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Artikel: The rôle of accretionary wedges in the growth of continents : asiatic examples from Argand to plate tectonics

Autor: engör, A.M. Celâl / Okuroullari, A. Haldun

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Franz Eduard Suess too passed away on 25th January, 1942, and, with Ampferer, retired in 1938 (he died in 1947), the mobilist movement lost its powerful leadership[13]). After World War II, the lead in global tectonics passed once more into the hands of the fixists both in Europe and in America, and most of the ideas I outlined so far were forgotten. When WILSON (1954) put forward his model of continental growth through orogeny, nearly three to two decades after the writings of Argand, Ampferer, Salomon-Calvi, and F.E. Suess had been published, the model of orogeny he used was still substantially the same as that employed by Eduard Suess in 1875! (Fig. 9).

The path of accretion tectonics trodden by Argand and his mobilist comrades had to be retravelled after the development of plate tectonics and the story we tell below of the tectonics of Asia may be interpreted as our not yet having reached the point on this particular path, where the magician of Neuchâtel and his companions might be awaiting our arrival.

In the second part of this paper, we describe some of the subduction-accretion-dominated Turkic-type orogenic belts of Central Asia (see Fig. 10) beginning with Argand's example of an accretionary – or Turkic-type in the sense here defined – orogenic belt, the Kuen-Lun, to document how Asia grew mainly during the Palaeozoic era and to contrast this with the Alpine and Himalayan type collisions of the Tethysides, in which continental enlargement took place mainly through continental collisions.

PART II

5. The palaeotectonic evolution of the Kuen-Lun/Songpan-Ganzi system

The Kuen-Lun is one of the most impressive mountain ranges of Asia, (Fig. 10) one that von RICHTHOFEN (1877, p. 223) designated as the "backbone of the eastern half of the continent". It was also on the example of the Kuen-Lun that one of the earliest theories of lateral continental accretion was proposed: "The Kuen-Lun thus appears to us as a sort of basement rooted into the oldest structure of the crust of the earth, a kind of pre-determined firm wall, onto which neighbouring areas were accreted through foldings of various orientations, until the whole formed a continent" (von RICHTHOFEN 1877, p. 225). As ŞENGÖR (1981, 1984) proposed and MOLNAR et al. (1987) and DEWEY at al. (1988a) corroborated, the Songpan-Ganzi accretionary complex (Fig. 10) largely forms a southerly appendage to the Kuen-Lun and represents an organic whole with it. As the Songpan-Ganzi System has been discussed in some detail elsewhere (ŞENGÖR 1984; ŞENGÖR & HSÜ 1984; KRÖNER & ŞENGÖR 1988; ŞENGÖR et al. 1988), we do not elaborate further on its geology below.

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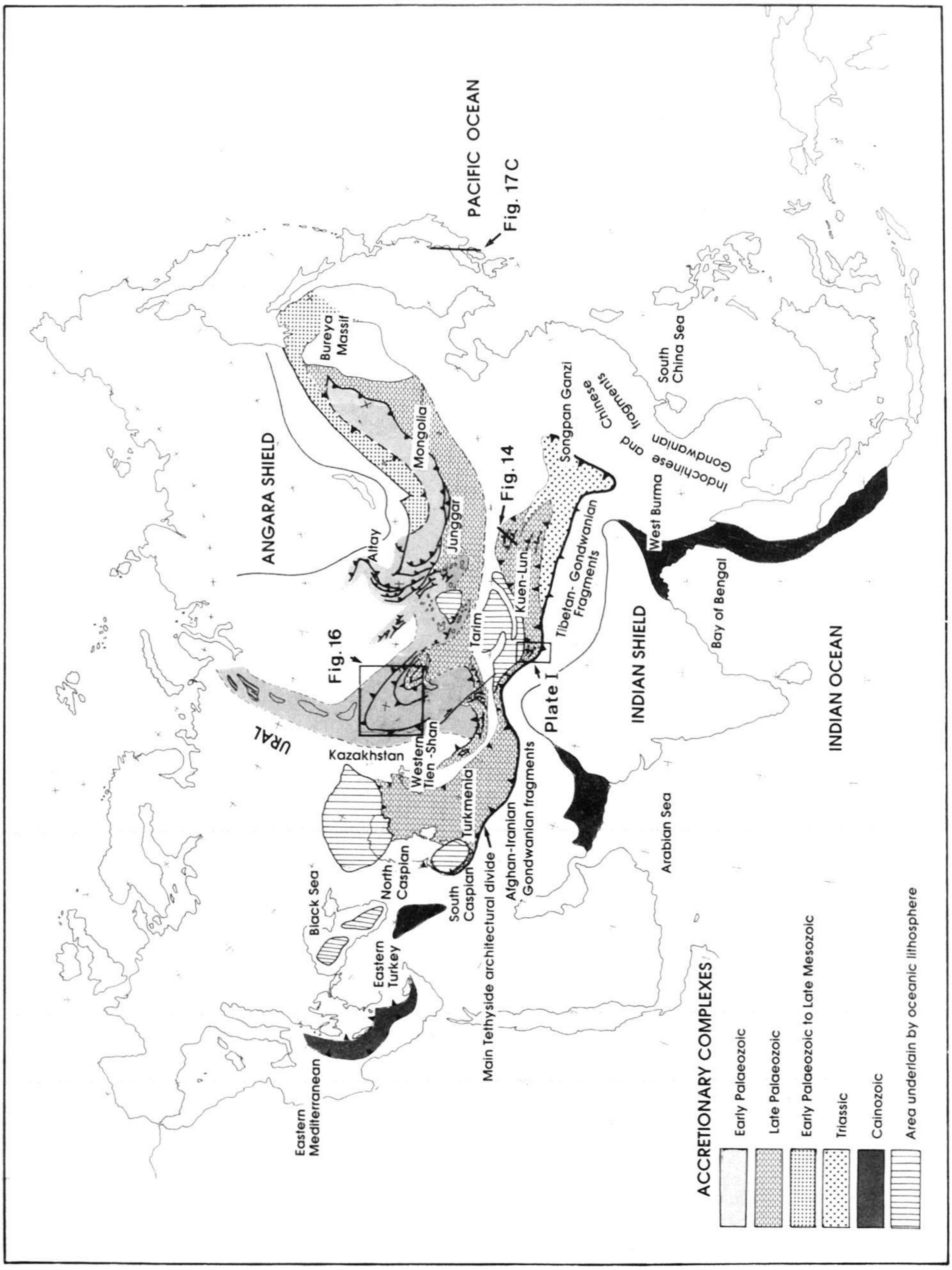
[13]) Influential mobilist leaders in the southern hemisphere, such as A.L. Du Toit and L. King survived the war, but were mostly interested in the extensional aspects of continental drift and did not make any significant contribution to orogeny in terms of drift. Little wonder that when eventually a mobilist theory of orogeny arose from the southern hemisphere, it interpreted orogeny as an extensional phenomenon! (Cf. CAREY 1958; see also CAREY 1988, p. 89–119).


PACIFIC OCEAN
Fig. 17 C
ANGARA SHIELD
Bureya Massif
Mongolia
Altay
Junggar
Fig. 14
Songpan Ganzi
Chinese fragments
Indochinese and Gondwanian
South China Sea
West Burma
Fig. 16
Tarim
Kuen-Lun
Tibetan-Gondwanian fragments
Plate I
URAL
Kazakhstan
Western Tien-Shan
Turkmenia
North Caspian
South Caspian
Black Sea
Eastern Turkey
Eastern Mediterranean
Main Tethyside architectural divide
Afghan-Iranian Gondwanian fragments
INDIAN SHIELD
Bay of Bengal
Arabian Sea
INDIAN OCEAN
ACCRETIONARY COMPLEXES
Early Palaeozoic
Late Palaeozoic
Early Palaeozoic to Late Mesozoic
Triassic
Cainozoic
Area underlain by oceanic lithosphere

5.1 *The Westernmost Kuen-Lun Mountains: a synopsis of observations*

So far the best-described part of the Kuen-Lun remains its western segment between the longitudes of 76°30′ and 80°00′ (Plate 1). Not only a number of expeditions have crossed it since the famous "Second Yarkand Mission" in 1874, but much recent Chinese and foreign effort also has concentrated on it in the last decade or so. The following account is based mainly on the reports of BLANFORD (1878), DE TERRA (1932), WYSS (1940), NORIN (1946) and von RICHTHOFEN's (1877) summary of still earlier observations supplemented by numerous other sources as cited below including the most recent Chinese (CHANG et al. 1989; DENG 1989; PAN 1991) Sino-French (FORT & DOLLFUS 1989; COLLOQUE KUNLUN-KARAKORUM 90, ARNAUD & HARRISON 1991, BOURJOT & AVOUAC 1991; MATTE et al. 1991) and the Italian expeditions (GAETANI et al. 1990; GAETANI & POGNANTE, in press). Observations available up to 1929 were synthesized, with a sketch geological map, in GRENARD (1929, pp. 335–341 and figs. 53 and 54). Observations made during the de Filippi expedition (1913–1914) are summarized in DAINELLI (1933 and 1934), but they mainly pertain to the western Qangtang block and only in extremely limited extent to the Kuen-Lun proper. BAUD (1989) also crossed the Western Kuen-Lun alone and published a synopsis with a block diagram.

Where our main sources disagree with the much more recent Chinese maps and reports, we followed the one whose description of field observations allowed a healthy assessment. This meant that in most cases we had to follow the older European descriptions and those reported by the recent Sino-European or Sino-American expeditions. Also we found that these descriptions allow a more internally consistent picture to be painted than most of the recent Chinese reports and published maps that not uncommonly contradict each other. The details of the most recent joint European-Chinese efforts here unfortunately have not yet been published. The little information that has appeared in abstracts and interim reports, or related to us by the participants (Professors Deng Wanming, Philippe Matte, Paul Tapponnier and Wang Yi) is largely consistent with the older European expedition reports as we indicate below. The following brief synopsis of the tectonics of the Western Kuen-Lun is constructed on the basis of three roughly N-S profiles and one geological map (Plates 1 and 2).

Three major roughly E-W trending tectonic zones may be distinguished between about Kökjar and Hotan. In the north a Quaternary flexural molasse basin (the Yecheng-Hotien Quaternary deep of MATTE et al. 1990b: Plate 1) contains a total maximum thickness of some 10 km sediments on the Tarim "basement". Of this thickness, some 6 to 8 km belong here to the Late Cainozoic alone and represent the fill proper of the Yecheng-Hotien *molasse basin* (cf. TIAN et al. 1989). Along the Kuen-

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Fig. 10. A partial tectonic map of Asia showing the accretionary complexes in parts of the Altaid and in the Tethyside tectonic collages. Circum-Pacific and northeast Asian tectonic collages are not shown at all. For sources see ŞENGÖR, OKUROĞULLARI & HSÜ, in prep. The *main Tethyside architectural divide* corresponds with the main Palaeo-Tethyan suture, north of which the Phanerozoic orogenic evolution was dominated by Turkic-type orogens and south of which by ordinary Himalayan-type orogens. In the accretionary complexes, small slivers of Precambrian continental material and magmatic arc axes are not shown. The boxed areas are shown in greater detail in Plate 1 and Fig. 16. The cross-section shown as Fig. 14 refers to the longest of the three sections (B) shown in Fig. 14.

Lun margin of this basin De Terra (1932) distinguished two formations in the Upper Tertiary (locality 1[14]), Plate 2A): The Kökyar Beds of ?Oligo-Miocene age, with a minimum visible thickness of 1.5 km, consist dominantly of conglomerates and sandstones. The basal conglomerate of the Kökyar Beds contains large and angular clasts of gneiss, granite, diabase, red and grey quartzites and quartz conglomerates, Devonian and Carboniferous limestone and dolomite and varicoloured conglomerates and quartzites. All of these rocks are found in the Kuen-Lun ranges to the south and represent products of its denudation. From the angularity and the size of the clasts, De Terra (1932) concluded a substantial relief at the time of the deposition of the Kökyar Beds (?Oligo-Miocene). An angular unconformity separates the Kökyar Beds from the younger (?Pliocene) Bora Beds, consisting of alternating hard and soft conglomerates, grey-green and reddish feldspar-rich sandstones, and marly and loess-bearing sandstones (for the easterly equivalents see Leuchs 1913; for a map of these, Zugmayer 1909, plate 17). The conglomerates of the Bora Beds contain rounder and smaller clasts than those of the Kökyar Beds. They also contain a much higher proportion of crystalline rocks in which greenstones predominate. The Bora Beds display north-vergent folds and thrust faults (e.g. Fort & Dollfus 1989, fig. 2) and are unconformably overlain by Quaternary clastics (for a discussion of the Quaternary deposits and their interpretation for the recent tectonics of the western Kuen-Lun see Fort & Dollfus 1989).

The shallow structure of the sedimentary fill of the Yecheng-Hotan molasse basin resembles that of the Alpine molasse: Thrust faults delimit the Kuen-Lun against the molasse basin. These faults commonly dip south steeply (50–70°) with the two exceptions of the north-dipping frontal faults south of Kilian Bazar (2) and Sanju (3) which may represent the surface expression of a triangle zone, although the youngest movement on the latter fault (3) may have had a normal sense.

Beds of the molasse basin fill immediately north of the boundary thrusts commonly dip north at average angles of 45 to 55° (4 and 5) and represent northern flanks of anticlines whose southern flanks have been overridden (see esp. De Terra 1932, p. 18, fig. 10). The dips may be locally steeply inclined to the south (Fig. 11) but generally they incline northwards and become much gentler farther north near Yecheng and beyond (De Terra 1932; Norin 1946).

Some of these anticlines, such as the one immediately east of Duwa (Plate 1), may be ramp anticlines betraying the presence of blind thrusts at depth.

The next zone consists of a narrow discontinuous band of late Palaeozoic and Mesozoic deposits that display strong to moderate, north-vergent similar and (especially in the Uralian, i.e. uppermost Carboniferous and lowermost Permian, and Mesozoic rocks: see below) flexural slip folding and cleavage development (Plate 2, locs. 6, 7, 8, 9). This zone is bounded by commonly steeply-south-dipping thrust faults. The stratigraphy of this zone may be summarized as follows: The youngest members belong to the Mesozoic to latest Permian terrestrial sedimentary rocks that rest apparently *conformably* on the underlying marine Permo-Carboniferous. The terrestrial sequence commences with a redbed formation also containing evaporites. It is overlain by coal-bearing grey shales and coarse sandstones. Finally, red and brown marl and sandstone

[14]) Hereinafter Arabic numerals in the text refer to localities shown on Plate 2.

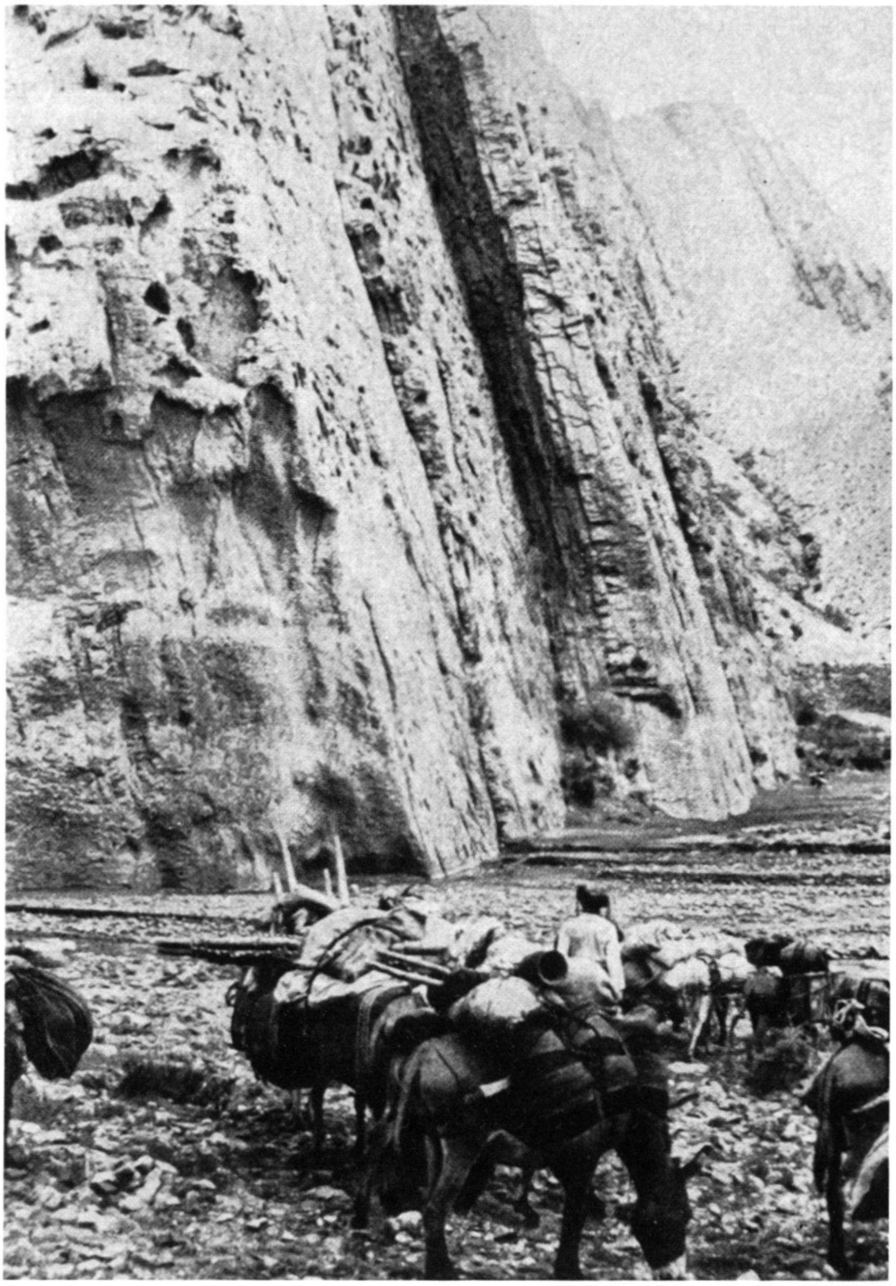

Fig. 11. Steeply south-dipping ?Middle Eocene limestones east of Sanju, near Uzun Sai (Photo: Filchner 1939, frontispiece).

beds cap the series whose age probably ranges into the Middle Jurassic (shown as "Angara facies" on Plate 1).

The lower part of the terrestrial sequence contains no clasts of late Palaeozoic sedimentary rocks, but instead contains those of cherty limestone, chert, quartz, and siliceous shales. Some beds are rich in clasts of greenschist-grade metamorphic rocks. Upwards, into the coal-bearing beds and above, the clast size increases and one encounters Devonian and other late Palaeozoic clasts (De Terra 1932, pp. 57ff).

Conformably underlying the Permo-Mesozoic terrestrial sequence are the Lower Permian shallow water limestones, dolomites and shales. These are in turn underlain by light grey fusulinid- and crinoid-bearing limestones and calcareous sandstones of latest Carboniferous-earliest Permian age, probably partly correlative with the Upper Carboniferous Tagarqi Group of the Tarim basin (6, 7, 8, 9, 10, 11; De Terra 1932, esp. p. 56; Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region 1985). The Permo-Carboniferous platform carbonates are in turn underlain by green-grey clastics of the Lower Carboniferous (12, 13; De Terra 1932), probably correlative with the Heshilapu Formation (Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region 1985, p. 23, table 7). This is part of the sequence that Matte et al. (1990a) call the "autochthonous" unit because they observed a migmatitic basement unconformably underlying red siltstones, sandstones, and conglomerates of Devonian age passing conformably into the Carboniferous platform carbonates. The unconformable contact could not be examined at outcorp, but "was visible in the landscape" (Prof. Paul Tapponnier, pers. comm., 1991). Matte et al. (1990a, 1991) considered the high-grade basement of probable Proterozoic age and as a part of the Tarim basement. Separated from this by commonly south-dipping thrusts is another sequence of dominantly clastic rocks including numerous volcanic tuff horizons (14, 18). In fact, north of Ak Mestcid ("White Mosque"), the Lower Carboniferous clastics are faulted against a 360 m-wide, strongly schistose green tuffite (14).

With the faulted contact we enter the third, and the widest of the east-west trending tectonic zones of the westernmost Kuen-Lun. In the regions east of about 77° 30′ east, a huge metamorphic basement consisting dominantly of pelitic rocks with steep foliation dominates the mountain range, which De Terra (1932) separated into two groups: a generally higher grade and supposedly older Karakash (= black stone or black shore)[15]) Group and a generally lower grade and supposedly younger Kilian Group. Devonian and Carboniferous rocks, mainly clastics, cover mostly the northern part of this zone in irregular patches and are involved in late north-vergent thrusting (at locality 26, for example, Carboniferous limestones were brecciated under a north-vergent thrust fault). This steep pelitic belt extends eastward to beyond 82°E with much the same characteristics as may be judged from the fragmentary observations of Zugmayer (1909) summarized by Leuchs (1913).

A peculiar Devonian development seems confined to the northwestern part of our area, between about 76°45′ and 77°25′ (18–22). Here, a thick metavolcanic sequence involving 3,000 m-thick locally pillowed diabases (Matte et al. 1990a) show mostly vertical to very steeply-dipping bedding between the metamorphic rocks of the Kilian Group and the overlying later Devonian clastics and tuffs (De Terra 1932). The mafic volcanics are in places vesicular and exhibit epidote or malachite filling the vesicles. Associated also are keratophyres in the Devonian magmatic rocks (De Terra 1932; Norin 1946), the whole much resembling the spilite-keratophyre associations known from young immature ensimatic island arcs and back-arc basins.

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[15]) In the Uygur dialect of the Turkish language *kash* (kax in Pinyin) has three meanings: a spotless white or black stone, shoreline and eyebrow. *Kara* is black. Thus Karakash is a redundant construction, if translated as "black stone". Black shore is a linguistically more acceptable translation, although both meanings make sense toponymically and likely refer to the dark masses of schists exposed along the Karakash River.

These volcanics are partly associated with middle to late Devonian shallow water siliceous limestones and dolomites (mainly to the north: De Terra 1932; loc. 21), and partly with red radiolarian cherts of alleged Carboniferous age (mainly to the south: Matte et al. 1990a)[16]). In the late Devonian and early Carboniferous volcanism became first shallow water and then subaerial with much tuff deposition. The tuffaceous late Devonian rocks associated with limestones (?24) are unconformably overlain in the third zone by a terrestrial clastic sequence that contains not only abundant clasts of the Devonian (and older?) deep water volcanics and sedimentary rocks, but is itself interlayered with tuff horizons indicating ongoing magmatism (e.g. 27, 38). De Terra (1932) called these terrestrial rocks the Tisnab Beds and assigned to them a probable Early Carboniferous age. Later Chinese work changed the age assignment to Late Devonian on the basis of plant fossils, but retained De Terra's name (Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region 1985). Both the Middle and Upper Devonian rocks resemble their correlatives along the southern foot of the Tian Shan. The Tiznap Formation, for example, probably correlates with the Altmeishibulaq Formation of the Kuruk-Tagh region and with similar and coeval rocks in the Keping region in the northern part of the Tarim basin (Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region 1985). This shows that the Devonian and older rocks of the northern part of the western Kuen-Lun ranges had already become a part of the Tarim block by the late Devonian (see esp. 26).

The "basement" rocks of the western Kuen-Lun underlying the Devonian (in the north) and Carboniferous (in the south) cover form an immensely thick sequence of metaclastic rocks, consisting dominantly of chlorite-quartz schists, phyllites, and locally garnet-bearing micaschists with abundant metaconglomeratic horizons, lower grade metagreywackes, and local limestones. This sequence has an ubiquitous steep schistosity that verges north in the north and south in the southern part of the third tectonic zone of the western Kuen-Lun (see the Appendix and also Leuchs 1913; Figs. 12 and 13).

As mentioned above, the pre-Devonian metaclastic rocks form De Terra's (1932) Kilian Group that he dated, on the basis of very sparse fossils of only uncertain identity (such as questionable graptolites, *Halysites)* and correlations with similar sequences elsewhere in the Kuen-Lun and the Pamirs, as Cambrian through Silurian. Dainelli (1934), following De Terra (1932), considered these rocks as dominantly pre-Silurian. In the Geological Map of the Qinghai-Xizang Plateau (1980, sheet 1) the same rocks are identified as lower Proterozoic, whereas the Geological Map of Xinjiang Uygur Autonomous Region (1985) shows them as parts of the lower middle Proterozoic Baxkorgan ("Head Fortress") Group. Liu et al. (1988, p. 2) refer these rocks to a

[16]) Prof. P. Matte and Dr. Wang Yi (pers. comm. 1991) have since informed us that the Carboniferous age report was not reliable. Prof. Deng Wanming (pers. comm. 1991) pointed out that north of the army station of Kudi, the cherts and pillow lavas were deformed and then intruded by a granite with a Zr-age of about 480 Ma (early Ordovician!)

[17]) Both Bashkorgan (Baxkörgan in Pinyin) and Tashkorgan (Taxkorgan in Pinyin) exist in the Kuen-Lun. The former is near 39° 5'N and 90° 15'E in the Altin Tagh (see Hedin 1966, sheet NJ 46), whereas the latter is to the west of Plate 1 in the westernmost Kuen-Lun (see Hedin 1966, sheet NJ 43; for a photo, Stein 1912, fig. 34). Both are near alleged Proterozoic outcrops. But here Tashkorgan is the appropriate appellation. It is a garnet-staurolite-bearing metapelite (Dr. Wang Yi, pers. comm. 1991).

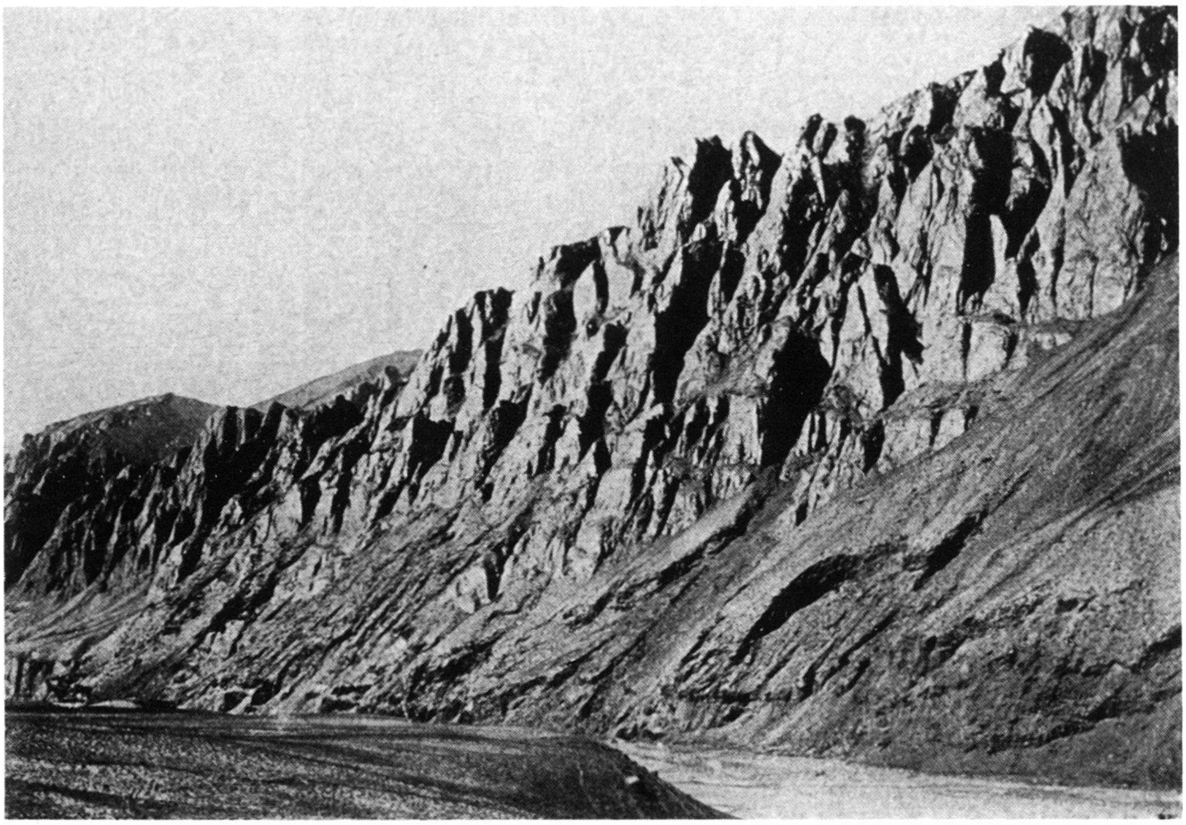

Fig. 12. Steeply dipping slates above the right bank of the Yürüng Kash River (Photo: STEIN 1912, fig. 329).

Fig. 13. South-vergent fabric, south of the Yürüng Kash River (Photo: STEIN 1912, fig. 323).

Taxkorgan ("Stone fortress")[17]) Group of Lower Proterozoic age! The recent investigations in this region, summarized by CHANG et al. (1989) give the metaclastics (= Kilian Group of DE TERRA 1932) an age range from Sinian to Ordovician, which is close to DE TERRA's (1932) and DAINELLI's (1934) original age assignment.

In places DE TERRA (1932) found rocks belonging to his Kilian Group allegedly resting unconformably on older gneisses and marbles that he defined to form an older Karakash Group. However, DE TERRA's description of this "unconformity" is equivocal, and, in places, the relationship between the Karakash and the Kilian groups seem transitional. In fact, on the Geological Map of Xinjiang Uygur Autonomous Region (1985) most of the rocks belonging to DE TERRA's Karakash Group are shown as parts of the upper middle Proterozoic Taxdaban ("Stone Pass") Group, i.e. as *younger* than those of his Kilian Group. DAINELLI (1934) lumped both of DE TERRA's Karakash and Kilian groups into *"Scisti cristallini di età indeterminata prevalentemente pre-siluriana"*, which we think is well-justified.

Neither can the "Kunlun Crystalline" (migmatitic gneisses, minor amphibolites, granitoids and orthogneisses) and the "Bazar Dara slates" (dark, litharenitic to sublitharenitic slates, siltstones and sandstones see also locs. 64, 65, 66) of GAETANI et al. (1990) and GAETANI & POGNANTE (in press) be directly compared with DE TERRA's (1932) Karakash and Kilian groups respectively.

We interpret both the Kilian and the Karakash groups of DE TERRA (1932) and the equivalent slates and chlorite schists farther east (LEUCHS 1913) as parts of an accretionary complex of possibly latest Proterozoic to Silurian age in the northern west Kuen-Lun and to ?Carboniferous (even Triassic?) in the southern west Kuen-Lun. The gneisses and marbles belonging to DE TERRA's (1932) Karakash Group are confined to aureoles of Palaeozoic to early Mesozoic granites (BLANFORD 1878; DE TERRA 1932; NORIN 1946) and are probably related to intrusions (e.g. 56, 72).

Even away from the major intrusions, however, the metamorphic grade of the Kuen-Lun "basement" (corresponding with the "Kunlun crystalline" of GAETANI et al. 1990) is unusually high for an accretionary complex. Although GAETANI et al. (1990) were unable to sample these rocks, WYSS (1940) provided detailed petrographic descriptions along a profile from Sanju, through Tam Karaul ("the wall watch-post or station"), Ali Nazar Kurgan and then up the Karakash Valley through Shahidullah, Suget Karaul ("the willow watch-post") to Kawak-Pass ("the hollow pass"). On the basis of the described mineral assemblages, Dr. A. İ. OKAY (pers. comm., 1990) estimates that metamorphic temperatures may have remained consistently around 500 °C, rising somewhat in the Karakash Valley, near major Mesozoic granodiorite plutons. In the same place (i.e. near Suget Karaul) OKAY estimated the maximum pressure as about 4 kb. Farther south, GAETANI & POGNANTE (in press) estimated temperatures above 600–650 °C on the basis of presumably anatectic quartzo-feldspathic leucosomes in the migmatitic gneisses, the apparent instability of muscovite + quartz assemblages and the plagioclase – hornblende ± clinopyroxene assemblages observed in the metabasics. These authors thought that a polyphase history, perhaps related to a retrograde path, is suggested by the replacement of clinopyroxene by pale-green amphibole.

The age of this metamorphism is bracketed best just to the south of Tam Karaul, where the metamorphic basement is unconformably covered by the clastic rocks of probable late Devonian age (38), for the same unconformable rocks just south of Ak

Shor Talak ("white, salty vineyard") are correlated with the Tiznap Formation on the Geological Map of Xinjiang Uygur Autonomous Region (1985). These outcrops do not at all occur on the Geological Map of the Qinghai-Xizang Plateau (1980, sheet 1), but are shown as Devonian on sheet 1 of Liu et al. (1988).

We compare the metamorphism of the Kuen-Lun basement with a similar high-grade metamorphism that has produced even migmatites in the Chugach metamorphic complex, interpreted as an accretionary flysch terrane metamorphosed and intruded during an episode of ridge subduction (cf. Hudson & Plafker 1982; Plafker et al. 1989, esp. fig. 15C).

The granitic rocks in the western Kuen-Lun are separated into two classes. The northern Kuen-Lun granitic rocks are mainly diorites, granodiorites, biotite monzo-granites, and biotite K-feldspar granites with ages ranging from 480 to 384 Ma (Zhang & Xie 1990). The so-called southern Kuen-Lun granitic rocks (e.g. 44, 47, 55, 63) are mostly granodiorites with ages ranging from 254 to 190 Ma (Zhang & Xie 1990; Gaetani & Pognante, in press). Northeast of Shahidullah, along the Karakash valley, Dainelli (1934, esp. fig. 60) reported both two-mica granites and granitoids. Near Suget Karaul (Plate 1), he reported a two-mica granite.

The southern boundary of the Kuen-Lun "basement" (the Kuen-Lun crystalline plus the Bazar Dara slates of Gaetani et al. 1990) is a mostly steeply south-dipping fault zone (67; De Terra 1932, esp. figs. 61 and 69; Gaetani et al. 1990; Matte et al. 1991; Gaetani & Pognante, in press) that abruptly juxtaposes a north-vergent fold and thrust belt carrying a typical "north Gondwana-Land" stratigraphy, including the ice-modified Horpa-Tso series of late Palaeozoic age (Norin 1946, 1976; also Matte et al. 1991), against the Kuen-Lun accretionary complex. This fold and thrust belt is called by De Terra (1932) *"Das Tethysfaltenland"* (the Tethyan folded country) and by Gaetani et al. (1990) and Gaetani & Pognante (in press) "Surukwat Thrust Sheets", and occupies the Qizil Aghil ("the red cattle-shed") and the western Loqzung Mountains on Norin's (1946) map. The intensity of folding here is much less than in the Kuen-Lun proper (Matte et al. 1991). Very near the suture, however, locally south-vergent major isoclinal folds affecting rocks as young as Turonian-Senonian limestones are seen (e.g. the structure forming the "Monte della Piega" ("mountain of the fold") of Dainelli (1933, figs. 19 and 22: 79°E and 35°20'N; also Dainelli 1934, fig. 106)). But these, too, are cut by steeply south dipping faults (Dainelli 1933, fig. 22). The abruptness of the contact, its fairly steep dip (see Gaetani et al. 1990, fig. 4) and smooth trace suggest a considerable, but probably pre-Eocene strike-slip displacement on this major discontinuity (because Eocene unconformably overlies it south of Ak-tagh: Plate 1), which marks the suture between the western Qangtang block and the Kuen-Lun accretionary complex, equivalent to Pan's (1991, fig. 1) Hunzan Hu-Jinsha Jiang suture.

A number of granodioritic and dioritic intrusions have been reported from within the Tethyan folded country by De Terra (1932, p. 96: the Sumdjiling pluton), Norin (1946, pp. 110–112: the Mawang-Kangri granodioritic laccoliths) and Gaetani et al. (1990) and Gaetani & Pognante (in press), and Matte et al. (1991), although, regrettably no age determinations are available, save for a "Cretaceous" age quoted from the Geological Map of the Qinghai-Xizang Plateau (1980) by Gaetani & Pognante (in press). Some of the smaller intrusions may be older, however, considering the fact that they have been metamorphosed in the west (Gaetani et al. 1990) and have been deformed together with the entire Tethyan folded country (Norin 1946). Şengör et al. (in press) suggested that they might be related to a south-dipping late Palaeozoic subduction under the northern margin of the western Qangtang block.

5.2 The late Proterozoic to middle Mesozoic geological history of the Kuen-Lun/Songpan-Ganzi accretionary complex

The interpretation of the tectonic evolution of the Kuen-Lun accretionary complex requires data not only from the Kuen-Lun itself but also from the Tarim basin. Space shortage here prohibits us from discussing the evolution of the Tarim basin in detail and we refer the interested reader to Hsü (1988, 1989), Li et al. (1987) and Tian et al. (1989), from whom we gathered the information we review below.

The proven Proterozoic rocks of the western Kuen-Lun are found in the Tekelik Tagh (Deer Mountain? or Axle-Tree Mountain = Tengelik Tagh) region (scattered localities between Ak Mestcid, shown in Plate 1, and to the south of Hasalbag – about 76°30′E and 37°30′N) and consist of lower tillites, volcanics and clastics and upper clastics and limestones of Sinian age overlying the stromatolitic Qingbaiko and Jixian Systems supposedly resting over the carbonates and clastics of the Changchen System that itself unconformably overlies the gneisses of the Sailajiaztag Group with a Rb-Sr isotopic age of about 1,760 Ma (Peng & Gao 1984; Liu et al. 1988, p. 6) reminiscent of the situation known from the Kuruk Tagh along the northeastern periphery of the Tarim basin (Norin 1937; Yang et al. 1986). Matte et al. (1990a) surmise that migmatites underlying Devonian rocks in the northern Kuen-Lun may be of Proterozoic age. They may indeed correspond with the Sailajiaztag Group, but we suspect that they may be younger.

Dominantly clastic sedimentation may have begun as early as the Sinian to the south of the Tekelik Tagh and equivalent Tarim fragments such as the Altun Mountains Precambrian fragment (Liu et al. 1988, p. 2), possibly in a south-facing (present orientation!) continental rise setting. North dipping subduction was clearly underway by the early Ordovician (perhaps even early Cambrian: cf. Arnaud & Vidal 1990) judging from the intrusion of the earlier northern Kuen-Lun granitic rocks. These granites intrude metapelitic rocks, here interpreted as accretionary complex material, perhaps implying considerable earlier subduction as well, although unequivocal evidence for this earlier subduction is not known, except for scattered Cambrian isotopic ages on intrusives (e.g. Arnaud & Vidal 1990).

As this subduction-accretion process continued, arc magmatism also marched southward through the Palaeozoic and early Mesozoic, much like the Mesozoic-Cainozoic picture in Japan (Taira 1965). In the northwestern part of the western Kuen-Lun the eruption of vast thicknesses of Devonian (and older: ? earliest Ordovician) diabases and keratophyres seem to us to signal a marginal (intra-fore-arc?) basin opening event, much like the Cretan basin in the southern Aegean, behind the huge Eastern Mediterranean accretionary complex and behind the late Cretaceous dioritic and granodioritic subduction-related intrusions in Crete itself (see Ercan & Türkecan 1985). This marginal basin appears to have closed before the deposition of the Tiznap Formation, which is likely the molasse associated with that closure.

The about 4 kb estimated metamorphic pressure near the Shahidullah magmatic axis indicates that the minimum thickness of the Kuen-Lun accretionary complex was about 12 km at the time of the metamorphism, i.e. in pre-late Devonian time, perhaps similar to the present-day Barbados accretionary complex (WESTBROOK et al. 1988).

By the time the early Mesozoic subduction-related plutons were being intruded, the subduction-accretion material now forming the "Xikang" part of the Songpan-Ganzi accretionary complex began to be deposited and accreted in the forearc area (DEWEY et al. 1988, fig. 10), although only very little, if any, of this material is now present in the westernmost Kuen-Lun (see MATTE et al. 1990a, 1990b, 1991; but see HUANG & CHEN 1987, esp. pp. 29ff and fig. 9). The composition of clasts in the Upper Permian to Middle Jurassic terrestrial sedimentary rocks along the northern foothills of the Kuen-Lun suggests the uplift and unroofing of the orogen, possibly with concurrent shortening. Whereas the lower part of the terrestrial succession contains only rocks from the accretionary prism and only those up to greenschist grade, higher, in the Jurassic part, larger clasts of Devonian and other late Palaeozoic rocks are seen. This may be interpreted as an early Mesozoic folding and uplift of the late Palaeozoic rocks, perhaps not unlike the folding of the late Palaeozoic rocks in the Kirgiz-Ata (Kirgiz Father) Valley in the High Alay range in the USSR (cf. ŞENGÖR 1990a, p. 86), which is located along the strike but farther to the northwest.

A picture very similar to that we just reviewed is seen in the Middle Kuen-Lun, where an undivided, foliated Ordovician, consisting mainly of sandstones, slates, mafic, intermediate, and felsic volcanics and marbles (equivalents of DE TERRA's [1932] Kilian and partly Karakash groups) is unconformably overlain by the calcareous siltstones and tuffaceous sandstones of the Middle Devonian Bulaq Bashi ("head of the spring") Group (BOGDANOVICH 1982, quoted after SUESS 1902, p. 244 and fig. 30; also in LEUCHS 1916, p. 93 and fig. 3 on plate II and GRENARD 1929, fig. 54; for recent terminology and reevaluation see BUREAU OF GEOLOGY AND MINERAL RESOURCES OF XINJIANG UYGUR AUTONOMOUS REGION 1985, pp. 12 and 19). Sven Hedin covered much the same ground as Bogdanovich in the Middle Kuen-Lun (compare plates II and III in BERKEY & MORRIS 1927) and his collections and notes have formed the basis of a report by BÄCKSTRÖM & JOHANSSON (1907) who found an extremely widespread, highly deformed "greywacke series" associated with "clay slates and phyllites" with subordinate limestone and dolomite marbles and granites dominating the geology of the region. As in the western Kuen-Lun the dips are generally steep: "In some parts the schistosity is specially developed, thus producing glistening separation plans *(sic!)*; the greenish greywackes here pass over into greenish schists with parallel jointing ..., the dark greywackes into darkly glistening hard schists, often rust-spotted ...; the dark more fine-grained greywacke-slates pass over into phyllitic schists which it has probably not been possible to separate from certain phyllites, not belonging to the greywacke series" (BÄCKSTRÖM & JOHANSSON 1907, p. 3). BÄCKSTRÖM & JOHANSSON (1907) noted the presence of some gneisses, metamorphic rocks with granulite texture, mica-schists and "hornfels-like rocks", but they expressed astonishment that "The occurrence of such rocks is surprisingly small in view of the region being mountainous; they are completely absent in the southern two thirds of the region covered by the map, and are only found to any extent in the north" (p. 5). This is much the same situation we know from the westernmost Kuen-Lun (see also GRENARD 1929, fig. 53).

A little to the east, MOLNAR et al. (1987) and BURCHFIEL et al. (1989) reported an ophiolitic mélange of presumed ?late Triassic age. This mélange is overlain by an unconformable conglomerate and sandstone unit containing clasts of ultramafic rock and limestone, which, farther south still, overlies unconformably late Triassic sandstones and shales containing thin coal seams.

In the Qilian Shan (on some older maps Richthofen Mountains: see Hedin 1966, sheet NJ 47), the easternmost extension of the Kuen-Lun proper (Figs. 10, 14 and 15), we again encounter the same Palaeozoic subduction-accretion complex that we recognized in the western Kuen-Lun (for a synopsis of a generalised stratigraphy of the Qilian Shan/Qinghai Nan Shan System, see Wang 1989, fig. 4). Two cross-sections across the Qilian Shan, one along the Beida He (Fig. 14C: approximately along 98°E meridian; Obruchev 1901, quoted after Suess 1902, fig. 24, Leuchs 1916, fig. 39 and Leuchs 1937, fig. 102) and the other along the 97°E meridian north of Shule He (Su-lo Ho or Suurin Gol in older maps: Fig. 14A; also see Hedin 1966, sheet NJ 47: Obruchev 1901, quoted after Leuchs 1916, fig. 41 and Leuchs 1937, fig. 104) show early Palaeozoic granite and "melaphyre" (ages of these rocks are checked against the Geological Map of the Qinghai-Xizang Plateau 1980, sheet 4) lying north or northeast of terrains consisting, at the base, of Silurian and older flysch with intercalated mafic volcanic slivers (dolerites), peridotites, and serpentinites (see, for example Du Rietz 1940, fig. c, p. 21), making up the so-called Nan-Shan sandstone of von Loczy (1893, p. 534; see also Du Rietz 1940). High grade metamorphic rocks are represented by rare gneisses, amphibolite schists, and marbles (e.g. in the Tulai Shan and Tulai Nan Shan (Fig. 14B; Suess 1902, p. 235; Ta Xue Shan in Tapponnier et al. 1990, fig. 1a). This in places is essentially a mélange (Fig. 15) and unconformably overlain by Devonian conglomerates passing into slates and sandstones locally containing tuffs and volcanic rocks. This Devonian itself is unconformably overlain by Carboniferous fusulinaceous limestones and coal beds. Much petrographic detail concerning the early and middle Palaeozoic igneous rocks of the Nan Shan is found in Du Rietz (1940) which clearly shows the development of magmatic arc/accretionary complex couples migrating southwards through the Palaeozoic, younger magmatic axes piercing through older subduction-accretion complexes.

Yet a higher unconformity separates all older formations from late Palaeozoic to early Mesozoic continental deposits with a mixed Permian Angara and Cathaysia flora (Li & Yao 1981). The entire section described above is multiply deformed with a dominant south vergence, except along its northern- or northeasternmost edge, where young (Mesozoic and younger) back-thrusts carry Carboniferous and Devonian accretionary complex rocks onto the early Palaeozoic arc massifs and cut the earlier developed south-vergent structures, just as in the westernmost Kuen-Lun (Fig. 14; for the recent episode of thrusting here see Tapponnier et al. 1990).

The entire Qinghai Nan Shan has a dominant south- to southwest-vergent alpinotype structure that formed mainly before the end of the Devonian. The Carboniferous and younger structures here have more of a germanotype character, creating elongate uplifts and basins of inconsistent vergence (see, esp. Bohlin 1937, and for the youngest structures that largely reactivate and mimic the older germanotype fabric, Tapponnier et al. 1990, fig. 10b). All of these observations are consistent with our reading of the information presented in the Geological Map of the Qinghai-Xizang Plateau (1980, sheets 3 and 4 and Liu et al. 1988, sheets 2 and 3) and suggest the presence of a south-facing accretionary complex in the Qilian Shan/Qinghai Nan Shan area of possibly

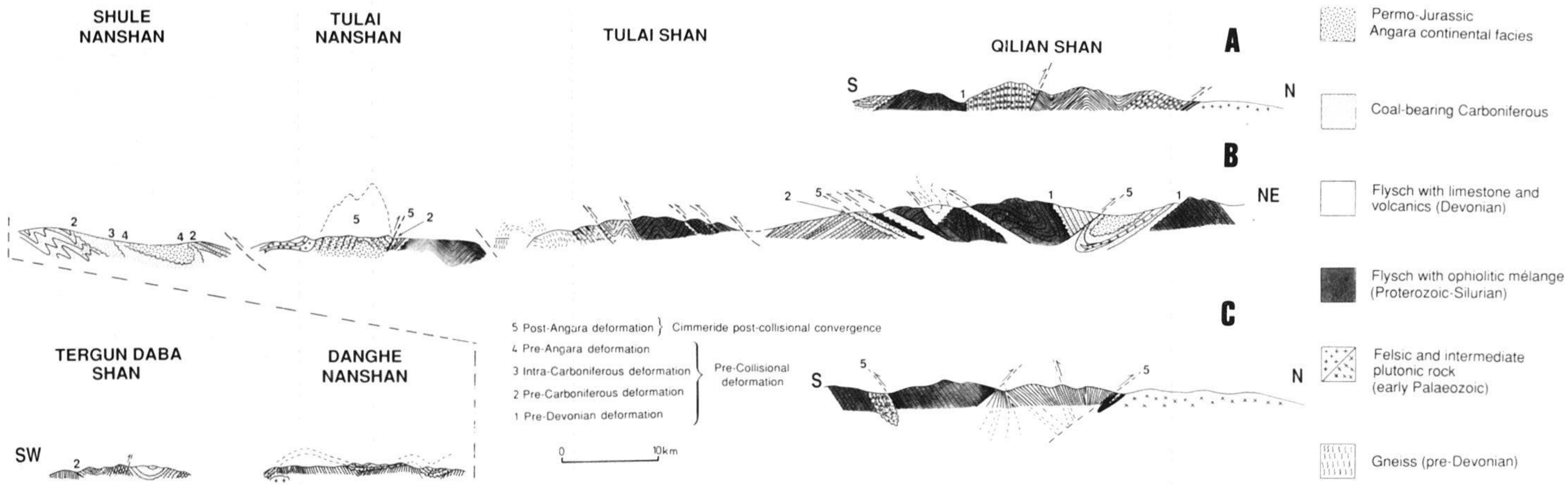

Fig. 14. Geological cross-sections across the Qilian Shan and the Qinghai Nanshan. A. Section north of Shule He (approximately along the 97°E meridian) is after Obruchev (1901), which we cite after Leuchs (1937). B. Section whose approximate location is shown in Fig. 10. The section is discontinuous and was pieced together from Obruchev's (1901) sections and checked against Loczy (1893), Bohlin (1937), Du Rietz (1940) and the Geological Map of the Qinghai-Xizang (Tibet) Plateau (1980). C. Section along the Beida He (approximately along the 98°E meridian). This is also after Obruchev (1901) cited after Suess (1902). Arabic numerals 1–5 indicate the major angular unconformities and therefore times of termination of major deformations. Within the power of resolution of the displayed data, they indicate essentially continuous deformation.

Fig. 15. A "knocker" in the Nanshan "sandstone" in the Qilian Shan on the left bank of the Masu He (Photo: STEIN 1912, fig. 233).

latest Proterozoic to Silurian ages across which magmatic activity migrated throughout the Palaeozoic (see esp. DU RIETZ 1940).

The considerations reviewed above suggest the following general picture of the Kuen-Lun: The entire area marked as Kuen-Lun on Fig. 10, including the Qilian Shan and Qinghai Nan Shan, plus the Anyemaqen Shan is probably not underlain by old continental pieces as previously assumed (e.g. ŞENGÖR et al. 1988; MATTE et al. 1990a), but consists of a possibly late Proterozoic to late Palaeozoic subduction-accretion complex of south facing (present-day geographic orientation). This complex contains numerous unconformities, as already noted by von LOCZY (1893) in the Qilian Shan/Qinghai Nan Shan, and later confirmed by all geologists who worked on the various parts of the Kuen-Lun. These various Palaeozoic unconformities of different ages that overlie the accretionary complex probably *do not* indicate discrete continental collision events as hitherto believed (e.g. DEWEY et al. 1988, ŞENGÖR et al. 1988; CHANG et al. 1989; MATTE et al. 1990a), but are products of sedimentation on top of an evolving accretionary complex. Subduction-related magmatism marched from north to south across this complex, as the complex itself grew southward from the earliest Palaeozoic to early Mesozoic, when it finally reached the Arka Tag/Anyemaqen Shan margin (cf. HARRIS et al. 1988, KIDD et al. 1988), where it formed the backstop to much of the Triassic accretionary complex of the Songpan-Ganzi System (ŞENGÖR 1981, 1984).

The first major collision along the Kuen-Lun/Songpan-Ganzi accretionary complex system occurred when the west and east Qangtang blocks and the Yangtze block collided with it in the latest Triassic to early Jurassic interval along the Ak Tagh ("white mountain")/Lake Lighten/Hoh Xil Shan/Litang/Longmen Shan suture belt (Şengör et al. 1988; Baud 1989). This line represents a fundamental boundary in the architecture of the Asiatic Tethysides separating areas of profoundly different structural styles (Fig. 10). To the north, prolonged subduction-accretion through the entire Palaeozoic and early Mesozoic created immense, south-facing Turkic-type orogenic belts dominated by subduction-accretion complexes with no major continental collisions. If there are *any* pre-Palaeozoic continental fragments within the Kuen-Lun/Songpan-Ganzi accretionary complex (e.g. the Songpan Massif?: Şengör et al. 1988), they most likely represent small Seychelles-type intra-oceanic continental fragments or Baja-California-Type strike-slip generated marginal slivers, with a minimum effect on the orogenic architecture.

By sharp contrast, to the south of the Ak Tagh/Lake Lighten/Hoh Xil Shan/Litang/Longmen Shan suture belt, the orogenic style is dominated by ordinary Himalayan-type mountain belts formed from the collision of major pieces of Gondwana-Land calved off its northern margin since the middle Palaeozoic (Şengör et al. 1988). Here, subduction-accretion complexes are much smaller and are found either squeezed into narrow linear suture zones or expelled in thin, long-travelled overthrust sheets (cf. Gansser 1974). In contrast to the northern Turkic-type orogens, most arcs in the Himalayan-type orogens are constructed through old continental crust (Gariépy et al. 1985) with few exceptions formed directly on ocean floor (Trommsdorff et al. 1982).

6. The Palaeotectonics of the Altaids

When we take a close look at the palaeotectonics of Central Asia north of the Tethysides, we notice that the Turkic-type orogenic architecture dominates the structure of an immense tectonic collage that surrounds the Angara craton like a richly ornamented necklace in the west, south and southeast, and which was named by Eduard Suess (1901, p. 250) the *Altaids*[18]). The Altaids consist almost entirely of

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[18]) Suess (1901, p. 250) defined the Altaids as follows: "In order to obtain an approximate idea of the configuration which is thus developed, let us imagine the whole of that part of Asia which lies to the south-west to be covered with water. Let an impulse originate from the Irtish or the Tarbagatai toward the south-west. Numerous long mountain waves arise one behind the other; at first they are more or less convex towards the south-west, as in the branches of the Thian-shan. They broaden out and elongate, or diverge from one another, where they find room enough, as on the Tchu and Ili. They crowd together and rise, towering up, where the space grows narrower, as in the Nan-shan. In places, they sweep past obstacles, stiff and straight, as in the Tsin-ling-shan, continually seeking a lateral prolongation; in other places, on the contrary, they are impeded by these obstacles, bent and turned aside. At first the universally predominant direction is to the north-west or west-north-west. It is these folds or waves that we group together as the *Altaids*".

The Altaids comprise much of what Suess termed the Asiatic structure, but it was mainly the core of Central Asia that he had in mind for the type Altaids. One of us suggested elsewhere (Şengör 1987) that this is how we should now best use the term Altaids and thus restricted them between the Angara craton and the Tethysides as Fig. 10 shows.