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A traverse through the western Kunlun (Xinjiang, China): tentative geodynamic implications for the Paleozoic and Mesozoic

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Abstract The northern part of the western Kunlun (southern margin of the Tarim basin) represents a Sinian rifted margin. To the south of this margin, the Sinian to Paleozoic Proto-Tethys Ocean formed. South-directed subduction of this ocean, beneath the continental southern Kunlun block during the Paleozoic, resulted in the collision between the northern and southern Kunlun blocks during the Devonian. The northern part of the Paleo-Tethys Ocean, located to the south of the southern Kunlun, was subducted to the north beneath the southern Kunlun during the Late Paleozoic to Early Mesozoic. This caused the formation of a subduction-accretion complex, including a sizeable accretionary wedge to the south of the southern Kunlun. A microcontinent (or oceanic plateau?), which we refer to as "Uygur terrane," collided with the subduction complex during the Late Triassic. Both elements together represent the Kara-Kunlun. Final closure of the Paleo-Tethys Ocean took place during the Early Jurassic when the next southerly located continental block collided with the Kara-Kunlun area. From at least the Late Paleozoic to the Early Jurassic, the Tarim basin must be considered a back-arc region. The Kengxiwar lineament, which "connects" the Karakorum fault in the west and the Ruoqiang-Xingxingxia/Altyn-Tagh fault zone in the east, shows signs of a polyphase strike-slip fault along which dextral and sinistral shearing occurred.

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Introduction

The western Kunlun Range and most of the Kara-Kunlun area was traversed in July and August of 1993. The 600 km long route followed the Xinjiang/Tibet Highway from Yecheng, at the southern margin of the Tarim basin, and reached the farthest point approximately 40 km northwest of Longmu Lake, which is also known as "Longmu Co," "Lung-Mu T'so," or "Tsaggar Tso" (Figs. 1 and 2), close to the Xinjiang/Tibet border. Our investigations were not restricted to the immediate vicinity of the highway. In several areas, we carried out detailed investigations in side valleys off the highway.

Until a few years ago, the study area had been "closed off" to western geoscientists for several decades. A 1988 Italian expedition team was the first foreign geological party to be allowed to study the geology of the area since 1949 (Gaetani et al. 1990). In 1989 and 1990, French geoscientists also carried out investigations in joint Sino-French expeditions (Pan et al. 1992). In the course of the Sino-French program, four geotraverses across the Kunlun Range were investigated (Xu et al. 1992). Hsü visited the western Kunlun in 1992 (Yao and Hsü 1994). These works increased the knowledge of the study area substantially. We consider the work by Xu et al. (1992) and the modern synopses by Pan et al. (1992) and Yao and Hsü (1994) especially meritorious. A review of the regional geology, the history of research and expedition results of early European geoscientists is given by Sengör and Okurogullari (1991).

Our investigations have to be viewed under the aspect of some particular circumstances. The southern part of the Kara-Kunlun is considerably less investigated than the northern parts of the study area. Budget

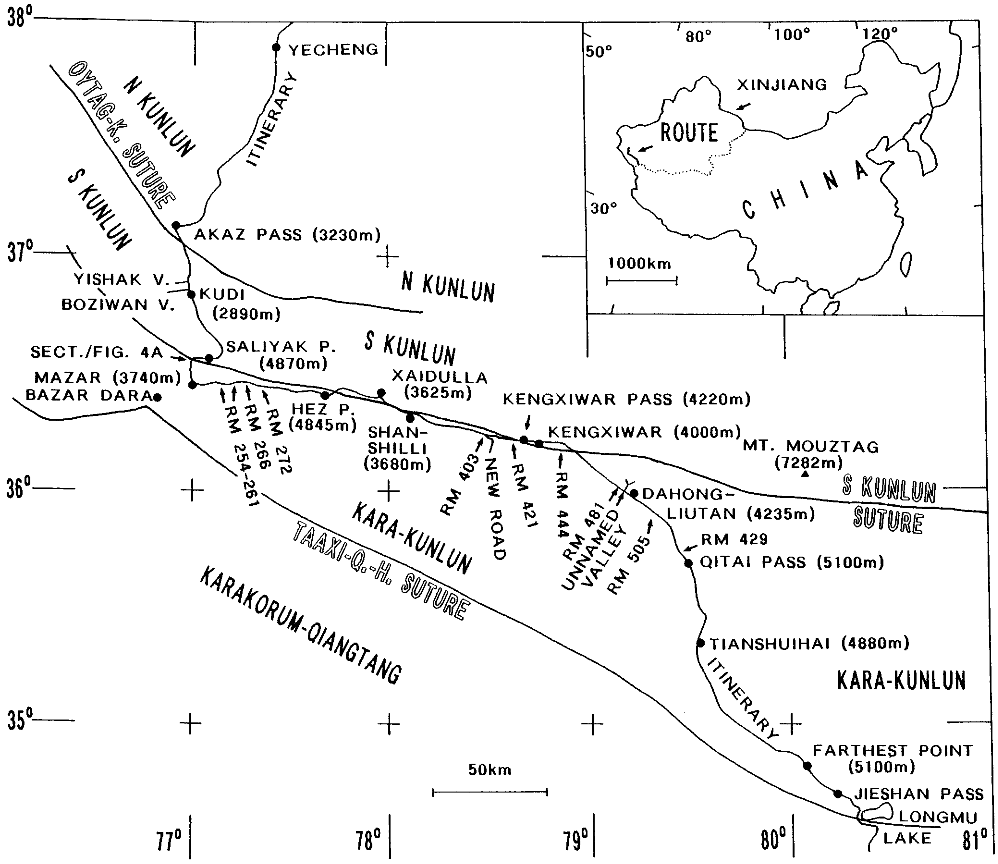


Fig. 1 Map of the route showing important locations mentioned in the text and main tectonic units (drawn after Liu et al. 1988; Gaetani et al. 1991; BGMR 1993). Altitude data, generally unavailable, were recorded using small field altimeters. According to Geatani et al. (1990) the altitude of the Akaz Pass ("Aq-Koram Pass") measures 3475 m and the altitude of the Saliyak Pass ("Cirag Saldi Pass") 5010 m

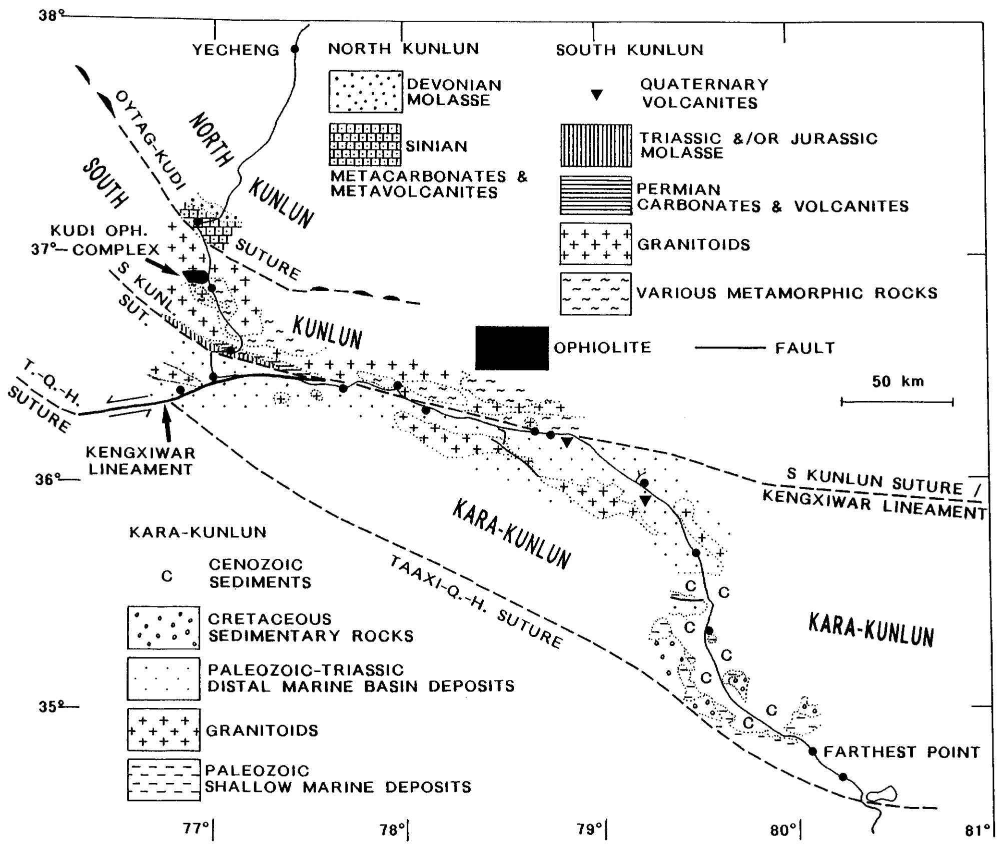


Fig. 2 Simplified map of the immediate area of the route. For names of the marked locations (*dots*) compare with Fig. 1 (drawn after Liu et al. 1988 and BGMR 1993 and our own observations). Due to scale problems, not all strata shown in Fig. 4 can be differentiated on this map

restraints, the limited time of 6 weeks for field work within the summer (the only season suitable for field work) and the Saliyak Pass schedule, which allows only one-way traffic for 1 or 2 days between longer time spans of the pass's closure, had an impact on the planning and execution of the traverse. Apparently, we had to face problems which other researchers had had working in that region (compare e.g. Desio 1991). We knew that we had to deal with various geological aspects. However, the planning could not provide for all geological phenomena to be treated equally in detail, nor could it provide for the collecting of very large data sets.

The western Kunlun is located south of the Tarim basin and north of the western part of the Tibetan plateau. It is one of the highest elevated mountain ranges (Mt. Kongur: 7719 m; Mt. Muztagata: 7546 m; Mt. Mouztag: 7282 m) with high local relief. To the east of Kudi, the range trends approximately 110°; to the west, the trend changes to approximately 135°. We refer to this area as the "Kudi orocline." The Kara-Kunlun area to the south of the western Kunlun represents the western part of the Tibetan plateau. The estimated average elevation of this low relief area is approximately 5000 m. To the south, the Kara-Kunlun is bordered by the Karakorum Range.

The study area comprises a significant portion of the complex continental Eurasia/India accretionary zone (Fig. 3). The northern Kunlun represents the southern geological continuation of the Tarim basin. It is separated from the southern Kunlun by the Oytag-Kudi suture. The southern Kunlun borders the Kara-Kunlun along the south Kunlun suture. The Taaxi-Qiaoertianshan-Hongshanhu suture, which we almost reached, separates the Kara-Kunlun from the Karakorum Range. The accretion of these units occurred during the Paleozoic and Mesozoic. The accretionary processes tend to become increasingly younger to the south.

Some important literature about the regional geology is difficult to obtain; therefore, the knowledge of this area is not yet widespread. We intend to combine the literature data and our own observations to put forward a preliminary account of the basic regional plate tectonic accretionary history. To do so we are applying fundamental methods of orogenic analysis.

Sensible "matching up" of suture zones with magmatic subduction-related belts should help to determine former subduction polarity. The age of subduction-related magmatites should help to date the time of subduction (possible indication for onset and cease). Cessation of subduction may be related to continental collision. Uplift, as a result of collision, should be reflected by the accumulation of coarse, often continental, molasse deposits. The age of a suture overlap assemblage or the age of a pluton intruding across a suture indicates a time as to when accretion must have been completed (Coney 1989). Also, we considered tectonostratigraphic terrane analysis as outlined by Howell et al. (1985) or Coney (1989).

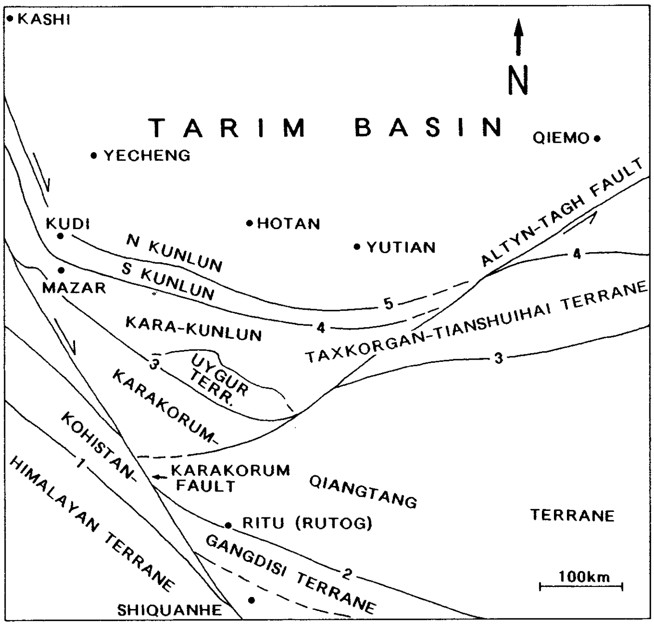


Fig. 3 Simplified map of sutures, major strike-slip faults and accreted terranes of the study area and adjacent regions (drawn mainly after Pan et al. 1992). *1* Indus-Yarlung-Zangbo suture; *2* Bangong-Nujiang suture; *3* Taaxi-Qiaoertianshan-Hongshanhu suture (towards the east referred to as "Litjian-Jinsha suture"); *4* South Kunlun suture; *5* Oytag-Kudi suture. The Taxkorgan-Tianshuihai terrane is referred to as "Songpan-Garze terrane" farther east

Although the main aim of the expedition was to understand the regional accretionary history, some special emphasis was put on the Kudi ophiolite complex, the south Kunlun suture, and the Kengxiwar lineament which is partially identical with that suture, as well as the tectofacies of sediments and their geodynamic significance.

We were lucky to be able to use a new geological map (BGMR 1993) of the study area. The age data of sedimentary rocks mentioned in the text mainly derive from this map, which lists fossil findings for the individual formations, but also from Liu et al. (1988) and Pan et al. (1992). The map by the Bureau of Geology and Mineral Resources of Xinjiang Uygur Autonomous Region (BGMR 1993) represents a further advancement on previous maps published by this institution.

Locations of the study area mentioned in the text are found in Fig. 1.

The northern Kunlun

The northern Kunlun represents the southern margin of the Tarim block which is pressed onto the Tarim basin by a major fault (Tian et al. 1989; Sengör and Okurogullari 1991; Arnaud et al. 1993; Brunel et al. 1994). The basement of the northern Kunlun is characterized by Middle and Late Proterozoic gneisses and migmatites (Pan et al. 1992). The basement may locally be intruded by a Proterozoic gneissic potassic granite (Xu et al. 1992).

The oldest strata, which are well-exposed around the Akaz Pass, are slightly metamorphosed Sinian laminated carbonates (stromatolites?) stratigraphically alternating with metavolcanites. There are also metamorphosed shales, marls, and tuffites. The laminated carbonates indicate a shallow marine environment on a subsiding shelf platform. Locally, alternations of parallel bedded limestone and dolomite occur. The metavolcanites represent former oceanic tholeiites (Pan et al. 1992). We assume that 1 km of thickness is not enough for this Sinian sequence. The age of the rocks is viewed controversially. Whereas Pan et al. (1992) assign a Sinian age, some Chinese scientists consider an Upper Permian age (K. J. Hsü, pers. commun.). However, there are a few aspects pointing to the likelihood of a Sinian age. Similar Sinian rocks of great thickness are known from the Tarim basin where they are overlain by Lower Paleozoic strata (Tian et al. 1989). Laminated carbonates (stromatolites) of Sinian age from the Yangtze region are also known to the authors. Also, structural observations make a Sinian age more probable because from the margin of the Tarim basin towards the southern limits of the northern Kunlun, the rocks display the overall tendency to dip to the north, exposing successively older rocks from north to south (see Fig. 13). The metamorphic rocks in question occur in the southern realm of the northern Kunlun, south of the nonmetamorphic Paleozoic deposits. The shallow marine Sinian strata south of Hotan, to the west of the study area, have been dated on the basis of microfloral and small shelly fossils (Yao and Hsü 1994).

In the northern Kunlun, the Sinian rocks are unconformably overlain by Upper Devonian red molasse clastics and acidic to intermediate volcanites. The Devonian clastics which have been dated by pollen analysis (Yao and Hsü 1994) represent fluviatile and alluvial fan deposits. They are texturally and compositionally of low maturity. Lithic fragments are derived from nearby granitoids, rhyolites, acidic to intermediate altered pyroclastics, and basic volcanites.

The Carboniferous and Permian are made up of marine carbonates (Pan et al. 1992; Yin 1992). These are well-dated for the entire Kunlun Range by bivalves, brachiopods, and corals (BGMR 1993).

Terrestrial coal-bearing clastics dominate the Jurassic deposits. The Cretaceous is represented mainly by continental red beds. The deposition of continental clastics also continued during the Cenozoic.

In the northern part of the northern Kunlun, the layers dip preferably towards the Tarim basin. The preferred dip of fold axes of the Sinian strata is gently towards 140° (see Fig. 8A).

The Oytag-Kudi suture

The Oytag-Kudi suture is characterized by the alignment of ophiolite bodies which appear to be narrow in plan view (Fig. 2; Liu et al. 1988). East of the Kudi orocline, the suture trends WNW. To the west, it takes a NW to NNW path (Liu et al. 1988). Among these ophiolites, ultramafic rocks, pillow lava, basalt, swarms of diabase dikes, and siliceous flysch deposits are known (Pan et al. 1992). Pan et al. (1992, their Fig. A-2) indicate that the suture dips to the southwest, approximately 12 km east of Kudi.

The southern Kunlun

The southern Kunlun is relatively narrow (Fig. 3). The basement of Late Paleozoic and younger cover rocks is largely composed of gneisses, amphibolites, and migmatitic gneisses. The gneisses and amphibolites were intruded by acidic and basic dikes which also experienced amphibolitic metamorphism (Pan et al. 1992). Along the N/S-trending Kudi Valley, the foliation of the metamorphic rocks generally dips in varying angles to the west. However, 1 km south of Kudi, the foliation dips steeply towards 190°.

Voluminous granitoids occur within the basement. Contact-metamorphic rocks can be studied in the Boziwan Valley and along the Xinjiang/Tibet Highway, north of the Boziwan River. Numerous and different kinds of radiometric data indicate two intrusive intervals (Xu et al. 1992; Zhang et al. 1992). On the basis of these data, Zhang et al. (1992) concluded that the granitoids, in the northern part of the southern Kunlun, were emplaced during the Paleozoic between 540 and 400 Ma (Middle Cambrian to Lower Devonian, according to Haq and van Eysinga 1987). Radiometric ages determined by Fan and Wang (1990) also fit into this time span. According to Zhang et al. (1992), a southern granitoid belt was emplaced during the Late Paleozoic and the Triassic between 260 and 200 Ma (Upper Permian to lowermost Jurassic, according to Haq and van Eysinga 1987). Tables of major, trace and rare earth element composition data have been published by Pan et al. (1992). The northern and the southern granitoids plot in the calc-alkaline region (Pan et al. 1992, their Fig. A-9). This is consistent with the findings by Fan and Wang (1990) and Zhang et al. (1992). These compositional considerations, as well as the 1000 km long linear extent (Xu et al. 1992) of these granitoid belts parallel to the orogen (see Fig. 11A), lead to the conclusion that the formation of these granitoids is closely related to the subduction of oceanic lithosphere. Hsü (1988) had already considered the batholithic intrusions of the Kunlun as the roots of volcanoes on an active plate margin (see also Sengör and Okurogullari 1991).

The traverse's segment from the area around the Oytag-Kudi suture to the northern part of the Kudi ophiolite complex is characterized by intense ductile and brittle shearing. Between the Oytag-Kudi suture and the Kudi ophiolite complex, close to the local bridge, the granitoids of the northern belt were mylonitized at strike-slip faults (protomylonites sensu Sibson 1977). At E/W- and NW/SE-trending shear zones, left-lateral shear sense was detected by the occurrence of aggregates of dynamically recrystallized, highly strained, fine-grained quartz grains displaying low-energy grain boundaries and grain elongation obliquely oriented to the main mylonitic foliation. Occasional sinistral shear band fabrics sensu Mawer (1992) can be observed. Along the synthetic foliation, hornblende porphyroclasts with the same extinction are left-laterally displaced. There are also sheared hornblende porphyroclasts which are displaced left-laterally and parallely to the main mylonitic foliation (compare White et al. 1986) displaying also the same extinction. Hornblende and feldspar porphyroclast systems with distinct stair-stepping tails (sensu Lister and Snoke 1984; Passchier and Simpson 1986; Simpson and De Paor 1993) also confirm the sinistral shear sense. Thin section evidence shows that younger right-lateral shearing occurred parallel to the N/S direction. North/south-trending mylonite intersects with the protomylonite and dextrally drags the main protomylonitic foliation. Moreover, dextral feldspar porphyroclast systems were observed within the mylonite. The granitoids were also intensely sheared by brittle E/W-trending faults.

In contrast to the northern Kunlun, there are no Sinian laminated marbles and interbedded metavolcanites. According to Pan et al. (1992), the basement is unconformably overlain by terrestrial Lower Devonian red molasse deposits (not occurring along the route) which grade upwards into carbonates, intercalated with Late Carboniferous to Permian volcanites of intermediate to basic composition. We found these volcanites alternating with stromatolitic carbonates of the Lower Permian east of Mazar. The Late Paleozoic age of the Carboniferous and Permian marine deposits of the Kunlun is well-documented by foraminifers, corals, bivalves and brachiopods (BGMR 1993; Yao and Hsü 1994).

East of Mazar, red continental clastics of the uppermost Triassic lie above the Paleozoic at an overturned angular unconformity (Fig. 4B). The Triassic sandstones and conglomerates represent alluvial fan deposits of low textural and compositional maturity. They contain limestone and dolomite fragments of reworked Carboniferous and Permian strata as well as lithic particles of chert, shale, and quartzite. The Triassic molasse deposits were shed from proximal sources. In the eastern Kunlun Range, the Triassic is well-dated by numerous kinds of fossils (Yang and Long 1990).

The Jurassic strata are similar to the ones of the northern Kunlun. They also are coal seam-bearing and represent intramontane basin-type deposits (Pan et al. 1993). They contrast with the underlying Triassic because they lack red color and because we found a significant amount of granitoid debris. The low textural and compositional maturity of the Jurassic indicates a close provenance. Although the deposits are rich in plant fossils and some have been identified by BGMR (1993), the authors are uncertain as to how the age has

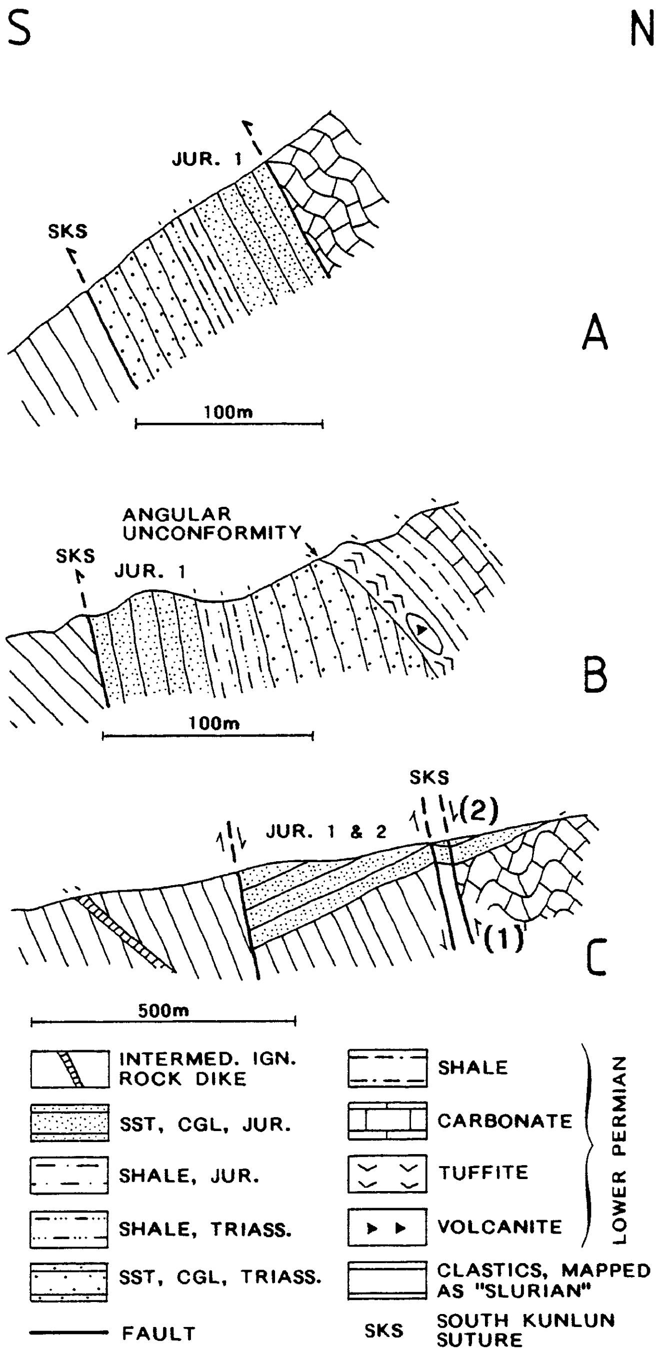


Fig. 4A–C Sketches of sections across the south Kunlun suture (*SKS*) which reveal tectonic movements between the uppermost Triassic and the Lower Permian (first unconformity in **B**) and during the Early Jurassic which is compressively deformed (**A, B**). Compression must have ceased before the Lower and Middle Jurassic (second unconformity in **C**). The tectonic interpretation of these sections with regard to their orogenic significance is given in the text. **A** Southern slope of the Saliyak Pass, approximately 10 km north of Mazar, elevation 4650 m. **B** Valley of a northern tributary of the Yarkant River, 26 road km east of Mazar, north of road mark 266, elevation 4000 m. **C** Wadi of a northern tributary of the Yarkant River, 32 road km east of Mazar, north of road mark 272, elevation 4100 m thus-far been accurately determined. The fossil leaves mentioned by BGMR (1993) are not very conclusive. However, Yao and Hsü (1994) mentioned the same coal-bearing strata for the area south of Hotan and the eastern Kunlun. At the latter region the Jurassic is overlying the well-dated Triassic (Yao and Hsü 1994).

According to Pan et al. (1993) – there are scattered small "red basins" which developed since the Cretaceous (also not occurring along the route).

The Kudi ophiolite complex

The Kudi ophiolite complex is located northwest of Kudi, in the northern part of the southern Kunlun. This rock unit is related to the Oytag-Kudi suture. A clear distinction must be made between the aforementioned narrow ophiolite bodies of the Oytag-Kudi suture which define the actual site of collision ("suture trace" sensu Sengör et al. 1988) and the Kudi ophiolite complex. The latter is a large rock unit differing in size and shape from the narrow ophiolite bodies of the suture in the strict sense. Compared with the other ophiolite bodies which are aligned, the Kudi ophiolite complex is also located "out of trend" to the south of the suture (Fig. 2). These circumstances show a perfect match with the situation depicted by Sengör et al. (1988, their Fig. 21A) which explains the general distinction between ophiolite bodies representing the suture trace and an obducted ophiolite nappe. Accordingly, the large Kudi ophiolite complex resembles a nappe more than an ophiolite slice of the suture trace. The nappe interpretation is also supported by our structural findings according to which the Kudi ophiolite complex rests more or less horizontally on top of granitoids and hornfels (Fig. 5). Therefore, it is reasonable to conclude that the Kudi complex was thrust from the suture in a southern direction.

North of Kudi, the northern part of this nappe is relatively well exposed along 8 km of the Xinjiang/Tibet Highway following the western slope of the Kudi Valley. Our investigations included these outcrops and those at the northern slope of the Boziwan Valley, a few kilometers west of the highway, as well as the river bed of the Yishak Valley. In the Boziwan Valley, the southern margin of the Kudi ophiolite complex is exposed.

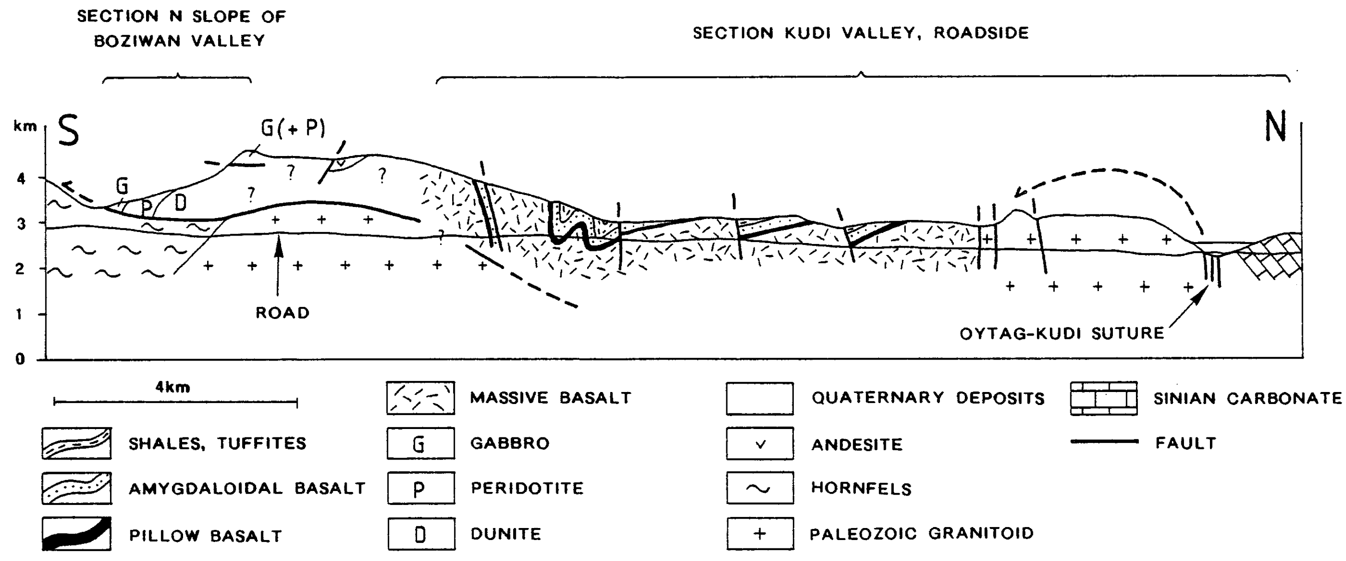
The layering of the Kudi ophiolite complex was investigated (Fig. 6). The lowermost level of oceanic lithosphere is represented by dunite which was studied at the northern slope of the Boziwan Valley at an altitude of approximately 4000 m. This upper mantle rock may display a coarse-grained, massive, structureless fabric. Occasionally, thin parallel laminations of chromite occur which can be intersected by thin (up to a few centimeters) pyroxenite dikes. Also, hornblendite dikes (up to 1.5 m thick) were observed within the dunite. The dunite layer is at least 200 m thick. Only the top part of this layer is exposed.

South of the dunite, at an altitude between 3300 and 3800 m, at least 100 m thick partly serpentinized peridotite was observed. There are two peridotite varieties. The first one is relatively fine-grained, massive, and structureless. The second one is characterized by the layering of pyroxene cumulates. Within the peridotite, pyroxenite bodies occur.

The next ophiolite layer consists of coarse-grained gabbro. The gabbro was studied south of the peridotite at an altitude of approximately 3200 m. The thickness of this layer measures at least 50 m. Only the base of this layer is exposed.

The following ophiolite layers were studied along the highway, north of Kudi. There, massive, generally fine-grained basalt with a thickness of several hundred

Fig. 5 Cross section of the Kudi ophiolite nappe, combining the two investigated sections of the Kudi and Bozivan valleys. Minor occurrences of metamorphic rocks other than hornfels are not shown



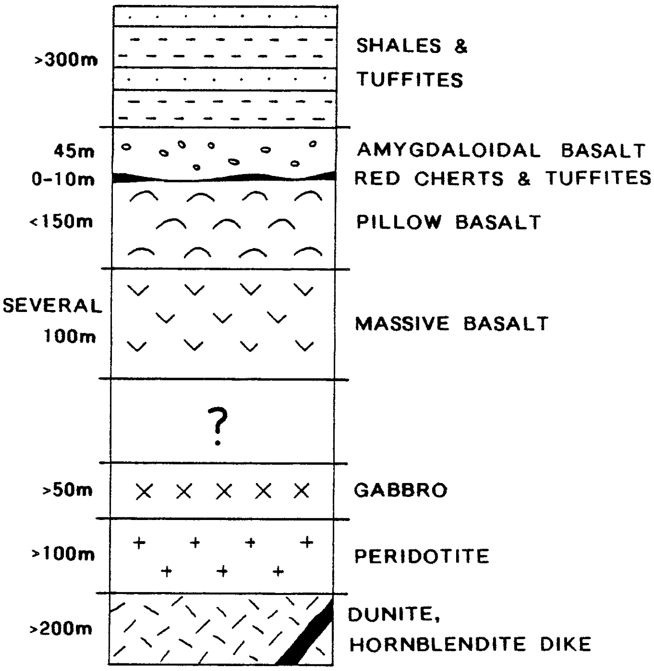


Fig. 6 Lithologies of the Kudi ophiolite complex

meters represents the lowest ophiolite level. The "stratigraphic" and tectonic relationship between the massive basalt and the gabbro from the Boziwan Valley are unknown.

Above the massive basalt, we found pillow lava which may be up to 150 m thick. The pillow lava and all following layers could also be studied in the river bed of the Yishak Valley. The diameter of the mainly spherical pillows usually does not exceed 1 m. The pillows display typical features such as altered glassy rims and amygdules mainly at the top.

Lenses of hematitic cherts (up to 2 dm thick) were observed in the top of the pillow layer. The cherts are associated with tuffites and shales. This layer measures 0–10 m.

The next layer towards the top is an amygdaloidal, massive, approximately 45 m thick, slightly red or brown basalt. Associated with this layer is a debris flow with a thickness of several decimeters (only observed in the Yishak Valley).

The uppermost layer consists mainly of red shales and green tuffites. Both rock types may occur in thin alternating layers of only a few centimeters or may occur monotonously for several meters or even tens of meters. The red shales are often intercalated with millimeters to centimeters thick gray-colored graded layers. The grain size of the tuffites ranges from clay to conglomeratic sandstone. Coarse tuffites from the Yishak Valley contain basic volcanic lithic components with plagioclase phenocrysts. The volcanic debris may exhibit devitrified glass components and fragments with flow fabrics like well-deformed vesicles. All facies types of these deposits appear to be silicified. At the base of this unit, thin (up to 1 dm thick) hematitic cherts frequently occur. This layer is at least 300 m thick.

According to Wang (1983), the total thickness of the ophiolite complex measures more than 2000 m. As explained above, the obducted ophiolite nappe is related to the Oytag-Kudi suture. This implies that it was thrust from there to a southern (south-southwest?) direction (Fig. 5). We could not find an exposed contact between the ophiolite complex and underlying rocks. However, the ophiolite complex is located on top of the granitoids and adjacent hornfels. Because we found neither granitoid dikes nor acidic pegmatite dikes which could genetically be related to granitoids within the intensely fractured complex, we must assume that the nappe emplacement postdates the age of the immediately underlying granitoids.

The northern part of the Kudi ophiolite complex gently dips towards the SSW (Fig. 5). The central part is tightly folded. In this segment the uppermost layers of the ophiolite complex are preserved in a syncline (slope to the west of the highway and Yishak Valley). The lowermost layers are exposed in an anticline in the south (Fig. 5). The general trend is approximately 110°. The fold axes (only three determined) dip at different angles to the ESE (Fig. 8B). The folds display a vergence opposite to the concluded direction of transport. This phenomenon may be attributed to postobductional compression related to subsequent orogenic processes.

Along the highway, the ophiolite nappe is intensely faulted (brittle deformation). The faults are mostly vertical or subvertical. There are cataclasis zones of up to 50 m in width. They are characterized by countless curved joints. Slickenlines could be measured at smaller faults. The dip angle of these striae is usually below 30° and indicates mainly lateral displacements. There are two sets of faults. The main set trends 120°, the other 85° (Fig. 8C). This brittle shear pattern is very similar to the ductile one of left-lateral shear sense observed north of the Kudi ophiolite (see above). However, we could not determine the shear sense for brittle faults of the Kudi ophiolite unit due to the sparseness of good shear sense criteria.

Age data pertaining to the Kudi ophiolite complex are seemingly controversial and difficult to interpret. According to the Institute of Geology and Mineral Resources, Urumqi, Xinjiang (correspondence), the radiolarian-bearing deposits at the top of the ophiolite complex date as Carboniferous to Permian and the pillow lava yields an Rb/Sr isochron age of 359 Ma (more details of the procedure left unmentioned). The latter date is very close to the Devonian/Carboniferous boundary (Haq and van Eysinga 1987). However, other radiometric data indicate that the basic to ultrabasic rocks are of Sinian to Early Paleozoic age. According to Pan et al. (1992), a model age of the pillow lava yielded an age of 600–900 Ma, and an amphibolitic dike within ultramafic rocks yielded an Rb/Sr isochron age of 816 Ma. According to Wang (1983), a quartz diorite, dated 517 Ma (K/Ar whole-rock age), intruded the volcanites of the complex. Xu et al. (1992) provided the following data for a granodiorite which intruded the pillow lava: an $^{40}Ar/^{39}Ar$ plateau age on hornblende of 474 Ma, an $^{40}Ar/^{39}Ar$–$^{39}Ar/^{36}Ar$ isochron age on biotite of 449 ± 24 Ma and a U/Pb concordant age on zircon of 458 Ma (Xu et al. 1992). In both cases the exact location of the intrusive contacts were left unmentioned. (Was the same place sampled?) Pan et al. (1992) attributed the intrusion of the granitoid into the Kudi ophiolite to a steeply dipping subduction zone (they must mean a postobductional intrusion). We are hesitant to assume such an intrusion (see above). If there is indeed a "younger" pillow lava, this would imply that the Kudi ophiolite nappe consists of at least two thrust units containing pillow lava. Our structural investigations, however, do not support this idea.

The south Kunlun suture and the Kengxiwar lineament

In the study area-the south Kunlun suture zone lacks outcrops of ophiolites which are found in other locations along this suture, e.g., 110 km east of Dahongliutan (Liu et al. 1988) or farther east (Chang et al. 1989; Pearce and Deng 1988).

Satellite images indicate that the approximately ESE-trending south Kunlun suture is generally identical with the Kengxiwar lineament. From the Hez Pass area, however, the lineament takes a different trend towards the west (Fig. 2).

In the study area, the suture separates Paleozoic to Triassic mainly fine-grained, marine basin deposits of the Kara-Kunlun from cover or basement rocks of the southern Kunlun.

In the western part of the suture, north of the Kengxiwar lineament, we investigated three sections (Fig. 4) with a key significance as to the understanding of some of the Mesozoic orogenic events.

At the western slope of the Saliyak Pass (Fig. 4A), we observed that the uppermost Triassic and the lowermost Jurassic of the southern Kunlun are pressed onto the Paleozoic of the Kara-Kunlun at a fault which dips at an angle of 65° to the NNE. The Mesozoic strata are tectonically overlain by the Lower Permian of the southern Kunlun. The transition between the Triassic and Jurassic is characterized by 10–20 m of shales (compare Gaetani et al. 1990, 1991).

In the valley of a northern tributary of the Yarkant River (Fig. 4B), we found an overturned unconformity between the Lower Permian and the uppermost Triassic deposits. The latter grades into the lowermost Jurassic by approximately 20 m of shaly deposits. The Jurassic beds are vertical and pressed onto the Paleozoic basin deposits of the Kara-Kunlun at a fault which dips to the NNE at an angle of approximately 75°.

In a wadi of another northern tributary of the Yarkant River (Fig. 4C), Lower and Middle Jurassic coal-bearing clastics unconformably overlap both the Paleozoic of the Kara-Kunlun as well as the Lower Permian carbonates and volcanites of the southern Kunlun, thus covering the suture. The Jurassic dips southward and displays monoclinal deformation above the suture along which the Lower Permian of the southern Kunlun was pressed onto the Paleozoic of the Kara-Kunlun in the subsurface. The monocline reveals an opposite shear sense in comparison to the compressive suture fault (Fig. 4C); therefore, the monocline postdates the orogenic compression.

Whereas the south Kunlun suture between the Saliyak and Hez passes dips steeply to the NNE, its orientation may vary east of the Hez Pass where it coincides with the Kengxiwar lineament. At the eastern slope of the Hez Pass (south of highway, altitude 4350 m), the fault, well-marked by a quartz dike, dips at an angle of 60° to the SSW between the fine-grained marine basin deposits of the Kara-Kunlun and the granitoids of the southern Kunlun. Similar observations were made farther east along the highway at an altitude of 3850 m.

The Kengxiwar lineament is the most prominent lineament of the study area (Figs. 7 and 11A and B); it mainly trends approximately 100°. It coincides with the wide valleys of the Yarkant and Karakax rivers as well as with tributaries of the latter. East of the study area, the Yurungkax River follows the lineament.

South of the south Kunlun suture (14–21 km east of Mazar, road marks 254–261), where the Yarkant Valley is exceptionally narrow, the brittle fault pattern of the Kengxiwar lineament was investigated along the road. There, only faults which showed slickenlines were measured. Among 64 faults, 70% displayed striae with dip angles below 31°. Among these strike-slip faults, most displayed a trend between 90 and 100° which is approximately parallel to the trend of the lineament (Fig. 8F). This way we can demonstrate significant strike-slip deformation at the Kengxiwar lineament. Because shear sense criteria are not well-developed, we analyzed the remaining strike-slip faults with regard to their geometric relationship to the main set of strike-slip faults in order to obtain clues as to the shear sense. We attempted to see whether they display a preferably synthetic dextral or sinistral orientation (compare Harding 1974, his Fig. 1) to the Kengxiwar lineament. The rose diagram (Fig. 8F) of all strike-slip faults indicates no significant difference in the amount of faults of synthetic dextral or synthetic sinistral orientation (i.e. no significant asymmetry). This result is ambiguous. It could be interpreted that both kinds of lateral movements occurred at the lineament or that the faults of seemingly dextral or sinistral synthetic orientation represent preexisting fractures whose orientation was suitable for reactivation, but are only variations of the main dextral(?) or sinistral(?) shear direction.

Map studies (Liu et al. 1988; BGMR 1993) and satellite image investigations by Gaetani et al. (1991) indicate a major left-lateral displacement of the Taaxi-Qiaoertianshan-Hongshanhu suture in the western part

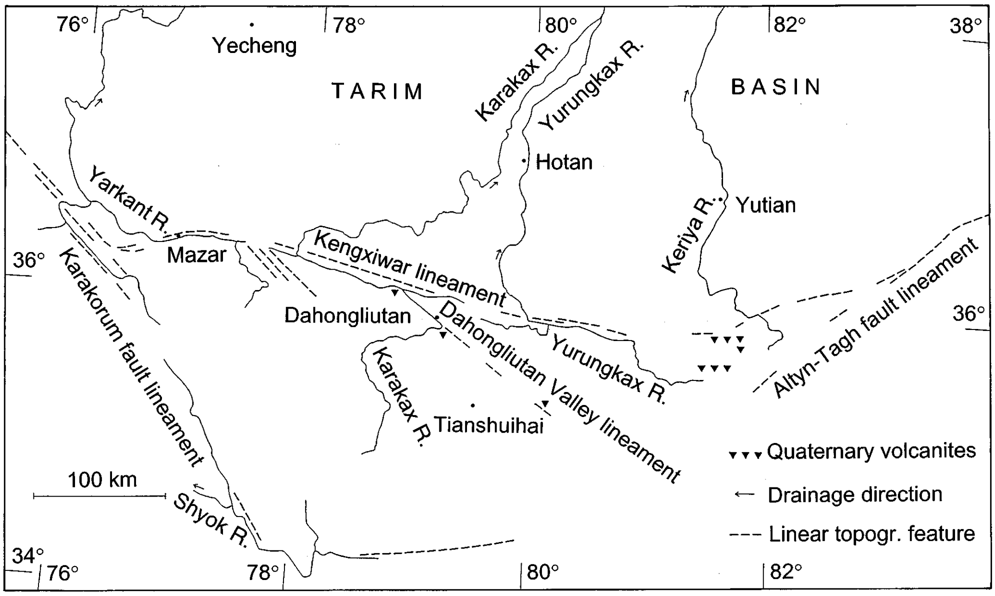


Fig. 7 Lineaments of the western Kunlun after Landsat-1,2,3-MSS scenes and GXUAR and AS (1987). Distribution of volcanites after Liu et al. (1988) and our own observations. Note how the drainage pattern and distribution of Quaternary volcanites is controlled by lineaments. With decreasing distance from the Karakorum fault lineament in the west and the Altyn-Tagh fault lineament (more accurately the "combined" Ruoqiang-Xingxingxia fault and the Altyn-Tagh fault south of their junction; compare Zhou and Graham 1996) towards the east, the linear topographic features along the Kengxiwar lineament become more curvilinear. Close to its western and eastern terminations, it appears that the Kengxiwar lineament bends and adapts to the trend of both faults: clockwise at the dextral Karakorum fault and counterclockwise at the left-slip zone of the "combined" Ruoqiang-Xingxingxia/Altyn-Tagh faults

of the lineament, west of Mazar, in the area of the Kudi orocline where the lineament's trend is approximately 75° (Fig. 2).

Farther east, where the lineament's trend is approximately 100 or 110°, straight lineaments join the Kengxiwar lineament from the south and terminate at the lineament. These smaller lineaments display an en échelon arrangement and geometric orientation of dextral synthetic strike-slip faults in relation to the Kengxiwar lineament (Fig. 7). According to Liu et al. (1988) and BGMR (1993), a fault of synthetic strike dextrally displaces the granitoid south of the new road (Fig. 2)! This points to the possibility of dextral faulting along the Kengxiwar lineament as the main dextral fault for a particular time.

Along the roadside, at Xaidulla (road mark 350–354), where the south Kunlun suture and the Kengxiwar lineament coincide, low-grade protomylonites and mylonites are exposed in contact-metamorphic rocks south of a granitoid which belongs to the southern Kunlun. They exhibit gently dipping stretching lineations and a vertical foliation which trends approximately 70°. The orientation of the stretching lineations indicates strike-slip movements. A dextral shear sense was determined for these fault rocks by grain shape-preferred orientation of elongated, dynamically recrystallized quartz grains, shear band fabrics, feldspar as well as chloritized biotite ("mica fish") porphyroclast systems. The grain shape-preferred orientation of quartz can be deflected at the shear bands. The Kengxiwar lineament at this segment trends approximately 100°.

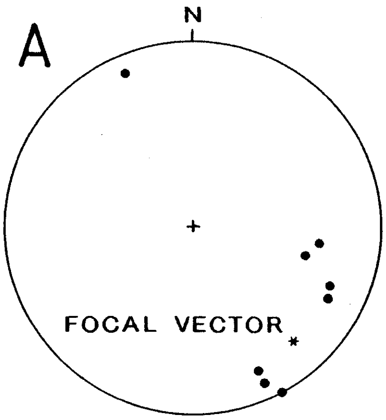
Mylonites of the northernmost part of the Kara-Kunlun, occurring within contact-metamorphic rocks north of a granitoid and only a few hundred meters south of the central part of the Kengxiwar lineament (40 km east of Shanshilli, elevation 3950 m, along a new road which joins the highway from the south at road mark 403), display horizontal stretching lineations and a foliation parallel to the lineament. The shear sense of these mylonites, which contain garnet and sillimanite, is dextral as indicated by an intense shear band fabric. Synthetic shearing may be so intense that dextral feldspar porphyroclast systems occur not only parallel to the main mylonitic foliation, but also parallel to the synthetic foliation. Quartz fabrics indicate that the dextral mylonite fabrics received a gentle ductile overprint by undetermined tectonic movement(s?).

The lack of ophiolites along some segments of the south Kunlun suture was attributed to strike-slip (Chang et al. 1989; Pan et al. 1992: recent left-lateral slip). One could also partly attribute the absence of ophiolite outcrops to suture-covering overlap assemblages or plutonic intrusions in the realm of the suture.

The Kara-Kunlun

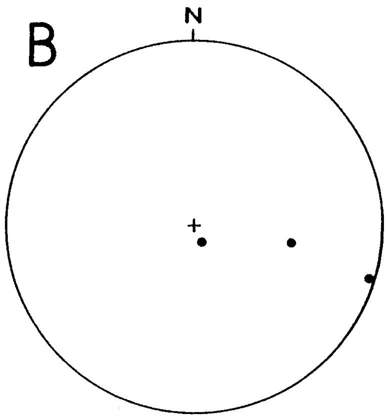
The Kara-Kunlun area is 30–120 km wide and represents the western part of the "Taxkorgan-Tianshuihai terrane" (Fig. 3) sensu Pan et al. (1992). In the Kara-

A



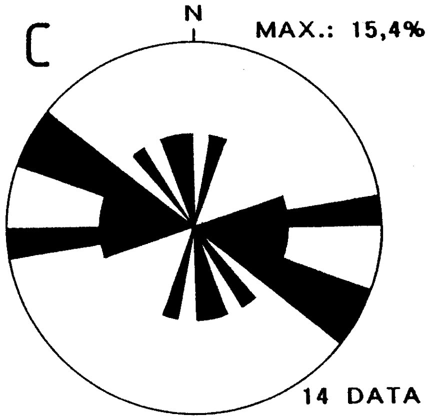
FOLD AXES / SINIAN
S SLOPE OF AKAZ PASS
N KUNLUN

B



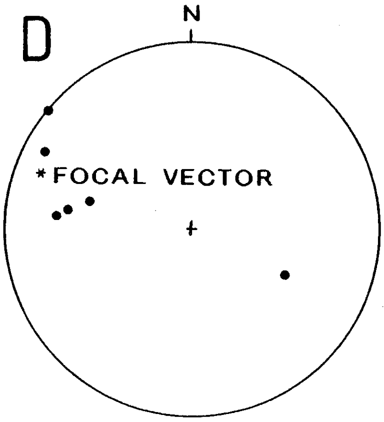
FOLD AXES / KUDI
OPHIOLITE COMPLEX
S KUNLUN

C



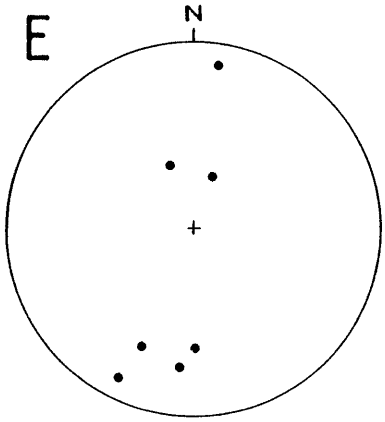
BRITTLE FAULTS (DIP ANGLE
OF SLICKENLINES ONLY 3-27°)
KUDI OPHIOLITE COMPLEX
S KUNLUN

D



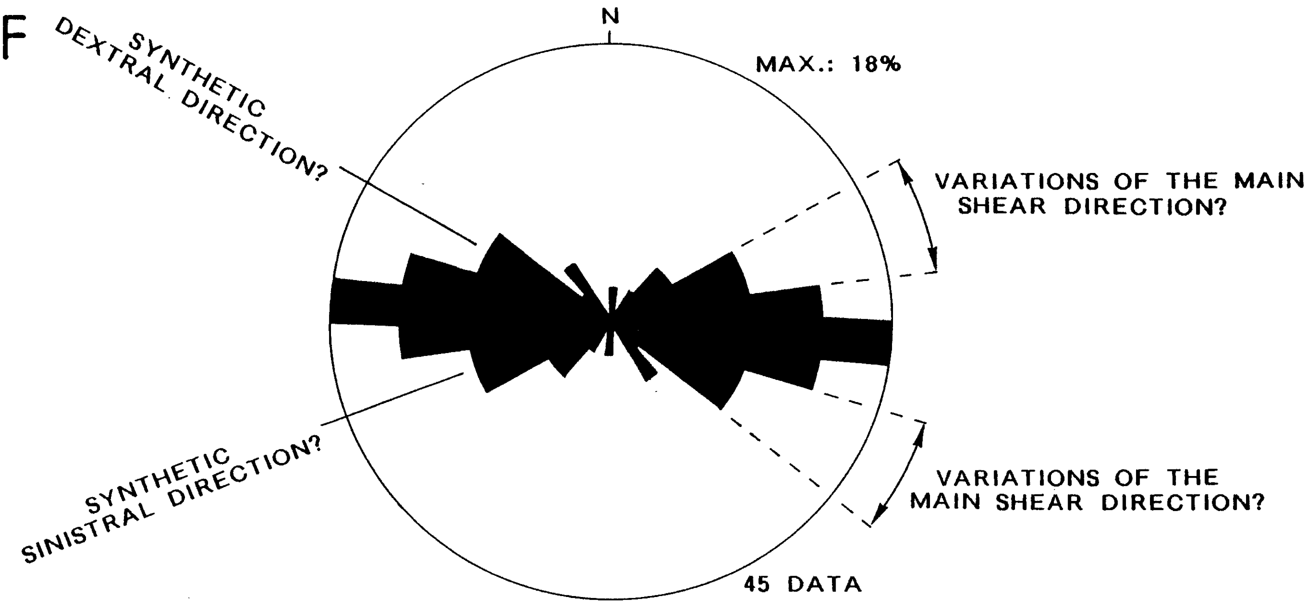
FOLD AXES
PALEOZOIC STRATA
MAZAR AREA
KARA-KUNLUN

E



S1 CLEAVAGE PLANES
PALEOZOIC STRATA
MAZAR AREA
KARA-KUNLUN

F



STRIKE-SLIP FAULTS AT THE KENGXIWAR LINEAMENT E MAZAR
KARA-KUNLUN

Kunlun, thick, mainly fine-grained, marine basin deposits are widely distributed and display some flyschoid characteristics. Dark shales are dominant. Also, distal siliciclastic turbidites and tuffites occur. In a wadi, 3 km west of Mazar, allodapic distal limestones in a 30 m thick sequence were locally observed. However, carbonates are very scarce. The total thickness of these basinal sediments may be in excess of 6000 m (Matte et al. 1992). According to Gaetani et al. (1990, 1991), who worked at the northwestern transition from the Kunlun to the Karakorum, the thickness of these rocks ("Bazar Dara slates") measures several thousand meters. Their age could range from the "Ordovician to the Triassic" (Pan et al. 1992) or from the "Cambrian to the Triassic" (Matte et al. 1992) or from the "Precambrian to the Mesozoic" (Yao and Hsü 1994). The rocks are unfossiliferous except for Paleozoic to Triassic fossils found in exotic limestone slabs (Yao and Hsü 1994). Yao and Hsü (1994) identified this rock zone as an ophiolite mélange which may contain slabs of serpentinites, gabbros, greenstones, and radiolarites. In the area of Mazar, fine- to coarse-grained laminated graywackes comprise granitoid debris. Metatuffites are composed of quartz, feldspar, and actinolite (both rock types are mapped as Silurian). At the Qitai Pass, fine- to coarse-grained graywackes (mapped as Triassic) contain granitoid debris and subordinate amounts of chert, phyllite, and quartzite fragments. Accessory minerals are zircon, apatite, muscovite, biotite, and chlorite. The composition of metasiltstones at Xaidulla (also mapped as Triassic) compares to that of the coarser material from the Qitai Pass. They contain quartz, feldspar, biotite, and muscovite. Accessory minerals are tourmaline, apatite, sphene, and ore minerals.

These clastics are either unmetamorphosed or display very low metamorphic grade in the west (Gaetani et al. 1990, 1991). Matte et al. (1991) found the Kara-Kunlun clastics to be "epizonal" metamorphites.

The Paleozoic/Triassic sequence was intruded by calc-alkaline and subduction-related granitoids (Zhang et al. 1992). These granitoids belong to the same granitoid suite as those in the southern part of the southern Kunlun. Different types of radiometric data by Xu et al. (1992) yield relatively young ages of between 185 and 200 Ma, which corresponds to the Lower Jurassic, according to Haq and van Eysinga (1987). A K/Ar biotite cooling age of 171.5 ± 5.4 Ma was reported by Gaetani et al. (1991).

Contact-metamorphic rocks are widely spread. At the surface, where granitoids are not present, contact metamorphism could be detected. This and the occurrence of tourmaline-bearing pegmatites within the Paleozoic/Triassic deposits indicates the extensive presence of granitoids in the subsurface.

The contact metamorphism was most likely accompanied by intense tectonism as indicated by the occurrence of the aforementioned mylonites at Xaidulla and along the new road. At the latter, we found slender tapered prisms of microboudinaged sillimanite in the mylonites (Fig. 9). The trains of these boudinaged porphyroclasts are parallely aligned and form a mineral stretching lineation which coincides with the other stretching lineation observed within the mylonites. Although one could also interpret these fabrics as being younger than the contact metamorphism, we prefer to conclude that mylonitization occurred during contact metamorphism because we found no evidence in that particular region of any other metamorphic event to which ductile shearing could be attributed.

Tourmaline-bearing pegmatites, occurring in the contact zone, may also be affected by this tectonism. We observed protomylonitic pegmatites along the new road.

In the area around Dahongliutan, we observed numerous pegmatite dikes. This coincides with an increase in metamorphic recrystallization. Instead of the common shales and slates, we found phyllites. Two observations in that area further support our idea of dynamic contact metamorphism. In an unnamed valley which joins the Dahongliutan Valley from the NE, pyrite porphyroblasts occur with long pressure shadows in the phyllites. The pressure shadows display remarkable parallelism even throughout larger outcrops. Around road mark 481, the phyllites show prismatic porphyroblasts which are asymmetrically boudinaged in a ductile matrix.

◀ **Fig. 8 A, B, D** Spot checks on fold axes, **C** strike-slip faults, and **E** S1 cleavage from the area of the Kudi orocline. **F** The rose diagram pertains to strike-slip faults measured along the Kengxiwar lineament (east of Mazar) with slickenline dips below 31° (see discussion in the text). The data were processed with "Gefüge 3" by Wallbrecher and Unzog

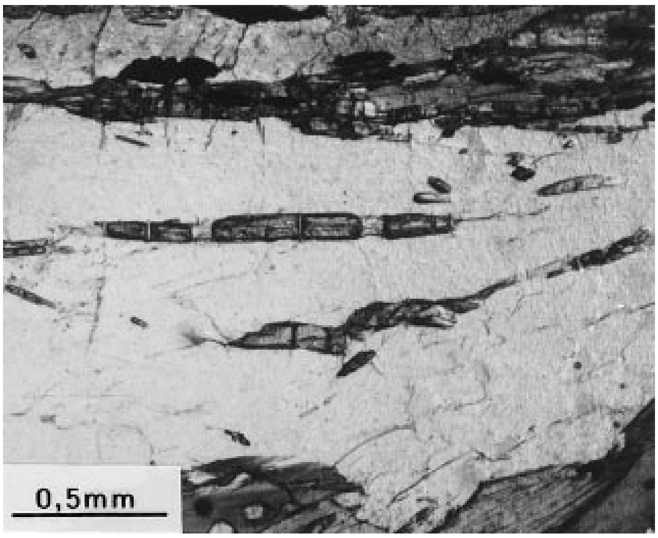


Fig. 9 Mylonite from the Kara-Kunlun found in the contact zone of a granitoid. Note the trains of microboudinaged sillimanite prisms (*dark*) embedded in highly strained quartz (*light*). The mylonitic foliation is parallel to the long sides of the photograph (sample from the new road at an elevation of 3950 m, uncrossed polars)

High-pressure metamorphic rocks are found in the Kara-Kunlun (Matte et al. 1991) which we could not investigate. According to Matte et al. (1991), this metamorphism may be of Paleozoic age. They further remarked that "lower grade metamorphism may be coeval with ductile, Cenozoic left-lateral shear."

In the area of Tianshuihai, in the central part of the southern Kara-Kunlun, Paleozoic to Triassic deposits are mapped (BGMR 1993). The Ordovician consists mainly of fossiliferous shallow marine carbonates, whereas the Carboniferous is mainly composed of limestones, sandstones, brachiopod-bearing shales and siltstones which also indicate shallow marine or platform conditions. The Devonian, Permian, and Triassic were not investigated but are also represented by shallow marine deposits (BGMR 1993). This Paleozoic to Triassic sequence is hundreds of meters thick and contains significant amounts of carbonate. The age of this sequence is well-documented by a mollusk and foraminifer fauna (BGMR 1993). The Carboniferous rocks display a paleo-relief which was partly buried by Upper Cretaceous continental and marine strata.

Following the Early Jurassic, terrestrial red basins formed which are scattered throughout the Kara-Kunlun area (Pan et al. 1992).

An alkali pluton complex occurs northwest of Mazar. Different types of radiometric data, reported by Pan et al. (1992) and Xie et al. (1992), indicate a Cenozoic age. Whereas Pan et al. (1992) attribute the intrusion to plate convergence and dextral shearing parallel to the famous Karakorum fault, Xie et al. (1992) conclude that the intrusion occurred in an anorogenic setting.

Quaternary volcanites occur at major lineaments (Fig. 7). At the junction of the NW-trending Dahongliutan Valley lineament with the Kengxiwar lineament (9 km east of Kengxiwar, south of road mark 444, altitude 4040 m), a 15 m thick basalt flow is located south of the river (Figs. 2 and 7). Approximately 20 km to the southeast of Dahongliutan (south of road mark 505, elevation 4530 m), a 10 m thick trachyte flow occurs to the south of the river (Figs. 2 and 7). This volcanite occurs at the Dahongliutan Valley lineament. Numerous authors have interpreted the origin of the Cenozoic volcanic magmas of the study area and beyond (Arnaud et al. 1992; Deng 1992; Polvé et al. 1992; Zhang and Xie 1992).

Approximately 8 km north of Tianshuihai, east of the highway, we observed a fault contact between the shallow marine deposits (laminated dolo- and calcisparites, intercalated with cherts and dolomitic siltstones) and the fine-grained marine clastics which underlie the earlier (see Fig. 11C; location could not be depicted in Fig. 2). Because the shallow marine deposits generally occur south of the fine-grained clastics, we conclude that they were thrust in a northern direction, and that the thrust plane has been deformed because we found it dipping at an angle of 50° to the NNE (Fig. 13).

In the western part of the Kara-Kunlun, the fold axes measured within the Paleozoic fine-grained basin deposits dip gently to the WNW (Fig. 8D). At the Qitai Pass, S or SSW fold vergences were locally observed (see Fig. 11D). Possible internal thrusts within these deposits could not be studied. The slaty cleavage planes (S1) among these rocks are genetically related to the observed folds (compare Fig. 8D with 8E). Locally, we observed a fracture cleavage (S2) among the fine-grained dark shales, as in the area west of Mazar or at the eastern slope of the Hez Pass. West of Mazar, S2 planes dip at varying angles either to the ESE or WNW. The S2 planes trend perpendicularly to S1. In a wadi 3 km east of Bazar Dara, at the southwestern margin of the Mazar pluton which is situated in the Kudi orocline, the fracture cleavage becomes increasingly closer spaced towards the pluton.

Gaetani et al. (1990, 1991) recognized "at least two phases of ductile folding: the first phase formed isoclinal folds with steeply dipping axial planes, whilst the second phase formed open folds with gently dipping axial surfaces." We could not distinguish different phases of folding, but only two different morphological types of folds, the first being overturned with axial planes dipping at 30–45°, and the second being open folds with vertical to steeply dipping axial planes. Matte et al. (1992) realized that the folding predates the granodiorite intrusions. This is consistent with some of our local findings.

The Upper Cretaceous deposits, which occur in the southern part of the Kara-Kunlun close to the Taaxi-Qiaoertianshan-Hongshanhu suture, are folded (open folds), which indicates uppermost Cretaceous to Cenozoic compression. According to Bourjot and Avouac (1991), the Kunlun Range is actively shortened and uplifted.

The Taaxi-Qiaoertianshan-Hongshanhu suture

Baud (1989) referred to this suture as a "cryptic suture." Ultramafic ophiolites are only sporadically exposed along this suture (Chang et al. 1989), which is widely covered by postaccretionary deposits (Liu et al. 1988; Chang et al. 1989; Pan et al. 1992; BGMR 1993) of the Middle Jurassic to Quaternary (Liu et al. 1988; Chang et al. 1989; BGMR 1993). The Middle Jurassic age of the suture overlap assemblage is documented by a brachiopod fauna (BGMR 1993). The suture also delineates blocks of marked difference (Pan et al. 1992).

Conclusions (geodynamic development)

In the western Kunlun and adjacent areas, subduction-related magmatites, ophiolite-bearing sutures, suture-overlap assemblages and molasse deposits occur. Their ages and interrelation allow us to date the most impor-

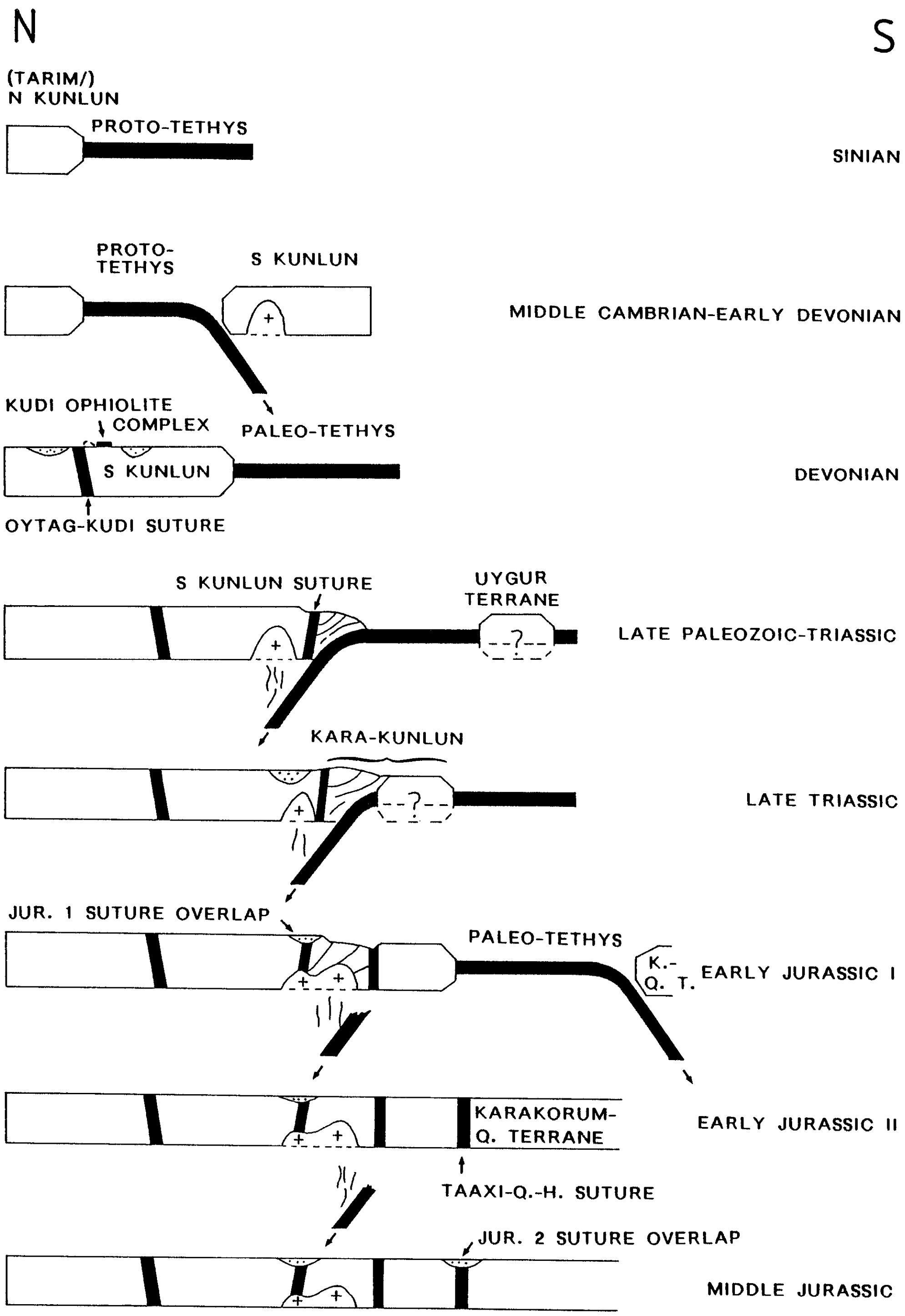


Fig. 10 Geodynamic development of the western Kunlun and the Kara-Kunlun as outlined in the text. Crustal nature of the Uygur terrane (continental or oceanic?) unknown

tant orogenic processes under the plate tectonic aspect and are summarized in Fig. 10. Some important results of the stratigraphic terrane analysis are depicted in Fig. 12, which summarizes times of activity of magmatic arcs.

The southern margin of the northern Kunlun displays the development of a subsiding shallow marine shelf of a passive continental margin during the Sinian as indicated by the great thickness of marine metasediments and the basic metavolcanites. Also, the aforementioned character of the metavolcanites (metamorphosed oceanic tholeiites) is consistent with this view. Along with Pan et al. (1992), we assume a Sinian rifting and a Sinian and Paleozoic ocean spreading to the south of the northern Kunlun, thus creating the Proto-Tethys Ocean. We are unable to say which continental mass drifted away from the southern margin of the northern Kunlun. However, we do not consider the southern Kunlun block to be a likely candidate because it lacks similar Sinian rocks.

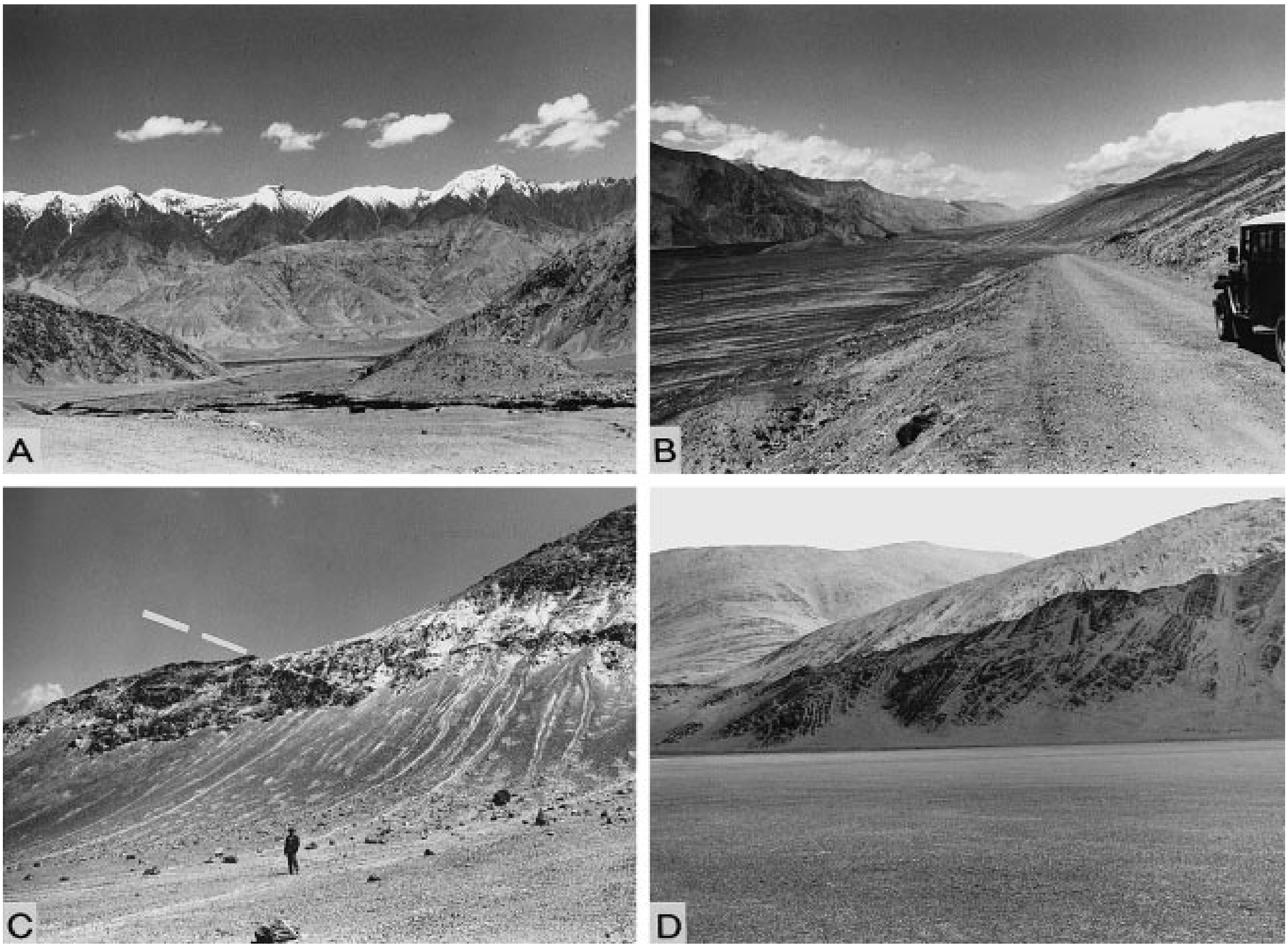


Fig. 11 **A** View towards the north from the northern Kara-Kunlun across the Karakax Valley (Kengxiwar lineament) to the southern margin of the southern Kunlun. Note the straight chain of *snow-covered mountains* which consist of metamorphic rocks and granitoids. **B** View along the Kengxiwar lineament to the west, at the western slope of the Kengxiwar Pass (road mark 421). The lineament is defined here by the valley of the Karakax River. **C** Fault contact 8 km north of Tianshuihai between overlying Paleozoic shallow marine carbonates (*light*) and Paleozoic fine-grained Late Paleozoic to Triassic clastics. The fault can be identified as a white line and is marked by *dashes*. **D** Folded Paleozoic to Triassic fine-grained clastic deposits of the Kara-Kunlun (4 km west of the Qitai Pass, road mark 429). Note the S or SSW fold vergence

The presently available ages of the northern subduction-related granitoids of the southern Kunlun indicate subduction of the Proto-Tethys from the Middle Cambrian to the Lower Devonian. Remnants of this ancient ocean can be found in the Oytag-Kudi suture and the Kudi ophiolite complex. Because this suture is located to the north of the granitoid belt, a south-dipping subduction zone beneath the southern Kunlun must be concluded. The age of the subducted lithosphere must consequently range from the Sinian to the Paleozoic. This is consistent with radiometric data by Wang (1983), Pan et al. (1992) and Xu et al. (1992).

Yao and Hsü (1994, their Fig. 11) depicted north-directed subduction beneath the Kunlun from the Proterozoic to the Carboniferous. This would imply that the Sinian sequence was deposited in an arc environment. Although these authors depicted only north-dipping Benioff zones below the Kunlun, they concluded that the Oytag-Kudi suture formed in a south-directed subduction zone (Yao and Hsü 1994, their abstract).

Due to subduction of the Proto-Thetys, the overriding southern Kunlun approached the underriding northern Kunlun. The collision between the northern and southern Kunlun occurred largely during the Devonian as indicated by the youngest granitoid age (possible cessation of subduction) in the northern part of the southern Kunlun of Lower Devonian and by the deposition of red molasse sediments which also date as Devonian (Upper Devonian age in the northern Kunlun and of Lower Devonian age in the southern Kunlun). Another aspect in favor of a Devonian collision is the similar stratigraphic development also in the time following the Devonian. In both areas, shallow marine carbonates were deposited during the Carboniferous and Permian. In the southern Kunlun, however, the

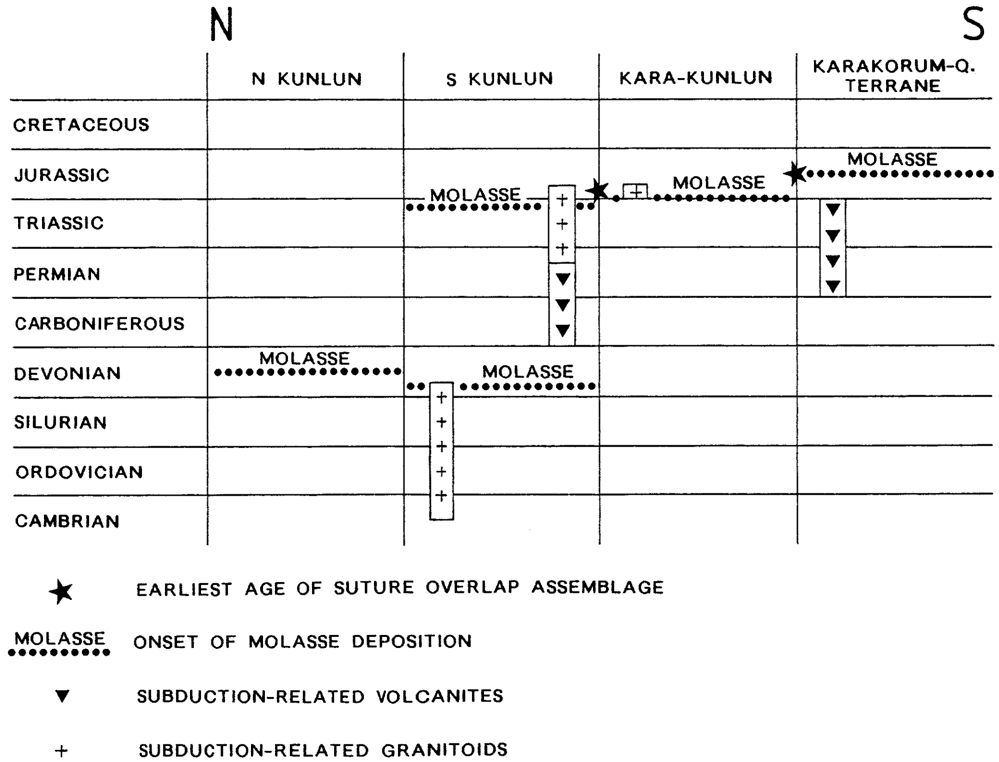


Fig. 12 Main elements of the tectonostratigraphic terrane analysis of the study area showing the thus-far known ages and spatial distribution of subduction-related magmatites, the position and earliest age of suture overlap assemblages, and the beginning of molasse deposition in the different areas. Note the close temporal coincidence of onset of Molasse deposition, youngest known subduction-related magmatite ages and deposition of suture overlap assemblages at adjacent parts of different blocks indicating the time of collision or accretion. From the time of accretion, neighboring blocks display a similar stratigraphic record. Orogenic activity becomes increasingly younger to the south. Data pertaining to the Karakorum-Qiangtang terrane after Pan et al. (1992)

carbonates are found with intercalations of volcanites. The Meso-Cenozoic deposits are characterized in the northern and southern Kunlun by continental clastics.

At the time of molasse deposition during the Devonian, volcanic activity can be documented for the northern Kunlun. There are no Devonian red molasse deposits in the Kara-Kunlun area.

Our concept of a Devonian collision implies that the Proto-Tethys-derived Kudi ophiolite complex was most likely obducted at the end of the Devonian or the Devonian/Carboniferous boundary, which is difficult to reconcile with the young age data by the IGMR for the uppermost layer of the Kudi ophiolite complex. We hesitate to accept these young ages mainly because of the granitoid age spectrum, the age of the Molasse deposits, and the older age data pertaining to the Kudi ophiolite complex.

In the course of the orogenic development of the western Kunlun, subduction beneath the southern Kunlun commenced again during the Late Paleozoic. This time, the southerly located Paleo-Tethys Ocean was subducted towards the north, thus forming the southern Permo-Triassic subduction-related granitoid belt of the southern Kunlun (Pan et al. 1992). According to Hsü (1988) and Pan et al. (1992), the Late Carboniferous to Permian volcanites of the southern Kunlun are of the calc-alkaline arc type. Therefore, the subduction could have started as early as the Late Carboniferous. We found Upper Permian deposits to be missing (angular unconformity; Fig. 4B). Because subduction occurred at this time, we attribute the absence of Upper Permian to subduction-related movements. The magmatic belt is related to the southerly located south Kunlun suture.

Chang et al. (1989) interpreted the whole western Kunlun as an accretionary wedge. More specifically, Hsü (1988) looked at the area south of the Kunlun arc as accretionary wedges which consist of Permo-Triassic turbidites deposited in deep-sea trenches or in fore-arc basins. There is no doubt that the zone of marine fine-grained basin deposits of the Paleozoic to Triassic of the Kara-Kunlun is indeed a large fore-arc subduction-accretion complex. The petrography and flyschoid facies of these deposits, their thickness and composition, as well as the observed vergences and the pronounced dip direction of the strata to the NNE are in agreement with the accretionary wedge interpretation. The wedge formed during the north-directed subduction of the northern Paleo-Tethys beneath the southern Kunlun. The southern part of that ocean was subducted to the south under the Karakorum-Qiangtang terrane, consisting of the older clastic material (Chang et al. 1989).

Because there is a significant facies difference between the flyschoid siliciclastic deposits of the northern Kara-Kunlun and the shallow marine carbonate-bearing sediments of the area of Tianshuihai, and because they are of the same age and separated by a fault, we consider the latter sequence to represent a separate terrane. Shallow marine deposition took place either on a small subsiding microcontinent or oceanic plateau which was a part of the Paleo-Tethys Ocean and was accreted onto the southern margin of the Kara-Kunlun subduction complex. We call this block "Uygur ter-

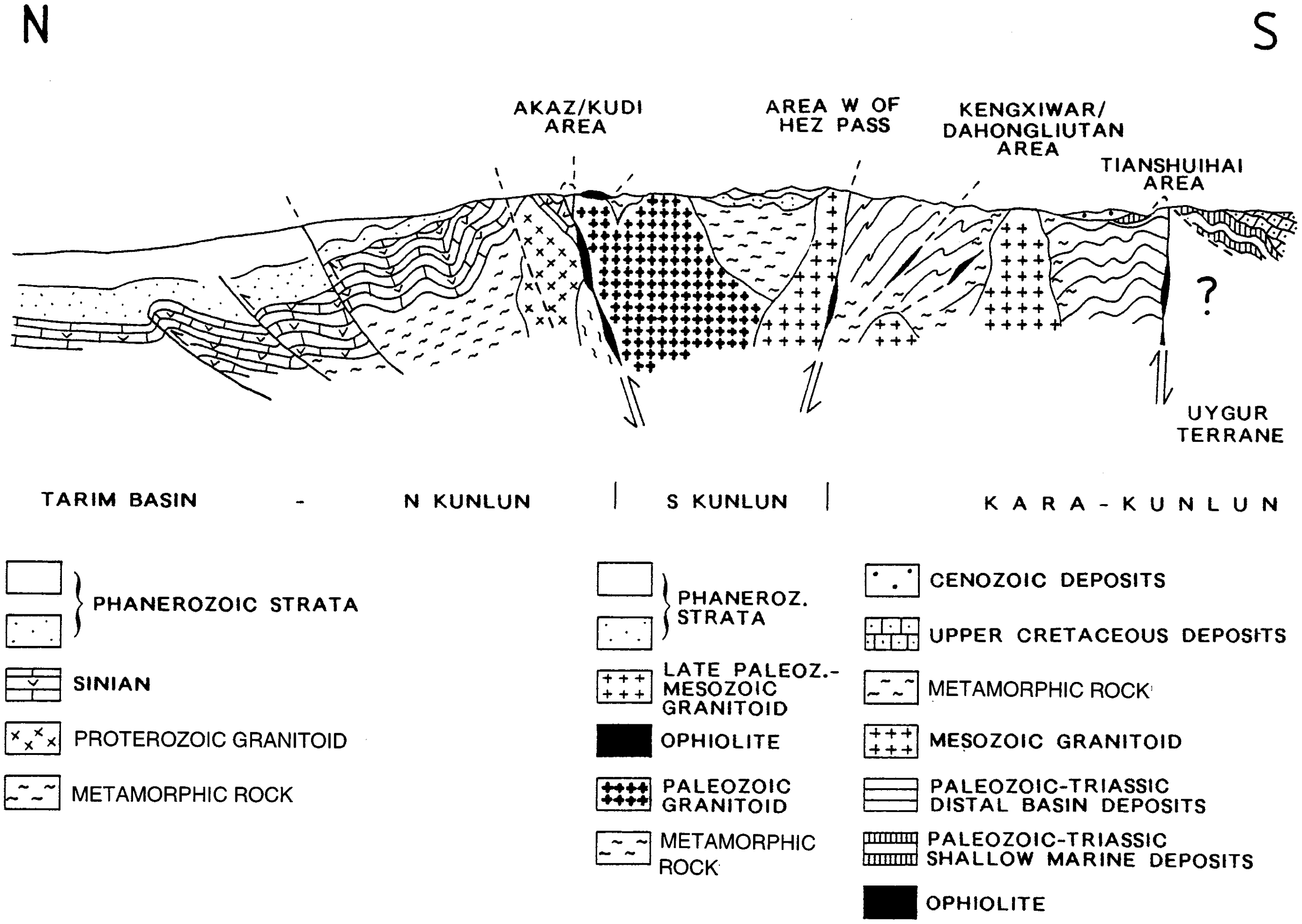


Fig. 13 Structural section across the Kunlun and Kara-Kunlun. The listed locations indicate areas where the depicted near-surface structures were observed. These locations are aligned in a NW–SE direction, reflecting our route. In order to display the proportions of the study area as realistically as possible, the observed structures were arranged in a N–S direction. Nevertheless, the regional structural style is well-documented this way

rane" (Figs. 3 and 10). The sedimentary facies of the Uygur terrane is akin to the shallow marine facies of the Karakorum-Qiangtang terrane (compare Chang et al. 1989), which, according to Pan et al. (1992), should be located farther to the south (see Fig. 3). (In fact, it cannot be ruled out that the Uygur terrane represents the Karakorum-Qiangtang terrane. If so, the basement of the Uygur terrane should be continental; compare Yao and Hsü 1994).

Accretion of the subduction complex must have been completed by the Early to Middle Jurassic because coarse continental deposits of this age cover the south Kunlun suture and the adjacent blocks as an overlap assemblage (Figs. 4C, 10 and 12). The shaly deposits at the Triassic/Jurassic boundary (Fig. 4A and B) indicate a short time interval of tectonic quiescence. The fact that the flyschoid facies of the northern Kara-Kunlun ends with the Triassic may have a tectonic reason. We suggest that the Uygur terrane collided with the subduction complex during the Late Triassic and put an end to wedge accretion. The resulting regional compression and uplift prevented marine fore-arc sedimentation and the coarse terrestrial Upper Triassic molasse deposits were shed (Fig. 4A and B). The composition of the overlying Lower Jurassic clastics indicates that the magmatic arc was already eroded to its granitoid roots by then.

The interpretation of the Kara-Kunlun as a Late Triassic to Early Jurassic accretion zone is suitable to explain the decreasing age of granitoids towards the south from the southern part of the southern Kunlun to the northern part of the Kara-Kunlun. With the growth of the accretion zone during plate convergence, the trench moved oceanwards, thus moving the magmatic front along towards the south until the northern parts of the subduction complex became the actual site of calc-alkaline granitoid intrusion (Fig. 10).

Closure of the Paleo-Tethys and accretion of the Karakorum-Qiangtang block to the northern units must have been completed by the Middle Jurassic because the Taaxi-Qiaoertianshan-Hongshanhu suture is covered by a Middle Jurassic overlap assemblage (Figs. 10 and 12). This harmonizes well with the Lower Jurassic age of the youngest granitoids in the northern part of the Kara-Kunlun (possible cessation of subduction due to collision). The tilting of the lowermost Jurassic strata (Fig. 4A and 4B) and thrusting of Lower Permian rocks onto the lowermost Jurassic (Fig. 4A) may have been caused by the collision of the Karakorum-Qiangtang block.

The Kunlun and Kara-Kunlun show signs of late tectonic activity. The fact that the Upper Cretaceous deposits of the Kara-Kunlun are folded indicates uppermost Cretaceous to Cenozoic compression. The occurrence of Quaternary volcanites at major lineaments (Fig. 7) can be explained by recent fault activity. The geology of Quaternary river terraces provides evidence for recent uplift of the study area.

It appears that dextral as well as sinistral shearing occurred along the Kengxiwar lineament. Mesozoic dextral shearing is indicated by the mylonites of the Kara-Kunlun. Considering the geometry of the Cenozoic propagating extrusion tectonics in Asia (e.g. Molnar and Tapponier 1975; Tapponier et al. 1982; Molnar 1988), the Kengxiwar lineament with its "100° trend" in the "vicinity" of the dextral Karakorum fault (Fig. 7) would be suitably oriented for recent dextral shearing – or at least better oriented for dextral than sinistral shearing. Moreover, neotectonic or recent east-west extension of the Tibet plateau (Tapponier et al. 1981; Dewey et al. 1988; Chang et al. 1989) is expected to result in dextral transfer shearing at the Kengxiwar lineament.

This view is inconsistent with Peltzer et al. (1989) and Pan et al. (1992) who observed a recent left-lateral shear sense which affects the modern drainage. Although we found no evidence on satellite images or in the field for left-lateral effects on the drainage, left-lateral displacements at the westernmost segment of the lineament are likely to have occurred (Liu et al. 1988; Gaetani et al. 1991).

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