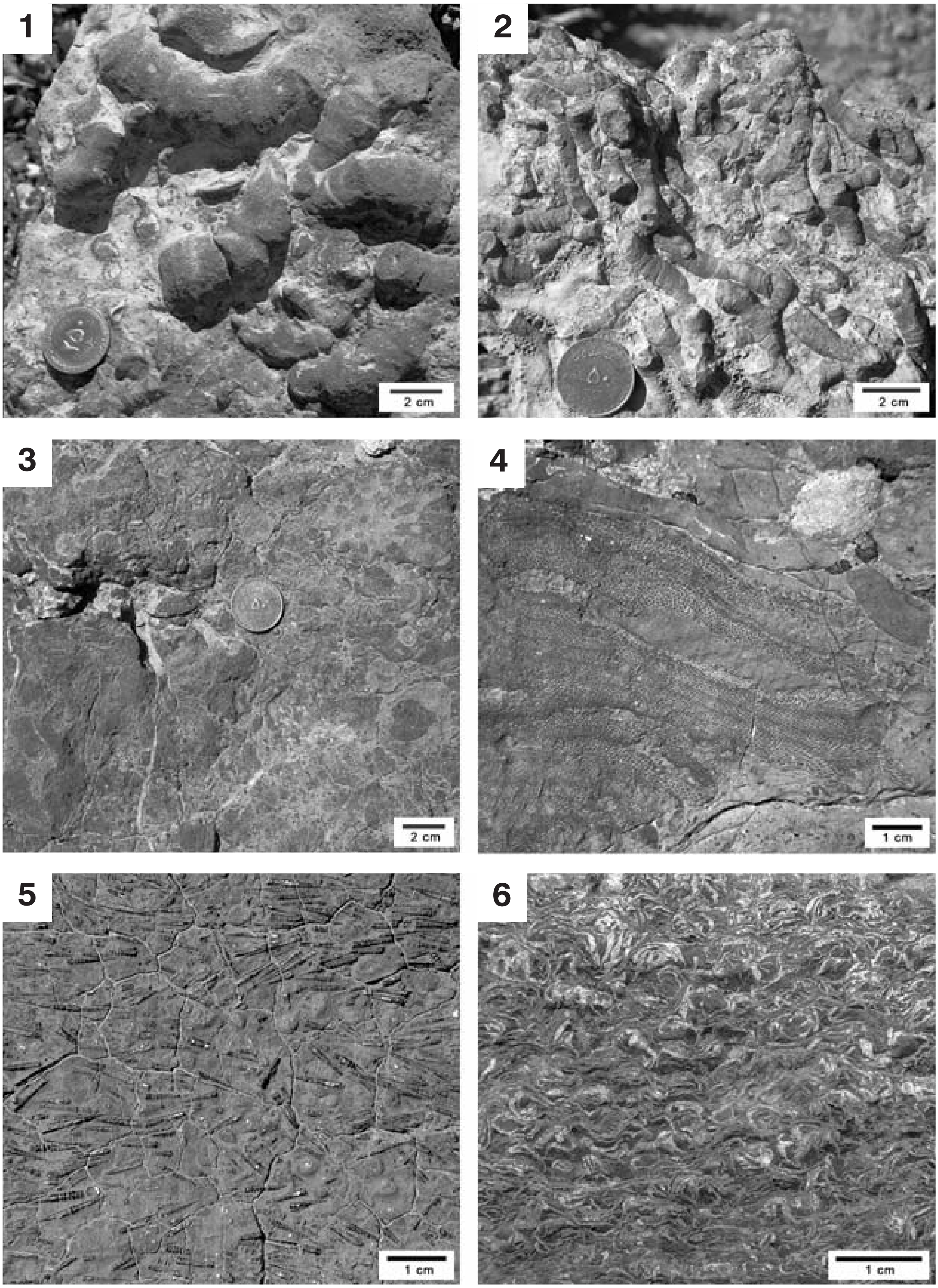

1
2 cm
2
2 cm
3
2 cm
4
1 cm
5
1 cm
6
1 cm

PLATE 8

Photographs of thin sections

1 – Mudstone with numerous oogonia of charophyte algae. Eifelian of Khoshyeilagh section (unit 29 in Text-fig. 10).

2 – Oogonium of charophyte alga associated with thin-shelled ostracod shells. Eifelian of Khoshyeilagh section (sample 197/2 in Text-fig. 10).

3 – Spiny acritarchs (Acanthomorphitae) in mudstone layer of Middle Devonian turbiditic sequence. Top of Aghdarband 2 section (unit 5, sample 199/2 in Text-fig. 4).

4 – *Baltisphaeridium brevispinosum* (EISENACK 1931). Same sample as Pl. 8, Fig. 3.

5 – *Endothyra* sp. in Namurian limestone breccia of Anarak 1 section (unit 76 in Text-fig. 21).

6 – Recrystallized microbial laminite with birdseyes in lower Bahram Formation of Pivehjan section (unit 12 of Text-fig. 13).

7 – *Endothyra* sp. in Lower Carboniferous (probably Visean) crinoidal-peloidal grainstone (Mobarak Formation) near Rudkaneh-e-Bakshah (loc. 234).

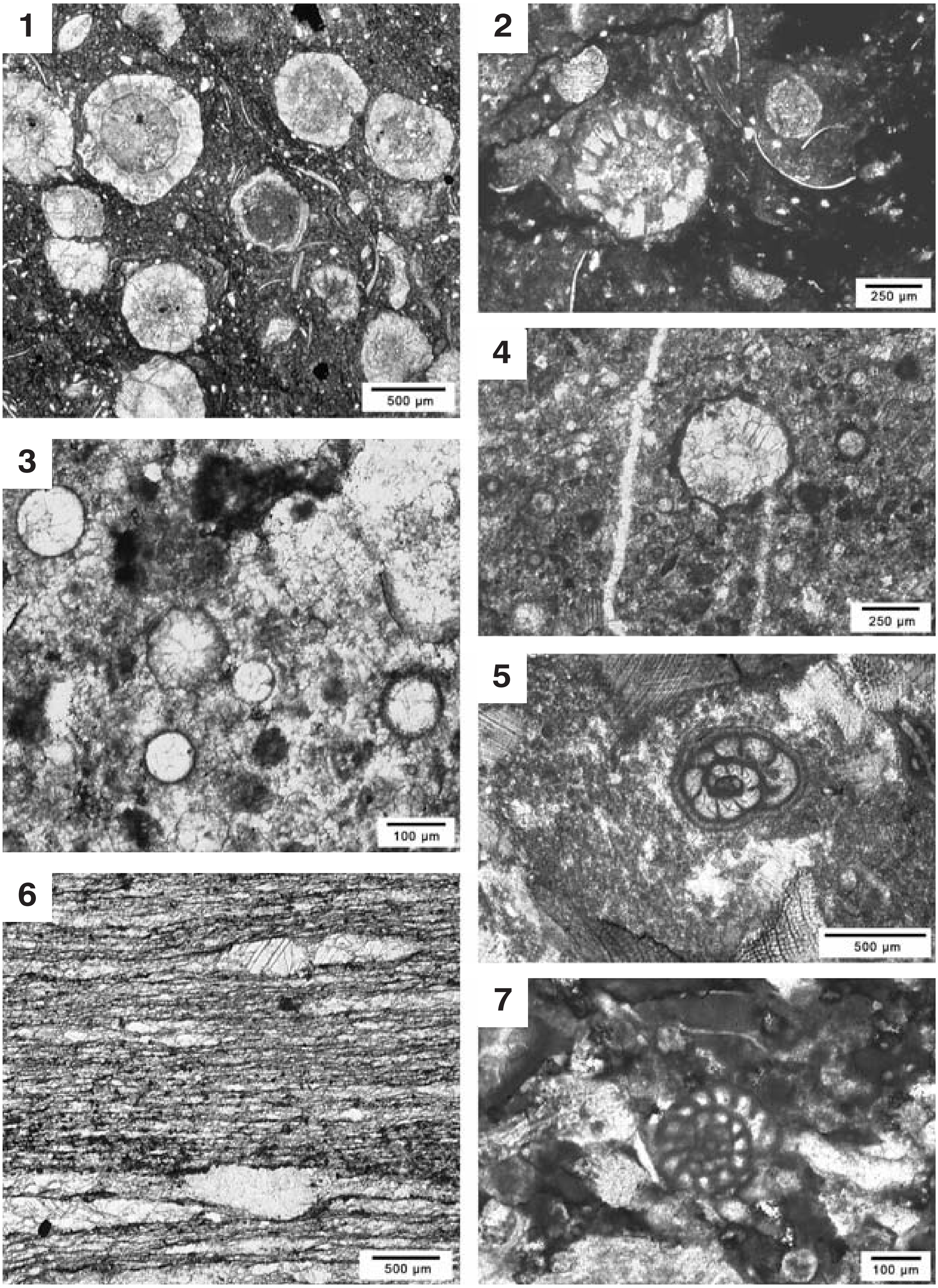

1
500 µm
2
250 µm
3
100 µm
4
250 µm
5
500 µm
6
500 µm
7
100 µm

PLATE 9

(1-4, 6 = bedding planes; 5 = vertical section; 7-9 = trilobites)

1 – Brachiopod valves and current-oriented tentaculitids in Frasnian skeletal packstone of Kuh-e-Rezaabad section (unit 11 of Text-fig. 9).

2 – Pavement of spiriferid brachiopods in Frasnian skeletal packstone of the Kuh-e-Rezaabad section (unit 11 of Text-fig. 9).

3 – Skeletal limestone crowded with brachiopods, tentaculitids and a pygidium fragment (arrowed) of *Heliopyge afghanica* (HAAS & MENSINK). Upper Givetian of Anarak section (sample 98/6 in Text-fig. 21).

4 – Black mudstone with cross sections of brachiopods. Upper Tournaisian of Bakshi section (unit 16 in Text-fig. 20).

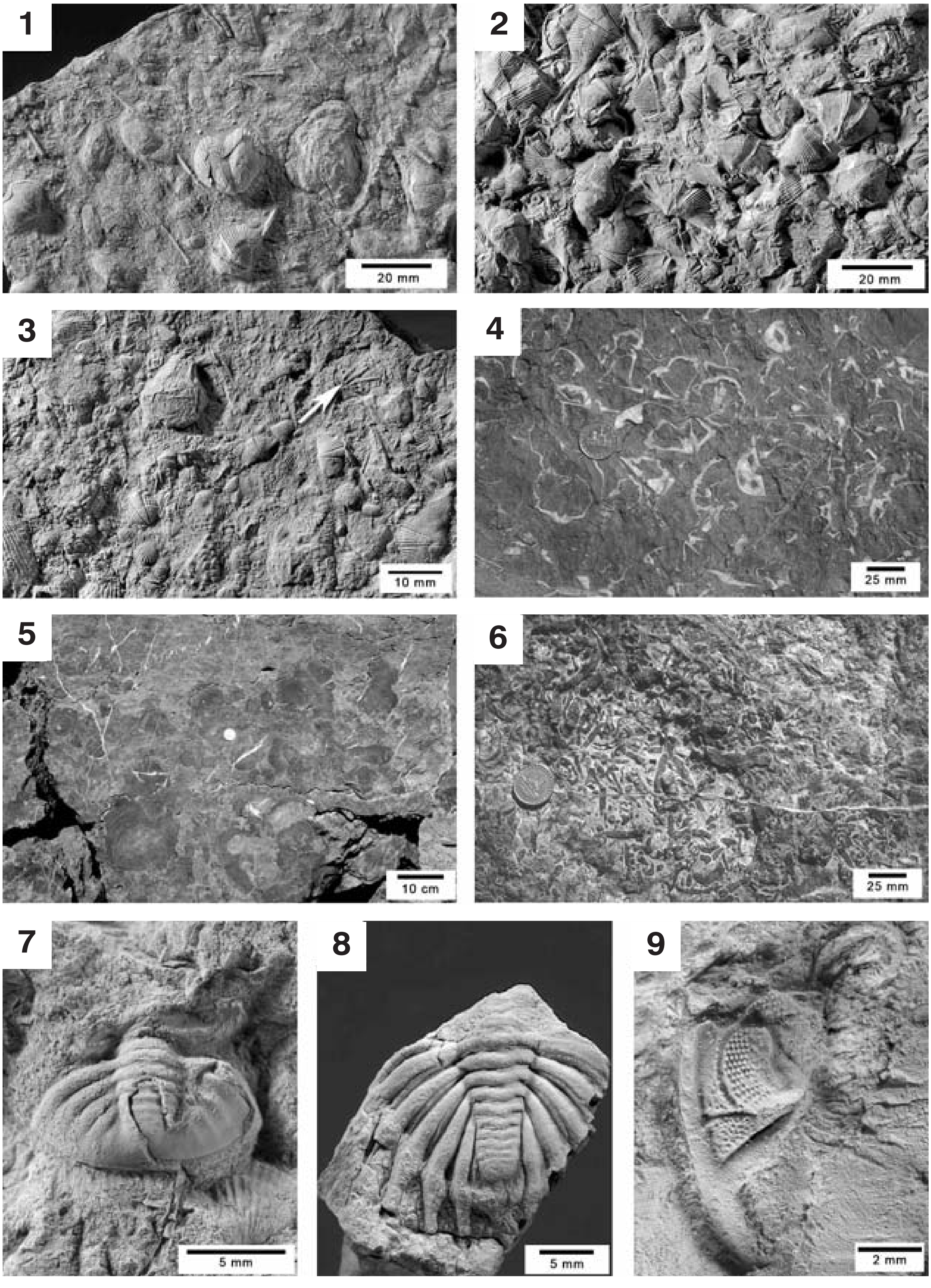
5 – Upper Givetian biostrome constructed of globular stromatoporoids and tabulate corals (cf. *Alveolites*). Kuh-e-Faghan 1 section (unit 9 of Text-fig. 14).

6 – Skeletal packstone crowded with fragments of ramose bryozoans in upper part of Frasnian biostrome. Rizu section (unit 13 of Text-fig. 30).

7 – Pygidium of *Phacops* (*Omegops*) *accipitrinus accipitrinus* (PHILLIPS 1841). Uppermost Famennian (Strunian) of Mazraeh-e-Kheradmand section (sample 147/6c in Text-fig. 26).

8 – Pygidium of *Neocalmonia* (*Heliopyge*) *marianae* (FARSAN 1981). Givetian of Robat-e Gharebil section (sample 165/5 in Text-fig. 11).

9 – Part of cephalon of *Neocalmonia* (*Heliopyge*) *marianae* (FARSAN 1981). Upper Givetian of Anarak 1 section (sample 98/8 in Text-fig. 21).


1
20 mm
2
20 mm
3
10 mm
4
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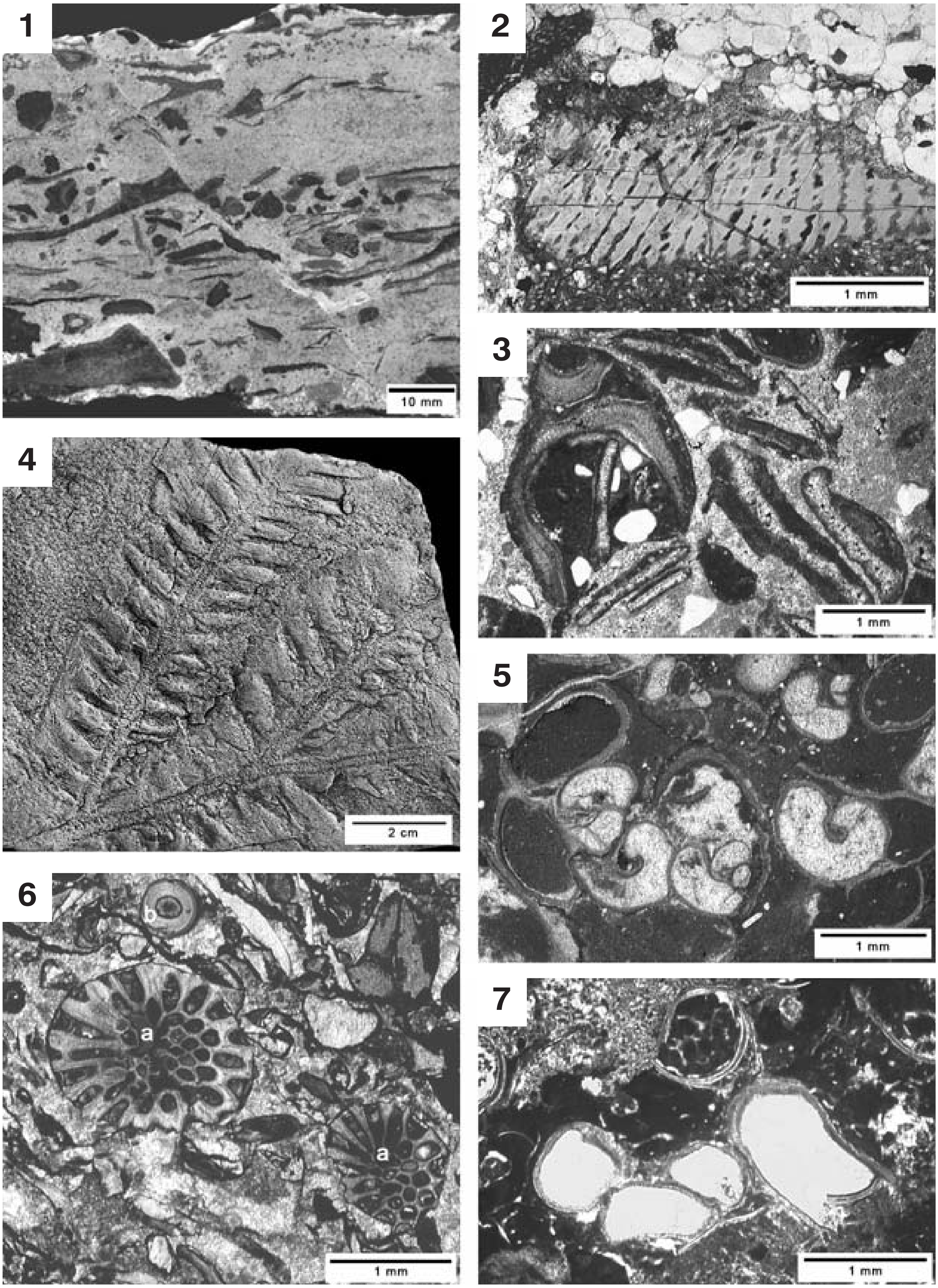
5
10 cm
6
25 mm
7
5 mm
8
5 mm
9
2 mm

PLATE 10

(2, 3, 5-7 = thin sections)

1 – Polished vertical section of Lower (?) Devonian placoderm bonebed on base of Zarand Formation in Kuh-e-Band-e-Obikh section (unit 4 in Text-fig. 23). Dark spots are fish remains and phosphatic nodules and clasts.
2 – Close-up of Pl. 10, Fig. 1. Reworked fish remain in siliciclastic matrix.
3 – Oncolitic packstone with microbially encrusted, recrystallized mollusc fragments in a quartz-bearing matrix. Famennian of Illanlu section (sample 191/21T in Text-fig. 6).
4 – *Scytophyllum persicum* (SCHENK) KILPPER from red siltstone member (probable Lower Triassic Sorkh Formation) of Kuh-e-Bashi section (sample 43/5 in Text-fig. 23).
5 – Doubtful serpulids (cf. *Trypanopora*) in Tournaisian skeletal wackestone of the Madbeiki section (sample 78/3 in Text-fig. 20).
6 – Ramose bryozoans (a) and ooid (b) in hematitic, oolitic brachiopod-crinoid packstone. Upper Frasnian of Howz-e-Dorah section (sample 175/15 in Text-fig. 16).
7 – Problematic sessile organism (microgastropod or serpulid) from topmost limestone member (18 in Text-fig. 20), Lower Carboniferous (Visean) of Rahdar section.


1
10 mm
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6
b
a
a
1 mm
7
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