# The geology and petroleum potential of the North Afghan platform and adjacent areas (northern Afghanistan, with parts of southern Turkmenistan, Uzbekistan and Tajikistan)

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# The geology and petroleum potential of the North Afghan platform and adjacent areas (northern Afghanistan, with parts of southern Turkmenistan, Uzbekistan and Tajikistan)

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**Abstract**

The North Afghan platform has a pre-Jurassic basement unconformably overlain by a Jurassic to Paleogene oil- and gas-bearing sedimentary rock platform cover, unconformably overlain by Neogene syn- and post-orogenic continental clastics.

The pre-Jurassic basement has four units: (1) An ?Ordovician to Lower Devonian passive margin succession developed on oceanic crust. (2) An Upper Devonian to Lower Carboniferous (Tournaisian) magmatic arc succession developed on the passive margin. (3) A Lower Carboniferous (?Visean) to Permian rift–passive margin succession. (4) A Triassic continental magmatic arc succession.

The Mesozoic–Palaeogene cover has three units: (1) A ?Late Triassic to Middle Jurassic rift succession is dominated by variable continental clastics. Thick, coarse, lenticular coal-bearing clastics were deposited by braided and meandering streams in linear grabens, while bauxites formed on the adjacent horsts. (2) A Middle to Upper Jurassic transgressive–regressive succession consists of mixed continental and marine Bathonian to Lower Kimmeridgian clastics and carbonates overlain by regressive Upper Kimmeridgian–Tithonian evaporite-bearing clastics. (3) A Cretaceous succession consists of Lower Cretaceous red beds with evaporites, resting unconformably on Jurassic and older deposits, overlain (usually unconformably) by Cenomanian to Maastrichtian shallow marine limestones, which form a fairly uniform transgressive succession across most of Afghanistan. (4) A Palaeogene succession rests on the Upper Cretaceous limestones, with a minor break marked by bauxite in places. Thin Palaeocene to Upper Eocene limestones with gypsum are overlain by thin conglomerates, which pass up into shales with a restricted brackish-water ?Upper Oligocene–?Lower Miocene marine fauna.

The Neogene succession consists of a variable thickness of coarse continental sediments derived from the rising Pamir mountains and adjacent ranges. Almost all the deformation of the North Afghan platform began in the Miocene.

Oil and gas traps are mainly in Upper Jurassic carbonates and Lower Cretaceous sandstones across the entire North Afghan block. Upper Jurassic carbonate traps, sealed by evaporites, occur mainly north of the southern limit of the Upper Jurassic salt. Lower Cretaceous traps consist of fine-grained continental sandstones, sealed by Aptian–Albian shales and siltstones. Upper Cretaceous–Palaeocene carbonates, sealed by Palaeogene shales are the main traps along the northern edge of the platform and in the Tajik basin.

Almost all the traps are broad anticlines related to Neogene wrench faulting, in this respect, like similar traps along the San Andreas fault. Hydrocarbon sources are in the Mesozoic section. The Lower–Middle Jurassic continental coal-bearing

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beds provide about 75% of the hydrocarbons; the Callovian–Oxfordian provides about 10%; the Neocomian a meagre 1%, and the Aptian–Albian about 14%. The coal-bearing source rocks decrease very markedly in thickness southwards cross the North Afghan platform.

Much of the hydrocarbon generation probably occurred during the Late Cretaceous–Paleogene and migrated to structural traps during Neogene deformation.

Since no regional structural dip aids southward hydrocarbon migration, and since the traps are all structural and somewhat small, then there is little chance of very large petroleum fields on the platform. Nevertheless, further studies of the North Afghan platform should be rewarding because: (a) the traps of strike–slip belts are difficult to find without detailed exploration; (b) the troubles of the last 20 years mean that almost no exploration has been done; and, (c) conditions may soon become more favorable. There should be ample potential for oil, and particularly gas, discoveries especially in the northern and western parts of the North Afghan platform. 

*Keywords:* North Afghan platform; geology; petroleum

## 1. Introduction

The North Afghan platform forms the Parapamisus and western Hindu Kush mountains and high plains of the Amu Darya basin, lying in northern Afghanistan and the southern parts of Turkmenistan, Uzbekistan and Tajikistan (Fig. 1). On this platform, relatively undeformed mostly clastic Jurassic to Recent sediments overlying deformed Triassic and older rocks (Fig. 2). On the south and east, the platform is sharply defined by the Harirud strike–slip and related faults (marked by the line of the Harirud and Pansjer rivers) (Sborshchikov et al., 1974). On the north and north–west, geophysics and borehole records show a gradual passage into the Murghab and Tadjik basins, filled with dominantly clastic Mesozoic–Quaternary sediments (Kingston and Clarke, 1995). These basins separate the North Afghanistan platform from the Turan platform of southern Eurasia, with which it is often grouped

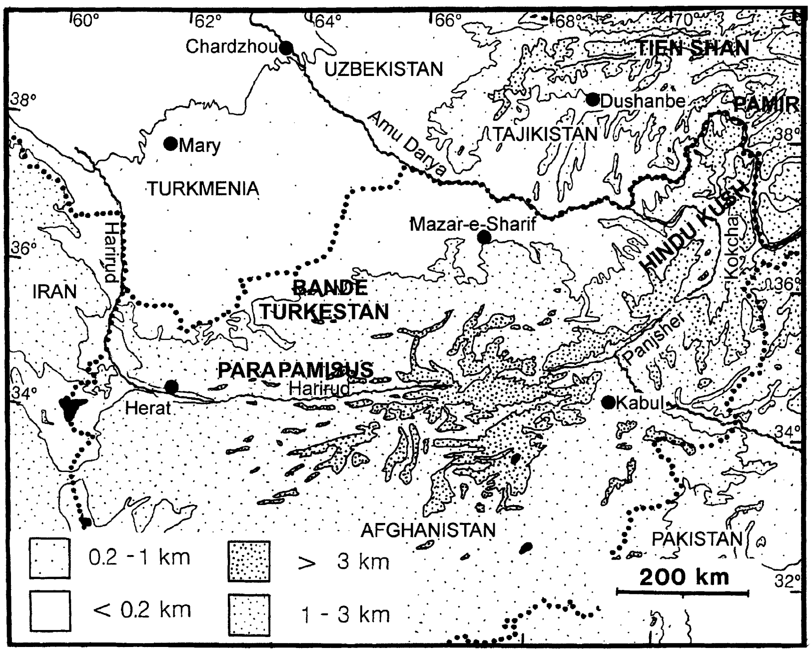


Fig. 1. Topographic and geographic name map of area.

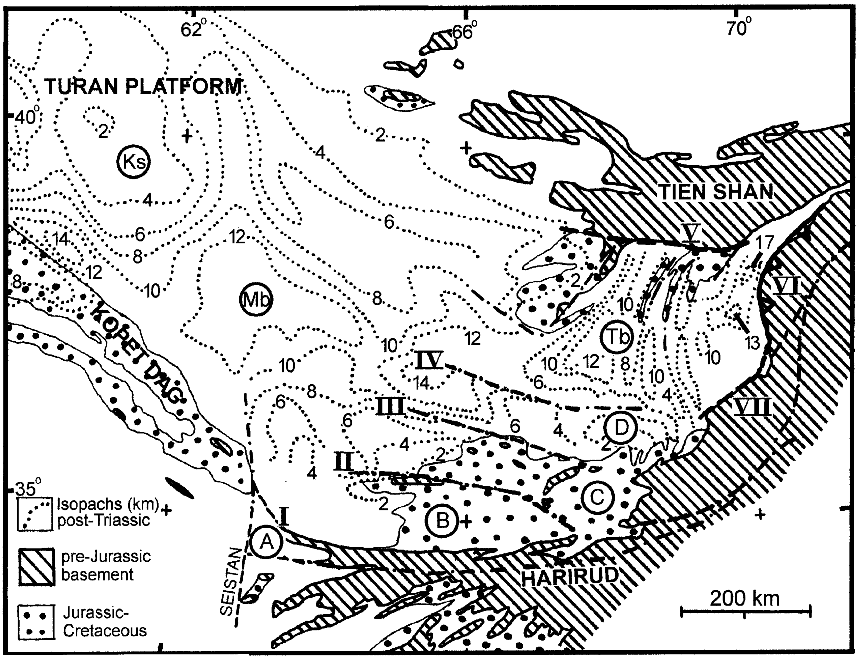


Fig. 2. General geology, tectonic units and features (from Abdullah et al., 1980), post-Triassic isopachs (Bratash et al., 1970; Vlasov et al., 1984; Artemjev and Kaban, 1994). North Afghan platform: A—Herat trough; B—Qualai Naw block; C—Maimana block; D—Sherbergnan block; Tb—Tajik basin; Mb—Murghab basin; Ks—Karakum spur (of Turan platform); Faults: I—Siabubak; II—Bande Turkestan; III—Anderab—Mirzawolang; IV—Alburz–Momul; V—South Gissar; VI—Darvaz thrust; VII—Ishkamish–Khohon.

(Sborshchikov et. al., 1974; Wolfart and Wittekind, 1980). To the west, all Afghanistan structures (together with those of the Murghab basin) are truncated by the Seistan fault and subsurface extensions (Kulakov, 1970).

The North Afghan platform has important oil and gas fields, and the newly independent states of southern Central Asia are now making plans to further develop these (Clarke, 1988, 1994; Sagers, 1994; Kingston and Clarke, 1995). It is also a critical area for evaluating Cenozoic continental collision in the area (Boulin and Bouyx, 1977; Boulin, 1981; Tapponnier et al., 1981; Sengor, 1984; Brookfield, 1992, 1994; Ricou, 1994). The geology of Afghanistan south and east of the Hari–Pansjer line is reasonably well known in the west from pre-1970s studies published in English, French or German (e.g. Desio et al., 1964; Bouyx, 1972; Wolfart and Wittekindt, 1980). However, the geology of northern Afghanistan is practically unknown in the west because most maps and reports were published in Russian and many were restricted. Though these maps and reports are now available, further field study will probably be impossible in the foreseeable future due to civil unrest and widespread land mines.

Thus, it seems timely to now summarize the extensive literature on the geology and petroleum resources of the North Afghanistan platform.

Northern Afghanistan has been comprehensively mapped at 1:500,000 scale (Department of Exploration of Gas and Petroleum, 1968) and the geology summarized in Bratash et al. (1970), Kulakov (1970), Sborshchikov et al. (1973) and Abdullah and Chymirov (1980). Adjacent areas of Turkmenistan, Uzbekistan and Tajikistan are summarized in Markovskiiy (1959), Luppov (1972), Tulyaganov (1972) and Clarke (1988). Where not otherwise stated, details are from these publications.

We do not assume ages for unfossiliferous rocks without direct biostratigraphic or radiometric evidence. Many units assigned to the Precambrian on metamorphic grade turn out to be Mesozoic and Cenozoic when dated. Hence, we use terms like pre-Carboniferous when only upper ages are determinable—usually from unconformable sediments. Also, sections should not be dated by comparing them with apparently similar dated sections across major faults or sutures.

## 2. Tectonic subdivisions

The North Afghan platform has a pre-Jurassic basement of pre-Carboniferous to Triassic rocks unconformably overlain by Jurassic to Recent sedimentary rocks. The pre-Jurassic basement is exposed mostly along the southern and eastern margins of the platform in the Parapamisus and Hindu Kush ranges. Northwards and westwards, it outcrops only in a few tectonic inliers, like the Bande Turkestan uplift. Along the southern edge and eastern edge of the platform, the basement is cut by an Early Mesozoic magmatic arc, which extends northwestwards (mostly obscured by the younger sediments) along the southern edge of the Amu Darya basin, and through the central Caspian Sea as far as the Crimea (Khain, 1979). It can also be traced through the North Pamir and into the Hindu Kush (Sengor et al., 1993). The North Afghan platform, unlike areas to the west and east, is presently in isostatic equilibrium (Kaban et al., 1998). Along its northern and western edges the platform drops beneath the Quaternary cover of the Tajik and Murghab basins. These basins separate the North Afghan platform from the Turan platform to the northwest and the Tien Shan mountains to the north (Fig. 2). It is convenient to discuss the geology of the North Afghan platform in terms of these three distinctive units.

### *2.1. Pre-Jurassic basement*

The pre-Jurassic basement of the platform is exposed in the Parapamisus, Bande Turkestan, and Hindu Kush Pamir mountains, where it consists of pre-Carboniferous to Triassic rocks deformed and intruded at the end of the Triassic, and again during younger Mesozoic–Cenozoic times. These reasonably well-studied mountains form the edge of the Jurassic and younger North Afghanistan platform (Wolfart and Wittekindt, 1980). The Parapamisus, north of the Harirud fault is basically the exposed southern edge of the North Afghan platform, though cut by a number of strike–slip faults. The Bande Turkestan is a part of the basement of the platform exposed along the oblique-slip Bande Turkestan fault. The Hindu Kush and north Pamir are thrust over the platform along the Ishkamish–Khohon and Darvaz fault zones and are tectonically complex due to Neogene deformation during the formation of the Pamir (Burtman and Molnar, 1993). The deformation associated with the collision of India with Asia has obscured many original structural and stratigraphic relationships close to the Harirud and related fault zones (Sborshchikov et al., 1974).

### *2.2. North Afghan platform cover*

The North Afghan platform cover consists of Mid-Mesozoic to Neogene sediments covering Palaeozoic–Triassic rocks and structures. The platform has four main areas separated by major faults: the Herat Trough, the Qualai Naw, Maimana and Sherbergnan blocks (Fig. 2). However, the dominantly right-lateral Neogene faults do not significantly offset any structures in the pre-Jurassic basement and have little effect on Mesozoic–Recent facies belts. To the north, the platform is faulted against the Tajik basin, while to the northwest, it passes gradually into the Murghab basin.

### *2.3. Tajik and Murghab basins*

The North Afghan platform drops north and northwest into two basins filled with thick Jurassic to Recent deposits and separated by a broad sill (Fig. 2). The Tadjik basin is separated by a major subsurface fault from the Sherbergnan platform area, while the Murghab basin lies northwest of, and is transitional to, the North Afghan platform. The Tajik basin is a typical southeastward-facing ‘passive margin’ basin involved in younger continental collision (Leith, 1985). Oceanic lithosphere is still descending beneath the Hindu Kush as shown by deep-focus earthquakes down to 200 km. (Mellors et al., 1995). The Murghab basin is less well known, but has a section similar to the North Afghan platform. Both basins have rift-type Triassic bimodal basic–acid extrusives interbedded with continental deposits at their bases, unconformable on deformed Paleozoic rocks, where exposed at the basin margins (Knyazev et al., 1971).

## 3. Pre-Jurassic basement

The pre-Jurassic stratigraphy of the North Afghan platform is relatively consistent and sections in the various area are similar (Figs. 3–7). Deformed and metamorphosed ?Lower and Middle Palaeozoic sediments and volcanics were intruded by granites and eroded prior to a Lower Carboniferous (Namurian) transgression. The entire pre-Carboniferous section is metamorphosed and highly deformed, so much of the stratigraphy is uncertain and disputable. Unconformable variable Mid–Late Carboniferous sediments and basalts are overlain by similarly variable Permian shallow marine and continental deposits. Unconformable on these are thick Triassic mostly subaerial volcanics and volcanogenic sediments, accompanied by large granitoid intrusions.

### *3.1. Herat Trough and Qualai Naw block*

In the Parapamisus and Bande Turkestan mountains, the pre-Tournaisian consists of thick pelitic and arenaceous schists, gneisses and marble, overlain by intermediate to acid volcanics of possible Upper Devonian to earliest Carboniferous age (Fig. 4). These are unconformably overlain by thick marine Lower (Tournaisian) to Middle Carboniferous fine-grained clastics ("flysch"), which pass north and east into thinner and coarser sections with thicker limestones in the Middle Carboniferous. The overlying unconformable Permian consists of coarser continental clastics ("molasse"), very like those of the southern Tien Shan (Burtman, 1975). These Permian clastics, like the Carboniferous, decrease in thickness and become coarser to the northeast. However, in the eastern Parapamisus, a thick Lower Permian marine section intervenes between the continental sediments and unconformably overlying marine Triassic (Fig. 4, column 3).

In the western Parapamisus, Lower Triassic coarse volcanogenic clastics rest on red Permian sandstones and pass up into interbedded tuff, sandstone and limestone, and thick acid and intermediate tuffs (Fig. 4, column 1). Unconformably above are Middle Triassic (Anisian) limestones overlain by thin shales. Above these is a thick Ladinian–Carnian coarsening upwards succession of volcanogenic siltstones and sandstones. Uplift of the western Paropamisus during

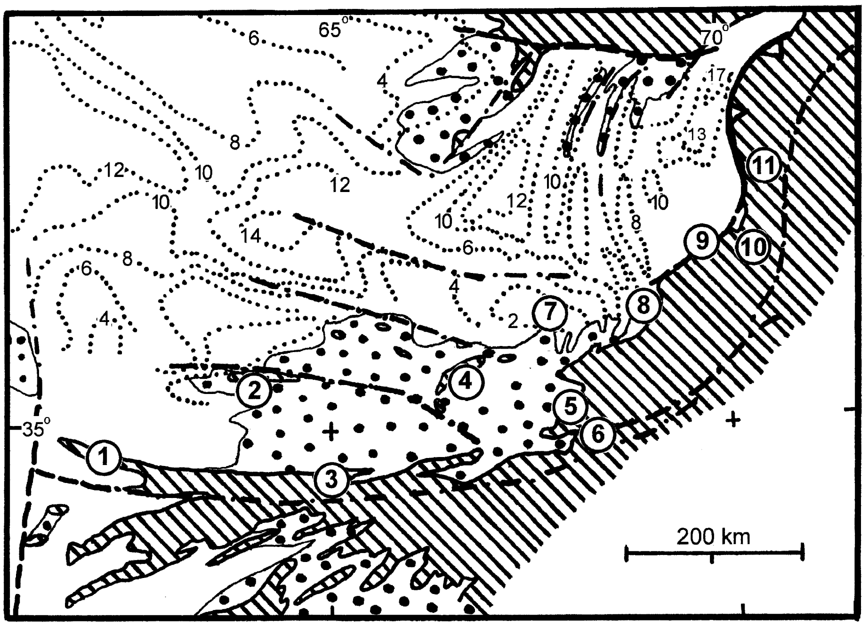


Fig. 3. Location map for pre-Jurassic sections.

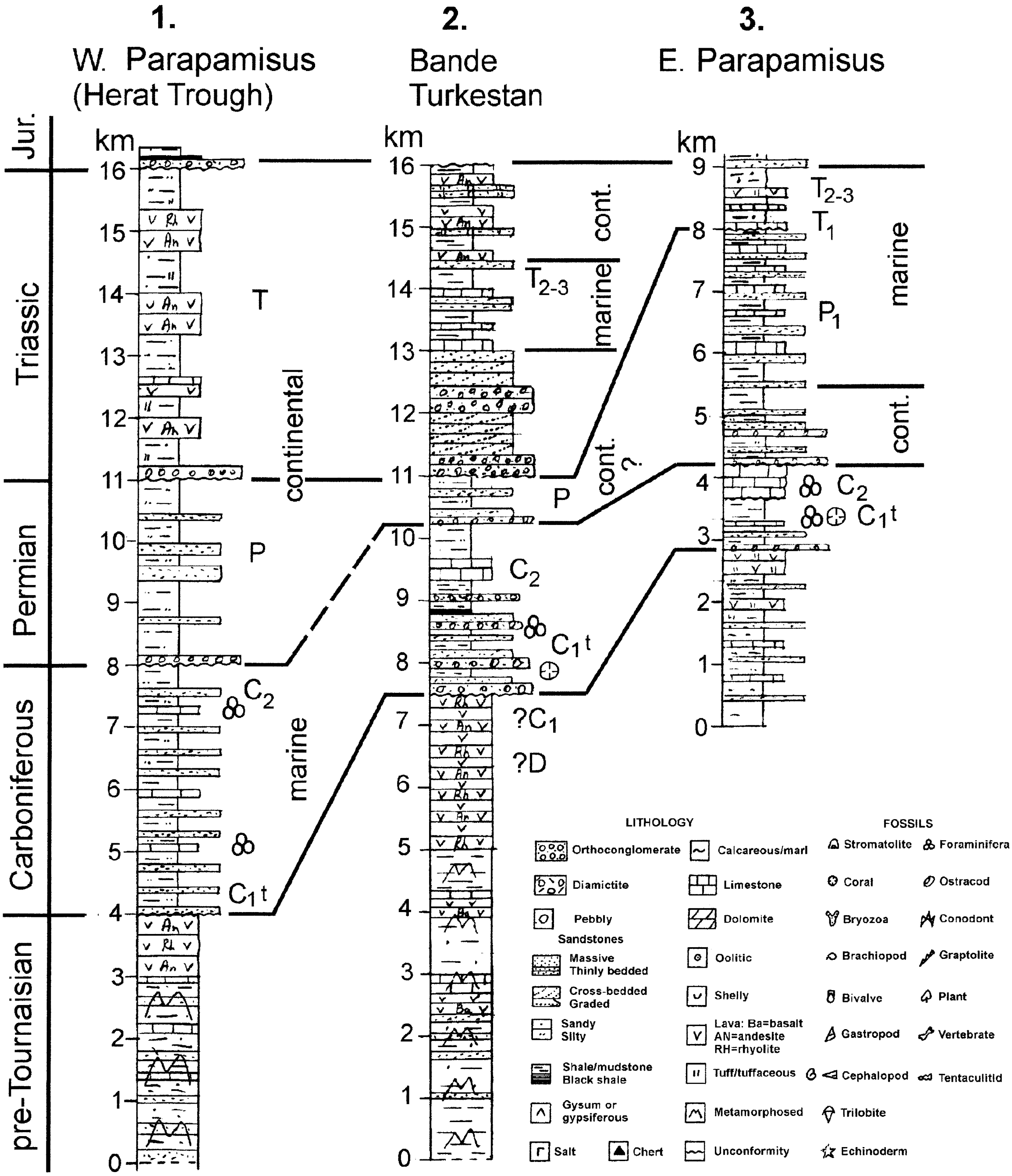


Fig. 4. Pre-Jurassic sections of the Herat Trough and Qualai Naw block. Data from Bratash et al. (1970), Weippert et al. (1970) and Wolfart and Wittekind (1980). See Fig. 3 for locations. Inset: legend for all sections.

the Early Triassic probably supplied the basal coarse non-marine clastics of the Bande Turkestan.

In the Bande Turkestan, the Lower Triassic consists of thin polymict sandstones and conglomerates, which rest unconformably on Permian red clastics and pass up into Middle Triassic limestones and shales, which apparently change eastwards into coarse continental clastics. Above are Ladinian–Norian volcanogenic sandstones and overlying shales. Thin Middle to Upper Triassic intermediate volcanics occur in places.

In the eastern Parapamisus, thick ?Permian to lowermost Triassic coarse multicoloured continental clastics (300–700 m) rest unconformably on Upper Carboniferous clastics, and pass up into Lower Triassic (Scythian) limestones and shales (Fig. 4, column 3). These, in turn, are overlain by Middle Triassic (Anisian) limestones passing up into interbedded shales and sandstones and thick unfossiliferous limestones. These are unconformably overlain by thick Upper Triassic intermediate volcanic and associated coarse clastics, which pass up into latest Triassic marine shales (Bratash et al., 1970).

All these western sections apparently lie north of the main Triassic magmatic arc axis of the Hindu Kush. Practically identical sections occur in northeastern Iran (Alavi, 1991; Ruttner, 1993) and in the southwestern Tarim basin (Lee, 1985). The Triassic sections in Parapamisus and Bande Turkestan, differ from those in the Hindu Kush to the east (Ehsan Sarwary, 1990).

### 3.2. Maimana block

In the Maimana block, the sections in the Bande Amir and western Hundu Kush are thinner than in the Parapamisus and Bande Turkestan, due to greater uplift and erosion related to the intrusion of Late Triassic–early Jurassic batholiths, which removed much of the pre-Jurassic record (Fig. 5).

In the southwestern Hindu Kush, metamorphosed Palaeozoic quartzose and pelitic schists, greenschists, marbles and limestones are interbedded with conglomerates and acid to intermediate volcanics, and Upper Devonian deep-water limestones (Bouyx, 1972; Boulin et al., 1987; Blaise et al., 1993) (Fig. 5,

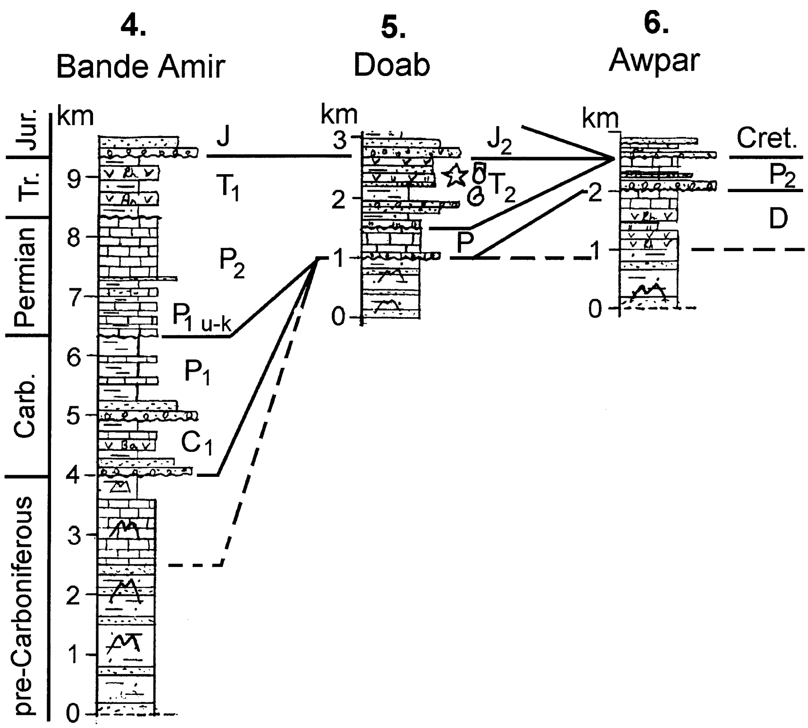


Fig. 5. Pre-Jurassic sections of the Maimana block. Data from Weippert (1964), Bouyx (1972), Boulin et al. (1977), Wolfart and Wittekind (1980) and Blaise et al. (1993). See Fig. 3 for locations.

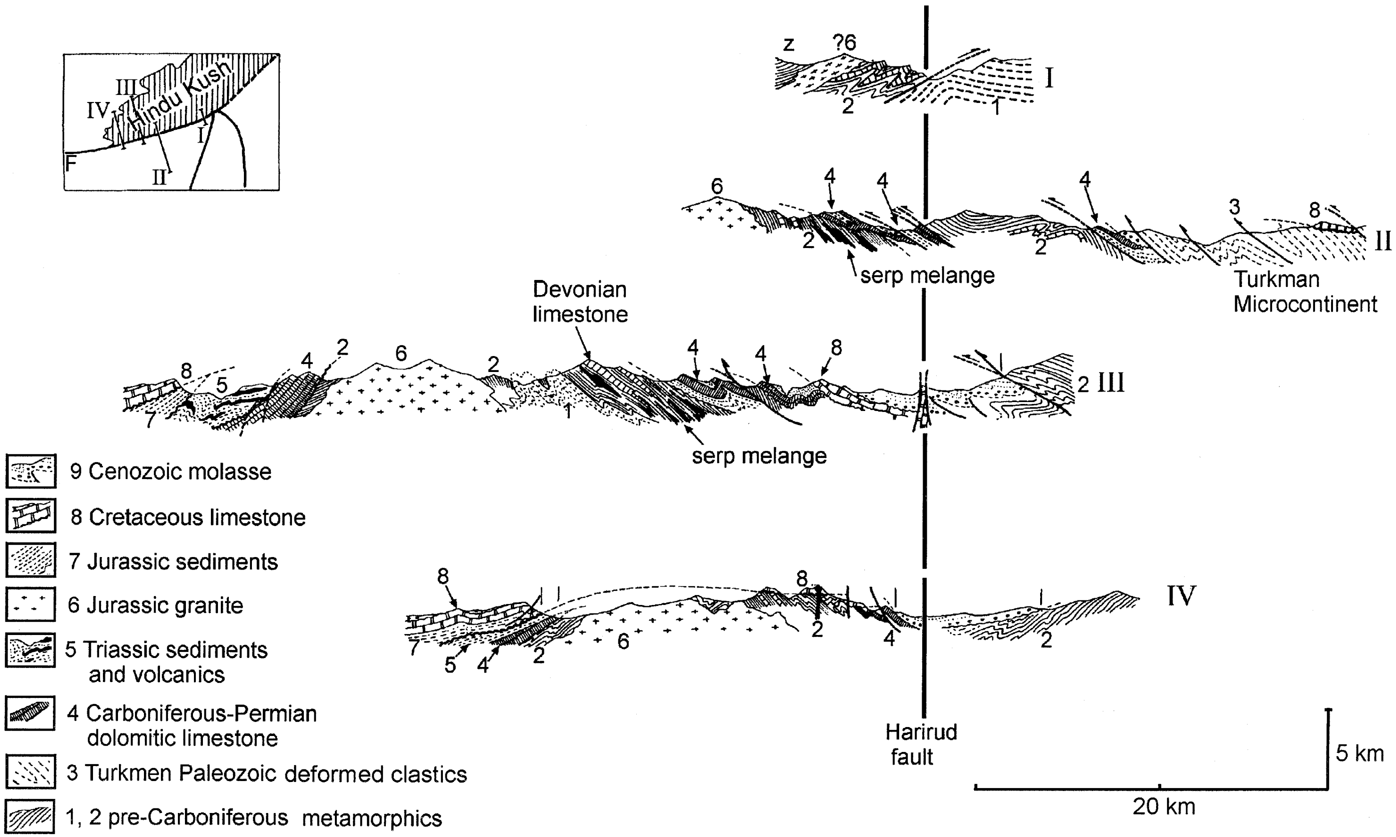


Fig. 6. Cross-sections across the southeastern Hindu Kush (modified from Boulin and Bouyx, 1977).

columns 5 and 6). To the south, the metamorphic rocks contain ophiolitic melanges, consisting of highly deformed schists (including glaucophane schists), serpentinites, radiolarian cherts, metagabbros and metabasalts (Bouyx and Collomb, 1985) (Fig. 6). The ophiolitic belt is unconformably overlain by a basal conglomerate, which contains unmetamorphosed Visean limestone pebbles, as well as metamorphosed older metasedimentary pebbles, and pebbles of acid volcanics and intrusives, suggesting that the main metamorphism was pre-Visean (Blaise et al., 1993). These conglomerates pass up into Permian (Artinskian to Murgabian) limestones (Bouyx, 1972). There are no thick Permo-Carboniferous post-orogenic clastics.

Sections are thicker in the Bande Amir inlier to the west (Fig. 5, column 4). Here, Lower Carboniferous clastics with interbedded basalts are unconformably overlain by coarse Lower Permian clastics, which pass up into thick Permian limestones, unconformably overlain by Triassic acid volcanics

All these sections are unconformably overlain by Triassic intermediate to acid volcanics and volcaniclastic sediments (where preserved).The Upper Triassic is best exposed in the western Hindu Kush where thick Upper Triassic–Lower Jurassic acid to intermediate lavas and volcaniclastic sediments rest unconformably on Permian limestones and are intruded by large granitoid batholiths (Boulin, 1988). The granitoids consist of I-type granitoids, which give latest Triassic Rb/Sr isochron ages ($210 \pm 10$, $212 \pm 20$ Ma), and younger S-type granitoids with Lower Jurassic Rb/Sr isochron ages ($193 \pm 4$ Ma) (Debon et al., 1987).

### 3.3. Sherbergnan block

In the Sherbergnan block, the sections in the Robatak uplift and western Hindu Kush are generally thicker than in the Maimana block, but thin markedly westwards (Fig. 7). The Robatak section is very similar to that of the Bande Amir section in the Maimana block.

In the central part of the Hindu Kush, thick pre-Devonian low-grade schists, quartzites and minor marbles, interbedded with basic lavas are unconformably overlain by bimodal ?Devonian volcanics, in turn unconformably overlain by ?Lower Carboniferous thick intermediate to acid volcanic section. Mid to Late Carboniferous limestones above are unconformably overlain by a thick Lower Permian mixed sedimentary succession (Fig. 7, column 8).

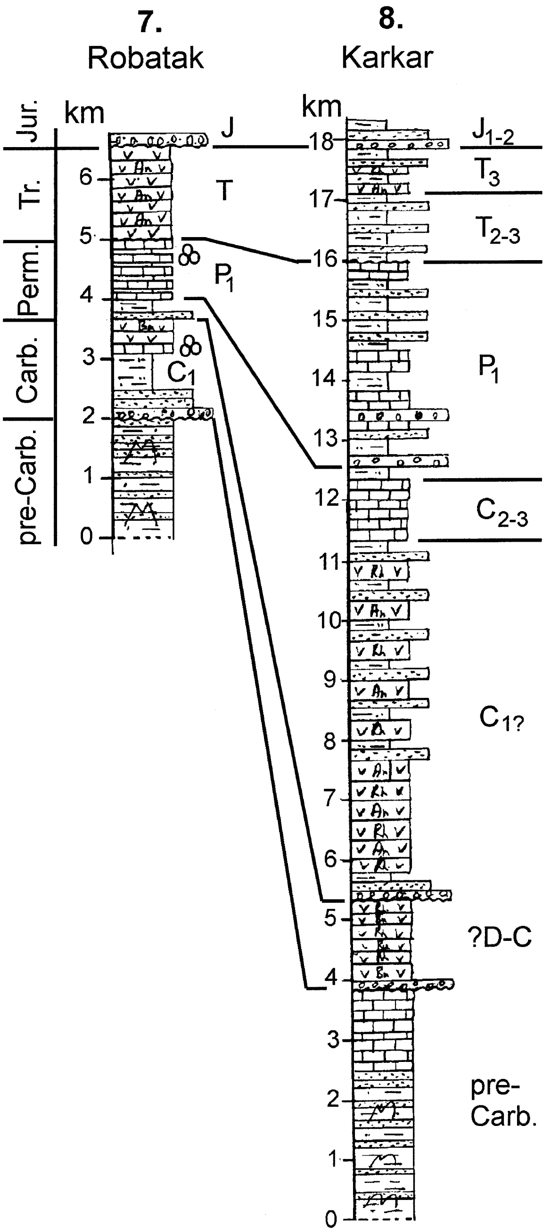


Fig. 7. Pre-Jurassic sections of the Sherbergnan block. Data from Hinze (1964), Bratash et al. (1970) and Wolfart and Wittekind (1980). See Fig. 3 for locations.

### 3.4. Badakshan (eastern edge of Tajik basin)

In Badakshan, the sections generally thin westwards (Fig. 8).

In the northern part of the Hindu Kush, various low grade metasediments pass up into thick limestones with Lower to Middle Devonian (Emsian–Eifelian) corals and crinoids, interbedded with slates. Kolcanov et al. (1971) recorded acid to intermediate volcanics interbedded with supposed Mid-Devonian siltstones and slates; however, the volcanics may be somewhat younger. To the north, the limestones thin and siltstones and slates dominate. Thick intermediate to acid volcanics unconformably overlie these Devonian limestones, and are interbedded with volcaniclastic sediments and marine limestones (Bazhenov and Burtman, 1986). The volcanics are unconformably overlain by thick, variable, dominantly clastic, Carboniferous succession.

Thick Permian clastic sections thin to the west, as in the Sherbergnan block, and pass into limestones, which progressively overstep onto metamorphics.

### 3.5. Interpretation

The characteristics of the pre-Jurassic basement can be used to tentatively outline stages of development. Since the area is so complicated, a detailed tectonic history cannot yet be written.

(1) A pre-Upper Devonian ?Ordovician to Lower Devonian stage consists of a passive margin developed on oceanic crust. The pre-Upper Devonian sections, though metamorphosed consist of mature shelf and passive margin sandstones, shales and limestones: thick, extensive Devonian limestones suggest a passive margin. There is not enough evidence preserved to determine the orientation of this passive margin.

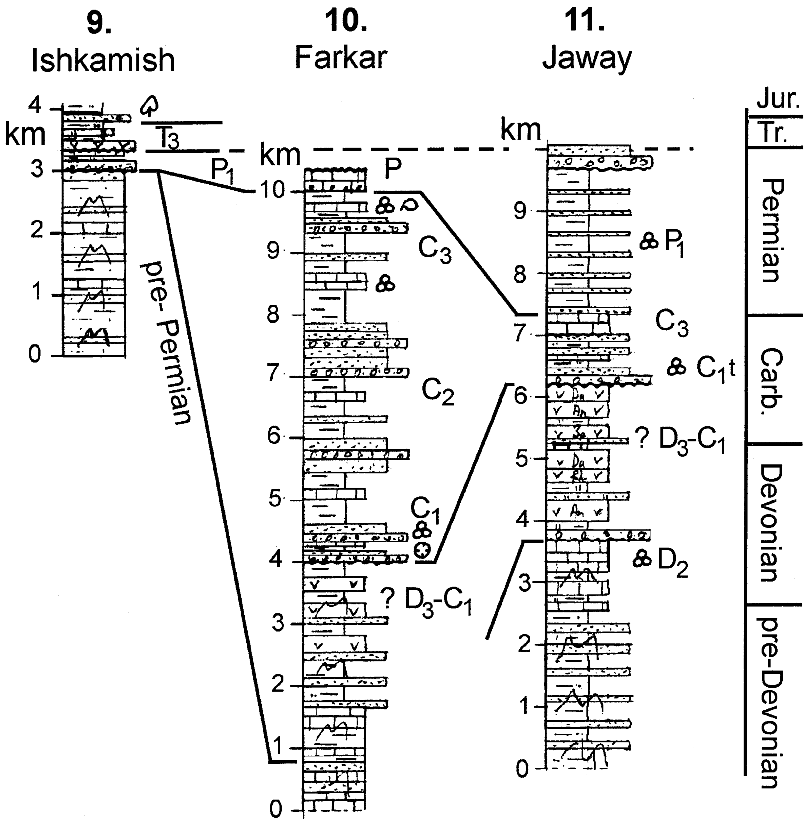


Fig. 8. Pre-Jurassic sections, eastern flank of the Tajik basin. Data from Hinze (1964), Bratash et al. (1970), Kafarskiy and Abdullah (1976) and Wolfart and Wittekind (1980). See Fig. 3 for locations.

(2) An Upper Devonian to Lower Carboniferous (Tournaisian) stage consists of a magmatic arc developed on the pre-Devonian passive margin. There are some problems with this, for example the bimodal volcanics of the Karkar area (Fig. 7, column 8). However, since these are overlain by thick Lower Carboniferous intermediate to acid volcanics and sediments, then a possible interpretation is that there was a phase of interarc rifting and oceanward migration of the active arc. The overall facies distributions in the southwestern Hindu Kush suggest a southeastward-facing Upper Devonian–Lower Carboniferous magmatic arc, which became inactive in the Visean.

(3) A Lower Carboniferous (?Visean) to Permian stage consists of a rift valley succession.

The very variable Carboniferous succession of basal clastics interbedded with alkaline basalts passing up into clastics and limestones is most like a rift succession. There are no large intrusions nor any major deformation at this time. Furthermore, there was little uplift and erosion after volcanic activity ceased. This rift succession is often unconformably overlain by thick Permian shelf limestones, marking the break-up unconformity and start of passive margin subsidence as an ocean opened on the south. This occurred at the same time as a continental collision of the North Afghan–Turan platform with the Tien Shan in the north (Bazhenov and Burtman, 1997). In both northwestern Afghanistan and Uzbekistan, the Permian consists of marine clastics passing up into red continental sediments between 1 and 3.8 km. Similar sections occur along the southern edge of the Tien Shan, south of the Carboniferous magmatic arcs and Permian granitoids of the Gissar range (Leonov, 1996).

(4) A Triassic magmatic arc stage consists of acid to intermediate volcanics interbedded with clastics and intruded by Upper Triassic granitoid batholiths.

In all sections, Permian and older rocks are unconformably overlain by Triassic marine and continental clastics associated with andesitic, dacitic and rhyolitic volcanics and pyroclastics (Weippert, 1964). The Triassic sections end within the Upper Triassic, and Jurassic sediments are everywhere unconformable on underlying rocks. The main axial granitoids of the Hindu Kush consist of I-type granitoids, which give latest Triassic (Rhaetian) Rb/Sr isochron ages ($210 \pm 10$, $212 \pm 20$ Ma), and younger S-type granitoids with Lower Jurassic Rb/Sr isochron ages ($193 \pm 4$ Ma)(Debon et al., 1987). K/Ar cooling ages range between 215 and 190 Ma (Desio et al., 1964; Blaise et al., 1970). All these features point to the development of an Andean arc on the southern edge of the North Afghan platform. This arc can be traced westwards into Iran and eastwards around the Pamir into the Kun Lun. The fore-arc and subduction zone are only preserved in the east where a fragment of the colliding microcontinent is preserved in the Pagman and Turkmen mountains, north of Kabul in Afghanistan (Blaise et al., 1977). Northeastwards, the arc disappears, probably due to erosion at the front of the Darvaz overthrust. However, it probably reappears in the North Pamir around Lake Karakul, where there are Upper Triassic granitoid complexes intruding thick Paleozoic metamorphosed sediments. On the North Afghan platform, the arc is unconformably overlain by several thousand metres of Jurassic coal-bearing continental clastics and Upper Jurassic limestone; in turn unconformably overlain by Lower Cretaceous acid volcanics and coarse clastics (Polyanskii, 1980). On the south, everything is smeared out along the Harirud fault zone.

Behind the Late Triassic magmatic arc, there are signs of back-arc rifting, which eventually rifted Northern Afghanistan from its parent Turan block during the Jurassic (Zonenshain and Le Pichon, 1986). These later Mesozoic events are inferred from the geology of the North Afghanistan platform cover and basins to the north.

## 4. ?Late Triassic to Paleogene cover

The deformed pre-Jurassic basement rocks are everywhere unconformably overlain (where not eroded away) by non-marine ?Late Triassic to Middle Jurassic coal-bearing continental deposits.

Rifting began during the Late Triassic on the northern edge of the North Afghanistan platform (at the same time as Triassic arc magmatism was active on the south). The resulting basin subsided throughout the Jurassic, tilting the North Afghan platform to the northwest; a tilting marked by the kaolinitic weathering of the exposed Parapamisus–Hindu Kush Triassic volcanics through the Early and Middle Jurassic. (Dastyar et al., 1990). The platform–basin transition can still be traced on the northwest where the platform runs into the Afghan–South Murghab basin. However, strike–slip faults now obscure the platform–basin transition on the north, where it is juxtaposed with the highly deformed Tadjik basin. The platform and basins host important oil and gas fields and have, hence, been studied extensively. Many English publications summarize petroleum production and prospects (Clarke, 1994; Sagers, 1994; Kingston and Clarke, 1995; Solob'yev et al., 1997). Works in English with seismic and/or borehole sections are Sharafi (1965), Majeed and Aurah (1967), Dzhalilov et al. (1982), Clarke (1988) and Dastyar et al. (1990).

Fig. 9 shows the location of sections of post-Triassic deposits of the North Afghan platform and Tajik and Murghab basins.

### *4.1. North Afghan platform*

The stratigraphy of the platform is not as well known as that of the basins to the north, partly because of the lack of early work and the instability of the last 20 years. Knowledge is almost entirely dependent on Russian and Afghan work in the 1960s and 1970s (Bratash et al., 1970; Sborshchikov et al., 1973). Figs. 10 and 11 summarize the Mesozoic–Cenozoic of the various units, which are easily correlated across the platform.

The Mesozoic–Palaeogene cover is divided into three stages: a rifting and basin formation stage from ?Late Triassic to Middle Jurassic; and two major transgressive–regressive stages, from Middle to Late Jurassic, and from Early Cretaceous to Oligocene times—though the latter is more complex (Polyanskii, 1980; Orudzheva and Kornenko, 1988).

(1) The *?Late Triassic to Middle Jurassic (Aalenian) stage* is dominated by variable continental clastics. Thick, coarse, lenticular coal-bearing clastics and transported bauxites were deposited by braided and meandering streams in linear grabens, while bauxites formed on the adjacent horsts. In the subsiding grabens, marginal coarse alluvial fans passed basinwards into braided and meandering stream and eventually into lake and swamp deposits, with diverse floras and thick peats (now coal) (Polyanskii, 1980). An unusually thick and complete Jurassic tuffaceous and coal-bearing clastic succession occurs in a graben around Doab in the Maimana block (Fig. 11, column 9). These very variable continental successions had practically filled the rift basins by the Middle Jurassic. Along the eastern edge of the platform, at the junction with the Hindu Kush Late

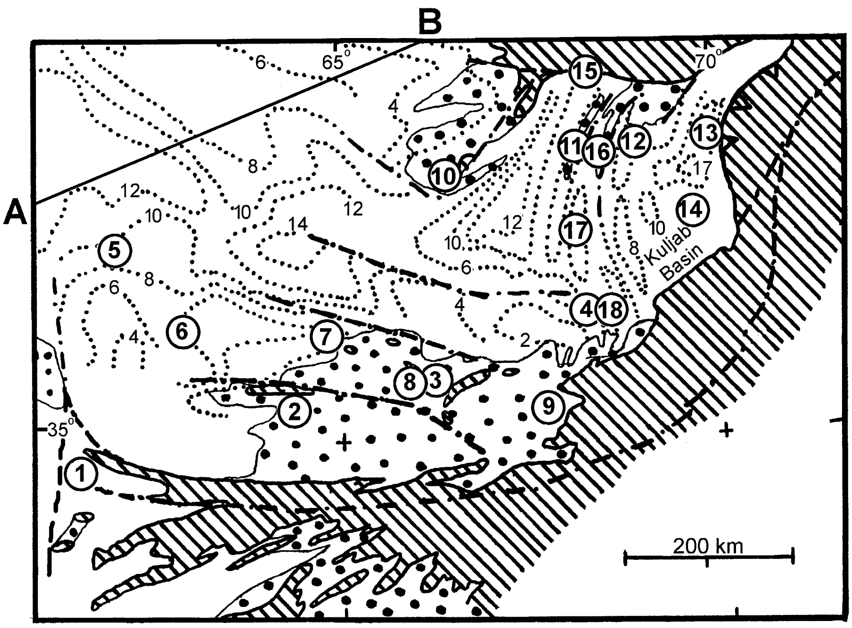


Fig. 9. Location of Jurassic–Recent sections. A–B is location of Fig. 14 cross-section.

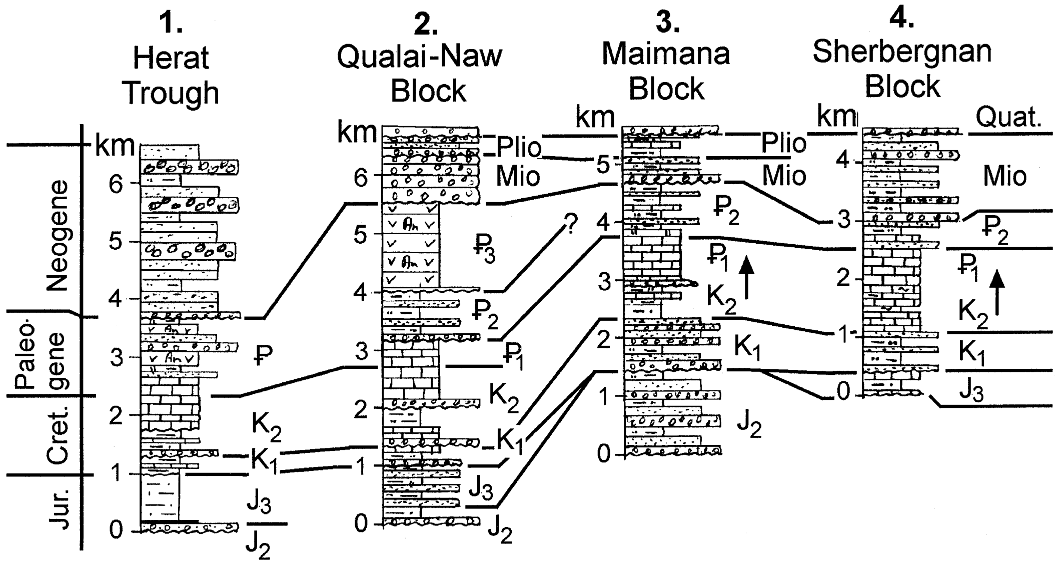


Fig. 10. Typical Jurassic–Recent sections in the four tectonic units of the North Afghan platform. Data from Benda (1964), Bratash et al. (1970) and Wolfart and Wittekind (1980). See Fig. 9 for locations.

Triassic acid to intermediate lavas and tuffs pass westwards into thicker continental sediments (up to 2 km thick), deposited on alluvial fans and by braided streams. Overlying Early Jurassic (Hettangian–Bajo-

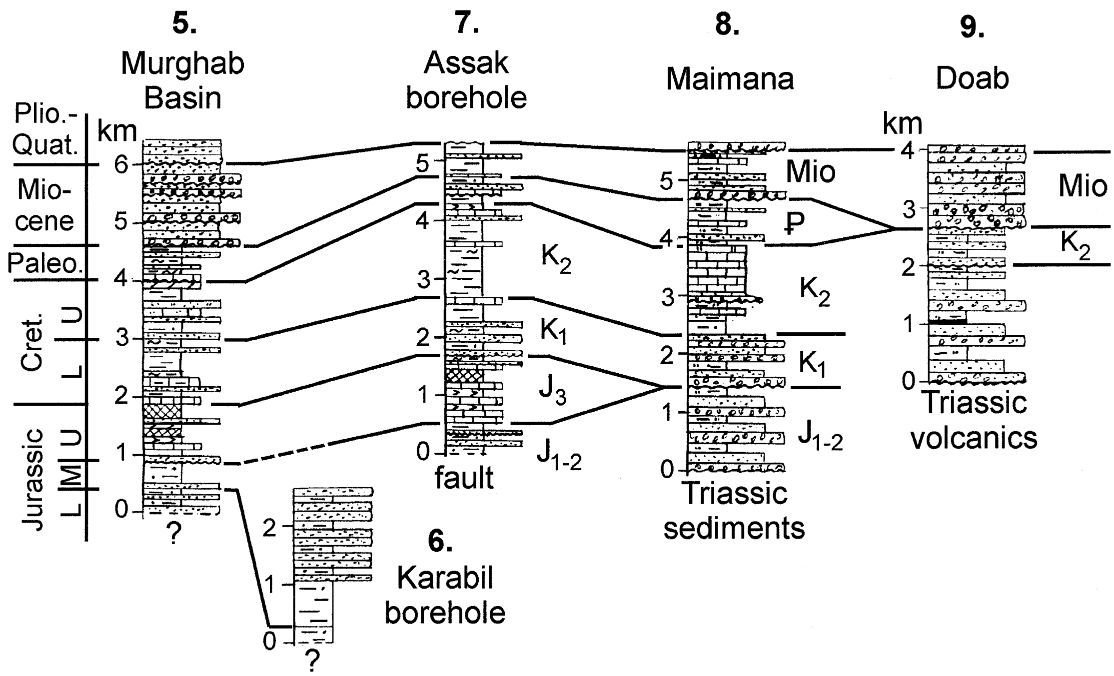


Fig. 11. Jurassic–Recent sections across the Maimana block. Data from Hinze (1964), Bratash et al. (1970), Luppov (1972), Knyazev and Mavyyev (1974) and Dastyar et al. (1990). See Fig. 9 for locations.

cian) rocks similarly consist of volcanic effusives on the northeast passing westwards into finer, more uniform, clastic sediments (up to 0.5 km thick), with well-developed, but still lensitic coal seams, deposited by meandering streams on wide alluvial floodplains. These Jurassic sediments have been removed on the west by pre-Cretaceous erosion. These Late Triassic–early Jurassic volcanics are the youngest of the Hindu Kush–North Pamir axis and are probably the surface manifestations of the large Early Jurassic axial batholiths.

The Middle Jurassic to Palaeogene stages are dominated by thin alternating continental and shallow marine clastics, carbonates and evaporites, which vary little in thickness across the entire area, and whose deposition was controlled by relative sea-level changes though they also show facies changes related to minor synsedimentary faulting (Polyanskii, 1980).

(2) *The Middle to Upper Jurassic stage* consists of mixed continental and marine Bathonian to Kimmeridgian sediments, which are overlain by regressive Upper Kimmeridgian–Tithonian evaporite-bearing deposits. From Late Aalenian to Bajocian times, a worldwide rise in sea level led to marine flooding of the North Afghan platform and deposition of marine clastics, unconformably on the underlying continental sediments. From Bajocian to Bathonian times, sea level rose still further and a more humid climate developed. Sediments consist of up to 1 km of fine-grained alluvial–lacustrine sediments in regular fining upwards small-scale cycles. At the margins of uplifts, rivers built deltas directly out into the sea: nearshore sands pass basinwards into silty clays and finally into marls and limestones. From Callovian to Oxfordian times, a great marine transgression inundated practically all the uplifts, depositing complex facies mosaics of marine clastics and carbonate sands. Callovian shoreline and shallow marine clastics pass up into open marine Oxfordian limestones and shales marking the maximum sea-level rise of the Jurassic. During the Oxfordian sea-level maximum, carbonates were deposited across practically the entire area. The overlying regressive Kimmeridgian and ?Tithonian consist of evaporites deposited in increasingly restricted and arid basins Red continental clastics at the margins pass into evaporites in the basin centres.

(3) *The Lower Cretaceous to Oligocene stage* is more complex. Lower Cretaceous red beds with evaporites rest unconformably on Jurassic and older deposits. These Lower Cretaceous redbeds are coarser in the south and pass northwards into finer-grained clastics. They are overlain by (usually unconformable) Upper Cretaceous (Cenomanian–Maastrichtian) shallow marine limestone, which form a fairly uniform transgressive succession across most of Afghanistan, It is these limestones, which cut across the Palaeozoic–Triassic metamorphic core of the Hindu Kush. Overlying the Upper Cretaceous limestones, with a minor break marked by bauxite in places, are thin Palaeoecene to Upper Eocene limestones with gypsum. An overlying thin conglomerate passes up into shales with a restricted brackish-water ?Upper Oligocene–?Lower Miocene marine fauna of foraminifera and gastropods. Above this is the great, but variable, thickness of coarse continental sediments derived from deformation and uplift caused by the development of the Pamir and adjacent ranges (Burtman and Molnar, 1993).

The Herat Trough and Qualai Naw blocks are different. Jurassic and Cretaceous rocks are absent. The Palaeogene indicates rapid subsidence. Sections consist of thick marine multicoloured conglomerates, sandstones and siltstones (‘flysch’) with interbedded acid and basic volcanics, which pass north into intermediate volcanics. Intensive volcanism started in Late Lutetian times and continued into the Late Eocene. The initial tuffs and acid to intermediate lavas are intruded by dikes and sills and overlain by porphyritic pyroxene- and hornblende-andesites. These are overlain by interbedded andesitic tuffs, breccias, and tuffaceous sandstones and clays, with minor volcaniclastic breccias and conglomerates (Wolfart and Wittekindt, 1980). This Late Eocene magmatic arc has no equivalent further east. The Palaeogene is unconformably overlain by Neogene–Quaternary coarse clastics up to 4000 m thick. The main post-Triassic faulting is Neogene (Sborshchikov et al., 1974).

### 4.2. Northern basins

The Tajik and Mughab basins developed in the Early Mesozoic and subsided throughout the Mesozoic and Cenozoic. Both show the same three sedimentary stages as the North Afghan platform, with similar thicknesses of sediment from Jurassic to Neogene, but much greater thicknesses of Neogene sediments. A 4–5-km-thick, mainly marine Jurassic to Palaeogene, passive margin succession is overlain (usually unconformably) by a 3–7-km-thick coarse continental orogenic clastic succession (Loziyev, 1976). The ?Triassic to Oligocene sediments outline a subsiding continental margin produced either by intracratonic rifting or by back-arc rifting (Leith, 1982). Back-arc rifting is more likely considering the history to the south, where Mesozoic arcs developed progressively from north to south across southern Afghanistan (Bouyx, 1972). However, the moderate thickness of the sediments (less than 12 km) point to a basement of thinned continental rather than oceanic lithosphere, except possibly beneath the Pamir where Recent deep-focus earthquakes indicate oceanic lithosphere (Billington et al., 1977). Since sediment thicknesses also increase southeastwards, the Murghab–Tajik rifts may have opened eastwards into an ocean (Thomas et al., 1999). The pre-Neogene passive margin was not deformed until the Miocene (around 25–20 Ma), after which both basins subsided as the Pamir and Hindu Kush were thrust northwards and northwestwards (Burtman and Molnar, 1993).

### 4.2.1. *Tadjik basin*

The Tadjik basin is now a westward-facing foreland fold and thrust belt (Leith, 1982). It has a southward thickening, mostly marine ?Late Triassic to Oligocene succession, overlain unconformably by coarse continental Miocene to Recent clastics (Babayev and Mavlyanov, 1967; Dzhalilov et al., 1982). On the south, Neogene deposits obscure its faulted contact with the Sherbergnan block. On the north, the folds and thrusts bend into the great right-lateral strike slip faults marking the southern edge of the Gissar range (Portnyagin et al., 1976). On the east, a belt of shallow earthquakes outlines

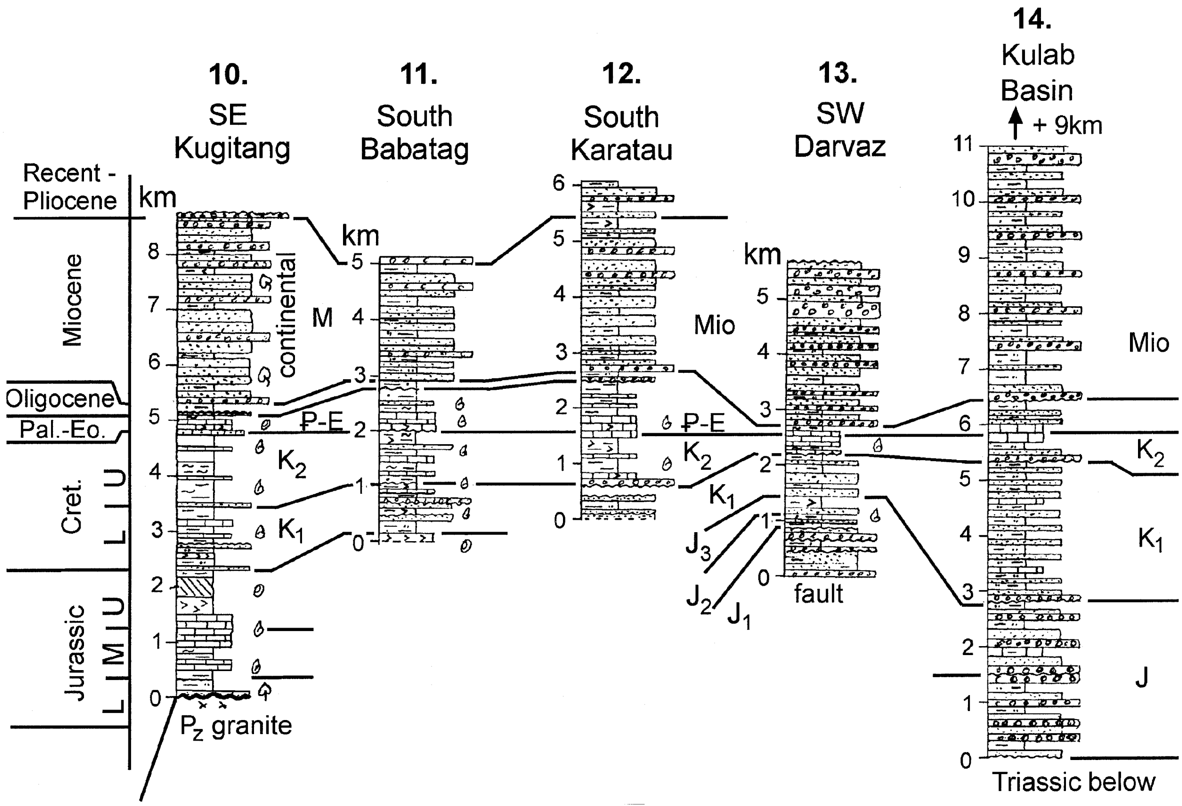


Fig. 12. Sections west–east across the Tajik basin. Data from Dzhalilov et al. (1982). See Fig. 9 for locations.

the active northwesterly directed thrusts, which carry the northwestern Pamir over the marginal depressions (Leith and Alvarez, 1985; Abers et al., 1988). From Miocene times onward, the basin sediments were continually deformed into great westward-facing fold–thrust arcs developed over a decollement surface of Jurassic salt. Bekker (1996) estimated, from tectonic shortening, that the ?Triassic to Oligocene basin is now less than half its original width. Palinspastic restoration of the northeastern Tajik basin, by reversing folds and thrust movements and restoring stratigraphic surfaces, show that it has undergone 85% (240 km) of northwest shortening (Bourgeois et al., 1997).

Two lines of sections show east–west (Fig. 12) and north–south (Fig. 13) trends.

Along the northern edge of the basin, post-Jurassic rocks rest on Palaeozoic basement. To the east and south, they rest on Jurassic evaporites, which are underlain by Lower Jurassic clastic sediments and Middle Jurassic limestones (Babayev and Mavlyanov, 1967). In the centre of the basin, the section starts with Upper Jurassic salt, overlain by about 1 km of Lower Cretaceous shelf sandstones and by about 2 km of Upper Cretaceous marine shales and limestones. The sections become thicker and more complete to the south and southeast. Between about 130 and 20 Ma, the tectonic subsidence and thermal subsidence curves correspond, and the 20–5-km-thick continental crust beneath the Tajik basin sediments is consistent with the 200% stretching factor calculated from the tectonic subsidence curve (Leith, 1985).

The Jurassic is most complete in boreholes in the western part of the basin, where it is divided up into five main units, practically identical to those of the North Afghan platform—though the base of the sections is not reached by boreholes (Timofeev et al., 1986):

(1) ?Upper Toarcian to Lower Bajocian deposits consist of up to 600 m of continental coal-bearing sediments with a diverse flora (as in Afghanistan). Pyroclastic material and interbeds are rare. The sediments were deposited with very variable thickness in rift depressions as alluvial fan–fan delta–swamp–lake complexes (Mal'tseva et al., 1979). The main source of these sediments was the Tien Shan to the north.

(2) Bajocian sediments consist of alternating marine and continental sandstones, siltstones and clays.

(3) Upper Bajocian to Lower Callovian deposits consist of transgressive marine clays, marls and limestones: from Bathonian to Early Callovian times onwards, nearshore marine sandstones alternate with the continental sediments.

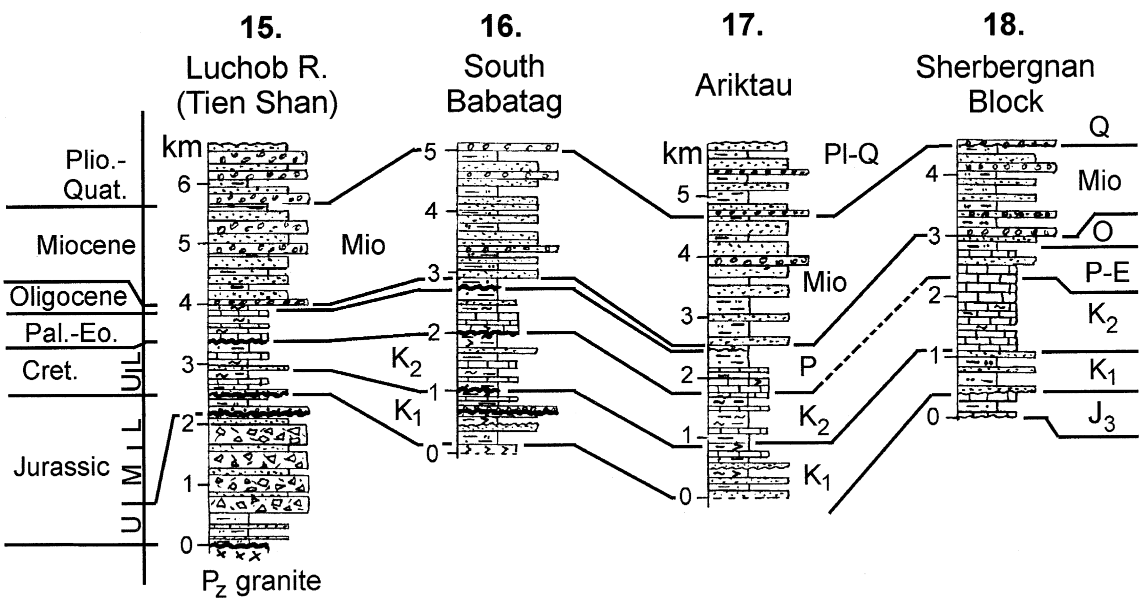


Fig. 13. Sections from north to south across the Tajik basin. Data from Dzhalilov et al. (1982). See Fig. 9 for locations.

(4) Middle Callovian to lowermost Kimmeridgian deposits consist of thick shallow marine limestones with coral bioherms.

(5) Kimmeridgian to ?Tithonian sediments consists of continental-evaporite unit of red clays, gypsum, halite and other evaporites.

All these units are continental to the east across the frontal thrusts of the western Pamir (Fig. 12, column 14). No marine deposits occur in these eastern sections, which, like those of Badakshan, have been displaced northwards during the Miocene formation of the Pamir. Jurassic sediments, apart from coarse Lower Jurassic in rifts, thin to the north in the Tien Shan (Fig. 13).

The Cretaceous is similarly most complete in western sections of the basin, where the Lower Cretaceous has three main units:

(1) ?Berriasian to Valanginian sediments are primarily continental red beds, up to 1000 m thick. They consist of conglomeratic lithic and felspathic sandstones, alternating with siltstones and shales. Fine-grained clastic sediments were transported into the Tajik basin from the north across a gently sloping land surface on the southern Tien Shan (Kariyev, 1978). The ?Berriasian to Lower Barremian is dominated by continental red beds, consisting of red clays with rare freshwater ostracods, siltstones and sandstones (which become conglomeratic to the north and pinch out in the southern Tien Shan). These pass up into Upper Valanginian to Hauterivian red clays, gypsum and dolomite with rare bivalves and ostracods, overlain by red sandstones and siltstones, again with rare freshwater bivalves and ostracods. During the Late Hauterivian, the basin area increased as a result of sedimentary build up and onlap. Marginal coarser clastic sediments transgressed northwards onto the southern Tien Shan.

(2) Upper Barremian to Lower Aptian sediments are dominated by thin lagoonal clastics. During the Upper Barremian, large lakes developed in the northwestern part of the Tajik basin, and these were temporarily flooded by the sea at times.

(3) Upper Aptian to Albian sediments are shallow marine. Glauconitic sandstones alternate with clays and limestones. During the Middle Aptian, the basin area increased still further accompanied by coarsening of clastic sediment immediately adjacent to the Gissar range. An Early Albian transgression inundated the entire Tajik basin, depositing interbedded clays, silts and carbonates.

The Upper Cretaceous consists of dominantly marine sediments with short marine regressions recorded by variegated lagoonal–continental sediments in the Cenomanian, Turonian and Santonian.

The lowermost Palaeogene consists of Early Palaeocene evaporitic facies (apparently conformably overlying Maastrichtian limestones), which pass up into marine limestones and shales of Palaeocene to Middle Eocene age. Overlying Middle Eocene to Oligocene sediments are sandier and increasingly 'lagoonal' and the Tajik basin was essentially filled by the Late Oligocene (Dzhalilov et al., 1982). However, a Late Oligocene to Early Miocene marine transgression deposited oyster-bearing limestones in the basin, before a marked regression in the Early Miocene (Glikman and Ishchenko, 1967). Rapid subsidence and the deposition of Middle Miocene coarse continental clastics mark the onset of Pamir deformation and Himalayan orogeny.

### *4.3. Murghab basin*

The Murghab basin lies at the southern edge of the Turan block, which is mostly masked by Neogene clastic sediments. The Turan block consists of highly fragmented and rifted pre-Jurassic basement, unconformably overlain by Mesozoic–Recent clastics of very variable thickness (Aptikaeva et al., 1996). On the north, the eroded Palaeozoic basement of the southern Tien Shan is unconformably overlain by Mesozoic–Recent sediments. In the Murghab basin, boreholes on tectonically uplifted blocks show variable volcaniclastic ?Triassic clastic sediments and interbedded limestones up to 6 km thick, below Mid-Jurassic clastic sediments and Upper Jurassic salt (Clarke, 1988). There is no sign of basement. The entire sequence could in fact be Jurassic. Most of the basin is beyond the reach of boreholes, though the thickening (of especially the basal Mesozoic clastics) can be seen in seismic sections (Fig. 14). The available sections (Fig. 11, columns 5 and 6) indicate that the thickness of younger sediment in the basin is almost entirely due to the Neogene clastics. The Mesozoic–Palaeogene section is almost identical to those of the North Afghan platform. The basin is in isostatic equilibrium and has not been affected

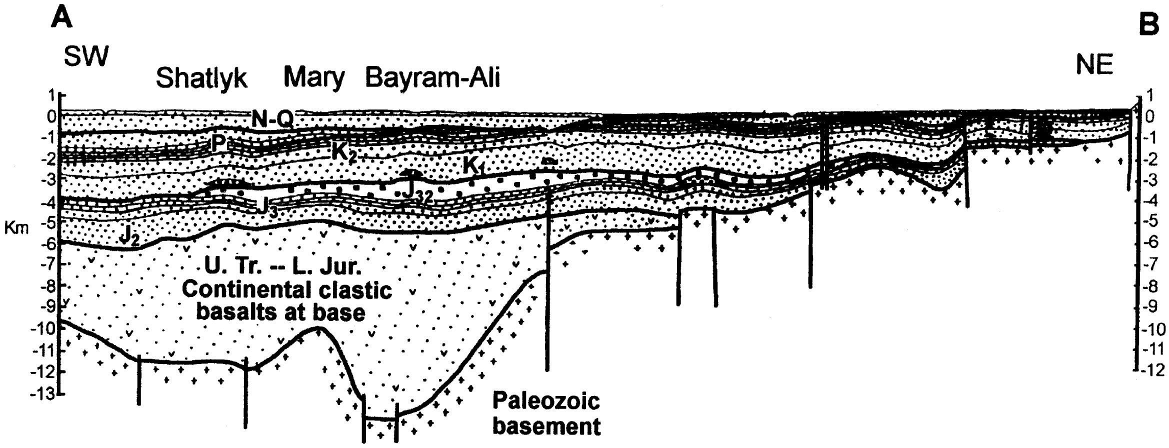


Fig. 14. Cross-section from the Tien Shan across the southeastern Turan platform (Karakum spur) to the Kopet Dag, showing Late Triassic to mid-Jurassic rift sediments overlain by mid-Jurassic and younger blanket sediments (modified from Bakirov et al., 1979). Location on Fig. 9. Cross-section is about 500 km long.

by post-Mesozoic tectonics to any great extent (Kaban et al., 1998).

The main phase of normal faulting predates the Callovian, which transgresses across a mosaic of blocks with thin pre-Callovian sections on folded basement, alternating with thick pre-Callovian clastic sections in rifts (Malzanov and Maltseva, 1968). The southern edge of the basin is marked by a rapid thinning of the Mesozoic–Cenozoic sequence across a presumed fault onto a presumed Palaeozoic basement, which, however, is only exposed along the extreme southern in the western Hindu Kush and westward. On the Turan platform to the north, an isolated buried northwest-trending rift, filled with over 10 km of Jurassic volcanics and clastics stretches along the Amu Darya between Chardzhou and Bukhara (Abidov et al., 1997).

## 5. Neogene orogenic sediments

During the Neogene, the North Afghan platform and adjacent areas were deformed by events associated with the collision of India with Asia. Present northward movement is concentrated within the Pamir arc. The Hindu Kush and Pamir were differentially pushed northwards and underwent progressively increasing uplift and erosion (Burtman and Molnar, 1993). Movement decreases towards the west, where anticlockwise rotation and less severe compression lifted up the Parapamisus and North Afghan platform along oblique strike–slip faults associated with local folding. At the same time the Murghab and Tajik basins started to sink below coarse clastic sediments derived from the uplifts. From the Herat Trough to the Kulab basin, Neogene mountain-derived clastics increase from 1–3 to 13 km (Figs. 10–13). At the point of greatest loading, the elbow junction of the western Hindu Kush–North Pamir, enormously thick Neogene clastics were deposited, up to 14 km in the Miocene alone (Fig. 12, column 14). The Tien Shan to the north also rose, and relatively thick Miocene sediments were deposited in the northern Tajik basin (Figs. 11 and 12).

Orogenic continental sedimentation began in the Early Miocene and progressively increased in coarseness and thickness into the Pleistocene. On the North Afghan platform, thin fine-grained and sometimes marine Late Palaeogene sediments are usually unconformably overlain by coarse continental Neogene clastics (Figs. 10–13). Miocene clastic sediments tend to be coarser and thicker next to the mountains and become thinner and finer-grained northwestward onto the North Afghan platform, and also southwards from the Tien Shan. Thus, the Miocene becomes thinner and finer-grained from Doab to Assak in the Maimana block (Fig. 11, nos. 9 to 7), and also westwards in the Tajik basin, though here complicated by the influence of the nearby Tien Shan (Fig. 13). Miocene clastic sediments also become progressively thicker and coarser through time, as the adjacent mountains increased in height (Dzhalilov et al., 1982).

By the Pliocene, most tectonic units of the North Afghan block were rising, except for the Kulab basin and local areas within the Tajik fold–thrust belt. In the Tajik basin thick Pliocene–Quaternary sediments are confined to synclines between the westwardly directed folds (Bekker, 1996). In the small Kulab reentrant basin between the Pamir and Hindu Kush, the very thick Pliocene–Quaternary sediments (Fig. 13, no. 14) are caused by the post-Miocene strong differential movement between the Pamir and Hindu Kush. This is also the basin area closest to subducting oceanic lithosphere beneath the Hindu Kush (Mellors et al., 1995). Pliocene–Quaternary deposits are elsewhere either thin of absent. For example, on the North Afghan platform there are only thin Pliocene–Quaternary clastics, and the area is now eroding. Clastic sediments are now mostly carried northwest by the Syr and Amu rivers into the Aral Sea basin.

## 6. Structure and tectonics

Practically all the deformation and topographic development of the North Afghan platform and adjacent mountains (including the Tien Shan and Pamir) began in the Miocene, caused by the indentation of Asia by northwestern India. Most of the deformation occurred within the last 5 Ma (Burtman and Molnar, 1993; Brookfield, 1994) (Fig. 15).

Structures associated with Triassic and older orogenies occur in the basement. These structures, truncated by Permian and Upper Cretaceous (Cenomanian) carbonates will not be discussed further here, except for determining displacements on some Neogene faults.

Structures associated with Triassic–Jurassic rifting are mostly confined to the northern and western parts of the North Afghan block, where rifting determined the structure and Mesozoic–Palaeogene development of the Tajik and Murgab basins. The rifts are mostly deeply buried below younger Mesozoic to Recent deposits. They are filled with Late Triassic to Mid-Jurassic continental clastics, which are the dominant source rocks for petroleum.

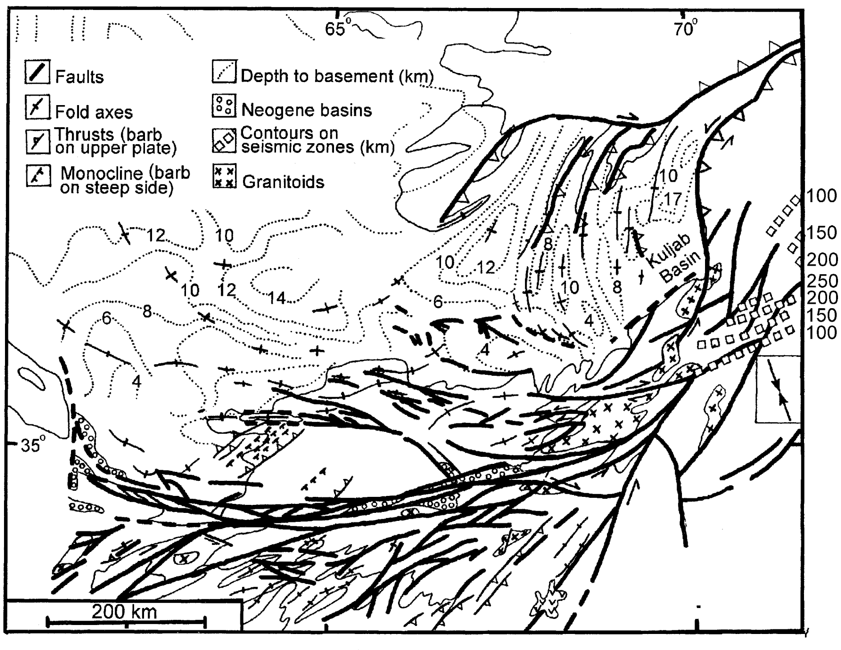


Fig. 15. Structural geology of the North Afghan platform (from Kafarskiy et al., 1975; Kafarskiy and Abdullah, 1976; Wolfart and Wittekindt, 1980; Vlasov et al., 1984): inset shows present plate convergence at Darvaz thrust (from Leith and Simpson, 1986).

The amount of Neogene northward movement increases logarithmically from west to east, from the Parapamisus to the Pamir (Bourgeois et al., 1997). This is shown by: (a) the increasing thickness of Miocene to Recent foredeep sediment from west to east; (b) by the increasing contrast between Mesozoic–Palaeogene facies across the bounding thrust (Kariyev, 1978; Burtman and Molnar, 1993); and (c) by the sense of fold and fault displacements in the area. We can discuss Neogene deformation in terms of three, reasonably distinct areas; the Harirud–Darvaz fault zone, changing from braided strike–slip to oblique thrust faulting along its length; the North Afghan platform with more diffuse strike–slip faults separated by zones of thrusting and folding; and, the Tajik basin, dominated by folds and thrusts (Fig. 15).

### *6.1. Harirud–Darvaz fault zone*

One of the obvious tectonic features of Afghanistan is the complex fault belt separating northern from central Afghanistan, running along the line of the Hari, Panjsher and Kokcha rivers (Wellman, 1965). The predominantly right-lateral strike–slip Harirud fault zone passes northeastwards and then northwards into the oblique left-lateral frontal Darvaz thrust of the North Pamir. Recent seismic activity is concentrated in the Darvaz–Chaman fault orientation, marking the left flank of the present Indian indentation of Asia (Sborshchikov et al., 1981).

The part of the Harirud fault west of Kabul is seismically almost inactive. This western part of the Harirud fault zone tends to show northward-directed oblique reverse faulting, with uplifted blocks of metamorphic rocks juxtaposed with Neogene grabens (Kulakov, 1970). Both the Paropamisus and Bande Turkestan ranges were uplifted as 'flower structures' along oblique right-lateral thrust strike–slip faults (Sborshchikov et al., 1974). Motion changes to southeastward directed oblique reverse faulting north of Kabul, where the oblique component of movement also changes—from dextral to sinistral as the fault bends into the Hindu Kush–Pamir trend.

The right-lateral displacement of the western Harirud fault zone is probably earlier than the left-lateral displacement on the Darvaz–Chaman fault trend. Both are post-early Miocene (Sborshchikov et al., 1974; Leith and Alvarez, 1985). Both faults cut Miocene clastics, though the Darvaz–Chaman zone is currently more active, with intense seismicity and with measurable displacements taking place (Kuchay and Trifonov, 1977). North and west of these faults, the deformation on the North Afghan platform and the Tajik basin is very different, though gradational.

### *6.2. North Afghan platform*

The three main fault zones of the North Afghan platform, noted earlier (Fig. 2), are conventionally thought of as reactivated basement faults (Kingston and Clarke, 1995). However, in fact, there is no evidence of pre-Neogene activity and each fault zone becomes less distinct northwards. So that the Alburz–Mormul oblique slip normal fault, though given prominence in Fig. 2, is in fact a rather minor zone of discontinuous faults, as shown in Fig. 15. Nevertheless, it does separate the North Afghan platform from the Tajik basin.

The major faults on the North Afghan platform are right-lateral strike–slip faults, which change from transpressional in the west (where they show thrusting and simple folding) to transtensional in the east (where the show normal faulting and rifting). Lateral displacements also increase from west to east, so that simple anticlines at their western ends change into sheared out folds and then into extensional grabens. The faults appear to die out westwards into lines of progressively flatter anticlines in the Murghab basin (Fig. 15). Almost all internal tectonic features of the North Afghan block can be related to movements associated with these faults (Sborshchikov et al., 1974; Boulin, 1981).

The Bande Turkestan fault is the best exposed and most thoroughly studied of these faults (Fig. 1). Its western end is a simple anticline, which passes eastwards into a highly compressed, fault-bounded horst–anticline, or flower structure, which forms the Bande Turkestan mountains (Sborshchikov et al., 1974). South of this anticline–horst, the almost horizontal carbonate cover of the Qualai Naw unit is disturbed by a belt of northeast trending southeast facing monoclinal flexures with steep southeastern limbs, often cut by thrust or reverse faults. These compressional structures die out to the east, where the supposed extension of the Bande Turkestan fault bends gradually northeastwards to run into the Darvaz thrust. However, there is no direct continuation, and a southeastern strand changes into the Yakovlang rift, a large asymmetrical half-graben, about 50 by 5–10 km, filled with Neogene clastics. It is downthrown about 1 km on the southwest and its floor gradually rises northeast into a zone of relatively small fault displacements (Sborshchikov et al., 1973).

The faults cut and offset domes and basins formed during deformation along the faults. Areas between the major faults are cut by smaller faults, and oblique thrusts and folds; the most prominent folds, though cut by faults, form the Bande Amir mountains (no. 4 in Fig. 3). These structures along the strike–slip faults and the oblique folds between them are the main petroleum-bearing structures on the platform (see Section 7).

The northern transition of the North Afghan platform into the Tajik basin is marked by a faulted monocline, which also bends and offsets part of the Tajik fold–thrust belt. Unfortunately, this area has been poorly studies, is mostly buried under Neogene sediments, and is now in a politically and militarily very unstable area.

### *6.3. Tajik basin*

The fold–thrust belt of the Tajik basins runs in a great westward-facing arc from the Tien Shan onto the North Afghan platform. The Mesozoic–Palaeogene sediments formed on southeastward-facing passively subsiding area with little syndepositional deformation (Leith, 1982). The thrust–fold system appears to have started in the Early to Mid-Miocene since strata of this age truncate some of the early folding and thrusting (Makhamov et al., 1985). The arcuate folds are limited by major outcropping strike–slip faults along their northern contact with the Tien Shan and also by buried strike–slip faults on the south.

The fold–thrust belt of the northern Tajik basin is controlled by decollement above Jurassic salt. The anticlines and synclines tend to be broader and more separated on the south and west and change northward and eastwards into more compressed faulted anticlines and synclines. They are bounded by, and pass into, dominantly eastward-dipping thrusts, which run into a decollement surface in the Upper Jurassic salt deposits (Bekker, 1996). On the north they are bent and sheared eastwards against the southern boundary faults of the Tien Shan (Loziyev, 1976). Westward displacements of up to 20 km can be demonstrated in some fold–thrust sections. Cumulatively, these displacements indicate that the northern Tajik basin has been shortened by over 50%.

The Tajik fold–thrust belt is often compared with the Jura mountains, which similarly moved westwards over a salt decollement (e.g. Leith and Alvarez, 1985). However, there are major differences. The Jura folds and thrust are cut by conjugate wrench faults, which take up extension across the arc. There are no such faults in the Tajik basin. The simplest explanation is that there is no extension across the arcs: the arcs are being compressed between the Tien Shan and the North Afghan platform. Though the westward gravity gliding of the fold–thrust belt may have been triggered by the northward movement and uplift of the North Pamir, the arcuate belt is also being squeezed westward by differential compression.

Pre-Neogene structures are buried beneath the Mesozoic–Cenozoic covers in most places. However, apart from reactivation of some Mesozoic rift faults, it is our contention that the main structures are entirely Neoegene.

### *6.4. Interpretation*

Most of the features of the western part of the area are directly comparable to those expected along a major right-lateral strike–slip fault (Fig. 16).

The western part of the Harirud fault, west of Kabul, is a classic dextral wrench fault (Sylvester, 1988). At its westernmost extremity, the complex horsetail splay of the Siabubak fault zone may be related to the northward movement of Iran along the right-lateral Seistan fault zone. In its central part the various strands form the typical braided network of a major transcurrent fault with various fault-bounded Neogene basins and uplifts along it (Christie-Blick and Biddle, 1985).

Likewise, the thrusts, monoclines and folds between the faults on the North Afghan platform are identical to structures developed around and between major strike–slip faults. Though distorted in the east

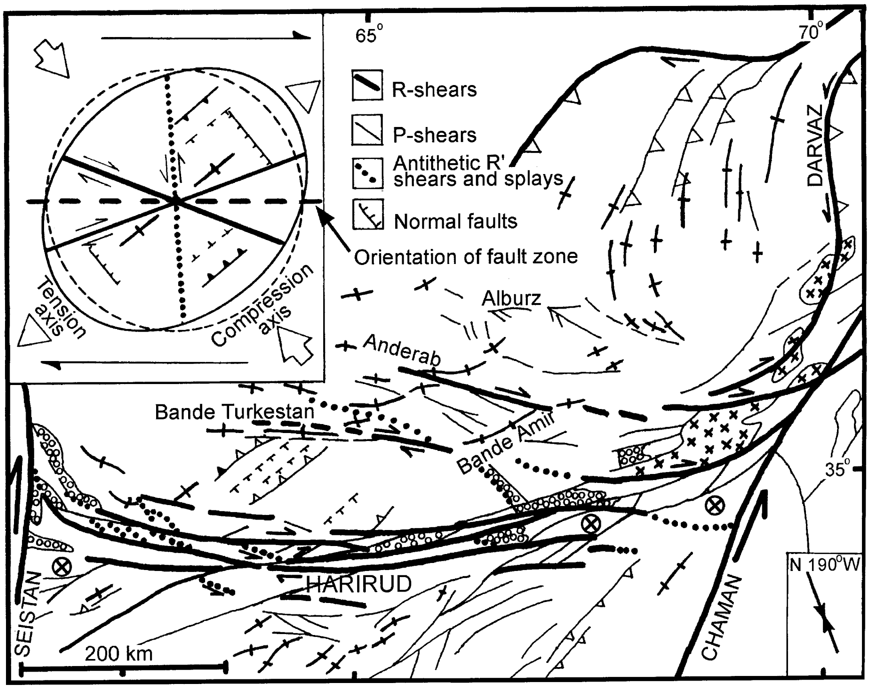


Fig. 16. Relative fault types and displacements, and related features compared with characteristics of right-lateral simple shear (from Sylvester, 1988) with interpreted Riedel shears, P shears, and antithetic R′ shears and splays.

by the indentation of the Hindu Kush and Pamir (and consequent left-lateral reversal of motion), it can be directly compared with experimental shear zones (Mandl, 1988).

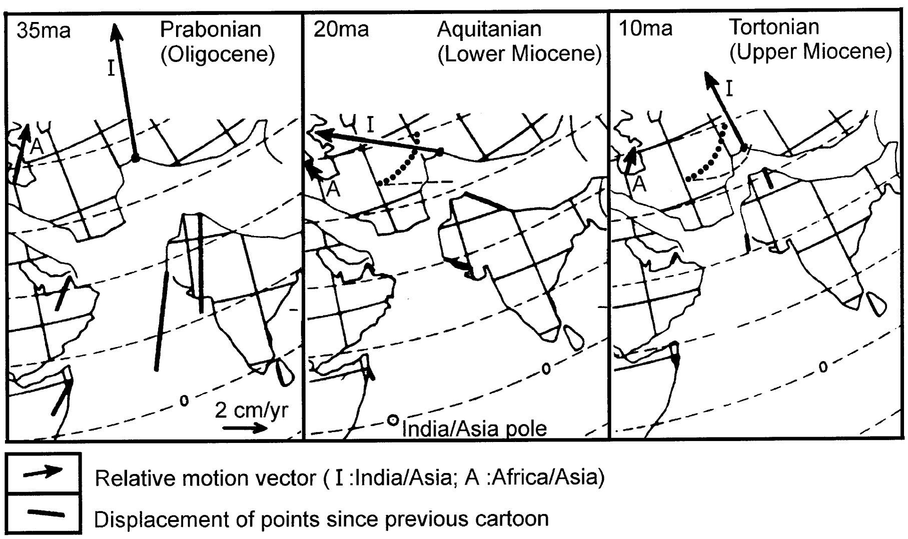


Fig. 17. Relative motion between India/Asia since Oligocene with Asia fixed (from Savostin et al., 1986). Present orientation of Harirud–Darvaz faults shown by dots. Relative motion shown by arrows: India, at 35 Ma—3.5 cm/year, at 20 Ma—3 cm/year, at 10 Ma—2 cm/year.

There are some problems. Seismic data show that only the north–south Darvaz–Chaman belt is currently active (Quittmeyer et al., 1979). As noted above, structural evidence shows that both Harirud and Darvaz–Chaman are post-early Miocene (Sborshchikov et al., 1974; Leith and Alvarez, 1985). However, the development of the Harirud and Darvaz–Chaman fault trends is readily apparent if the plate motions of India relative to Asia are plotted for Late Oligocene to Pliocene times (Fig. 17). The western part of the Harirud fault lines up as a strike–slip zone at about 40° to the northwest compression of India against Asia from 35 Ma (Oligocene) to 20 Ma (Lower Miocene). Similarly, the Darvaz–Chaman fault zone lines up at about 40° to the northward compression of India against Asia from 20 to 10 Ma (Upper Miocene), and continuing to the present with a slight northwesterly change. Both angles are compatible with the angle between the axis of maximum compression and the overall trend of a strike–slip fault under simple shear (see inset, Fig. 16). The large northwesterly compression of India relative to Asia from 25 to 20 Ma, also accounts for the large displacements of rock units along the Harirud fault. Thus, the Palaeozoic core of the Turkmen and Paghman mountains north of Kabul is offset over 600 km westwards to reappear in the triangular area just southwest of Herat (Fig. 16).

## 7. Petroleum geology

The general location and relationship of petroleum fields to tectonics is outlined by Samsonow, (1994), Otto (1997), Persits et al. (1997) and Wandrey and Law (1997). Little is known in detail of Afghan hydrocarbon fields (Kingston and Clarke, 1995); however, some extrapolation is possible from fields in southern Uzbekistan and eastern Turkmenistan over the western Afghan borders (Clarke, 1994; Sagers, 1994).

### *7.1. Traps*

Oil and gas traps are mainly in Upper Jurassic carbonates and Lower Cretaceous sandstones across the entire North Afghan block (Kingston and Clarke, 1995). Almost all are structural, broad anticlines related to Neogene wrench faulting (Fig. 18). In this respect they are comparable with similar traps along the San Andreas trend (Harding, 1976). However, in other respects, particularly in the age and nature of source and trap rocks, they are not. Much of the gas

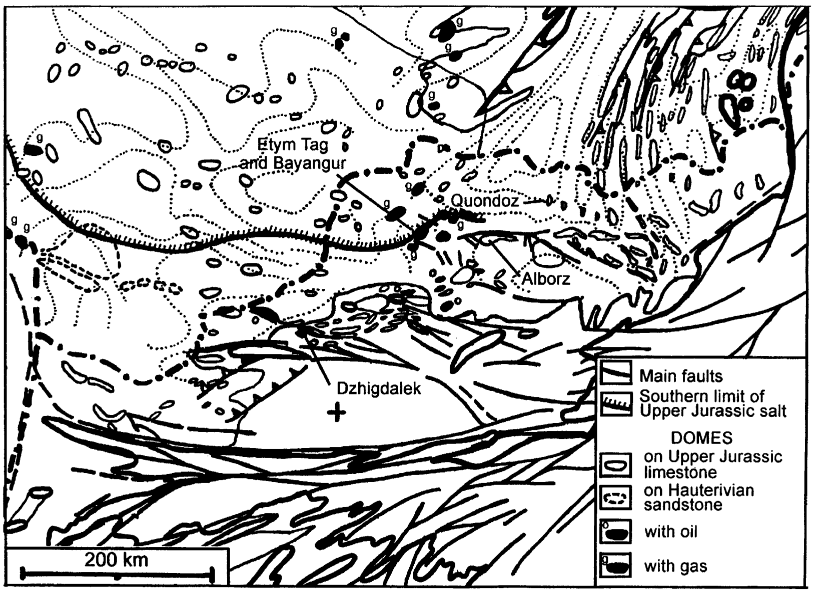


Fig. 18. Petroleum map of the North Afghan platform. Data from Clarke (1988, 1994) Samsonov (1994) and Bekker (1996). Legend for faults and isopachs on Fig. 15.

is sour gas, due to reactions with Mesozoic evaporites (Solob'yev et al., 1997).

Upper Jurassic carbonate traps occur mainly in the western and northern parts of the area, north of the limit of the Upper Jurassic salt. Here, the Callovian and Oxfordian carbonate reservoirs are effectively sealed by overlying Kimmeridgian–Tithonian salt and anhydrite. There are no large oil or gas deposits in post-Jurassic rocks where this Upper Jurassic salt is present. The small oil and gas fields in post-Jurassic rocks of the North Afghan platform derive from relatively meagre Lower Cretaceous–Palaeogene sources (see below). Towards the east and south, the evaporite and carbonate caps were eroded during the Early Cretaceous regression. In this area, hydrocarbons have migrated further up to collect in the Lower Cretaceous traps. There is no data on Upper Jurassic carbonate porosity and permeability in Afghanistan. In adjacent Uzbekistan, producing Upper Jurassic carbonates have porosities ranging from 9% to 20% (Clarke, 1994).

Lower Cretaceous (Hauterivian) sandstone traps consist of red continental fine-grained silty beds, which are sealed by Aptian–Albian shales and silt-

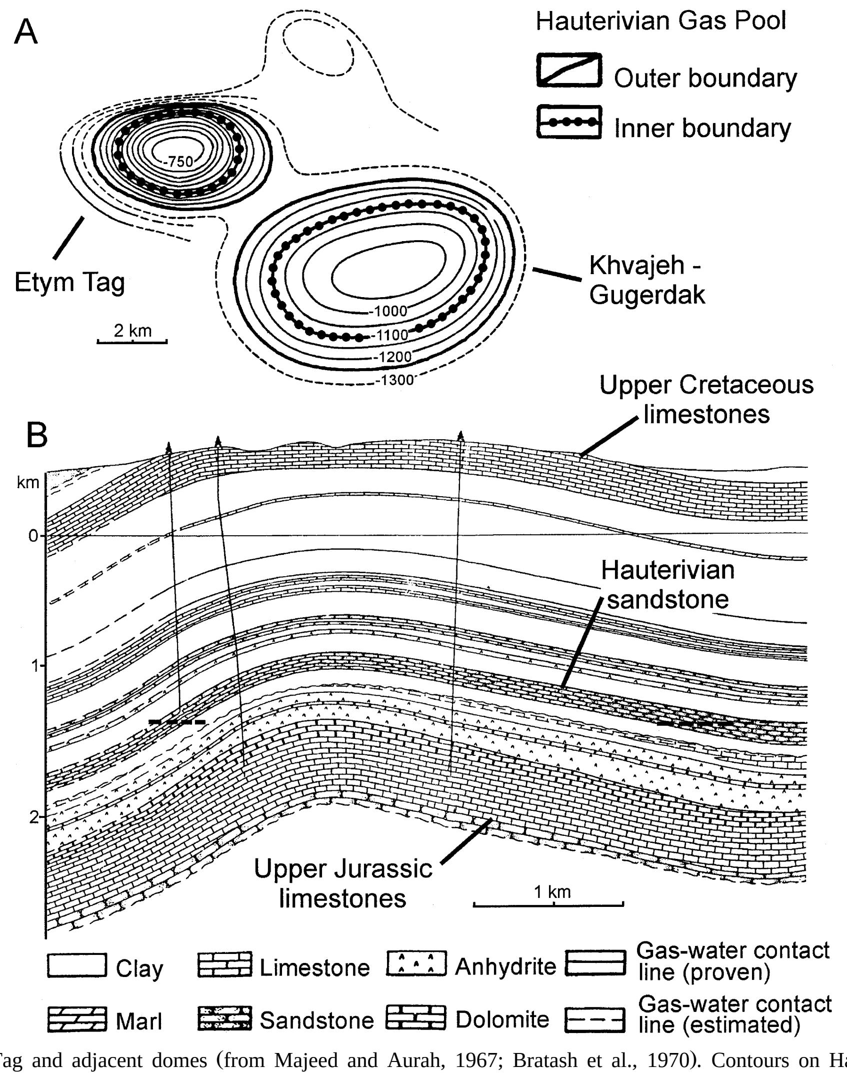


Fig. 19. (A) Etym Tag and adjacent domes (from Majeed and Aurah, 1967; Bratash et al., 1970). Contours on Hauterivian sandstone. Location on Fig. 18. (B) Cross-section through Etym Tag dome.

stones. The silty sandstones pass eastwards and southwards into conglomeratic facies unsuitable as reservoirs. Thus, like the Jurassic, economic petroleum deposits occur on the western and northern edges of the block. The Lower Cretaceous silty sandstones have porosities ranging from 6% to 14% and permeabilities ranging from 100 to 600 md (Kingston and Clarke, 1995). These are reduced in places by secondary evaporitic cements (Kryuchkov, 1997).

Latest Cretaceous–Palaeocene (Maastrichtian–Danian) carbonates are the main traps in the western edge of the Qualai–Naw unit and in the Tajik basin and are sealed by overlying Palaeogene shales. However, over most of the North Afghan platform, these carbonates are very thin and Miocene and younger erosion has removed much of the Palaeogene section. Porosities range from 16% to 18% (Kingston and Clarke, 1995).

The anticlinal closures, which form the traps, are, like those along the San Andreas fault, of three main types: small displacement traps, intermediate displacement traps and large displacement traps (Harding, 1974).

Small displacement traps have displacements too small to disrupt facies or general structural continuity. They form a series of slightly offset *en echelon* folds, which straddle the incipient wrench faults. Small displacement traps dominate the western and northwestern parts of the North Afghan platform and Murghab basin, where the large strike–slip faults of the central platform die out into parallel open folds and domes (Fig. 18). Here, a series of parallel and slightly offset closures lie along the fault trends. At the northwestern end of the Alburz–Mormul fault, the Etym–Tag and adjacent domes produce gas from Hauterivian sandstones (Fig. 19). Five kilometres east, the Bayangur group of domes show greater compression and are cut by very minor strike–slip faults (Fig. 20).

Intermediate displacement traps have displacements sufficient to cause through-going faulting and significant strike–slip displacements. *En echelon* anticlines are offset so that only half of the original fold may be present on one side of the fault. Furthermore, oblique slip may form half domes and depressions. At the northwestern end of the Bande Turkestan fault, a group of domes parallel to the fault trace appear to show intermediate displacements (Fig. 21).

Large displacement traps have large through-going faults, with increased structural relief on the associated folds, which, however, may be severely disrupted near the fault zone. Early domal structures are offset large distances. A good example of large displacement traps is further along the Alburz–Mormul fault from the Bayangur group, where the Alburz group of elongate domes lie south of, and are truncated by strands of the fault zone (Fig. 22).

North of the platform, the traps are typical compressed anticlines associated with the Tajik fold–thrust belt (Fig. 23).

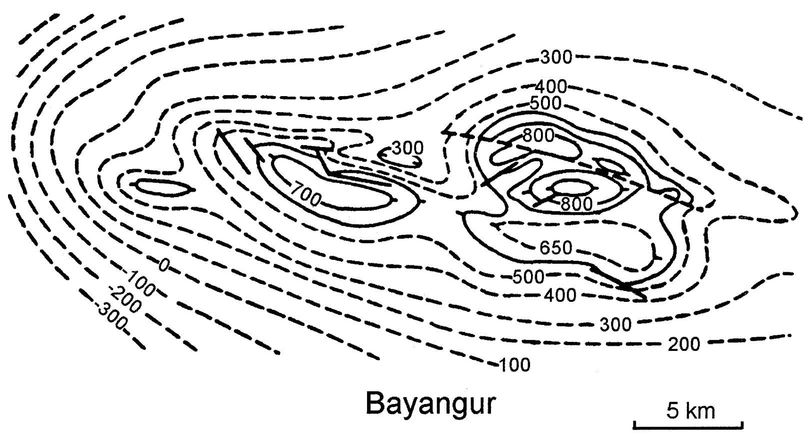


Fig. 20. Bayangur and adjacent domes (Bratash et al., 1970). Contours on Palaeocene marl. Location on Fig. 18.

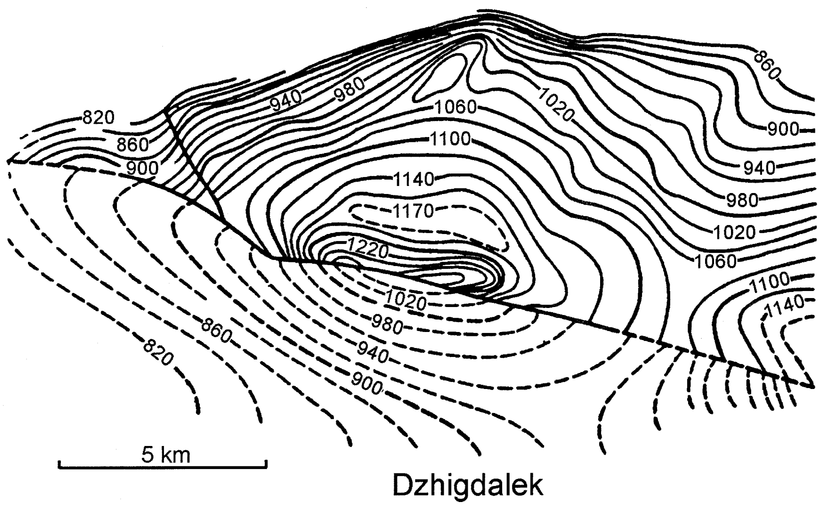


Fig. 21. Dzhigdalek high (Bratash et al., 1970). Contours on Lower Cretaceous red beds. Location on Fig. 18.

### *7.2. Source rocks, generation and migration of oil and gas*

Source rocks have been studied only northwest of our area, in the Amu Darya petroleum province (Chetverikova et al., 1982). Here, the hydrocarbon sources occur in the Mesozoic section and are dominated by the Lower–Middle Jurassic continental coal-bearing beds, which provides about 75% of the hydrocarbon yield. These humic coals yield mostly type-III kerogens. The Callovian–Oxfordian marine section provides 10% of the hydrocarbon yield of predominantly type-II kerogens. The mixed marine–continental Neocomian and Aptian–Albian provide a meagre 1% and about 14%, respectively. Presumably the hydrocarbons are mixed . The coal-bearing clastic source rocks decrease very markedly in thickness onto the North Afghan platform (Fig. 24).

The average geothermal gradient of the North Afghan producing wells is about 34.6°C/km. Under the (dubious) assumption that this gradient was oper-

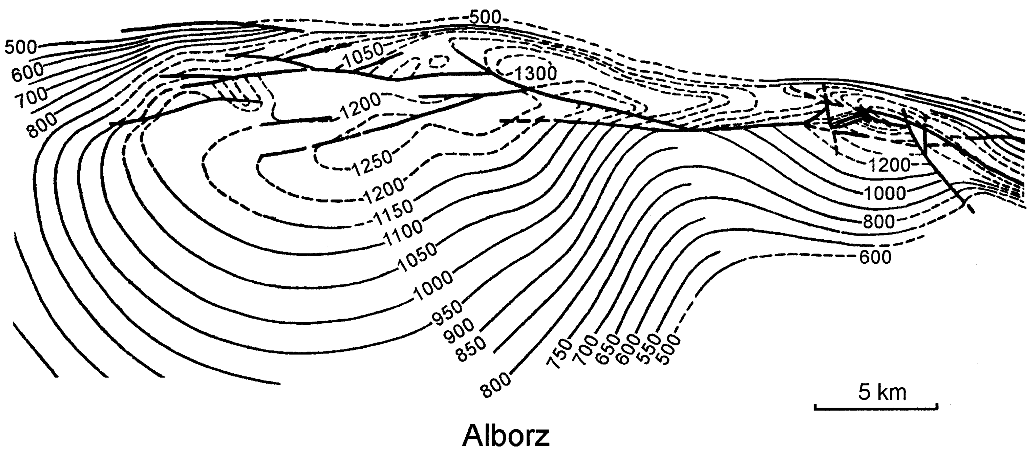


Fig. 22. Alborz high (Bratash et al., 1970). Contours on base of Upper Campanian carbonates. Location on Fig. 18.

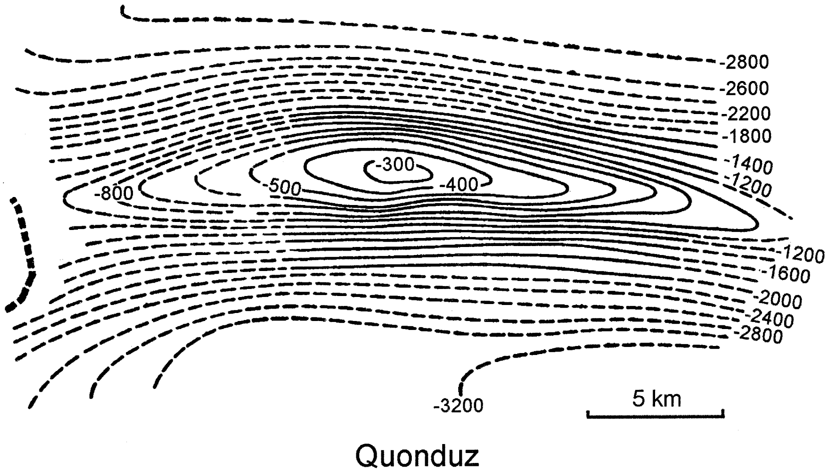

Fig. 23. Quondoz anticline (Bratash et al., 1970). Contours on top of Palaeocene carbonates. Location on Fig. 18.

ating during oil and gas genesis and migration, then the North Afghan platform is mostly gas-prone (Kingston and Clarke, 1995) and (a) the Jurassic carbonates are in the thermal gas window in all areas; (b) the Hauterivian Cretaceous sandstones are in the thermal gas window in the deeper parts of the Tajik and Murghab basins, but partly in the oil window on the edges of the basins and on the North

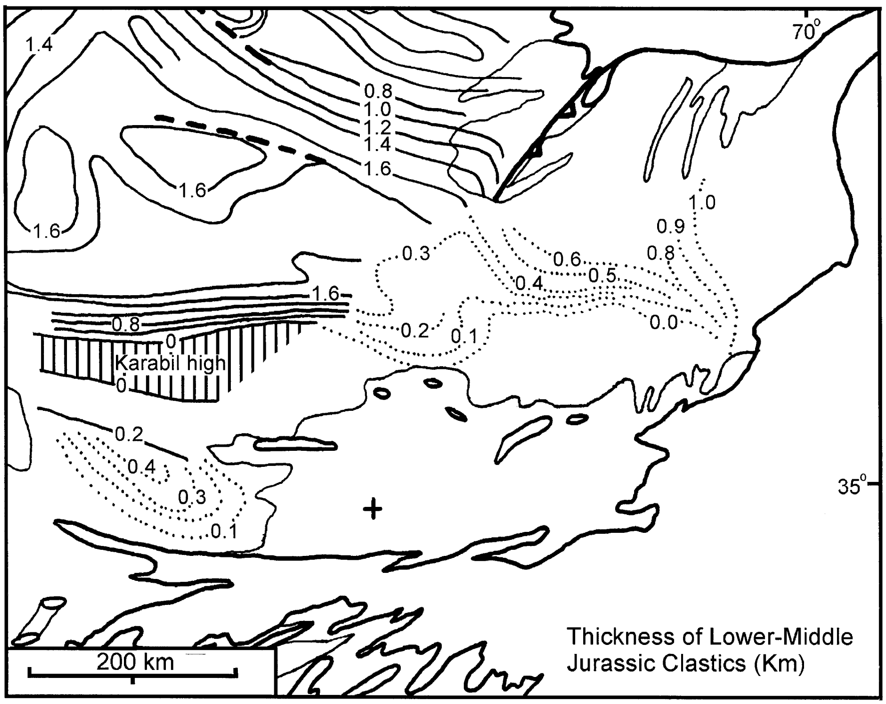

Fig. 24. Thickness of Lower to Middle Jurassic clastic sediments. Solid lines from Mal'tsever et al. (1979); dotted lines from Kingston and Clarke (1995): note incompatible.

Afghan platform; and (c) the Maastrichtian–Danian carbonates are in the oil window.

However, most of the Jurassic to Quaternary sections are only 4 and 6 km thick (Fig. 10), and the Lower Jurassic continental and marine Upper Jurassic sources not only have different predominant kerogen types, but probably different geothermal gradients during hydrocarbon generation. The likely burial history for each zones can be worked out from average thicknesses for each zone and the times of oil generation and migration inferred (Hunt, 1996). Thus, for the Lower Jurassic, the type-III kerogens, under a pull-apart basin geothermal gradient of 45°C/km would be in the oil window around a burial depth of 3 km. For all the sections, this is reached only during the latest Cretaceous to Oligocene. For the Upper Jurassic, the type-II kerogens, under the same geothermal gradient (considering that the overall tectonic situation is a back-arc basin), would reach the oil window at a much lower depth of between 1 and 3 km. For the Upper Jurassic in all sections this is reached in the Upper Cretaceous to Oligocene: at the same time and, in part, earlier than the Lower Jurassic.

High-sulphur sour gas is common in Upper Jurassic carbonates in the southern part of the Turan platform beneath the Upper Jurassic evaporite seal, and seems related to both evaporites and deeper burial with higher temperatures (Solob'yev et al., 1997).

### 7.3. Prospects

The bulk of hydrocarbon generation seems to have occurred in a relatively stable tectonic interval between the formation of a back-arc basin in the Jurassic and the formation of the Pamir starting in the Miocene. The accumulation of the hydrocarbons in the present structural traps is probably entirely Neogene. Although the dominant Lower Jurassic source beds are now in the thermal gas window, there was ample time during the Early Tertiary for them to migrate into the dominant Lower Cretaceous reservoirs, in the absence of the Upper Jurassic evaporitic cap.

There is no regional structural dip aiding southward hydrocarbon migration, and the traps are all structural and somewhat small. There is, thus, small chance of discovering very large petroleum fields on the platform. On the other hand, the probable Early Tertiary generation of most of the petroleum, and the Late Tertiary accumulation in traps beneath thick synorogenic clastics, suggests that little might actually have been lost at the surface. Modern detailed studies of the North Afghan platform should be rewarding because: (a) the isolated and sporadic traps of strike–slip belts make traps difficult to find without modern exploration techniques; and (b) the political troubles of the last 20 years mean that almost no exploration has been done. When political conditions become favourable, there should be ample potential especially in the northern and western parts of the North Afghan platform.

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