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Devonian/Lower Carboniferous stratigraphy, facies patterns and palaeogeography of Iran. Part I. Southeastern Iran[(1)]

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ABSTRACT:

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The mountains N of Kerman in southeastern Iran are a key region for Devonian/Lower Carboniferous stratigraphy of a still poorly known segment on the northern margin of Gondwana and display a great diversity of neritic depositional environments. The hitherto applied subdivision into lithostratigraphic formations has been calibrated by means of conodonts and brachiopods allowing good correlations of 36 sections, the majority of them ranging from the top of the Cambrian or the Silurian into the Lower Permian. Upper Cambrian sandstones or Silurian carbonates are unconformably overlain by red siliciclastics of uncertain Early to early Middle Devonian age (Padeha Formation) which in turn pass into skeletal limestones (upper Middle Devonian to Tournaisian Bahram and Sardar Formations). The latter are erosionally capped by Permian platform carbonates (Jamal Formation). Facies patterns during 5 intervals from the Silurian into the Tournaisian show evolution from a carbonate platform and a siliciclastic shelf during the Silurian and the Early Devonian into shallow open marine embayments during the late Middle and Late Devonian, and a carbonate platform during the Early Carboniferous. Sharp boundaries between Upper Devonian facies belts appear controlled by synsedimentary epeirogenic movements which may have been active since the Early Palaeozoic.

Key words: Iran, Devonian, Lower Carboniferous, Permian, Stratigraphy, Sedimentology, Facies patterns, Palaeogeography.

INTRODUCTION

The tectonically highly complicated mountainous area of Iran has attracted geologists since the middle of the 19th century; studies on Palaeozoic stratigraphy and palaeogeography, however, are relatively scarce. Rocks of Devonian and Early Carboniferous age are widespread throughout the country, but occur in structurally isolated units which render reconstruction of depositional patterns extremely difficult. Structurally, Iran can

[1]Part II will be devoted to northern and central Iran

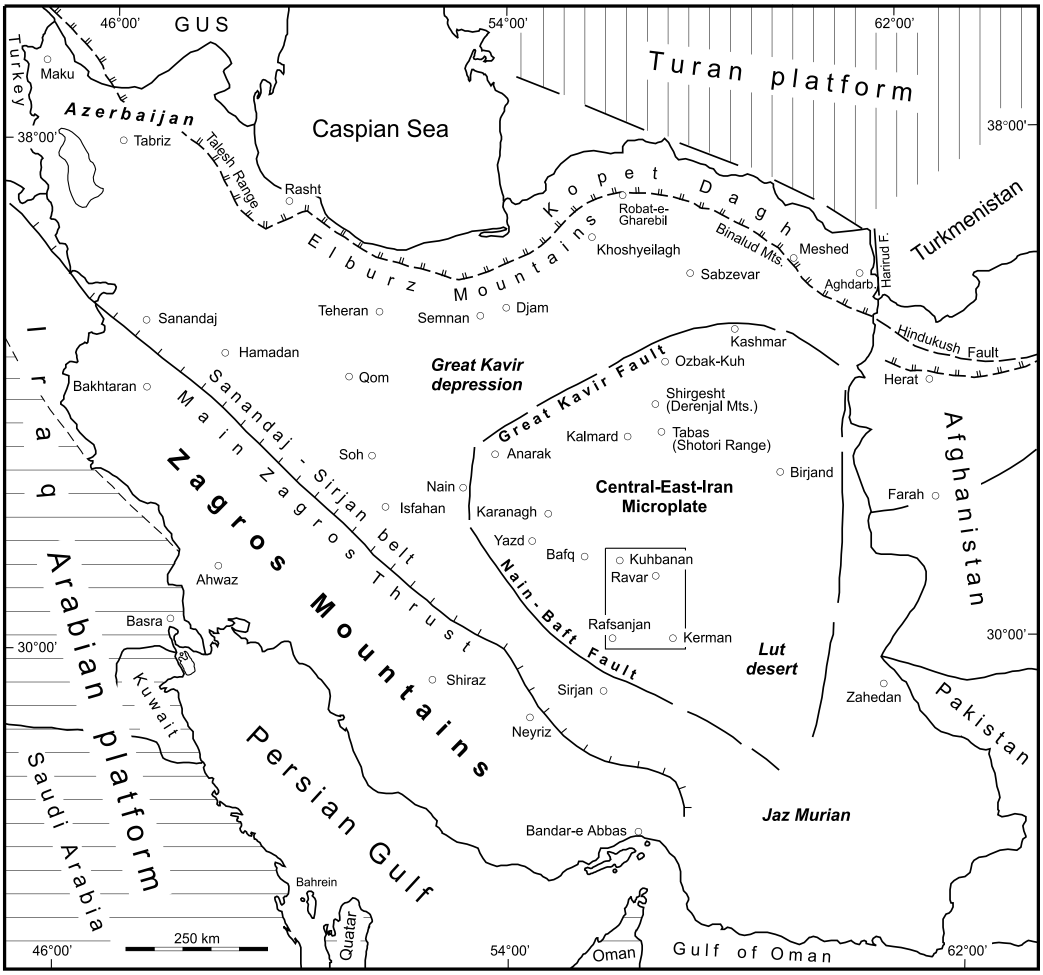

Fig. 1. Major structural units of Iran (modified from SOFFEL & *al*. 1996); square indicates location of the study area (Text-fig. 3)

be subdivided into three units separated by suture zones, partly associated with ophiolite belts (WEBER-DIEFENBACH & *al*. 1986, SOFFEL & *al.* 1996, DAVOUDZADEH 1997) (Text-fig. 1):

(1) The Zagros fold belt, limited by the Persian Gulf in the SW and by the Main Zagros thrust zone in the NE.

(2) Central Iran, comprising the southern Elburz Mountains, their eastward prolongation in the Binalud Mountains, northwestern Iran (Azerbaijan), the mosaic of various minor blocks which compose the Central-East-Iran Microplate, the Great Kavir depression and the Sanandaj-Sirjan belt NE of the Main Zagros thrust zone.

(3) The northern zone which comprises the Caspian depression, the northern Elburz Mountains and their continuation towards the west (Talesh Range) and the east (Kopet Dagh).

During the Palaeozoic, units (1) and (2) were part of the northern margin of Gondwana which during Devonian times was situated at 20-25° S of the equator (GOLONKA & *al*. 1994). This cratonic area was covered by a large shelf sea and was separated from unit (3) as part of the southern margin of Laurasia (Turan Plate) by the Palaeo-Tethys. The latter was eliminated by early Cimmerian movements in the Middle Triassic and is now visible only as a narrow thrust zone separating the northern from the southern Elburz and in a few remnants of pre-Upper Triassic ophiolites associated with metamorphic flysch deposits in the northern Binalud Mountains (ALAVI 1991). Our research covers central Iran (unit 2) and some of the few Devonian/Lower Carboniferous outcrops in the Kopet Dagh and in the Talesh Range (unit 3). The Zagros Mountains (unit 1) were largely emergent during the Devonian/Lower Carboniferous, subject to erosion and only patchily covered with continental or marginal marine deposits. It is the aim of our study to present biostratigraphic and sedimentologic data and their results gathered during nine field seasons from 1994 to 2002 in collaboration with geologists from the Geological Survey of Iran (GSI). The majority of the areas and sections described in the following paragraphs, have never been examined in detail. Our new data permit to elucidate the depositional history over a time span of about 80 million years and to reconstruct the palaeogeography and facies patterns of a hitherto poorly known segment of the northern margin of Gondwana during subsequent intervals of the Late Silurian into the Early Carboniferous.

PREVIOUS WORK

The first reports on the occurrence of Devonian and Lower Carboniferous rocks in Iran date from the middle of the 19th century (VIQUESNEL 1850, LOFTUS 1855), but these early works are now merely of historical interest. In the subsequent hundred years little more than 10 publications (list in DÜRKOOP & *al*. 1979) have touched the same subject among which FRECH & ARTHABER's (1900) work with the first geological maps of Iran is worth mentioning. A decisive impulse for the study of Devonian rocks has been systematic mapping of the country at 1:250.000 scale which started in 1959 and is now almost complete. The 1:100.000 mapping project is in progress and has considerably facilitated our research. An important step in the geological reconnaissance of the country is the "Treatise on the Geology of Iran" (ed. by A. HUSHMAND-ZADEH, work in progress) which shall comprise all aspects of stratigraphy, economic geology, geodynamics, metamorphism, magmatism, and geomorphology, including maps on the same subjects. Published volumes covering the topic and area of the present study were compiled by ALAVI-NAINI (1993) and GHAVIDEL-SYOOKI (1994). Preliminary results of our investigations were presented by WENDT & *al*. (1997). Other contributions relevant to our study of Devonian/Lower Carboniferous rocks were published during the last four decades and will be referred to below.

LITHOSTRATIGRAPHY

In the early 1960's, RUTTNER and his collaborators subdivided the Devonian/Lower Carboniferous sequence in east-central Iran into several lithostratigraphic formations which subsequently were applied in geological maps. This basic work, however, which was intended to accompany the geological map of the Ozbak-Kuh Mountains N of Tabas, has never been published, and original information about these units had to be adopted from a later work by RUTTNER & *al*. (1968) and from a compilation of STÖCKLIN & SETUDEHNIA (1991). The lithostratigraphic characterization of these formations and their biostratigraphic boundaries are still a matter of individual interpretation.

Unfortunately, RUTTNER had chosen the Ozbak-Kuh Mountains as type localities for his newly established formations. Few other areas in Iran appear less suitable for such a lithostratigraphic framework. Numerous faults and overthrusts have fragmented the entire range into a puzzle of minor slices and blocks which rarely allow to follow undisturbed successions for more than a few hundred metres. If these formation names are used with some confidence for future geological mapping, they should be newly defined and re-established in structurally less disturbed zones, e.g. in the Kerman area or in the Shotori Range S of Tabas. The application of these units, however, can be recommended only with utmost reserve because they imply a stratigraphic precision which is barely documented. Moreover, their boundaries are partly diachronous (WENDT & *al*. 1997) and rapid lateral facies changes make their application rather arbitrary. Other lithostratigraphic formations were established (and are better defined there) in the Elburz Mountains. Apart from their occurrence in other parts of the country, they show little difference compared to their equivalents in central Iran. Text-figs 2 and 4 are a compilation of all available data about the lithostratigraphic subdivision of the Devonian and Carboniferous in Iran. The most widely used formation concepts are summarized as follows.

Niur Formation, Shabdjereh Formation (Silurian)

Deposits of the Niur Formation are known from the eastern Elburz through eastern Iran into the Kerman area. In the type section (Niur village in the Ozbak-Kuh Mountains), this formation consists of lime- and dolostones with some intercalated shales and is said to be 446 m thick; the base, however, is cut by a fault (RUTTNER & *al*. 1968). In a reference section in the Derenjal Mountains farther S, the same unit contains siliciclastic intercalations and some volcanic dykes and is 626 m thick (RUTTNER & *al*. 1968). Brachiopods, corals, and molluscs indicate that these rocks were deposited in a shallow open marine environment. They comprise almost the entire Silurian (FLÜGEL 1962, RUTTNER & *al*. 1968, FLÜGEL & SALEH 1970). We found a hitherto unknown lithology of red cephalopod limestones in the Kuh-e Faghan range SE of Kashmar which has yielded Llandovery conodonts. A Wenlock age of the Niur Formation is indicated in the Kerman area by BRICE (1999a) and NIKO & *al.* (1999, 2000) and at Robat-e Gharebil (eastern Elburz) by COCKS (1979) and BRICE & *al*. (1974). According to HUBMANN (1991) the upper part of the formation may reach into the Lochkovian.

A much younger age (late Emsian) has been claimed by WEDDIGE (1984a) from the Binalud Mountains, but it must be questioned if these beds can still be attributed to the Niur Formation. In the northern part of the Kerman area, HAMEDI (1995) established the term Shabdjereh Formation for a more siliciclastic lithology of the Niur Formation. We obtained conodonts from the upper part of this formation near Fathabad which have yielded a late Llandoverian to early Wenlockian age.

Padeha Formation, Muli Formation (Lower to lower Middle Devonian)

The carbonate-shale sequence of the Niur Formation is transient into, or sharply overlain by, red clays, sandstones, and conglomerates with intercalated intertidal dolomites and gypsum layers indicating deposition in a very shallow shelf sea with local sebkha conditions. Also this formation has been established in the Ozbak-Kuh Mountains by RUTTNER (unpublished) where it is said to be 492 m thick, a rather arbitrary value because of intense faulting in this area. A thickness of 730 m is reported from a reference section in the Derenjal Mountains by RUTTNER & *al.* (1968). In other areas, the thickness is considerably less. Deposits of the Padeha Formation are widespread in Iran and occur in the Djam area (ALAVI-NAINI 1972), in the eastern Elburz (BOZORGNIA 1973, JENNY 1977, STAMPFLI 1978, GHAVIDEL-SYOOKI 1994) to central Iran (SHARKOWSKI & *al.* 1984), eastern Iran (Kashmar, Binalud, Shotori Range, Ozbak-Kuh, Derenjal Mountains) and in the Kerman area (see below). Where the red siliciclastics of the Padeha Formation directly overly similar rocks of Late Cambrian age, the boundary between both units is often difficult to recognize. Organic remains are virtually lacking in the Padeha Formation. Locally, some placoderm remains are found which, however, are of poor biostratigraphic value. KALANTARI (1981) figured some brachiopods from Khoshyeilagh (eastern Elburz), but it must be questioned if they have really been found in the Padeha Formation. From the age of the underlying Niur and the overlying Sibzar and Bahram Formations, it becomes evident that the Padeha Formation comprises the Lower and lower Middle Devonian. This conclusion contrasts with that of GHAVIDEL-SYOOKI (1994) and DASTANPOUR (1996a) who, based on palynomorphs, attribute an early Frasnian age to the upper part of the Padeha Formation. There is no evidence for the presumed gap at the top of the formation ("Eifelian hiatus", WEDDIGE (1983, 1984a, b) because in undisturbed sections the boundary towards the overlying Sibzar or Bahram Formations is gradational (WENDT & *al.* 1997).

In northwestern Iran (Azerbaijan), a metamorphic complex of gneisses, amphibolites, micaschists, and phyllites of presumed Precambrian age is overlain by some tens of metres of quartzitic sandstones grading upwards into a thick succession of well-bedded dolomites which has been labelled as Muli Formation by ALAVI & BOLOURCHI (1973). In the type locality near Maku, this formation is said to be 1175 m thick, but this estimate is far too high because it does not take into account the intense folding and faulting of these rocks. Brachiopods, gastropods, rugose and tabulate corals, stromatoporoids, and tentaculitids suggest an Early to Middle Devonian age for the Muli Formation which consequently can be considered as an approximate time-equivalent of the Padeha Formation. In contrast to the latter, the Muli Formation represents a carbonate platform with some siliciclastic influx.

In the Talesh Range (northwestern Elburz) a totally different lithology of condensed red cephalopod limestones has been found by ANNELLS & *al.* (1975) and dated by HAMDI (1975) as uppermost Silurian and Lower Devonian.

Sibzar Formation (upper Middle Devonian)

This formation has first been recognized in the Ozbak-Kuh Mountains by FLÜGEL & RUTTNER (1962) as "grey dolomite" and was subsequently described in more detail from the Derenjal Mountains by RUTTNER & *al.* (1968). It occurs from the Binalud Mountains (WEDDIGE 1984a) to Anarak (SHARKOVSKI & *al.* 1984), Soh (ZAHEDI 1973), Shotori Range, and the area N of Kerman, but disappears farther S and E. The Sibzar Formation is mostly dolomitic with occasional calcareous intercalations. Cyclic patterns of massive dolomite, microbial lamination with local tepees, and erosional surfaces indicate sedimentation in shallow subtidal to supratidal environments. The thickness of the formation is generally in the order of some tens of metres but may attain about 100 m at Anarak, 200 m at Kashmar and more than 300 m in the Derenjal Mountains. Due to the overall dolomitization and predominant inter- to supratidal conditions, organic remains are very rare and restricted to a few rugose and tabulate corals in the subtidal members. Near Kalshaneh (Derenjal Mountains) we discovered a 25 m thick biostrome constructed of colonial rugose and thamnoporid corals. This is also the only locality so far where base and top of the formation could be dated by conodonts (WENDT & *al.* 1997). They document that the entire >300 m thick pile has been deposited in early Givetian times (*hemiansatus* to Lower *varcus* Zone). There is no evidence for a Frasnian age of the Sibzar Formation (DASTANPOUR 1997). The upper part of the Muli Formation in Azerbaijan is a time- and facies-equivalent of the Sibzar Formation.

Bahram (including Shishtu) Formation, Kereshk Formation, Khoshyeilagh Formation, Geirud Formation, Ilanqareh Formation, Rahdar Formation (upper Middle and Upper Devonian)

In contrast to the Padeha and Sibzar Formations which, because of non-deposition, are absent in some parts of Iran (e.g. in the central Elburz), deposits of the Bahram Formation or its equivalents are present (if not eroded prior to the Permian transgression) all over northern, central and eastern Iran. They are only missing in the Zagros Mountains and in some zones west of the Lut Desert. This formation, also established (but not defined) in the Ozbak-Kuh Mountains, consists of a very heterogeneous succession of skeletal pack- to grainstones with local biostromes in the lower part, massive or laminated dolomites, medium- to coarse-grained sandstones, and shales. They reflect deposition in a shallow open marine sea with local clastic influx from nearby eroded land areas and temporarily restricted conditions. Sebkha environment has only been reported from Djam (ALAVI-NAINI 1972). Generally, the limestones of the Bahram Formation are very fossiliferous and contain conodonts, brachiopods, tentaculitids, crinoids, bryozoans, rugose and tabulate corals, stromatoporoids, trilobites and rare molluscs (Pl. 5, Figs 2, 3, 5, 6, 7; Pl. 6, Fig. 5). In dolomitic intercalations, placoderm remains are locally abundant (e. g. at Shams Abad). Our brachiopod, tentaculitid, and conodont datings confirm previous age attributions (WEDDIGE 1983, 1984a; WENDT & *al.* 1997) and indicate that the Bahram Formation comprises the time-span of the late Middle and the entire Late Devonian. Only in the southern Davaran Mountains (Shams Abad, Kereshk) Eifelian ages were obtained from a very similar lithology which correspond to the "phosphate" and "lower carbonate unit" of the Kereshk Group (=Formation) of DIMITRIJEVIC (1973). In previous publications and maps, the age of the Bahram Formation is limited to the Frasnian, though there is no obvious lithologic and mappable change toward the overlying Famennian "Shishtu Formation". We therefore avoid the latter term and propose to extend the Bahram Formation until the top of the Famennian. Insignificant local facies changes towards a more shaly lithology do not justify a proper lithostratigraphic term.

A unique lithology of red, partly nodular limestones with a high quartz content and common omission surfaces, has been discovered in the Shotori Range near Tabas by STÖCKLIN & *al.* (1965). In addition to abundant brachiopods, these "cephalopod limestones" have yielded the only important goniatite and clymeniid faunas known so far from Iran (WALLISER 1966). In the southern Shotori Range, they comprise the entire Famennian (WENDT & *al.* 1997, YAZDI 1999), but farther N, at Niaz, goniatites occur already in the middle Frasnian.

The thickness of the Bahram Formation ranges from 100 m metres (Horik) to over 300 m (Shotori Range, Ozbak-Kuh, N of Kerman) and depends not only on the rate of subsidence but also on the level of the pre-Permian erosion.

In the eastern Elburz, BOZORGNIA (1973) established the Khoshyeilagh Formation for a succession which shows little difference compared to the Bahram Formation and covers more or less the same interval (late Middle to Late Devonian). Also the Geirud Formation of the central Elburz which was coined by ASSERETO (1963) for a 750 m thick pile of bioclastic limestones and sandstones with local basalt flows, is similar to the Bahram Formation. In his original definition, ASSERETO (1963) proposed that the Geirud Formation should include the Upper Devonian, the entire Carboniferous and possibly even the basal Permian but, later, STEPANOV (1971) restricted this term to the Frasnian to lower Tournaisian portion corresponding to ASSERETO's (1963) member A whereas members B and C were included in the Mobarak Formation (see below).

Because of its lithologic similarity and age, there was no need to create another formation name (Ilanqareh Formation, ALAVI & BOLOURCHI 1973) for the same sequence in Azerbaijan. Another, more local name is the Rahdar Formation, introduced by AGHANABATI (1977) in the Kalmard area for a reduced sequence of lime- and dolostones whose poor fossil content indicates a Famennian age. Because all these formation names have the same meaning and can be applied only in their regional context, we prefer the most widely used term Bahram Formation (though the term Geirud Formation has priority).

Sardar Formation, Mobarak Formation, Gachal Formation (Lower Carboniferous)

The Sardar Formation was established by STÖCKLIN & *al.* (1965) for a succession of shales with intercalated sandstones and limestones in the Sardar valley E of Tabas. In the type section, the formation is >660 m thick, but the base is concealed and disturbed. In a more complete reference section farther S at

Howz-e-Dorah the Sardar Formation is in contact with the underlying Shishtu and the overlying Jamal Formation; it is 570 m thick. According to STÖCKLIN & *al*. (1965) both contacts are discontinuous and imply gaps of unknown duration. Because of the poor fossil record, the Sardar Formation was originally thought to comprise the Visean and the lower part of the Namurian. More precise conodont data by YAZDI (1999) indicate that the base of the Sardar Formation is of early Visean (*texanus* Zone) age while the upper part is not well dated and may range into the early Westphalian. A presumed extension of the Sardar Formation into the early Permian (RUTTNER & *al*. 1968) has not been confirmed. As a consequence of our elimination of the Shishtu Formation, we include also the Tournaisian in the Sardar Formation. The term is widely used on geological maps in central and eastern Iran between Kerman, Tabas and Yazd.

The Mobarak Formation was originally coined in the central Elburz as "Mobarak Limestone" for up to 450 m thick dark, well-bedded limestones with some shales at the base conformably overlying the Geirud Formation or, locally and unconformably, the Cambrian Mila Formation. The sediments of the Mobarak Formation are overlain, with an erosional contact, by the Lower Permian Dorud Formation or by Triassic breccias and/or oolitic limestones. STEPANOV (1971) proposed to give the Mobarak Limestone the rank of formation; it embraces late Tournaisian and Visean. Subsequently, the application of this term has been extended over the entire Elburz Mountains from the Talesh Range in the west to the Kopet Dagh in the east.

The Gachal Formation, with members A-D and a total thickness of up to 400 m, was introduced by AGHANABATI (1977) in the Kalmard area W of Tabas. It is a time equivalent of the Mobarak Limestone in the central Elburz as well as of the upper portion of the Shishtu and the lower part of the Sardar Formation in the Shotori Range, but is distinguished from both lithologies by an intercalated evaporitic facies in its upper part (member C), unknown from other areas in Iran.

Zarand Formation (Devonian-Tournaisian)

This term is introduced here for a heterogeneous sequence of mainly red sandstones, quartzites, shales (in some levels grey or black), laminated dolomites and very rare limestones which in the past was mapped as Padeha, Sibzar, Bahram, Shishtu and Sardar Formations without showing their lithological properties. The type section is at Kuh-e Tizi (Text-fig. 12; Pl. 4, Fig. 2) where this sequence crops out in a perfectly exposed and undisturbed pile of 435 m. Strongly contrasting thicknesses in other localities (70 m near Kuhbanan, 115 m near Gask, 210 m at Miyan Rud, 360 m. at Bannenstan, over 600 m near Darejus) are mainly due to the erosional level of the overlying Permian Jamal Formation rather than to differential subsidence and sediment accumulation. The deposits of the Zarand Formation are virtually unfossiliferous which makes their correlation with the above mentioned equivalents uncertain. Locally, rare placoderm and other vertebrate remains were discovered which, however, are of poor biostratigraphic value (Pl. 5, Figs 1, 4). The deposits of the Zarand Formation are conformably underlain by Silurian limestones or dolomites (Niur Formation), such as in Banenstan, Khanug, Fathabad and Aberun, or unconformably by Upper Cambrian siliciclastics, such as in Espidou, Kuh-e Tizi, Dorah-e Shahdad and Miyan Rud, and unconformably overlain by platform carbonates of the Permian Jamal Formation. The extremely rare fossiliferous levels within the Zarand Formation indicate Lochkovian (Sultanabad, Kuhbanan), Givetian (Kuh-e Tizi, Dorah-e Shahdad), late Famennian/early Tournaisian (Kuh-e-Tir) and late Tournaisian/early Visean (Dorah-e Shahdad) ages. At Kuh-e Tizi (Text-fig. 12) a calcareous level with *Umbellina* was found (Pl. 5, Fig. 4); it is probably not younger than Famennian. Thus, the Zarand Formation may span the entire Devonian and the Tournaisian, but is mostly reduced to an unknown fraction of this time-span due to its erosional upper boundary.

Hutk Formation (Lower Carboniferous)

Another lithostratigraphic term is newly established here for a carbonate sequence previously overlooked or simply included in the Sardar Formation. In contrast to the latter, this sequence represents a carbonate platform with an intermittent siliciclastic influx. It consists of well-bedded or massive dolomites and crinoid limestones, often with a high quartz content, with intercalated cross-bedded ferruginous sandstones. As type section we have chosen the topmost part of the Hutk profile below the Permian transgression (Text-fig. 5) where this formation is about 100 m thick. Similar values have been found in Gazestan (125 m, Text-fig. 6; Pl. 1, Fig. 2) and Ravar Gorge (100 m, Text-fig. 8); greater thicknesses occur in the Davaran Mountains (150 m in Arjasb, >200 m in Shams Abad, Text-fig. 10). The carbonates of the Hutk Formation are conformably underlain by skeletal limestones of the Bahram or Sardar Formations and overlain, with an erosional boundary, by the platform carbonates of the Permian Jamal Formation. Skeletal remains are scarce and are restricted to crinoid ossicles, poorly preserved brachiopods and sparse tabulate corals (*Syringopora*). The age of the Hutk Formation is Tournaisian-Visean, as is indicated by rare brachiopods and conodonts from the upper part (Hutk, Shams Abad) as well as from the underlying beds (Arjasb, Hutk). HUCKRIEDE & *al*. (1962, p. 53ff.) list some brachiopods and conodonts from the Morad anticline near Shams Abad which also suggest that the Hutk Formation extends into the lower Visean.

Jamal Formation, Ruteh Formation, Khan Formation (Permian)

STÖCKLIN & *al*. (1965) introduced the term Jamal Formation for a several hundred metres thick, cliff-forming unit of dark, pale-grey weathering dolomites in the Shotori Range E of Tabas which are ubiquitous also in the Kerman area. The sequence starts with cyclically deposited (sub-, inter- and supratidal) carbonates which grade upwards into more massive members. Overall dolomitization has destroyed the majority of organic remains, but in calcareous interbeds of the basal and topmost parts of the sequence, foraminifera and calcareous algae occur. They indicate an early Late Permian age of the Jamal Formation. Similar ages have been obtained from rare corals, molluscs and conodonts in the Tabas area (STÖCKLIN & SETUDEHNIA 1991). The Ruteh Formation in Azerbaijan, the Dorud Formation in the Elburz Mountains and the Khan Formation In the Kalmard area are facies equivalents of the Jamal Formation in other parts of Iran, locally with an increased siliciclastic input.

BIOSTRATIGRAPHY

Rapid lateral changes of lithologies and thicknesses render mere lithostratigraphic correlations, even in neighbouring areas, very unreliable. Therefore, the application of the lithostratigraphic units outlined above, is often questionable and arbitrary because these names pretend a stratigraphic precision which generally is not documented. Though such a stratigraphic simplification is generally practized on geological maps, it must be emphasized that calibration and correlation of sections can only be achieved by biostratigraphic data. Throughout Iran in Devonian and Early Carboniferous times, however, shallow water conditions prevailed under which familiar index fossils such as cephalopods and conodonts are extremely rare or absent. Consequently, the biostratigraphic framework presented in this paper must be considered tentative. Best time resolutions were achieved in the Givetian and Upper Devonian, locally also in Lower Carboniferous, while reliable datings in the Lower Devonian and Eifelian are extremely scarce or lacking. Calibration of the sections is based on the following groups of organisms:

Conodonts

A total of 352 conodont samples, 2-5 kg each, have been collected and processed for the present study, but only about one third have yielded conodont elements. In addition, the conodont fauna is very sparse in these samples; only a few of them contain more than 50 conodont elements. Conodont frequency, averaging below 5 specimens per kilogram of rock, is significantly lower in the Kerman area than in coeval strata of central and eastern Iran (ASHOURI 1990; YAZDI 1996, 1999). In particular pre-Givetian conodont faunas are very rare, low in diversity and represented by shallow-water forms. Moreover, they often include endemic forms of *Icriodus* unknown outside of Iran. Givetian faunas are slightly more frequent and similar to coeval faunas from the Variscan realm of Europe and from shelf areas of Australia and North America (see also WEDDIGE 1984b). The index taxa, however, are lacking in the majority of the samples so that only a rough age assessment was possible. Late Devonian faunas are remarkably low in diversity and dominated by shallow-water icriodids and polygnatids. Representatives of *Palmatolepis* are extremely rare. A similar composition of Late Devonian faunas resulting from shallow-water conditions was also reported by WEDDIGE (1984b) from the Ozbak-Kuh area and from northeastern Iran. In spite of their relatively poor recovery and the lack of index taxa, conodonts are still the best biostratigraphic markers, but a detailed zonal subdivision of our sections could not be achieved anywhere. A list of determined conodont species and their occurrence in the figured sections is given in Table 1. The ages of these faunas are listed in Appendix 2.

Brachiopods

In the majority of the study areas, brachiopods are very abundant, in particular in the limestones of the Bahram Formation; they are less common in the Niur and Sardar Formations. Their monographic study by one of us (N. F.) is in preparation. The results obtained so far have yielded very valuable data for biostratigraphic calibration and correlation of our sections. A compilation of the taxa determined so far from the

Hutk, Bidou Gorge and Gerik sections is given in Table 2. A total of 99 brachiopod faunas has been collected, among which 49 are from the Kerman area. Important contributions to the systematic study of Devonian brachiopods from Iran are the publications of GAETANI (1965), SARTENAER (1966), BRICE & *al.* (1974, 1978), AHMADZADEH-HERAVI (1975), DASTANPOUR (1990), and BRICE (1999b).

The brachiopods from the Devonian/Lower Carboniferous represent very diversified associations which consist (with decreasing abundance) of Spiriferida, Atrypida, Rhynchonellida, Orthida and Productida. Middle Devonian taxa show close relationships to those of Afghanistan, Libya and Poland. Upper Devonian brachiopods are mostly cosmopolitan and have been reported from Asia (China, Kasakhstan, Turkestan, Pamir, Afghanistan), Europe (western and central, Poland) and North America. Tournaisian brachiopods from Iran show affinities to forms from Afghanistan, Libya, Algeria, and western Europe.

Goniatites, clymeniids

Because of the overall neritic environment, cephalopods are extremely rare in the Devonian and Carboniferous of Iran. The only noteworthy exception is the Fammenian "cephalopod limestone" (STÖCKLIN & *al.* 1965) of the Shotori Range, in particular in the surroundings of Niaz and E of Posha. Unfortunately, the latter area is adjacent to a major N-S running fault, and the fossiliferous outcrops are extremely dislocated and fragmented. The undisturbed sections farther S in the same mountain range at Howz-e-Dorah are much less fossiliferous. An isolated outcrop of the same facies was discovered by RUTTNER & *al.* (1968) 6 km WSW of Shirgesht and has yielded some Famennian goniatites and clymeniids. These and the previous findings were described by WALLISER (1966). Isolated specimens of Upper Devonian cephalopods were reported by RIVIÈRE (1931, 1934) and DASHTBAN (1995) from the central and eastern Elburz Mountains and by HAMEDANI (1996) from the Isfahan area. Carboniferous goniatites were described from the Ozbak-Kuh Mountains and the Shotori Range by WALLISER (1966) and from a red nodular limestone in the Anarak area (central Iran) by KORN & *al.* (1999).

Trilobites

Apart from three brief reports (ZAHEDI 1973, BRICE & *al.* 1974, FEIST & *al.* 1999), trilobites have not been recorded from Devonian/Lower Carboniferous strata in Iran. This reflects the extreme scarceness of this group, rather than a mere gap in our knowledge. Given the wide distribution of shallow water and the presence of very fossiliferous deposits during this interval, this observation is surprising and may be explained partly by the poor preservational state of trilobites. In fact, trilobite fragments are rather common in thin sections (Pl. 5, Fig. 6). We found several species in the eastern Elburz, in central Iran (Yazd) and in the Kerman area. Eight species belong to the Asteropyginids, four to the Phacopids. All show close affinities to forms from Afghanistan. The occurrence of *Phacops* (*Omegops*) sp. is remarkable because it documents the presence of uppermost Famennian ("Strunian") in Iran. A systematic study of these discoveries is in preparation.

Other groups

Palynomorphs (Acritarchs, spores, pollens) have yielded useful biostratigraphic data from otherwise unfossiliferous deposits, in particular in the Zagros Mountains which were a continental area during the Devonian (GHAVIDEL-SYOOKI 1994). We have obtained a few biostratigraphic data from Upper Devonian and Lower Carboniferous black shales and dark marlstones casually processed for palynomorph extraction.

Calcareous algae and foraminifera have provided important data for the age of the Jamal Formation but are virtually absent in older deposits. An exeption are the umbellinaceans, considered as charophyte gyrogonia or utricles (TAPPAN 1980, 936). They are common in the Bahram Formation (Pl. 6, Fig. 1) and occur also in some calcareous levels of the more nearshore Zarand Formation (Pl. 5, Fig. 4).

Tentaculitids are most common in marly interbeds and on bedding planes of the calcareous lower Bahram Formation (Pl. 6, Fig. 5; Pl. 7, Fig. 2) and, in addition to the co-existing brachiopods, have provided good biostratigraphical indications. Some sections (e.g. Khoshyeilagh, Anarak) have yielded such abundant and continuous tentaculitid faunas, that elaboration of an additional Givetian to Frasnian biostratigraphic scale based on tentaculitids would be a challenge. A systematic description of 38 species from Iran and their palaeobiogeographical implications is in preparation.

Bryozoans are mostly small ramose or encrusting forms and common in the Upper Devonian Bahram (Pl. 6, Fig. 5) and the Lower Carboniferous Sardar Formation; but their biostratigraphic value is poor.

Sections / Samples / Brachiopod taxa	Hutk												Bidou Gorge					Gerik		
	103/5B	103/6	116/3	103/7	103/28B	103/28T	103/30T	103/38M	103/38T	103/40	103/49	149/2	107/3B	107/3T	107/7M	107/8	107/15	101/18-20	101/28	114/20
Douvillina thomasi		●		●																
Schellwienella crenistria												●								
Schwellwienella percha												●								
Productella baitalensis					●	●			●											●
Productella robertsoni					●	●				●										
Productella subaculeata							●													
Productus productus												●								
Buxtonia scabicula					●	●														
Gypidula globa	●		●																	
Ripidorhynchus elburzensis																				●
Ripidorhynchus kotalensis							●	●												
Cyphoterorhynchus arpaensis	●																			
Cyphoterorhynchus koraghensis		●																		
Gastrodetoechia iranica								●												
Centrorhynchus deltidialis deltidialis								●												
Centrorhynchus deltidialis transversa									●	●										
Evanescirostrum sp.									●											
Desquamatia (?*Seratrypa*) *derelictus*																			●	
Spinatrypa chitralensis															●	●	●		●	
Athyris gentilis																●				
Athyris chitralensis									●	●									●	
Athyris gurdoni									●	●									●	
Composita bellula											●									
Rigauxia acutosina																●				
Tylothyris laminosa												●								
Syringothyris subcuspidatoides												●								
Cyrtospirifer animanensis																			●	
Cyrtospirifer archiaci	●			●																
Cyrtospirifer asiaticus																				●
Cyrtospirifer conoideus																			●	
Cyrtospirifer gosseleti								●	●	●										
Cyrtospirifer kindlei									●	●										
Cyrtospirifer pamiricus													●				●	●		
Cyrtospirifer parilis	●		●													●		●		
Cyrtospirifer verneuli echinosus																●			●	
Uchtospirifer multiplicatus														●				●		
Uchtospirifer multiplicatus minor														●				●		
Uchtospirifer multiplicatus minor n. ssp.														●				●		
Uchtospirifer tichonovitchi																●				
Uchtospirifer n. sp.																		●		
Cyrtiopsis prepta															●					
Unispirifer unicus												●			●					
Saharonetes saharensis												●								
Syringospira prima									●											
Theodossia leonenkoi																	●			

Tab. 2. Composition and occurrence of brachiopod faunas in the sections of Hutk (Text-fig. 5), Bidou Gorge/Hodjedk and Gerik (Text-fig. 6).

Placoderms and other fish remains are particularly common in dolomitic interbeds of the Bahram and Zarand Formations and may locally form bonebeds (Shams Abad, Kuh-e Tizi, Dorah-e Shahdad; Pl. 5, Figs 1, 4). Generic determination of these fragments is futile, but at least a Devonian age of these usually unfossiliferous levels is highly probable. Residues of conodont samples have yielded some undeterminable shark teeth. Dipnoan teeth, already mentioned by HUCKRIEDE & *al*. (1962) were found in Shams Abad (Text-fig. 10) and Barfab. A bone fragment of an acanthodian from Gask (Text-fig. 12) sugests a Devonian age (M. RÜCKLIN, pers. comm.).

DEVONIAN VOLCANISM

Vestiges of volcanic activity during the Devonian are known from various regions, in particular in northern Iran. They consist of sills, dykes and lava flows and are reported from Azerbaijan (ALAVI & BOLOURCHI 1973), from the central (ASSERETO 1963, GAETANI 1965) and eastern Elburz (GHAVIDEL-SYOOKI 1994), the Binalud Mountains (LAMMERER & *al*. 1984), Aghdarband (RUTTNER 1991) and from central Iran (Dehbid, Kharanag). The rocks are mostly described as basalt, diabase and dacite to andesite. In the central Elburz Mountains, up to 400 m thick lava flows are intercalated in the Upper Devonian Geirud Formation. Several hundred metres thick, highly altered basalts are mentioned from the southern Lakar Kuh which, according to KLUYVER & *al*. (1983) pass upwards into lapilli tuffs. Farther west the volcanic activity appears to decrease, and in Banenstan, Kereshk and Chahkin only a few, 1-5 m thick basaltic sills occur in Upper Devonian calcareous and siliciclastic deposits. Absolute ages for these occurrences of volcanics are not available, and some may be considerably younger than the Upper Devonian sedimentary rocks into which they are intruded.

A yet unsolved problem is the age and geotectonic position of basic and ultrabasic rocks in the Sanandaj-Sirjan Belt and near Anarak (WEBER-DIEFENBACH & *al*. 1986, DAVOUDZADEH & WEBER-DIEFENBACH 1987). They are said to be intercalated in a “geosynclinal” sequence of metasediments from which K/Ar radiometric datings between 408 and 345 MA were obtained. The tectonic complications in these areas in which certainly younger ophiolites occur in close association with Upper Cretaceous pelagic limestones, cast some doubt on the presumed Devonian age of the volcanics. Moreover, the juxtaposition of shallow marine unmetamorphosed Devonian rocks and the mentioned pelagic volcano-sedimentary sequence near Anarak is hardly compatible with a Devonian age of the latter.

THE KERMAN - KUHBANAN - RAVAR AREA

The mountain ranges N and NW of Kerman (Text-fig. 3) are a key region of the Palaeozoic in Iran and therefore have been a subject of previous stratigraphic studies. Apart from a few hints on the presence of Devonian-Carboniferous rocks in this area in the travel reports by STAHL (1897), PILGRIM (1925), DE BÖCKH & *al*. (1929), and others which are merely of historical importance, it is the merit of HUCKRIEDE & *al*. (1962) to have focussed interest on the highly variable depositional conditions in this area during the Palaeozoic and to have compiled the first reliable data on Palaeozoic and Mesozoic biostratigraphy. As one of the main results of their studies, these authors presented the first detailed geological map (1:250 000) of the area, several sections through the entire Phanerozoic and some sketches illustrating facies distributions in space and time. Later, DIMITRIJEVIC (1973), KLUYVER & *al*. (1983), DASTANPOUR (1990, 1996a) and WENDT & *al*. (1997) have contributed to the knowledge of the Devonian stratigraphy in the Kerman region. In recent years new geologic maps at the 1:100 000 scale were published which have facilitated our search for new and hitherto unknown sections.

In the above mentioned publications, the Upper Silurian to Lower Carboniferous sequence is generally labelled as Niur, Padeha, Sibzar, Bahram, Shishtu, and Sardar Formations, even if the equivalent lithologies and stratigraphic evidence have not been found. We use these terms only in order to permit correlation of our sections with previously mapped and described units.

The study area is part of the Kerman-Tabas Block which constitutes one of the individual structural units of the Central-East-Iranian Microplate. The entire zone is dissected by important NW-SE to N-S trending strike-slip faults (e. g. Kuhbanan Fault, Behabad Fault, Lakar Kuh Fault, Bafq-Baghin Fault) which separate major synclines and anticlines (e. g. Bidu syncline, Gask syncline, Kamkun anticline) from wide Quaternary plains with a poorly known substrate. These structures in turn are often complicated by minor folds and monoclines and offset by vertical to steeply inclined fracture zones. Compressional movements appear to have been much more intense than is shown on geologic maps. The major phase of mountain-building occurred during post-Cenomanian/pre-Eocene and Oligocene times. This tectonic complication and shortening had to be ignored in our reconstruction of palaeogeographic maps (Text-figs 14-18) which therefore cannot be considered as a true to scale image of equivalent depositional patterns. The whole area is again and again affected by sometimes devastating earthquakes.

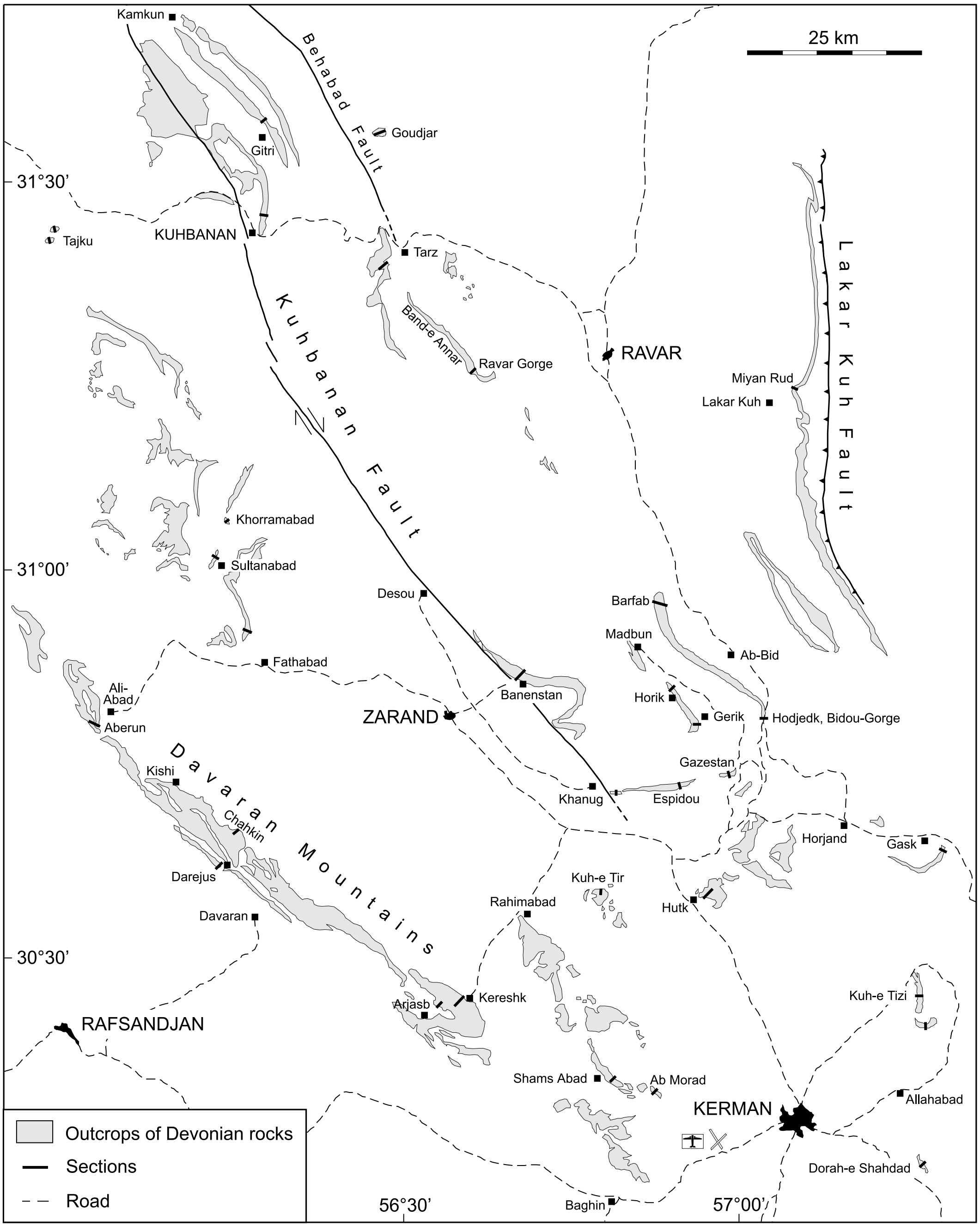

Fig. 3. Distribution of Devonian rocks in the Kerman - Kuhbanan - Ravar area, compiled from 1:250 000 and 1:100 000 geological maps, and from own observations

The substrate of the Devonian

In the majority of our studied sections, the Devonian/Lower Carboniferous sequence has enormous gaps at the base and at the top (Text-fig. 4). In contrast to their presumed wide distribution on geologic maps, only in a few areas have well documented Silurian rocks (Niur Formation) been found to underlie conformably the red beds of the Padeha or Zarand Formations (e.g. at Khanug, Banenstan and N of Fathabad, see below). DIMITRIJEVIC (1973) reported some poorly preserved brachiopods from the "phosphate unit" of his so-called Kereshk Group in the southeastern Davaran Mountains, to which he assigned a possible Silurian to Early Devonian age. HUCKRIEDE & *al.* (1962) mention some localities with Silurian brachiopods and cephalopods, but their age attri-

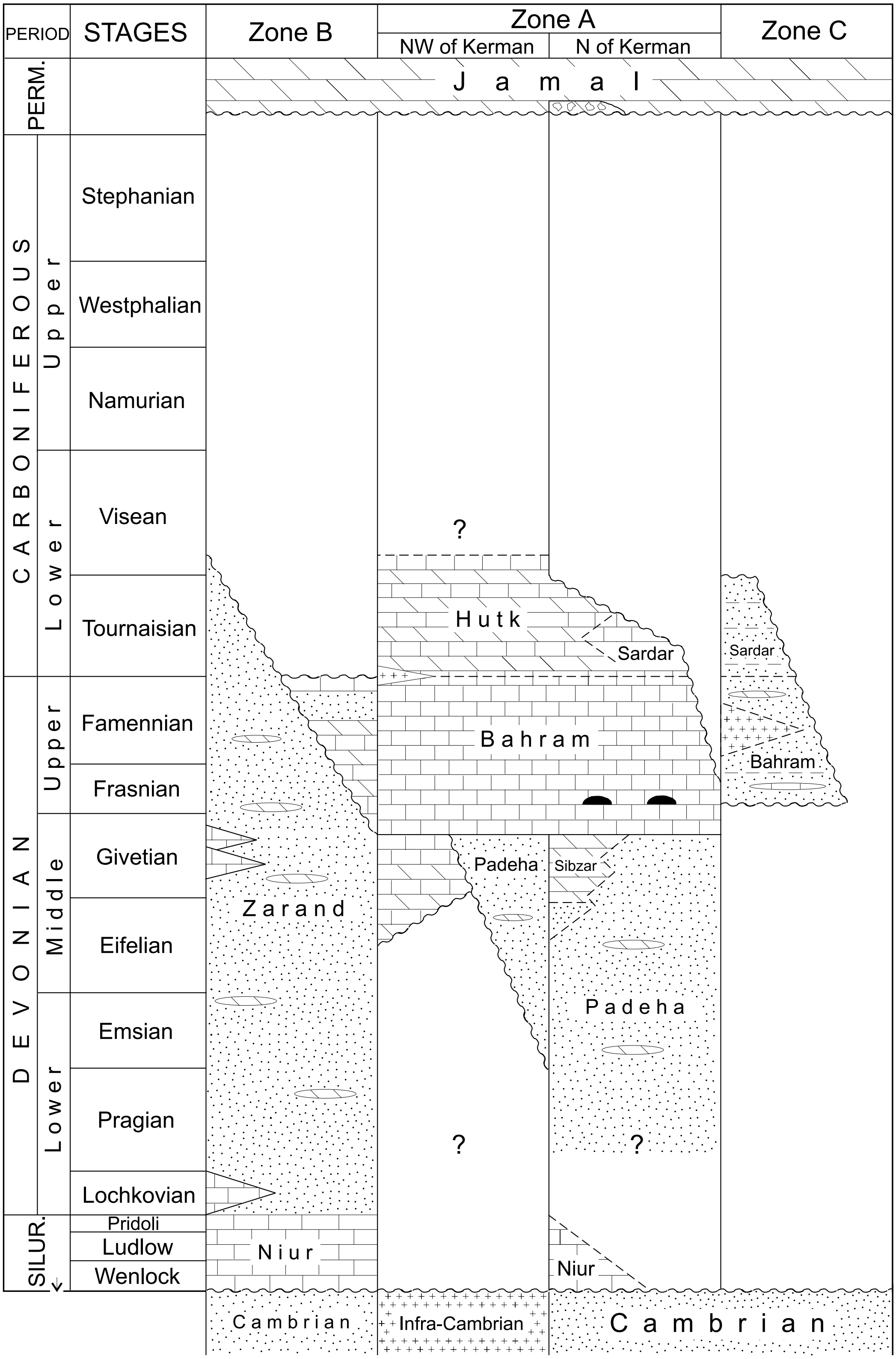

Fig. 4. Silurian to Permian lithostratigraphic formations in the Kerman - Kuhbanan - Ravar area. Sources as in Text-fig. 2. For legend see Text-fig. 5. Black segments = biostromes. Broken lines indicate uncertain boundaries

butions ("Ordovician to Silurian") cover a wide temporal range. Rocks of Ordovician age are even less precisely documented; according to REITZ & DAVOUDZADEH (1995), their thickness is in the order of 60-150 m. More commonly, in the Kerman area Devonian strata are underlain by red siliciclastics and dolomites of Cambrian age. This is the case at Dorah-e Shahdad, Kuh-e Tizi, Bidou Gorge, Gerik, Gazestan, Kuh-e-Kanseh, Ravar Gorge, and in the surroundings of Kuhbanan. Because the lithology of both the Cambrian (Lalun, Mila, and Kuhbanan Formations) and the overlying Lower Devonian (Zarand and Padeha Formations) rocks is very similar and biostratigraphic evidence in the two units is almost lacking, it is sometimes arbitrary to establish the exact boundary between the two systems, in spite of the enormous gap which it implies. We have used the following depositional features as a clue for this hiatus:

* angular unconformity (Kuh-e-Kanseh),
* erosional surface with noticeable relief (Kuh-e Tizi, Espidou, Gask, Kuh-e-Kanseh),
* polymict basal conglomerate (Kuhbanan, Espidou, Gask, Kuh-e-Kanseh),
* coarse breccia (Ravar Gorge, Chahkin),
* flat pebble conglomerate consisting of reworked underlying rocks (Gerik),
* palaeosol (Espidou), and
* abrupt lithologic change (Dorah-e Shahdad).

The Late Cambrian to Early Devonian hiatus which comprises a time span of the order of up to 100 Ma, can be explained only by a widespread pre-Devonian emersion and erosion which spared a few areas with preserved Ordovician-Silurian remnants. In the southeastern Davaran Mountains (Shams Abad, Ab-Morad), this erosion has cut down even onto the Infracambrian Rizu or the upper Precambrian Morad Series (HUCKRIEDE & *al.* 1962, DIMITRIJEVIC 1973).

The upper boundary of the Devonian/Lower Carboniferous

Generally without visible angular unconformity, the Devonian/Lower Carboniferous succession is overlain by well-bedded, grading into massive, dolomites of the Jamal Formation which constitute a prominent, several hundred metres thick escarpment. Its basal portion is of early Late Permian age (STÖCKLIN 1972 and own data) thus documenting another important hiatus comprising the following intervals:

* unidentified portions of the Devonian to Early Permian (Zone B – see below, parts of Lakar Kuh),
* late Frasnian to Early Permian (Bidou Gorge),
* late Frasnian to ?Middle Triassic (Gask),
* late Famennian to Early Permian (Gerik, Horik, Kuhbanan),
* Visean to Early Permian (Hutk, Kuh-e Tizi, Dorah-e Shahdad, Ravar Gorge, Gazestan, Shams Abad),

The base of the Jamal Formation is generally a paraconformity, often difficult to recognize in the field. In some places, however, it is marked either by a megabreccia (Hutk), by a palaeosol (Gazestan, Kuh-e-Kanseh, Gerik, Khanug, Banenstan, Gask, Aberun), by a hardground (Ravar Gorge), by a faint erosional surface with reworked pebbles (Bidou Gorge), or by an angular unconformity (Gazestan, Bidou Gorge, Tajku, Kuh-e-Kanseh, E of Khorramabad; Pl. 1, Fig. 2; Pl. 4, Fig. 3; Pl. 7, Fig. 6).

REGIONAL STRATIGRAPHY AND SEDIMENTOLOGY

Hutk

The perfectly exposed section of the recumbant anticline E of Hutk (Text-fig. 5; Pl. 1, Fig. 1) is the most complete, fossiliferous and best dated one of the Kerman area. It has often been studied but never been examined and sampled over its entire thickness (TIPPER 1921, PILGRIM 1925, HUCKRIEDE & *al.* 1962, GOLSHANI & *al.* 1973, JANVIER 1974, BLIECK & GOUJET 1978, DASTANPOUR 1990 and 1996a, WENDT & *al.* 1997, BRICE 1999a and 1999b, BRICE & *al.* 1999). The red siliciclastics of the Padeha Formation crop out in the core of the anticline, but their base is not exposed. BLIECK & GOUJET (1978) found some thelodont remains suggesting a Gedinnian-Siegenian age for the top of the Padeha sandstones. Locally at their top, a 0.3-1.5 m thick polymict conglomerate (2) of poorly rounded quartz pebbles and coarse sandstones occurs, which is not consistant laterally. The overlying skeletal limestones of the Bahram Formation consist of an alternation of 4 main lithologies:

(1) dark skeletal, well-bedded, partly nodular, highly fossiliferous limestones with abundant brachiopods, tentaculitids, and crinoid remains, as well as gastropods, bryozoans, pelecypods, and rare trilobites. 40 m above the base of the Bahram Formation a 20 cm-thick level with *Cystihexagonaria* occurs which was already mentioned by HUCKRIEDE & *al.* (1962, p. 59). The corals are mostly in place and form a small biostrome encrusting a thin oncolite layer (8).

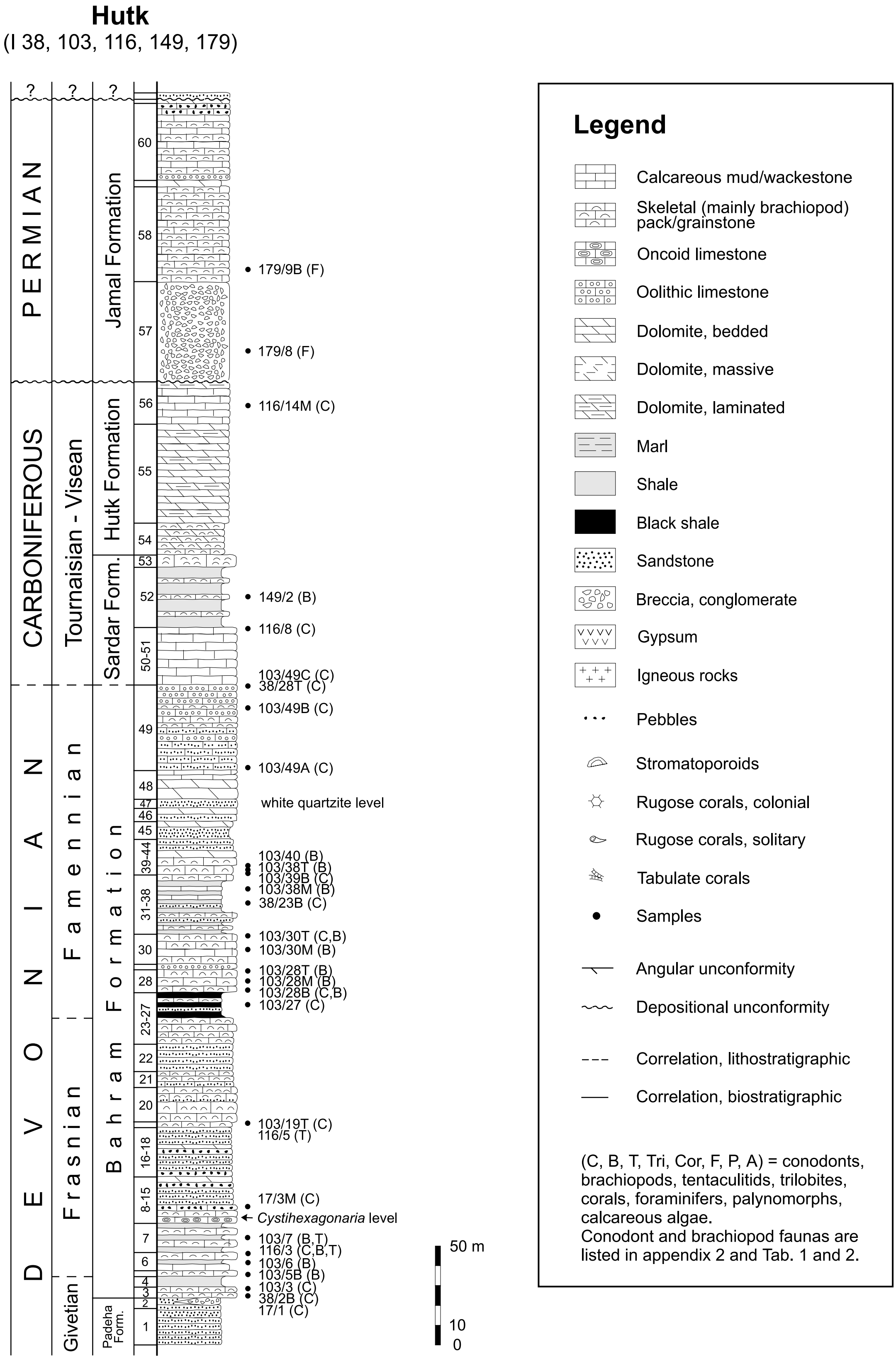

Fig. 5. Hutk section. Compare Pl. 1, Fig. 1

(2) grey and black shales with thin interbeds of skeletal limestone.

(3) cross-bedded or laminated red or yellowish quartzose sandstones with thin intercalations of red shale. Unit 47 is a 6 m-thick conspicuous bed of white quartzite (Pl. 1, Fig. 1).

(4) yellowish-weathering intertidal dolomites with microbial lamination and birdseye structures.

The alternation and repetition of these lithologies do not show a significant or regular trend. They represent minor oscillations of sea-level in which (1) and (2) represent the deepest and (3) and (4) the shallowest members. It is not possible to correlate these oscillations with neighbouring sections farther N and S.

The upper Givetian to Tournaisian sequence is 460 m thick and well dated by 17 conodont, 12 brachiopod, and 3 tentaculitid faunas. In contrast to earlier studies by DASTANPOUR (1990, 1996a), our conodont data show that the base of the Bahram Formation is upper Givetian. The Givetian/Frasnian boundary can be precisely fixed by brachiopod faunas at the base of unit 5. The Frasnian/Famennian boundary is somewhere between unit 20 and 26 and can be probably more precisely defined by closer conodont sampling. The uppermost part of the Bahram Formation consists of dark grey oolitic grainstones (Pl. 6, Fig. 4) passing into thick-bedded mudstones. This transition marks the approximate Devonian/Carboniferous boundary. The lower part of the Tournaisian is represented by shales and bioclastic grainstones with abundant brachiopods (52; Pl. 7, Fig. 4). They grade into intertidal dolomites indicating the existence of a hitherto unknown carbonate platform of Tournaisian age (Hutk Formation). The top of the dolomites is an erosional surface with a relief of several metres overlain by a 50-80 m thick breccia (57). The clasts of the breccia are very poorly sorted (0.5 to 50 cm, some up to 5 m) and consist of grey or reddish dolomite probably derived from the underlying carbonate platform, and a black detrital limestone. Samples of the latter have yielded sparse foraminifera of Early(?) Permian age. This breccia marks the transgression of the Jamal Formation which farther N (Gazestan, Kuh-e-Kanseh, Bidou Gorge, Gerik, Horik) cuts down onto Upper Devonian strata. In the Hutk section this formation is markedly reduced (approximately 125 m) with respect to neighbouring areas.

Gazestan

A hitherto undescribed section 19 km NNE of Hutk, on the southern flank of a tectonically isolated, 3019 m high mountain E of the small village of Gazestan, shows a more open marine development of the Upper Devonian (Text-fig. 6; Pl. 1, Fig. 2). The foothills are formed by a several hundred metres succession of red, generally cross-bedded sandstones grading into dark red silty shales with thin gypsum and dolomite levels. The Cambrian/Devonian unconformity must be searched for probably not much below this transitional zone, but could not be clearly defined. The upper part of the Padeha Formation, which in this locality has a total thickness of about 275 m, consists of an alternation of cross-bedded sandstones and silty dolomitic shales with occasional mudcracks. In contrast to the Hutk section, skeletal limestones with brachiopods and tentaculitids prevail in the Bahram Formation at Gazestan. The first rugose and tabulate corals appear 20 m above the base; higher up, a 12 m thick biostrome (20-22) constructed of stromatoporoids, rugose and tabulate corals, is very conspicuous. The limestones of the Bahram Formation are 185 m thick and mostly of Frasnian age. In a zone close to the Frasnian-Famennian boundary, two units of black shales with interbedded skeletal limestones occur, separated by 10 m of thick-bedded brachiopod limestones. The lower shale unit (43) is still crowded with tentaculitids, the upper one (45) contains numerous productid spines. The upper part of the sequence consists of brownish weathering, sandy dolomite with some intercalated limestone beds. In the latter, poorly preserved brachiopods and some tabulate corals (*Syringopora*) were found which did not yield precise biostratigraphic data. The boundary with the Jamal dolomites is marked by a 1 m bed of quartzitic sandstone passing into a 1.5 m palaeosol and by a faint angular unconformity (Pl. 1, Fig. 2).

Bidou Gorge, Hodjedk

The above described sequence of Gazestan continues northward in the mountain range of Kuh-e-Kanseh which, at its southern termination, shows a similar succession (Text-fig. 6; Pl. 1, Fig. 3). GOLSHANI & *al*. (1972) drew attention to an easily accessible section 10 km farther N, incised by the Bidou River into the same mountain range upstream the village of Tangal-e-Ab-e-Garm. From the basal part of the Bahram Formation they mentioned plant (*Lepidosigillaria*) and fish remains (acanthodians, arthrodires, and crossopterygians). The Hodjedk section is located a few km north of the gorge, but is incomplete due to a fault at the top (WENDT & *al*. 1997). Because the Padeha and the lower part of the Bahram Formation are not well exposed along the Bidou River, we have integrated both sections into Text-fig. 6. The boundary between the two formations can be clearly established at the base of a 1 m bed of sandy dolomite (7)

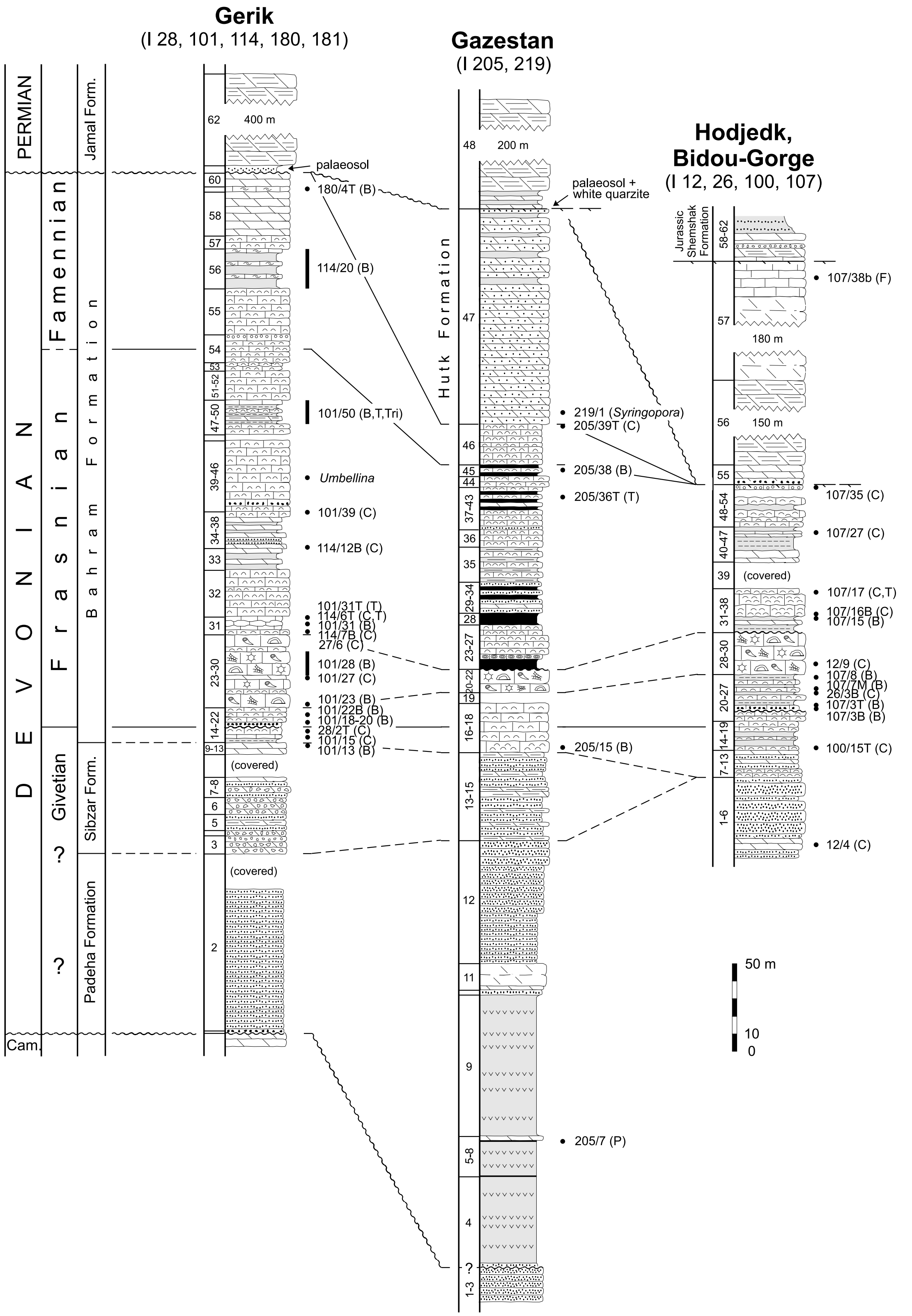

Fig. 6. Correlation of the Gerik, Gazestan, and Hodjedk/Bidou Gorge sections; for legend see Text-fig. 5. Compare Pl. 1, Fig. 2; Pl. 2, Fig. 1

with the first gastropods and other shell fragments. The Givetian portion of the Bahram Formation is about 30 m thick and consists of an alternation of skeletal wackestones with brachiopods, crinoids, molluscs and trilobites (Pl. 5, Figs 2, 3, 6), fine-grained sandstones with rare plant remains (*Lepidodendropsis*) as well as some dolomitic intercalations. A conodont date (*timorensis* to *disparilis* Zone) was obtained from the middle part (15) of this succession. The Givetian/Frasnian boundary can be placed within a sequence of skeletal limestones, with two erosional surfaces indicating minor breaks in sedimentation. A conspicuous biostrome (28-30), mentioned by GOLSHANI & *al*. (1972), is 24 m thick and contains numerous stromatoporoids as well as rugose (*Cystihexagonaria*, *Disphyllum*) and tabulate corals (*Alveolites*, *Pachypora*) generally in place (Pl. 7, Fig. 3). The sharp boundary towards the overlying shales with shelly interbeds suggests another minor depositional discontinuity. The remainder of the Frasnian has yielded four conodont assemblages, all indicating zones 11-13 of the upper Frasnian; it consists of an alternation of skeletal packstones with brachiopods, molluscs, crinoids and tentaculitids (Pl. 5, Fig. 5), shales, and some dolomitic interbeds. The topmost layer, a black oolitic grainstone (Pl. 6, Fig. 3) with numerous gastropods (54), has an almost undetectible discontinuity surface, sharply overlain by a grey dolomite with reworked clasts of black oolite and scattered ooids (Pl. 7, Fig. 5). This bed is the base of the Permian Jamal Formation which extends almost over the entire length of the gorge. On the western face of the entrance into the valley, an angular unconformity of 10° marks this boundary (Pl. 7, Fig. 6). As usual, this formation consists of well-bedded, laminated dolomite (220 m) in the lower (56), and massive dolomite (230 m) in the upper part (57). The topmost 10 metres are intertidal and shallow subtidal limestones containing sparse foraminifera of early Late Permian age. They are capped by a kaolinite (58) indicating another important hiatus prior to onset of the Lower Jurassic Shemshak Formation.

Gerik

About 10 km W of Bidou Gorge, an uplift in the core of the Bidou syncline exposes a much thicker and more complete section of the Devonian (Text-fig. 6; Pl. 2, Fig. 1). It was cursorily studied by DASTANPOUR (1990, 1996a) who, on the basis of brachiopods, recognized part of it as Frasnian and Famennian. Our reexamination of the same section (WENDT & *al*. 1997) has yielded new conodont data and has shown that deposits of both Padeha and Sibzar Formations are represented at Gerik. As a result of our subsequent studies we now present a complete profile from the top of the Cambrian to the base of the Permian Jamal Formation from this locality.

The foothills of the monocline consist of a several hundred metres thick succession of red sandstones and shales which, according to the 1:100 000 map (sheet Zarand), comprise the Cambrian Mila and Lower Devonian Padeha Formation. An erosional surface and a thin conglomerate with pebbles reworked from the substrate (1) may represent the Cambrian/Devonian disconformity. Consequently, we attribute the topmost 100 m of the “Old Red” series (*sensu* HUCKRIEDE & *al*. 1962) to the Padeha Formation. The Sibzar Formation, not shown in DASTANPOUR‘s (1996a) section, is 63 m thick and consists of strongly brecciated dolomites (3-13). Conodonts from 2 m above the last dolomite bed indicate a Givetian age for the basal portion of the Bahram Formation. The Frasnian is thicker than at Bidou Gorge (215 vs. 135 m). Also the coral-stromatoporoid facies (23-30) in the lower portion of this succession is thicker (41 m), better developed than at Bidou Gorge, and consists of several biostromal lenses with intercalated skeletal limestones (Pl. 7, Fig. 1). The remainder of the Upper Devonian sequence is represented by fossiliferous pack/grainstones with brachiopods, bryozoans, crinoids, tentaculitids (Pl. 6, Fig. 5; Pl. 7, Fig. 2), *Umbellina* (Pl. 6, Fig. 1) and rare gastropods. The Frasnian/Famennian boundary could not be established exactly and is placed in a 60 m interval between the last occurrence of tentaculitids (50) and a brachiopod fauna of early Famennian age (56). In the topmost 35 m of the Bahram Formation, a transition from well-bedded skeletal packstones (Pl. 5, Fig. 7) into laminated dolomites, indicating a regressive phase, is observed. This unit which, according to brachiopods, is still early Famennian; it is capped by a conspicuous, dark red marker bed, up to 3 m thick (61), pinching out laterally. It consists of a hematitic oolite at the base grading upwards into a fine- to medium-grained red sandstone with pisolites (Pl. 6, Fig. 7; Pl. 7, Fig. 7) and, finally, into a fine-grained sand- to siltstone. We interpret this level as a palaeosol formed during a long period of subaerial exposure prior to the onset of deposition of the intertidal Jamal Formation. The latter forms the surrounding peaks as well as the headwaters of the narrow gorge between Gerik and Rigabad.

Horik

In a small gorge between the villages of Horik and Silakhor, 7 km NW of Gerik and in the same structural unit, a succession of Early Devonian (?) to Permian age is easily accessible (Text-fig. 7). It shows some remarkable dissimilarities compared to the Gerik section. The Sibzar Formation is only 27 m thick; the overlying Bahram Formation is reduced to 100 m. Conodont recovery from the latter was poor: only three of broad Middle to Late Devonian age. There is no trace of a biostromal facies in this section. A brachiopod coquina near the top of the Bahram Formation has yielded a late Famennian age showing that Lower Carboniferous strata have been eroded prior to the transgression of the Permian Jamal dolomites. The latter reflect a subtidal environment in their lower part, but their base is not exposed.

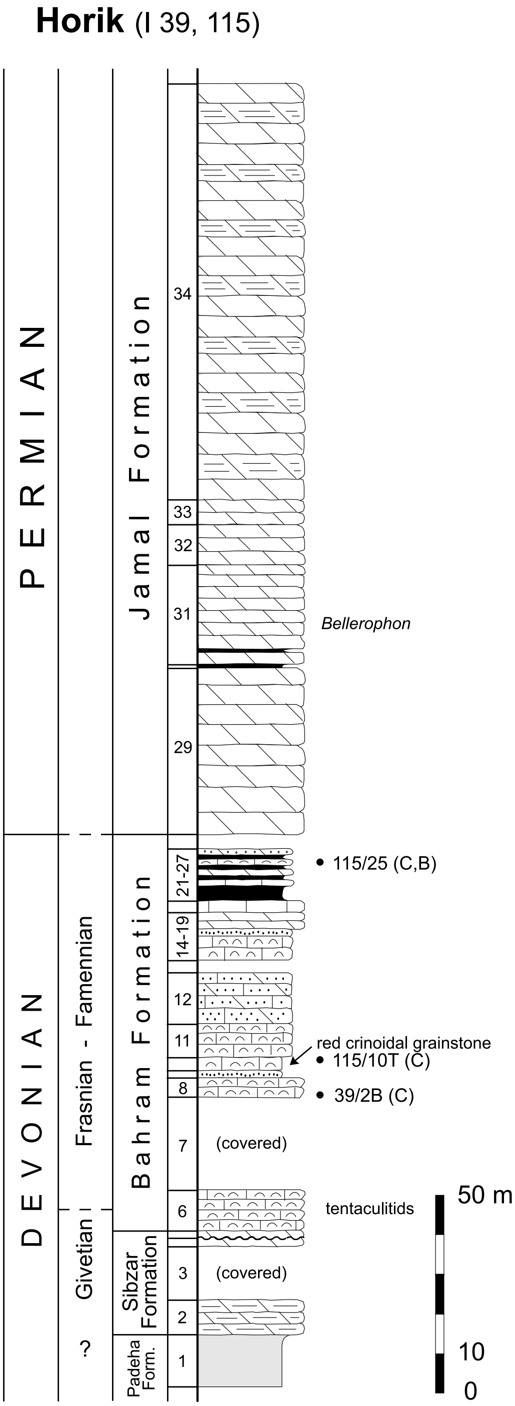

Fig. 7. Horik section; for legend see Text-fig. 5

Ravar Gorge

17 km W of the town of Ravar, an unnamed river cuts the Band-e-Annar mountain range and exposes a complete succession from Upper Cambrian (not mapped as such on sheet Ravar 1:100.000) to Jurassic (Text-fig. 8; Pl. 2, Figs 2, 3), briefly mentioned by STÖCKLIN (1961). The lower part of the gorge is occupied by over a thousand metres of red unfossiliferous cross-bedded sandstones. Stromatolitic dolomites in its lower portion suggest a Cambrian age. A coarse, poorly sorted breccia of dolomite and sandstone clasts (3), 235 m below the top of the "Old Red", is interpreted by us as the Cambrian/Lower Devonian unconformity. A 17 m unit of intertidal dolomite (10) may be considered as equivalent of the Sibzar Formation. The onset of limestone deposition (Bahram Formation), with a high content of coarse quartz grains at the base, could not be precisely dated, but 3 metres above that level, brachiopods and tentaculitids indicate an early Frasnian age. The biostromal facies is restricted to a 2 m bed (23) with stromatoporoids and colonial rugose corals 63 m above the base of the Bahram Formation. Below and above this level skeletal limestones prevail, interrupted by medium- to thick-bedded dolomites, shales, and quartzose sandstones with ripple marks. We have tentatively placed the Frasnian/Famennian boundary above the last occurrence of tentaculitids (40). The Famennian to Tournaisian portion of the succession consists of poorly fossiliferous calcareous sandstones and dolomites which have yielded only approximate biostratigraphic data. A conspicuous depositional unconformity with a dm-scale relief and an iron-stained hardground marks the top of this sequence. It is levelled by 1 m of black shale grading upwards into a several hundred metres thick pile of thick-bedded dolomite (Permian Jamal Formation) which constitutes the steep cliffs in the upper part of the gorge.

Lakar Kuh

This 90 km long monocline which is limited by the N-S running Lakar Kuh Fault in the east, offers spectacular sections from the upper Precambrian into the Upper Cretaceous (Text-fig. 9; Pl. 3, Fig. 1) but, due to its remoteness and safety problems, is almost inaccessible. STÖCKLIN's (1961) observation of a gap between the Cambrian and the presumed Upper Devonian/ Lower Carboniferous was confirmed by TERMIER & *al.* (1975) who noted that Permian Jamal dolomites may directly overlie Lower or Middle Cambrian stromatolites. According to KLUYVER & *al.* (1983), the Upper Devonian Bahram Formation rests unconformably on Upper Cambrian Derenjal Formation with a palaeosol at the base. They described the thickest and most complete Upper Devonian/Lower Carboniferous sequence from the southern end of the mountain range where the Devonian consists of 200 m of limestones, dolostones, sandstones and shales with an intercalated 400 m thick basalt flow. Brachiopods from an interval 60 to 125 m above the base of the Bahram Formation indicate the presence of Upper Frasnian/Lower Famennian equivalents. The Lower Carboniferous Sardar Formation is said to be 280 m thick and predominantly siliciclastic. Farther N, the Devonian is reduced to 135 m or com-

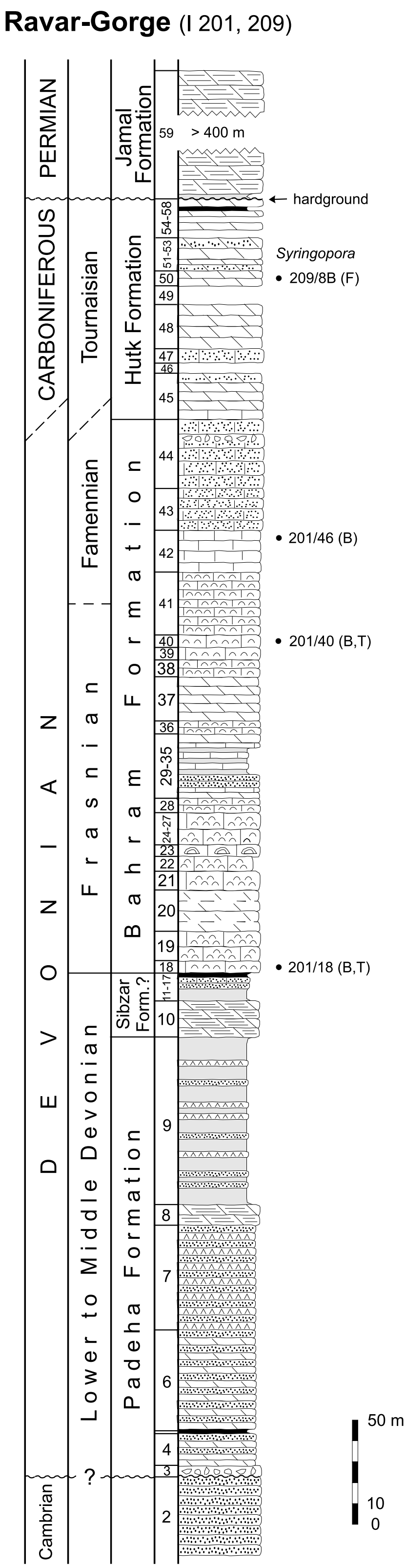

Fig. 8. Ravar Gorge section; for legend see Text-fig. 5; compare Pl 2, Figs 2, 3

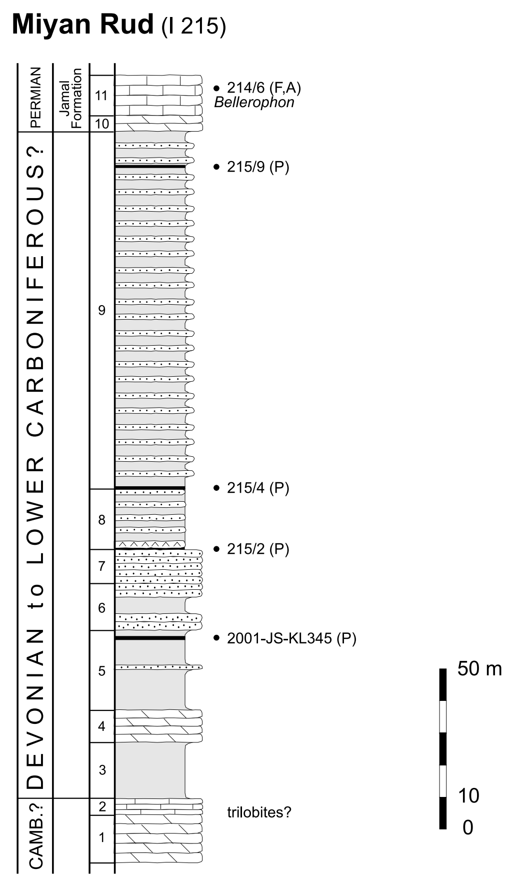

Fig. 9. Miyan Rud S section; for legend see Text-fig. 5; compare Pl. 3, Fig. 1

pletely lacking. These enormous gaps suggest the existence of a land area whose boundaries can only tentatively be traced in the Lakar Kuh area (Text-figs 15, 16) and whose major part is now concealed by Quaternary deposits of the Lut Desert farther E. We examined two sections on both sides of the only valley (Miyan Rud) which cuts the entire range. Here, the interval between Cambrian stromatolites and Permian Jamal dolomites consists of 200 m of well-bedded sandstones with intercalated red clays. Four black-shale levels were sampled for palynomorphs but did not yield any stratigraphic data. We could not find any obvious palaeosols or depositional unconformities, so that one can only speculate if this sequence represents equivalents of the Devonian (and Lower Carboniferous?).

Shams Abad

The Davaran Mountains NW of Kerman extend for about 125 km in a NW-SE direction and appear tectonically more shortened than the areas described above. Five sections were examined to elucidate the stratigraphy of the northeastern part of the range which belongs to the open marine development of Zone A (see below). The two Shams Abad sections (E and W) (Text-fig. 10; Pl. 3, Fig. 2) are situated in the Kuh-e-Zanqu range, 3 km ESE of the village of Shams Abad on the northeastern flank of a monocline formed by Infracambrian to Lower Carboniferous rocks thrust over Jurassic sandstones and shales. A similar sequence, 4.5 km to the ESE (Morad anticline) was described by HUCKRIEDE & *al.* (1962, p. 53ff.); another one, at the same place as our Shams Abad E section, was figured by DIMITRIJEVIC (1973) and DASTANPOUR (1990, 1996a). In this area Devonian carbonates of the Kereshk Formation directly overlie intensely weathered rhyolites of the Infracambrian Rizu series, thus indicating an upflifted and emergent zone during the lower Palaeozoic. The relief on top of the volcanics is locally covered by a conglomerate of reworked Infracambrian igneous rocks interpreted as an alluvial fan by DASTANPOUR (1991). In our section, marine limestones level up to 10 m depressions on the surface of the rhyolites. The Devonian/

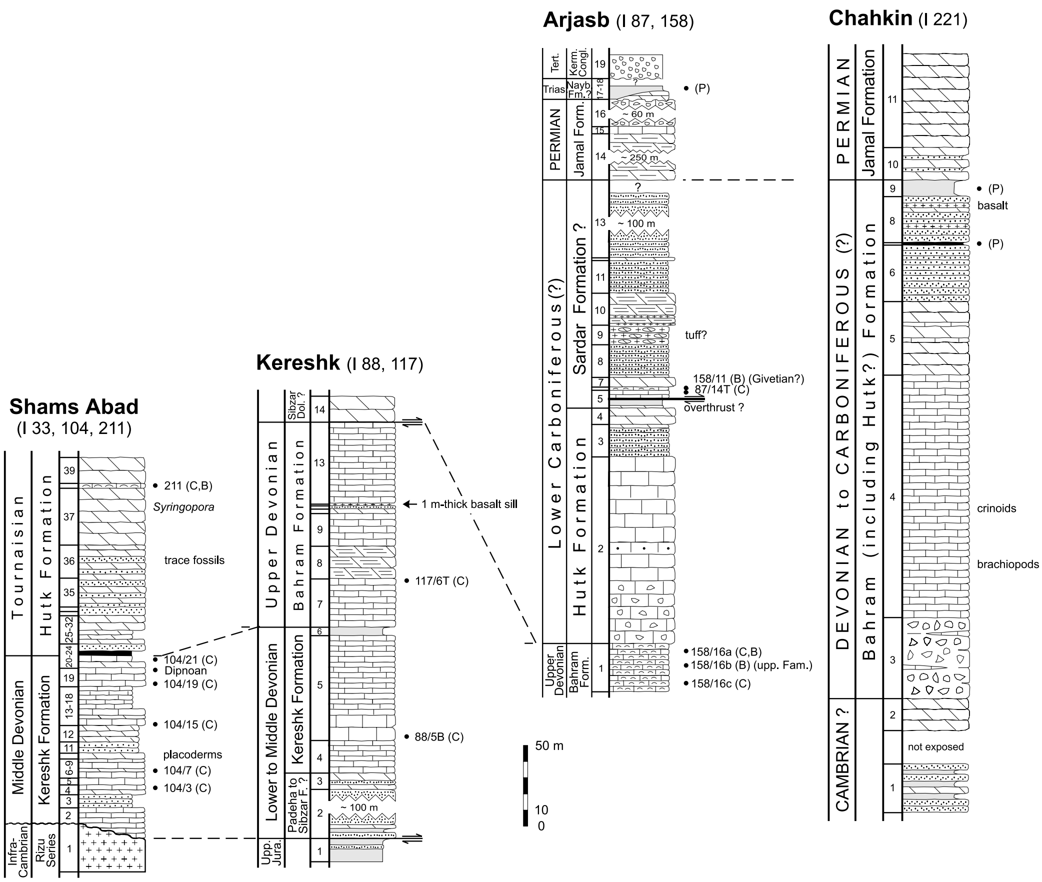

Fig. 10. Shams Abad E (compare Pl. 3, Fig. 2), Kereshk, Arjasb and Chahkin sections; for legend see Text-fig. 5

Lower Carboniferous succession can be roughly divided into two units:

(1) A basal, 90-120 m thick alternation of well-bedded skeletal packstones, oolites (Pl. 6, Fig. 2), dark-grey dolomites, quartzose sandstones and shales (2-28). Some dolomitic intercalations contain abundant placoderm and other fish remains, which may form veritable bonebeds ("phosphate unit" of DIMITRIJEVIC 1973). Calcareous interbeds contain brachiopods and tentaculitids, as well as rare bryozoans, rugose corals and stromatoporoids. Conodont samples indicate a Middle Devonian (mostly Eifelian) age for this unit of the "Kereshk Formation" which may be coeval to the oldest marine levels of the Morad anticline (HUCKRIEDE & *al*. 1962, p. 53); but they are inconsistent with those of DASTANPOUR (1990) who attributed the entire lower 180 m of his section to the Frasnian.

(2) An upper, 100-200 m cliff-forming succession of unfossiliferous thick-bedded dolomites with intercalated fine-grained sandstones and shales (29-36), representing a carbonate platform with an oscillating siliciclasic influx. The only biostratigraphic attribution for this unit was obtained from a limestone band (35) 100 m above the base with a few Tournaisian brachiopods and conodonts.

Kereshk

The mountain range of Kuh-e-Kereshk, about 25 km WNW from Shams Abad, consists of several superimposed slices of Devonian rocks thrust over Middle to Upper Jurassic sandstones and shales. DASTANPOUR (1990, 1996a) described a poorly dated ("possibly Devonian") section from the vicinity (Neddenu). We examined a sequence on the northeastern flank of the mountain range, 1 km WSW of the village of Kereshk (Text-fig. 10), which exhibits some noticeable differences compared to the mountain range of Kuh-e-Zanqu farther E. Several overthrusts have shortened the original distances between the two areas and have thus obscured Devonian depositional patterns.

The calcareous Devonian sequence is underlain by about 150 m of unfossiliferous white quartzitic sandstone with some dolomitic interlayers grading upwards into grey dolomites with thin sandy interbeds. This unit may correspond to the Padeha and Sibzar Formations in the area N of Kerman. They pass into laminated (microstylolitized) black limestone with some shell debris and crinoid ossicles (Pl. 6, Fig. 6) which recall a similar but much thicker lithology of Middle to Late Devonian age in the Binalud Mountains. Conodonts show an Eifelian age of the lower and a late Famennian age of the uppermost part of the series. A 1 m basalt sill 50 m below the top indicates volcanic activity, also evident farther N. Several slices of Sibzar(?) dolomite and Padeha(?) sandstone are thrust over the above succession which itself appears tectonically intact.

Arjasb

On the southwestern flank of Kuh-e-Kereshk, 2 km NE of the village of Arjasb, a succession (Text-fig. 10) was studied along a small valley cutting through an overturned anticline. It can be considered as the stratigraphic continuation of the Kereshk section, though reliable correlation between the two sections has not been achieved. HUCKRIEDE & *al*. (1962, p. 62 ff.) briefly described the same section (as "Argaz") in which they listed Upper Devonian and Lower Carboniferous brachiopods and vertebrate remains. The oldest dated member crops out somewhat below the crest of the mountain range and consists of well-bedded, partly nodular skeletal packstones with abundant brachiopods. Due to tectonic repetitions, their thickness can only be estimated as 150-200 metres. Two conodont samples from the topmost 25 metres have yielded late Famennian ages. This member shows the typical lithology of the Bahram Formation and is abruptly overlain by a prominent 120 m escarpment of black massive limestone and dolomite (2). The lower 40-50 m are brecciated and show a good fitting of the clasts. This phenomenon and the occurrence of neptunian dykes filled with red mudstone indicate a synsedimentary tectonic origin of the breccia. HUCKRIEDE & *al*. (1962) have assumed an Early Carboniferous age for this member. It is overlain by a marl/limestone intercalation (5) with Givetian brachiopods and conodonts indicating a thrust between units 4 and 5 which, however, could not be detected in outcrop. No biostratigraphic data are available for the remainder of the succession which is about 250 m thick and consists of red fine-grained sandstones with some intercalations of inter- to subtidal dolomites. The contact with the Permian Jamal Formation is not exposed.

Chahkin

HUCKRIEDE & *al*. (1962, p. 61) mentioned the presence of calcareous Givetian/Frasnian in the central Davaran Mountains, but their estimated thickness of about 1000 m is certainly overestimated and probably an effect of tectonic repetitions. The lower part of the gorge WSW of the village of Chahkin ("Tscharkin" *in*

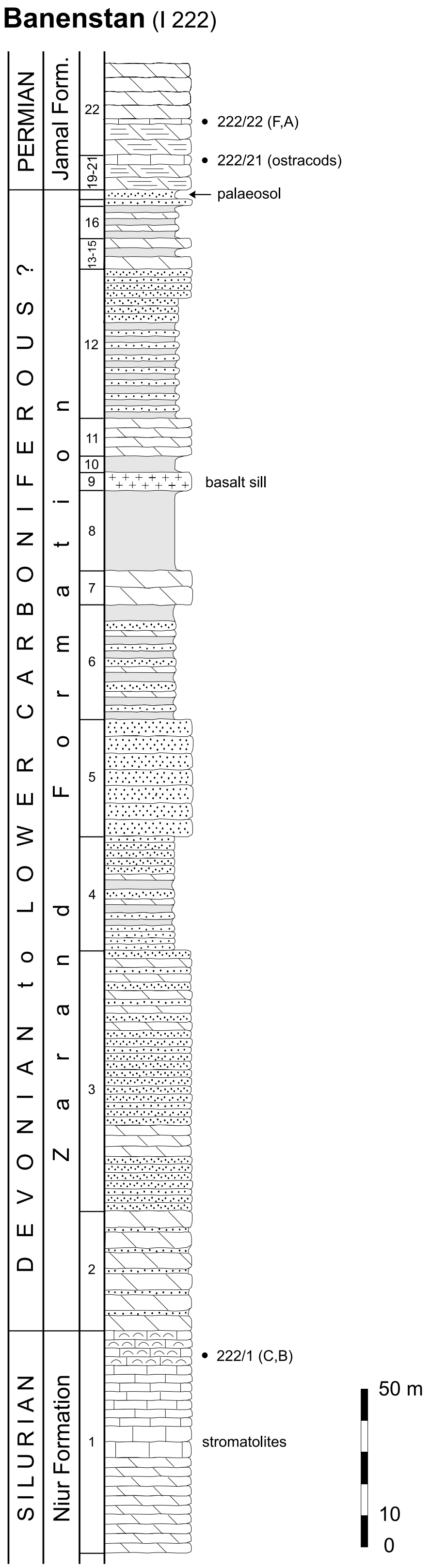

Fig. 11. Banenstan section; for legend see Text-fig. 5; compare Pl. 4, Fig. 1.

HUCKRIEDE & *al*. 1962) exposes over 1000 m of lower Palaeozoic quartzites with some dolomitic interbeds (Text-fig 10). They are sharply overlain by a breccia of limestone clasts with some intercalated shelly limestones (3) marking the onset of open marine conditions in the late Givetian or early Frasnian. This breccia passes into well-bedded skeletal limestones with brachiopods, crinoid remains and a few solitary rugose corals (4) grading into thick-bedded dolomites (5). The overlying quartzitic sandstones (6-8) which contain two basalt sills, may represent the remainder of the Devonian (and the Tournaisian?). Two black shale levels (7, 9) were sampled for palynomorphs but have yielded only a few unspecific taxa. The contact with the Jamal dolomite is concealed in our section but, apart from a local minor fault, appears depositional.

Kuh-e Tir

According to the 1:100 000 map (sheet Zarand), this tectonically isolated rocky mountain, 14 km W of Hutk, exhibits a succession of Padeha (Lower Devonian?) to Shotori (Middle Triassic) Formations including Upper Devonian and Lower Carboniferous equivalents similar to the Hutk section. A closer inspection, however, reveals that only two lithologic members can be distinguished: (1) about 200 m of red quartzitic sandstones (Zarand Formation), sharply overlain by (2) well-bedded intertidal, grading upwards into thick-bedded and massive Jamal dolomite which forms the peak of the mountain. Near a new trench for a water reservoir we collected a few poorly preserved productid and strophomenid brachiopods from a thin level 120 m below the top of (1); these indicate a late Famennian or early Tournaisian age for the sandstones. This still unsatisfactory but nevertheless important new interpretation of the succession relates this section much more to the distant Kuh-e Tizi and Dorah-e Shahdad areas rather than to the nearby Hutk section and shows that the Devonian/Lower Carboniferous facies belt of zone B is sharply separated from the coeval open marine development of zone A in the S and E (see below).

Khanug, Espidou, Banenstan

A succession similar to the latter is shown on sheet Zarand 3 km ESE of the village of Khanug and 15 km N of Kuh-e Tir (Pl. 3, Fig. 3). Red cross-bedded sandstones with siltstone interbeds (Zarand/Padeha Formation) overlie very fossiliferous, dark grey limestones, shales, and dolomites of the Niur Formation. The boundary between the two lithologies appears sharp but does not show an obvious break in sedimentation. From the topmost limestone layer we collected brachiopods, bryozoans, rugose and tabulate corals of Silurian (Wenlock) age. Also from "Khanuk" but with enigmatic coordinates, BRICE (1999a) described a brachiopod fauna of the same age. Both faunas show that the red siliciclastics of the Zarand Formation are probably of Early Devonian (including Late Silurian?) age. They grade upwards into 20 m of thick-bedded dolomite

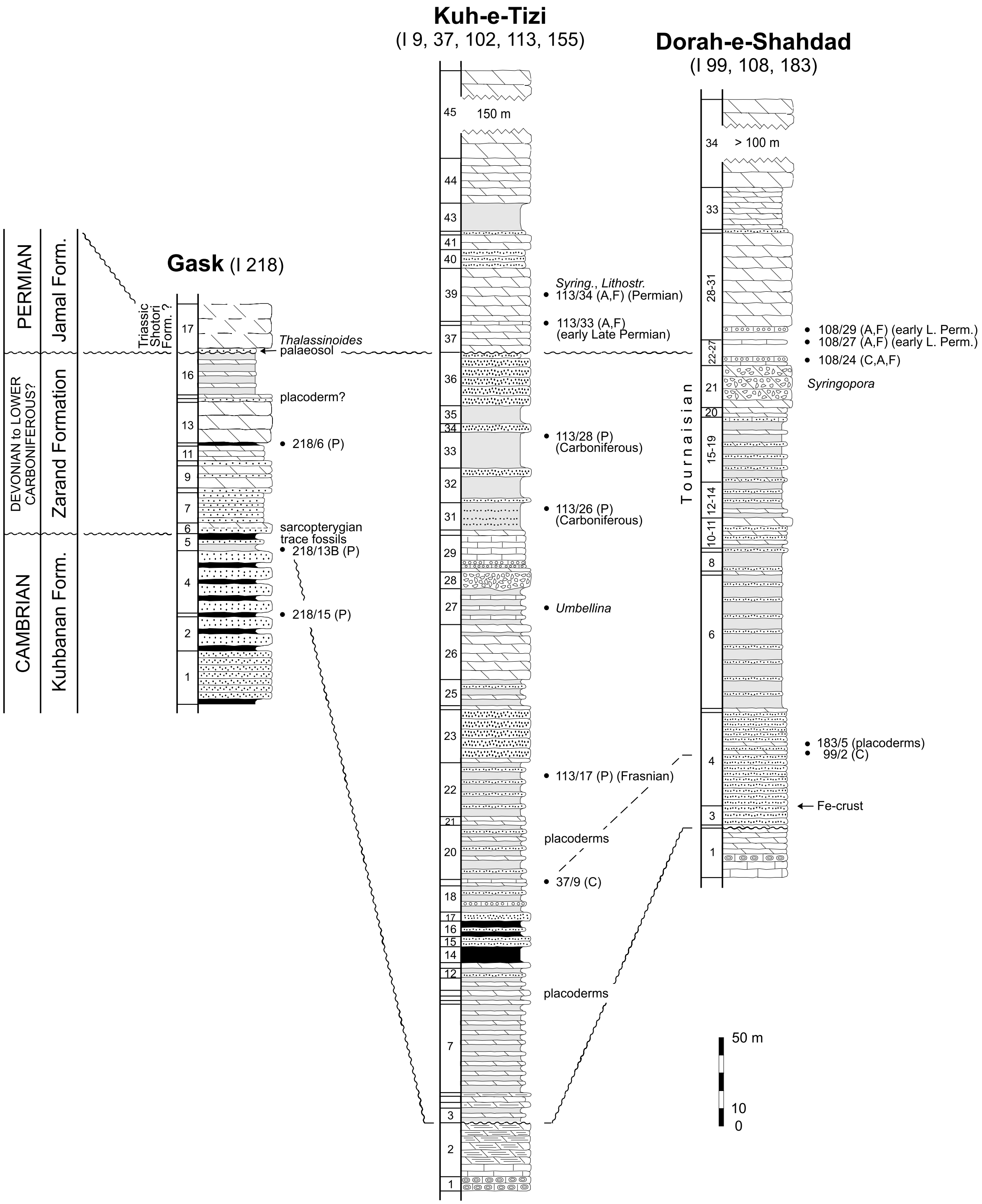

Fig. 12. Correlation of the Gask, Kuh-e Tizi (compare Pl. 4, Fig. 2) and Dorah-e Shahdad sections; for legend see Text-fig. 5; compare Pl. 4, Fig. 2

which in turn is capped by 1.5 m of dark red coarse sandstone of probable continental origin. This level is unconformably overlain by a thick pile of laminated dolomite (Jamal Formation) with reworked quartz grains at the base. We could not find any trace of the marine intercalations within the "Padeha" sandstones mentioned by HUCKRIEDE & *al*. (1962, p. 49, Text-fig. 27). On the contrary, 10 km farther E, the entire Cambrian to ?Devonian succession is siliciclastic with no trace of the calcareous Niur Formation. In this area (2 km W of the village of Espidou), Cambrian sandstones with some dolomitic layers near the top are capped by an erosional surface indicating a major gap probably due to emersion. The overlying red shales and white sandstones of the Zarand Formation are 160 m thick and grade (!) into the dolomitic succession of the Jamal Formation without any noticeable break in sedimentation.

Towards the northwestern termination of the same mountain range near Banenstan, 21 km NW of Khanug, the Zarand Formation is considerably thicker than at Khanug (360 m vs. 200 m).

Dorah-e Shahdad

This southernmost outcrop of Palaeozoic strata in the Kerman area (Text-fig. 12), about 15 km ESE of the periphery of the town, was briefly described by HUCKRIEDE & *al*. (1962, p. 69) and has become famous as one of the few places in Iran where Upper Cambrian trilobites have been found (WOLFART 1974). Well-bedded carbonates of this age are overlain by red sandstones and shales ("Old Red") with some dolomite interbeds which contain abundant phosphate pebbles and placoderm remains (Pl. 5, Fig. 1). This succession can be roughly correlated with the Kuh-e Tizi section, but is considerably reduced in thickness (estimates by HUCKRIEDE & *al*. 1962 are far too high). Due to a more nearshore position of this area during the Devonian, skeletal limestones are totally lacking at Dorah-e Shahdad. As can be argued from two conodont samples, the major part of the Zarand Formation is of Lower Carboniferous age. The Lower Carboniferous/ Permian boundary can be rather precisely fixed at the top of an oolitic limestone which has yielded upper Tournaisian/lower Visean conodonts. Two limestone levels (27, 29) near the base of the Jamal dolomites contain calcareous algae (*Pseudovermiporella, Permocalculus,* ?*Tauridium*) and foraminifera (*Paraglobivalvulina, Calvezina, Pachyphloia, Geinitzia, Tuberitina, Stipulina,* ?*Sichotenella*) clearly indicating an early Late Permian age for the lower part of the Jamal Formation.

Kuh-e Tizi

A Lower Cambrian to Middle Triassic succession is perfectly exposed on the western flank of the monocline of Kuh-e Tizi, 25 km NE of Kerman (Text-fig. 12; Pl. 4, Fig. 2); it can be followed along strike for about 6 km in a N-S direction. It has previously been described by HUCKRIEDE & *al*. (1962, p. 66 ff.), DASTANPOUR (1990, 1996a), and WENDT & *al*. (1997). Because this section represents the relatively best dated one among the predominantly siliciclastic nearshore successions of the Devonian/Carboniferous, we have chosen it as type section for the Zarand Formation. A prominent 30 m interval of laminated dolomite (2, no. 52-53 in HUCKRIEDE & *al*. 1962) with an 8 m band of oncolitic limestone at the base (1, no. 54 in HUCKRIEDE & *al*. 1962) forms the crest of a small ridge in the foothills (Pl. 4, Fig. 2). The surface of the dolomite shows erosional relief and probably marks the Cambrian/Devonian boundary which, due to the lack of distinctive organic remains, cannot be better established. Placoderm fragments in a thin dolomite bed 70 m higher in the succession indicate an Early or Middle Devonian age for the alternation of red shales and dolomites (3-13). A band of three discrete crinoid/brachiopod limestone beds, each 1 m thick and separated by dark shales (19, no. 36 in HUCKRIEDE & *al*. 1962), is the only evidence of open marine conditions in the entire Devonian/Lower Carboniferous succession. On the basis of new samples the previous attribution of this level to the late Emsian/early Eifelian by WENDT & *al*. (1997) must be rectified as lower/middle Givetian (*varcus-* to *hermanni-cristatus* Zone). A wackestone/ grainstone unit (27) with vertebrate remains and *Umbellina* (Pl. 5, Fig. 4) may still be attributed to the Upper Devonian. It is truncated by a laterally very discontinuous (5-15 m) breccia (28) of poorly sorted limestone clasts in a dolomitic matrix which marks a local unconformity of unknown age. Shales separating four distinct levels of quartzitic, laminated or cross-bedded sandstone (32-36) have yielded poorly preserved palynomorphs of probable Tournaisian age. The Carboniferous/Permian boundary is marked by the sudden onset of subtidal, grading into intertidal, dolomites of the Jamal Formation which overlies the topmost sandstone level with a sharp contact. Calcareous interbeds (38-39) in the lower part of the predominantly dolomitic succession contain sparse rugose (*Lithostrotion*) and tabulate corals (*Syringopora*), as well as calcareous algae (*Permocalculus, Gymnocodium, Atractyliopsis*, *Mizzia*) and foraminifera (*Tuberitina*) indicating an early Late Permian age for the base of the Jamal Formation. This thick pile of dolomites forming the crest of the Kuh-e Tizi range is unconformably overlain by limestones with coralline sponges and pelecypods of the Upper Triassic Nayband Formation.

Three km S of this section, the monocline is offset by an E-W fault beyond which the Cambrian to Permian succession is again completely exposed. Examination of a 525 m section in this area did not reveal any marker bed to correlate with the Kuh-e Tizi section thus emphasizing the rapid lateral facies change within the siliciclastic-dolomitic sequence and the unreliability of mere lithostratigraphic divisions.

Gask

Devonian strata are again exposed about 20 km N of Kuh-e Tizi, on the overturned flank of a small monocline SE of the Gask syncline (Text-fig. 12), but are considerably reduced compared to the two foregoing sections. The basal portion (1-5) consists of a cyclic sequence in which each cycle starts with a conglomerate, grading into cross-bedded, bioturbated sandstones which in turn pass into black shales. This part, attributed to the upper Cambrian Kuhbanan Formation on the 1 : 100 000 map (sheet Horjand), is erosionally capped by a conglomerate (6) consisting of phosphate and quartzitic sandstone pebbles in a sandy matrix; it contains some fragments of sarcopterygian fish indicating a probable Late Devonian age. We could not find any skeletal remains in the overlying sandstones and dolomites, but HUCKRIEDE & *al*. (1962, p. 65) mentioned Frasnian brachiopods from dolomitic shales at the top (16). They are capped by a thin palaeosol followed by a thick pile of massive dolomites (Triassic Shotori Formation?). These enormous gaps at the base and at the top document long periods of continental conditions and erosion preceding and following a short interval of nearshore and sebkha deposition which probably represent only a small fraction (Givetian-Frasnian?) of the Devonian.

Sections W of the Kuhbanan Fault

The unnamed mountains extending for about 75 km in a NW direction from W of Zarand to W of Kuhbanan (including the Shabdjereh wedge and Giverun diapir in HUCKRIEDE & *al.*1962) show a Devonian to Permian succession similar to the area E of the Kuhbanan Fault (Banenstan, Khanug) (Text-fig. 13). The lower Palaeozoic consists of a >1000 m succession of red siliciclastics and dolomites from which Cambrian (HUCKRIEDE & *al*. 1962) and Silurian (HAMEDI 1995 and own data) fossils have been reported. The upper portion of this “Old Red” may locally comprise Lower Devonian remnants (Zarand Formation). With a sharp lithological boundary, they are overlain by a several hundred metres pile of well-bedded dolomites which, in comparison with neighbouring areas, are Permian Jamal Formation. Five sections have been examined in this range: N of Fathabad, Sultanabad, S and SE of Khorramabad, and surroundings of Tajku.

N of Fathabad, the Niur (= Shabdjereh) Formation consists of >600 m of dolomites and dolomitic clays the upper part of which were dated by conodonts as upper Llandovery/lower Wenlock. They are overlain by quartzitic sandstones, shales and dolomites of the Zarand Formation. A thin limestone level at the base of the Jamal dolomites, with quartz grains, crinoids, ostracodes and shell debris, marks a distinct transgressive boundary. A stromatolite level 20 m above this boundary can probably be correlated with a similar one in the same stratigraphic position farther N in the Kuhbanan region (WENDT & *al*. 1997).

From Shabdjereh, but without a precise location, NASEHI (1997) described a 380 m thick succession of gypsum and sandstones with some limestone intercalations, despite our extensive field studies in this area, could not be traced. Therefore, the existence of the Lower and Middle Devonian conodont faunas listed in that paper, must be strongly doubted. The mountain range, 2.5 km E of the Shabdjereh and 1 km N of Sultanabad, consists of a sandstone-dolomite sequence overlain by Jamal dolomite with the above-mentioned stromatolite level 10 m above the base of the latter. The lowest exposed parts of the Zarand Formation are dolomitic and contain five levels of black limestone. Huge conodont samples taken from all levels were almost barren; only the lowermost one yielded a few conodont fragments indicating an Early Devonian (Lochkovian) age (Text-fig. 13).

Already HUCKRIEDE & *al*. (1962, fig. 9) have observed that in the northwestern part of the mountain range (Kuh-e-Fathabad, S of Tajku), Middle Cambrian sandstones are directly overlain by Permo-Triassic dolomites. Surprising is that ZHI-WEN & JAFARY-SADR (1993) figured a very generalized section from the same locality showing fossiliferous Niur (Silurian) and Padeha Formations (Lower Devonian) with brachiopods and crinoids, overthrusted by Triassic limestones. Examination of three sections in this area has confirmed the view of HUCKRIEDE & *al*. (1962), but did not verify ZHI-WEN & JAFARY-SADR‘s (1993) stratigraphic and tectonic interpretations. The lowermost 30 m of the intertidal dolomites of the Jamal Formation are calcareous wacke- and grainstones with ooids, crinoid, and other skeletal remains but did not yield any diagnostic

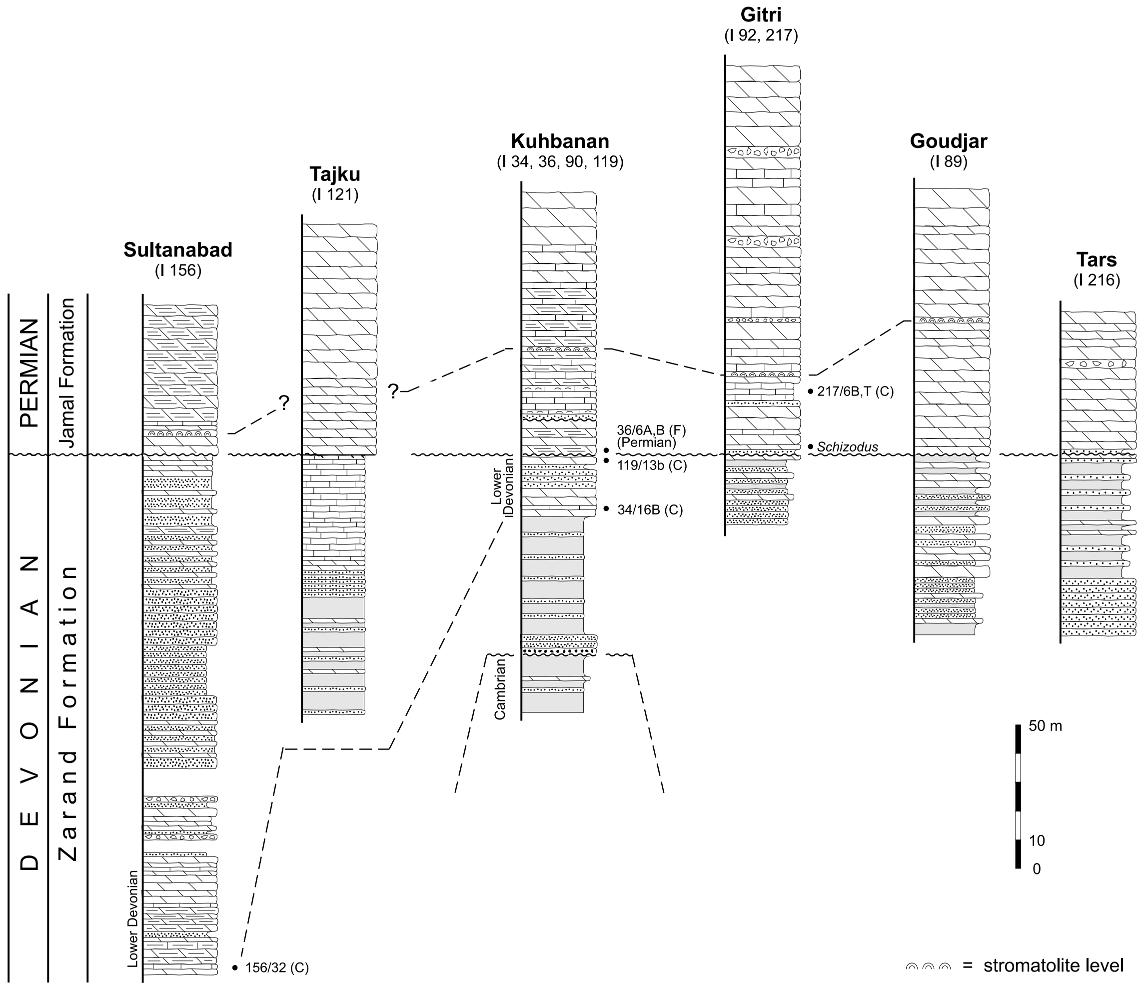

Fig. 13. Correlation of sections W of the Kuhbanan Fault; for legend see Text-fig. 5

organisms. Locally, the "Old Red"/Permian boundary is marked by an angular unconformity of 10° (Pl. 4, Fig. 3).

Kuhbanan

In the core of an overturned anticline, immediately N of the township of Kuhbanan, a complete succession of Lower to Middle Cambrian sandstones and dolomites is exposed (HUCKRIEDE & *al*. 1962, p. 34) (Text-fig. 13). They are overlain, after a pronounced hiatus and a transgression conglomerate (no. 20 in HUCKRIEDE & *al*. 1962), by 40 m of red shales with intercalated sandstones which we attribute to the Zarand Formation. During a first reconnaissance (WENDT & *al*. 1997) we found a few conodont fragments in the basal limestone bed above the shales suggesting a pre-Frasnian age. A more precise date is now provided by another sample indicating an Early Devonian (Lochkovian) age showing that almost the entire Devonian has been eroded (or never deposited?) prior to the Permian transgression. Calcareous intercalations in the basal Jamal dolomites contain some undeterminable foraminifera and calcareous algae (*Atractyliopsis carnica*, *Connexia*, *Permocalculus*, *Gymnocodium* cf. *japonicum*, *Ortonella*), Bryozoa (*Acanthocladia guadelupensis*) indicating late early and early late Permian ages. They show that the several hundred m thick pile of cyclically deposited dolomites must be attributed to the Permian Jamal rather than to the Devonian Bahram Formation. Thirty-five m above the base of the dolomites we found a stromatolitic marker bed (WENDT & *al*. 1997, figs 13, 14) which can be correlated with the Fathabad-Tajku area in the west, as well as with the Gitri and Goudjar sections farther N and NE (Text-fig. 13).

Gitri

In the 30 km long Kamkun anticline, which is bounded by the Kuhbanan Fault in the W and the Behabad Fault in the E, red beds of the Lower Cambrian Lalun Formation (probably including some Zarand Formation remnants at the top) are directly overlain by Permian dolomites (Text-fig. 13). As a consequence of our new conodont data from Kuhbanan, the former attribution of the dolomites constituting the crest on both flanks of the anticline, as "Bahram Dolomite" (WENDT & *al*. 1997) must be changed to Jamal dolomite. The top of the red beds occupying the open valley in the core of the anticline shows a faint relief which is levelled by a breccia of dolomite clasts in a sandy matrix crowded with an almost monospecific pelecypod fauna (*Schizodus)*. This is the base of the Jamal Formation in which, 23 m above the base, the above mentioned stromatolitic marker bed is typically developed.

Goudjar

The moncline of Goudjar immediately E of the Behabad Fault shows a sequence (Text-fig. 13) which was mapped as post-Lower Devonian and Lower/Middle Triassic by STÖCKLIN (1961), as Permo-Triassic by HUCKRIEDE & *al*. (1962), and as Devonian-Carboniferous overlain by Middle Triassic Shotori Formation on sheet Ravar of the 1:250 000 geological map. In an unpublished report of A. KARIMI BAVANDPUR, the foothills consisting of intertidal dolomites, red sandstones and shales with gypsum layers are attributed to the Infracambrian to Middle Cambrian Soltanieh to Derenjal Formations, and the overlying 400 m of dolomites to the Middle Triassic Shotori Formation. We assume that, in comparison with the nearby Kuhbanan and Gitri sections, the upper part of the sandstone-dolomite-shale sequence may include Lower Devonian equivalents, but we could not locate the Cambrian/Devonian boundary. The thick pile of well-bedded, grading into massive, dolomites forming the crest of the mountain range is Permian Jamal Formation as is indicated by foraminifera from the upper calcareous portion of the succession. A stromatolite level, 44 m above the base of the Jamal dolomite, can be correlated with a similar one at Kuhbanan and Gitri.

FACIES PATTERN AND PALAEOGEOGRAPHY

Only a few attempts have been made so far to sketch Devonian/Lower Carboniferous facies patterns in Iran. HUCKRIEDE & *al*. (1962, pp. 161-163) distinguished a poorly fossiliferous siliciclastic-dolomitic lithology in the Kuhbanan-Ravar-Zarand area from another one N and NW of Kerman in which skeletal limestones predominate. No additional data for the Kerman area were available for BRICE & *al*. (1978) and WEDDIGE's (1984b) Lower Devonian to Upper Carboniferous palaeogeographical maps which cover Iran and neighbouring countries. In DASTANPOUR's (1996a) simplified reconstruction of the Upper Devonian palaeogeography, the Kerman area is situated on the southeastern margin of a "marine off-shore platform" which occupies all central and northern Iran except an enigmatic island ("Tabas Block"). His presumed four transgression-regression cycles during the late Frasnian to early Tournasian (DASTANPOUR 1997) are not supported by stratigraphic data and are pure fiction.

From the preceding paragraphs it becomes evident that Devonian and Lower Carboniferous facies patterns in the Kerman area reflect considerable vertical and lateral variations in which significant trends in space and time are difficult to recognize. Moreover, due to scarcity of biostratigraphic data, calibration and correlation of sections had to be based partly on unsatisfactory lithostratigraphic comparisons. The maps of facies patterns for the successive intervals shown in Text-figs 14-18 must therefore be considered as a first attempt of palaeogeographic interpretation of our data. Because of our punctual rather than regionally extensive field observations, boundaries of these facies belts are necessarily approximate.

Silurian

As shown on Text-fig. 14, deposits of the Silurian Niur (and the coeval Shabdjereh) Formation are represented only in the central part of the study area from the NW Davaran Mountains in the W to the eastern flank of the Bidou syncline (Ab Bid) in the E. They overlie poorly documented Ordovician or transgress on Infracambrian igneous rocks and consist of several transgressive-regressive cycles oscillating from fluvial into marginal marine environments. The upper part of the sequence reflects inter- to shallow subtidal conditions documented by stromatolites, mud cracks and wave ripples, grading into subtidal deposits with brachiopods and tabulate corals. HAMEDI (1995) observed contrasting thicknesses of the Silurian E and W of the Kuhbanan Fault (609.20 m vs. 1068.45 m - *sic*!) suggesting NW-SE trending, tectonically controlled depocentres already envisaged by HUCKRIEDE & *al*. (1962, p. 160). The few available other data indicate decreasing thicknesses towards N, E and S. The absence of Silurian deposits in the majority of the studied sections is probably due to non-deposition and/or pre-Devonian erosion, but it cannot be excluded that some Silurian equivalents are present in the lower portion of the Padeha and Zarand Formations (see below).

Lower Devonian

Because of the extreme scarcity of organic remains and the resulting difficulties of stratigraphic correlations, deposits of the Padeha (and equivalents of the Zarand) Formation have not been studied in detail by us. The map of facies distributions (Text-fig. 15) shows widely distributed siliciclastics with some intercalated intertidal dolomites. These predominantly red (upper part of the "Old Red" of HUCKRIEDE & *al*. 1962) sandstones and shales represent nearshore and delta environments in which trough cross bedding, wave ripples and occasional mud cracks reflect extremely shallow

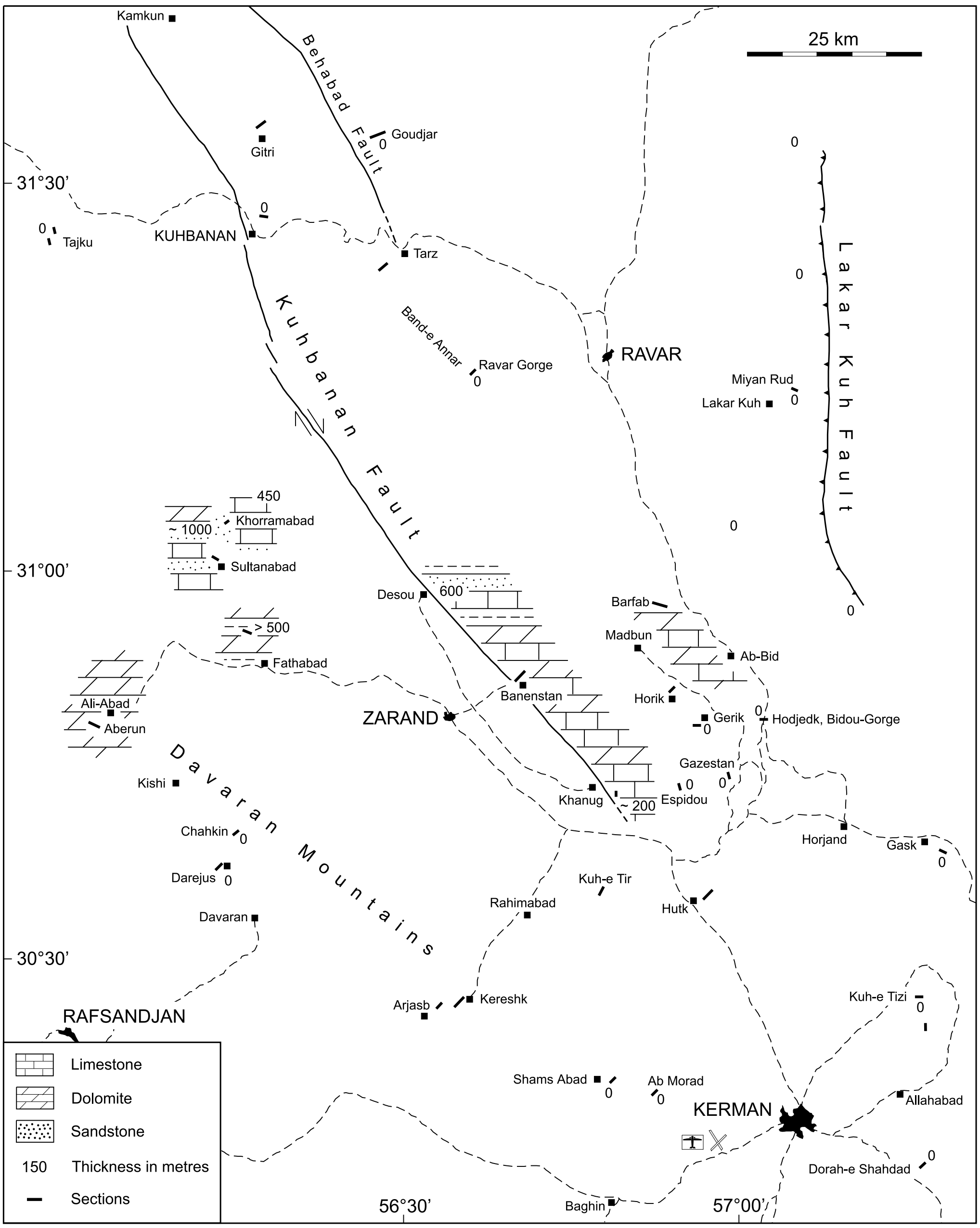

Fig. 14. Silurian (Niur Formation) facies pattern; for legend see Text-fig. 5

water with possible fluvial intercalations. Rare placoderm remains may document slightly deeper marine conditions. Unidentifiable plant remains were swept in from land areas located farther E and S. In restricted areas (Gazestan, Barfab, Ravar Gorge) along the eastern margin of this shelf, intercalations of gypsum (Pl. 2, Fig. 3) indicate local sebka conditions. The area E of a line running approximately from Ravar to Horjand and Kuh-e Tizi was emergent, as was a small sector W of Kerman.

Early Middle Devonian

In two disjunct areas (Arjasb to Horik and Ravar Gorge), a 10-60 m dolomitic member is conformably intercalated between the Padeha and the Bahram Formation which may be coeval with the Sibzar Formation of the Tabas region (Text-fig. 16). Because diagnostic organic remains have not been found in this unit, it is inferred only from the stratigraphic position that this dolomiite is similar in age to the Sibzar

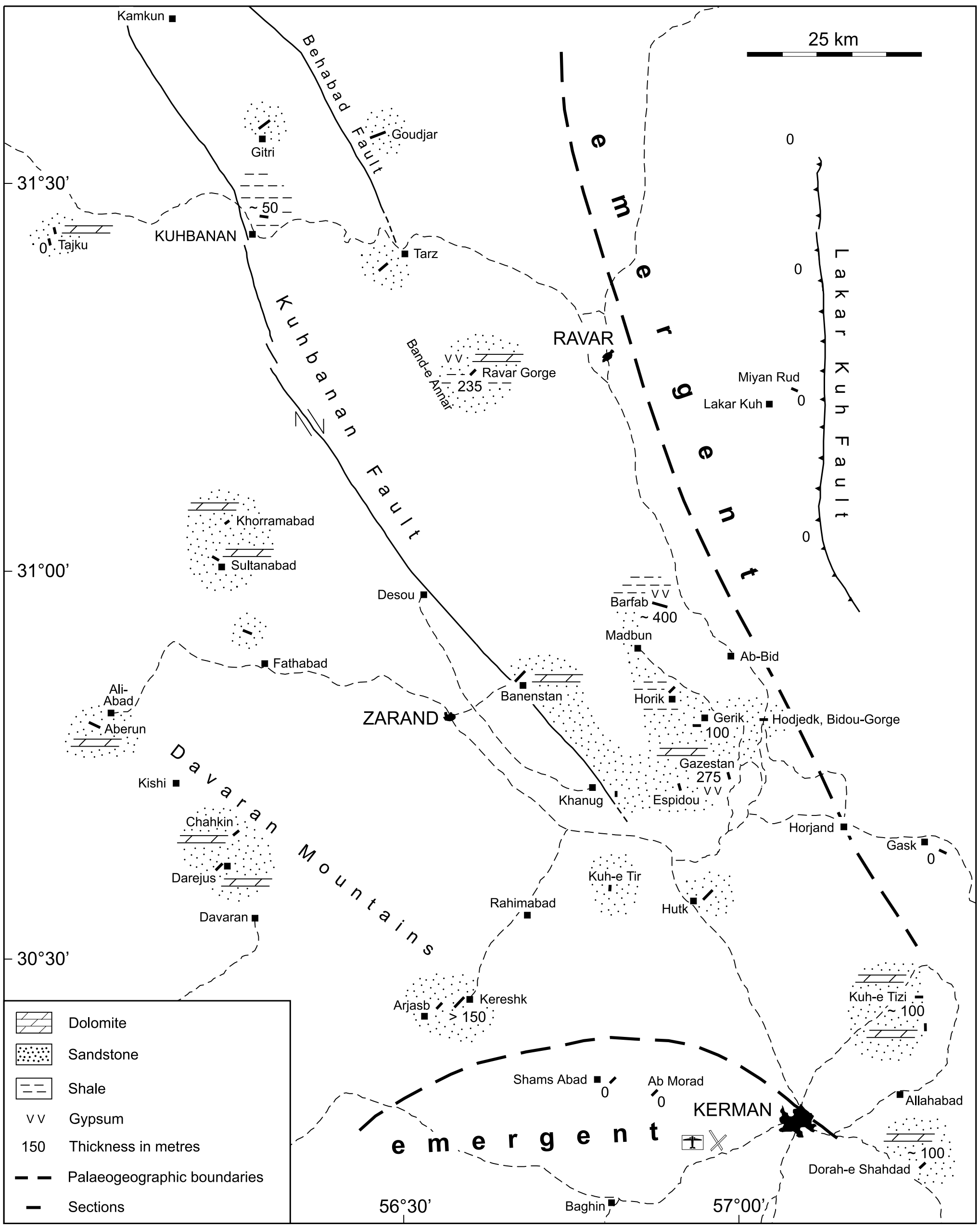

Fig. 15. Lower Devonian (Padeha Formation) facies pattern; for legend see Text-fig. 5

Dolomite of the Derenjal Mountains (WENDT & *al.* 1997). Generally, the dolomite is finely laminated and interspersed with birdseye structures showing deposition in an intertidal environment. In Gerik, this member contains sedimentary breccias and interfingers with grey and reddish quartzitic sandstones. In the SW Davaran Mountains, lithologically similar dolomites appear in the same stratigraphic position but their thickness cannot be assessed because of intense faulting and thrusting. From these few occurrences, the outlines of two carbonate platforms of very limited regional extent and duration (lower Givetian?) can be traced. We assume that in the area of Tarz-Goudjar-Gitri and in the vicinity of the southern platform, red siliciclastics were deposited during the same interval, but biostratigraphic evidence for such a correlation is not available. The Lakar Kuh was still emergent at this time.

Late Middle and Upper Devonian

In post-Padeha- and -Sibzar times a relative rise of sea level flooded the pre-existing carbonate platforms and surrounding siliciclastic shelves (Text-fig. 17). It is

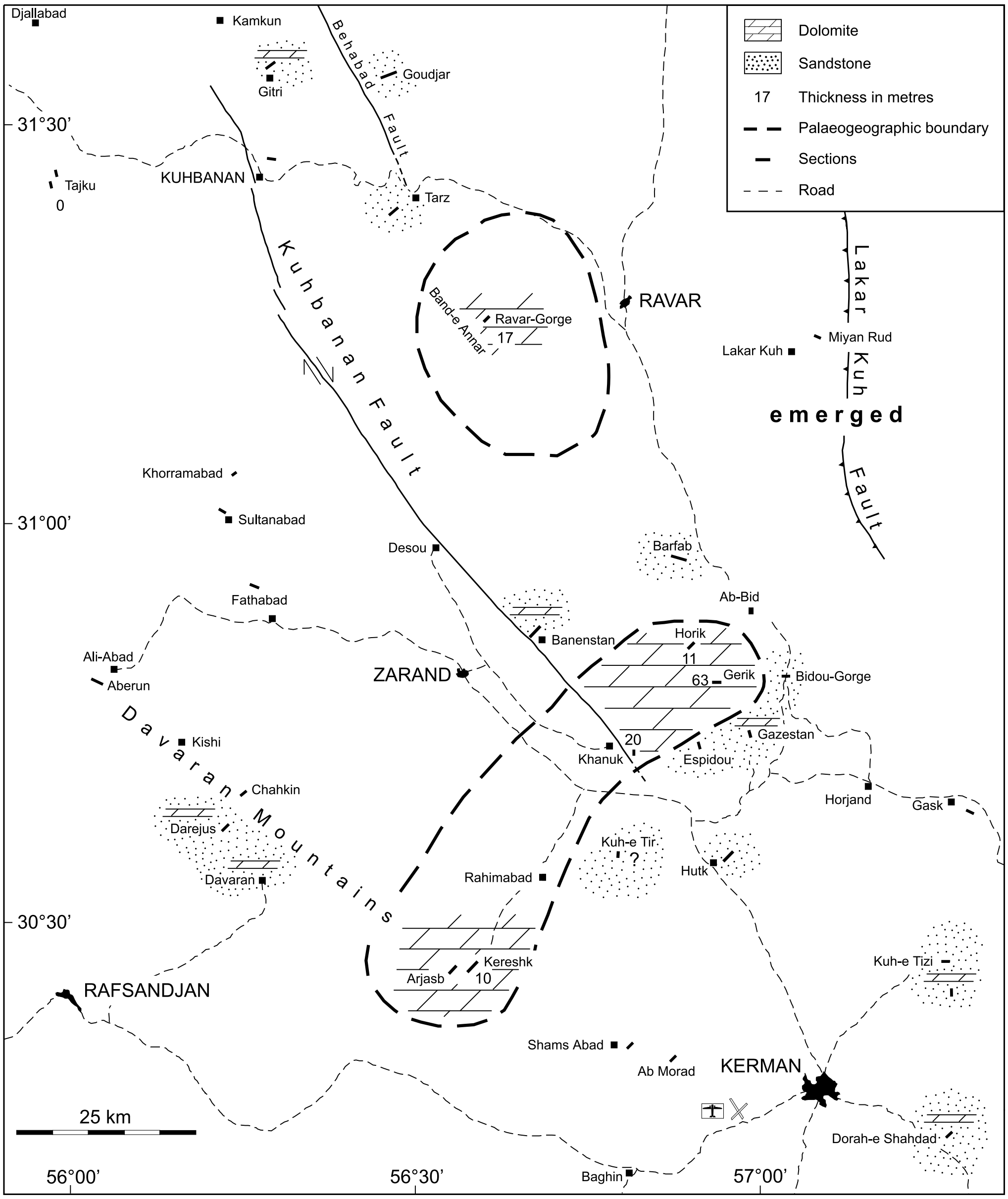

Fig. 16. Lower Givetian (?) (Sibzar Formation) facies pattern; for legend see Text-fig. 5

surprising that, after a long period of nearshore and intertidal conditions during the Early and early Middle Devonian, the onset of open marine conditions appears diachronous. The oldest ages (Eifelian *costatus* to *ensensis* Zone) were obtained from the Kereshk Formation at Shams Abad and Kereshk, whereas samples from a lithostratigraphically similar position at Hutk, Bidou Gorge and Gerik are middle to late Givetian. The transition of the red siliciclastics of the Padeha Formation into grey dolomites, limestones and shales of the Sibzar or Bahram formations is sharp but does not show evidence of a conspicuous break in sedimentation (WENDT & *al.* 1997). During the Frasnian and Famennian an open marine environment was established, documented by skeletal limestones, sandstones, shales, and dolomites. Three zones representing contrasting depositional patterns and environments can be distinguished:

Zone A

In a shallow open marine belt extending from the central Davaran Mountains in the SW towards Hutk in the S to Ravar Gorge and Lakar Kuh in the N, several hundred metres of skeletal pack- and wackestones were

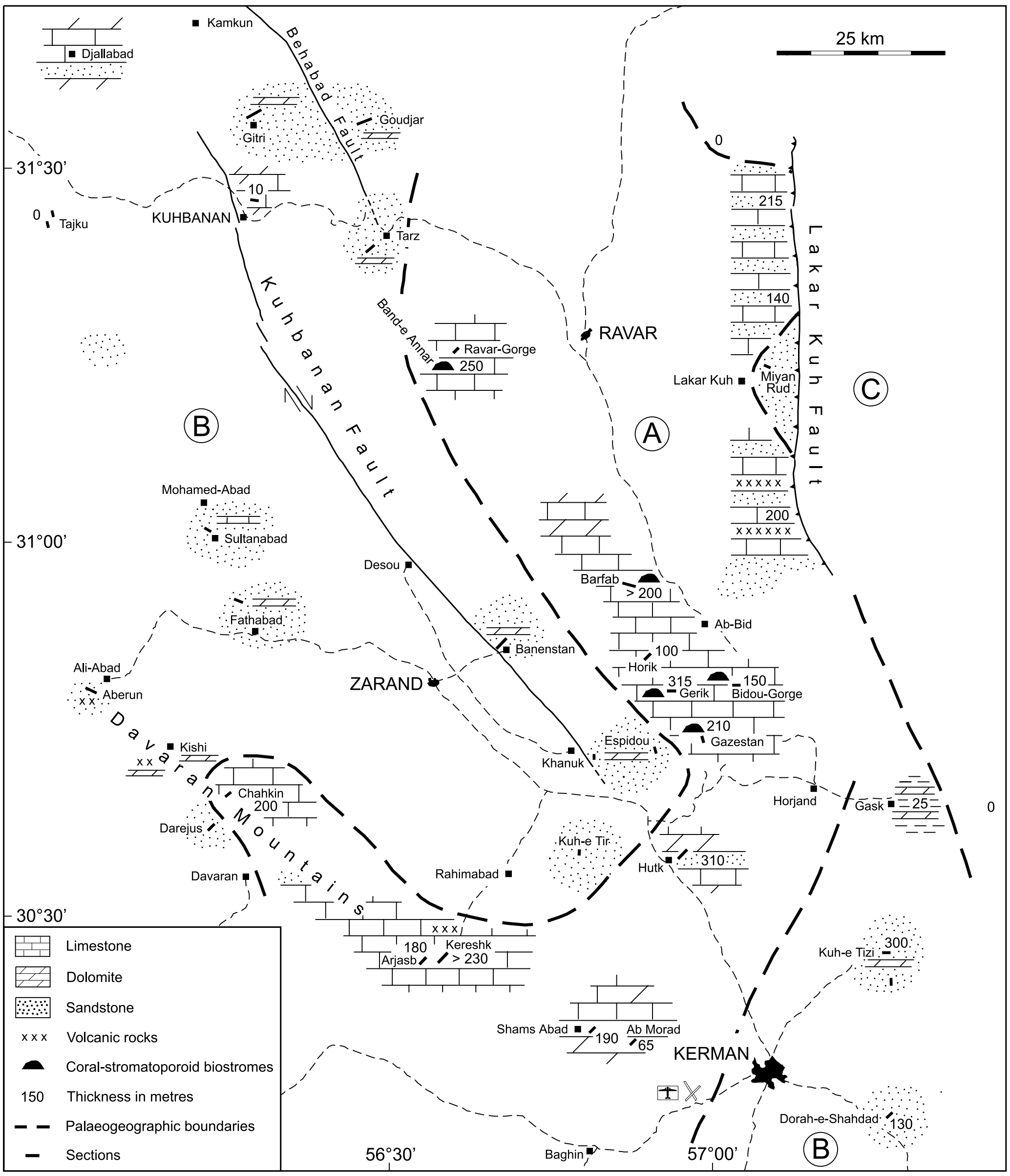

Fig. 17. Upper Givetian to Famennian (Bahram Formation) facies pattern. Lakar Kuh data from KLUYVER & *al.* (1983); for legend see Text-fig. 5

deposited. Conodonts, brachiopods, and tentaculitids permit good biostratigraphic resolution of this interval and show that the sedimentation from the Middle Devonian into the Tournaisian was virtually continuous. Repeated intercalations of quartzose cross-bedded sandstones and intertidal dolomites reflect minor oscillations of sea level which, however, cannot be correlated between neighbouring sections.

Frasnian biostromes

Reports on Devonian buildups in Iran are scarce compared to coeval ones in other parts of the world and show that they are much less prominent though the conditions for reef growth during this period appear favourable. Givetian and Frasnian reef builders are reported from the Elburz Mountains (GHODS 1982, BRICE & *al*. 1974), Isfahan (HAMEDANI 1996), Shirgesht (RUTTNER & *al.* 1968), and the Kerman area (HUCKRIEDE & *al*. 1962; DASTANPOUR 1990, 1996a, b; WENDT & *al*. 1997). BRICE & *al*. (1999) and MISTIAEN (1999) emphasize the affinities of Iranian rugose coral and stromatoporoid faunas to those of Afghanistan, South China, Australia, Europe, and North America. A catalogue of Palaeozoic rugose and tabulate corals from Iran has been compiled by AHMADZADEH HERAVI & KHAKSAR (1999).

In the lower Frasnian of Gazestan, Bidou Gorge (Pl. 7, Fig. 3), Gerik (Pl. 7, Fig. 1) and Barfab, stacked biostromal lenses, each 0.5 to 12 m thick, are developed which in the past were erroneously interpreted as barrier reefs by GOLSHANI & *al*. (1973) or as fore, main and back reefs by DASTANPOUR (1996b). These lenses occur repeatedly through a thickness of 12 to 40 m; only in Ravar Gorge and Barfab they are reduced to a single, 2 m coral-stromatoporoid biostrome. Farther S, the biostromal facies thins out; and at Hutk only one, dm-thin *Cystihexagonaria* bed is present. In Shams Abad a few isolated stromatoporoids and rugose corals but no biostromes were found. This gradual disappearance of the biostromal facies coincides with an increased clastic influx from the S and E. Brachiopod and conodont data indicate that the coral levels of the Kerman area were formed during the early to mid-Frasnian and disappear before the end of the Frasnian thus confirming ages given by BRICE & *al*. (1999).

Some of the most common rugose coral and stromatoporoid taxa were described and figured by ROHART (1999) and MISTIAEN (1999), respectively. They are most abundant and diversified in Gerik and Bidou Gorge and comprise solitary *(Temnophyllum, Macgeea, Sinodisphyllum, Peneckiella*) as well as colonial Rugosa (*Disphyllum, Hexagonaria, Cystihexagonaria*), Tabulata (*Alveolites, Thamnopora*, *Aulopora, Cladochonus*) and hemisperical (*Actinostroma*), lamellar (*Stictostroma*, *Clathrocoilona, Habrostroma*), and dendroid (*Dendrostroma, Stachyodes*) stromatoporoids. The reef builders are partly in place, partly overturned and accumulated, probably by storm events. Generally, a zonation within the biostromal limestones is not recognizeable; only at Bidou Gorge the topmost levels consist of a massive occurrence of dendroid stromatoporoids.

Zone B

East of Kerman and in an embayment W of zone A, i. e. from Gitri – Goudjar in the N to Kuh-e Tir and the western Davaran Mountains in the S, a predominantly siliciclastic facies (Zarand Formation) is developed in the Devonian. This zone has a similar position and direction to the “Bafq-Kerman Ridge” of HUCKRIEDE & *al.* (1962, p. 161) which was assumed to persist from the Ordovician into the Middle Devonian. The Devonian succession consists of almost unfossiliferous red cross-bedded sandstones, siltstones, and shales with some intercalated laminated dolomites and very rare black limestones. Because of the extreme scarcity of reliable biostratigraphic data, correlation with the sequence of zone A is unsatisfactory. The few conodont and brachiopod data indicate Early Devonian to late Famennian/early Tournaisian ages (see above). As a whole, they suggest that the red siliciclastics (upper “Old Red” of HUCKRIEDE & *al*. 1962) are partly coeval with the open marine succession of zone A and include equivalents of the Padeha to Bahram Formations. They represent a nearshore environment with possible local fluvial influence.

The boundaries between zone A and B can only approximately be traced, but nevertheless it is striking that an interfingering between the two contrasting facies belts has not been observed. On the contrary, in some places this boundary appears extremely sharp. This is obvious from neighbouring but extremely different sections such as Gazestan (A) compared to Espidou (B), Hutk (A) compared to Kuh-e Tir (B), Ravar Gorge (A) compared to Tarz (B) and Chahkin (A) compared to Darejus (B). As is evident from geologic maps, this boundary does not coincide with later tectonic lineaments. We therefore assume that transcurrent faults active during the Devonian were responsible for the contrasting facies patterns. The direction of the western limit of zone A is parallel to the Kuhbanan Fault suggesting that the latter may have been active already during the Devonian or earlier. Similar contrasting facies belts which could be traced through a long interval (Middle/Late Cambrian to Early Carboniferous) and seem related to epeirogentic movements, were observed by ALAVI-NAINI (1972) in the Djam region S of the eastern Elburz.

Zone C

In the Lakar Kuh, a predominantly siliciclastic facies with intercalated limestones, attributed to the Upper Devonian Bahram Formation, transgresses over peneplained Middle/Upper Cambrian sandstones and stromatolitic dolomites with a palaeosol at the base (KLUYVER & *al*. 1983). In the central part of the mountain range, the interval of non-deposition may have been even longer; deposits of presumed Early Carboniferous age overlie Cambrian sandstones. Permian Jamal dolomite is in sedimentary contact with Cambrian sandstones 12-20 km E and SE of Gask (sheet Horjand 1 : 100 000). These gaps mark the western margin of an emergent zone in the area of the present Lut Desert where Palaeozoic rocks are not exposed. This land area may have been connected to another one in the southern Zagros Mountains where continental Lower to Upper Devonian or Permian sandstones (Faraghan Formation) overlie Silurian shales (GHAVIDEL-SYOOKI 1994).

Tournaisian

There is no obvious depositional variation at the Famennian/Tournaisian transition (Text-fig. 18). Lower Carboniferous facies patterns, though less precisely

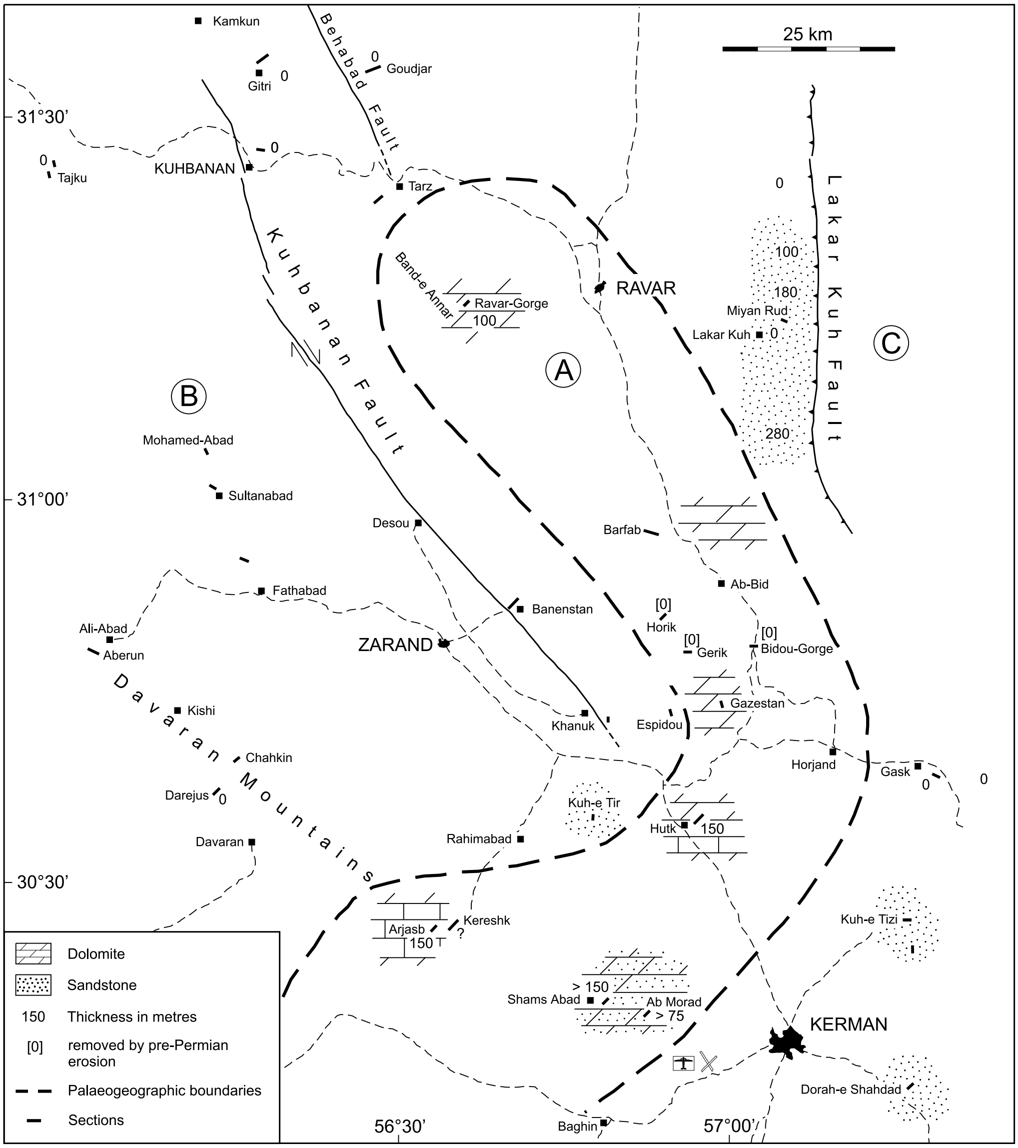

Fig. 18. Tournaisian (Hutk and Sardar Formation) facies pattern; for legend see Text-fig. 5

established biostratigraphically, exhibit similar boundaries compared to those of the Upper Devonian. A new palaeogeographic element is the discrimination of a carbonate platform in zone A during the Tournaisian (Hutk Formation) of which, however, only a few remnants are preserved due to pre-Permian erosion. This platform is well documented in the Hutk section where it consists of intertidal to shallow subtidal dolomites. We assume that similar massive carbonates in a not yet well documented stratigraphic position and with some siliciclastic influx, as in Ravar Gorge, Gazestan, Shams Abad, and Arjasb, are contemporaneous. They indicate an extension of this platform towards N and S.

The upper part of the Zarand Formation in zone B may comprise Lower Carboniferous equivalents as is shown by sparse brachiopods of poorly defined age at Kuh-e Tir. Also in this zone, however, pre-Permian erosion has left only unidentified vestiges of a siliciclastic shelf which extended W and N of the Tournaisian carbonate platform. The Kuhbanan area was continental from the Early Devonian into the late Early Permian, as was the area E and SE of Gask. Cross-bedded sandstones with a palaeosol at the base N and S of Lakar Kuh were deposited close to the shoreline in a proximal deltaic environment.

CONCLUSIONS

During the Palaeozoic, Iran S of the northern Elburz Mountains was a segment of the northern margin of Gondwana and was covered by a serveral km thick discontinuous pile of shallow marine, occasionally fluvial, sediments. The desintegration of this large shelf area began during the Middle Triassic with the closure of the Palaeo-Tethys and the separation and rotation of the Central-East-Iran microplate. Subsequent oceanization and mountain building culminated during several episodes in the Cretaceous and Tertiary. As a result of this fragmentation, Devonian/Lower Carboniferous deposits of the previously coherent shelf are now preserved as tectonically isolated remnants which render delineation of facies patterns and palaeogeographic boundaries extremely difficult. The present work is the first compilation of a great number of new, detailed biostratigraphic data covering the major part of Iran, with the aim to reconstruct the sedimentary history of a hitherto poorly known interval crucial for the understanding of the geotectonic evolution of northern Gondwana. The first part of this work covers an approximately 20 000 km^2 large area in eastern Iran, in which the Devonian/Lower Carboniferous stratigraphy is better documented and facies patterns are more diversified than in the central and northern parts of the country. The second part will include the latter region under the same aspects. The following results have been obtained:

1. 34 sections, the majority of them comprising the time span from the top of the Cambrian into the early Late Permian, were examined and sampled for biostratigraphic and sedimentologic studies.

2. Calibration and correlation of the sections was mostly achieved by conodonts and brachiopds, to a lesser extent by tentaculites, palynomorphs, foraminifera, calcareous algae and some minor groups. Due to the overall paucity or absence of common index fossils, age attributions had partly to be approximate or tentative. Best time resolutions were attained in Givetian to Tournaisian sequences, whereas reliable biostratigraphic data for the Lower and early Middle Devonian are extremely scarce. Therefore, deposits of this age were only locally included in our studies.

3. Throughout Iran a lithostratigraphic division of Devonian/Lower Carboniferous deposits into the following formations (and their local synonyms) is applied which, however, are unsufficiently defined: Padeha (Lower Devonian to Eifelian), Sibzar (lower Givetian? only patchily developed), Bahram (upper Givetian to Famennian), Sardar (Lower Carboniferous). We propose to abandon the term Shishtu Formation (Famennian/Lower Tournaisian) because it cannot be clearly distinguished from the Bahram Formation. The thickness of the Givetian to Tournaisian Bahram and Sardar Formations is highly variable (between 100 and 375 m) and not only reflects the rate of subsidence and accumulation but also the level of the pre-Permian erosion. The boundaries of the formations mentioned above appear diachronous.

4. Two formations are newly introduced: Zarand Formation for a predominantly siliciclastic nearshore development during the Devonian/Lower Carboniferous, and Hutk Formation for a hitherto unrecognized carbonate platform facies of Early Carboniferous age.

5. In most areas the Devonian/Lower Carboniferous sequence is encompassed by two enormous gaps. Red siliciclastics of poorly defined Early to early Middle Devonian age overlie Middle or Upper Cambrian deposits of similar lithology (lower part of the "Old Red") indicating a long interval of emergence which spared only a few remnants of rare Ordovician and, more widespread, Silurian deposits. The top of all studied sequences is marked by the transgression of the Permian

Jamal Formation which has cut down onto different levels of the Frasnian to Tournaisian. This boundary is distinguished by hitherto unrecognized palaeosols, erosional surfaces and local angular unconformities.

6. Spatial distributions of lithofacies and palaeogeographical boundaries were sketched for 5 successive intervals: Silurian (Niur Formation), Early to early Middle Devonian (Padeha Formation), ?early Givetian (Sibzar Formation), late Givetian/Late Devonian (Bahram and Zarand Formations) and Early Carboniferous (Sardar and Hutk Formations). The best documentation has been achieved for the intervals of the late Givetian and the Late Devonian in which three facies belts can be distinguished: (A) an open marine belt characterized by skeletal limestones, (B) a nearshore belt of predominantly red siliciclastics with some intertidal dolomites (Zarand Formation), and (C) a continental area. The sharp boundaries between these belts suggest that they were determined by syndepositional epeirogenetic movements, possibly active since the early Palaeozoic.

7. Despite the palaeo-position of Iran in the southern tropical realm, organic buildups are much less conspicuous than in coeval regions of northern Gondwana. Fringing or barrier reefs are nowhere developed; also carbonate platforms are only of very limited extent. The only vestiges of local reef growth are stratiform biostromes which were constructed during the early to middle Frasnian. They form laterally discontinuous, stacked lenses, up to 12 m thick, which consist of a diversified *in-situ* assemblage of stromatoporoids, tabulate and rugose corals. The decrease of reef builders towards S appears related to an increase of siliciclastic influx from adjacent emergent areas.

8. At various levels, basic volcanics are intercalated in the Upper Devonian and Lower Carboniferous sequence. They occur as a few metres thick sills, but up to 400 m thick lava flows are also reported which manifest a volcanic activity of still poorly precised age.

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Appendix 1: Coordinates of sections (B = base, T = top)

Aberun (I 223)
B: N 30° 48,086'; E 56°03,258'
T: N 30° 48,046; E 58° 03,050'

Arjasb (I 87, I 158)
B: N 30° 26,500'; E 56° 33,335'
T: N 30° 26,360'; E 56° 32,941'

Banenstan (I 29-32, I 222)
B: N 30° 52,058'; E 56° 39,810'
T: N 30° 52,439'; E 56° 40,325'

Barfab (I 225)
B: N 30° 56,049'; E 56° 53,868'
T: N 30° 56,022'; E 56° 53,468'

Bidou Gorge (I 107)
B: N 30° 48,705'; E 57° 01,865'
T: N 30° 48,680'; E 57° 01,450'

Chahkin (I 221)
B: N 30° 40,392'; E 56° 15,770'
T: N 30° 39,758'; E 56° 15,261'

Darejus (I 159)
B: N 30° 36,382'; E 56° 13,598'
T: N 30° 36,560'; E 56° 13,915'

Dorah-e Shahdad (I 99, I 108, I 183)
B: N 30° 13,820'; E 57° 15,811'
T: N 30° 13,738'; E 57° 16,055'

Espidou (I 206)
B: N 30° 43,643'; E 56° 54,178'
T: N 30° 43,836'; E 56° 54,238'

Fathabad (I 220)
B: N 30° 58,849'; E 56° 12,011'
T: N 30° 58,482'; E 56° 12,023'

Gazestan (I 205, I 219)
B: N 30° 43,614', E 56° 58,599'
T: N 30° 43,944'; E 56° 58,612'

Gask (I 218)
B: N 30° 38,694'; E 57° 18,034'
T: N 30° 38,635'; E 57° 18,095'

Gerik (I 27, I 28, I 101, I 114, I 180)
B: N 30° 48,000'; E 56° 56,080'
T: N 30° 48,623'; E 56° 56,151'

Gitri (I 92, I 217)
B: N 31° 32,268'; E 56° 18,526'

Goudjar (I 89, I 213)
B: N 31° 33,360'; E 56° 28,386'
T: N 31° 31,947'; E 56° 28,184'

Hodjedk (I 12, I 26, I 100, I 105, I 106)
B: N 30° 49,500'; E 57° 02,182'

Horik (I 39, I 115)
B: N 30° 51,148'; E 56° 53,292'
T: N 30° 51,310': E 56° 53,472'

Hutk (I 11, I 17, I 38, I 103, I 116, I 149, I 179)
B: N 30° 34,303'; E 56° 56,933'
T: N 30° 34,775'; E 56° 56,978'

Kereshk (I 88, I 117)
B: N 30° 27,064'; E 56° 35,651'
T: N 30° 26,523'; E 56° 35,012'

Khanug (I 182)
B: N 30° 42,755'; E 56° 48,899'
T: N 30° 43,026'; E 56° 48,960'

SE of Khorramabad (I 249, I 250)
B: N 31° 01,784'; E 56° 16,705'

Kuhbanan (I 16, I 34, I 36, I 90, I 119)
B: N 31° 26,613'; E 56° 17,203'

Kuh-e-Kanseh (I 247)
B: N 30° 43,490'; E 57° 00,959'
T: N 30° 43,604'; E 57° 00,454'

Kuh-e Tir (I 150)
B: N 30° 34,910'; E 56° 47,997'

Kuh-e Tizi (I 9, I 37, I 102, I 113, I 155, I 177, I 178)
B: N 30° 27,052'; E 57° 15,308'
M: N 30° 26,911'; E 57° 15,576' (Frasnian)

Kuh-e Tizi S Range (I 157)
B: N 30° 24,932'; E 57° 16,154'

Miyan Rud S (I 215)
B: N 31° 13,995'; E 57° 05,826'
T: N 31° 14,152'; E 57° 05,807'

Miyan Rud N (I 214)
B: N 31° 14,867'; E 57°06,350'
T: N 31° 15,001'; E 57° 06,321'

Mohammed Abad (I 95, I 96, I 97)
B: N 31° 03,563'; E 56° 13,834'

Ravar Gorge (I 201, I 209)
B: N 31° 14,773'; E 56° 36,823'
T: N 31° 14,456'; E 56° 36,168'

Shams Abad E (I 33, I 104, I 211)
B: N 30° 20,877'; E 56° 48,376'
T: N 30° 20,931'; E 56° 47,903'

Shams Abad W (I 111)
B: N 30° 20,625'; E 56° 48,583'

Sultanabad (I 156)
B: N 31° 01,707'; E 56° 13,844'

Tajku (I 121, I 122, I 123, I 124)
I 121: N 31° 25,699'; E 55° 56,464'
I 123: N 31° 24,256'; E 55° 56,821'

Tarz (I 216)
B: N 31° 23,540'; E 56°, 29,285'

Appendix 2: Ages of conodont samples listed in Table 1

Section	Sample no.	Age
Hutk	17/1	Middle Devonian
	38/2B	*timorensis - norrisi*
	103/3	*disparilis - asymmetricus*?
	116/3	upper Givetian / lower Frasnian
	17/3M	Frasnian
	103/19T	Frasnian
	103/27	*triangularis - crepida*
	103/28B	*triangularis - crepida*
	103/30T	Famennian
	38/23B	Famennian
	103/39B	Middle *triangularis - marginifera*
	103/49A	Uppermost *marginifera* - Middle *expansa*
	103/49B	Middle *expansa*
	103/49C	Uppermost Famennian - Tournaisian
	38/28T	Middle *expansa - praesulcata*
	116/8	Tournaisian
	116/14M	Visean
Bidou Gorge	12/4	Givetian
	100/15T	*timorensis - disparilis*
	26/3B	Frasnian Zone 1-2
	12/9	Frasnian
	107/16B	Frasnian Zone 11-13
	107/17	Frasnian Zone 11-13
	107/27	Frasnian Zone 11-13
	107/35	Frasnian Zone 11-13
Gerik	101/15	Givetian
	28/2T	*varcus*
	101/27	Givetian - Frasnian
	27/6	Givetian - Frasnian
	114/7B	Frasnian
	114/6T	Frasnian Zone 11-13
	114/12B	Frasnian
	101/39	Frasnian
Shams Abad	104/3	*costatus - ensensis*
	104/7	Middle or Upper Devonian
	104/15	*costatus - ensensis*
	104/19	*costatus - ensensis*
	104/21	Middle Devonian
	211	uppermost Famennian (?) - Tournaisian
Horik	39/2B	Middle - Upper Devonian
	115/10T	Lower Famennian?
	115/25	Uppermost *marginifera* - Upper *praesulcata*
Kuh-e Tizi	37/9	*varcus - hermanni cristatus*
Arjasb	158/16c	Upper *marginifera - praesulcata*
	158/16a	*marginifera - expansa*
	87/14T	Givetian?
Kereshk	88/5B	*costatus - ensensis*
	117/6T	*trachytera - expansa*
Banenstan	222/1	Silurian
Gazestan	205/39T	Middle *crepida* - Lower *praesulcata*
Kuhbanan	34/16B	Lochkovian
	119/3B	Lochkovian
Fathabad	I 220/5T	upper Llandovery - lower Wenlock
Sultanabad	156/32	Lochkovian
Dorah-e-Shahdad	99/2	Givetian
	108/24	Upper Tournaisian - Lower Visean

Conodont taxa / **Sections**	**Hutk**																	**Hodjedk / Bidou Gorge**							**Gerik**								
Samples	17/1	38/2B	103/3	116/3	38/5B	17/3M	103/19T	103/27	103/28B	38/23B	103/39B	103/49A	103/49B	103/49C	38/28T	116/8	116/14M	100/15T	26/3B	12/9	107/16B	107/17	107/27	107/35	101/15	28/2T	101/27	27/6	114/7B	114/6T	114/12B	101/39	101/49
Icriodus excavatus	●				●	●																											
Icriodus brevis		●	●																														
Icriodus cf. *struvei*		●																															
Icriodus difficilis			●																														
Icriodus expansus			●	●		●													●														
Polygnathus dubius			●																●														
Polygnathus pollocki			●																●														
Icriodus cf. *brevis*				●																													
Icriodus alternatus alternatus							●														●												
Icriodus subterminus						●	●												●		●	●	●	●	●	●	●	●		●		●	●
Polygnathus cf. *P. pennatus*						●																											
Polygnathus zinaidae						●																											
Polygnathus politus							●														●	●							●			●	
Polygnathus webbi							●																●									●	
Polygnathus brevilaminus								●																									
Polygnathus planarius								●																									
Polygnathus aff. *P. evidens*								●																									
Polygnathus cf. *cornutus*								●	●																								
Icriodus cornutus										●	●																						
Peleksygnathus inclinatus										●																							
Polygnathus ancyrognathoideus											●																						
Pandorinellina cf. *insita*												●	●																				
Pelekysgnathus brevis												●																					
Bispathodus aculeatus aculeatus													●		●																		
Bispathodus aculeatus plumulus													●																				
Bispathodus costatus													●																				
Pseudopolygnathus brevipennatus													●																				
Polygnathus communis communis														●																			
Clydagnathus cavusformis															●																		
Polygnathus inornatus																●																	
Cavusgnathus naviculus																	●																
Polygnathus xylus																		●							●								
Ancyrodella pristina																			●														
Polygnathus cf. *P. politus*																			●				●		●	●	●	●					
Polygnathus cf. *P. aspelundi*																				●				●			●		●	●			
Polygnathus aequalis																										●	●						
Icriodus symmetricus																											●						
Polygnathus elegantulus																											●						
Polygnathus alatus																												●			●	●	

Tab.1. Composition and occurrence of conodont faunas in Text-figs 5-8, 10-13. Abbreviations: K. T. = Kuh-e Tizi, Ker. = Kereshk, Ba. = Banenstan, Ga. = Gazestan, Kuh. = Kuhbanan, Su. = Sultanabad, D. S. = Dorah-e Shahdad.

Conodont taxa / **Sections**	**Shams Abad**							**Horik**			**K.T.**		**Arjasb**			**Ker.**		**Ba.**	**Ga.**	**Kuh.**		**Su.**	**D.S.**	
Samples	104/3	104/7	33/4T	104/15	104/19	104/21	211	39/2B	115/10T	115/25	37/9	113/33	87/14T	158/16a	158/16c	88/5B	117/6T	222/1	205/39T	34/16B	119/13B	156/32	99/2	108/24
Icriodus regularicrescens	●																							
Polygnathus linguiformis ssp.	●	●									●													
Icriodus cf. *I. excavatus*			●																					
Polygnathus angustipennatus				●	●											●								
Icriodus cf. *struvei*				●	●	●										●								
Polygnathus eiflius					●																			
Polygnathus inornatus							●																	
Clydagnathus cavusformis							●																	
Icriodus sp. A								●																
Icriodus subterminus									●															
Pelekysgnathus sp. A									●															
Pandorinellina cf. *insita*										●				●			●							
Pelekysgnathus inclinatus										●					●									
Polygnathus cf. *P. longiposticus*										●									●					
Icriodus excavatus											●													
Polygnathus semicostatus														●	●				●					
Polygnathus xylus											●		●											
Hindeodus sp.												●												
Icriodus cornutus																	●							
Polygnathus nodocostatus																	●							
Ozarkodina sp.																		●						
Eognathodus sp.																				●	●	●		
Cavusgnathus cf. *C. convecsus*																								●
Polygnathus bischoffi																								●
Polygnathus communis communis																								●

Tab.1. (continued) Composition and occurrence of conodont faunas in Text-figs 5-8, 10-13. Abbreviations: K. T. = Kuh-e Tizi, Ker. = Kereshk, Ba. = Banenstan, Ga. = Gazestan, Kuh. = Kuhbanan, Su. = Sultanabad, D. S. = Dorah-e Shahdad.

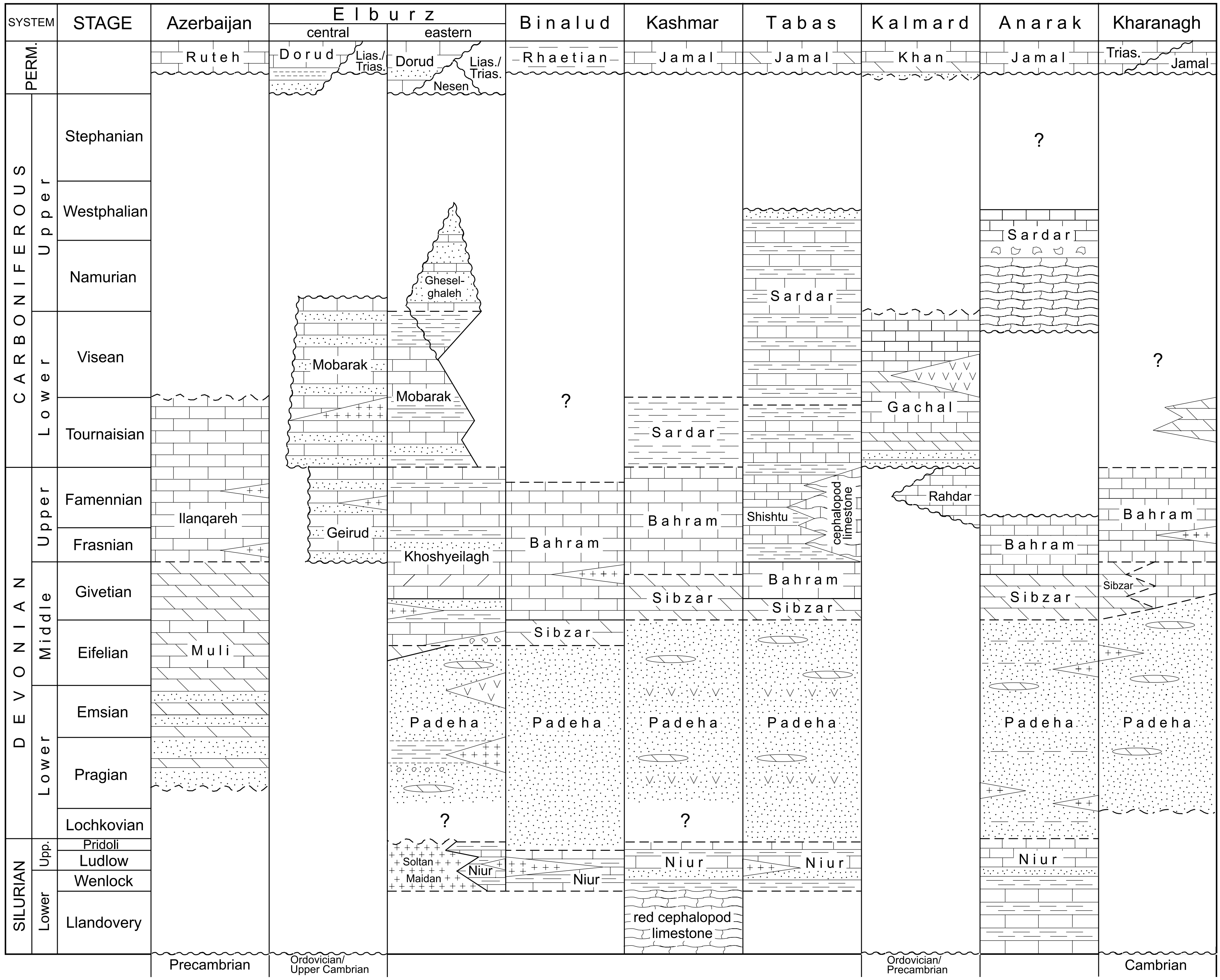

Fig. 2. Synoptic view of Silurian to Permian lithostratigraphic formations in Iran. The Tabas column comprises Ozbakh-Kuh, Sirgesht Mountains and Shotori Range. Based on all available sources (publications, geological maps) and own data. For legend see Text-fig. 5. Broken lines indicate uncertain boundaries. Lithologies within individual formations are arbitrary

PLATE 1

1 – The recumbant anticline near Hutk. In the core overturned red beds of the Padeha Formation (P) crop out. They are overlain by skeletal limestones, shales, dolomites and sandstones of the Bahram Formation (B). The white band (arrow) is a 6 m bed of quartzite (bed 47 in Text-fig. 5). The steep face of the mountain up to the crest is formed by dark oolites of the upper Bahram Formation (no. 49 in Text-fig. 5).

2 – The Gazestan section seen from the W. The reddish-weathering beds on the right slope are Bahram (B) and Hutk Formation (H), capped, with angular unconformity (arrow) by dolomites of the Permian Jamal Formation (J). Compare Text-fig. 6.

3 – The southern termination of Kuh-e-Kanseh, 3 km E of the Gazestan section. The upper portion of the foothills are occupied by red beds of the Padeha Formation (P) terminating with a white quartzite. Both base and top of the Bahram Formation (B) are distinct lithologic boundaries (arrows). The crest of the mountain is formed by Permian Jamal dolomites (J).

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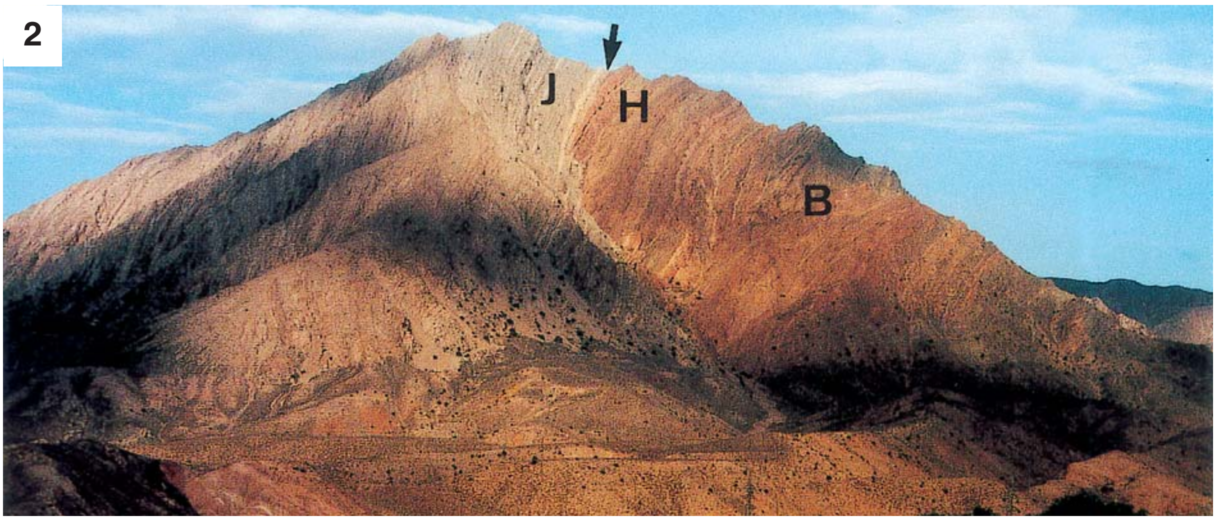

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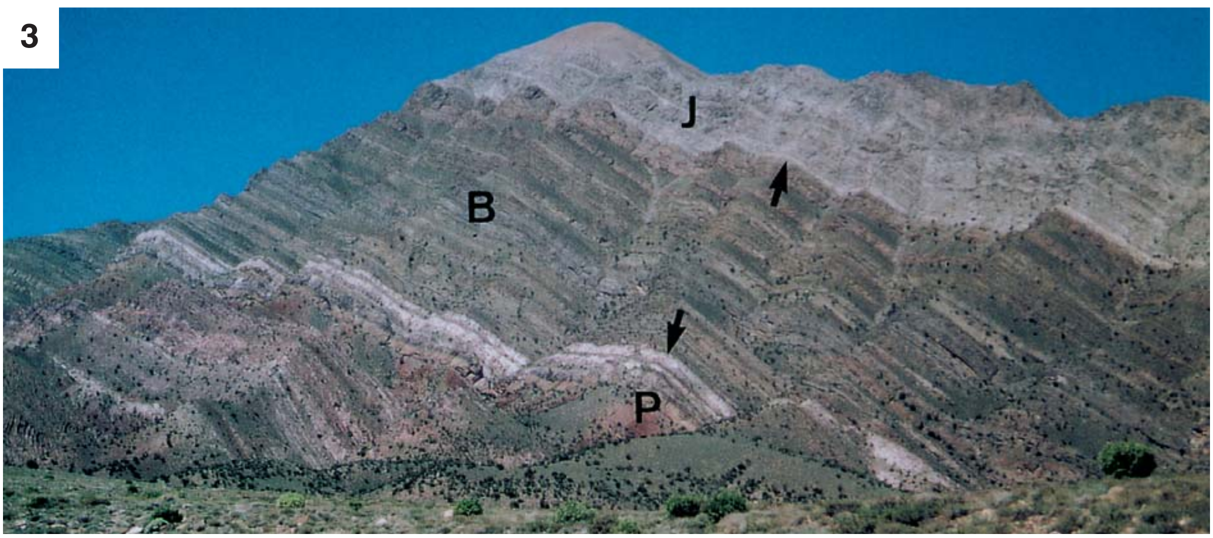

PLATE 2

1 – The western face of the Gerik monocline. Cambrian red clays (C) behind the village of Shahzadeh Mohammad are overlain by Padeha (P) and Sibzar Formation (S) followed by Bahram Formation (B). The right peak consists of Permian Jamal Formation. Compare Text-fig. 6.

2 – The NE flank of Band-e Annar, 17 km W of Ravar (NW of Ravar Gorge). The foothills are Cambrian "Old Red" (C) overlain by Padeha (P) and Bahram Formation (B). Compare Text-fig. 8.

3 – Ravar Gorge. Upper part of the Padeha Formation (P) with gypsum levels (g, no. 9 in Text-fig. 8), overlain by ?Sibzar dolomite (S, no. 10 in Text-fig. 8).

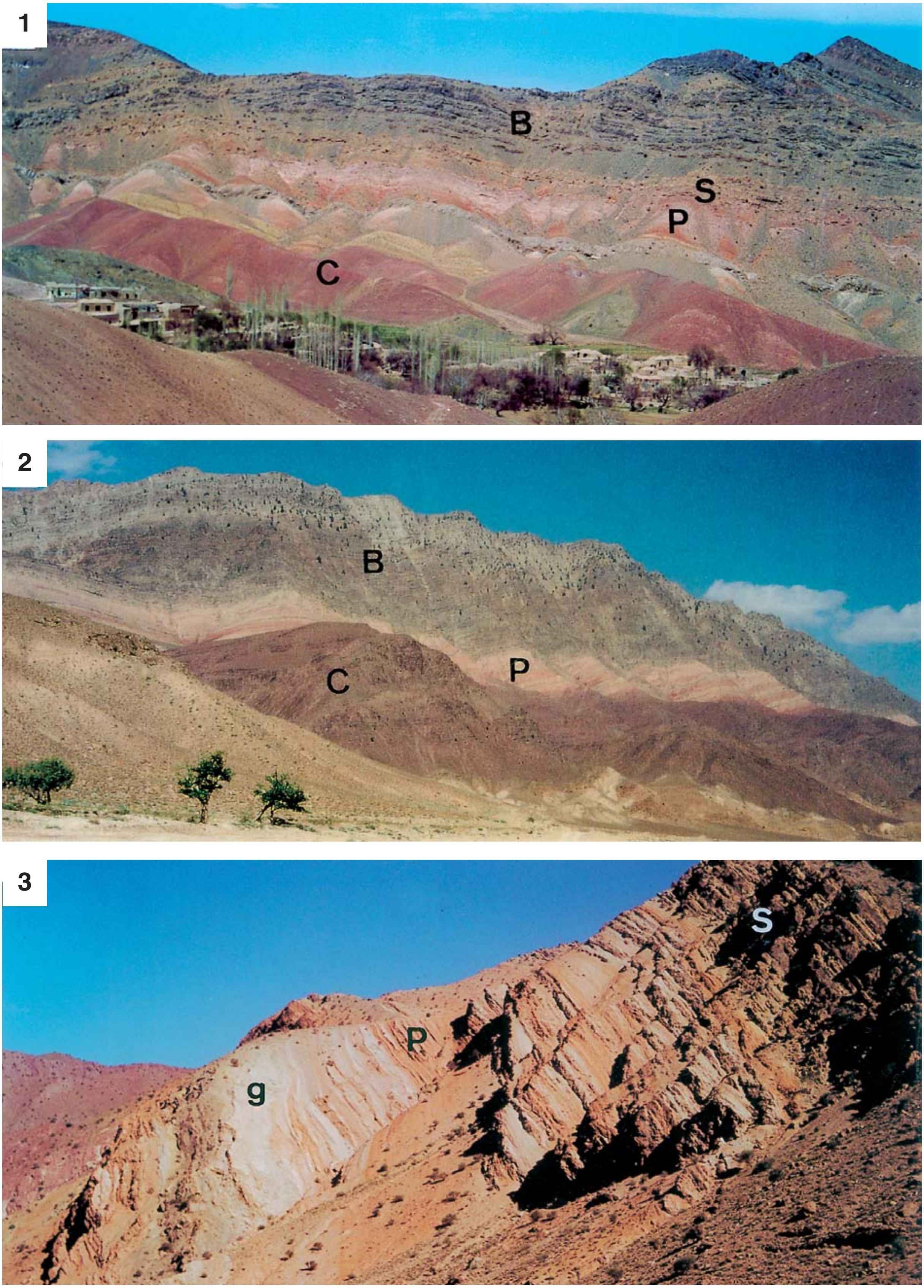
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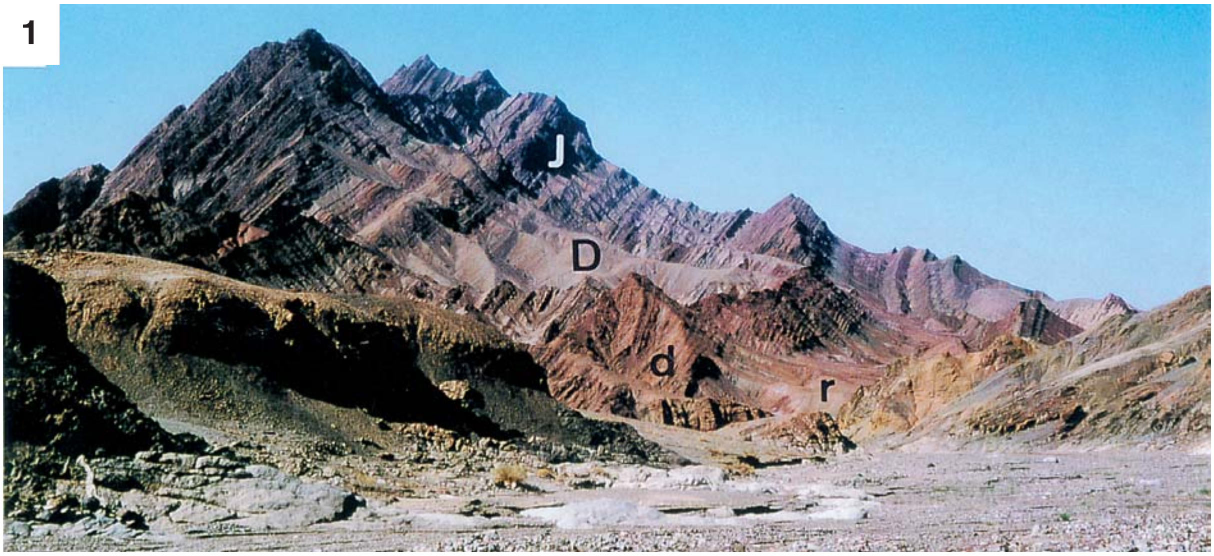
PLATE 3

1 – The Miyan Rud N section in the central part of the monocline of Lakar Kuh. At the base red beds (r) and dolomites with stromatolites (d) of the Cambrian Derenjal (?) Formation, in the centre Devonian/Lower Carboniferous(?) quartzites and shales (D), erosionally capped by Permian Jamal dolomite (J). Compare Text-fig. 9.

2 – The Shams Abad E section. Skeletal limestones (l) and dolomites (d) of the Middle/Upper Devonian Bahram Formation level a relief on top of Infra-Cambrian rhyolites (C). The crest of the mountain consists of well-bedded dolomites of the Lower Carboniferous Hutk Formation (H). Compare Text-fig. 10.

3 – The Silurian to Permian sequence 3 km E of Khanug. The ridge in the right centre is Silurian Niur Formation (N) overlain by red beds of the Zarand (Padeha) Formation (Z) truncated in turn by Permian Jamal dolomite (J) with a palaeosol at the base.

1



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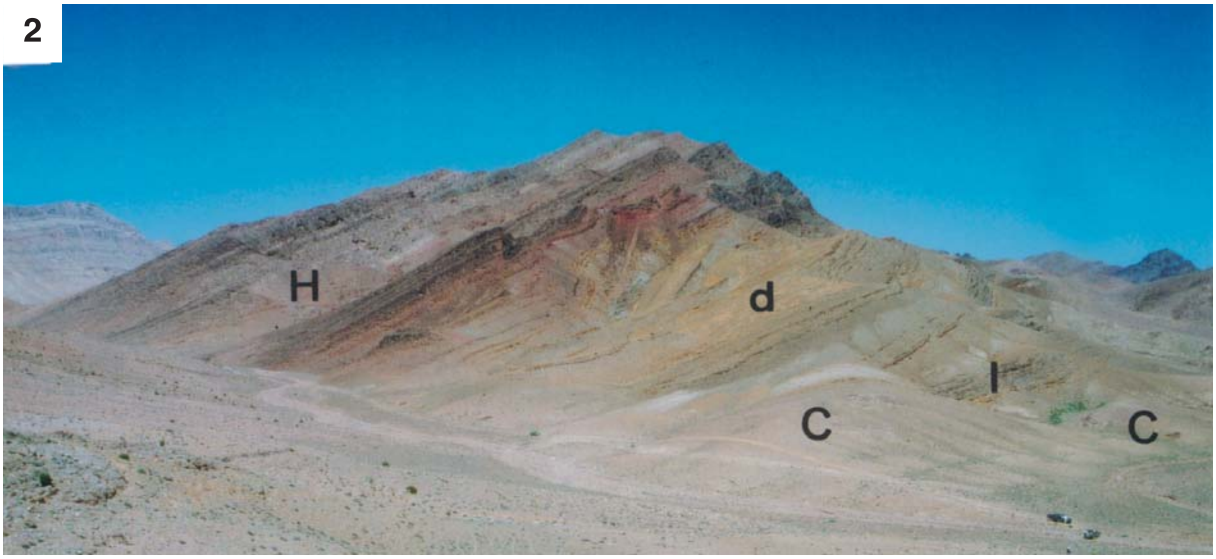

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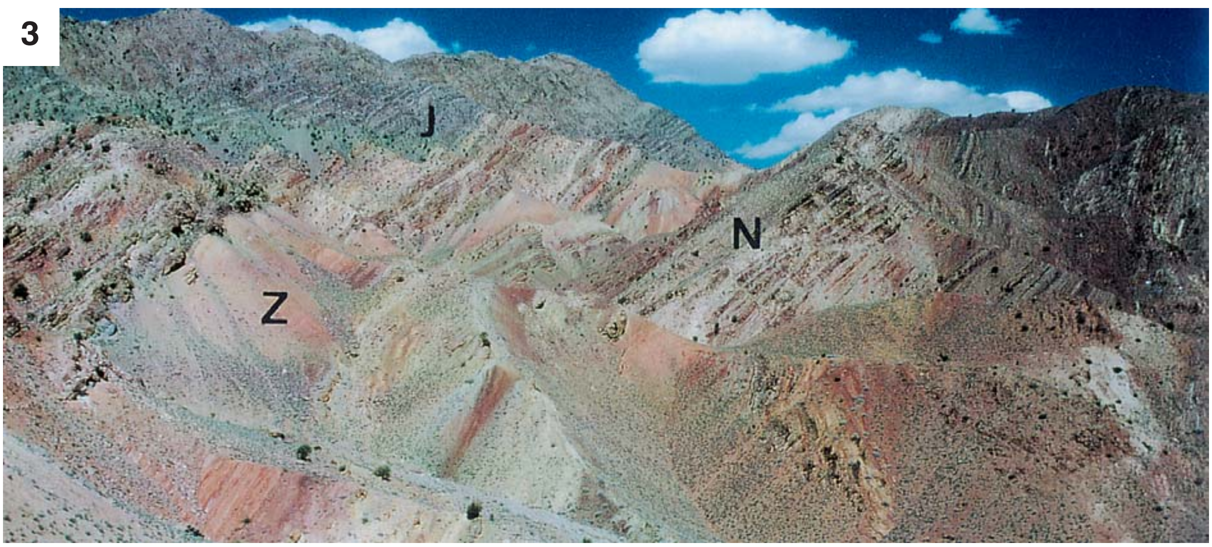

PLATE 4

1 – Section near the village of Banenstan. N = limestones and dolomites of the Niur Formation, Z = Zarand Padeha) Formation capped by Permian Jamal dolomite (J) with a palaeosol at the base. Compare Text-fig. 11.

2 – Type section of the Zarand Formation at Kuh-e Tizi. The prominent crest in the centre (C) is the assumed top of the Cambrian (unit 2 in Text-fig. 12), capped (arrow) by shales, sandstones and dolomites of the Zarand Formation (Z) with a distinct dolomite ridge (d) in the upper part (unit 26 in Text-fig. 12). The steep face of the ridge consists of Permian Jamal dolomite (J).

3 – Angular unconformity (arrowed) between Cambrian (including parts of the Devonian/Lower Carboniferous Zarand Formation?) red beds (C) and well-bedded dolomites of the Permian Jamal Formation (J) exhibiting a pronounced cyclicity. 1 km SW of Tajku (I 121).

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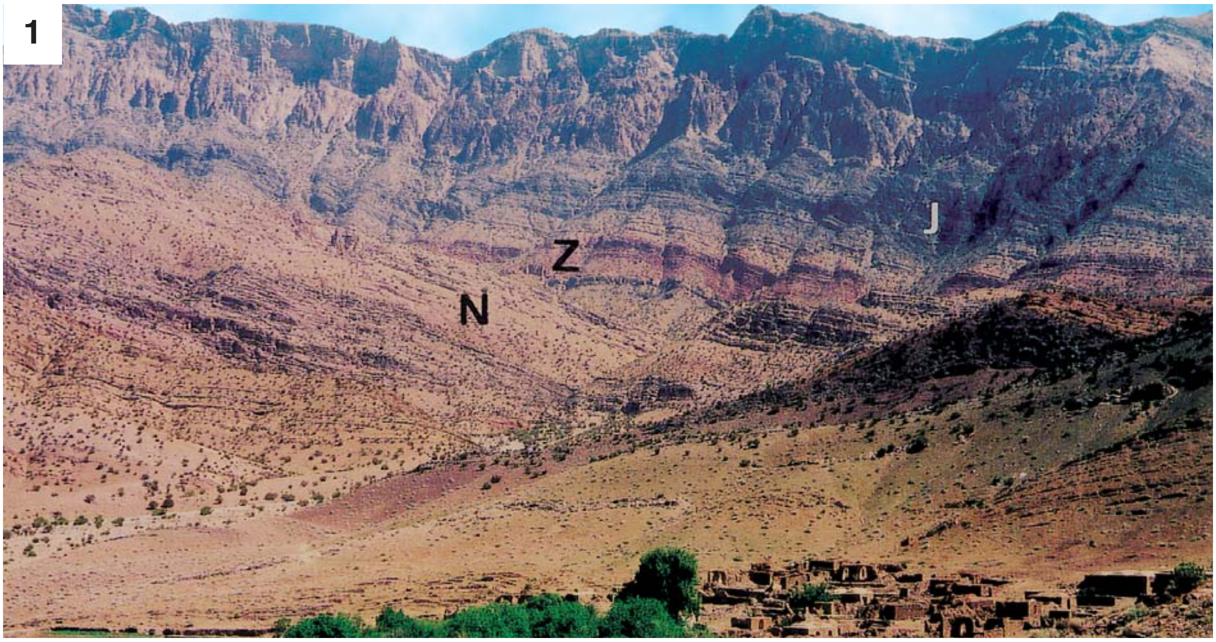

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PLATE 5

1 – Dolomitic bonebed with placoderm fragment (centre), phosphatized shell debris (dark rodlets) and subangular quartz grains (white spots) from unit 8 of the Dorah-e Shahdad section (Text-fig. 12). Zarand Formation (Givetian/lower Frasnian). Thin section no. 99/2.

2 – Poorly washed grainstone with brachiopod, crinoid and gastropod debris showing micritic envelopes (arrowed) from unit 49 of the Bidou Gorge section (Text-fig. 6). Bahram Formation (Frasnian Zone 11-13). Thin section no. 107/30a.

3 – Brachiopod-crinoid grainstone from unit 8 of the Hodjedk section (Text-fig. 6). Note algal (?) perforations (left arrow) and microbial crust on brachiopod shell (right arrow). Lower Bahram Formation (upper Givetian). Thin section no. 100/8.

4 – Grainstone with bone fragment (centre), micritic envelopes on recrystallized mollusc debris and *Umbellina* (arrowed) from unit 27 of the Kuh-e Tizi section (Text-fig. 12). Zarand Formation (Upper Devonian). Thin section no. 102/22.

5 – Packstone with mollusc, brachiopod and crinoid debris from unit 49 of the Bidou Gorge section (Text-fig. 6). Bahram Formation (Frasnian Zone 11-13). Thin section no. 107/30b.

6 – Fragment of trilobite carapace with canaliculi from unit 8 of the Hodjedk section (Text-fig. 6). Lower Bahram Formation (upper Givetian). Thin section no. 100/8.

7 – Partly dolomitized crinoid-brachiopod packstone from unit 57 of the Gerik section (Text-fig. 6). Bahram Formation (lower Famennian). Thin section no. 114/21.

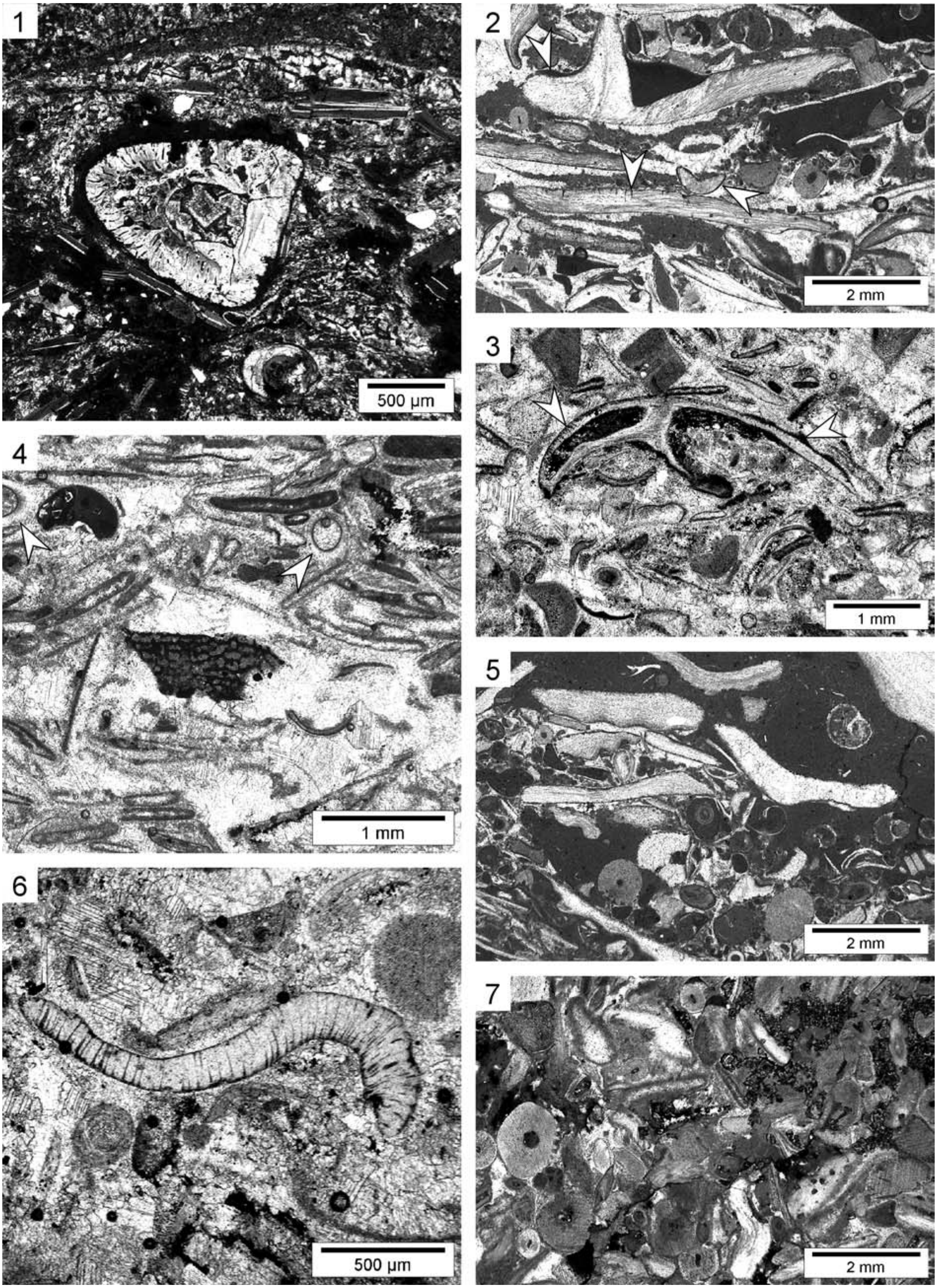
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Plate 6

1 – Peloidal wackestone with *Umbellina* from unit 43 of the Gerik section (Text-fig. 6). Bahram Formation (upper Frasnian). Thin section no. 101/43.

2 – Wackestone with pelecypod debris and large intraclast from unit 15 of the Shams Abad section (Text-fig. 10). Ooids are common in both the intraclasts and in the matrix. Kereshk Formation (Eifelian). Thin section no. 104/15.

3 – Grainstone with grain aggregates, intraclasts and ooids from unit 54 of the Bidou Gorge section (Text-fig. 6). Topmost layer of the Bahram Formation (Frasnian Zone 11-13). Thin section no. 107/35T.

4 – Allochthonous ooids in peloid-intraclast grainstone from unit 49 of the Hutk section (Text-fig. 5). Upper Bahram Formation (upper Famennian). Thin section no.103/49b.

5 – Cone-in-cone current-accumulated tentaculitids (centre), bryozoans (arrowed) and productid spine (upper right) from unit 50 of the Gerik section (Text-fig. 6). Bahram Formation (upper Frasnian). Thin section no. 101/50a.

6 – Recrystallized mud/wackestone with sparse crinoids (arrowed). Numerous microstylolites give the rock a laminated appearance. Unit 13 of the Kereshk section (Text-fig. 10). Bahram Formation (upper Famennian). Thin section no. 117/1.

7 – Palaeosol consisting of subrounded quartz grains in a hematitic matrix with large pisoids from unit 61 of the Gerik section (Text-fig. 6) marking the boundary between the Bahram Formation (lower Famennian) and the Jamal Formation (Permian). Compare Pl. 7, Fig 7. Thin section no. 180/2b2.

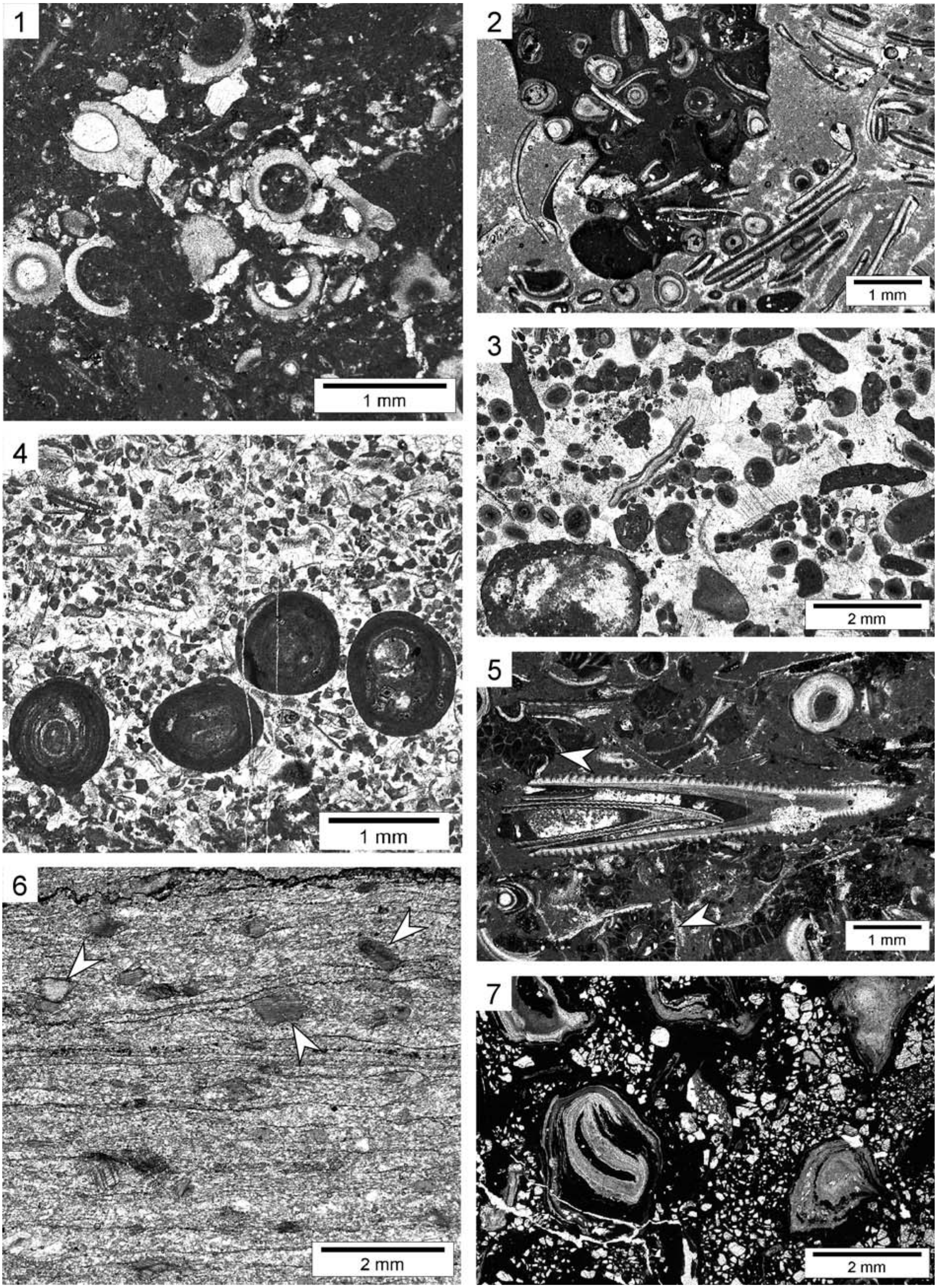
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Plate 7

1 – Naturally weathered surface near base of biostrome (unit 23 in Text-fig. 6) with storm or current accumulated fragments of solitary rugose corals (cf. *Temnophyllum*). Bahram Formation (lower Frasnian), Gerik section. Sample no. 101/23.

2 – Current-oriented tentaculitids on naturally weathered bedding plane of nodular limestone overlying biostrome of Gerik section (unit 31 in Text-fig. 6). Bahram Formation (Frasnian Zone 11-13). Sample no. 27/6.

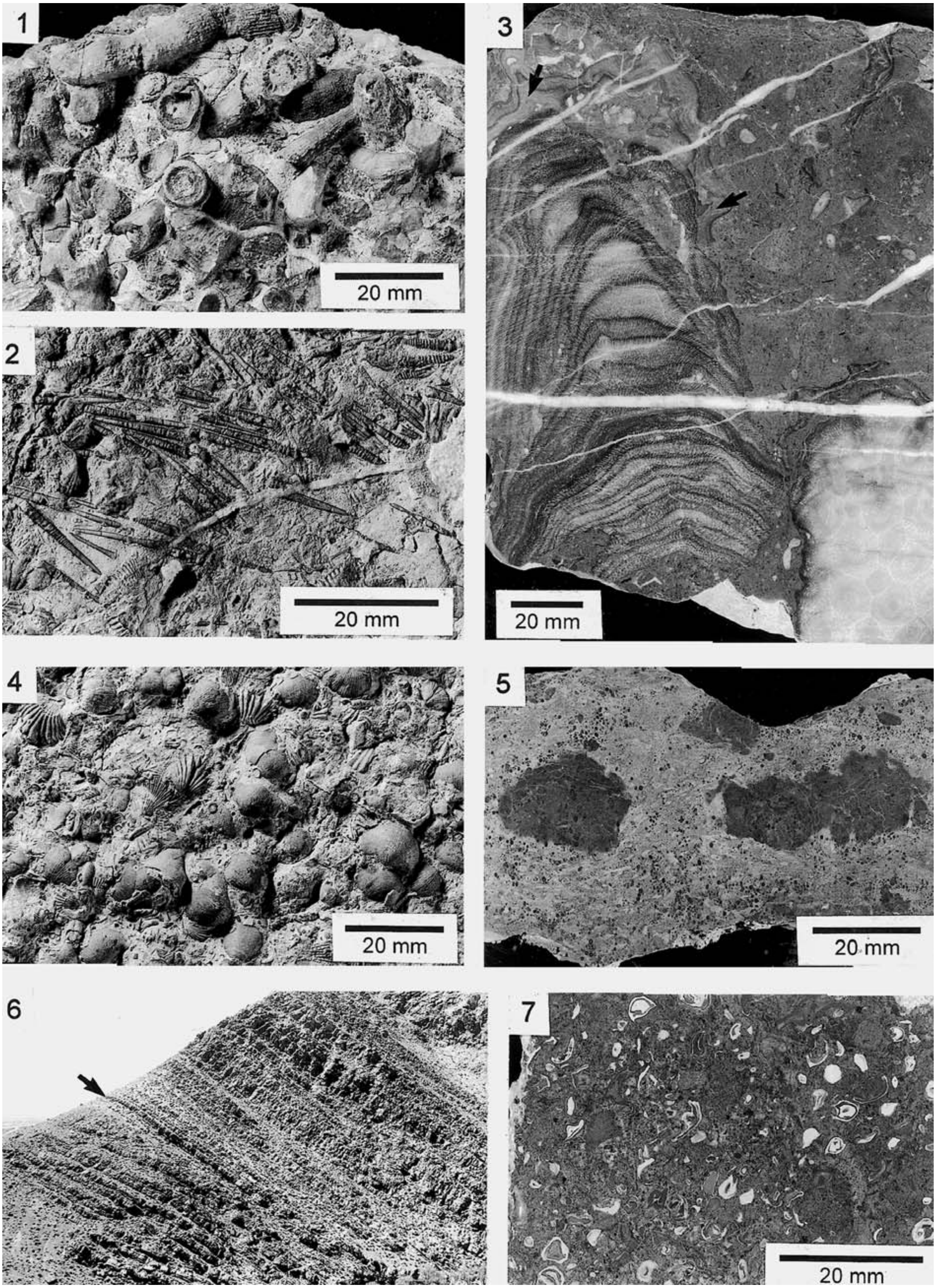
3 – Polished slab of biostromal framestone with *Cystihexagonaria* (bottom right) and *Alveolites* (left) with seasonal (?) growth increments. The tabulate coral is encrusted by a stromatoporoid (arrows). The interstice between the frame-builders (top right) consists of skeletal wacke- to floatstone. Unit 28 of Bidou Gorge section (Text-fig. 6). Bahram Formation (lower Frasnian). Sample no. 107/9.

4 – Naturally weathered surface of brachiopod coquina with numerous spiriferids (*Tylothyris*) and strophomenids (*Schwellwienella*). Middle part of unit 52 of the Hutk section (Text-fig. 5). Sardar Formation (Tournaisian). Sample no. 149/2.

5 – Polished slab of dolomitzed wackestone with large lithoclasts (dark), ooids and *Umbellina*, all reworked from underlying upper Frasnian oolite. Unit 55 of the Bidou Gorge section (Text-fig. 6). Base of Jamal Formation (Permian). Sample no. 107/36a.

6 – Angular unconformity (arrowed) between the Frasnian Bahram Formation (below) and the Permian Jamal dolomite (above). Mouth of Bidou River opposite the Bidou Gorge section (Text-fig. 6). Trees on right lower margin (asterisk) are about 3 m high.

7 – Polished slab of hematitic palaeosol with pisoids (white) marking the boundary between the lower Famennian Bahram Formation and the Permian Jamal Formation. Unit 61 of Gerik section (Text-fig. 6). Compare Pl. 6, Fig. 7. Sample no. 180/2b.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