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The rôle of Accretionary Wedges in the growth of continents: Asiatic examples from Argand to Plate Tectonics

By A.M. CELÂL ŞENGÖR[1, 2] and A. HALDUN OKUROĞULLARI[1]

> *"... let us listen to the ancient hymn, the spectacular song of the seas, that has saluted so many chains rising to the light."* ARGAND[3]

ABSTRACT

One of the early triumphs of global comparative tectonics was the recognition of a fairly irregular radial migration of orogenic deformation away from stable continental interiors. Suess interpreted this as continental growth. The theory of continental drift, moulded by Argand's genius into a form capable of answering the demands of continental tectonics, provided the first satisfactory explanation of peripheral continental growth and why it was somewhat haphazard. The composite nature of continents found a ready explanation in the theory of plate tectonics, but suture *zones* were early stereotyped into Salomon-Calvi's suture *lines* (his *Synaphie),* although many orogenic belts do not possess a readily recognisable Indus-type clean suture line. In many mountain belts, zones of continental collision are marked by wide belts of accreted sedimentary rocks, commonly with steep structures, forming trapped accretionary complexes. In his subductionless view of continental drift Argand recognised the importance of accretionary material that he thought had been skimmed off the ocean floor by floating sialic rafts. He portrayed broad, accretionary material-filled suture zones in maps and in sections and contrasted them implicitly with narrow suture lines devoid of such accretionary cushions.

As Argand noticed, the architecture of Asia contains numerous examples of large accretionary complexes. In the Altaids they dominate the structure and in the Cimmerides they play a significant rôle. Only in the Alpides they have a subordinate place in the orogenic architecture, which is a joint function of the size of ocean lost and the amount of sediment supplied.

The presence of giant accretionary complexes in continental architecture has important implications for the structure and composition of the lower crust, the nature of continental anisotropies, and the overall growth of the continental crust.

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[3] All quotations in this paper from Argand's *La Tectonique de l'Asie* were made from Carozzi's translation with small occasional changes (CAROZZI 1977), but the paginations indicated are those of the original. Similarly, the quotations from Suess' *Das Antlitz der Erde* are from the authorized English translation by Sollas (SOLLAS 1904–1924), in places modified by us to improve the translation, but the paginations are those of the original work. All other non-English quotations were translated freely by us.

ZUSAMMENFASSUNG

Einer der frühesten Triumphe der globalen vergleichenden Tektonik ist die Anerkennung eines unregelmässigen Wanderns der Orogenese von zentralen Kratonen gegen die Ränder der Kontinente gewesen, welches Suess als irregulären kontinentalen Wachstum deutete. Die Kontinentaldrifttheorie, geschmiedet durch Argands Genius in eine, den Forderungen der kontinentalen Tektonik entsprechende Form, gab die erste befriedigende Erklärung des peripheren kontinentalen Wachstums und warum dieser unregelmässig vor sich gehen sollte. Obwohl der kompliziert zusammengesetzte Aufbau der Kontinente im Rahmen der Plattentektonik eine einfache Erklärung fand, wurden die kontinentalen Kollisionszonen rasch in die Naht*linien* ("Synaphien") von Salomon-Calvi stereotypisiert, ungeachtet des Fehlens solcher Indus-Sutur-ähnlicher Linien in vielen orogenen Gürteln, wo die Kollisionszonen durch breite Anhäufungen früherer Akkretionskeile markiert sind. Trotz seiner subduktionslosen Auffassung der kontinentalen Wanderungen hat Argand die Wichtigkeit solchen angehäuften ozeanischen Materials anerkannt. Er stellte sie in Karten und Profilen zeichnerisch dar und hob den Unterschied zwischen diesen und den linearen Nahtzonen implizit hervor.

Wie bereits von Argand erkannt, befinden sich viele Beispiele grosser Akkretionskeile in der Architektur Asiens. Dominant sind sie in der Struktur der Altaiden und spielen auch eine nicht unbedeutende Rolle in den Kimmeriden. Eine untergeordnete Stellung nehmen sie nur im orogenen Aufbau der Alpiden ein. Existenz und Ausmass der Akkretionskomplexe scheinen eine Funktion der Grösse des abgeführten Ozeans und der Sedimentzufuhr zu sein.

Das Vorhandensein gewaltiger Akkretionskeile im Aufbau der kontinentalen Kruste hat sehr wichtige Implikationen für die Struktur und die Zusammensetzung der unteren Kruste, für die Beschaffenheit der krustalen Anisotropien und für das allgemeine Wachstum der Kontinente.

1. Introduction

The purpose of this paper is to present some speculations on how the continental crust may have been constructed through the accumulation, and consolidation by magmatism and metamorphism, of accretionary wedges formed during the destruction of oceans. This is related below on Asiatic examples and within the framework of an historical sketch of the evolution of the relevant ideas, in which Emile Argand appears as the leading actor with his prophetic pronouncements on the tectonics of Asia. The speculations we develop suggest answers to such questions as to why in some places the lower continental crust may consist of up to 90% of pelitic material (e.g. Reid et al. 1989, p. 378 and the references cited therein); why the lower crust is seen commonly to be complexly layered (e.g. Brown et al. 1986); and why in Central Asia suture *lines* similar to the one along the Indus and the Yarlung Zangbo in the Himalaya (Gansser 1980) are so rare. All these features seem to result from the widespread occurrence of an hitherto little-considered type of an orogenic belt, in which accretionary wedges are by far the most dominant component. Owing to its prevalence in the structure of areas in Asia inhabited almost exclusively by Turkic peoples[4]), Şengör (in press) called this type of orogenic belt the *Turkic-type* (see also footnote 18 below). The Turkic-type

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[4]) The Turkic peoples are those that are historically and linguistically connected with the T'u-chüeh, a name given by the Chinese to a nomadic people who in 552 AD founded under the leadership of Bumin Khagan a vast empire that stretched from the upper course of the Amur River to the Black Sea and that covered much of the area of the Altaids and the Cimmerides (cf. Şengör 1987 and Fig. 1). Although the earlier Hsiung-nu (the *Kun*, probably originally meaning "man") who had founded a similar empire under Mao-tun in the second century B.C. were also Turkic, the T'u-chüeh were the first Turkic people to leave a written record. In addition to the Turks of the present-day Turkey, the Uzbek, the Kazakh, the Kirgiz, the Turkmen, the Yakut and the Uighur (Uygur) constitute, among others, the most important Turkic peoples.

orogenic belts form, upon collision, a species of the superfamily of non-continental-override-type collisional orogens (NCOB or Himalayan-type) in Şengör's (1990a, table II) classification.

In the following paragraphs we first review the history of ideas that led to Argand's model of accretion and continental growth through continental drift (Part I), and then discuss accretion tectonics and the enlargement of continents in the framework of our view of the widespread occurrence of Turkic-type orogenic belts as a tribute to the enormous insight Argand had into accretionary tectonics (Part II).

PART I

2. Argand's predecessors in the study of continental growth[5])

A long-held view in geology is that orogeny makes continental crust (Şengör 1990a). This view has developed gradually from older ideas that first equated continent-making with mountain-making and then recognized mountain-making as only a stage in a longer process of continent-making.

2.1 Theories of continental growth until the nineteenth century

Until about the end of the first quarter of the nineteenth century, two main opinions sought to explain the origin and history of our continents. The neptunist view from the Sumerian flood legends (cf. Heidel 1949; Lambert & Millard 1969) to Werner (cf. Bingel 1934) considered them as original irregularities on the surface of our planet, explaining their growth or destruction as functions of the movements of the hydrosphere, thus taking the "obvious" immobility of the *terra firma* and the high mobility of the waters for granted. By contrast, plutonists from Eratosthenes and Strabo (e.g. Strabo, I, 3.10) to Leopold von Buch (von Buch 1825, p. 110; 1830, p. 63)[6]) and Hopkins (1835 and 1847) based their views on the effects of volcanoes and earthquakes and maintained that the present irregularities of the planet's surface were results of deformation generated by vertical (radial) motions that were caused by its "internal fire". The one enduring feature of these early plutonist theories of continent-generation which influenced later ideas was that continent-making and mountain-making were thought to be related processes, both being results of the internal energy of the earth.

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[5]) Continental *growth* here designates only the growth of one particular continent and not necessarily a net gain of continental mass. It is thus used differently from most modern authors (cf. Dewey & Windley 1981, p. 191). In the sense *growth* is used here, it is equivalent to what Dewey & Windley (1981, p. 191) call *accretion*. In the penultimate section of this paper we briefly discuss to what extent accretion *à la* Dewey & Windley may represent net gain of continental mass.

The reason we use *growth* in such a loose sense is because for growth in the sense of net gain in mass to be recognised, a continental crust as distinct from a mantle and/or an oceanic crust had to be distinguished first. This happened during Argand's lifetime and partly through the help of the theory of continental drift. Since a part of this paper deals with the history of ideas, employment of the modern meaning of growth could have led to confusion.

[6]) All page numbers of the publications of Leopold von Buch in this paper refer to those in his *Gesammelte Schriften* edited by Julius Ewald and his collaborators.

2.2 Theories of continental growth in the nineteenth century

In 1831 Elie de Beaumont argued that mountain ranges were produced by horizontal shortening resulting from the thermal contraction of the earth (cf. Şengör 1990a, p. 17, footnote 7). He and Dufrénoy recognised further that areas of orogenic deformation corresponded with areas of thick marine sediment accumulation (especially for the Jurassic: see Dufrénoy & Elie de Beaumont 1848). Elie de Beaumont (1852) later argued that the crushing of a marine trough between the jaws of the adjoining table-lands led to the "filling" of the trough with folded sedimentary rocks. Ongoing shortening led to the overflow of the contents of the former trough and resulted in the generation of a mountain range.

Argand later found this idea of "filling" extremely fruitful:

> "I shall never sufficiently stress what geology owes to the fruitful concept of *filling,* the apex of the thinking of Elie de Beaumont, which includes, clearly expressed or in a strongly implied form, most of the ideas with which tectonics has lived for a long time and with which it will always live, as long as the use of the concept is precisely regulated: the idea of framed folding, the idea of geosyncline, the idea of double chain and of double overturning, the ideas of unilateral overturning, of true foredeep, and of foreland" (Argand 1924, p. 327).

The real founder of the geosynclinal theory of mountain-building in a contractionist framework was James Dwight Dana. His associated ideas concerning progressive *continental stabilization* have long been misinterpreted as implying *continental accretion* by orogenic consolidation of peripheral geosynclinal systems (e.g. Haug 1900, p. 630; 1907, p. 166; Aubouin 1965, p. 12; Dott 1979, pp. 252–253; for criticisms of this misunderstanding see Schuchert 1923, p. 197; Stille 1940, p. 6). Dana thought that the continents represented earlier solidified portions of a magma (or migma) ocean that once covered the earth, while the floors of the present oceans had solidified later. Thermal contraction was thus thought to have been more vigorous in the oceans and this contraction was believed to have caused the largest compressive stresses near the continents whose commonly NW-SE- or NE-SW-trending margins – Dana's "cleavage structure of the globe" (Dana 1875, pp. 746–747) – were thus thrown into broad folds of crustal dimensions: a geanticline formed adjacent to the ocean succeeded continentward by a geosyncline (Dana 1873, 1875). Dana (1873, pp. 8 and 15) emphasized that *the geosynclines were kept filled by shallow water sediments* during their development. When finally the geosyncline collapsed under ongoing shortening and the thermal weakening of its depressed floor, a mountain range was catastrophically created that consisted mainly of continental sedimentary rocks⁷).

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7) We here follow Fischer's (1976, p. 2) nomenclature: "Sedimentation occurs in two great realms: that related to the continental masses, and that of the great oceans ... *Continental sedimentation,* in this sense, includes not only the materials conventionally classified under this name, formed in streams and lakes and swamps, but also the deposits of the epicontinental seas, including the great limestone platforms and the evaporites of the interior basins. *Oceanic sediments* include the *pelagic deposits* as well as the turbiditic sediments of abyssal plains and trenches, and the volcanic-rich sequences near island arcs" (italics Fischer's).

Dana further argued that geosynclinal chains became younger away from a stable continental interior, indicating the progressive consolidation of the continent from its centre towards its periphery. But this did *not* mean continental growth, because geanticlines delimiting geosynclines against oceans were considered parts of continents (see the discussion in Schuchert 1923, pp. 157–158). Dana thought that continents and oceans had not only differentiated early in earth's history, but that they were permanent features of the globe, thus ruling out any significant continental growth during the geological history (Dana 1873, pp. 51–52).

Dana's views provided a unified, easy-to-understand theory of sedimentation and mountain-building. He had inherited the catastrophist and regularist *Leitbild* of his European predecessors (cf. Şengör 1991c), and his views were also firmly rooted almost exclusively in continental geology and what he had learned of oceanic islands (but *not* of ocean floors) during the Wilkes Expedition to the Pacific Ocean.

Eduard Suess (1875) spotted three problems in Dana's scheme: 1) The various regularities assumed by Dana in the spatial aspects of mountain belts: Suess was unable to agree with any of Dana's principal conclusions regarding spatial regularities of orogeny: Mountain belts did not preferably grow along or close to the present continental margins; their trends did not commonly follow preferred NE-SW or NW-SE striking "cleavage planes" (cf. Dana 1875, pp. 746–747); they did indeed generally become younger away from central stable regions, but Suess pointed out that this was a fairly haphazard process, younger chains commonly migrating back towards the continental interior and reactivating older ones (esp. Suess 1875, p. 55). 2) Suess (1875) did not think that mountain-building was a catastrophic process (see esp. Şengör 1991c). 3) Suess showed that the sedimentary rocks involved in mountain building were not exclusively of continental type as Dana had assumed[8]).

Suess' point that *oceanic* sedimentary rocks, i.e. former ocean floors, are involved in mountain building (Suess 1875, pp. 99ff; also Suess 1893, 1895 esp. pp. 1115–1116) and that they now form parts of *continents* was of enormous importance, because it showed that continents and oceans are not permanent features as Dana believed and that continents may be enlarged at the expense of oceans.

Suess also showed how sediments on ocean floors could be added to continents. He argued that orogenic belts were fundamentally asymmetric objects and that their vergence commonly developed towards a topographically inferior foreland (Suess 1883, p. 187: they "overthrust the subsidence"). Perhaps inspired by Holmquist's (1901, figs. 3 and 4; see also Suess 1901, figs. 22 and 23; reproduced here as Fig. 1B)

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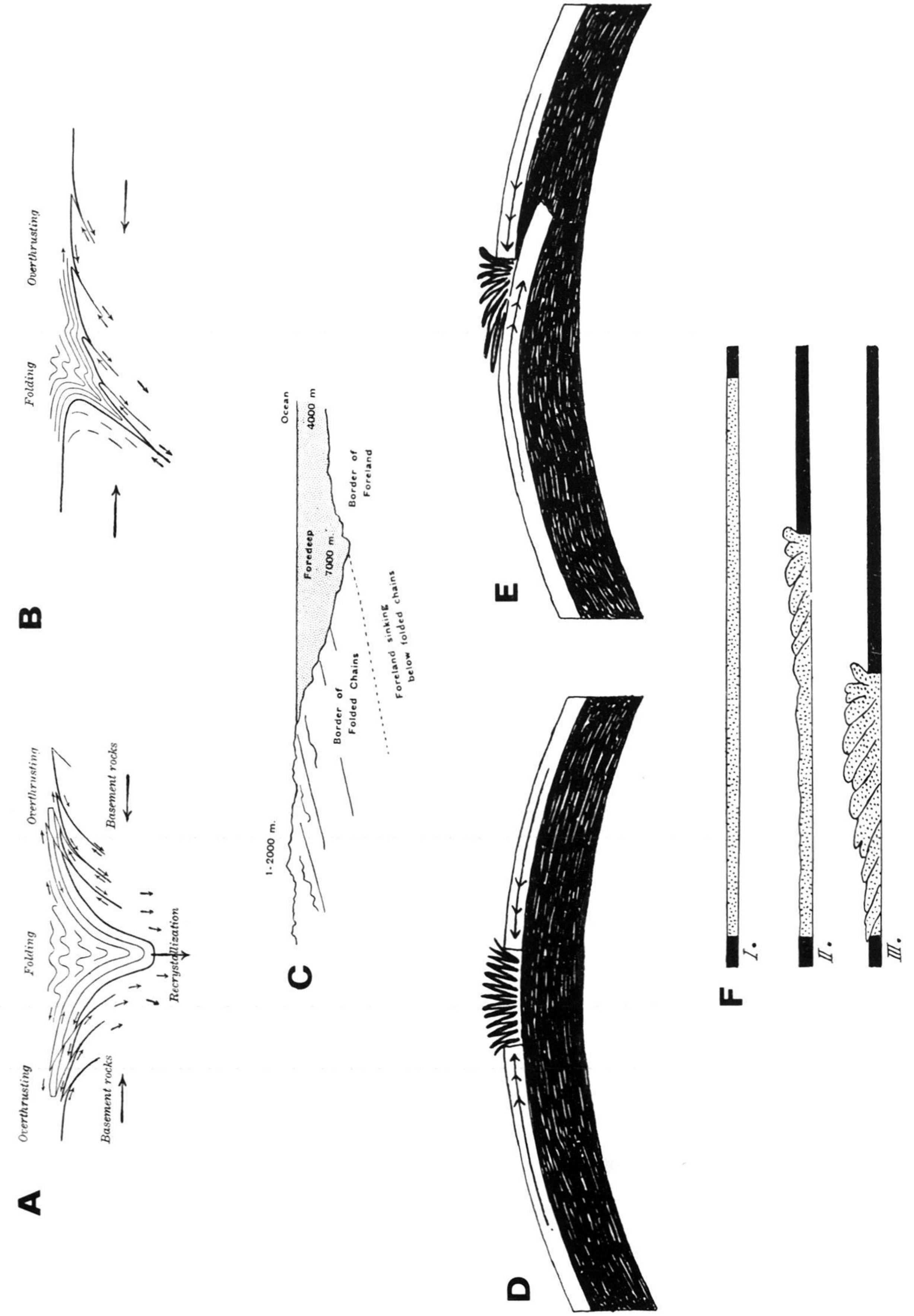
[8]) Hsü (1973, p. 67) wrote that Suess "was wrong, however, to cite the Triassic of the eastern Alps, known to us as a tidal-flat complex (e.g. Fischer 1963), to prove his point that the Alpine carbonates are largely pelagic ... Suess was evidently not a sedimentologist". This criticism is, however, totally unfair. Suess simply pointed out that as one went from southern Germany towards the Alps, the sediments generally became relatively *more pelagic*. "This, for example, applies in an excellent way to the Rhaetian Stage, *whose certain variations* I view with certainty to be representatives of the *deep zones of the one and the same marine realm*" (Suess 1875, p. 98, italics ours). Indeed, as one moves southward along a palaeogeographically reconstructed late Triassic profile in the Eastern Alps (e.g. Laubscher & Bernoulli 1977, fig. 4), one goes from the European platform through the Alpine shelf finally to a deep marine environment (the *Hallstätter facies)*, however its setting is interpreted (e.g. Tollmann 1976, pp. 479ff, esp. 501ff; Lein 1985). What Hsü (1973) says is true only of the southern limit of the Dachstein reef facies (cf. Fischer 1975), to which Suess (1875) had not limited his argument.


A
Overthrusting
Folding
Overthrusting
Basement rocks
Recrystallization
Basement rocks
B
Folding
Overthrusting
C
1:2000 m.
Ocean
4000 m
Foredeep
7000 m.
Border of Foreland
Border of Folded Chains
Foreland sinking below folded chains
D
E
F
I.
II.
III.

interpretation of the orogenic architecture in Scandinavia, Suess (1924) interpreted deep-sea trenches as places where oceanic sediments became incorporated into the folded margins of the continents by offscraping above giant thrust faults (Fig. 1C). He thus maintained that continents grew peripherally at the expense of oceans. Sometimes two continents would become welded to one another by the contents of the former ocean floors and the "filling" of the intervening marine space as the two nuclei approached one another (Suess 1895, p. 1116).

Suess also recognised important extensional and some strike-slip events in terrestrial tectonics and noted that extension commonly took place in regions where compressive deformations no longer occurred (see esp. Suess 1909, pp. 304–330, 720–721 for extension; Suess 1883, pp. 153ff for strike-slip).

Thus, when Argand formally commenced his geological studies in 1905, Suess had nearly completed the theoretical foundations of his terrestrial tectonics, on which Argand was to construct one of the most elegant conceptual monuments in the history of our science.

3. Argand, Mobilism and Continental Growth

Between 1905 and 1915 Argand devoted his energies mostly to sorting out the structure of the Alps and began developing an interest in global tectonics, especially of Eurasia. His Alpine studies led to his corroboration and amplification of Suess' views on the one-sidedness of the Alpine edifice, the immense mobility betrayed by the highly complex nappe structures, and the deep-sea nature of the Alpine "geosynclinal" sedimentary rocks (Argand 1909, 1911, 1916). His efforts to reconstruct the history of evolution of the Alps culminated in the theory of embryotectonics, which was little more than shortening a composite geosyncline along giant recumbent folds that eventually had come to rest one upon the other in the present-day structure of the Alps. As Şengör has shown elsewhere (Şengör 1982), Argand's embryotectonics was a bold combination of the fixist views of Suess and Haug. But Argand was quick to recognise that continuous shortening could not create both the geosyncline and the mountain range that resulted from its collapse:

> "The classical concept *(i.e. Dana's and Stille's versions of the contraction theory)* combined with that of basement folds certainly allows bold interpretations. Here is one that I have considered: the Mediterranean-type seas, the marginal seas, and the oceans be but basement synclines. These geosynclines of a new type, formed by lateral compression and becoming the location of more particular types of lateral compressions, generating

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Fig. 1. A. Holmquist's hypothetical explanation of the Scandinavian overthrusts. The symmetric case (Holmquist 1901 and Suess 1901). B. Holmquist's hypothetical explanation of the Scandinavian overthrusts. The asymmetric case (Holmquist 1901 and Suess 1901). C. Suess' model of oceanic underthrusting and marginal folding associated with growth of mountains (Suess 1924, drawn before 26th April 1914). D. Ampferer's model of symmetric accretionary orogeny (compare with Holmquist's symmetric case; Ampferer 1928). E. Ampferer's model of asymmetric accretionary orogeny with *Verschluckung* (compare with Holmquist's asymmetric case and Suess' model of orogeny; Ampferer 1928). F. Ampferer's model of the progressive growth of an accretionary wedge (I, II and III).

> chains, would unquestionably explain many features. In that respect one thinks immediately of all kinds of island festoons, of the Oceanides, and of the elongated crests that sinuate in the middle of the Atlantic and in the western portion of the Indian Ocean *(these are the ideas that led to Argand's theory of embryotectonics and they make clear Haug's influence).* This concept leads directly to the idea of the continuity and particularly of the universality of folding, which becomes the only major aspect *(legacy of two great Swiss predecessors, Arnold Escher von der Linth and Albert Heim?)* Indeed, considering from this viewpoint the closed environment formed by the entire planet, one encompasses in one swoop, and rightly so, the totality of the horizontal and vertical aspects of the deformation. It becomes completely useless to ask oneself if the radial movements follow or precede originally the tangential movements, and what their reciprocal relationships are. This question, debated by generations of geologists, is justified on the scale of small entities, but is meaningless with respect to the whole. The incapacity of the plastic media to transmit, beyond a certain distance, an effective effort is not an insurmountable obstacle if one assumes for the upper part of the oceanic substratum the same kind of heterogeneity that is displayed so clearly by the continental substratum. Thus renewed, the classical concept would allow extensive enrichments, and a long time would elapse before these sources would be depleted. *Unfortunately, in relation to all this, there is isostasy, and as we shall see much more"* (Argand 1924, p. 291, italics and italicised annotations in parentheses ours).

Argand thus recognised that continuous shortening leading to a unicausal history of geosynclines and orogens would not do largely because of isostasy. It was at this point that Wegener's theory of continental drift rendered him decisive help. Wegener 1915, 1920) had shown that continental extension would lead to thinning and eventual separation of two continents, the space in between being filled with the sima (Fig. 2). This made Argand realise that his geosynclines might have been nothing more than former oceans! This revelation not only solved the problem of creating basins without violating isostasy, it also showed that Steinmann's (1905) and Suess' (1909, pp. 644–646 and note 55 on p. 654) point about the presence of pelagic sediments in close association with ophiolites in mountain belts being analogous to the situation in the

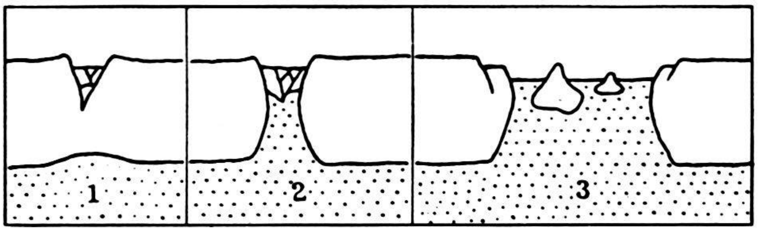

Fig. 2. Wegener's model of continental rifting showing three successive stages. 1) Origin of a rift valley; 2) Extension and further thinning of the sial under the rift; 3) Origin of an ocean with two small continental fragments (Wegener 1920, fig. 10).

present-day oceans on the basis of the Challenger Expedition results, was essentially correct (see also STEINMANN 1925). Argand, like SUESS (1909, p. 722 and note 52 on pp. 737–738) and WEGENER (1915, p. 15, footnote and p. 69) before him, no longer needed the concept of a geosyncline:

> "The mobilistic theory has somewhat neglected the concept of geosyncline. It is therefore appropriate to sketch a connecting link. A geosyncline will generally result from a horizontal *traction* that stretches the raft of sial. The stretching is at first easier in the deeper part of the sial rather than in the upper part, where extension fractures may develop. While thinning, the sial sinks and develops a depression: the subsidence inherent in the geosynclinal process does not, therefore, stem from an original radial stress; it is only the vertical effect of a horizontal distension. The overburden of the deposits helps of course to accentuate the alveole, but the latter is not necessarily the original feature. Until compensation, the sima rises under the sial; this behaviour accounts for the frequent association of green rocks with bathyal and abyssal sediments *(this sentence refers directly to the observations by Steinmann and Suess as mentioned above)*. The mixture of abyssal with shallower sediments takes place through submarine sliding on the *(continental)* slope...
>
> If traction continues, instead of giving way to compression the sial continues to stretch and the sima appears at the bottom of the alveole. Along the transverse alignments where such a condition occurs, the geosynclinal condition is replaced by the oceanic condition; if such a situation becomes generalized, only an ocean is left. If a compression occurs at this stage or just before it, when the sial is really very thin, the lack of synergy will lead to the generation of one or two trends of marginal chains, of Circumpacific type, and not of the double chain of geosynclinal type. If the compression continues, the latter type will establish itself gradually and may perhaps eventually predominate, but the traces of the simple or double marginal condition will persist, although veiled" (ARGAND 1924, p. 299, italicised annotations in parentheses ours).

The geosyncline thus became only a certain stage in the development of an ocean (either at the beginning, or near the end, i.e. when the ocean is narrow such as the Red Sea or the Eastern Mediterranean) and consequently lost its central rôle in the theory of orogeny!

Argand then applied these views to the entire history of Asia, concluding that the Palaeozoic orogenic belts surrounding the southern and southeastern periphery of the Angaran Shield had resulted from the elimination of an immense geosyncline that had resulted from "a very old Precambrian continental displacement that could have led to the separation of the oldest nuclei of the Serindian *(i.e. the Tarim block of the Chinese literature)*, Sinian and Siberian massifs" (ARGAND 1924, p. 251; italicised annotation between parentheses is ours). These nuclei later reconverged as seen in Fig. 3 and gave rise to the late Proterozoic and the early and late Palaeozoic orogenies of Central Asia, creating what Eduard Suess had termed the Altaids (SUESS 1901, p. 250; see ARGAND 1924, pp. 183–194, 223, 250–251; see also footnote 18 below).

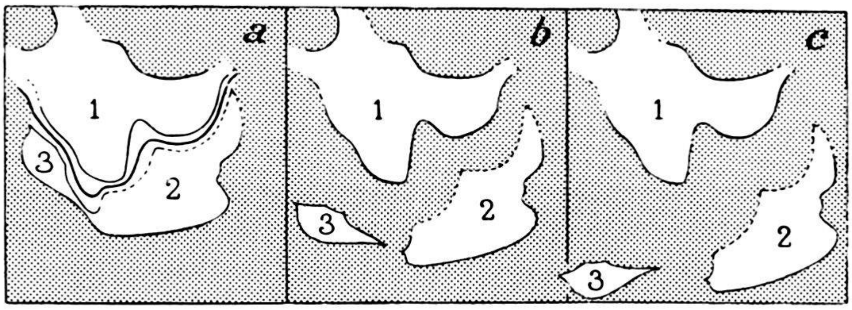

Fig. 3. Argand's "very ancient Asiatic drifts" presented in descending order of time. Key to numbers: 1. Siberian massif (Angara craton), 2. Sinian massif, and 3. Serindian massif (Tarim "craton"). Argand visualized the geometry shown in c as having evolved from a geometry similar to that shown in a by rifting and opening of *oceans* (shown shaded, Argand 1924, fig. 7; shading added by us to improve clarity).

When one reads Argand's description of the evolution of the Altaids in the light of what he said of geosynclines and his heritage of Suessian tectonics, one recognises that Argand thought of the Palaeozoic evolution of Asia in terms of both accretion⁹) *and* collision processes. It is, however, unfortunate that he was so brief in his narrative of the particulars of the Palaeozoic tectonic history of Asia, which he moreover related using the old fixist terminology!

But in one place, in his classic, Argand's narrative becomes explicit and his nomenclature novel, where he depicts the tectonics of accretion at the southern continental margin of his Serindian massif, as seen today in the structure of the Kuen-Lun range in northern Tibet (Fig. 4). In the second part of this paper the same locality will form our point of departure as the best example illustrating our present views of the tectonics of accretion in Asia! The two following quotations, presented by reversing the order of

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⁹) Accretion as used in this paper, by which we mean exclusively the process of subduction-accretion that results from offscraping or the process of skimming that results from a Wegener-type continental drift, should not be confused with what has so far been termed "terrane accretion" (e.g. Jones et al. 1983., pp. 27ff; Nur & Ben-Avraham 1983). "Terrane accretion" denotes the collision of individual, coherent "terranes", i.e. "fault-bounded geologic entities of regional extent that are characterized by geological histories different from those of neighbouring terranes" (cf. Jones et al. 1983; Schermer et al. 1984), with a host continent. In this view, terranes may range from the size of the exotic blocks in mélange complexes to sizeable continental pieces. However, the word "terrane" is so inclusive that an entire subduction-accretion prism may also be implied by it. Elsewhere (Şengör 1990a, 1990b, 1991b; Şengör & Dewey 1990) Şengör has discussed at length why the tectonic analysis of orogenic systems in terms of terranes is not useful and may indeed lead to confusion and scientific sterility, and we do not repeat those arguments here.

In contrast to the vague concept of terrane accretion (which Hashimoto & Uyeda 1983, p.v., term *accretion-collision,* perhaps to distinguish it from *subduction-accretion),* subduction-accretion is a well-defined process, whereby the sedimentary cover of downgoing plates, together with occasional slivers of the material making up the basement of the plate, are transferred to growing accretionary wedges at the prow of overriding plates. In Argand's subductionless view of continental drift a similar process was envisaged to occur by skimming the top of the sima at the front of continental rafts drifting through the sima.

Both in Argand's world and in plate tectonics, accretion may be interrupted or altogether terminated by collisions. Tectonic objects formed from both accretionary complexes and collided buoyant objects constitute *tectonic* or *orogenic collages.* If more than one subduction-accretion prism come together without involving coherent buoyant entities such as island arcs or microcontinents, they simply form *accretionary complexes* (cf. Şengör & Yilmaz 1981; Şengör 1990a).

their occurrence in Argand's text, show how far "the magician ... Emile Argand" (LUGEON 1940, p. 49) anticipated our present views:

> "Therefore it is very likely that during Palaeozoic times, *the centre of what is called the Tethys* between India and Serindia *resembled more an ocean* than a marine embayment *(Argand here refers to Neumayr's map of the Central Mediterranean, which shows a narrow marine gulf to occupy the future site of the Kuen-Lun. See ŞENGÖR 1984, fig. 2 for a reproduction of Neumayr's map)* and *the young Kuen-Lun,* born from a continental slope that from Serindia sloped toward the open sea, *resembled by its deformation the Circumpacific chains* rather than half of a double chain rising from a geosyncline" (ARGAND 1924, p. 244, italics and the italicised annotation in parentheses ours) *"The Indo-Serindian space, perhaps too wide in these remote times to be designated a geosyncline,* gave rise, immediately adjacent to Serindia, to pre-Devonian folds followed by Hercynian folds: *this complex wrinkle*¹⁰) *was the material for the future Kuen-Lun"* (ARGAND 1924, pp. 243–244, italics ours).

In Fig. 4 we indicated the location of Argand's *bourrelet complexe* that later formed the Kuen-Lun. Notice there that Argand added a further wedge of accretionary material to the Kuen-Lun which represented the sedimentary fill of the Tethys, thus suggesting that accretion continued from pre-Devonian times until the closure of the Tethys in the Himalaya! We know now that the situation in Tibet is more complicated than this hypothesis implies¹¹) (e.g. ŞENGÖR et al. 1988), but the additional wedge that Argand sketched does indeed exist and resides in the Songpan-Ganzi System (ŞENGÖR 1981, 1984; ŞENGÖR et al. 1988; see also Fig. 10 below).

In Fig. 4, clean-cut thrusts as well as complex recumbent folds are seen. This distinction, i.e. that between a *nappe du second genre* (thrust slice) and a *nappe du premier genre* (large recumbent fold) had already attracted some attention in the Alps (see TERMIER 1906) and Argand attached to it a genetic significance related to the final state of stretching during the opening of an ocean.

> "Clean-cut thrusts whose neatness originates from the fact that the old distensions had reached, along the particular transverse alignment, a perfect disjunction of the two sials. In this case, any subsequent thrust is necessarily clean-cut" (ARGAND 1924, p. 348).

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¹⁰) In the original, Argand uses *bourrelet,* which Carozzi translates as "wrinkle". *Bourrelet* literally may mean a rim or a swelling, a bulge, as well as a cushion or a pad. In geology *bourrer* refers to thickening of incompetent media under shortening. We find it significant that Argand should have selected *bourrelet* to describe the complex folds that formed at a continental slope. Instead of Carozzi's "wrinkle" we should have used "complexly folded cushion".

¹¹) As recently as 1979 some thought that the whole of Tibet may have been underlain by an accretionary prism: "The northern border, now occupied by these eastern and western Kun Lun ranges and the Altyn Tagh, consists dominantly of medium to high-grade regionally metamorphosed rocks, whose deformation and metamorphism is pre-Devonian ... and, in places Precambrian ... From this region all the way south to the Indus Suture the rocks in the undissected part of the plateau ... [are] interpreted ... as a huge accretionary prism of sediments, mostly derived from the extensive area of late Palaeozoic orogenesis in Central Asia ..., (ŞENGÖR & KIDD 1979, p. 370). The plate tectonics context apart, this is much the same picture that Argand had.

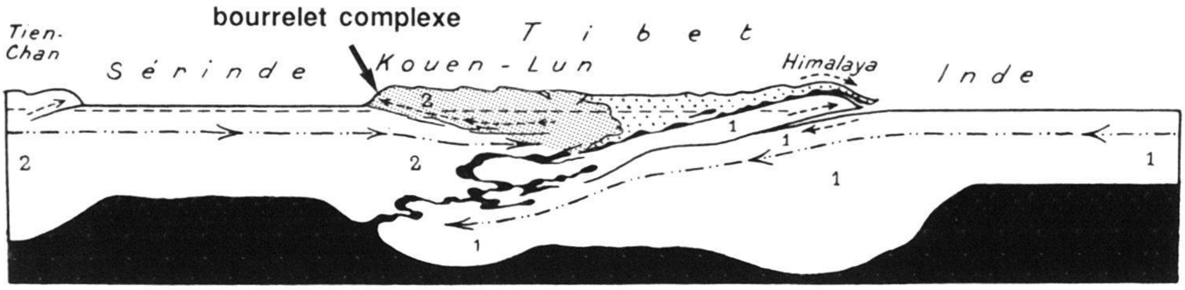

Fig. 4. Argand's cross-section across the Tibetan high plateau showing Serindia, Kuen-Lun and the Himalaya. The *bourrelet complexe* (shown by dense stippling added to Argand's figure by us) represents, according to Argand, an earlier accretionary complex that formed along the southern margin of the "Serindian block" (i.e. the Tarim) than the mainly Mesozoic one shown by Argand himself with sparse stippling ("The tectonic products arisen from the axial zone of the Tethys": ARGAND 1924, p. 348). ARGAND (1924 fig. 13).

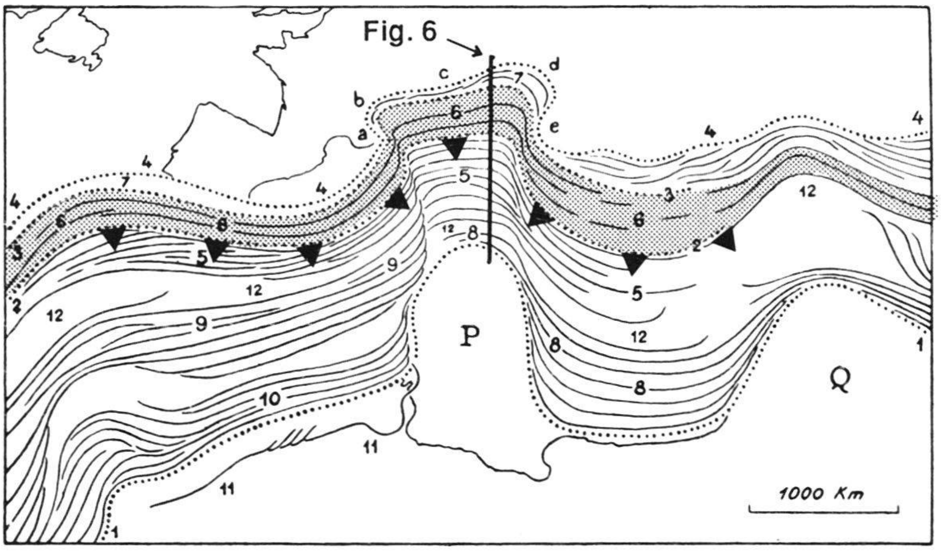

Fig. 5. The march of embryonic cordilleras in the Tethys before the final Alpine paroxysm after ARGAND (1924, fig. 20A; shading and black triangles added by us to improve clarity).

Gondwanian continental margin: 2. Lower limit of the Gondwanian continental slope; 1. Upper limit of the Gondwanian continental slope. P. African Promontory *(Adriatic Promontory);* Q. Arabian Promontory.

Eurasian continental margin: 3. Lower limit of the Eurasian continental slope; 4. Upper limit of the Eurasian continental slope; a) Ligurian promontory; b) Hemicyclic reentrant of the western Alps; c) Bohemian salient; d) Hemicyclic reentrant of the Carpathian region; e) Getic promontory.

Axial zone of the Tethys: 6. Axial zone of the Tethys (stippled), in part overridden in the south. 7 through 11 are embryonic nappes. The accretionary material is in the "axial zone". See Fig. 6 for the style of accretion in the axial zone.

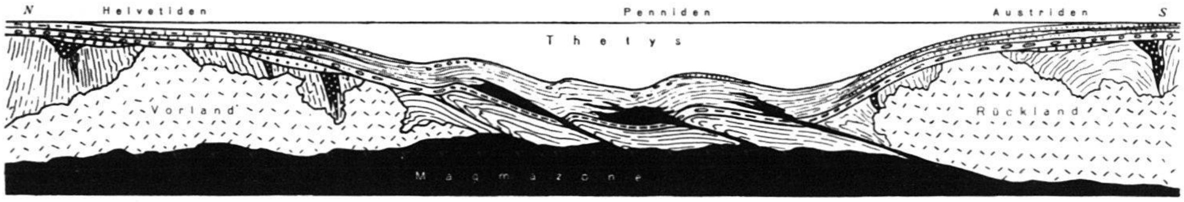

Fig. 6. Structural style of accretion in the axial part of Argand's Tethys according to STAUB (1924, fig. 61: note the misspelling as "Thetys"). See Fig. 5 for a map view and for the location of this schematic cross-section.

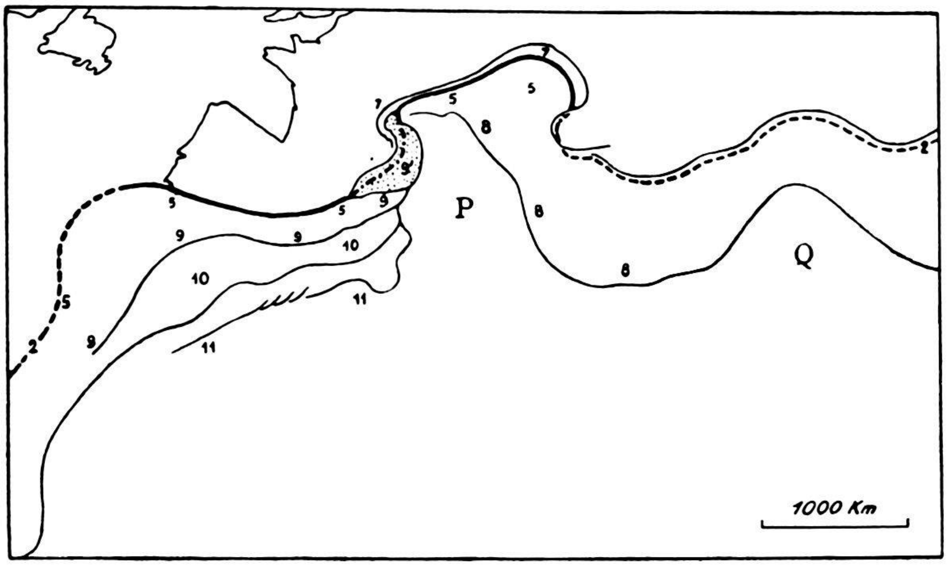

Fig. 7. Suture map of the Mediterranean orogenic belt according to Argand (1924, fig. 21). Dotted area represents the Pennine accretionary material "in the few regions in which they are not covered by other nappes" (Argand 1924, p. 360). Note the difference between suture *lines* and suture *zones* in this map.

Thus, Argand clearly underlined that he thought that not only the Kuen-Lun, but the entire Tibetan high plateau and the Himalaya had resulted from the closure of the Tethyan *ocean* that also partly supplied the material to the construction of these regions.

Argand did not leave us a cross-sectional view of the process of accretion, although he did depict it on a map (Fig. 5). We couple this map with a section by Staub (1924), in which the details of the accretion process, by thrust stacking and close to isoclinal folding, are clearly visible (Fig. 6)[12]).

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[12]) We included Staub's sketch to supplement Argand's with much reluctance. Staub was a Kober-Stillean in his *Leitbild* (cf. Şengör 1991c) and his mobilist views became progressively more fixist as he drifted away from Argand's influence over the years. In 1924, under the influence of Argand's grandiose views, he was a full-fledged mobilist, but already displaying his Kober-Stillean *regularistic* tendencies such as the assumption of a bilateral symmetry of the Alpine System about an Adria-axis or the regularly north-vergent structure of the *entire* Alpine System between Gibraltar and Iran. In 1928, in his *Bewegungsmechanismus der Erde*, he abandoned a part of his mobilistic views in favour of a fixed Pacific Ocean supposedly formed through a catastrophic departure of the Moon and resorted more and more to a geometrically neat and episodically evolving earth model. In *Der Bau der Glarneralpen* of 1954 he emphasized long-lived, autochthonous lineaments in the crust, and finally, in his posthumously published *Neue Wege zum Verständnis des Ostalpen-Baues* (Staub 1971) he appeared as a full-fledged fixist with a partially contractionist framework.

All this makes us wonder how much Staub really understood Argand and how much, in the early years of his career, he was following the bright beacon of Argand simply as a bandwagon jumper. The fact that he never noticed Argand's significant 1934 revision of the theory of embryotectonics betrays, we are afraid, that Staub must have had a fairly limited understanding of Argand's views.

The only reason why we included the 1924 cross-section by Staub in our Fig. 6 as a further elucidation of Argand's views is that it was drawn at a time when Staub was in closer professional contact with Argand than later and that between 1924 and 1928, when Staub had the same cross-section reproduced in the *Bewegungsmechanismus* (fig. 1), no serious objections were raised against it.

Argand thus noticed that the closure of major oceans produced accretionary complexes that added to continents. Fig. 7 shows the situation in the Mediterranean area after continental collision, in which Argand clearly distinguished suture *lines* from accretionary material-filled suture *zones*. These two styles of continental apposition were elaborated by different people following Argand's presentation.

4. Post-Argandian mobilism and continental growth before plate tectonics

The man who developed the ideas and the terminology about suture *lines* after Argand was Wilhelm Salomon-Calvi, one of the few outstanding field geologists of the early part of this century, who became convinced of the reality of continental drift:

> "If the assumption that continents drift towards one another and thus may come into contact is correct, then surfaces of apposition *(Zusammenschubflächen)* must form. *These will be similar to faults,* because along them masses come into contact with one another, which had not been in touch before. But they have a completely different character and a completely different meaning. That is why we use a special expression for them in what follows" (SALOMON-CALVI 1930, p. 4, italics ours).

The special expression Salomon-Calvi invented was *Synaphie* (from the Greek συναφεια meaning union, unity of rythm, concordance) that may be anglicised as synaphia. He had also thought of *suture* (in German *Narbe),* but decided against it,

> "because a suture is a healed wound of a former injury, but synaphia is a welded juncture that brings together two masses that had not been one before" (SALOMON-CALVI 1930, p. 20).

This distinction between a suture and a synaphia shows clearly how well Salomon-Calvi appreciated the implications of continental drift in terms of a tremendous continental mobility.

Salomon-Calvi considered synaphias as *lines* of apposition, although he pointed out in 1936 that such lines may be multi-branched encircling former "betwixt lands" *(Zwischenländer:* SALOMON-CALVI 1936, p. 12; compare with Wegener's "microcontinent" depicted in Fig. 2). This "clean" conception of synaphias resulted from the fact that Salomon-Calvi developed his views on the examples of faults that formed following continental collision and that only partly followed the real suture zones (e.g. the Tonale line in the Alps, the North Anatolian fault in Turkey).

If dominance of folding in orogeny was a Swiss heritage through Escher and the father Heim, the dominance of thrust faulting was an Austrian conviction inherited mainly from von Richthofen's Vorarlberg work and Eduard Suess. Otto Ampferer realised very early that the enormous shortening seen in the sedimentary cover of the Alps could not have been parallelled by a similar shortening of the crust that underlay it, unless considerable portions of the crust had disappeared in a manner reminiscent of HOLMQUIST's (1901) suggestion. This, Ampferer called *Verschluckung* in 1911 (AMPFERER & HAMMER 1911, p. 699 as *Verschluckungszone)* and depicted it in a schematic section in 1928 (Fig. 1E).

The essence of Ampferer's concept was that the entire process of orogenesis was really nothing more than movement along one immense thrust fault (e.g. AMPFERER 1928, p. 346) along which the cover of the underthrusting plate was scraped off and piled up in the form of a huge accretionary prism (Fig. 1E). In a subsequent figure (Fig. 1F), Ampferer showed how he thought that wedge would grow, in criticism of ARGAND's (1916, 1924) synchronously-moving embryonic folds.

How the accretionary masses Ampferer described are accommodated in a completed orogenic edifice and what they imply in terms of the palaeogeography of the orogen was discussed by another Austrian, namely Franz Eduard Suess, Eduard Suess' geologist son. In his incredibly perceptive, but regrettably diffuse writings, SUESS (1937, 1938, 1939) pointed out that most orogens consist of three main tectonic units: 1) A "producing slab" *(erzeugende Scholle)* is represented by the highest far-thrusted unit including evidence of past magmatic activity. This overlies 2) an "overridden zone" *(überfahrene Zone)*, composed of numerous metamorphosed thrust slices. 3) Finally an "unburdened foreland" *(unbelastete Zone)* contains offscraped continental margin and foredeep sedimentary rocks piled up in essentially unmetamorphosed nappes (Fig. 8). SUESS (1937, p. 11) pointed out that the metamorphosed sedimentary rocks of the "overridden zone" corresponded with an older foredeep in front of the magmatic "producing slab". Suess thus implied that the sedimentary rocks of the orogen that now lay under the "producing slab" represented a scraped off and accreted pile, emphasizing

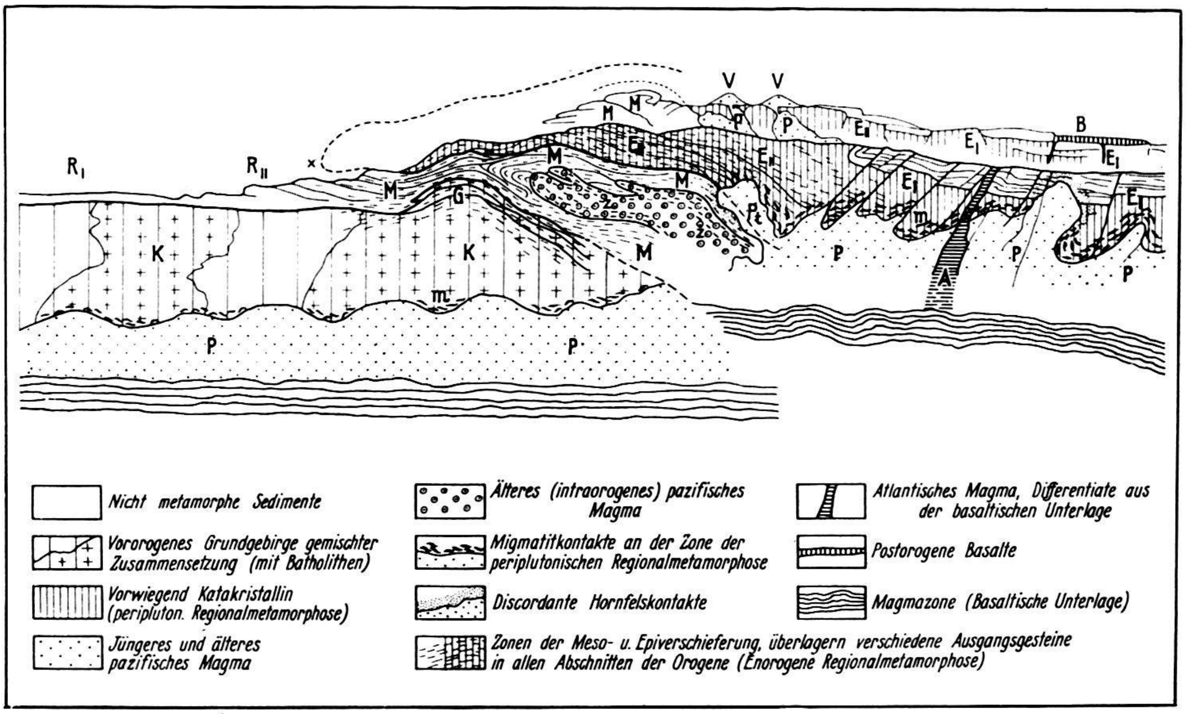

Fig. 8. Franz Eduard Suess' ideal collisional orogen. E. *Erzeugende Scholle* ("producing block"), with evidence for extensive former magmatic activity and with batholiths of "Pacific-type magma" (i.e. calc-alkalic), shown with P. V's are crestal volcanoes of calc-alkalic affinity. M – Metamorphic fold and thrust zone (the "overridden zone"). K – Crystalline basement of the foreland. The "overridden zone" corresponds largely with Argand's accretionary Penninic axial Tethys (SUESS 1937, fig. 1).

that "The characteristics of the orogen are most fully developed in the 'continental margin ranges'. Where they are juxtaposed against a foreign foreland, palaeogeography and tectonics indicate drift over large distances" (Suess 1937, p. VI).

Thus, before Argand died on 17th September, 1940, in the midst of an unprecedented world conflagration, not only the gross architecture of the accretionary terrains had been understood, but also some of the ideas concerning the aid they might render in studying the history of past oceans had been developed. Suture zones containing them were recognised to be an end-member in a spectrum, whose opposite end was formed by the clean suture lines, the synaphias of Salomon-Calvi.

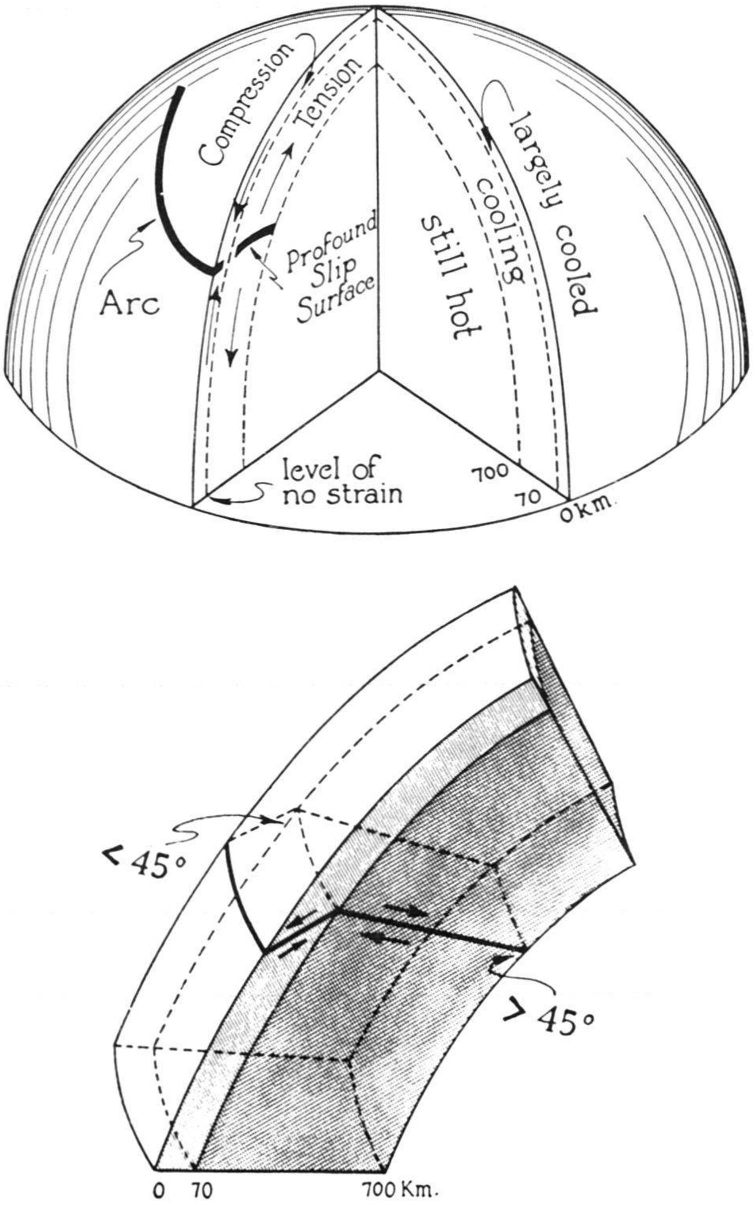

Fig. 9. Scheidegger's development of the contraction theory that Wilson (1954) used as a basis for his views on the consequences and causes of orogenic deformation. Compare this with Suess' description in Suess (1875, p. 146). Copied from Wilson (1954, fig. 13).

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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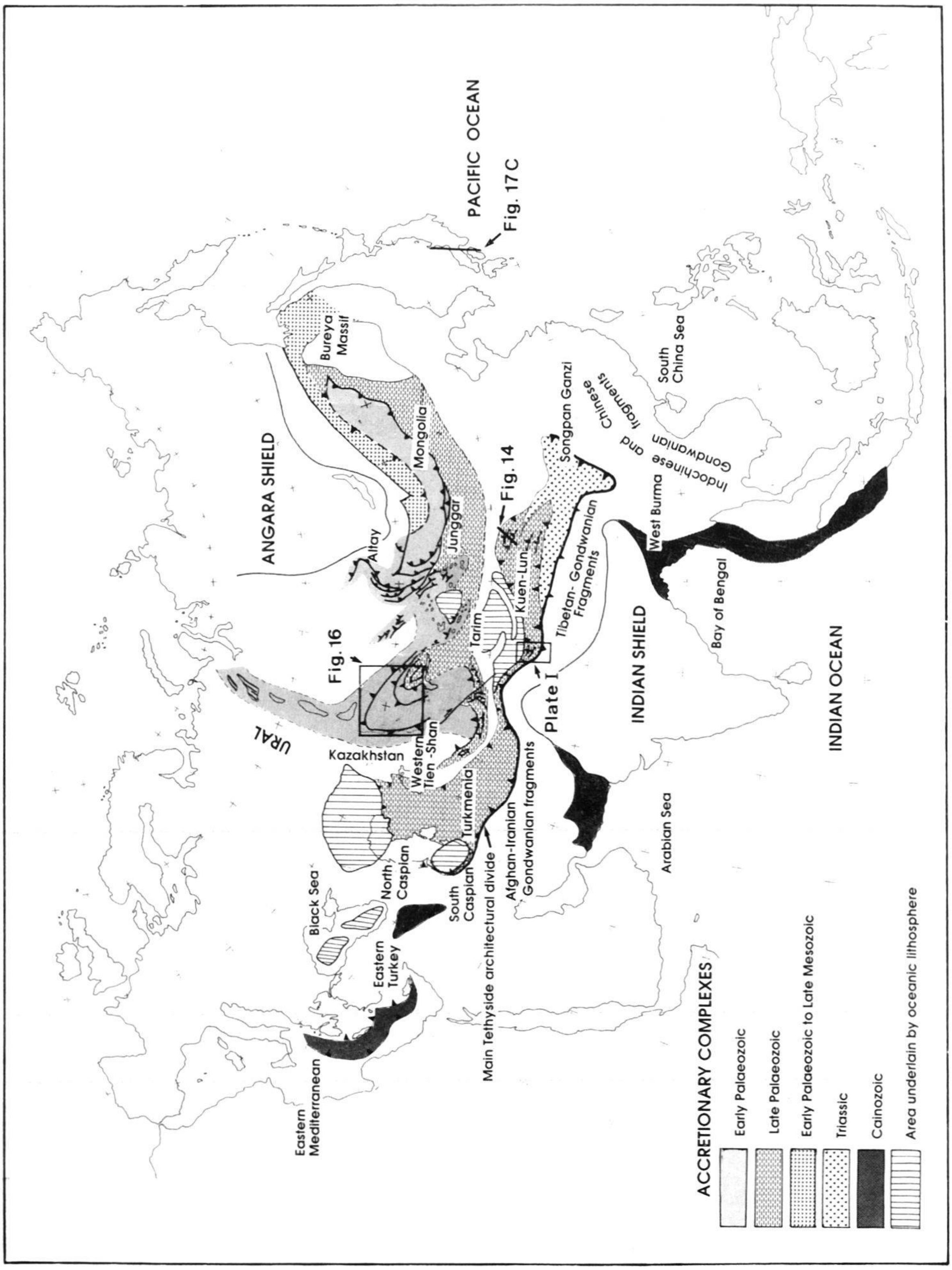
[13]) Influential mobilist leaders in the southern hemisphere, such as A.L. Du Toit and L. King survived the war, but were mostly interested in the extensional aspects of continental drift and did not make any significant contribution to orogeny in terms of drift. Little wonder that when eventually a 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
Tibetan- Gondwanian Fragments
Kuen-Lun
Tarim
Fig. 16
URAL
Kazakhstan
Western Tien -Shan
Plate I
INDIAN SHIELD
Bay of Bengal
INDIAN OCEAN
Turkmenia
North Caspian
South Caspian
Black Sea
Eastern Turkey
Eastern Mediterranean
Main Tethyside architectural divide
Afghan-Iranian Gondwanian fragments
Arabian Sea
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

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

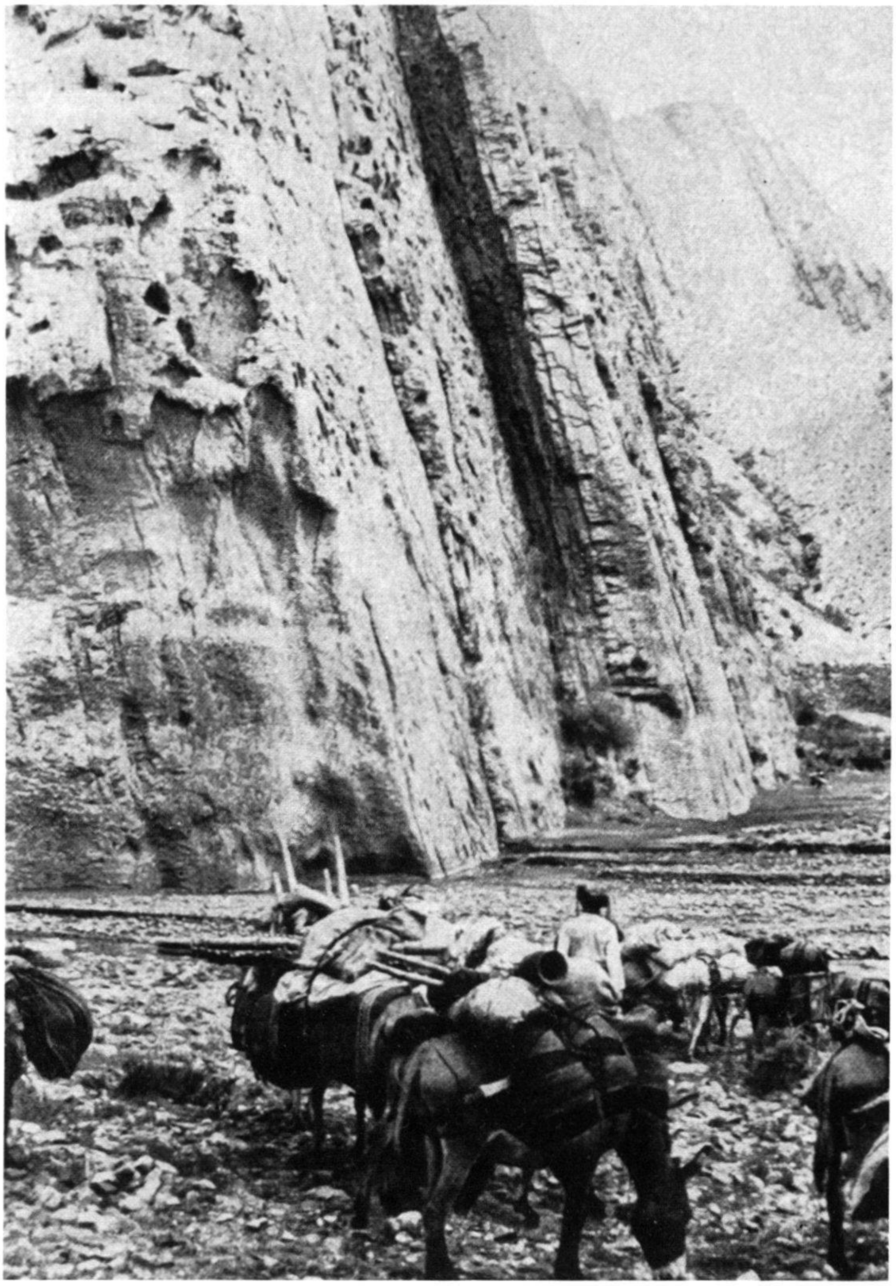

Fig. 11. Steeply south-dipping ?Middle Eocene limestones east of Sanju, near Uzun Sai (Photo: FILCHNER 1939, frontispiece).

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

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[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 (Baxkorgan 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).

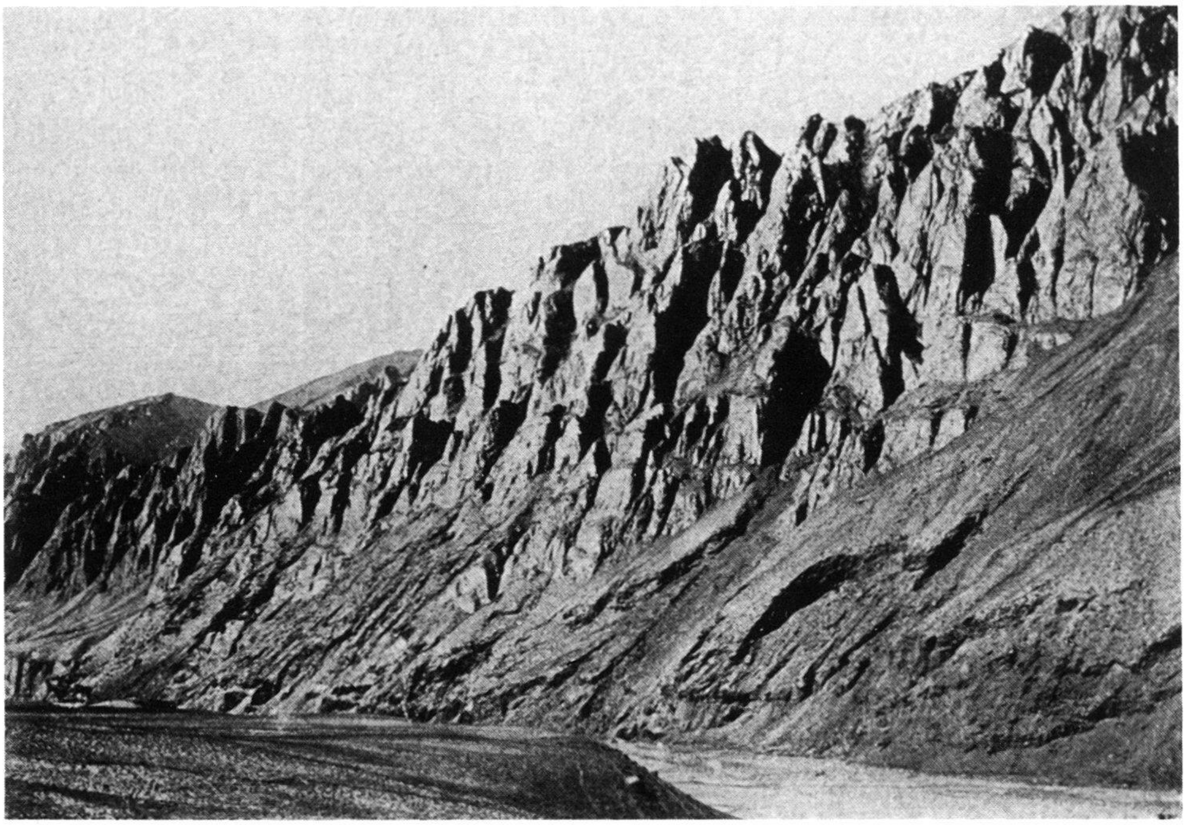

Fig. 12. Steeply dipping slates above the right bank of the Yürüng Kash River (Photo: Stein 1912, fig. 329).

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 monzogranites, 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

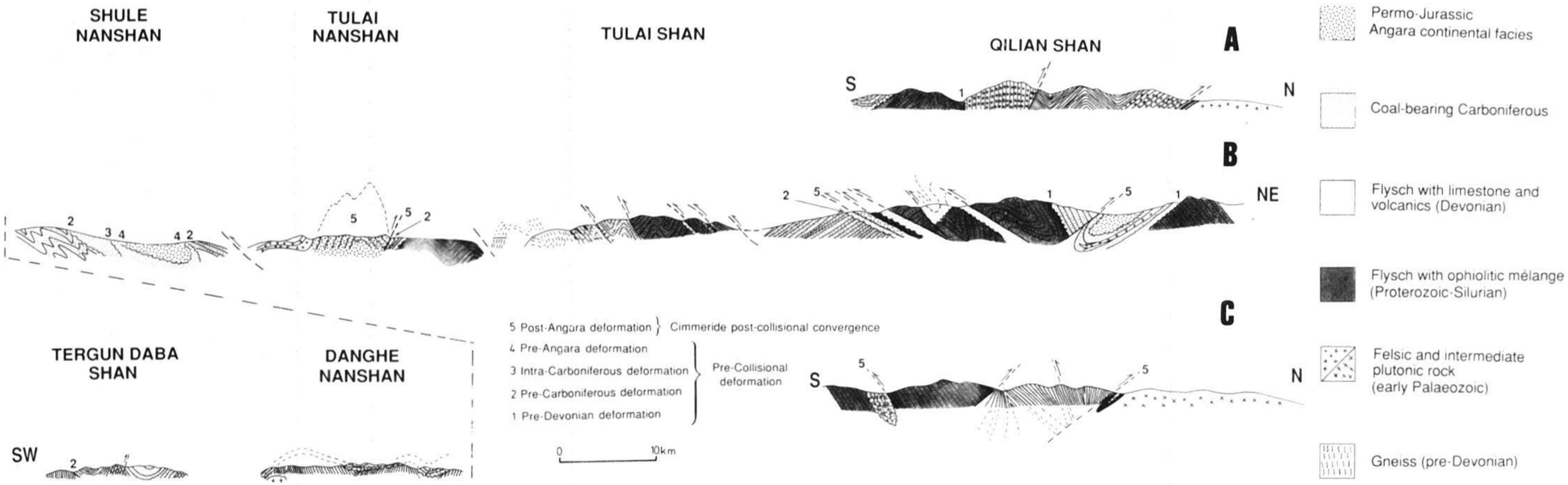

Fig. 14. Geological cross-sections across the Qilian Shan and the Qinghai Nanshan. A. Section north of Shule He (approximately along the 97°E meridian) is after Obruchev (1901), which we cite after Leuchs (1937). B. Section whose approximate location is shown in Fig. 10. The section is discontinuous 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.

Palaeozoic and subordinate latest Proterozoic and early Mesozoic subduction-accretion complexes with vanishingly small areas of Precambrian continental crust that in places forms cores of Altaid magmatic arcs as largely recognised by Peive et al. already by 1976 (Peive et al., undated). Fig. 10 exhibits an incomplete tectonic map showing the extent of some of the major Altaid accretionary complexes. As in the Kuen-Lun, many of these were later invaded by arc magmas and became arc massifs to younger subduction-accretion prisms. The detailed description of the whole of this vastly complicated tectonic collage cannot be given here owing to space shortage, but will appear elsewhere (Şengör, Okuroğullari & Hsü, in prep.). In the following subsection we outline the tectonics of a small but representative section of the Altaids, namely the Central Kazakhstan ranges.

6.1 Palaeotectonic evolution of Central Kazakhstan

Fig. 16 is a highly simplified and schematized tectonic map of the northern and central parts of the Kazakhstan Continent of Zonenshain (1973) and Zonenshain et al. (1990) or Kazakhstania of Ziegler et al. (1979). Precambrian continental crust exists in the north, in the Kökchetav ("Mountain of Kökche") Massif (Golovanov et al. 1969) and in the west, in the Ulutau ("Great Mountain") Massif. Smaller slivers of Precambrian continental crustal material have been reported also from the highly fragmented Yerementau and the Aktau-Mointy massifs (Karyayev 1984; Mossakovsky & Dergunov 1985). A scatter of isotopic ages, mostly of sixties vintage, and ranging from a Rb-Sr phengite age of 1,300 ± 200 to a Zr age of 1,040 Ma on a granitic gneiss has been reported from the basement of the Kökchetav Massif (Sobolev et al. 1982). The oldest unconformable shallow marine Vendian-Cambrian[19]) quartz-bearing arkoses contain detrital zircons dated at 1,200 ± 100 Ma, providing a lower age limit (Sobolev et al. 1982). The oldest sequences in the Ulutau Massif consisting of a Vendian-Cambrian quartz-arkose provide similarly old detrital zircons (1,220 ± 100 Ma:

In the present usage of the Soviet geologists, what we call the Altaids corresponds largely, but not entirely, with the "Central Asian Folded Region" (Yanshin et al. 1966, pp. 162ff), "Central Asian Foldbelt" (Zonenshain et al. 1990, fig. 1 and pp. 55ff) or "Central Asian Mountain Belt" (Khain 1990). Dr. Lev P. Zonenshain (pers. comm., 1991) suggested that we use the Soviet term rather than Suess' designation. However, not only is "Central Asia" a vague geographical concept, no longer used by geographers (for the vagueness, see the discussion in von Richthofen 1877, pp. 3–8; for the current geographical usage see Domrös et al. 1981, p. 191) but the Soviet term "Central Asian Foldbelt" leaves out both the Urals and the Mongolo-Okhotsk Orogenic Complex (e.g. Yanshin et al. 1966; Zonenshain et al. 1990), which the term Altaid includes. Because in this study we include in our discussion the entire late Proterozoic to middle Mesozoic orogenic collage that accreted around the Angara craton with the exception of its northeastern margin, "Altaid" is preferable to just "Central Asian Foldbelt". That is also why Şengör (in press) has abandoned his earlier suggestion to call the Turkic-type orogenic belts "Central Asian type" (Şengör 1991b).

[19]) Mossakovsky & Dergunov (1985, p. 1207) give the age of the deposit in the Kökchetav as Vendian. However, Jagoutz et al.'s (1990) 533 + 20 Ma metamorphic age of the basement underlying the unconformable deposits would make this age impossible, even within the limits of error of the isotopic dating according to both the DNAG and the Harland et al. (1989) time scales. That is why we gave the age as Vendian-Cambrian. However, a Vendian age becomes possible, if the base of the Cambrian can be pulled up to 550 Ma (on the basis of Dallmeyer & Gibbons' 1987, ^{40}Ar/^{39}Ar mineral dates of the Penmynydd schists in Anglesey: W.S. McKerrow, written comm., 1988).

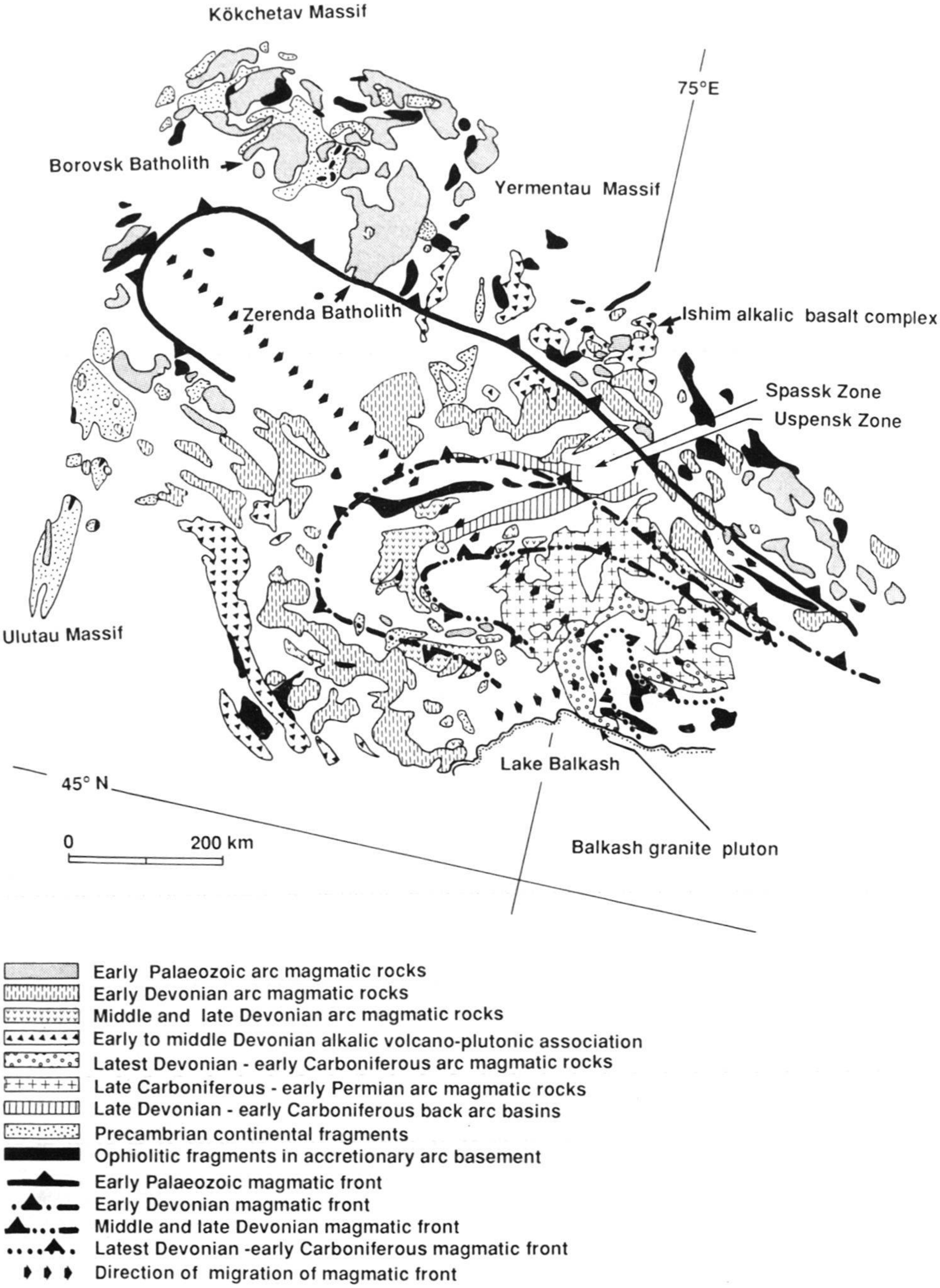

Fig. 16. Schematic tectonic map of Central Kazakhstan showing the positions of successive palaeomagmatic fronts and the associated arc-related plutons. Also shown are the Precambrian continental slivers and the Spassk and Uspensk late Devonian-early Carboniferous marginal (?back-arc) basin remnants. The map was simplified from Karyayev (1984, fig. 1). For location, see Fig. 10.

Sobolev et al. 1982) that led Mossakovsky & Dergunov (1985, p. 1207) to suggest that the Kökchetav and the Ulutau massifs may have had a common cover sequence consisting of shallow water quartzites. More recent studies have shown that in the Kökchetav Massif metamorphic diamonds, indicating pressure values of ≥ 40 kbar and temperatures > 900–1,000°C, were formed during a subduction episode at 533 ± 20 Ma BP that metamorphosed rocks that had largely formed more than 2 Ga ago (Jagoutz et al. 1989; Sobolev & Shatsky 1990).

As the map shown in Fig. 16 displays, a remarkably concentric arrangement of magmatic arcs of various ages is seen in Central Kazakhstan, whereby the innermost arc is the youngest (see also Karaulov 1981, and Markova 1982, fig. 1). With the exception of a few slivers of continental crust already mentioned, the oldest of these arcs that probably already had begun developing in the latest Proterozoic in the Chinghiz-Tarbagatai range, grew on oceanic crust (Markova 1982, fig. 16, loc. 7; Karyayev 1984; Kheraskova 1986) and in the northwest may have been responsible for generating the diamondiferous ultra-high pressure metamorphic rocks in the Kökchetav Massif. The Cambro-Ordovician rocks of the Central Kazakhstan area consist both of volcanic (e.g. Dzhangabul, Ashchikol, Köksengir, Kendykta, and Sagsk suites: Karyayev 1984) and sedimentary assemblages. Of the sedimentary rocks, the Cambrian deposits consist generally of cherts and oceanic mudstones (e.g. Akdym, Kosgobay, and Tekturmay suites; Karyayev 1984), whereas Ordovician rocks are mainly flyschoid clastics (e.g. Yerkebidaik, Angrensor, Sargaldak, and Lidiyevsk suites: Karyayev 1984). But even what Karyayev (1984) calls "island arc/porphyrite association" is seldom purely igneous, but commonly occurs as a mixture of igneous rocks and flysch, deep-sea chert, reefal limestone and other rock types, occurring in both mélanges and in less disrupted stratal successions.

In the Chinghiz-Tarbagatai the inital ?Vendian to Middle Cambrian submarine volcanism was tholeiitic in composition, but in the middle Cambrian changed to calc-alkalic, indicating a certain maturity of the island arc system that had developed on oceanic substrate (Mossakovsky & Dergunov 1985).

In the Cambrian and much of the Ordovician, the structural polarity of the Chinghiz-Tarbagatai system faced the northeast (present geographic coordinates) as shown by the dominant northeasterly vergence (Mossakovsky & Dergunov 1985). In the latest Ordovician to Silurian the polarity flipped (see Markova 1982, fig. 16, for a graphic depiction) and at the same time thick sequences of red to varicoloured sandstones, conglomerates, and argillites, with green rocks locally playing a significant part, began to be deposited to the southwest and south of the Cambro-Ordovician magmatic arc (e.g. Oroy, Karaaygyr ("black stallion"), Sulysor suites: Karyayev 1984). Farther north, in the Kalmyk-Kul (Kalmyk Lake) region, the middle late Ordovician flyschoid argillites, siltstones, and sandstones represent a typical forearc to the south of the Borovsk magmatic complex intruded into the Kökchetav Massif (Golovanov et al. 1969). Zonenshain et al. (1990, fig. 55) display a superb structural cross-section across the Chingiz Mountains, after Markova (1982, fig. 7), which shows all the hallmarks of a subduction-accretion complex.

There has been tremendous controversy in the Soviet geological literature as to whether these Ordovician-Silurian deposits belong to "geosynclinal flysch stages" or to "orogenic molasse stages"! The cause of the controversy is that in places these dominantly clastic sequences rest with important unconformities on older rocks, whereas in others the contacts are transitional. The sequences contain, in places, both terrestrial (redbeds) and marine sedimentary rocks, the latter displaying typical turbidite characteristics. Some authors have been unable to find any profound tectonic change between the so-called "geosynclinal" stages and the "molasse" stages in Central Kazakhstan: "According to the V.M. Tseisler classification... this structural stage of Central Kazakhstan Caledonides represents its so-called molasse synclinoria, marked by a replacement of the geosynclinal complex by the molasse without a substantial structural remodeling, and also by a gradual replacement, going up the section, of marine deposits by the continental" (Karyayev 1984, p. 327).

All these difficulties vanish when we view the so-called "molasse stage" in the early Palaeozoic sections in Central Kazakhstan as the expression of deposition in forearc and inner trench slope basins. This explains why in places the "molasse" is conformable on older deposits while in others it is sharply unconformable (inner trench slope *vs.* forearc deposition), why in some places it is subaerial, while in others it is submarine (outer high *vs.* submarine forearc deposition), and why no "substantial structural remodeling" takes place during the "molasse" time (because it too is a part of the growing accretionary complex). Major "synorogenic" batholiths (e.g. Zerenda, Krykkuduk, Chet, Borovsk) intruded while the so-called "molasse" deposition was going on and the "molasse" commonly does sit in prominent forearc positions on highly deformed "volcanic – sedimentary – siliceous deposits" in front of the arc intrusives (e.g. the Borovsk complex/Kalmyk-Kul forearc basin: Golovanov et al. 1969, fig. 1). These intrusives are clearly arc-related and were intruded coevally with deposition in forearcs.

In the early Devonian, the arc magmatic axis invaded the former forearc areas and created new subduction-accretion complexes and forearcs in front of itself where "continental molasse and tephroid formation" (e.g. Zharsor suite: Karyayev 1984) was deposited. Through the middle and late Devonian the magmatic axis shifted farther to the south and southeast in the east and north, and northeast in the extreme southwestern part (Kurchavov 1985), and in the retroarc area alkalic volcanic and volcanoplutonic complexes (e.g. Ishim alkalic complex: Fig. 16) and even high-K granites (e.g. Orlinogorsk) originated, indicating that the production of continental crust through subduction-accretion and magmatism by the middle Devonian had reached a mature stage. The middle to late Devonian arc included the Kyzylespa and Prostornansk granites. In the foredeep, flysch, and in the forearc area shallower "molasse" deposition was characterized by such suites as Akbastau and Ordobay (Karyayev 1984).

In the latest Devonian to earliest Carboniferous interval the arc shifted still farther away from the back-arc area, where an extensional basin originated in the present-day Uspensk and Spassk zones that also coincided with a major marine transgression in Central Kazakhstan. The arc thus separated a partly epicontinental marine region in the back-arc area from a much deeper marine realm in the trench/forearc region. The

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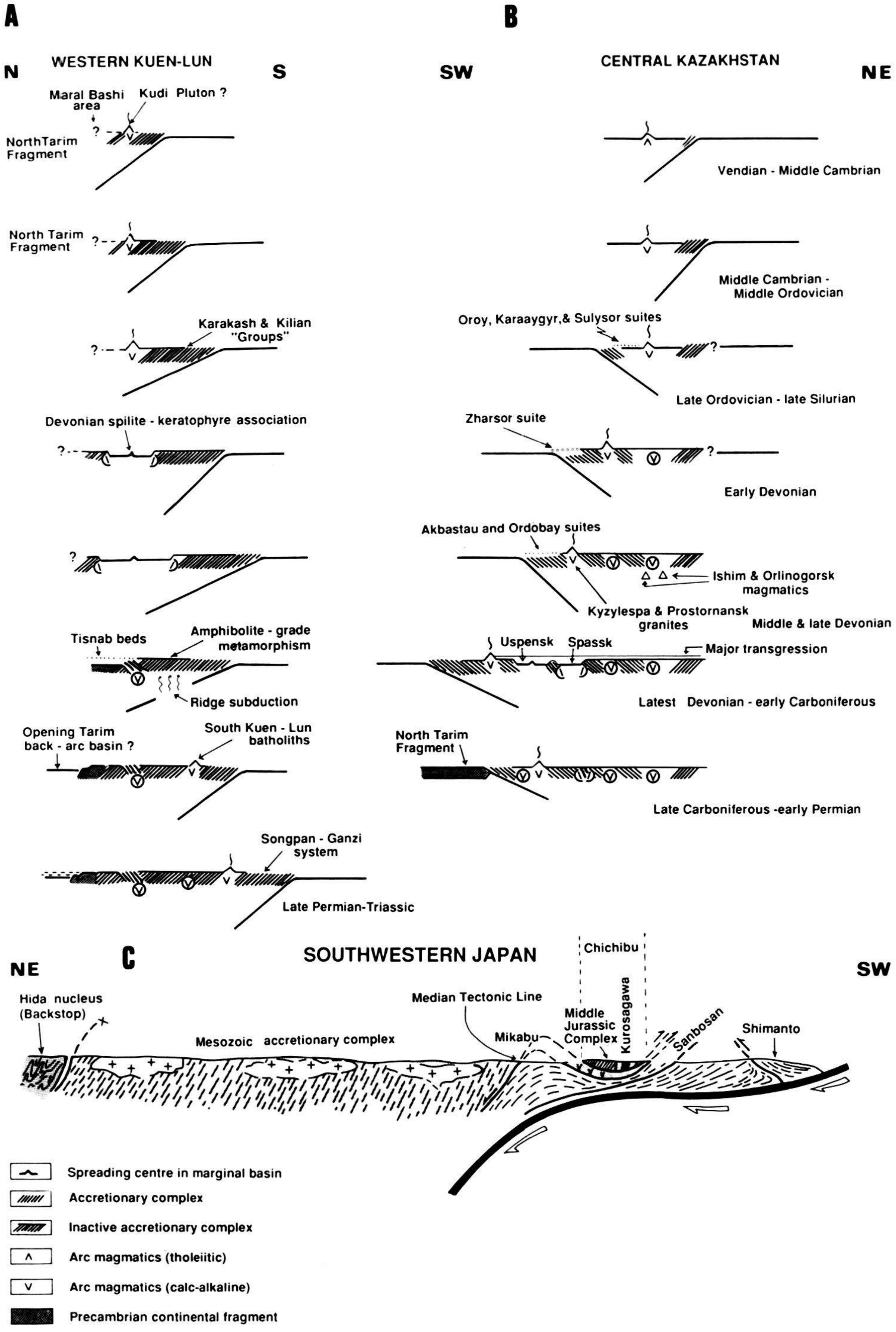
Fig. 17. Schematic sections illustrating the hypothesis outlined in this paper for the evolution of the Kuen-Lun (A) and the Kazakhstan Microcontinent (B). Both are compared with a schematic cross-section across southern Japan (C) from about Muroto-zaki to Toyama, which Şengör visited in 1988 under the guidance of Dr. Shigenori Maruyama.


A
N
WESTERN KUEN-LUN
S
Maral Bashi area
Kudi Pluton ?
NorthTarim Fragment
North Tarim Fragment
Karakash & Kilian "Groups"
Devonian spilite - keratophyre association
Tisnab beds
Amphibolite - grade metamorphism
Ridge subduction
Opening Tarim back - arc basin ?
South Kuen - Lun batholiths
Songpan - Ganzi system
Late Permian-Triassic
B
SW
CENTRAL KAZAKHSTAN
NE
Vendian - Middle Cambrian
Middle Cambrian - Middle Ordovician
Oroy, Karaaygyr,& Sulysor suites
Late Ordovician - late Silurian
Zharsor suite
Early Devonian
Akbastau and Ordobay suites
Ishim & Orlinogorsk magmatics
Kyzylespa & Prostornansk granites
Middle & late Devonian
Uspensk
Spassk
Major transgression
Latest Devonian - early Carboniferous
North Tarim Fragment
Late Carboniferous -early Permian
C
NE
SOUTHWESTERN JAPAN
SW
Chichibu
Hida nucleus (Backstop)
Mesozoic accretionary complex
Median Tectonic Line
Mikabu
Middle Jurassic Complex
Kurosagawa
Sanbosan
Shimanto
Spreading centre in marginal basin
Accretionary complex
Inactive accretionary complex
Arc magmatics (tholeiitic)
Arc magmatics (calc-alkaline)
Precambrian continental fragment

Balkash granitic complex intruded in the arc region, while both flysch and shallow water limestones, and terrestrial clastics were being deposited in the trench/forearc area (Karyayev 1984).

In the late Carboniferous-Permian interval the arc axis shifted only slightly back into the retroarc area, which might indicate imminent collision with a continent and/or another accretionary complex that might have foreshortened the forearc. Full-scale collision indeed was underway with the north Tarim-Tien Shan fragment by the later Permian which switched off arc magmatism and generated an areal, silicic alkalic to subalkalic magmatism associated with continental collision (e.g. the alaskites, alkalic granites, syenites and monzonites of the Bayanaul, Tluembet, Barkanas and Koytas igneous complexes: Karyayev 1984).

Fig. 17 summarizes the way in which the Central Kazakhstan "microcontinent" formed through the Palaeozoic, (for a partly different interpretation, see Markova 1982, fig. 15 and pp. 122ff) and compares it with the evolution of the Kuen-Lun/Songpan-Ganzi system. A third object of comparison displays a present-day example of an accretionary complex, through which arc magmatism migrated during the Mesozoic-Cainozoic interval, namely Japan. In all three cases, the basic story is the same, namely the building out of subduction-accretion complexes in front of backstops of diverse nature and concurrently with the growth of the subduction-accretion complexes, the migration of magmatic arc axes across them in the direction of the ocean. In both the Kuen-Lun and in Kazakhstan, basins seem to have opened in the back-arc area (?back-arc basins) but later closed, before a terminal collision choked the subduction zone that governed the growth of the subduction-accretion complex. In Kazakhstan and in Japan metamorphism of the accretionary complex is mainly of greenschist grade, rising to amphibolite grade only near major plutons and in small relicts of older continental crust that have nothing to do with the metamorphism of the accretionary complex itself (Sobolev et al. 1982; Geological Atlas of Japan 1982). Only in the western Kuen-Lun we have encountered a widespread amphibolite-grade metamorphism that appears to have produced locally migmatites (Wyss 1940). This finds its analogue in the Chugach Mountains accretionary complex of Alaska and may have been related to ridge subduction (Plafker et al. 1989).

Fig. 10 shows the vast areas occupied by accretionary complexes in Asia implying that nearly all of the Altaid Asia formed through processes very similar to those we infer to have governed the evolution of the Kuen-Lun and the Central Kazakhstan ranges. In other words, the Turkic-Style orogeny dominated not only the northern part of the Cimmerides, but also most of the Altaid Asia. In the next section we discuss what this may mean for our understanding of continental growth and architecture.

7. Discussion

7.1 Tectonic analysis of Turkic-type orogens and the palaeotectonics of Central Asia

In the early days of plate tectonics, the Alps and the Himalaya coloured profoundly the popular image of collision-type orogenic belts, in which extremely narrow sutures essentially represented surfaces along which two colliding continents were apposed (cf. Gansser 1966, esp. p. 842; also Dewey & Bird 1970, figs. 2G, 11E, F, G and 13). By

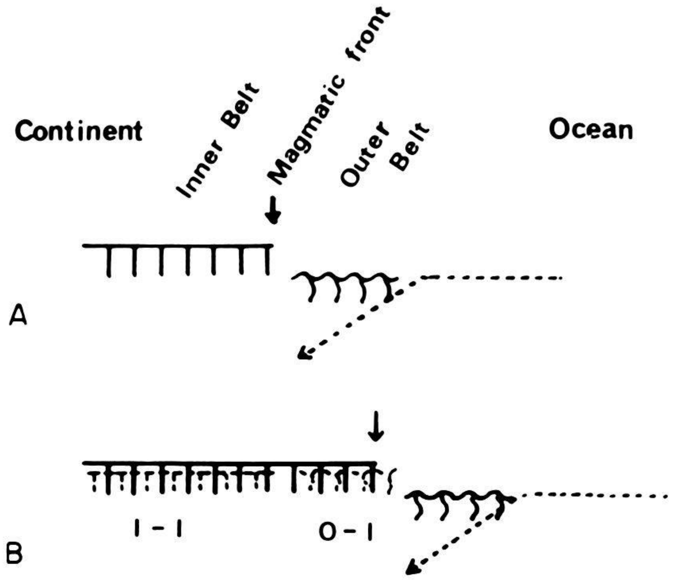


Fig. 18. Overlapping of the inner and outer belts (portion indicated as 0–1), as magmatic front migrates oceanward from stage A to stage B in Japan (from Matsuda & Uyeda 1971, fig. 6). This is precisely the situation observed in the Kuen-Lun and in Kazakhstan.

contrast, geologists working around the Pacific Ocean, especially those in North America (Hamilton 1969; Hsü 1971, 1972), Japan (Matsuda & Uyeda 1971), Australia (Crook 1969; Rutland 1973, 1976) and New Zealand (Landis & Bishop 1972) knew that the continental edge does not stay fixed during subductive removal of ocean floor and that it may move oceanward with respect to the continental interior by the addition of subduction-accretion material to the original continental margin. Matsuda & Uyeda (1971) explicitly pointed out that the arc magmatic axis may track the receding trench and eventually come to occupy areas underlain by accretionary material not originally a part of the continent (Fig. 18), and observed prophetically that "It is a task for the future to understand fully the tectonic significance of these migrations and changes of magmatic fronts" (Matsuda & Uyeda 1971, 0.16). A year later Hsü (1972 p. 38) christened this kind of accretionary margins "Franciscan subtype" of Pacific-type convergent margins, although he did not emphasize the migration of the arc-related igneous activity to invade former subduction-accretion complexes.

This idea of lateral continental growth by subduction-accretion did not gain much popularity (e.g. Rutland 1976), perhaps because of Dickinson's influential 1973 paper, in which he showed that arc-trench gaps grow with time not only by trench retreat, but also by the retreat of the magmatic axis into the arc internal side, *i.e. away from the ocean*20)*.* Dickinson (1973, table 1) displayed an impressive array of examples, but did not discuss the nature of the *arc basement.* Thus his readers did not realize that in Japan, for example, the magmatic arc was nested on a former subduction-accre-

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20) Also most non-Soviet authors were not aware of Peive's and his colleagues' work on the growth of Central Asia in the seventies, which could have helped them to recognize the general applicability of the model put forward by Matsuda and Uyeda and Hsü.

tion complex, which, for time intervals longer than those considered by DICKINSON (1973), essentially invalidated his thesis. Neither did DICKINSON (1973) consider very wide extant forearc wedges such as Makran (600 km arc-trench separation in Pakistan: ŞENGÖR 1990a). In 1977, however, Dickinson paid a visit to Japan and was quick to realize that indeed the arc massif at least in southwestern Japan was formed by what he called "Palaeopacific oceanic facies", thus corroborating MATSUDA & UYEDA's (1971) earlier inference (DICKINSON 1977, esp. fig. 2 and p. 950ff). DICKINSON (1977) further generalized this picture to much of the western U.S. Cordillera.

As work in such places as Alaska progressed, however, MATSUDA & UYEDA's (1971), and DICKINSON's (1977) – and indeed Peive's and his collaborators' – point began to receive wider recognition that arc massifs themselves indeed may be made up of old subduction-accretion complexes and such complexes, now intruded by arc plutons, covered by arc volcanics plus intra-arc basin deposits in addition to older forearc and/or inner trench slope deposits, and in places finally invaded by collision-related magmatic rocks, may occupy huge areas and make up much of the continental crust of certain orogens (e.g. JONES et al. 1982, 1987). Because subduction-accretion complexes habitually contain diverse slivers of ophiolites and/or deep-sea deposits, in a confusing array of thrust fault-bounded packages, ophiolite trains in such terrains lose their reliability as suture zone indicators. Large, along-strike sideways motion characterizes many of the active subduction-accretion complexes (e.g. KARIG 1980; MOORE & SILVER 1983, esp. fig. 10) and similar faults probably also affected older ones, perhaps intercalating arc magmatics into even the distal parts of coeval subduction-accretion complexes.

One can readily appreciate the grave difficulties of trying to define tectonic units and to identify past plate tectonic environments in such a mess of highly deformed oceanic, trench and arc-trench gap sedimentary rocks, arc, collisional, and even perhaps rift magmatics, where reliable tracers such as shelf/slope breaks of normal Atlantic-type continental margins or Indus-type clean suture zones are absent. OBRUCHEV's (1915, plate I) graphic summary of the disparate views concerning the orientation of the dominant trend-lines in the Russian Altay proposed between 1833 and 1914 is a remarkable document displaying the difficulties of tectonic synthesis in regions dominated by subduction-accretion/magmatic arc complexes. It was the frustration encountered in such terrains in the western North America and Alaska, which had refused to fit into the neat Alpine, Himalayan, or the Andean straightjackets, which derailed regional tectonic research into the seductive labyrinth of terranology (cf. ŞENGÖR 1990b; ŞENGÖR & DEWEY 1990). It is easy to see the need for the comfort of alleviating "the immediate necessity of incorporating every facet of geologic development in a single encompassing model" (WILLIAMS & HATCHER 1983, p. 34) in a place where every other outcrop turns out to be a multiply deformed chert/slate/greywacke succession, here overlain by reefal limestone, there intruded by a granodiorite stock, in yet another place cooked up to amphibolite grade! But, we think, precisely in such monotonously chaotic places does the geologist need a good working model to guide him out of a maze of detailed but unconstraining observations to arrive at a final synthetic understanding.

For an understanding of the palaeotectonic evolution of Central Asia, including the whole of the Altaids and the northern moeity of the Cimmerides, we suggest, therefore, that we view them in the light of the accumulation and consolidation of giant subduction-accretion complexes (for a similar early suggestion for only the western part of the Altaids, see Dickinson 1974, esp. fig. 10), whose oceanward growth is commonly tracked by the migration into them of arc magmatic axes. Present-day examples of such huge accretionary complexes are not many, being confined to Alaska, Makran, Barbados, and the eastern Mediterranean, but both Alaska and Japan contain well-studied and long-lived examples.

In tectonic collages dominated by Turkic-type orogenic belts, the first step in tectonic analysis would be to map out the arc axes and then to delimit the various accretionary complexes whose collisional agglomeration would be the final stage in the growth of the collage. No clean ophiolitic sutures would exist in such places (because ophiolite slivers are commonly found throughout the "basement!") and suture locations would have to be inferred using other means than tracing neat and clean ophiolitic outcrop trains bordering well-defined and narrow magmatic arc belts of the type Indus/Transhimalaya suture/arc couple. The grave difficulty of finding sutures in such settings is perhaps best exemplified by the fact that no suture line can be identified between the Sengihe and Halmahera island arcs whose large accretionary forearcs collided only in the course of the Quaternary (Silver & Moore 1978; Hamilton 1979).

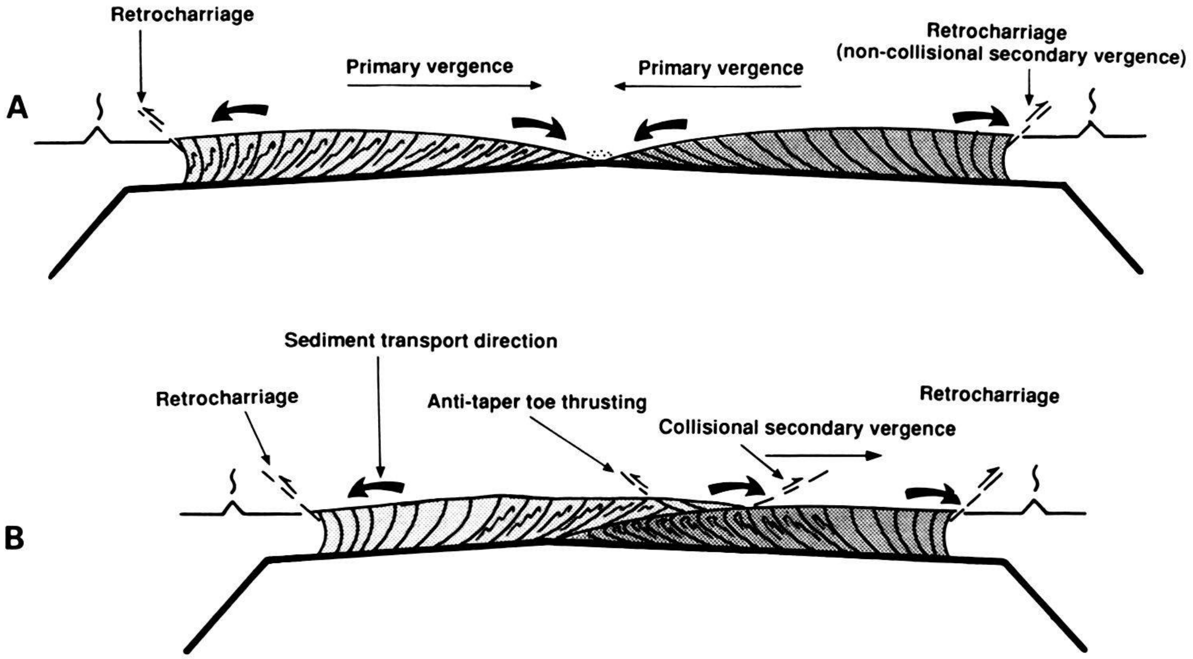

Fig. 19. Collision of two accretionary wedges. A. The situation just before the collision: In both wedges, the primary vergence is generally oceanward with secondary vergence developing locally in places where anti-taper toe thrusting (shown in B) or backthrusting behind outer non-volcanic highs occur. In case of anti-taper toe thrusting, the secondary vergence and sediment provenance have opposite senses. In case of backthrusting behind non-volcanic outer highs sediment provenance and secondary vergence have the same senses. B. The situation after the collision: Collision-induced secondary vergence is antithetic to anti-taper toe thrusting of the overriding wedge and synthetic to backthrusting behind outer non-volcanic high of the underthrusting wedge. Collision-induced sediment provenance and sediment provenance from outer non-volcanic highs into former forearc areas are the same, but may have small differences in sediment composition. See text for further discussion.

Neither is it possible to identify this suture farther north, in Mindanao, where the collision was in the late Miocene and the region is now subaerial (cf. Şengör 1990a).

Only combined sedimentological/structural studies perhaps coupled with careful seismic reflexion profiling may aid in locating sutures between two collided subduction-accretion complexes by documenting abrupt and regional reversals of vergence overprinting an older, uniformly-vergent but multiply-deformed package, accompanied by a reversal of clastic provenance. This reversal would likely occur under abyssal conditions, where the toe regions of subduction-accretion complexes habitually reside (Fig. 19). This would provide one criterion to distinguish this sort of collision-induced vergence reversal from retrocharriage behind outer non-volcanic highs along the margins of forearc basins (Fig. 19B; except in such unusual cases as the 7 km-deep Weber forearc: Hamilton 1979). Coeval reversal of clastic sediment provenance would discriminate between anti-taper toe thrusting (Seely 1977) and collisional vergence flip (Fig. 19B).

Another guide that might constrain the location of the suture between two colliding accretionary complexes might be the detailed detrital mineralogy of the arenaceous components of the colliding forearc prisms. This difference would disappear, however, shortly before the collision, and could only constrain the location of the suture within a broad zone.

The best way to locate the suture in such areas is to reconstruct the individual accretionary complexes to their pre-collisional geometry using structural, sedimentologic and partly petrologic criteria in the light of their presently active examples. This would mean a model-guided iterative field study that avoids purely descriptive cataloging of rocks in the field, but undertakes description and model-building simultaneously, in a manner reminiscent of William Morris Davis' "explanatory description" of landforms (Davis 1912).

7.2 Turkic-type orogenic belts and the composition of the lower continental crust

If continents may be significantly enlarged by the growth of subduction-accretion complexes through the mechanism depicted in Figs. 17 and 18, then one would expect a fairly uniform pelitic composition of the entire undifferentiated "new" continental crust thus formed, because shales form more than 60% of the world sediment repository (Potter et al. 1980) and pelitic material forms over 70% of all pelagic sediments deposited in the world ocean (Lisitzin 1972), a part of which gets accumulated in subduction-accretion prisms.

Methods to estimate the composition of the lower continental crust are either direct, based on relatively rare exposures of the lower crustal rocks mostly in orogenic belts and on lower crustal xenoliths brought up by igneous processes, or indirect, based either on geophysical observations of seismic velocities and heat flow or on theoretical mass balance calculations. Most petrologic and geophysical models infer a mostly mafic, anhydrous, unradiogenic, and, relative to the upper crust, incompatible element-depleted lower crust, yet many exposed high grade terrains, presumably of lower crustal origin, have pelitic protoliths showing none of the above characteristics (Fountain & Salisbury 1981; Percival & Card 1983). The fact that the average continental crust is more silicic than it ought to be if it indeed came out of the mantle led some to suppose that to achieve this composition, the lower, mafic crust must be delaminated away to "subtract" the residual mafic component following igneous differentiation in zones of crustal thickening (e.g. TURCOTTE 1989).

The dominance of Turkic-type orogens in substantial areas of the continental crust such as Central Asia, where variously modified subduction-accretion complexes form the continental crust, may be one important way of making a crust more silicic than basalt. As REID et al. (1989) emphasized, although basalts are parental to continental crustal growth, and McKENZIE & O'NIONS (in press) have shown that this growth is dominated by calc-alkalic basalts generated in island arcs above descending slabs, individual continents may be enlarged and thus substantial areas of continental crust may be structured by sedimentary/structural processes involved in the construction of subduction-accretion complexes. McKENZIE & O'NIONS (in press) pointed out, on the basis of the inversion of NANCE & TAYLOR's (1976) analyses of post-Archean shales, that their mean rare-earth element concentrations indicate that the melting conditions (mainly in the garnet peridotite stability field, but in the presence of 40% amphibole peridotite, generating melt fractions of about 0.4%), were essentially the same as those that produced the calc-alkalic basalts from Java. The erosion of the parental igneous rocks that culminated in the production of the shales, the transport of the shales into the oceans, where they make up 70% of all pelagic sediment, and the final incorporation of those shales into subduction-accretion complexes is the modern view of the old cycle glyptogenesis → lithogenesis → orogenesis (HAUG 1921) that generates the continental crust.

To what extent this cyclical process actually has added to the bulk of Asia in the Phanerozoic through the construction of the Altaids can be directly assessed by isotopic methods such as a careful measurement of the Nd-Sm model ages of the shales being eroded from the Altaids. The finer size fraction of the fluvial sediments carried by the Irtysh-Ob river system is in this regard an ideal target to establish the Nd-Sm model age of the entire Altaid tectonic collage, although isotopic sampling of limited areas within the Altaid collage has begun to indicate already that in considerable regions the continental crust was made entirely during the Palaeozoic (e.g. KWON et al. 1989).

What this discussion does not consider is how much igneous rock gets underplated beneath subduction-accretion complexes when they become sites of arc magmatism or ridge subduction, or post-collisional magmatism. We suspect that it eventually must amount to significantly less than 50%, because many well-developed magmatic subduction-accretion complexes today have mature thicknesses at or near the continental average of about 30–35 km. Underplating must also be a spatially heterogeneous process, because arc axes prograde oceanward commonly in discrete jumps and rarely in continuous sweeps.

7.3 Turkic-type orogenic belts and the structure of the lower crust

One important characteristic of many subduction-accretion complexes is that in addition to frontal accretion, much sediment is dragged down under the accretionary prism (BANGS & WESTBROOK 1991), of which a part gets underplated (e.g. CLOOS & SHREVE 1988) and the rest subducted (e.g. MOORE 1975). The sediments dragged down

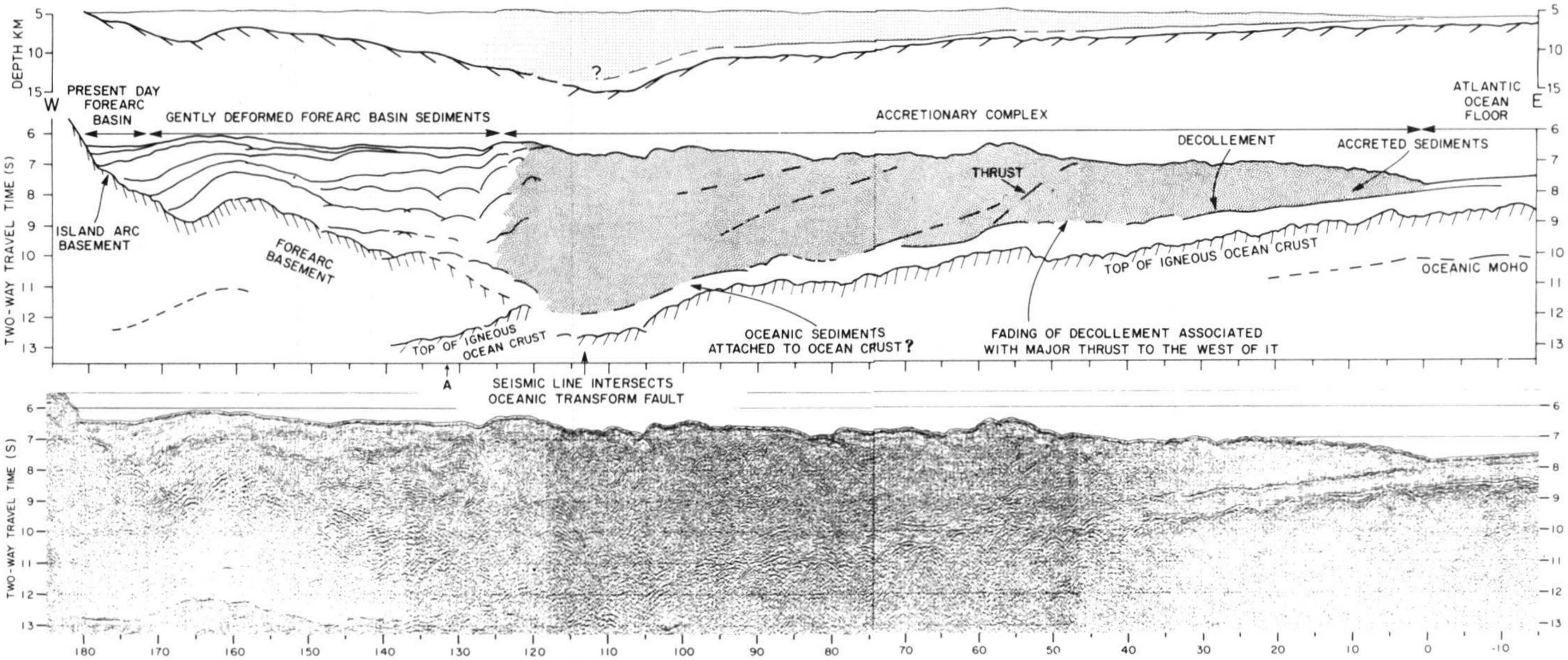

Fig. 20. A seismic reflexion profile across the Barbados accretionary complex (after Westbrook et al. 1988). Notice the distinct layering along the base of the wedge and how the lateral continuity of that layering deteriorates towards the back of the wedge, passing into broadly arched reflexions first (between 20 and 35 km) and then into crossing arcuate events (behind 35 km). Discussion is in the text.

under the accretionary complexes commonly give rise to near planar to very broadly undulating reflectors near the toe of the accretionary complex (Fig. 20; for details see Bangs & Westbrook 1991, fig. 5). The reflectors become broadly arched near the middle of the wedge and finally deteriorate into crossing arcuate events near the backstop in the rear parts of the accretionary complex. These are three of the four classes of reflexion response of the lower crust distinguished by Smithson (1986). Bangs & Westbrook (1991) were able to trace the decollement horizon for 108 km from the toe of the Barbados wedge, i.e. about half its width. Farther back, the decollement horizon becomes deformed mainly by thrusting. Following a collision, the near planar to very broadly undulating reflectors are unlikely to survive as such and would probably turn into either broadly arched or crossing arcuate reflexion events, depending on the intensity of the deformation. Massive intrusions into the accretionary complex would also destroy a part of the reflectors created by sediment underthrusting. It is likely, however, that segments of these reflectors would survive syn- and post-collisional convergence and orogenic magmatic events and would appear as "lower crustal reflectors" under the well-developed, thick accretionary complexes such as that of the Olympic Peninsula in the northwestern United States (thickness under the Peripheral Fault about 40 km!: Brandon & Calderwood 1990) which themselves would be largely acoustically opaque owing to the complex state of the deformation in them. Moore & Silver (1983) display in their fig. 9 such a prominent group of broadly arched reflectors between 5.5 and 6.5 seconds beneath the Molucca Sea collided accretionary complex west of the Snellius Ridge. More recently the Babel Working Group (1990) has published a seismic reflexion profile across the Svecofennides in the Baltic Shield, in which crossing arcuate events were interpreted as representing lower parts of a fossil accretionary complex (see Babel Working Group 1990, figs. 3a, b, and 5). Windley (1991) interprets the Svecofennides in a manner similar to our interpretation of the Altaids and has suggested that they may be a Proterozoic analogue of the Altaid collage (Prof. B.F. Windley, pers. comm. 1991).

Sediment underthrusting and underplating – even underplating of parts of the oceanic crust – under accretionary complexes provides a way of creating laterally persistent reflectors (between > 100 and 50 km across-strike width, if the present Barbados decollement and the 50% post-collisional shortening in Tibet are taken as possible extremes) at depths ranging from a few to 30 km underlying a highly deformed and diffractive crust, where surface geology would give no indication whatever that laterally continuous reflectors might exist at mid- to lower crustal depths.

8. Conclusions

The main conclusion of this study is that very substantial continental enlargement – not necessarily continental "growth" as this term is now commonly understood – by subduction-accretion has been likely a common process responsible for the primary structuration of the continental crust in the history of our planet as exemplified by the late Proterozoic to middle Mesozoic tectonic history of its largest continent, Asia. As subduction-accretion complexes grow, three main processes contribute to their consolidation and augmentation of their thickness. In decreasing importance these are: 1) Invasion of former forearc areas by arc plutons by the trenchward shifting of the magmatic arc axis as the trench recedes. A corollary to DICKINSON's (1973) view that the arc-trench gap area grows by the regression of the trench oceanward and an opposite retreat of the arc axis continentward in modern arcs might be that for trench and arc axis to move together oceanward, the forearc width, i.e. the width of the accretionary complex, probably must become larger than any of the examples considered by DICKINSON (1973), i.e. more than about 500 km. 2) Continuing bulk shortening of the subduction-accretion complex. 3) Metamorphism of the accretionary complex up to high amphibolite grade either by ridge subduction (PLAFKER et al. 1989), or by the exposure of the bottom of the accretionary complex to hot asthenosphere by steepening of subduction angle.

Subduction-accretion complexes become further deformed and thickened when they are involved in a major continental collision and not uncommonly their lower parts undergo partial melting leading to post-collisional magmatism (e.g. the Permo-Triassic episode in Kazakhstan: see esp. fig. 3 in KARYAYEV 1984; the latest Jurassic-early Cretaceous episode in the Songpan-Ganzi System: ŞENGÖR et al. (in press); the late Miocene to present episode in the East Anatolian Accretionary Complex: PEARCE et al. (1990)), that further differentiates the chemistry of the thus produced continental crust, whose bulk composition would be more silicic than basalt.

Although abundant ophiolitic slivers would exist in vast areas occupied by Turkic-type orogens, these would not necessarily mark the sites of sutures. Intra-accretionary prism thrust faults, but very especially large strike-slip faults, would likely juxtapose assemblages formed in distant regions and deformed and metamorphosed at different structural levels. These faults may mislead the mapping geologist into thinking that they represent sutures, bounding different "terranes". Observations such as these, interpreted in a simplistic manner that does not recognise the vicissitudes of the internal dynamics of accretionary complexes, have indeed led to such agnostic statements as "many nappelike bodies have been thrust onto the continental margin or onto previously accreted terranes, but there is no evidence of concomitant arc and subduction activity. This makes it exceedingly difficult to apply simple plate tectonic models to any specific locale as causes and effects within the entire system cannot yet be related" (BEN-AVRAHAM et al. 1981, p. 52), or "Classic plate tectonic signatures are largely absent or obscure along the margins of the terranes. This suggests most of the sutures which must exist between terranes... are either cryptic or the assembly was made by processes not yet fully understood in classical plate tectonic theory" (CONEY 1981, p. 27).

The one lesson we have learned from the palaeotectonics of Central Asia is that vast areas of continental crust accumulated and consolidated essentially *without involving many collisions!* Hence the enormous architectural difference between the Turkic-type orogens and the "classical" Alpine, Himalayan, and Andean stereotypes, and the tremendous uniformity of structural style throughout much of Central Asia. This is probably also true for much of the western North American Cordillera as recognised by some already in the late sixties and early seventies (e.g. HAMILTON 1969; HSÜ 1971, 1972; BURCHFIEL & DAVIS 1975; DICKINSON 1976, 1977).

The recognition of the Turkic-style orogeny also has taught us a very efficient mode of making continental crust that has a fairly uniform pelitic composition and a reflective lower crust as observed in many places in the continents.

The reason why the tremendous importance of this style of orogeny was not widely recognised earlier was, we think, the undue emphasis placed on Alpine- and Himalayan-type collisional orogens (cf. Şengör 1990a and in press), conditioned by the familiarity of the world geologic community with the tectonics of the Tethysides (cf. Şengör 1989). Few tectonic geologists in the past have looked at orogeny at a truly global scale, and of those who did, few approached the breadth Argand (1924) displayed in his immortal *La Tectonique de l'Asie.* In that work, Argand recognised the occurrence and importance of what we here call Turkic-type orogeny, despite the fact that he never recognised subduction. His recognition was based on the previous ideas that Eduard Suess had developed on marginal continental growth by destroying oceans and led to still more sophisticated models by Otto Ampferer and Franz Eduard Suess. Their views were largely forgotten, however, under the dominance of the Kober-Stille school until the rise of plate tectonics; even with plate tectonics, it has taken a considerable time to recognise the presence and widespread occurrence of Turkic-type orogenic belts owing to their highly complicated and difficult-to-analyse internal architecture.

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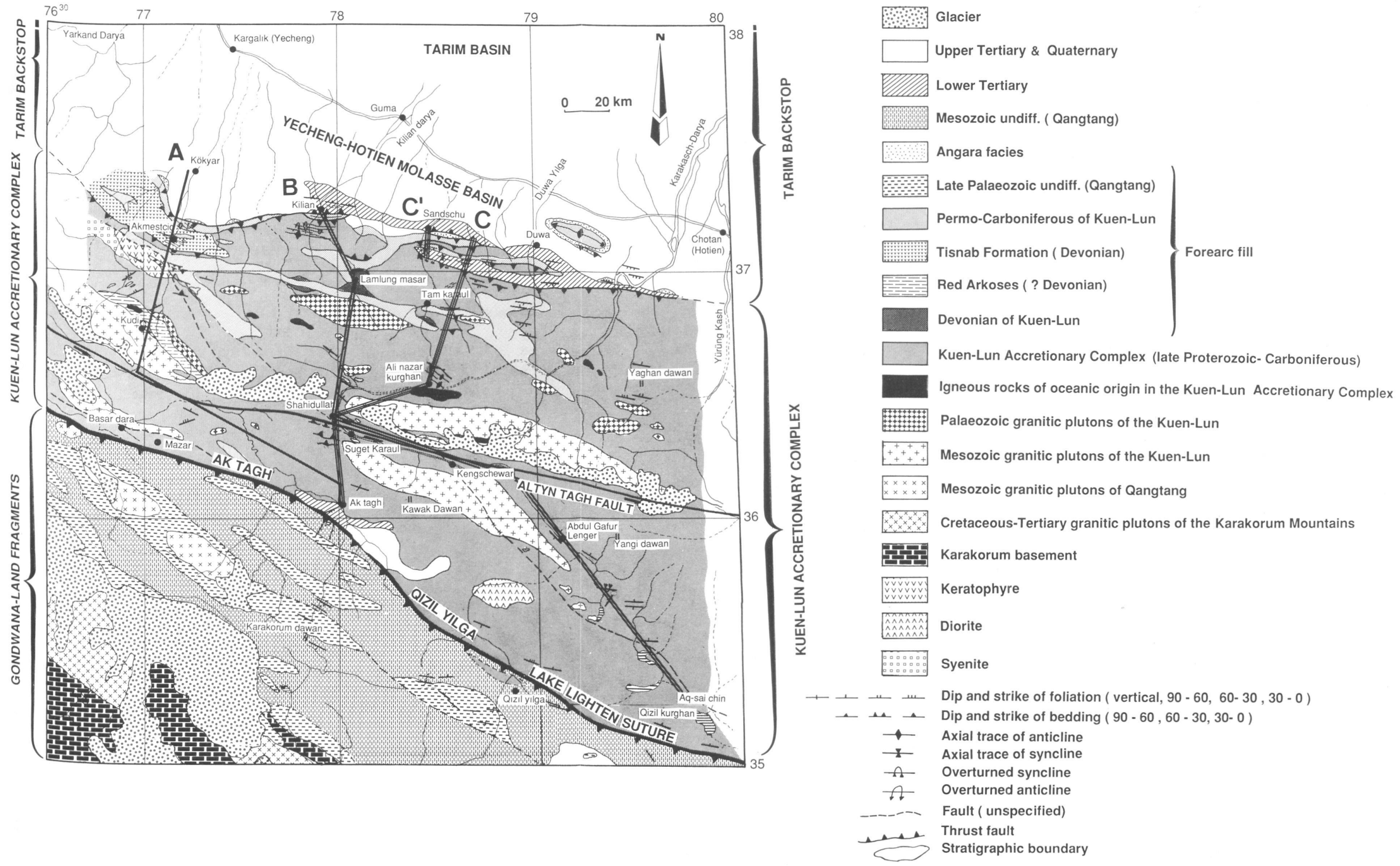
Plate 1

A simplified geological-tectonic map of the westernmost Kuen-Lun prepared on the basis of observations reported by BLANFORD (1878), DE TERRA (1932), WYSS (1940), NORIN (1946) supplemented by the Geological Map of the Qinghai-Xizang Plateau (1980), the Geological Map of the Uygur Autonomous Region (1985) and LIU et al. (1988), plus the ERTS images E-2256-04472-6 and E-1457-04522-6. Because we used DE TERRA's (1932, pl. 1) map as the base map, the longitude and latitude readings do not exactly correspond with those in modern maps.
Some toponymy conforms to those given in the foldout map in the COLLOQUE KUNLUN-KARAKORUM 90 to enable the reader to compare our map with the information given in the abstracts of the COLLOQUE.


76°30
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TARIM BACKSTOP
KUEN-LUN ACCRETIONARY COMPLEX
GONDWANA-LAND FRAGMENTS
TARIM BASIN
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Kargalık (Yecheng)
Guma
Kilian darya
YECHENG-HOTIEN MOLASSE BASIN
Duwa Yilga
Karakasch-Darya
Chotan (Hotien)
A
Kökyar
B
Kilian
C'
Sandschu
C
Duwa
Akmestci
Lamlung masar
Tam karaul
Kudi
Ali nazar kurghan
Yaghan dawan
Yürüng Kash
Shahidulla
Basar dara
Mazar
Suget Karaul
Kengschewar
AK TAGH
ALTYN TAGH FAULT
Ak tagh
Kawak Dawan
Abdul Gafur Lenger
Yangi dawan
Karakorum dawan
QIZIL YILGA
LAKE LIGHTEN SUTURE
Qizil yilga
Aq-sai chin
Qizil kurghan
Glacier
Upper Tertiary & Quaternary
Lower Tertiary
Mesozoic undiff. (Qangtang)
Angara facies
Late Palaeozoic undiff. (Qangtang)
Permo-Carboniferous of Kuen-Lun
Tisnab Formation (Devonian)
Red Arkoses (? Devonian)
Devonian of Kuen-Lun
Forearc fill
Kuen-Lun Accretionary Complex (late Proterozoic- Carboniferous)
Igneous rocks of oceanic origin in the Kuen-Lun Accretionary Complex
Palaeozoic granitic plutons of the Kuen-Lun
Mesozoic granitic plutons of the Kuen-Lun
Mesozoic granitic plutons of Qangtang
Cretaceous-Tertiary granitic plutons of the Karakorum Mountains
Karakorum basement
Keratophyre
Diorite
Syenite
Dip and strike of foliation (vertical, 90 - 60, 60- 30 , 30 - 0)
Dip and strike of bedding (90 - 60 , 60 - 30, 30- 0)
Axial trace of anticline
Axial trace of syncline
Overturned syncline
Overturned anticline
Fault (unspecified)
Thrust fault
Stratigraphic boundary

Plate 2

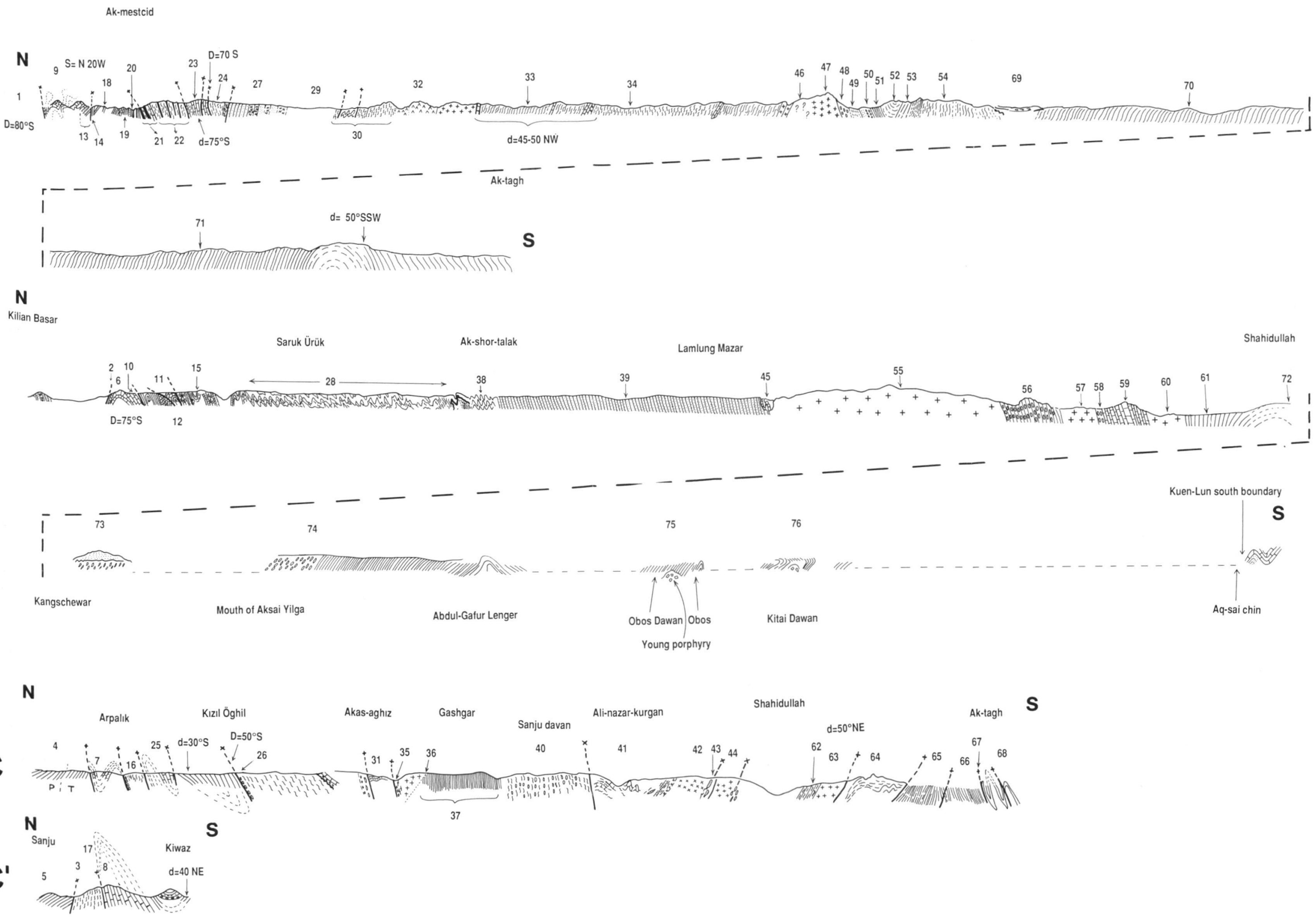
A. Geological cross-section from about Kök-yar to Ak-tagh.

B. Geological cross-section from about Kilian Basar to Aq-sai Chin.

C. Geological cross-section from about Arpalik to Ak-tagh.

C′. Geological cross-section from Sanju to Kiwaz.

For sources and the description of the numbered localities see the text and the Appendix. In these sections, notice the persistent steepness of the foliation! For locations of the cross-sections, see Plate 1.


Ak-mestcid
N
A
9
S= N 20W
1
D=80°S
18
20
13
14
19
21
22
23
D=70 S
24
d=75°S
27
29
30
32
33
d=45-50 NW
34
46
47
48
49
50
51
52
53
54
69
70
Ak-tagh
71
d= 50°SSW
S
N
Kilian Basar
B
Saruk Ürük
Ak-shor-talak
Lamlung Mazar
Shahidullah
2
6
10
11
15
D=75°S
12
28
38
39
45
55
56
57
58
59
60
61
72
73
74
75
76
Kuen-Lun south boundary
S
Kangschewar
Mouth of Aksai Yilga
Abdul-Gafur Lenger
Obos Dawan
Obos
Young porphyry
Kitai Dawan
Aq-sai chin
N
C
Arpalık
Kızıl Öghil
Akas-aghız
Gashgar
Sanju davan
Ali-nazar-kurgan
Shahidullah
Ak-tagh
S
4
7
16
25
d=30°S
D=50°S
26
P
T
31
35
36
37
40
41
42
43
44
62
d=50°NE
63
64
65
66
67
68
N
Sanju
S
Kiwaz
C'
5
3
17
8
d=40 NE

APPENDIX

Notes on Plate 2, Sections A–C′

In the following descriptions – means a *conformable* contact; ~ means an *unconformable* contact.

For localities 1–3 see the text.

C 4: P – Pleistocene conglomerates and gravel, stratified sand deposits and laminated silt.
T – Tertiary formations of the Tarim Basin (Norin 1946). For T see C′ 5 below.

C′ 5: Bottom to top: Red sandstones – Coarse, grey calcareous sandstones and chloritic marls with *Gryphaea:* Middle Eocene (Norin 1946, p. 20; for the uncertainty on the species see Blanford 1878, p. 22, and footnote 2).

C 6: Light grey dolomitic limestone with strong, steeply N-Dipping foliation – Reddish grey limestones with no fossils (De Terra 1932). Perhaps Partly equivalent to the Upper Carboniferous Tagarqi Group consisting of 308 m of carbonates. Lower part contains *Protritices* and ostracodes; upper part *Pseudoschwagerina,* indicating the presence of Asselian and possibly also Sakmarian (Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region 1985).

C 7: Grey, semi-crystalline limestones: Carboniferous-Permian (Norin 1946).

C′ 8: Grey, semi-crystalline limestone containing *Spirifer (striatus?)* and *Fenestellae* (Blanford 1878). Wyss (1940) collected here an Uralian (uppermost Carboniferous) fauna.

A 9: Fusulinid-bearing, dark grey, hard limestones, cut by numerous faults and slickensides. In the stream bed, *Schwagerina*-bearing whitish grey limestone – Greyish red well-bedded crinoid limestone. General strike N 25 W, dip 40 E (De Terra 1932).

B 10: North to south between two thrust faults: Strongly flattened, nodular, foliated limestone-Sandstone alternating with siliceous calcareous schists – Green-grey quartzite schists.

B 11: Dark, thinly-bedded limestone.

B 12: Grey-green sandstones (?Lower Carboniferous) =? Heshilapu Formation.

A 13: Grey-green clastics: Lower Carboniferous (probably Heshilapu Formation equivalent: Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region 1985).

A 14: Greenschists: 360 m thick (visible structural thickness), strongly schistose green tuffite (De Terra 1932).

B 15: Phyllites and "quartzite schist" (De Terra 1932).

C 16: Strongly brecciated fault contact: quartzose biotite-chlorite and chlorit-sericite schists (identical in character to the contact seen at loc. 26: see below) (De Terra 1932).

C′ 17: Chlorite schists (Blanford 1878).

A 18: Reddish violet and green-grey Tisnab Beds. Farther south red, quartzitic sandstones and red conglomerates. Clasts consist of red hornstein, porphyry, greenschist or tuffite and quartzite. Southward, the conglomerate becomes coarser. All this is underlain by tuff schists of Devonian age (De Terra 1932).

A 19: South of a steep fault are reddish-grey, poorly-bedded limestones (?Devonian), underlain by red slates with 60° dip to the NE (De Terra 1932).

A 20: South of a steep fault follow sandstones, tuffs and diabase interlayers. To the S, the diabases become foliated (De Terra 1932).

A 21: Marbles and limestones are interlayered with diabases tectonically, farther south follow:

A 22: Strongly foliated, steeply south-dipping diabases and tuffs (De Terra 1932).

A 23: From north to south between two faults: reddish crystalline limestone, foliated and strongly dislocated exhibiting numerous slickensides. Then across a schist band, 75° S-dipping dark grey limestones and reddish marbles alternate (De Terra 1932).

A 24: Green tuff-schists (De Terra 1932) containing chlorite (Blanford 1878, p. 42). Followed southward by foliated marble (De Terra 1932).

C 25: Grey, semi-crystalline limestone with moderate to steep southerly dip (Norin 1946).

C 26: Fault breccia, containing angular and subangular fragments and blocks of Carboniferous grey limestone. The thrust mass consists of chlorite-albite schists, green-gray calcareous, epidote-chlorite-albite schist, quartzose chlorite-biotite, chlorite-muscovite schists that are fine-grained and titanite-rich. Grade of metamorphism increases southward (Norin 1946).

In the parallel Sanju Valley to the west, the same section contains, in the north, a very thick, monotonous series of coarse, grey-green phyllitic greywackes with rounded conglomerate clasts. This is followed southwards by a large thickness of monomict limestone conglomerate, which is then succeeded by an alternation of phyllitic slates and beds of white limestone and marble (Norin 1948).

This section is unconformably overlain by a sequence, consisting at the base of a very coarse conglomerate of crystalline schists, quartz clasts and limestones (clast size generally 10–20 cm with some 50-cm clasts), overlain by a black, massive siltstone with solitary milky quartz fragments and finally a bluish black carbonaceous limestone with fossil fragments and one coral.

A 27: Foliated greywacke and quartzite according to De Terra (1932). In the same section, along ± 77°20′E (Achiq Yilga), Norin (1948) describes keratophyre, porphyry and pyroclastics with undefined Palaeozoic limestone.

B 28: Schists and quartzitic sandstones (De Terra 1932).

A 29: Loess.

A 30: Phyllites and "green, foliated, siliceous rocks" (De Terra 1932).

C 31: Dark, violet-grey, very fine-grained quartzitic arkoses and conglomerates (Blanford 1878; Norin 1946).

A 32: Chloritic schists (Blanford 1878).

A 34: Quartzite and hornblende-schists. Cut in all directions by quartz veins with black tourmaline (Blanford 1878).

C 35: Strongly brecciated granite.

C 36: One possible unconformity here? (see Blanford 1878, p. 21).

Note: Observations by Norin and Stoliczka (Blanford 1878) differ considerably regarding localities 31, 35 and 36 possibly because of the intimate tectonic intermixing of granite, veined gneiss, and schists. De Terra agrees more closely with Norin whom we followed in our depiction of the section.

C 37: Steep dips of schistosity according to Blanford (1878).

B 38: Foliated conglomerates consisting of reddish quartz and alternating with quartzites (De Terra 1932). The Geological Map of Xinjiang Uygur Autonomous Region (1985) shows these as belonging to the "Upper Devonian Tiznab Formation". The Bureau of Geology and Mineral resources of Xinjiang Uygur Autonomous Region (1985, p. 20) describes the rocks as mottled clastic rocks of continental origin with the plant fossils of *Trachytriletes subminor* and *Lepidozonotriletes normalis.*

B 39: Very coarse-grained greywackes and quartz schists with conglomeratic schists. Clasts are quartz and black siliceous schists. The whole is very strongly folded (Norin 1946).

C 40: Locally abundant garnet-bearing micaschists, cut in places by veins of jade (Blanford 1878).

C 41: A highly deformed sequence consisting of garnet-muscovite schists, massive quartzites, quartz schists, dolerites and mafic alkalic rocks (Norin 1946). Intruded by

C 42: Plagioclase amphibolite (metagabbro) (Norin 1946).

C 43: Micro-folded calc-schists and granitic cataclasite marking the location of a south-vergent thrust fault (Norin 1946).

C 44: Fine-grained granodiorite.

C 45: Grey-white and grey-blue, foliated marble folded with the greywackes and quartz schists. Contact with the granite is intrusive with many schist xenoliths according to De Terra (1932); faulted according to Norin (1946).

A 46: Arkoses?

A 47: Granite

A 48: Gneiss

A 49: Shales

A 50: Conglomerates and sandstones

A 51: Shales

A 52: Conglomerates as in locality 31 according to Blanford (1878). Norin (1946) here describes violet, fine-grained arkoses (?Angara beds of Mesozoic age).

Note: Observations by Norin (1946) and Stoliczka (Blanford 1878) contradict each other here exactly as in the case of localities 31, 35 and 36 and probably for a similar reason. That is why the relations between the successive rock types in localities 46 through 52 are not indicated.

A 53: Black slates (Blanford 1878).

A 54: Quartz greywackes (Blanford 1878).

B 55: Hornblende-rich biotite granite with many mafic xenoliths. Granite is visibly foliated and locally porphyritic. The foliated structure is especially emphasized by feldspars (De Terra 1932). The Geological Map of the

Xinjiang Uygur Autonomous Region (1985) indicates that this is an "early Variscan" granodiorite, while the Geological Map of the Qinghai-Xizang (Tibet) Plateau (1980) maps it as "middle Variscan". Liu et al. (1988) have it as partly Indosinian (Triassic) and partly early Yenshanian (Jurassic). We follow Liu et al. (1988) in the light of the recent synthesis of the Kuen-Lun granitic rocks by Zhang & Xie (1990).

B 56: Injection gneisses and hornblende gneisses, likely a highly foliated marginal facies of the granodiorite (De Terra 1932).

B 57: Porphyry granite stock intruding and partially melting the hornblende gneisses of locality 56, which is invaded by numerous aplitic dykes emanating from the granite (De Terra 1932). If the hornblende gneisses are indeed a marginal facies of the granodiorite in locality 55, then the porphyry granite here must be younger. Liu et al. (1988) indeed show it as younger (Yenshanian) than the granodiorite (Indosinian).

B 58: Strongly folded migmatitic gneisses and hornblende schists (De Terra 1932).

B 59: Blue-grey, banded and foliated marbles (De Terra 1932).

B 60: Granite

B 61: Quartz-schists, grading southwards into hornblende and chlorite schists. From here southward, the dominant vergence of the schistosity is southward (De Terra 1932).

C 62: Graphitic phyllites and quartzite schists, passing southward into hornblende and chlorite schists. The contact with the granite (locality 63) is intrusive as indicated by the xenoliths of the schists in the granite and aplite veins in the schists (De Terra 1932).

C 63: Granite

C 64: The granite is thrust southward onto a sequence of quartz schists, coralline marbles and calc-phyllites showing more than one phase of folding (De Terra 1932).

C 65: Dark slates and quartz-greywackes. Near the fault contact with the rocks of locality 64 are graphite phyllites. Southward, the dark slates disappear and the sequence is represented only by green-grayish "quartzite schists".

C 66: Across a south-vergent fault contact are steeply south-dipping (note change of vergence!) titanite schists and quartz-phyllites.

Note: The pelites in localities 65 and 66 form the Bazar Dara Slates of Gaetani et al. (1990). The ages of these may even reach into the Triassic!

C 67: A steeply south-dipping fault forms the boundary between the steep pelite belt of the Kuen-Lun and the north-vergent, tightly folded and thrust western Qang-Tang stratigraphy constituting the "Surukwat Thrust Sheets" of Gaetani et al. (1990) and the "Tethysfaltenland" of De Terra (1932). This fault here represents the fundamental architectural divide in the Tethysides (see Fig. 10) and corresponds with the main Palaeo-Tethyan suture here cf. Şengör (1984).

C 68: The Surukwat Thrust Sheets. The stratigraphy here consists, from base to top, of 1) grey to bluish calcareous slate and yellowish grey calcareous sandstone – 2) black, somewhat silicified coralline limestone – 3) black to yellowish grey calcareous sandstone with crinoids – 4) red crinoidal limestone with brachiopods – 5) schistose, whitish-yellow crinoidal limestone – 6) reddish-white diplopora-bearing limestone, 1–2 are Carboniferous, 3–4 are Permian and 5–6 are Triassic in age (De Terra 1932). For more extensive description with rich fossil lists see also Dainelli (1933, 1934).

A 69: Mesozoic continental formations of the "Angara facies" (Blanford 1878).

A 70: Grey and pink schists with local graphitic layers (Blanford 1878).

A 71: Grey or brownish, silky micarchist (Blanford 1878).

A 72: Between Shahidullah and to the east-southeast of Kangschewar:

In Suget Karaul: Migmatitic gneiss with interlayers of ophicalcite and hornblende schists.

About 10 km up the Karakash Valley 7 miles to the east-southeast of Balakchi: "Jade" mines. (Blanford 1878). These are mainly nephrite mines (see De Terra 1932, p. 44). Nephrite occurs in veins in mica or hornblende schists and the veins contain much dolomite (Blanford 1878). The dips of schists are either vertical or inclined very steeply to the south. 2–3 m thick lenses of white-yellow or white-green ophicalcite occur in finely platy chlorite or hornblende schists, locally with gneissic texture. In these are veins of epidote-albite, pure serpentinite, and nephrite. There are also orthogneisses, amphibolite schists, and calc-silicate hornfels. Most of these rocks seem to have developed by the contact effects of the biotite-granites in the area (Blanford 1878; De Terra 1932; Wyss 1940). Towards Kangschewar again nephrite and jadeite mines. Here too they occur in association with ophicalcite in hornblende schists and gneisses (De Terra 1932).

At Kangschewar a diorite yielded a Zr age of about 470 Ma. To the southwest, at the Sanshiliyingfang military base a 192 Ma Zr age was obtained on a granite. Farther east, at the Qiyi bridge, there is a Rb-Sr biotite age of 215 Ma on a granite (all the ages according to pers. comm. from Dr. Wang Yi, 1991).

B 73: Gneiss underlying red arkoses.

B 74: Migmatites and garnet gneisses near the granite contact passing southeastward into aplite-infested schists. These then give way to garnetiferous micaschists with numerous pegmatites and quartz veins that become fewer as one moves away from the major intrusion (see Fig. 11). Finally the pelites become dark phyllites and quartz schists. Near Abdul Gâfur Lenger the schistosity is folded by an upright, open, slightly north-vergent fold.

B 75: Greywackes, quartz schists, phyllites with upright to somewhat south-vergent close folds.

B 76: Greywackes, quartz schists and phyllites continue, but here with at least one major recumbent fold (DE TERRA 1932, p. 40; NORIN 1946, p. 32).

Strongly folded phyllites and quartz-schists, greywackes continue south-southeastwards all the way to Aq-sai Chin, where HEDIN (1909, p. 95) found "blood-red conglomerate, which lay upon green schists". The conglomerate was later found to be Tertiary in age covering deformed Cretaceous rocks that in turn rest unconformably on the older phyllites, quartz-schists and greywackes (cf. DE TERRA 1932; NORIN 1946, 1974, 1979).

Note: 75 and 76 are equivalents of the Bazar Dara slates of GAETANI et al. (1990) and the monotonous pelites of MATTE et al. (1991) whose age may reach into the Triassic. DAINELLI (1934, map) included these in his *"scisti cristallini di età indeterminata prevalentemente pre-siluriana"*, hinting that not all crystalline schists in the Kuen-Lun were pre-Silurian.