Austrian Journal of Earth Sciences | Volume 107/1 | 169 - 232 | Vienna | 2014

A new look at the Altaids: A superorogenic complex in Northern and Central Asia as a factory of continental crust. Part I: Geological data compilation (exclusive of palaeomagnetic observations)

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KEYWORDS

subduction-accretion complexes
growth of continental crust
Central and Northern Asia
Eduard Suess
island arcs
Altaids

It ain't what they call you, it's what you answer to.
William Claude Dukenfield (alias W. C. Fields)

Abstract

The Altaids are one of the largest superorogenic complexes in the world in which two genetically closely related orogenic complexes ended up generating much of northern Asia during the Palaeozoic and the early and medial Mesozoic. This immense superorogenic complex evolved as a consequence of the development of two large island arc systems called the Kipchak and the Tuva-Mongol arcs and that were similar in size to the present-day Southwest Pacific arc chains. They both have rifted from the then combined (or close) Siberian and Russian cratons during the latest Neoproterozoic/earliest Cambrian following the Baykalide/Preuralide orogeny. As a consequence of this rifting, the Khanty-Mansi Ocean opened behind them and they faced the Turkestan and the Khangai-Khantey Oceans, respectively. It is at the expense of these oceans that these two arc systems generated large subduction-accretion complexes. The Kipchak Arc was completely detached from the Siberian craton during the Neoproterozoic and it was reconnected with it along its trend by means of ensimatic arc systems that formed along its strike during the medial to late Cambrian. These ensimatic arcs also accumulated large volumes of subduction-accretion complexes in front of them during their migratory development throughout the Palaeozoic and, in Mongolia and in the Russian Far East, into the medial Mesozoic. As the accretionary complexes grew, magmatic fronts of their arcs migrated into them, turning them into arc massifs by magmatism and HT/LP metamorphism in arc cores. Especially near the Siberian Craton and in the Khangai-Khantey Ocean, the subduction-accretion complexes were fed by turbidites shed from old continental crustal pieces. Where arc magmatic axes migrated into such accretionary complexes, the material of which is of ancient continental provenance, they in places exhibit Proterozoic zircon ages and isotopic signatures inherited from their ancient source terrains leading to the mistaken conclusion of the presence of ancient continental crust under such arcs. It seems imperative to have proper field geological data together with the isotopic work to derive any reliable conclusions concerning crustal growth rates.

We have compiled 1090 new, mostly zircon ages of magmatic and some metamorphic rocks from the literature for the whole of the Altaid supeororogenic complex. These ages show continuous arc activity from the Ediacaran into the early Cretaceous in the Altaids, although arc magmatism turned off already in the Triassic in the western Altaids. Much of the succeeding alkalic magmatism in the western moiety of the superorogenic complex was related to strike-slip activity opening the West Siberian basins such as the Nurol and Nadym and the large pull-apart basins of Alakol, Junggar and Turfan. There are numerous other smaller areas of extension related to the late Altaid strike-slip activity and they too have alkalic magmatism associated with them. Some of the alkalic granites not related to the late strike-slip activity may have been related to slab fall-off after terminal collisions, although this is now difficult to document with any confidence. It is noteworthy that no Tibet-type collisional plateaux were ever produced as a consequence of Altaid collisions.

We have been able to find no evidence anywhere in the Altaids for independent trans-oceanic migrations of numerous 'terranes' tied to individual subduction zones. Only two major subduction zones were responsible for the entire Altaid evolution from the beginning to the end and this is consistent not only with the present tectonics of the earth, where major subduction zones display great spatial continuity and temporal persistence, but also with the tomographic observations on well-imaged former subduction zones such as those associated with the Tethyan and the North American Cordilleran chains.

The entire Altaid collage now occupies some 8,745,000 km^2. At least half of this area represents juvenile addition to the continental crust during the Ediacaran to the earliest Cretaceous interval. That is more than 10% of the entire land area of the Asian continent. Similar events are now going on in the Nipponides in eastern Asia, in the Oceanian arc systems in the southwestern Pacific Ocean

and in places around the Caribbea and the southern Antilles. Altaids were one of the main factories—if not the main factory— for the generation of the continental crustal during the earlier half of the Phanerozoic on our earth. This was not because the growth rate of the crust was unusual, but because so much of it was produced in such a huge area and in an interval of some half a billion years.

1. Introduction[1]

In the third volume of *Das Antlitz der Erde* (*The Face of the Earth*), Eduard Suess (1901) pointed out that mountain ranges to the south and west of the East Siberian table-land consisted mostly of Palaeozoic schists, slates and clastic sedimentary rocks, serpentinites and mafic rocks, all intruded by granites and overlain by diverse types of mainly intermediate and felsic volcanic rocks and terrestrial and shallow water sedimentary blankets during much of the Palaeozoic. It is these mountain ranges that he collectively called the Altaids after the Altay Mountains in the present Russian Federation (Fig. 1), i.e., the

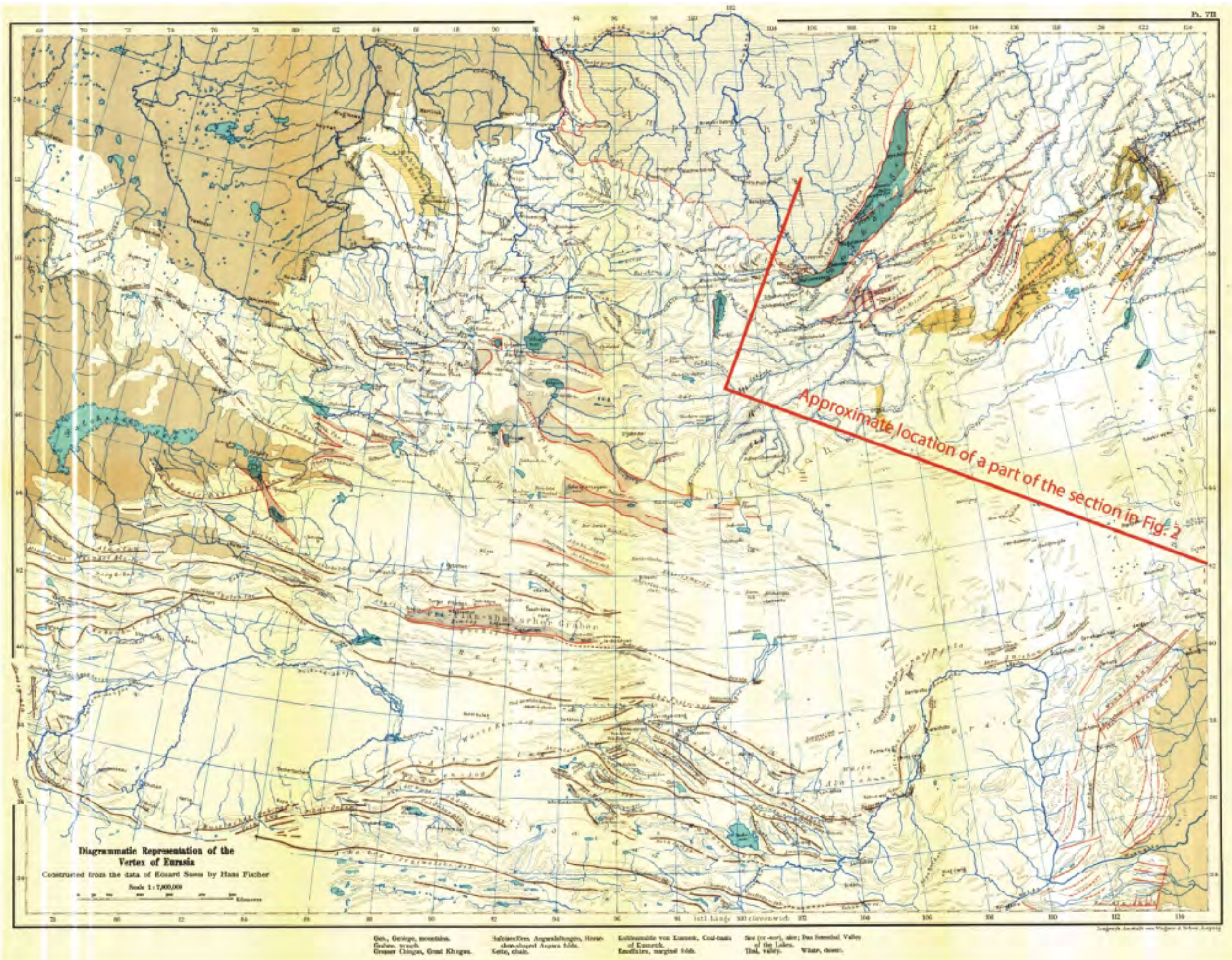

Figure 1: Suess' map of the Altaids (Suess, 1901, Plate VII; we here reproduce the English version from Suess, 1908, plate VII). Brown lines represent the trend lines of individual parts of the Altaids, i.e., the average strike of the beds and thrust faults. The red lines are what Suess called disjunctive lines, bounding basins younger than the Altaid folds. Suess thought they were mostly normal faults. We now know that many had started their lives as normal faults indeed, but after the medial Triassic began turning into thrust faults. Grey areas are regions of subsidence. Suess thought the entire Siberian craton was one such area. Large areas of brownish grey colour are regions of faultless gentle subsidence, covered by deposits of Mesozoic and Cainozoic ages. Buff-coloured areas are regions of coal deposits. Lakes are greenish blue.

[1] In the following paper, we use capital F to refer to our own figures as Fig. and lower case f to refer to figures that we cite from the literature, as fig. Designations as Lower, Middle and Upper in formal rock and time-rock stratigraphic terms are all capitalised. Those as early, medial and late in time stratigraphic units are not capitalised, contrary to the recommendations of the *International Stratigraphic Guide* (Salvador et al., 1994), simply because time corresponding to the deposition of certain rock groups cannot be formalised where not even units can be defined (note the disclaimer in the *International Chronostratigraphic Chart* of the IUGS International Commission on Stratigraphy {http://www.stratigraphy.org/ICSchart/ChronostratChart2013-01.jpg} : 'Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do.. '). We write Gondwana-Land when we mean Suess' large continent in the southern hemisphere and not Gondwana, which designates a historical region in Central India, after which a number of geological entities such as the Gondwana System or the Plateau of Gondwana had been named already. Gondwania, as suggested by Hans Stille, may be used as a substitute for Gondwana-Land, but not Gondwana. We also spell Cainozoic in the way recommended by the Royal Society of London, simply because it represents a correct transliteration from the original Greek words, unlike the inexplicably incorrect Cenozoic.

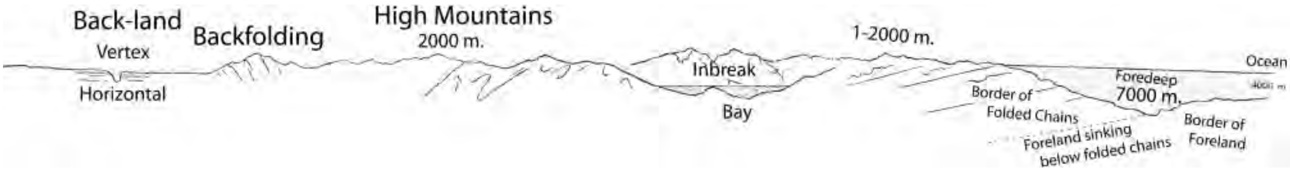

Figure 2: Suess' cross-section across Asia published in the English edition of the *Antlitz* (Suess, 1924). If one wished to draw a cross-section across the Altaids today, say along the red line shown in Fig. 1, one would have to add only details, but would not need to change the main character of the structure depicted. The line of section in Fig. 1 does not reach the shore so stops at about where it says 1-2000 m. on the section. In this figure we have only enlarged the lettering for easier reading.

'Gold Mountain' of the Turkic peoples and the Kin Shan of the ancient Chinese. Suess noted, following such distinguished predecessors as Alexander von Humboldt (1843), that the paucity of gneisses in these mountains was surprising, because, until that time, most well-studied mountain ranges appeared to contain a large proportion of gneisses in their structure (particularly along their 'axial' parts). Suess further pointed out that mountains with a significant proportion of older gneisses in their structure had well-defined fore- and hinterlands; in other words, they were long and narrow, linear/arcuate, structures, as mountain systems had long been considered since Dicaearchus of Messana and Eratosthenes of Cyrene first attempted to define a major mountain range in the third and the second centuries BCE, namely the 'Taurus,' coincident with the present Alpine-Himalayan orographic system. Suess realised that if every range in Central Asia were assumed to be an independent orogenic belt (as some 'terrane' enthusiasts claim in our own day: e.g, Badarch et al., 2002; Kröner et al., 2007, 2014; Parfenov et al., 2003; Windley et al., 2007; Buslov, 2011; Wilhelm et al., 2012), no sense could be made of its tectonic evolution. Every range within Suess' Altaids possessed an internal structure that was a direct continuation of the neighbouring ranges along and across the strike and only when all of them were considered together it became possible to reconstruct an intelligible structure and history (Fig. 2).

2 Suess' Altaids

We cite in the following paragraphs Suess' own definition and characterisation of the Atlaids in full, because, a century after his death, his remarkable understanding of this largest mountain system of Asia has long been forgotten and inappropriate names are being attached to it by those who no longer remember his message. This amnesia not only blinds the geologist to the unity of the structure and history of this mountain system and leads to a confusion in our understanding of how the continental crust is made. Needless to say, it also represents an ungrateful (and unnecessary) violation of Suess' priority. In the following long quotation, we reprint the explanatory footnotes added to it in Şengör and Natal'in (2007, pp. 210-222, footnotes 5-35), because many of the geographical names and the concepts Suess used are no longer current and because Şengör and Natal'in (2007) is unfortunately not easily accessible. The old names and concepts may hinder comprehension if left unexplained:

'Directing our attention to any single mountain chain, such as the Caucasus, Carpathians, Pyrenees, or Appalachians, we may inquire whether its structure is symmetrical or asymmetrical, on which side its foreland lies, whether it is divided into several ranges, and so on. But the several ranges of the Ancient Vertex [Fig. 3] do not lend themselves to such an inquiry. They owe their outer form, as well as their internal structure, to a very general and extensive process of folding and subsequent disjunctive dislocation[2]*, and perhaps also in isolated cases to particularly long granite trains which reveal themselves in the relief of the country. In the east, as on the Gazimur*[3]*, for example, where the discordant Devonian is folded, it is possible that posthumous folding*[4] *may have taken place in addition.*

Also in the chains belonging to the first group, one sees, as a rule, long along-strike continuations and one notices the obstacles that have narrowed the areas of the development of the folds. But in the mountains of the vertex the scale of inde-

[2] Disjunctive dislocation is a term Suess borrowed from Russian geologists working in Central Asia: 'Finally, in the best-known parts of the mountainous region, and particularly across the lower Selenga, we see undoubted subsidence troughs. Our Russian colleagues describe them by the very expressive term "disjunctive dislocations." Indeed it would be impossible to explain the formation of a series of sub-parallel fractures and troughs, the course of which corresponds for long distances with the strike of the ancient folds, without assuming a certain amount of extension, acting approximately in the orientation of the shortening expressed by the ancient folding. This extension may result in disjunction, i.e., it may give rise to fissures and also to subsidence of long strips of land between these fissures. Eruptive rocks of different ages may then accompany the disjunction.' (Suess, 1901, pp. 55-56; also see Fig. 1 herein). In Russian, however, the term 'disjunctive dislocation' simply refers to faults—as opposed to folds that are known as 'plicative dislocations' (e.g., Kosygin, 1952, pp. 36-40, 1969, pp. 110-181; Obrutchev, 1959, pp. 212-213). Some of Suess' disjunctive dislocations, which he interpreted exclusively as normal faults, are now known to be thrust faults delimiting ramp-valley basins formed from the shortening of late Palaeozoic rifts (e.g., Turfan: see Allen et al., 1995); others are pull-apart basins along Mesozoic and Cainozoic strike-slip faults.

[3] A left-hand tributary of the Argun (Ergun He in Chinese; the upper course of the Amur) joining it in the Russian Federation just southwest of the Chinese town of Qiyahe (53ºN, 120º30'E). Here a polymetallic mineralisation produced much silver that had been exploited since 1778. Later Uranium was also found.

[4] 'Posthumous folding' is a concept introduced by Suess to describe younger folding coincident in direction and, at least in part, in areal influence with an older episode of folding. He conceived it while studying the post-Palaeozoic folds of the Paris Basin and southern England, which closely follow those of Palaeozoic age: 'Godwin Austen in his now famous treatise on this subject [the reference here is to the famous coal treatise by Godwin-Austen, published in 1856] even maintained as a universal law that when any zone of the earth's crust is considerably folded or fractured, subsequent disturbances follow the previous lines, and this simply because these lines appear to be lines of least resistance.

pendence is much smaller. There are signs of back-folding towards the amphitheatre [Figs. 2 and 3], and we observe on a still larger scale the march of a common folding towards the exterior, namely towards the south-east, south, and south-west [see especially Fig. 2].

The universality and the persistence of the movement are revealed not only by the horseshoe-shaped folds of the Angara series in the centre of the ancient vertex [Fig. 3]; the same feature is repeated in Minussinsk [see Fig. 3 for location]; but even outside the vertex, in the basin of the upper Amur[5] and in Manchuria[6], the plains themselves lying between the mountain chains everywhere present more or less obvious traces of folding. Such traces are to be met with extending upwards [in age] even as far as the Gobi deposits[7]. With so extensive a movement it only remains, in tracing out the trend-lines[8], to discover the region where this general movement originated. I use the term region because, little as we know of the detailed structure of the ancient vertex, yet it is now quite evident that the movement issued neither from a point nor from a straight line, but in all probability from a region bounded by an arc convex towards the south, such as would connect, the directions of the Baikal and the Sayan[9].

But there exist in the interior of Asia other mountain chains, rising high into the region of eternal snow, which are more recent than the ancient vertex and different in direction. They are sometimes so closely crowded together that the bottoms

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These results are far reaching in their significance. Even if it should be shown later that some of the lines in question do not traverse the whole distance as continuous folds, but that contiguous anticlines running in the same direction replace each other, as in the Jura, yet this will not affect the fact that there exists a system of folds formed under a movement to the north-east and north, which strikes to the north-west in France, curves round in an arc to westnorth-west and west in the region of the Channel, and extends with a westerly strike through the south of England to Weymouth and the Mendips. These lines correspond, however, to the downthrown segments of the Armorican arc and join together the projecting horsts. The region was folded, as we have seen, at the close of the Carboniferous period, was covered with younger sediments and subsided; then there occurred in the same place a folding of the younger sediments, and this more recent folding coincides in direction with the older folding which preceded it. This phenomenon we term *posthumous folding*. It is very likely that in most other mountain systems repeated movements in the same direction have occurred at very different times.' (Suess, 1888, pp. 112 and 114; italics Suess'). Later, it came to be used by some as the rejuvenation of particular folds, for which Suess never intended it. For subsequent employment of this expression in tectonics, see especially Stille (1924, p. 41; Bucher, 1933, pp. 374-377, with criticism of Suess' view; Murawski, 1971; Şengör, 1985, pp. 207-209). The subsequent misuse of Suess' term is another example of the distortion of his ideas by later authors who have not read the *Antlitz* completely, as a 'long argument' against the uplift theory of Leopold von Buch, Sir Charles Lyell, Bernhard Studer, and Léonce Élie de Beaumont and confused Suess' global tectonic theory with those of other contractionist fixists of the nineteenth century such as Léonce Élie de Beaumont, James D. Dana and Joseph Le Conte.

[5] The Heilongjiang of the Chinese, the Amur is the boundary river between China and Russia in eastern Asia roughly between the meridians of 117ºE and 135ºE, so between the cities of Manzhouli and Khabarovsk.

[6] A historical region comprising the present northwesternmost Chinese provinces of Heilongiang, Jilin and Liaoning, originally the home of the Manchu people of Turco-Mongolian stock (Altaid in its ethnographical and linguistic sense).

[7] The Gobi deposits are the Gobi Series of Obruchev (1900, p. 69) corresponding to the Han Hai Beds of von Richthofen (1877, p. 25: Han Hai means 'dry sea' in Chinese. On his p. 25, von Richthofen cites Carl Ritter as quoting Julius Klaproth, who allegedly had written that a Chinese author from the second half of the 18th century had hypothesized that the floor of the Tarim Basin had been once a sea (an interpretation corroborated by recent research: Erol et al., 1996). Von Richthofen thoroughly miscites Ritter here. He writes that the citation is from the fifth volume of Ritter's *Asien*, p. 325; yet in reality he cites vol. III, p. 495 {Ritter, 1834}. But there is no reference to the second half of the 18th century in that place. In Klaproth's *Tableaux Historiques de l'Asie* {Klaproth, 1826}, which von Richthofen cites after Ritter, the passage in question occurs on pp. 181-182, with the reference to the 'last century', and also not just on p. 182). The age of the Gobi deposits long remained unknown, but was suspected to be Cainozoic. Initially, this was corroborated by the discovery in them of a *Rhinoceros* sp. in eastern Mongolia (Suess, 1899; translated into Russian in Sherbakov et al: Suess, 1960). This was the level of knowledge available to Suess in 1901: 'The Gobi sediments rest unconformably on the denuded remains of the ancient mountains; they consist of fine-grained conglomerate, friable sandstone, red and greenish marls, and white calcareous marls. The basalt mountain of Chernaya Gora (Black Mountain) situated a little south of the plain of Daitchin Dala, furnishes evidence to show that the Gobi sediments are in part older, and in part younger than the basalt. Here these sediments are dislocated and strike to the east-north-east, that is in the same direction as the underlying formations. Further south a large part of the central depression is covered by horizontal sediments of the same kind, broken-up into tabular patches. The discovery of the jaw of rhinoceros or Aceratherium [sic] in the white marl of the table-mountain of Kuldyin-Gobi has shown that the fresh-water deposits are of middle or late Tertiary age.' (Suess, 1901, p. 131).
Later, the Central Asiatic Expeditions of the American Museum of Natural History discovered that the Gobi series was no series at all, but consisted of continental deposits ranging in age from the Lower Cretaceous to the present and containing significant stratigraphic breaks spanning different intervals in different basins. The geologists of the Central Asiatic Expedition divided them into fifteen formations. They contain fossils of dinosaurs, Middle Tertiary mammals and mammals that just preceded the Ice Age (Berkey and Morris, 1924, esp. figure 16; 1927, pp. 40-41; Andrews, 1932, especially chapters IV, XIII, XIV, XV, XVII, XIX, XX, XXV, XXXIII, XXXVI, XXXVII, XXXVIII, XLI; additional information concerning Andrews' expeditions is to be gleaned from Gallenkamp, 2001: this book has a useful bibliography of Andrews' publications, which are many; see Bausum, 2000, for some excellent photographs of Andrews' expeditions and a brief biography of him; for some of the spectacular recent dinosaur finds in these deposits, see Novacek, 1996). For a modern geological assessment of these deposits, see Anonymous (1989, chs. 14 through 16) and Anonymous (1991, esp. chs. 11 through 13).

[8] By trend-lines (*Leitlinien* in the German original: Suess, 1883, pp. 302-305; translated as *lignes directrices* into French; in the English edition Hertha B. C. Sollas rendered it both as trend-lines and as 'guiding lines': Suess, 1904, p. 231), Suess means the collective average of the trend of fold axes, strike directions of beds and schistosity, and main faults in any given cross-section in any deformed area. For the usage of this concept in pre-plate tectonic context see Bertrand (1897, p. X), Chamberlin (1924), Ampferer (1938) and Kraus (1949). For its — we believe unjustified — criticism, see Tietze (1917, pp. 333ff.) and Stille (1927, pp. 1-9). As Bertrand (1897) rightly emphasised, it is an extremely useful concept, unfortunately too little used today, except in geological mapping by some structural geologists under the designation 'form surfaces' in English (see an excellent presentation of this technique in Hobbs et al., 1976, pp. 365- 370, esp. figure 8.15; what Suess was doing was essentially form surface mapping on a continental scale!). For instance, in plate-boundary-related structures, such as orogens or taphrogens, trend-lines roughly parallel the plate boundary and are useful guides to the discovery of former plate boundaries (see, for example Şengör et al., 1993a; Şengör and Natalin, 1996a; Burchfiel and Chen, 2012, especially figs. 2-11A, 12-3, 16-6, 16-7).

[9] By the Baykal and Sayan directions, Suess here means NE and NW respectively; i.e., the 'Sayan direction' refers to the northwesterly direction.

of the valleys maintain over long distances an absolute height of 4,000 metres or even more, and they present stupendous and general elevations above which the relative height of the snow-peaks is comparatively trifling. The central Kuen-Lun affords an example of this structure. But wherever these mighty mountain masses are cut into by deep transverse valleys, as between Min-tschou[10] and the "Red Basin,"[11] we only observe crowded folds; and if the whole of the central Kuen-Lun were worn down to the level of the sea, it would present on the whole an appearance similar to that of the ancient vertex, that is a great number of parallel folds, interrupted here and there by the enlarged base of a granite mass. It is the same with the eastern Gobi; this also is a sea of more or less denuded folds [Fig. 4].

In these systems of crowded folds the separate chains do not possess the same degree of individuality as is observed in the Caucasus and similar chains; and thus it happens, as in the Nan Shan[12], for example, that we find, one after another, chains formed sometimes of gneiss, sometimes of sedimentary formations, the Carboniferous in particular; this is intelligible, as soon as we regard these chains as waves belonging to a common movement[13]; but considered separately, their diverse composition becomes incomprehensible. This unity of the movement accounts for the absence, within the chains, of a contrast, such as occurs in the Alps and the Himalaya, with an alien foreland of different structure. It is the difference which exits between the waves of the open sea and the breakers on the shore.

In a remarkable lecture delivered on 3rd May, 1886, Tscherski made known his views on the structure of Inner Asia, views which were far in advance of the theories of his time [14].

When he had fully recognised the convergence of the folded ranges of the Baikal and the Sayan towards the region of the southern Baikal [Fig. 3], and had obtained a clear idea of the arc formed by these vast mountain tracts, he came to the conclusion that the western limit of this arc was to be found in about lat. 54ºN, on the upper Kan[15], that is at the boundary between the east and west Sayan [Fig. 3]. From here onwards we again meet with a dominant direction opposed to that of the Sayan, or to the westsouth-west and south-west. This direction is followed not only by the west Sayan but also by the western Altay almost down to lat. 50ºN, especially by the Kusnetskii Alatau[16] and Salair[17]. On the Bukhtarma[18] and on the Irtysh [Fig. 3][19], towards Semipalatinsk [50º 26'N, 80º 16'E], the direction turns again to the west-north-west.

In a later passage Tscherski appears to distinguish not two, but three arcs concave to the north, namely the Baykal arc, the Sayan arc (by which we must understand west Sayan), and the arc of Altay.

Tscherski's keen glance penetrated yet farther. He had heard of the recently discovered evidence that the chains of the Tien-Shan are continued towards Europe[20] and he at once recognised that the Tarbagatai[21], Boro-Khoro[22], and all the other long ranges of the Tien-Shan, follow the direction of the mountains on the Irtysh. "It would thus seem" Tscherski adds in a note, "as though the folding forces, shifting gradually from east to

[10] This is the present-day Min Xian (34º20'N, 104º09'E) in the Chinese province of Gansu. Suess describes the geology of the 'Central Kuen-Lun' (i.e., the Qilian Shan {=Richthofen Mts.}, Qinghai Nan Shan {=South Koko Nor Range}, Burhan Budai Shan, Hoh Xil Shan and the Tanggula Mountains of the present Chinese terminology) using the expedition report of Count Béla Széchenyi, where Ludwig von Lóczy wrote the geology. See especially Lóczy (1893, pp. 619-667 and figure 111). The area today corresponds mostly to the northern part of the Songpan-Ganzi System, where the Kuen-Lun passes along the strike eastward into the Qin-Ling (Şengör, 1984; Şengör and Hsü, 1984, Şengör and Natal'in, 1996a; Burchfiel and Chen, 2012), considered to be the Eastern Kuen-Lun by Ferdinand von Richthofen in his classical China. Also see footnote 12 below.

[11] This is another name for the Sichuan Basin as indicated in the French translation of the *Antlitz*: 'le «Bassin Rouge» du Sétchouen' (Suess, 1902, p. 248).

[12] Nan Shan simply means 'South Mountain'. There are many Nan Shans in what we today consider the eastern termination of the Kuen-Lun, but Suess considers it the Middle Kuen-Lun (e.g., from north to south, Yema Nan Shan, Tulai Nan Shan {=Te-Ho-Lo Nan-Shan Ling = Alexander III Range}, Danghe Nan Shan {=Humboldt Range}, Shule Nan Shan, Qinghai Nan Shan) following the terminology of his friend Ferdinand von Richthofen. What Suess means under Nan Shan corresponds to the present Yema and Tulai Nan Shan ranges. (The names following the present Chinese toponymy after equality signs are those used in the geological literature in the late 19th and early 20th centuries and are to be found also in Hedin, 1966.).

[13] See especially Şengör and Okuroğulları (1991, fig. 14, cross-section B).

[14] This lecture was cited by Suess as follows: J. D. Tschersky, On the tectonics of the mountainous country forming part of the north-western region of Central Asia, Trav. Soc. Nat. Saint-Pétersb., 1886, XVII, Heft 2, pp. 51-58. But Suess knew of it only through a translation by V. A. Obruchev (see Obruchev's letter to Suess, dated 20th April 1891 {new style; 2nd May, 1891 old style} Obruchev, 1891{1964}, p. 244). The original reference is entitled (only in the contents list of the *Trudi Sankt-Peterburgskago Obshestva Estesvoispitatelei*, v. XVII, no. 2) 'K Geologii Vnutrennei Azii', i.e., 'On the geology of Inner Asia.' In the main text, the text of the lecture has no title. See Cherskiy (1886).

[15] One of the right-hand tributaries of the Yenisey (the river between Kansk and Krasnoyarsk in Fig. 3). It joins the Yenisey at Ust Kan (i.e., 'Mouth of the Kan': 56º 32'N, 93º 47'E).

[16] A west-southwest-concave mountain range extending from about the city of Tomsk (56º30'N, 85º05'E) in the north to the town of Askiz (53º12'N, 90º 31'E) where the Kuznetskii Alatau abuts against the Western Sayan across the upper course of the Yenisey.

[17] A west-southwest-concave, low mountain range, extending from the city of Novosibirsk (55º04'N, 83º05'E) in the north to Lake Teletsk in the south (i.e. to about 51º30'N, 88ºE).

[18] One of the right-hand tributaries of the Irtysh joining it at Oktyabr'sky at 49º36'N, 83º41'E. Now its former mouth region is entirely occupied by the Bukhtarma Reservoir in Kazakhstan, constructed in 1960.

[19] One of the great Siberian rivers, which is born along the southwestern slopes of the Mongolian (or the 'Greater') Altay Mountains and joins the Ob at the city of Khanty-Mansiysk (61º 01'N, 69ºE) in the Western Siberian Lowlands (Fig. 3).

[20] Although Suess here cites no literature, the implicit reference is to the following, cited in the second part of the first volume of the *Antlitz*: Karpinsky (1883) and also to his own more detailed discussion of the same topic: Suess (1885, chapter 8; Fig. 5 herein).

[21] A south-convex mountain range just south of Lake Zaisan. It extends roughly from 48ºN, 80ºE in the west to 47ºN, 87ºE. It forms the water divide between Lake Zaisan and Lake Balkhash.

[22] The northernmost branch of the Tien Shan framing the Junggar Basin to the southwest. It extends from 45ºN and 80ºE (where it meets the Junggarian Alatau, i.e., the 'Red Mountain of Junggaria') to 43ºN and 85ºE, where it merges into the main trunk of the Tien Shan.

west, had successively affected increasingly younger deposits."

We certainly perceive that towards the exterior, and consequently also towards the west, more and more recent marine deposits take part in the structure of the Eurasiatic folds. Correspondingly we recognise towards the interior indications of great antiquity. The folds of Archaean gneiss on Lake Baikal were formed and denuded in Precambrian times, and towards the west the ancient vertex has arrested, like a horst, or, to use Tscherski's expression, like "an immovable wall," the further development of the eastern branches of the Altay. But that did not prevent the formation of posthumous folds within the space bounded by the Precambrian folds and their ancient fracture, nor the plication, far out on the Gazimur and near to Urga[23], of the unconformable Devonian sediments, and some perhaps even still younger, which are thrown into great folds parallel to the ancient vertex.

In considering the relative age of these great units of the earth's crust we will therefore use the terms "old" or "young" almost in the sense they bear when we compare the age of living persons.

As soon as we adopt this point of view it becomes more important to know when these various tectonic movements have commenced than when they have come to close. Considered thus, the displacement towards the west, conjectured by Tscherski, has actually taken place.

The hypothetical axis of the constriction of the Archaean folds within the overfolded syncline of Olkhon lies in the Primorskiy Khrebet[24], near Bugul'deyka [52º 32'N 106º 05'E], and nearly coincides with the meridian of 106º.

The constriction of the posthumous folds of the Angara series within the amphitheatre may be said to coincide approximately with the meridian of 101º.

The bend of the horseshoe-shaped Devonian folds of Minussinsk, on the Yenisey below the Tuba[25], follows the meridian of 91º.

If we include the bend of the Altay in the Belukha[26] in this comparison, then the centre of this bend is approximately marked by the meridian of 87º.

The Altay rises west of the ancient Baykalian vertex and of the intermediate region of Minussinsk, as an independent and younger vertex. Towards the east and south its development has been checked. The most important of its eastern branches, the Kusnetskii Alatau, probably proceeds from the region north of the upper Katun[27]: it passes Lake Teletsk on the east and, describing a gentle arc, reaches the plain east of the town of Tomsk [56º 30'N, 85º 05'E; Figure C9]. It is probable that south-east of this branch come other branches, slightly divergent from one another, which extend to the Saksar[28] and the Izykh[29], near the town of Minussinsk. The quiet exterior region of the Altay describes an arc to the south. In the middle of this arc stand the highest peaks. The western part presents on the Irtysh a north-west strike, but it is not possible to assign a boundary on the south-west to the younger vertex.

In order to obtain an approximate idea of the configuration which is thus developed, let us imagine the whole part of Asia which lies to the south-west to be covered with water. Let an impulse originate from the Irtysh or the Tarbagatai and let us follow its effects towards 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 Tien-Shan. They broaden out and elongate, or diverge from one another, where they find room enough, as on the Chu[30] and the Ili[31]. They crowd together and rise, towering up, where the space grows narrower, as in the Nan Shan. Sometimes they sweep past obstacles, stiff and straight, as in the Qin-Ling-Shan, continually seeking a lateral prolongation; sometimes, on the contrary, they are impeded by these obstacles, bent and turned aside. At first the universally prodominent direction is to the north-west or west-north-west. It is these folds or waves that we group together as the Altaids.' (Suess, 1901, pp. 246-250, emphasis is his).

Suess thus recognised a very wide area of mountain-building extending from the shores of Lake Baykal and the Yenisey to the Turkmenian and the Tibetan highlands. Folding towards the exterior of this large region had been, in many places, followed by steep faulting, some of the steep faults bounding basins, which Suess called, following his Russian colleagues, 'disjunctive'. In wide areas, granite trains accompanied the

[23] Urga (from *oergeë* meaning 'residence' in Mongolian; also *Niislel Khureheh*, i.e., 'capital camp' in Mongolian) is the former name, most widely used in the western literature, of Ulan Bator (Ulaanbaatar=Red Hero), the capital of Mongolia (at 47º 54'N and 106º 52'E). Before 1911 its official name was Ikh Khureheh, i.e. 'Great Camp' in Mongolian or simply as Khureheh, i. e., 'Camp'. It was renamed after the foundation of the new Mongolian state under Soviet influence in 1921. The name Urga, however continued in sporadic use in the western geological literature until almost the sixties of the twentieth century.

[24] Mountain range along the northwestern shore of Lake Baykal. Primorye, in Russian, means maritime and Primorskii Khrebet means Maritime Range (not to be confused with the Primorye region extending along the Russian Pacific coast between the latitudes of 51ºN and 42ºN!), retaining in this appellation thus the old Turkic and Chinese designation of Baykal as a sea (Chinese: *Bei Hai*, i.e., northern sea; Turkic: *Baykal Tengizi* or *Dengizi*, i.e., the sea of the rich lake. In the Turkic languages of Central Asia *Tengiz* or *Dengiz* refers to any large water body, be it a large river, be it a large lake, ocean or even an artificial reservoir).

[25] A right-hand tributary of the Yenisey, joining it just north of the town of Minussinsk (Fig. 3).

[26] This is the highest point in the Altay Mountains (elevation 4506 m; location: 49º 50'N, 86º 44'E).

[27] One of the two main source rivers of the Ob, born in the Gorny Altay (i.e., 'Mountainous Altay') in the Katun Range, just southeast of the point 50ºN, 85ºE, at the Russia/Kazakhstan frontier.

[28] A high area (maximum elevation 914 m) some 50 km west of Minussinsk with NNW-striking steep beds.

[29] A north-south trending range with steep bedding striking similarly to those in the Saksar area, centred on 54ºN and 90ºE to the northwest of Saksar. Its maximum elevation is 682 m.

[30] Central Asian river born in the Talas Range of western Tien-Shan through the coalescence of many streams west of Bishkek (42º 54'N, 74º 32'E) and ends in the swamps (roughly centred at 45ºN and 68ºE) of western Betpak-Dala, i.e., the Hunger (or Kirgiz) Steppes.

[31] Central Asian river that is born in the Tien Shan west of Ürümqi (43º 44'N, 87º 34'E; formerly Dihua) and empties into Lake Balkhash.

ranges. Within this vast region. Suess recognised an hitherto unsuspected unity in the whole of this vast region of Asia and decided that this unity had to be expressed under a single and new appellation. He appropriately chose the name of the ore-rich Altay, the first-studied and the best-known part, at the heart of the mountain system he was describing (e.g., Patrin, 1783; Renovantz, 1788; Hermann, 1801[32]; von Ledebour, 1829, 1830 and undated[33]; von Humboldt, 1831, pp. 25-47 and 187-

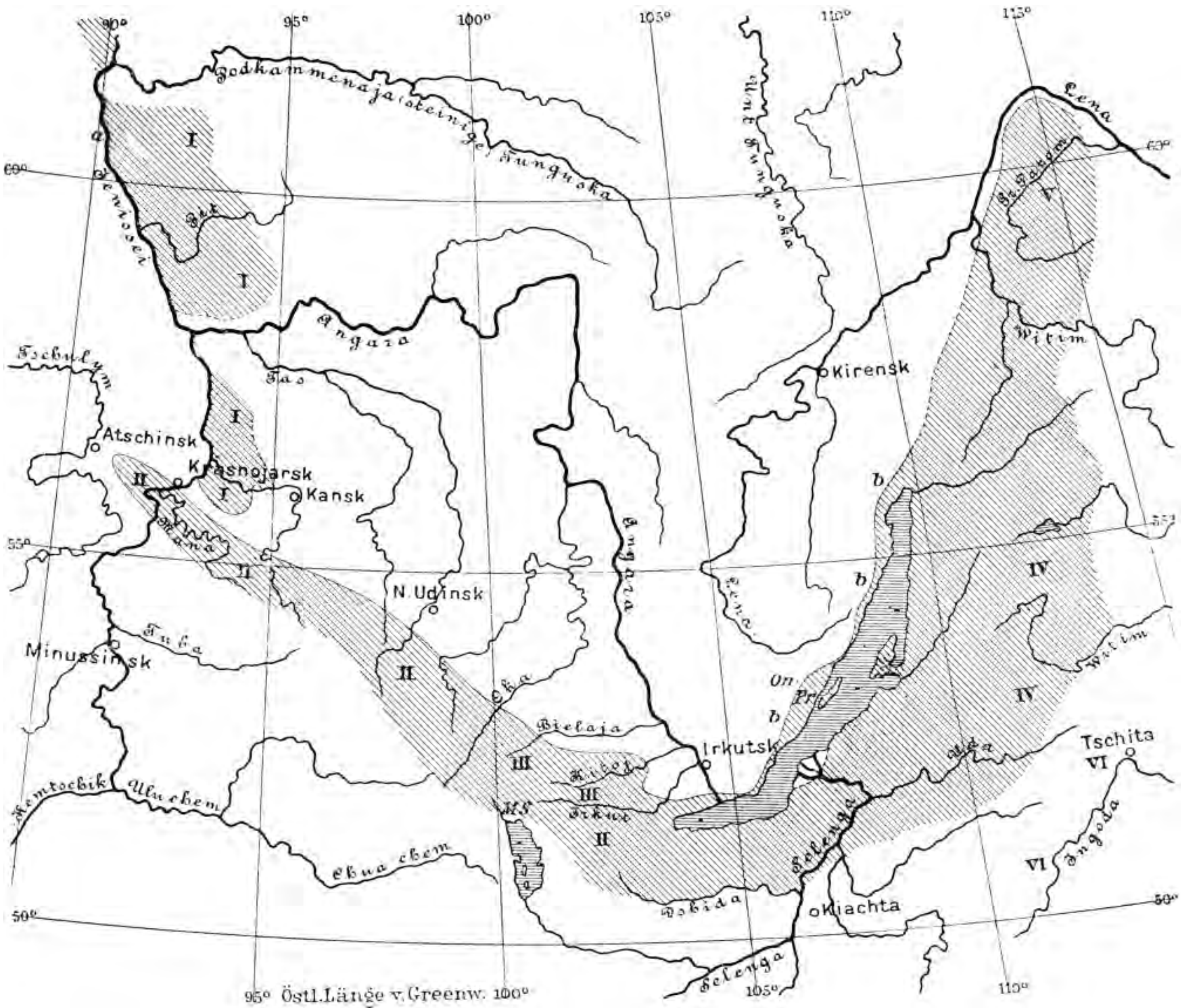

Figure 3: The Amphitheatre of Irkutsk: the core region of the ancient vertex of Asia (I-V; from Suess, 1901, figure 2; this Figure is copied from the English edition). The backfolding mentioned by Suess is towards the concave side of the amphitheatre, i.e., towards the internal side of his 'Asiatic structure'. It took place at different times with varying intensities well into Jurassic time. Key to abbreviations: Pr=Primorie Range, On=Onot Range, MS=Munku Sardyk (Mönh Sarydag: 3492 m). In the following explanation, statements outside parentheses are Suess', those within parentheses are our modern interpretation of the same rock groups and areas: I=Archaean masses on the middle Yenisey, called the 'Horst on the Yenisey' by Yatchevski in 1894 (now late Proterozoic rocks of the Yenisey Kryazh including the Isakovskaya island arc that collided with the Angaran Craton 800 Ma ago), II=East Sayan or the Ergik-targak fold belt (now the late Proterozoic to early Palaeozoic Baykalide and Altaid units: Derba, North Sayan, and Utkhum-Oka), III=Alps on the Kitoia and the Tunka (now mostly Riphean rocks: Darkhat unit and the Barguzin microcontinent), IV=Southern continuation of the high plateau of Vitim (now the northern end of the Barguzin microcontinent), V=Patom Highland (Patom foldbelt). The Amphitheatre of Irkutsk more or less coincides with the Baykalides of Shatski.

[32] To our knowledge, the first thrust fault ever described from anywhere in the world, apart from mines in small scale, was from the Altay, namely, Benedikt Hermann's (alias German Ivan Filippovich: 1755-1815) famous description of granite thrusting over schists just below the confluence of the Irtysh and the Narym, between rivers Bareshnikov and Kozlovka (Hermann,1801, pp. 108-113 and fig. 14 between pp. 108 and 109; see Rose, 1837, pp. 610-613; von Humboldt, 1843, p. 306; Suess, 1901, p. 205). This discovery Hermann interpreted in terms of horizontal shortening, but he was deeply puzzled. Hermann's discovery has so far not been noticed by historians of geology and that is why we think it appropriate to give here a full translation of the relevant passage from his important book showing Hermann's struggle to make his discovery conform to what was at the time known and to diminish the significance of the unusual phenomenon he observed (Appendix I). Unfortunately, in his biography of Hermann, Flügel (2006) does not seem to have recognised the importance of Hermann's discovery and the controversies it led to later. He cites von Humboldt (on pp. 162-163 and in footnote 157 on pp. 313-314), but neither Rose nor Hermann himself. This is another example of how little the early and important work on the Altay is now remembered. Suess partly misquotes Hermann, however. Şengör has carefully gone over the page Suess indicates in Hermann (1788, p. 108), but he could find not

194; 1843, pp. 228-411; Ritter, 1832[34], pp. 472-1143; Rose, 1837, pp. 503-613; Tchihatcheff, 1845a, b[35]; Brongniart et al., 1845; von Helmersen, 1848; von Cotta, 1871; for the much more abundant literature between the seventies of the nineteenth century and 1901, see the first seven chapters in Suess, 1901; for a list of the special geological studies undertaken along the Transsiberian Railroad and a summary of their principal results, see Comité Géologique de Russie, 1900[36]), to lend its name to characterise the entire ensemble and called it the Altaids.

The problem then became that both the structure and the history Suess reconstructed of the Central Asian mountain ranges (including the intervening basins) made little sense in terms of the contraction theory he was advocating. He was not much bothered by this, and, towards the end of his life, he openly admitted that the contraction theory had turned out to be inadequate to explain the tectonic behaviour of our planet (Suess, 1909, p. 721; but also see Suess, 1913a). This unexpected volte-face annoyed many of his contemporaries and successors, who henceforth clung to the theory and repudiated Suess' interpretation of the global tectonics and with it, naturally, the tectonics of Central Asia (see Şengör, 1998, p. 79, for quotations and discussion; see also especially Şengör and Natal'in, 2007). Suess clearly implied, in the sketches he sent to Prof. W. J. Sollas, the editor of the English translation

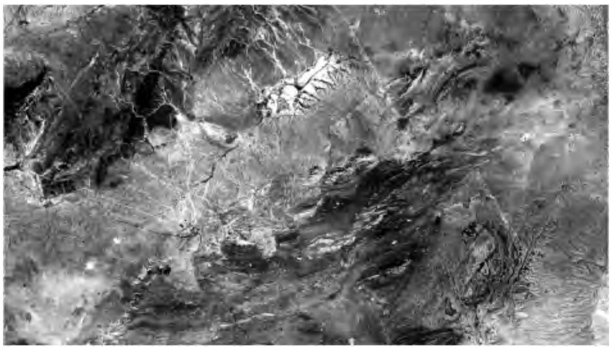

Figure 4: The 'sea of more or less denuded folds' of the Gobi. Mosaic of images from Google Earth. The image is bounded by the following coordinates: 110°54' and 111°10' N and 44°38' and 44°53' N. The north is towards the top of the page. The folds belong to the medial Paleozoic rocks of the South Gobi unit (Şengör and Natalin, 1996a). Eduard Suess was never able to see this geology as we now can, but the denuded folds of the Gobi presented themselves to his extraordinary mind's eye with the same clarity as they do to us through high-precision satellite images.

the slightest indication of a thrust relationship in the Altay on that page, which is located in the middle of a description of the Ural. Elsewhere in that book (Hermann, 1786, 1787) he also failed to find even an allusion to such a relationship. Neither is there any mention of such a thing in Hermann's Ural book (Hermann, 1789). Indeed in his *Der Altai*, Cotta (1871) does discuss this relationship but with reference to Helmersen's 1834 journey (Helmersen, 1848) and not to Hermann, although Hermann's book (1786-1788) was cited for other purposes. Both Rose (1837, p. 612, note 1) and von Humboldt (1843, pp. 306-307 and note on p. 306, which is not cited by Suess) cite the correct source by Hermann called *Mineralogische Reisen*, 1795, v. III, p. 85. Although Rose gives the correct reference, Humboldt's reference is not entirely correct! The description referred to by Rose, von Humboldt and Suess, as we indicated above, occurs on pp. 108 through 113 of volume III of a book entitled *Mineralogische Reisen in Sibirien vom Jahr 1783 bis 1796* (so von Humboldt's title and year and Suess' page number are separately correct!). Hermann's *Mineralogische Reisen in Sibirien vom Jahr 1783 bis 1796* is a very rare book, however, and it is just possible that Suess either never saw it or only had had limited access and later confused his notes. For example, it does not appear in *The National Union Catalog, Pre-1956 Imprints*, v. 242, of the American Library Association, 1972 and neither is it in the Ward and Carozzi (1984) catalogue of the history of geology holdings at the Library of the University of Illinois at Urbana-Champaign. In view of his hesitant tone in the description quoted below, Şengör has searched through Hermann's book devoted to the origin of mountains and their present structure that postdates his Siberian journeys (Hermann, 1797) and in that place there is indeed an indirect allusion to his discovery of such a relationship not only in the Altay, but also in the Ural. Strangely, however, Hermann quotes others to introduce his discussion that granite is not always at the bottom of the stratigraphic pile: 'The more thoroughly the mountains are observed in modern times, the more one finds exceptions from the old rules. For example, that Mr. Voigt found granite on top of hornblende schists belongs here. And apart from this case, also the occurrence next to one another of rock layers to be described (of Ehrenberg near Ilmenau) provides proof that granite is not always the oldest rock and taken as a whole this mountain has other characteristics contradicting the opinions taken granted until now in mountain-science. This sort of juxtaposition of various rock types (*Nebeneinanderstehen verschidener Gebirgsarten*) one finds also frequently in other mountains, for example in the Urals, the Altay, especially also in Switzerland and Mr. de Saussure has encountered many of them in Mt. Jovet in a stretch of 3000 fathoms. But from all these one may not deduce the secondary origin of granite, because first, the overlying of granite on hornblende schists can be just apparent, and secondly, even if this were not the case, granite and syenite are just varieties of the same original rock type' (Hermann, 1897, pp. 100f.). But in an earlier place (p. 50, footnote 1) he assures us that 'it is true that one has no definite proof that granite really has been observed to overlie any other rock type.' Hermann's 1897 book is not the most clearly written discussion we have ever read. As we quote above, he was still somewhat hesitant by the time his 1801 volume was being written, but much less so than in 1797! All this confusion shows how much the geology of the Altay mountains forced the observers of the 18th century to think twice about their received views of mountain structure and how difficult they found it to change them in view of the great complications of the geology revealed to their eyes. Reading the literature of our own days, we note that most geologists still find the Altay and the Altaids puzzling, because they have not read or understood Suess' basic message that no part of the Altaids can be comprehended if taken in isolation.

[33] This 'undated' is an atlas of 8 large sheets of maps, cross-sections and panoramic views of the Altay and the Junggarian Steppe, probably intended to be folded and bound with the volumes. In the copy in Şengör's library, which we used, the atlas sheets have been bound separately between soft covers under the title *Atlas zu Ledebours Reisen* issued by G. Reimer, Berlin. That is why we do not cite it separately in the literature list at the end of this paper.

[34] Ritter's book has an atlas. However, this atlas consists of individual map sheets drawn at different times by different cartographers for Ritter's book and then bound together. The copy Şengör has in his library, which we used, has no title page and some of the maps also do not have titles. We therefore here refer to two single sheets from it that are indispensible for following Ritter's text: Grimm and Mahlmann (1839a and b). A comparison of these maps with our Fig. 1 shows the great progress that occurred during the nineteenth century about our knowledge of the geography of the Altay and the general region of the Altaids.

[35] For a recent Russian translation without the scientific parts and the atlas, see: Chihatchev (1974).

[36] Especially in the gold-bearing districts of the Altay and the Altaids in general, these studies were undertaken in greater detail than elsewhere along the route of the railroad. However, all along the route the geology was done in a strip of about 1000 km average width by outstanding geologists. Suess was able to use these reports and it was these great reports, mostly, plus Suess' correspondance with some of their authors, which rendered to him the keys to the structure of the Altaids.

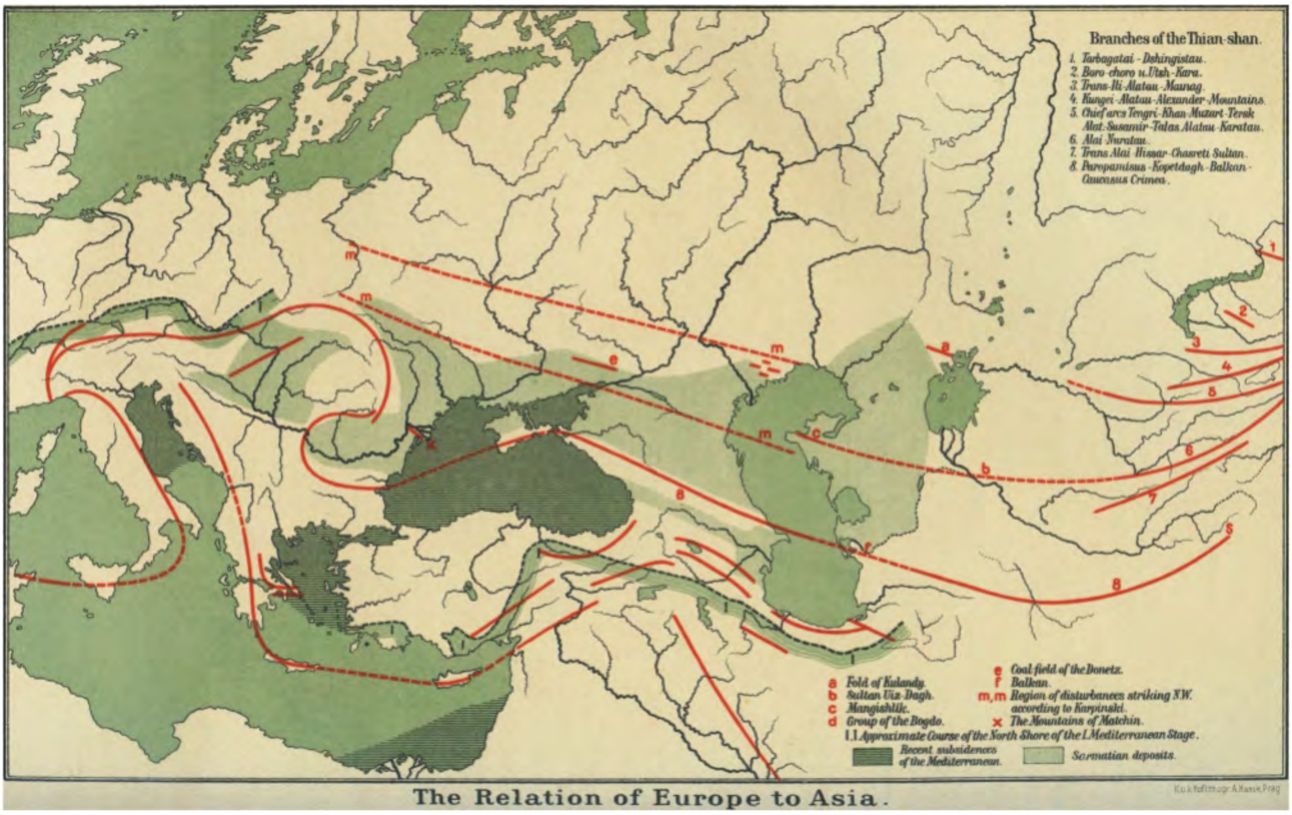

FIGURE 5: The connexion of Asiatic to European structure according to Eduard Suess' conception in 1885, following the great Russian geologist A. P. Karpinsky's ideas, published in Karpinsky (1883). The part of this map west of the Caspian Sea in the southern Russian Platform, Suess took from Karpinsky (Karpinsky, 1883, figure 1). The trend-lines of dislocations continuing from the Tien-Shan into Europe, Suess called the Karpinsky Lines (see especially footnote 1 on p. 150 in the 1939 reprint of Karpinsky's paper). It was because of this alleged connexion that Suess called the Hercynian orogenic system in Europe 'European Altaids.' We now know, though, that the Tien Shan does not continue into Europe as our Fig. 6 shows. The trend-line Suess labelled 8, however, belongs not to the Tien Shan, but to the Alay-Gissar ranges continuing into northern Black Sea via the Scythide units in Turkmenistan (see fig. 6 in Natal'in and Şengör, 2005). The connexion of the dotted trend-line b to the Tien Shan are incorrect from the viewpoint of our present knowledge. Line c, the Mangyshlak, does not connect with the Tien Shan (Natal'in and Şengör, 2005). We emphasise, however, that Suess only dotted it to underline its provisional nature. He was justified in his hesitation. By contrast, the only dotted part in his trend-line 8 is the short segment f (identified as the Balkan) passing south of the lagoon of the Karabugaz Gol in the eastern Caspian Sea. As the Scythides are not parts of the Altaids, we uphold Suess' definition of Altaids here, but show that they do not enter Europe along the Karpinsky Lines as he believed they did. Thus, neither the European Hercynides (Bertrand, 1887, after Suess, 1886) nor their American continuation, the Greater Appalachides (Stille, 1940, p. 33), can be considered parts of the Altaids any more. It is important to underline here that not Suess' concept of the Altaids, but one of its applications, is here altered.

of the *Antlitz* (Suess, 1924, foldout entitled 'Explanatory diagrams supplied by Prof. Suess': see Fig. 2 herein) that the orogenic events within Asia and those now shaping the margins of the Pacific were the same sorts of events. Suess' only true heir, Émile Argand, put it poetically thus (one should read Argand's words with Fig. 2 in view to see how much they echo Suess' thoughts):

'We have questioned all of Asia, and she has responded rather generously; she has informed us of other lands, and there are few she does not help us to understand better. We have reached in the end the Japanese islands, which are nobly curved and as if bent over the secret of the waters. Let us rest in these well-built lands where each morning the rising sun begins to light up Eurasia. The Fuji at dawn announces the glory of the day to come. From the depths of the blue immensity, waves rise, break and thunder: they tell of the beautiful fugacity of appearances, of the measured equilibrium of things. Under our feet, less agile waves crowd themselves in the black depths. Far away, behind us, as far as the heart of the continent, other and still other waves, exhausted by time, congealed in the splendid torpor of the old chains, are reanimated through the immense efforts of the heavy basement waves. This is how in the course of time wavering veils concealed the old heart of the world. The waves pass and as in the old dreams of Asia they all together tell the evanescence of the universe. How many times did the sun shine, how many times did the wind howl over the desolate tundras, over the bleak immensity of the Siberian taigas, over the brown deserts where the Earth's salt shines, over the high peaks capped with silver, over the shivering jungles, over the undulating forests of the tropics! Day after day, through infinite time, the scenery has changed in imperceptible features. Let us smile at the illusion of eternity that appears in these things, and while so many temporary aspects fade away, let us listen to the ancient hymn, the spectacular song of the seas, that has saluted so many chains rising to the light.' (Argand, 1924, p. 329).

It has remained everywhere fashionable to admire and cite Suess throughout what Şengör (1998) called the 'Dark Intermezzo' in the history of tectonics (from 1924 to 1965) —but few of those who cited him understood what he had said. Only the emergence of plate tectonics showed us why it was so difficult to understand Suess before plate tectonics: he had correctly recognised both the structure and the major elements of the history of the Altaids as being those of 'arcs', but what he wrote about 'arcs' did not make sense in the way the Beaumontian contraction tectonics explained the origin and the environments in deep sea trenches and island festoons (e.g., Stille, 1919, 1920). Most of his readers assumed that because Suess was a contractionist, his world had to be like that of the Beaumontian contractionists. The way Suess had visualised the tectonics of the 'arcs' has become common wisdom only through plate tectonics[37], despite the fact that a belief in the significance of the formation of 'arcs' in mountain building remained a popular topic throughout the twentieth century largely because of Suess' influence (see, for example Kayser, 1905, 1912; Sacco, 1906; Ogawa, 1907; Andrée, 1914; Taylor, 1910, 1921; Argand, 1916, 1920, 1924; Hobbs, 1921; Chamberlin, 1924; Daly, 1926; Staub,1928 and Lee, 1929, 1931) despite the emphatic contrary interpretation of Ferdinand von Richthofen (von Richthofen, 1900, 1901, 1902, 1903a, b; only Emmanuel Kayser was inclined to accept a limited version of von Richthofen's view). Later in the century, ideas similar to, and derivative from, Suess' ideas, mixed with the interpretations of prominent Kober-Stillean theoreticians (Şengör, 1982a, b), such as Haug (1907, 1908-1911), Kober (1911, 1921, 1928, 1931, 1942), Jeffreys (1924), Stille (1924, 1940), the mobilist Kober-Stillean Staub (1928), Bucher (1933), van Bemmelen (1949, 1954), continued to be prominent (e.g., Lake, 1931; Kay, 1942, 1944, 1947, 1951, 1952; Lee, 1952; Umbgrove, 1947; Benioff,1954). That mixing Suess' interpretations with the Kober-Stillean *Leitbilder* created internally inconsistent schemes in most cases seemed to bother nobody, although Wegener-Argandians frequently pointed this out. They remained in a minority, however, and published books and papers (e.g., Taylor, 1910, 1921; Wing Easton, 1921; Argand, 1924, 1928; Daly, 1926; Holmes, 1928, 1929; Salomon-Calvi, 1930, 1931a, b, 1933; Russo, 1933, 1950; Choubert, 1935; Halm, 1935; DuToit, 1927, 1937; Smit Sibinga, 1937) that are important only in retrospect (because they were widely ignored), except the Wegener-Argandian fixist Wilson (1950, 1954, 1957). It was Wilson, who finally converted to mobilism (Wilson, 1963) and ended up inventing plate tectonics (Wilson, 1965).

Shortly after Suess died on 26th April 1914, the world was engulfed in flames and Russia, Mongolia and northern China became essentially inaccessible to western geologists and his large database has long remained the only source of reliable information about vast areas in Asia, especially in its enlarged form in the French edition by Emmanuel de Margerie (*La Face de la Terre*; Suess, 1897, 1900, 1902, 1911, 1913b, 1918a, 1918b). De Margerie improved Suess' presentation by publishing figures from the literature that Suess had used but not been able to publish owing to the high cost of reproduction. De Margerie had some additional figures drawn expressly for the French edition. He also augmented Suess' bibliography mostly by adding references to the literature that had appeared between the publication of the German original and the French translation (for a detailed account of the history of the translation of the *Antlitz* into French, see de Margerie, 1943, pp. 374-659). In order to appreciate the importance of the improvement de Margerie undertook with Suess' permission and help, one has to realise that de Margerie (1862-1953) was one of the greatest bibliographers of geology in the history of our science, whom Émile Argand had referred to as 'the prince of bibliographers' (de Margerie, 1943, p. 652). De Margerie was the author of the first *Catalogue des Bibliographies Géologiques* (de Margerie, 1896; see also de Margerie, 1943, pp. 348-373, for a history of this vast bibliographic project) and he also helped Argand by supplying him with literature while the latter was working on his epochal tectonic map of Eurasia (Argand, 1928).

Suess' *Antlitz* still remains a valuable source for the more remote areas of Asia (see, for example, Şengör and Okuroğulları, 1991). After plate tectonics, the inaccessibilty of the vast territories of the Union of Soviet Socialist Republics and of the People's Republic of China, did little to encourage geologists from the western world to tackle the problems posed by the vast Altaid orogenic complex until the reforms of Deng Xiaoping in China and Mikhail Sergeyevich Gorbachev in Russia. By that time, much of what Suess had said was long forgotten in a torn world, except by a few dedicated readers of old literature.

3. Tectonic theory from Suess to plate tectonics and its influence on the evolution of ideas on the Altaids

As we pointed out above, when Eduard Suess began looking at the Altaids with a view to understanding their structure, mountain architecture had long been considered as one of a long and narrow edifice created at the expense of a pre-existing basin of more-or-less similar plan that the American geologist James Dwight Dana had first called a geocline (Dana, 1863, p. 722), then, geosynclinal (Dana, 1873) and later geosyncline (Dana, 1894; see Şengör, 1998, 2003). This view had been born in the 1820's in the Alps (Élie de Beaumont, 1828a, b), still the most intensively studied mountain range. The basic outlines of the geology of the Alps had been learnt fast because they are tiny and have been easily accessible since antiquity. Their small size is a function of the mode of their formation: they were in fact squeezed out of a small basin, squashed between two continental pieces. Although we did not know for the longest time (and really still do not) how exactly this happened, already by 1828, we had learnt that a basin had been squeezed between its two walls to make them. Finding this out was a tremendous achievement and the honour

[37] Compare Fig. 2 with any modern cross-section across a deep-sea trench at a subduction zone. For one such comparison, see Şengör (2006, fig. 13 A-F).

belongs to the predecessors of our French colleagues (mainly to Élie de Beaumont: see Élie de Beaumont, 1828a, b, 1829, 1852; Dufrénoy and Élie de Beaumont, 1848; see also Şengör, 1998 and 2003, pp. 93-97 and 123)!

As luck (or perhaps bad luck) would have it, the next mountain range similarly studied, the New York Appalachians, rendered a similar picture to its American students (cf. Şengör, 2003, pp. 123-133), where the term geosyncline was born. Squashing basins to make mountains became a dogma as soon as it was thought that thermal contraction was a good *realis causa* (Élie de Beaumont 1829; Dana, 1873). Such a simple way of mountain-making was also easy to visualise. Although this simple jaws of the vise analogy (*…comme les deux mâchoirs d'un étau…:* Élie de Beaumont 1852, p. 1317) was never to Suess' liking, he, too, nevertheless could distinguish in his studies in the European ranges forelands and hinterlands, between which mountain ranges had formed by shortening.

When he began looking at the mountains of Central Asia, however, Suess was shocked to find mountain ranges having no forelands—with at best a hinterland in the Siberian tableland, which we today call Siberian Craton! They had the same sort of rocks and structures as any other mountain belt, such as folds and faults and schistosity, but he could not find what caused the shortening. The more he searched, the more he realised that he had before him a mountain system immensely wider than all other mountain belts he had thus far come to know. Earlier, he had likened his asymmetric mountain structures, consisting of uniformly inclined folds and similarly verging thrust faults, to waves breaking on a beach. In Central Asia, the waves were there, but not the beach! So he likened them to the waves in the open ocean. This metaphor greatly angered his contemporaries, who had grown up in the comfort of the jaws-of-the-vise analogy of mountain-building. There were actually some among them who had come to dislike the jaws-of-the-vise model, and they had gone back to the old vertical uplift models, but they too could not understand how the structures populating Central Asia could possibly have formed.

In the meantime, Suess had become fond of another metaphor: He was saying that he could find no better analogue for mountain building than to imagine an object wounding his hand in such a way as to crowd the skin into folds on one side and to tear it on another allowing some bleeding. The blood represented the lava poured out by the volcanoes, the crowded skin the folds of the mountain belt and the wound the normal faults that commonly ended up bounding the internal sides of mountains (Suess, 1875, p. 28; 1878). Although the metaphor was new, the idea was not. Suess had published the idea already in 1873, but it had made no waves. When he again published it in his *Entstehung der Alpen* in 1875, the great importance of this image of mountain-building raised no eyebrows, because Suess had said that he had become an adherent of the contraction theory. His readers took this statement to imply that he had become a follower of Élie de Beaumont and James Dwight Dana and obviously did not bother to pay attention to the geometry and kinematics of deformation that Suess held responsible for the origin of mountain belts. Only when he republished his ideas on the geometry and the kinematics of mountain building in a small pamphlet (Suess, 1878) and then again in *Das Antlitz der Erde*, some finally woke up to the significance of what he was saying. Some of his critics, even some among his own pupils (e.g., Bittner, 1887), thought that he was ignoring Newton's simple principle of action and reaction. They could not understand how contraction could make mountains shorten on one side and extend on the other. Other adversaries laughed at him and pointed out that his metaphor very nicely showed the absurdity of his thinking, as only an agent coming out of the sky (*ex coelo*), one of them said, could create a similar wound in the crust of the earth (e.g., Löwl, 1906, p. 173).

Evidently, these critics were ignorant of convection currents in the interior of the earth, then already being considered by some physicists to provide the necessary friction to fold and tear the crust in the way Suess had imagined (e.g., Fisher, 1889, pp. 77 and 322; also John Perry in 1895a, b, c; see England et al., 2007). This ignorance cost tectonics dearly (see England et al., 2007; Şengör, 2009).

Suess had not made his message easy to understand (see Şengör, this volume) and, after his death, the geological community promptly threw away his model of mountain building (with such remarkable exceptions as Otto Ampferer, Frank Bursley Taylor, Alfred Wegener, Émile Argand and his own son Franz Eduard Suess). He had written no short and handy textbook as did his less sophisticated successors later, such as Leopold Kober, Hans Stille or Walter H. Bucher, and careless critics, such as Emil Tietze, Ferdinand Löwl and Alexander Supan. His *magnum opus*, the *Antlitz*, hid many of his interpretations amidst long and detailed, masterfully documented and properly weighted regional descriptions. One had to study Suess' entire book carefully to understand its message. The regional plan of the narrative obscured the theoretical 'long argument' aspect of the *Antlitz.* Those few who understood what Suess had written became mobilists. After Suess, the world of tectonics went by and large back to simplistic models of narrow and long mountain belts, squeezed out of geosynclines; even some of the mobilists could not entirely free themselves from the paralysing influence of the theory of geosynclines (Şengör, 1982a, b; 1998).

As mentioned above, only three years after Suess' death, the mountains of Central Asia were convulsed not by any tectonic crisis, but by a social revolution that rendered them essentially inaccessible to most of humanity, so, for three quarters of a century, Suess' Altaids ceased to occupy the majority of the world's geologists. Western Europeans and North Americans did continue thinking of them, but now in a Platonic way, and the models they came up with to explain them reflected it: the Altaids became an imaginary mountain belt, conceived in the image of the mountain belts the westerners were familiar with. Text-books mentioned what they ought to be like in the framework of their 'tectonic faiths,' rather than what they were really like (e.g., Haug, 1908-1911; Kober, 1921, 1928; Stille, 1924;

Staub, 1928; Bucher, 1933[38]). The Soviet geologists, recovering from the devastations of a savage revolution and now labouring under a new state religion, began adopting bits and pieces of the foreign faiths as St. Augustine had done with Platonism. Western text-books and monographs with their imaginary Altaid pictures were read avidly, some even translated (Haug, 1933; Argand, 1935; Staub, 1938; Stille[39], 1964, 1968) and those considered most suitable to the new deterministic and regularistic state religion found a fertile ground to sew their seeds.

The initial Soviet models were just like the Kober-Stillean fixist models: Arkhangelsky (1939), in fact, noted that the influence of German authors, especially Stille, had become very significant in the last 10-15 years. Many Soviet geologists followed Stille's concepts implicitly. His ideas were incorporated into university courses, in which many generations of Soviet geologists became trained (Spizharsky, 1973, p. 47). Indeed, the historicity of the geosynclinal model appealed strongly to the historicity of Marxism, and the regularistic world of tectonics the Kober-Stillean models portrayed, gave comfort to the deterministic economic future the Soviet Union was hoping for. That hope generated a great impetus to geological mapping with a view to exploiting the natural resources: the Soviet leaders were more keen to change Nature than to understand it, following one of the gloriously uninformed theses of Karl Marx on Ludwig Feuerbach[40] and they advised their scientists accordingly. A similar development was observed in Maoist China somewhat later, where the country was covered by the 1:200,000 geological maps in an amazingly short time span; but the quality of the maps turned out to be very uneven.

The general result of these totalitarian policies was a great proliferation of observations. Many new natural resources were indeed found in the USSR thanks to the great competence of the empire-trained Russian geologists. A similar thing happened in the People's Republic of China, largely because of the European-trained geologists, such as Li Siguang and Huang Jiqing. Scientists, however, are notoriously difficult to stop being also philosophers intent on understanding, notwithstanding the admonition of the Soviet and Chinese state prophet Marx. The more the observations accumulated, the less comfortably the Altaids seemed to fit the models imported from western Europe and North America. The result was that both the Soviet and the Chinese geologists started to improvise their own models, but they seemed stuck on two issues: They took both the geosynclines and the stop-and-go manner of mountain building for facts. All their efforts began revolving around this double axis. They initially took the 'great Altaid geosyncline' as a fact and gave its products new names: Stille had called them Ural-Amurian Orogen in 1928. Yanshin[41] (1964) changed the name to Central Asian Foldbelt excluding the Urals and comprehending in it both the early and the late Palaeozoic structures; a year later Muratov (1965) called the products of the assumed geosyncline Ural-Mongolian Foldbelt.

When the Soviet geologists came to realise that the standard geosyncline models taken from western Europe and North America did not work, they thought of dividing the Altaid edifice into smaller geosynclines by introducing all sorts of platforms, median massifs, blocks and uplifts into and between individual geosynclines or parts of geosynclines and naming those either individually or uniting them into a system and giving that system yet a newer name (see Janschin, 1968). This gave them smaller orogens, like the Alps, so readily explicable in terms of geosynclines and orogenic phases (see Şengör and Natal'in, 2007). When that attempt was in turn defeated by the uniformity of the structure and the history of the Altaids, they then began inventing new sorts of geosynclines. Some of these were so bizzare (e.g., 'areal-' {Zaitsev, 1990} or 'mosaic-type geosynclines': {Peive et al., 1972}) as to render the relation to the original concept hopelessly remote and the possibility of testing by prediction out of the question.

As if these difficulties were not enough, the structure of the science in the totalitarian USSR, divided into the rival fractions of the All-Union Geological Commission (VSEGEI), Academy institutions, and universities, plus the local geological surveys, greatly hampered communication. Even between individual Academy institutes, there were at times such strained relations that their scientists were barely on speaking terms with one another. In this regard, the People's Republic of China fared no better.

In this compartmentalised and totalitarian environment, the numerous models, generated on as large and as difficult an orogenic system as the Altaids, could hardly be fairly and efficiently tested by the entire community. The language on the Altaids became splintered into local dialects, barely comprehensible to each other; the models erected turned into private properties of the institute leaders who were commonly very jealous of them and they often degenerated into a string of hollow names investing *ad hoc* concepts. Such giants as Dmitrii Ivanovich Mushketov (1882-1938) died in the Gulag, such lone thinkers as Mikhail Mikhailovich Tetyayev (1882-1956) paid for

[38] Let us note here that Bucher's book was reprinted once by its original publisher, the Princeton University Press in 1941, and thrice reprinted later by Hafner Press in New York: once in 1957, then again in 1964, and finally again in 1968. This shows the dearth of genuinely new information on global tectonics during the Dark Intermezzo. Had German not lost its position as the international language of science after World War II, Kober's and Stille's books would no doubt have been reprinted also.

[39] The late Russian geologist Academician Viktor Efimovich Khain told Şengör that typescripts of a Russian translation of Stille's *Grundfragen der Vergleichenden Tektonik* were available in Baku in the fifties of the twentieth century and that he had read it as a geologist working for the Oil Exploration Trust of Azerbaijan, Aznefterasvedka. Khain thought that the translation had been made after World War II, but before 1954 (Khain to Şengör, personal communication in İstanbul on 25th December 1993).

[40] 'Die Philosophen haben die Welt nur verschieden interpretiert; es kommt aber darauf an, sie zu verändern' (Philosophers have variously interpreted the world; the thing that needs doing, however, is to change it) *Karl Marx Friedrich Engels Werke*, v. 3 (1845 bis 1846): Institut für Marxismus-Leninismus beim ZK der SED, Dietz Verlag, Berlin (1969), p. 535, thesis 11.

[41] When transliterated into German, this name is spelled as Janschin.

their independent thinking with their freedom[42]. Many a modest brain, because of his apparent faith in the state religion and loyalty to its high priests, was brought to dominate geniuses. It is a tribute to the skill and perseverance of our Soviet colleagues that, even in such an isolated and adverse environment, they relentlessly questioned the Altaids as if to put to shame those social theorists who claim that social environment in science governs everything. The Soviet geology rolled on standing on the shoulders of the intellectual descendants of a Karpinsky, of a Pavlov, of a Loewinson-Lessing, of an Obruchev, of a Mushketov, of a Cherskiy, of an Inostrantsev ... and ever produced great observations, depicted in superb geological maps (for lists of some of the small-scale Soviet maps, see Zhamoida, 1976 and Petrov et al., 2000; for a history of geological cartography in Russia, see Burde et al., 2000). We see a similar development in the People's Republic of China, where, however, an inhumane 'cultural revolution,' delayed recovery for a long time.

It was finally realised almost everywhere that neither the classical geosynclinal models, nor the phase-bound tectonic events could explain the structure or the history of what Suess had called the Altaids. They had too uniform a structure and seemed too different from all other classically studied geosynclinal belts exactly as Suess had pointed out almost a century earlier (for the problems faced by the Soviet geologists, Janschin's 1968 article provides an excellent example).

When plate tectonics reached the Soviet Union, such able geologists as Lev Zonenshain were on the verge of going back to Suess (e.g., Zonenshain, 1972, 1973). They had clearly denounced the stop-and-go model of mountain building, and the 'geosynclinal' models they were entertaining had become so different from any geosyncline which the classical geology had been familiar with, that it was in our view inevitable that some of them would have eventually thought of looking for present-day analogues of what they were seeing in the field. In fact, some of their foreign guests, such as the American geologists John Rodgers and Warren B. Hamilton (e.g., Hamilton, 1970), had begun making suggestions in that direction.

4. Altaids and plate tectonics

It was at this time that the plate tectonic models burst on the Soviet and Chinese geologists, and, within a decade or so, the Soviet Union had become history. Soon, however, it looked as if the events of the twenties and the thirties of the twentieth century were repeating themselves on a different stage: new social upheavals in Russia and China coincided with a flood of new geological models into both countrys. What had come with text-books in the twenties and the thirties now came with their authors in the form of visiting scientists. The visitors have since been trying enthusiastically to apply their knowledge to new field areas and the hosts have been enthusiastically trying to fit their areas into the imported new knowledge. Soviet technology in the earth sciences had lagged behind the developments in the west, so the newcomers brought with them the possibility of making up the deficit. A craze of black-box geology has swept across the earth sciences in Russia. The laboratory measurements, however, soon outpaced the observations on field relations, making their interpretations *ad hoc* (Şengör, 2014). Because the areas were little-known to westerners and its literature was in languages few geologists commanded in the west, reviewing the new cooperative papers has faced a serious barrier and the quality of reviewing declined; the editors of western journals began giving preferential treatment to papers reporting new quantitative laboratory results, the field bases of which they were hardly able to assess satisfactorily (cf. Şengör, 2014).

Therein lurks, we think, a grave danger: The Altaid research in the Soviet Union had gone through a grueling eighty years trying to come to grips with this extraordinarily difficult mountain system in terms of imported models, long believed sacrosanct. It has managed to get rid of them gradually and at great intellectual (and human) cost on the basis of fine field observations (see especially Şengör and Natal'in, 2007). It cannot afford to go into another phase of sacrosanct imported models now, at the expense of those observations. The initial Altaid model by Suess (1901) had been solidly based on field observations by local geologists and comparative tectonic thinking that encompassed the entire planet. We ought not to do less in our age of almost infinite means of excellent and diverse observations.

Observations hammered into ready-made simplistic models would be like diamonds thrown into dustbins. Any model that attempts to understand the nature and evolution of the Altaids must consider them as a whole and in the light of the experience gained by its geologists during the entire last century, evaluated in terms of the entire conceptual richness which global tectonics today offers us. It is only through a careful comparative anatomy and functional morphology of mountain belts that we can hope to understand the structure and the evolution of the Altaids (cf. Şengör, 2014).

5. 'Terranology'

In the eighties of the twentieth century, just before the former Soviet territory opened up to international field work in geology and just after China began allowing collaborative geological research with the west, a new fashion irrupted in the North American Cordillera: terranology (for a presentation and a thorough critique of terranology, see Şengör 1990a, b; 2014; Şengör and Dewey, 1990; Şengör and Natal'in, 2007). The promoters of this new fashion thought that the interpretations of orogenic belts that had immediately followed the rise of plate tectonics had not done justice to the complexity mountain belts. They argued that genetic connexions had been assumed where they could not be rigorously demonstrated and

[42] Both Mushketov and Tetyayev had the posthumous honour of being included among the *Repressed Geologists* (Orlov, 1999, pp. 224 and 307), a book published for the tercentenary celebrations of the Russian Geological Survey. That book is a roll call of honour for those geologists killed, imprisoned or otherwise repressed by the totalitarian Soviet regime during its 72-year reign of terror.

that, it was claimed, had done much harm to our understanding of orogenic processes. What these geologists instead recommended was to define ‘terranes’, i.e., fault-bounded independent entities with geological histories different from their surroundings and to disclaim any suspicion of what the relation across the mute fault-bounded margins were (or might have been) until they were ‘proven’. Terranologists have thus failed to understand that by introducing arbitrary discontinuities into areas of uncertainy, one also reduced the possibility of testing the interpretation of the nature of the uncertainties (Şengör, 2014).

In some criticisms of these ideas, it was pointed out that data underlying almost any interpretation in geology are almost always incomplete. Dewey, in a seminal paper (Dewey, 1975a), had demonstrated that plate tectonics had shown us how and why our dataset in orogenic belts not only is, but must by nature be, woefully inadequate and unique reconstructions of orogenic events are usually simply impossible (see also Dewey, 1975b, 1976). Good interpretations required testable models based on a detailed knowledge of the processes as Suess had recognised nearly a century and a half ago.

That is why, introducing the term and the methodology of terranology into the Altaids has given exactly the same results as the attempts of interpreting them in terms of geosynclines did earlier. In the case of geosynclinal interpretations, every Altaid mountain range had become the product of an individual geosyncline. The initial plate tectonic models have followed that pattern and tried to see in every range a collisional mountain belt (e.g., Zonenshain et al., 1990). These parochial interpretations, of the kind that Prince Piotr A. Tchihatcheff had tried in the first modern geological study of the Altay (Tchihatcheff, 1845a, b), within the framework of the mountain building theories of his teachers Leopold von Buch and Élie de Beaumont, were precisely what Suess had warned the Altaid workers to shy away from. As the Soviet geologists had converged on a more integral interpretation of the entire Altaid System, the newest publications are converging on a model similar to the one suggested by Şengör et al. (1993, 1994; Şengör and Natal'in, 1996a, b, 2004), but still with an attempt to combine plate tectonics with terranology (e.g., Kröner et al., 2005, 2007, 2014; Wilhelm et al., 2012). It is the purpose of his paper to document that no data collected in the last twenty years justify such a combination and that Suess' holistic view of the Atlaids in terms of a single superorogenic system, as translated into plate tectonics by Şengör et al. (1993, 1994) and Şengör and Natal'in (1996a, b, 2004a), still explains the available observations better than any of its later rivals.

6. The term 'Altaids' and ist importance

That is also why, we urge the Altaid researchers to refrain from calling them by names, such as 'Central Asian Orogenic Belt' (Yanshin, 1964; this would be like calling the Hercynides 'Central European Orogenic Belt'), or Central Asian Orogenic System (CAOS) for the sake of a foppish acronym, based on 'standard' models developed on dissimilar mountain belts and now known to be obsolete. The Soviet workers had attached to the Altaids different regional names, partly because of the great difficulty of understanding them within the compass of a single model and partly because of the inter-institution rivalries in the former Soviet Union. Many had long forgotten, or indeed never learnt, what Suess had written. Attaching to the Altaids arbitrary names would be like calling the feathered dinosaurs *Caudipteryx zoui* or a *Sinosauropteryx prima* or a *Incisivosaurus gauthieri* mere reptiles or mere birds; one would miss an entire new class of animals in doing so. Calling Altaids by regional names bereft of any tectonic implication, applicable to any old mountain range, would have a similar effect. Suess' appellation Altaids implies a unity of the system and a type of mountain-building, called Turkic-type by Şengör and Okuroğulları (1991) and Şengör and Natal'in (1996b), different from those of ordinary collisional belts known from western Europe and eastern North America, on the basis of which most of the plate tectonic models of collisional orogeny had been constructed (see Şengör and Natal'in, 1996b).

7. The methodology of studying Turkic-type orogens

The tiring monotony of the basalt/chert/turbidite- and granitoid-dominated rock types of the Altaids (including their metamorphic equivalents although there are almost no metamorphosed felsic and intermediate intrusions outside the pre-Altaid cores and along large shear zones) and their very complicated penetrative internal structure make it extremely difficult to find markers to outline their large-scale structures on a continent scale. This long has been a widespread problem in the Altaids inhibiting recognition of their architecture (Şengör et al., 1993a, 1994; Şengör and Natal'in, 1996a, b, 2004a). In addition, ophiolite belts were found to be misleading guides for outlining their first-order tectonic units, i.e., the smallest independently functioning plate-tectonic apparatuses, because ophiolites occurred dispersed throughout the "basement" of much of the Altaid edifice ranging from substantial former backstops to interleaves in subduction-accretion wedges (Şengör and Okuroğulları, 1991; Şengör, 1992, 1993; Şengör et al., 1993a, 1994; Şengör and Natal'in, 1996a, b, 2004b; see Fig. 6). The longest ophiolite belts in the Altaids, viz. the 470 to 450 Ma-old Chara ophiolite belt (Ermolov, 2013), are at most 200 km long, embedded in accretionary wedge material (Fig. 6, long, unlabeled ophiolite belts), as opposed to the thousands of kilometres of length displayed by the Tethyside sutures, generally sandwiched between old continental material (Fig. 7).

Thus, neither rock associations nor structures could be used to trace the lateral continuity of primary tectonic units in the Altaids.

In the absence of any other markers, we have employed a methodology first used by Suess: using arc axes to follow the orogenic trend-line (Suess, 1901; see Fig. 8). We have further refined his method and followed not the axis as a whole, but the magmatic fronts in the palaeo-magmatic arcs of the Altaids as structural markers to trace the continuity and to reconstruct the primary relationships of the Altaid tectonic units. It has long been known that subduction zones tend to be continuous along their strike for thousands of kilometres and, unless trapped between continental walls, as between North and South America or between South America and Antarctica, or between Africa and Europe, they never form short, discontinuous plate boundaries (Fig. 9).

Even in the extremely complex zone of convergence between Asia and Australia today there is only a single subduction zone: the one that comes from Myanmar, delimiting the Andaman, Sumatra, Java, Timor islands and the Banda Arc and then swinging north passing west of Halmahera and the Spice Islands of Ternate, Tidore, Mare, Moti and Makian and a number of other small islands; from there its motion is taken over and transformed farther north by the Philippine Transform Fault (see especially Burchfiel and Chen, 2012, figs. 16-13, 16-20 and 16-21). The remnant subduction zone under Sengihe was the southerly continuation of the Luzon Arc, which was the northearn continuation of northeast Borneo from at least the Eocene to the medial Miocene, when it disintegrated as a consequence of the collision with the Philippine arc. Let us recall, however, that the Luzon arc had been a part of the Philippine arc (see especially Hall, 2002, figures 14 through 22). Remnants of the subduction boundary delimiting the Philippine Sea plate in Hall's (2002) fig. 15 now form dormant and semi-dormant subduction zone segments in the Sulu and the Celebes seas (Hamilton, 1979).

The current multi-plate and block geometry of Southeast Asia

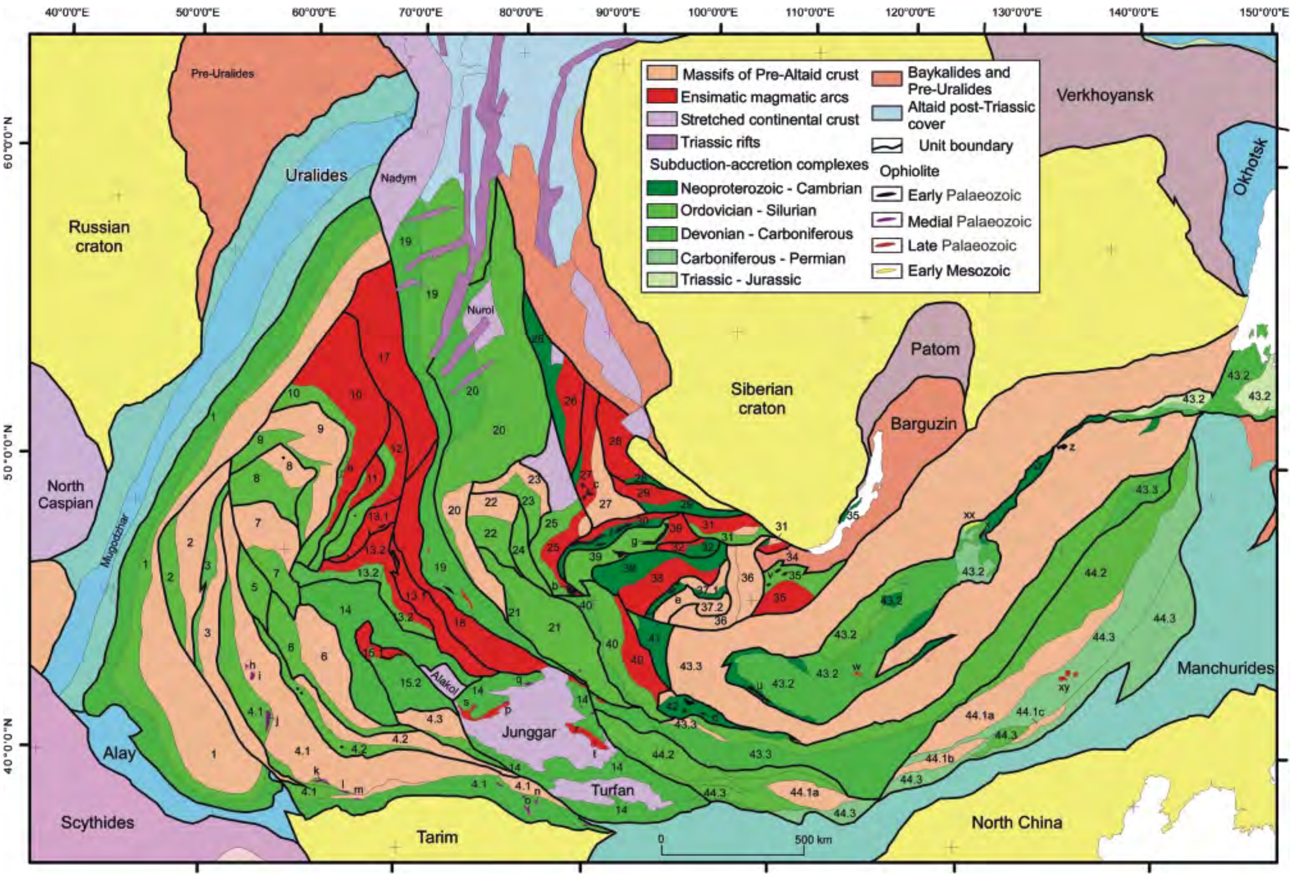

Figure 6: Tectonic map of the Altaids also showing the ophiolite occurrences within it. The map is based on an equidistant conical projection in which the central meridian is 95° and the standard parallels are 1:15.0 and 2:85.0; latitude of origin is 30.0. The same base map is used also for our locality map for the isotopic ages in Fig. 10. The Arabic numerals and the lower case letters attached to some of them correspond with to the first-order tectonic units of the Altaids (for the definition of first- and second-order tectonic units, see Şengör and Natal'in, 2007). Lower case letters correspond with to the individual ophiolite and ophirag occurrences. Key to the first-order tectonic units: 1. Valerianov-Chatkal, 2. Turgay, 3. Baykonur-Talas, 4.1 Djezkazgan-Kirgiz, 4.2 Jalair-Naiman, 4.3 or 16. Borotala, 5. Sarysu, 6. Atasu-Mointy, 7. Tengiz, 8. Kalmyk Kol-Kökchetav, 9. Ishim-Stepnyak, 10. Ishkeolmes, 11. Selety, 12. Akdym, 13.1 - Boshchekul-Tarbagatay, 13. 2 - Bayanaul-Akbastau, 14. Tekturmas, 15. Junggar-Balkhash, 16 or 4.3. Borotala, 17. Tar-Muromtsev, 18. Zharma-Saur, 19. Ob-Zaisan-Surgut, 20. Kolyvan-Rudny Altay, 21. Gorny Altay, 22. Charysh-Chuya-Barnaul, 23. Salair-Kuzbas, 24. Anuy-Chuya, 25. Eastern Altay, 26. Kozhykhov, 27. Kuznetskii Alatau, 28. Belyk, 29. Kizir-Kazyr, 30. North Sayan, 31. Utkhum-Oka, 32. Ulugoi, 33. Gargan, 34. Kitoy, 35. Dzhida, 36. Darkhat, 37. Sangilen, 38. Eastern Tannuola, 39. Western Sayan, 40. Kobdin, 41. Ozernaya, 42. Han-Taishir, 43. Tuva-Mongol (43.1. Tuva-Mongol Arc Massif, 43.2. Khangay-Khantey, 43.3. South Mongolian), 44. South Gobi. Key to selected ophiolite and ophirag occurrences in the Altaids (the criterion of selection was simply availability of description in the literature and size suitable for illustration at the scale of this map): a. Kuyanbai, b. Eastern Altay ophirags, c. Kuznetskii Alatau basement, d. Han-Taishir (transliterated as Khantaishir in some publications), e. Agardag, f. Boruss mélange with ophirags, g. Kurtushiba, h. Kara-Archa ophirags, i. Kenkol, j. Toluk, k. Karachi-Karakty, l. Karadzhorgo, m. Archaly, n. Youshugou ophirags, o. South Tien Shan ophirags, p. Dabut, q. Honguleleng, r. Karameili, s. Mayila, t. Aermentai, u. Bayankhongor, v. Dzida, w. ophirags in Khangai-Khantei, x. Kulinda, y. Molodovsk, z. Gorbits, xx. Ust-Trua, xy. Hegeshan. For the description of these ophiolite and ophirag occurrences, see Şengör and Natal'in (2005).

evolved from an earlier, much simpler four-plate system as reconstructed by Hall (2002). The most prominent feature of Hall's reconstructions is the continuity of subduction zones along strike and the absence of independently-moving 'terranes.' In the entire oriental face of Asia only two major subduction zones governed the evolution from the Cretaceous to the present day, not unlike the Altaid evolution between the Ediacaran and the earliest Cretaceous as reconstructed by Şengör et al. (1993a, 1994) and Şengör and Natal'in, 1996a). Neither is this dissimilar to the situation inferred for eastern Asia (Şengör and Natal'in, 1996a) and the western United States during the Mesozoic and the earliest Cainozoic on the basis of recent tomographic data by Sigloch and Mihalynuk (2013; also see Goes, 2013). As Dan McKenzie pointed out already in his classic 1972 paper on the active tectonics of the Mediterranean, plates disintegrate when subduction zones run into continents. Menard (1978) and Wortel and Cloetingh (1983) also argued, on the basis of the fate of the Farallon Plate, that when a major plate boundary, especially a ridge, approaches a subduction zone obliquely, the underthrusting plate tends to disintegrate just before the collision between the ridge and the subduction zone that is about to consume it.

Populous groups of microplates are thus not a feature of large expanses of oceanic realms but form near convergent boundaries. They hardly ever carry old continental material in forms of small continental 'terranes' attached to rapidly moving microplates across major oceanic spaces, as shown by the immensely long Cimmerian Continent that carried a thin and long strip of northern Gondwana-Land to Laurasia atop one subduction zone during the evolution of the Tethyan Realm in the late Palaeozoic to the medial Mesozoic interval (Şengör and Natal'in, 1996a) and the long subduction zones Hall (2002) reconstructed. Motion of small arc 'terranes' would have to be attached to small subduction zones and it is unlikely that such small entities would be able to sustain themselves dynamically over long time periods.

This continuity of subduction zones brings with it the continuity of the magmatic arcs that form above them. Although the arcs are continuous in space, magmatic activity along them is also continuous only if viewed in windows of about 60 to 40-million-year time intervals (Şengör, 1990a; Şengör et al., 1991, 1993b; Fig. 9). This has a variety of reasons ranging from variations in slab dip, through oblique or piecemeal subduction of ridges, subduction of various high-standing buoyant objects such as oceanic plateaux and large guyots to inhomogeneities in the structure of the underthrusting oceanic lithosphere, such as major fracture zones.

If the subduction-accretion complexes become very wide (commonly, but not invariably > 600 km), the arc magmatic axis behind them begins to migrate oceanward and invades the subduction-accretion complex and turns it into an arc massif (Matsuda and Uyeda, 1971) in the terminology of Dickinson and Seeley (1979). If this process occurs more than once, a continent is built consisting entirely of subduction-accretion material plus arc magmatic and metamorphic rocks (Şengör

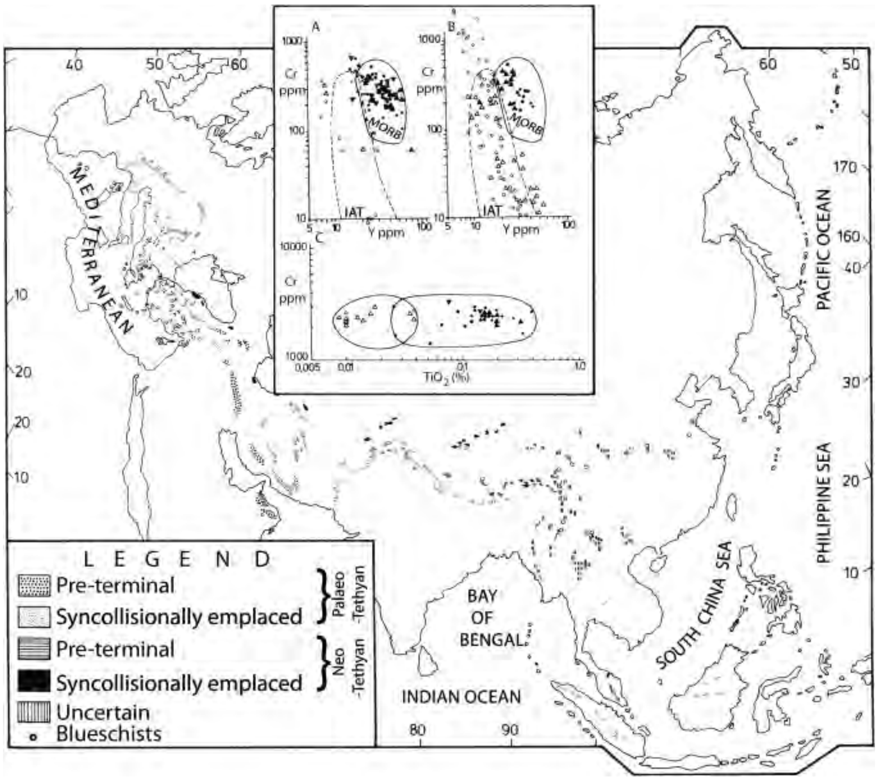

Figure 7: Ophiolites of the Tethysides (updated from Şengör, 1990a, fig. 18). Compare this distribution with the distribution of ophiolites within the Altaids shown in Fig. 6. Inset A and B: Distribution of basalt analyses from some of the Tethyside ophiolites and ophirags on the Cr-Y discrimination diagram of Pearce. A: empty circles = Pindos; empty triangles=Vorinous, X=Pindos ('massive lavas'); black circles=Austrian ophirags; black right-side-up triangles =Northern Appenine ophiolites and ophirags; black circles=Corsican ophiolites; black upside-down triangles=Corsican ophirags; black diamonds=Othris ophiolites. B: empty circles=Troodos ophiolite; empty triangles= Semail ophiolite; black circles=Tibetan ophiolites and ophirags; black triangles=Masirah Island ophiolites; black squares=Sistan suture ophirags. C: Cr-TiO_2 plot for tectonised ultramafic rocks from some of the Tethyan ophiolites and ophirags: Supra-subduction-zone (SSZ) ophiolites: empty circles=Semail ophiolite; empty triangles Troodos ophiolite; empty squares Vorinous ophiolite; 'MORB' ophiolites and ophirags: black circles=Inzecca; black right-side-up triangles=Ligurian ophiolites and ophirags; black squares: Lanzo subcontinental mantle fragment; black upside-down triangles=Othris ophiolites; black diamonds=others. A, B and C are from Pearce et al. (1984). Notice in this map that most of the pre-terminal ophiolites fall into Pearce et al.'s IAT (island arc tholeiite) and SSZ fields, whereas many syn-collisionally emplaced ophirags and ophiolites (in the syn-collisional class true ophiolites are very rare; they are mostly ophirags). Many of the syn-collisionally emplaced ophiolites are of 'MORB' signature. In the Tethysides, most of the SSZ ophiolites belong to the Ayyubids (Şengör and Stock, 2014).

and Natal'in, 1996b; Şengör, 1999, 2014). Once such continents, newly formed from subduction-accretion complexes, are further deformed, say during collisions, it becomes very difficult to decipher their large-scale structure owing to absence of marker lithologies in their basalt-chert-turbidite dominated monotonous and highly deformed triplet. This would be similar to the difficulties encountered for years in older Precambrian terrains, where uncertainty concerning the architecture of the Archaean areas has led to questions whether they were constructed by plate tectonics or by other, now no longer active processes (for examples of both sides of the question, see Dewey and Spall, 1975; Burke et al., 1976; O'Neill and Wyman, 2006; Dewey, 2007; Hamilton, 2007, 2011; Polat, 2012, 2013; Polat and Santosh, 2013; Huang et al., 2013; also see the two recent compendia: de Wit and Ashwal, 1997 and Dilek and Furnes, 2014).

It was in part the desperation of the field geologist in the past that culminated in subdividing regions underlain by such complexes with persistently repetitive basalt-chert-turbidite- and granite packages and highly complicated structures in very large, in places sub-continent size, areas, into innumerable packages called 'terranes,' (Irwin, 1972, in the Klamath Moun-

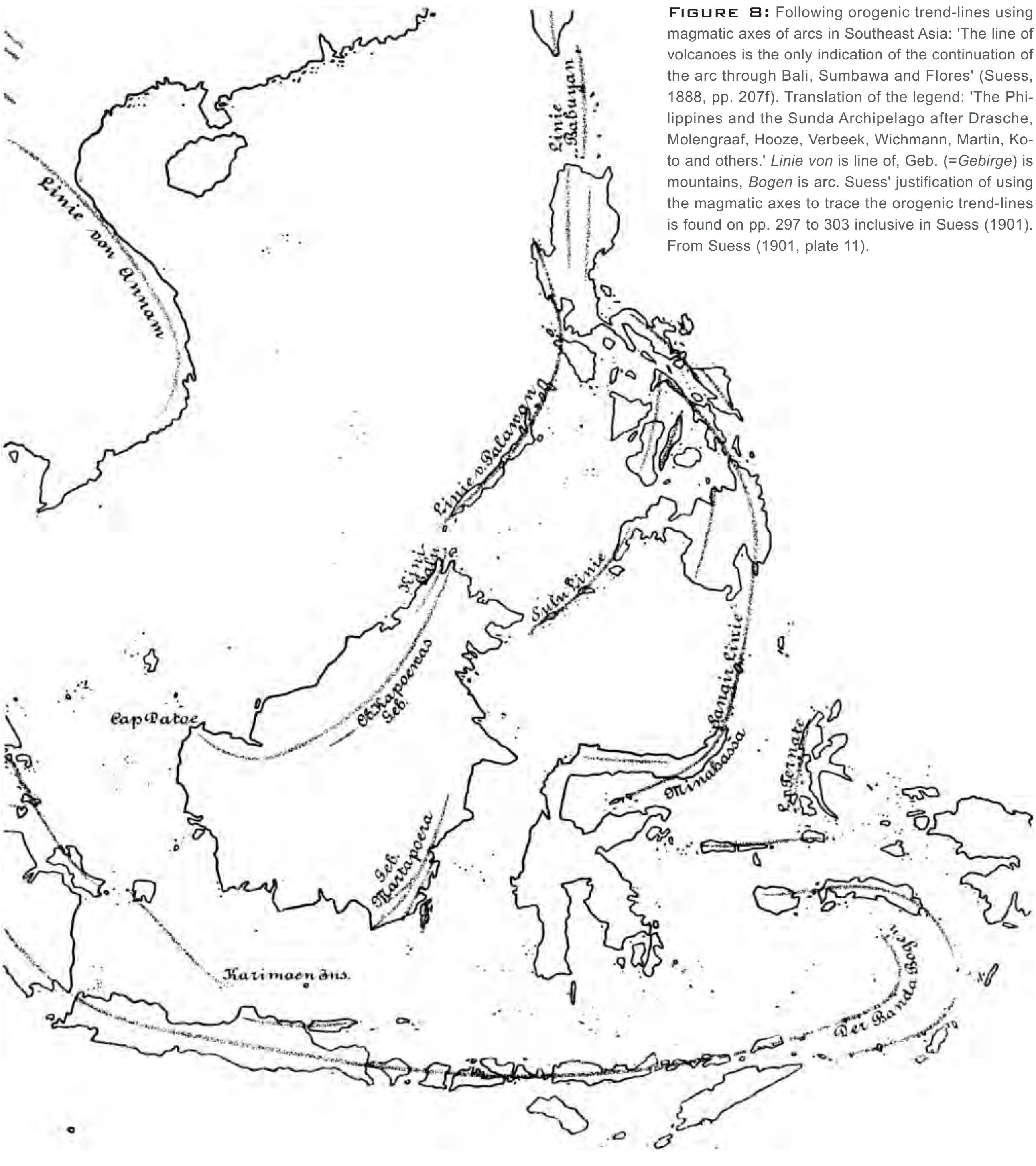

FIGURE 8: Following orogenic trend-lines using magmatic axes of arcs in Southeast Asia: 'The line of volcanoes is the only indication of the continuation of the arc through Bali, Sumbawa and Flores' (Suess, 1888, pp. 207f). Translation of the legend: 'The Philippines and the Sunda Archipelago after Drasche, Molengraaf, Hooze, Verbeek, Wichmann, Martin, Koto and others.' *Linie von* is line of, Geb. (=*Gebirge*) is mountains, *Bogen* is arc. Suess' justification of using the magmatic axes to trace the orogenic trend-lines is found on pp. 297 to 303 inclusive in Suess (1901). From Suess (1901, plate 11).

tains in northern California and southwestern Oregon, the structure of which greatly resembles major parts of the Altaids) making out of orogenic belts patternless, mute mosaics (Şengör, 1990b, 2014; Şengör and Dewey, 1990).

To overcome this difficulty of 'losing one's way' in persistently repetitive basalt-chert-turbidite- and granite packages and highly complicated structures, Şengör and Okuroğulları (1991) and Şengör et al. (1993a) have suggested using magmatic fronts that move into subduction-accretion complexes as structural markers to reconstruct the original continuity of now-deformed and disrupted subduction-accretion complexes.

Owing to the geometry of the mantle wedge and the kinematics of the plates surrounding it beneath a magmatic arc, the already generated magma is concentrated at the minimum pressure site at the tip of the wedge, from where it is supplied to the surface. Some magma does escape to the surface 'behind' this tip, but no magma normally can form and reach the surface 'in front' of it simply because of the cold geothermal regime there (Spiegelman and McKenzie, 1988)[43]. This explains the old observation that magmatic arcs have very sharp fronts, but diffuse backs. Moreover, as the accretionary wedge grows oceanward, the magmatic front does not sweep forward, but normally jumps episodically for distances (a few hundreds of km) longer than the width of major magmatic axes (~ 50 km) in arcs (e.g., Parfenov and Natal'in, 1977, 1986; Jackson and McKenzie, 1984, fig. 38), enabling the geologist to recognise fossil magmatic fronts in the field. In the following description of the Altaids, we shall see particularly fine examples of such jumped fronts in the Kazakhstan/Tien Shan and the Altay/Sayan sectors (Şengör and Natal'in, 1996a). It was the recognition of such fronts that enabled Şengör and Okuroğulları (1991) and Şengör et al. (1993a, 1994) to sort out the hitherto enigmatic structure of the entire Altaid orogenic collage and the Kuen-Lun. To illustrate the methodology of using magmatic fronts to establish the architecture and to elucidate the history of a complex orogenic collage, Şengör and Natal'in (1996a) drew the spatial/temporal development of the magmatic fronts in the most complicated part of the Altaids, namely the Kazakhstan/Tien Shan and the Altay/Sayan sectors in their figs. 19 through 26. We do not repeat that demonstration here and refer the reader to that earlier paper.

The post-early Carboniferous deformation of the entire Altaid collage, although considerable, involving a number of large strike-slip faults, at least two of which (Irtysh and the Gornostaev Fault Zones: Şengör et al., 1993a and Şengör and Natal'in, 1996a) with displacements reaching 2000 km, managed to distort somewhat, but not entirely efface the main disposition of the magmatic fronts. But the Ordovician deformation very extensively disrupted the primary magmatic front geometry that had existed before that time. The 'tentative' interpretation offered in Şengör and Natal'in (1996a), which improved upon, but did not fundamentally alter that in Şengör et al. (1993a) shows how the magmatic fronts can be robustly employed for a quick overview of an extremely complicated collage consisting dominantly of monotonous subduction-accretion material.

What underlies the magmatic fronts are the units carrying the magmatic arcs. Since Şengör and Natal'in (1996a), a vast amount of high quality isotopic age data have been gathered, although the basic geological field work described in most of the publications in which the ages were reported do not measure up to the high quality of the laboratory measurements. In the following, we have updated, using the information published in the literature since 1996, the basic geological description of the Altaid tectonic units published in Şengör and Natal'in (1996a). Our initial descriptions required revision in fewer places than we had anticipated and nowhere have the new age determinations led to any significant departure from the definition or the history of the units or the position of the magmatic fronts defined in Şengör and Natal'in (1996a). In the following section we present our updated descriptions of the Altaid tectonic units. In many places the reader will find verbatim repetitions of sections of the descriptions from Şengör and Natal'in (1996a). We did not reference that paper repeatedly, but we invite the reader to compare the descriptions below and those in Şengör and Natal'in (1996a) to form an opinion of the continuity of the descriptions and the interpretations and where they changed and/or added to.

We have found a number of the interpretations of parts of the Altaids published after Şengör and Natal'in (1996a), simplistic, many *ad hoc*, i.e., they had not been fitted into the overall Altaid structure and history, as recommended by Suess (1901). This appears to have led to much mutual incompatibilty among the various publications. Most criticisms of the Şengör et al.'s (1993a) and Şengör and Natal'in's (1996a, b) papers are either internally inconsistent or repeat the interpretations they allegedly refute. For instance, collisions of 'terranes' are reported without any of the hallmarks of continental or arc collisions such as flexural foreland basins (known since Suess first emphasised it; see also Janschin, 1968) or ophiolitic sutures between colliding entities with different geological histories. When questioned, the authors say the two pieces may have been juxtaposetd by strike-slip faulting (Dewey et al.'s, 1986, 'transform sutures'), but cannot find an answer to the question how this differs from what Şengör et al. (1993a) and Şengör and Natal'in (1996a) had said. Others reject the Kipchak arc model, but give the southwest Pacific as an actualistic example for the Altaid evolution. Şengör (2014) pointed out that Şengör et al. (1993a) and Şengör and Natal'in (1996a, b) had said precisely the same thing and indicated that he

[43] For 'abnormal' instances such as ridge subduction during which arc magmatism may invade the forearc for a short while, see De Long and Fox (1977). In another 'abnormal instance,' in compressional arcs, extensional features open perpendicular to the trench trend in the forearc areas and these tap the arc magmatism from the main axis as seen in the northern compressional arc of the Cascade Arc in Oregon, where volcanic vents line up in an east-west direction west-, i.e., trenchward, of the main magmatic front along the Oregon/Washington state frontier and another line just north of it: http://geomaps.wr.usgs.gov/pacnw/graphic/d1.gif, last visited on 7th February 2014.

could not understand the substance of the criticism directed against the Kipchak Arc model. Others (e.g. Safonova et al., 2011) present the Altaid evolution as an important 'new concept' of how to make the continental crust, ignoring the fact that the title of the *Nature* paper by Şengör et al. (1993a) and the title of Natal'in and Şengör (1996b) were both about the growth of the continental crust. Some of the authors of the Safonova et al. (2011) paper now claim, however, that not much continental crust was generated in the Altaids, but on the basis of a very limited population of old zircons interpreted essentially in a geological void (Kröner et al., 2014). There are even papers that take the structures reported in Şengör et al (1993a) and Şengör and Natal'in (1996a) and simply rename them without acknowleding the fact that they had been previously discovered and named (e.g., Lehmann et al., 2009 reproduce a figure of the Irtysh and Gornostaev faults in their fig. 1 and call them together the 'Transeurasian fault', introducing this thoroughly inappropriate name—these faults traverse only northern Asia—without the slightest indication that they thereby arbitrarily change the name of a structure previously discovered and named). We do not discuss such cases in any detail in the present paper, except what we believe to be a serious misinterpretation of isotopic data by Kröner etal. (2014). It would be a tedious task to write about the objections lacking substance to the model by Şengör and his co-authors. We only mention these few examples here to illustrate what we conceive as the paucity of scientific care and scholarly rigour in a regrettably large section of the Altaid literature in the twenty-first century; we expect, however, that the reader will reach his or her own conclusions by reading what is written below.

Table I lists (in the electronic supplement) all the new isotopic ages we have collected from the literature. There, the longitude and latitude of the locality of the collected sample, name of the pluton and/or rock massif from which the sample had been taken, rock type, dated mineral, dating method, age, error margin and reference are reported. We have repeated many of the ages below just to show how they fit into the structure and the history of the Altaids. Fig. 10 shows our localities that are keyed to Table I. Figs. 11A-F display histograms of ages of arc magmatic rocks, high pressure and ultra high pressure rocks, rocks affected by strike-slip activity along shear zones active within the Altaids and especially along the Irtysh and the Gornostaev fault zones, alkalic magmatic rocks and the spreading ages of ophiolites known from the Altaid orogenic collage. The rocks represented by these histograms have also been plotted on the reconstructions, where many had to be grouped together to allow display at the chosen scale. All the literature on which Table I and Figs 10 and 11 are based are listed in the electronic supplement to this paper.

In the second part of this paper (Şengör et al., in press), we present our compilation of the available reliable palaeomagnetic data from the Altaids and present new reconstructions in terms of twelve time-lapse frames on the basis of all the data reviewed in both parts. Plate I in Part II is the tectonic map we compiled in 1995. We publish it in the second part of this paper (Şengör et al., in press) to show the basis of the hypothesis advanced in Şengör and Natal'in (1996a). The purpose of that map is not so much the display of data that are more than a decade old, but the still-valid methodology of constructing such a map as reflected mainly in its legend. The reader will note that what we have done there is precisely the opposite of what is recommended in various papers on 'terranology,' but very much along the lines followed by Suess, viewed with plate tectonic spectacles.

8. Primary tectonic units of the Altaids

The initial exercise with the evolution of magmatic fronts gave us the hint that what we expect to see in the Altaids is mostly disrupted fragments of two main arc systems, the Kipchak in the west and the Tuva-Mongol in the east including their constituent units such as the original backstop, magmatic axis and the forearc region (Şengör et al. 1993a, 1994; Şengör and Natal'in, 1996a). During the Altaid evolution, the arcs began their activity on pre-Altaid fragments and episodically jumped onto their subduction-accretion complexes. In some, when the subduction accretion complex was shaved away by what we call arc-shaving strike-slip faults (Şengör and Natal'in, 2004; fig. 9), magmatic arc axis either remained on the pre-Altaid massif or migrated back into it. Almost

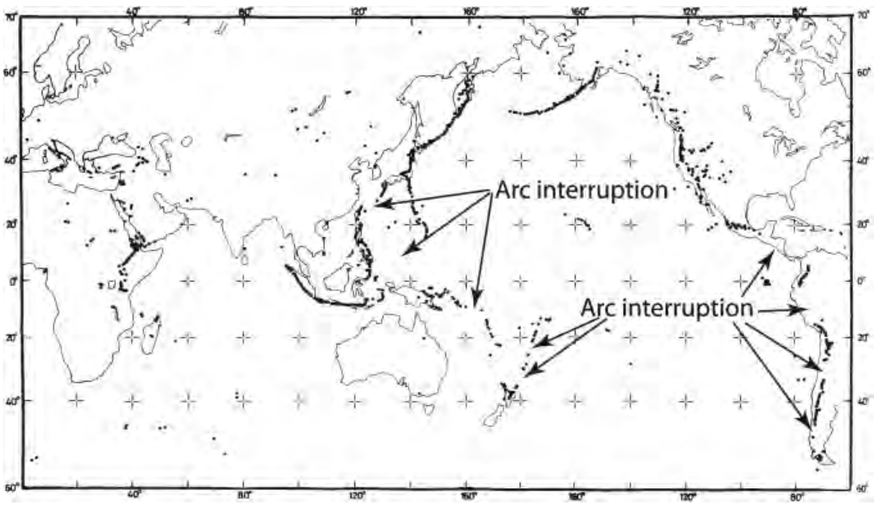

Figure 9: Present-day magmatism on earth (from Şengör et al., 1993b), showing the interruption dons in the major arc systems. Such interruptions only disappear completely when the arc activity on any given arc is plotted for a time interval of some 60 to 40 million years. That is why we have taken broad time intervals for our reconstructions in the second part of this paper (Şengör et al., in press). Only then can one follow the magmatic fronts with any confidence. Despite the present much denser data points than in 1995, the arc magmatic fronts still 'jump' forward and do not 'sweep' forward as illustrated in Şengör an Natal'in (1996a, figs. 21-19 to 21-24).

all Altaid tectonic units are strike-slip fault-bounded. In most, the strike-slip is associated with coeval convergence and is located behind fore-arc slivers. In many they move entire arcs (arc-slicing faults). Towards the end of the Altaid evolution (beginning with the medial Carboniferous in the west and with the Jurassic in the east) strike-slip disrupted the entire collage. Some of the previously emplaced units became re-disrupted.

We now look at the composition (i.e., the stratigraphy) of the individual units and their internal architecture (i.e., the structure) and the kind and timing of the events along the boundaries between them. The numbering of the units is similar to the one used in Şengör et al. (1993a and 1994), and Şengör and Natal'in (1996a) but enlarged to embrace the few newly-erected units. Our updating concerns mainly the addition of 1090 high-quality isotopic ages we compiled from the published literature and the reliable palaeomagnetic data (in Part II: Şengör et al., in press). For all the unreferenced ages, see Table I. In the text below we do not give the error margins of the ages we quote from the literature. For those, Table I should be consulted. Below, if the age is a Zr age, we normally do not indicate this, because most ages we used are Zr ages. Only if a different dating method was used, it is indicated in the text below. All the quoted ages in Table I have their methods indicated. For all the units, see Fig. 6:

1 Valerianov-Chatkal (Pre-Altaid continental basement, Altaid accretionary complex and magmatic arc): pre-Vendian[44] metamorphic basement with 820-915 Ma granites (K-Ar: Osmonbetov et al., 1982); Vendian unconformable diamictites forming rift deposits with possible Lower Vendian bimodal volcanics; unconformably overlying are Cambrian and Ordovician black slates, limestones and phosphorites (Ahmedjanov et al., 1979; Osmonbetov et al., 1982; Burtman, 2006a, b); Ordovician to Lower Devonian arc magmatics including both plutons and volcanics (from this suite an age of 416 Ma was obtained: loc. 1-1, Table I); unconformable Middle and Upper Devonian red clastics and Lower Carboniferous limestones; mainly Upper Carboniferous to ?Permian arc magmatism (loc. 1-1, Table I) plus some alkalic felsic magmatism related to post-collisional events such as strike-slip and/or possible slab break-off; an age of 276 Ma on a granite dyke probably belongs to this episode (loc. 1-2, Table I). Loc. 1-3 (Table I) contains basalts (Ar-Ar ages 261, 249, 247 Ma) and rhyolites (246 Ma; also Ar-Ar), a bimodal suite indicating the post-collisional disruption of the Altaid collage. Ages of 317 Ma (from a low greenschist metapelite), 256 Ma and 242 Ma (from two deformed granites) have been obtained from along the Talasso-Fergana Fault (Loc. 1-4, Table I) giving glimpses into the timing of the earliest strike-slip movement along this long-lived structure as suggested by Şengör et al. (1993a) and Şengör and Natal'in (1996a). In the accretionary complexes, we have from Ordovician to Devonian fragments of ophiolites (too small to be shown in our Fig. 6, green and blueschists involved in the accretionary complex; uppermost Carboniferous to Lower Permian red clastics overlie the suture to its south and west (Afonichev and Vlasov, 1984).

2. Turgay (Pre-Altaid continental basement, Altaid accretionary complex, and magmatic arc, buried under 2 km thick Mesozoic-Cenozoic sedimentary cover, identified on basis of drill-hole and aeromagnetic data): Pre-Altaid basement consisting of metamorphic porphyroids and magmatic arc with presumed Ordovician granites and accretionary wedge with presumed Ordovician clastic rocks (Abdulin and Zaitsev, 1976; Zaitsev, 1984). No newer rock type, structural or age data have come to our notice about this buried unit and neither are there any isotopic ages reported.

3. Baykonur-Talas (Pre-Altaid continental basement, early Palaeozoic Altaid accretionary complex, and magmatic arc): Pre-Altaid basement consists of Riphean rock assemblages indicating older subduction-accretion complexes and magmatic arc affinities plus dolomites of uncertain palaeotectonic setting. Degterev and Ryazantsev (2007 and 2011) and Burtman (2006a) have identified the Riphean rocks as indicating a rift setting. However, the presence of numerous ultramafic lenses within the package suggests rather an accretionary complex, although independent of the Altaids and including bits of the record of a previous rift. Vendian is unconformable and is made up of conglomerate, sandstone, differentiated volcanic rocks and glaciogenic diamictite (Kheraskova, 1981, 1986); recently Meert et al. (2011) published pictures of striated clasts from these rocks, but this interpretation does not necessarily invalidate the rift interpretation as the volcanics indicate. In Antarctica and India, for example, rifts did form under glacial cover during the late Palaeozic Gondwanian glaciation and the Neoproterozoic diamictites here may have formed under a similar regime.

Rhyolitic tuffs from among the volcanic rocks have recently yielded an age of 766 Ma (loc. 3-1, Table I), i.e., Cryogenian in the new Precambrian geological scale (Gradstein et al., 2012). Cambrian shale and deep-water limestones, Ordovician cherts and shale and medial-late Ordovician andesitic basalts, sandstones, shales, conglomerates and siltstones with abundant trilobites. To the west, in the Bayknour area, Vendian through Middle Ordovician clastic rocks interpreted as an accretionary complex, overlain by Middle to Upper Ordovician island arc volcanics and related volcanoclastics (Chakabaev, 1981; Afonichev and Vlasov, 1984, plate 20; Kheraskova, 1986). Windley et al. (2007) have recently identified the rocks here as belonging to an Atlantic-type continental margin. However, the presence of andesitic volcanics and the nearly exclusive

[44] As in our earlier publications, we here use Sokolov's (1952) Vendian, both because that is what is reported in our sources and because the lower boundary of the Ediacaran is uncertain. Wherever digital age data are available, we use the IUGS International Commission on Stratigraphy International Chronostratigraphic Chart v 2013/01 to give Series or Stage or age and epoch equivalents (http://www.stratigraphy.org/ICSchart/Chronostrat Chart2013-01.jpg). That is why in some places the reader will see 'Vendian' and in others 'Ediacaran.' This is not because of inconsistency in our usage, but because correlation of Vendian to Ediacaran is not possible (except at the lower boundary of the Cambrian) barring where there is precise isotopic age dating.

dominance of deformed clastic rocks underlying them and in part in front of them are in contrast with that interpretation and is in agreement with what had been claimed originally by Şengör and Natal'in (1996a), which we follow here.

4.1 Djezkazgan-Kirgiz (Essentially identical with the Chu-Terskey unit of Şengör et al., 1993a, 1994; Pre-Altaid continental basement, Altaid Palaeozoic magmatic arc and accretionary complex): Pre-Altaid basement with gneisses and schists of 1100 to 540 Ma isotopic ages; unconformably overlain by Vendian-Lower Cambrian rocks which are similar to unit 3; Middle Cambrian to Ordovician-Silurian volcanics and volcanoclastics; Ordovician, Silurian, and Devonian granites. Of these, loc. 4.1-1 (Table I), has one age from the Ediacaran (562 Ma) and another from the Cambrian (540 Ma), both from granitic gneisses. A shear zone of 471 and 469 Ma Ar-Ar ages cuts these basement units and early Ordovician eclogites now dated as 474 Ma La-Hf, 464 and 462 Ma Sm-Nd, as indicated in our loc. 4.1-1, (Table I) are spatially associated with these. These are all parts of the basement, formerly broadly called 'pre-Vendian' (Şengör et al., 1993; Şengör and Natal'in, 1996a). It is now possible that the basement ages here extend into the very base of the Cambrian, in part representing Altaid arc-related rejuvenation. The basement was later disrupted by early Ordovician deformation characterised by shear zones generating mylonitic gneisses. In this locality a foliated metagabbro gave an age of 531 Ma (Terreneuvian, Stage 2). We think it belongs to the earliest phase of the Altaid arc activity here, caught up in the later basement disruption of arc basement, as it is spatially associated with the shear zone and with a foliated granodiorite-quartz diorite that yielded an age of 471 Ma (loc. 4.1-1, Table I). Such shear zones are critical places from where one needs detailed structural data; we have not been able to find any detailed structural studies from here and we are therefore unable to tell whether the shear zone reported may have been associated with a marginal basin opening here as suspected by Şengör and Natal'in (1996a). Nearby, an unfoliated granodiorite gave an age of 472 Ma. Away from the zone of early Ordovican disruption of the arc massif, we get a 451 Ma rhyolite, a 448 Ma porphyritic basaltic andesite and a 414 Ma granite (all at loc. 4.1-1, Table I). A 320 Ma mid-Carboniferous leucogabbro is herein related to the extension, related to the strike-slip, and extension dominated internal disruption of the Altaid collage (Şengör et al., 1993; Şengör and Natal'in, 1996a; see the reconstructions to be published in Part II: Şengör et al., in press).

In Loc. 4.1-2 (Table I) there is a granodiorite of 514-Ma age and a 432 Ma basaltic layer. In the famed Makbal Complex nearby, there is a high pressure talcschist giving two CHIME ages of 481 and 480 Ma corroborating an earlier K-Ar age of 482 Ma on an eclogite. From the Makbal itself, we have a 509 Ma age on a chloritoid-phengite schist. This is corroborated by a SHRIMP age of 509 Ma on an eclogite. We have further SHRIMP ages on an eclogite of 498 Ma and on a chloritoid talcschist of 502 Ma and Lu-Hf ages of 470 and 486 Ma. All these ages on high pressure rocks come from the southern boundary of the arc massif of the Djezkazgan-Kirgiz arc with a pre-Altaid basement, and represents the regurgitation of the subduction zone.

Loc. 4.1-3 in Table I has yielded the following ages: a granitoid of medial Cambrian Epoch 2, Age 4 (511 Ma), a Paibian granite (498 Ma), a Darriwilian granite (465 Ma), a Katian granodiorite (446 Ma) and a Hirnantian dolerite (443 Ma). In this region, a Wenlockian Ar-Ar cooling age was obtained from a dolerite and a Famennian cooling age from a granite. We believe these are related to the deformation of the arc massif as it was being sheared against the Borotala (unit no. 3; see the reconstructions in Part II: Şengör et al., in press). Farther to the north and north-northeast, we have a Llandovery (Rhoddanian) granodiorite age of 441 Ma (loc. 4.1-4, Table I). Here a Capitanian lamprophyre dyke we consider a part of the post collisional strike-slip and extensional disruption of the Altaid units as suggested in Şengör et al. (1993 and Şengör and Natal'in (1996a). To the immediate northeast of locality 4.1-4, in locality 4.1-5 (Table I), immediately to the west of Issyk Kol (Warm Lake), we have a Dariwillian diorite (461 Ma) plus a Katian diorite of 451-Ma age. Just as in the previous locality, we have here a Sakmarian granite and an alkali syenite giving 292 Ma ages. These, like the lamprophyre dyke mentioned above, are representatives of the post collisional strike-slip and extensional disruption of the Altaid units as Siberia was shearing right-laterally against the Russian Craton (Şengör et al., in press). As we go south of locality 4.1-5 (Table I), we come to locality 4.1-6 in the arc massif with a pre-Altaid basement. Near the Altaid accretionary complex boundary, but still within the arc massif, we are presented with a Darriwillian diorite (466 Ma) in this locality. Farther to the east, there is a large, gold-bearing shear zone containing Permian granites and one diorite that are dated (loc. 4.1-7, Table I): 291 Ma granites and a 294 Ma diorite. Within the shear zone, deformed granites gave ages of 288, 284, 280, 268 Ma suggesting the presence of a long-lived Permian shear zone here, as expected from the overall structural evolution of the Altaid System (see the reconstructions in Part II: Şengör et al., in press).

Still farther east, in loc. 4.1-8 (Table I), the magmatic arc is represented by, among others, two dated hornblende granodiorites of 437 and 247 Ma and one 470 diorite age. The extreme youth of the latter granodiorite here shows how deeply the later strike-slip shaving cut into the southern edge of this unit, leading to the nucleation of later magmatics on an Ordovician to Silurian arc. The southern boundary of the arc contains blueschists with ages ranging from 320 to 301 Ma, dated by Rb-Sr, Ar-Ar and SIMS methods (loc. 4.1-8, Table I). A 299 Ma granulite was probably related to large crustal uplift related to the large Permian shear zone here (see Şengör et al., 1993 and Şengör and Natal'in, 1996a). Immediately to the east (locality 4.1-9, Table I), the arc assemblage contains the following dated rocks: diorite (409 Ma), monzodiorite (398 Ma), hornblende granite (433 Ma) and granites (ages range from 419 to 352 Ma). A 276 Ma quartz syenite probably is related to the Permian shear here.

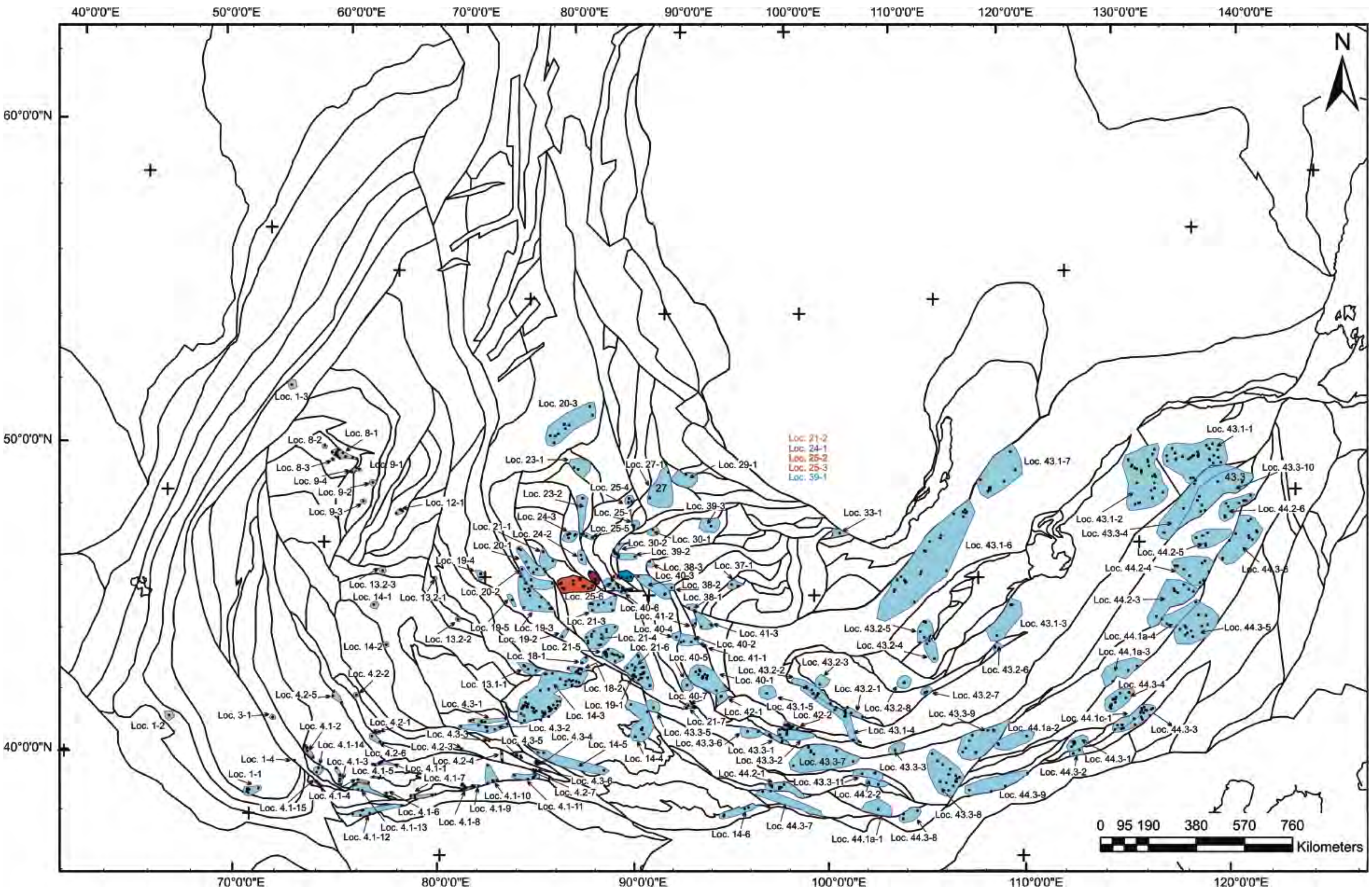

Figure 10: Localities of the stations in which isotopic ages were measured by the authors listed in Table I. The localities are in pale blue, except in the west-central part of the Altaids, where they are so close to one another that their numbers could not be written near them. There a colour code is introduced and keyed to the coloured locality list appearing northwest of Lake Baykal. The ages reported in each locality are to be found in Table I with the relevant information and the references. The map base is the same as that in Fig. 6 showing the outlines of the same tectonic units. Here the ophiolites and the ophirags shown in Fig. 6 are not separately shown.

In loc. 4.1-10 (Table I) we have, unsurprisingly, a similar assemblage: the oldest dated rock here is a 430 Ma alkali feldspar granite, 361 Ma basaltic andesite, and granites with ages ranging from 322 to 313. A monzodiorite in this suite of rocks yielded an age of 325 Ma. Finally, there is here also a Permian high-K granite with an age of 277 Ma. The following rocks have been strongly affected by dextral strike-slip deformation (as predicted by the model of Natal'in and Şengör, 2005, fig. 11) in greenschist facies giving late Permian Ar-Ar ages of 263 to 252 Ma on micaschists and a granite. The easternmost tip of the unit (loc. 4.1-11, Table I) has the following dated arc rocks: a 341-Ma granitic mylonite, clearly a product of shearing an older arc rock, a 320 Ma biotite diorite, and arc volcanics ranging in composition from basaltic andesites and trachyandesites to basalts with an age range of 312 Ma to 355 Ma. Permian granitoids with ages from 296 to 287 are probably results of the post-collisional disruption of the Altaid collage.

We now step into the accretionary complex of the Djezkazgan-Kirgiz arc fragment, consisting of ophiolites with sedimentary rocks bearing Cambrian-early Ordovician microfossils (Ghes and Bakirov, 1993), high pressure schists (Liou et al., 1989) and Ordovician turbidites (Afonichev and Vlasov, 1984, plate 118; Osmonbetov et al., 1982). In the southern part of the unit, the accretionary complex was enlarged in the Silurian-early Carboniferous.

In the Atbashi (Horse's Head) Range (loc. 4.1-12, Table I), there are two suites of granitoids: an early Devonian one (417 to 410 Ma) and a Permian one (286 to 282 Ma). This is consistent with what we know from the regions farther west; but here the Altaid arc basement is an Altaid accretionary complex as opposed to the pre-Altaid basement. The accretionary complex contains high-pressure rock assemlages indicating subduction, the ages of which range from 327 to 281 Ma. Here, subduction most likely lasted into the Artinskian or even into the later early Triassic (Xiao et al., 2009). This is consistent with the presence of late Permian ophiolites in the southernmost units of the Tien Shan, both in Russia and in China (e.g. Xiao et al., 2009). In the same locality there is a dated alkalic gabbro with a 284 Ma age. A carbon-rich sericite schist with the same 284 Ma age, but obtained by the Ar-Ar method, is reported. This is the youngest Altaid region west of Mongolia.

In the immediate north of the Atbashi Range (loc. 4.1-13, Table I), the accretionary complex, previously identified as being of medial Cambrian to Silurian in age, has in it a dated medial Cambrian granodiorite (516 Ma) and a dated medial Cambrian diorite. Then we have Ordovician diorites of 498 and 453 Ma and a Telychian diorite of 435 Ma. A Telychian granite (437 Ma) is also reported. To the south, where the age of the accretionary complex reaches into the Carboniferous, there are earliest Permian granites and other granitoids (293 and 291 Ma). To the northeast, within the same accretionary complex (Loc. 4.1-14, Table I), we have the following ages: on a granite (452 and 462 Ma), and on a granodiorite (482) indicating magmatic arc activity during the medial and late Ordovician.

Along the southeastern boundary of the Djezkazgan-Kirgiz arc extends the southern continuation of the Talasso-Fergana fault that juxtaposes the arc against the Tarim craton, from where we here have two mylonitized granites giving ages of 728 and 778 Ma (Loc. 4.1-15, Table I). These granites give Ar-Ar ages on muscovites of 217 Ma and on biotites of 199 Ma showing the timing of the strike-slip deformation. Deformed pegmatitic granites along the fault zone give two 279 Ma ages. An Ar-Ar age of the muscovites of the same granites yielded 227, 241 and 195 Ma ages. An Ar-Ar age on a phengite from sheared metapelites gave 250 Ma. A muscovite age from a micaschist using the Ar-Ar method yielded a 312 Ma. The ages postdating the Altaid evolution (i.e. those that are in the Mesozoic) clearly indicate the continuing disruption of the Altaid collage and its rejuvenation during the Cimmeride evolution to the south as already pointed out by Şengör (1987, fig. 2) and Şengör and Natal'in (1996a).

Detailed reports on the geochemistry of the Kurtushiba (g in Fig. 6), Kara-Archa (h), Kenkol (i) and Toluk (j) ophiolites from the Djezkazgan-Kirgiz unit exist (for those see Şengör and Natal'in, 2004, p. 708). These are all ophirags within the Altaid accretionary wedge. Fossils from their pelagic sediments indicate Cambrian to Middle Ordovician ages. The associated basalts are mostly of MORB-type, but Toluk (j in Fig. 6) also has E- and T-MORB features suggesting it has also ocean island remnants. Toluk also has arc-like features suggesting also that its ophirags also include supra-subduction zone oceanic basement. In the Kara-Archa (h in Fig. 6) there are volcanics covering the ophiolite pseudostratigraphy and this has been taken to indicate an ensimatic arc.

4.2 Jalair-Naiman (Pre-Altaid continental crust, possible early Palaeozoic marginal sea complex, early Palaeozoic magmatic arc, and accretionary complex): Precambrian gneisses, schists, amphibolites with isotopic ages around 1800 Ma (Cakabaev 1981a) unconformably overlain by Vendian-early Cambrian schist, dolomites and quartzites. These two assemblages form a narrow sliver originally believed to have rifted off the unit 4.1 (Şengör and Natal'in, 1996a; see Abdulin and Patalakha, 1981; Chakabaev, 1981b) leading to marginal basin opening. However, our later studies did not reveal any additional support for this original interpretation and we now think that the Jalair-Nayman unit may be another link within the Kipchak Arc. However, the existence of a shear zone of Ordovician age here may still favour our old interpretation. Our inability to find more data on this area leaves us undecided. It is clear that new structural studies are needed here and that is why we leave our original reconstruction unchanged but note that this is one problem area that needs a careful new consideration.

Locality 4.2-1 (Table I) consists of three tectonic slivers. The northeastern sliver contains well-foliated granitic gneisses with a Proterozoic age of 1789 Ma. Also a gneissic granite with an age of 741 Ma age and a metadacite with an age of 534 Ma. Southeast of these are garnet pyroxenite of 489 Ma and a granodiorite has 508 Ma. Microdiamonds, cited from these rocks, are said to be sitting in dykes cutting the gneissic granites (Alexeev et a., 2011). To the immediate southeast, an Archaean age of 2791 Ma was obtained; a Proterozoic sliver gave an age of 2187 Ma on a fine-grained felsic gneiss. According to Alekseev et al. (2011), the high pressure rocks represent a suture between the two slivers, although no indication of a collision is cited (ultra-high pressure metamorphism indicates subduction and not collision; the size of the sliver containing them suggests it was probably brought sideways by strike-slip into its present location between the pre-Altaid arc basement and the Altaid accretionary complex). Unfortunately, the Archaean and the Proterozoic ages are of no help in identifying separate independent entities, because they are too scattered. All three of the blocks we cite, form the basement of an arc that had magmatism during the Ediacaran and a Cambrian-Ordovician accretionary complex growth with turbidites and lenses of cherts and ophiolites.

In loc. 4.2-2 (Table I) to the north, there is a granodiorite of 480 Ma and a metadacite of 477 Ma. These are Cambro-Ordovician ages indicating the activity of the arc here while the associated accretionary complex was growing. There are also Middle-Upper Ordovician island arc volcanics and volcanoclastic rocks. (Abdulin and Patalakha, 1981). In loc. 4.2-3 (Table I) to the east of locality 4.2-1, an age of 294 Ma was obtained from a granite that sits right on the pre-Altaid arc massif/Altaid accretionary complex boundary parallel with the late strike-slip faults to the south mentioned above. Farther to the southeast, in loc. 4.2-4 (Table I), both arc activity of latest Devonian-Carboniferous age and later disruption magmatism, which produced quartz porphyries, are seen. The Devonian ages are obtained from rhyolites and dated at 370 and 363 Ma. The Carboniferous is represented by a dacite (354 Ma) and a granite (302 Ma). Finally a Permian quarz porphyry gives 259 Ma, related to strike-slip as in the previous locality.

We have documented arc activity from this unit in the Ediacaran, Cambrian, Ordovician, Devonian and Carboniferous. By late Ordovician time, the northern half of the arc had switched off because of its strike-slip emplacement behind the Djezkazgan-Kirgiz unit (see the reconstructions in Part II: Şengör et al., in press). In the south, there was arc activity during the late Devonian and the Carboniferous, but the sparsity of dates does not allow us to see whether there was any Silurian activity. Locality 4.2-5 (Table I) is within the accretionary complex and has three 'plagiogranite' (i.e., trondjhemite) Zr-ages of 520,

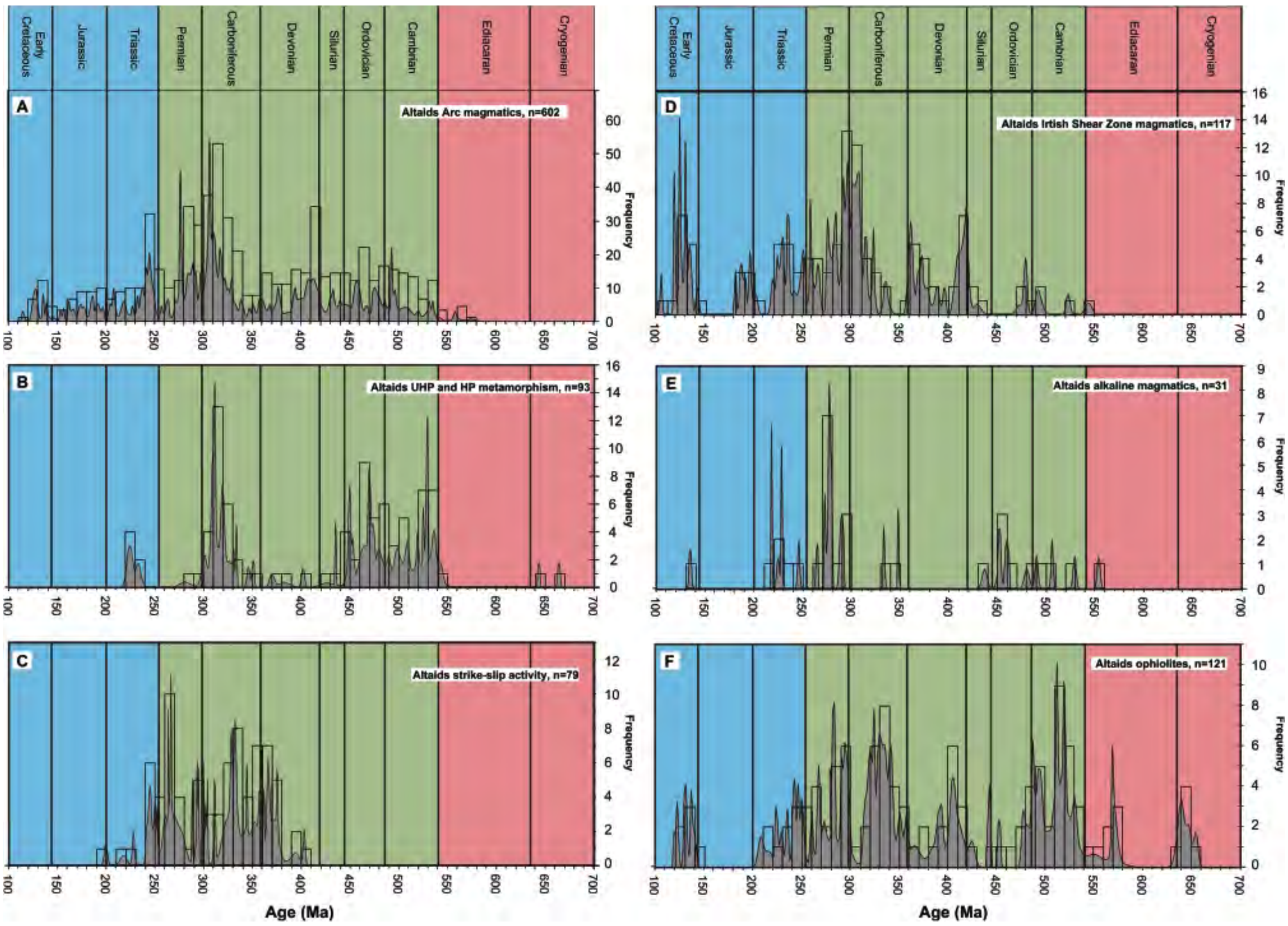

Figure 11: Frequency and probability distribution of isotopic ages from the Altaids. In all graphs, the histograms show bins at every 10 million years and the number of ages that fall into those bins. The continuous graphs show the probability distribution. The histograms were created using the software Isoplot 3.0 by Ludwig (2003). A: Distribution of the arc magmatic ages. B: Distribution of ultra high and high P/low T ages. C: Distribution of ages related to metamorphic rocks produced by the strike-slip activity in the Altaids. D: Distribution of ages related to magmatic rocks produced by the strike-slip activity along the Irtysh/Gornostaev Keirogen in the Altaids. E: Distribution of the alkalic magmatic rock ages in the Altaids. F: Distribution of ophiolite spreading ages in the Altaids.

519 and 512 Ma. Also in the accretionary complex is locality 4.2-6 (Table I) yielding a 521 Ma age on another ‘plagiogranite’. The plagiogranite localities are all in ophirags (Fig. 6). These ophirags are stratigraphically covered by Cambro-Ordovician turbidites and they were together deformed during the Ordovician-(?) Silurian interval and added to the subduction-accretion complex.

Along the boundary between the Jalair-Nayman (4.2) and the Borotala (4.3) units there is a gneiss with an Ar-Ar biotite age of 250 Ma (loc. 4-2-7, Table I) here indicating the age of the post-collisional rejuvenation, by strike-slip faulting, of this boundary when the dominant event was already the left-lateral motion of Siberian Craton with respect to the Russian Craton and the churning of the western Altaid units between them (see the reconstructions in Part II: Şengör et al., in press).

4.3 or 16. Borotala (Pre-Altaid continental basement, early Palaeozoic magmatic arc and accretionary complex): Precambrian? gneisses, migmatites, marbles, and schists form cores of gneiss-migmatite domes and are surrounded by presumably Riphean porphyroids, quartzites, and gneisses yielding a 1000 Ma zircon age (Nikitchenko, 1978; Chakabaev 1981b); stratigraphically above are Vendian diamictites, dolomites, and limestones with flint nodules, carbon-rich shales. Above these rocks, but with unclear structural relationship are Cambro-Ordovician conglomerates and sandstones with phosphate-bearing nodules and cherty mudstones with high V content possibly indicating a lively biological activity here probably because of upwelling at a westward-facing (from south-southwest to west) continental margin. Above the organic rich mudstone there are thin basalt flows and diabases which are in turn overlain by 1030 m-thick Ordovician platform limestones (Afonichev and Vlasov, 1984, plate 36; Skrinnik, written communication, 2006). All these units crop out along the northernmost edge of the Borotala unit. To the south are porphyroids, spilites, and late Ordovician limestones embedded in shales belonging to the arc magmatic axis and to an accretionary complex.

In loc. 4.3-1 (Table I), medial to late Ordovician metagabbros (453 Ma), granodiorites (460 Ma), quartz diorites (463 and 462 Ma), diorites (461 Ma) and muscovite-bearing granites (448 Ma), all intruded into the pre-Altaid basement, constitute the products of the magmatic arc here. In the same place, Devonian tuffs (416 Ma) and rhyolites (386 Ma) probably indicate a continuation of arc activity. Alternatively, they may be related to extension caused by the strike-slip stacking of the future Kazakhstan units (see the reconstructions in Part II: Şengör et al., in press). The latter interpretation is supported by the presence of a Permian (298 Ma) alkalic feldspar granite nearby, as the strike-slip systems within the Altaid collage in the western Altaids were repeatedly rejuvenated well into the Cainozoic by the orogenies taking place to their south. To the south, still within the area of the pre-Altaid basement, is locality 4.3-2 (Table I) containing late Devonian biotite-monzodiorites (371 Ma), granodiorite porphyry (366 Ma), earliest Carboniferous andesite (356 Ma). The late Carboniferous is represented by granodiorite porphyry (317 Ma) and two dacite samples (both giving 316 Ma). All these rocks indicate continuing subduction. A 289 Ma granite porphyry and an alkalic feldspar granite of 292 Ma reflect early Permian activity, probably related to collage disruption.

Within the accretionary complex of the Borotala unit, loc. 4.3-3 (Table I) has a single age: 360 Ma volcanics continuing the late Devonian arc activity. To the southeast, in loc. 4.3-4 (Table I), in the innermost part of the accretionary complex, we have a biotite granodiorite of early Devonian age (412 Ma), but the later ones are all much younger: a rhyolite (316 Ma), four granitoids (309, 301, 294 and 280 Ma), biotite-granite (296 Ma), granodiorite (294 Ma), a biotite-diorite (281 Ma) and a K-granite (280 Ma). Except the high K-granite, we think all these rocks belong to the arc phase of this unit. The high-K granite may be a crustal melt related to the disruption of the Altaid collage in the Permian.

To the northwest of the previous locality is loc. 4.3-5 (Table I) sitting in a more external position within the accretionary complex than the previous locality, we have three granitoids with ages 294, 272, 266 Ma. One granodiorite yielded 285 Ma and a K-granite of 266 Ma. Consistent with their external position with respect to the previous locality, these rocks are younger than the ones located more internally within the accretionary complex and indicate the outward migration of the magmatic front during its very last gasps.

Derictly south of the locality 4.3-4 (Table I), is the locality 4.3-6 containing a single granitoid with an age of 315 Ma.

5. Sarysu (Altaid accretionary complex and magmatic arc): This unit is poorly-exposed, being covered by Devonian and younger sedimentary rocks. Below these are Cambrian arc volcanics (only the Upper Cambrian is palaeontologically dated). We then have, in isolated outcrops, Lower Ordovician clastics, argillites, cherts, and sandstones, basalts with no obvious relationship to the basement or to each other. These are followed by late Ordovician clastics and calc-alkalic volcanics (Chakabaev, 1981a). Lower Silurian is represented at its base by green sandstones (perhaps tuffaceous) followed by variegated sandstones reaching an aggregate structural thickness of 3500 metres. Finally the Devonian rocks cover everything unconformably (Bekjanov, 2002; Skrinnik, personal communication, 2002).

6. Atasu-Mointy (Mostly identical with the Atasu-Mointy unit of Şengör et al., 1993a, 1994; Pre-Altaid continental basement, early Palaeozoic-Silurian magmatic arc and accretionary complex): In this unit, we do not have substantial newer information than that already provided in Şengör and Natal’in (1996a), which we repeat for the sake of completeness below. Precambrian granite-gneisses, schists, quartzites, marbles, and porphyroids with isotopic ages ranging from 800 to 1800 Ma (Peive and Mossakovsky, 1982) are overlain by a sedimentary cover consisting of Vendian diamictites and carbonates, Cambrian-early Ordovician clastic rocks (in places dolomites and cherty carbonate), late Ordovician limestones (in places clastics), Silurian, Devonian and Carboniferous calc-alkalic volcanics, clastic rocks and limestones. The basement and cover are in-

truded by a wide variety of the Late Ordovician, Silurian, Devonian and late Palaeozoic granites (Afonichev and Vlasov 1984; Chakobaev 1981). A Precambrian age of 880 Ma on a porphyroid gneiss has been reported by Khalilov et al. (1993) and corroborates the earlier reports. However, the available younger isotopic ages in the literature are all K-Ar on plutons and we do not find them terribly reliable. We therefore have not included them in our compilation. The accretionary complex is made up of strongly deformed Lower Ordovician cherts and Middle-Upper Ordovician and Lower Silurian (in the southeast) turbidites.

7. Tengiz (Essentially identical with the Tengiz unit of Şengör et al., 1993a, 1994; Pre-Altaid continental basement, Altaid Vendian-early Palaeozoic magmatic arc and accretionary complex): the pre-Altaid basement consists of metamorphic porphyroids, amphibolites, and schists presumably of Precambrian age (Filatova 1983). Structurally above are Vendian, Cambrian and Ordovician basalts, andesites, volcanoclastic rocks, limestones, and mudstones; late Ordovician and Silurian granites. The accretionary complex is made up of rare lenses of serpentinites and basalts, Upper Cambrian-Lower Ordovician cherts and shales (Gerasimova, 1985, Gerasimova and Kurkovskaya 1993), Middle-Upper Ordovician turbidites and what is described as olistostromes (we suspect these 'olistostromes' to be mélanges; Chakabaev 1981a). Silurian shallow-marine varicolored arkose sandstone, tuffaceous sandstone and mudstones are a fore-arc sedimentary filling. Ordovician island arc volcanics overlay the accretionary complex in the northeast as a result of migration of the magmatic front. Both the Atasu-Mointy and the Tengiz units are examples from where we have no new age data. Yet, they seamlessy merge into the Altaid evolution model of Şengör et al. (1993a) and Şengör and Natal'in (1996a) despite the many new age data from their neighbouring units. This increases our confidence in the field data we have used in the past and still use today from the rich Russian geological literature.

8. Kalmyk Kol-Kökchetav (Much the same as the Kalmyk Kol-Kökchetav unit of Şengör et al., 1993a, 1994, except its southeastern part; Pre-Altaid continental basement, Altaid Vendian-early Palaeozoic magmatic arc and accretionary complex): the Kökchetav Precambrian block consists of the various porphyroides, schists, amphibolites, phyllites, marbles, and dolomites unconformably overlain by Upper Riphean quartzite and schists (Rozen, 1971; Filatova, 1983). Diamond- and coesite-bearing rocks have been found among Precambrian gneisses, granite-gneisses, schists, granulites, amphibolites, quartzites, marbles, and eclogites in the southern part of the block (Sobolev and Shatsky, 1990). High- and ultra-high-pressure rocks in this unit, including coesite and diamonds, have recently been extensively dated. Locality 8-1 (Table I) has the following ages. The oldest date is a 537 Ma SHRIMP age coming from a diamond-bearing pelitic gneiss. The following zircon ages of the peak metamorphism are the following: a 530 Ma age from another diamond-bearing pelitic gneiss; from a gneiss 528 Ma. The Sm-Nd ages come from three eclogites (535, 533 and 528 Ma) and Ar-Ar ages are from a diamond-bearing gneiss of 517 Ma, two quartz-rich eclogites of 528 and 525 Ma. The rest are gneisses and schists from which a biotite (531 Ma) and phengites (two 529 Ma ages, 522, 519 Ma) were dated. De Grave et al. (2006) found a muscovite Ar-Ar age of 478 Ma. They call this a subduction-collision age, but no evidence for a collision is provided, apart from three references to Dobretsov et al. (2005a, b, 2006), in which there is no demonstration of a collision. In fact, a 'plagiogranite' age from the Shalkar ophiolite (loc. 8-2, Table I) from the Kalmyk Kol-Kökchetav massif yielded a 485±6 Ma spreading age predating the presumed collision by only 7 Ma, or even perhaps only 1 Ma, if one takes the lower boundary of the error margin.

In loc. 8-1 (Table I) retrograde metamorphism has been dated yielding the following ages: from a granite gneiss 510, from a diamond-bearing gneiss we have 507, from a pelitic gneiss also 507 Ma. The Ar-Ar ages from hornblende, biotites and muscovites spread from 523 Ma to 446 Ma. The youngest ages of retrograde metmorphism are some 32 Ma younger than the presumed collision age by De Grave et al. (2006), which would indicate a very long-lived collision, unlikely between such small entities as parts of the Kalmyk Kol-Kökchetav unit (in comparison, the 45 Ma old collision in the Himalaya created the entire Tibetan Plateau, whereas an only 15 Ma collision created the entire Turkish-Iranian High Plateau. Such immense entities never existed in the Kalmyk Kol-Kökchetav unit. In fact, the coeval sedimentary rocks are all marine. We are not aware that sea-level had ever been 5 or even 2 km higher than today in the entire geological record to cover a Tibet- or even Turkish-Iranian-type plateau here).

Structural geology done here indicates that the lineations are not parallel with the dip, as would have been required in a head-on collision, but parallel with the strike of the foliations indicating transport close to horizontal, i.e., in a strike-slip sense (Theunissen et al., 2000, fig. 2) as predicted by the Şengör et al. (1993) and Şengör and Natal'in (1996a) model.

Unconformably overlying Vendian-Cambrian diamictites, basalts, rhyolites, rare andesite-basalts, and volcanoclastic rocks are intruded by ultramafic-mafic layered plutons indicating an extensional environment, most likely in a magmatic arc setting. Cambrian shallow-marine carbonates, shales, and sandstones, Middle Ordovician clastics, Upper Ordovician tuffs, conglomerates, and intermediate volcanics together with vast granodiorites that are characterized by isotopic ages varying from 500 to 410 Ma (Chakabaev 1981a, Afonichev and Vlasov 1984) indicate a long-lived magmatic arc, from the latest early Cambrian to the early Devonian, although arc activity may have started even earlier as indicated by older andesitic basalts. From this suite we have only a single granite age of 413 Ma (loc. 8-3, Table I), which, however, corroborates the earlier age assignments. The Kalmyk-Kol accretionary complex is made up of Vendian to Ordovician ophirags, pelagic cherts and turbidites invaded by the migrating late Ordovician magmatic front (Chakabaev, 1981a; Afonichev and Vlasov 1984, Ivanov et al., 1988).

9. Ishim-Stepnyak (Pre-Altaid continental crust, Vendian-early Palaeozoic magmatic arc and accretionary complex): Precambrian gneisses, amphibolites, schists and marbles are scarcely exposed but occur abundantly as xenoliths in the late Ordovician granites. Vendian rocks in the northern part of the unit are similar to the ones of the unit 8. In the southern part, they are represented by quartzites, carbonates, and black shales. Cambrian to Silurian island arc volcanics, tuffs, reef limestones that are significant in the upper part of the stratigraphic succession, along with the late Ordovician granitic plutons compose the main part of the unit.

Loc. 9-1 (Table I) has yielded a rhyolite age of 437 Ma suggesting ongoing magmatism during the early Silurian. To the east-southeast of loc. 9-1, in loc. 9-2 (Table I), there is a tonalite of 457 Ma, indicating late Ordovician activity. To the south of the two previous localities is loc. 9-3 (Table I) containing two tonalites with ages of 452 and 447 Ma indicating Ordovician to Silurian arc activity. The accretionary complex consists of the Middle Ordovician turbidites with random slivers of cherts, basalts, and serpentinites (Spiridonov 1991; Chakabaev 1981a; Afonichev and Vlasov 1984).

In locality 9-4, there is a hybrid [sic] granodiorite age of 480.6±, 5.0 Ma within rocks that are of palaeontologically well-dated Caradoc (Sandbian-Katian) age. Thus this rock is thought to be an older block caught up within the accretionary complex. Because an appropriate geological map has not been provided by the people who dated the rock (Kröner et al., 2008), we cannot tell how the emplacement took place. This rock has also inherited zircon ages spreading from 3,888 to 983 Ma clearly showing that this block is from some pre-Altaid continental arc core, even perhaps from the pre-Altaid core of the Ishim-Stepnyak unit itself! Kröner et al (2008) suggest that these blocks may have come from the Kökchetav Massif. This is entirely possible by coastwise strike-slip transport of arc massif slivers along strike-slip faults, but because Kröner et al. (2008) have not done the geology in the area, we have no data to say one way or the other. From the same place a leucocratic granite gave an age of 431 Ma indicating the invasion of the accretionary complex by the arc axis.

11. Selety (Pre-Altaid continental crust, early Palaeozoic magmatic arc and accretionary complex): the pre-Altaid basement consists of quartzite and phyllites occurring in fault contacts with Palaeozoic rocks. Precambrian arc massif basement of the Selety unit consists of gneisses, micaschists, quartzites and marbles, reflecting here the former presence of a platform or Atlantic-type continental margin regime. Ediacaran rocks cover these and include quartz sandstones, quartz-sericite schists, conglomerates and carbon-rich shales. The Palaeozoic rocks consist of thick Lower Cambrian basalts, dacites and tuffs, with shales and trilobite- and archaeocyatith-bearing limestones. Then Middle Cambrian to lower Ordivician clastic sedimentary rocks and limestones containing blocks of cherts and basalts, but no continental Precambrian knockers exist in any of the blocky rocks of the Selety unit, which is significant for their interpretation as discussed below. Siliceous shales are also present in the Lower Ordovician. Then flysch and debris flow deposits (inappropriately called 'olistostromes' in the literature) of Llandeilo age follow. The so-called 'olistostromes' include blocks of cherts and limestones and may even be mélanges. The magmatic arc activity is indicated by Lower-Middle Cambrian island arc basalts, andesitic basalts, trachyandesites, rhyodacites, tuffs, medial Cambrian gabbro, diorites, and plagiogranites, and by Ordovician granites. The accretionary complex consists of Ordovician flysch, mélange, and tuffs (Chakabaev 1981a; Zaitsev 1984). This same mélange continues into the Ashgill and the bocks in these younger deposits consist of porphyries, cherts, limestones and reworked clastic rocks. We again emphasise the lack of any Precambrian basement blocks. All the blocks in the so-called 'olistostromes' are either arc-derived or plucked from deep-sea deposits.

The sequences we cited above have been considered rift deposits of an alleged extremely long and thin rift that traverses several of our units (Dektyarev, 2011). Interestingly, the rift, supposedly of late Cambrian age, coincides in what we consider to be an accretionary complex in the Jalair-Nayman unit in which high to ultrahigh pressure metamorphism was raging at the same time! We therefore prefer the interpretation of a subduction-accretion setting for the rocks we cited above and not a rift one. This is in accord with the total absence of any extensional structure ever cited from this alleged rift.

We have no new age data from the Ishkeolmes and the Selety units. Yet the dates established by the older field work cited in Şengör et al. (1993a) and Şengör and Natal'in (1996a) place these units into their proper places in the Şengör et al. (1993a) and Şengör and Natal'in (1996a) models also in the light of the newer dates from their surrounding units.

12. Akdym (Vendian-early Palaeozoic magmatic arc and accretionary complex): The magmatic arc is mainly concealed beneath the West Siberian Basin. On outcrop it consists of rhyolite, dacite, basalt, and tuff which are believed to be Vendian-Cambrian or medial Ordovician, and of fossil-bearing Upper Ordovician calc-alkalic volcanics (Borisenok et al., 1985). The accretionary complex is made up of serpentinite mélange, Vendian-Cambrian subalkalic and tholeiitic basalts, hyaloclastites, limestones, Upper Cambrian-Middle Ordovician cherts, Upper Ordovician (Caradoc) clastic rocks and debris flow deposits (Borisenok et al., 1985). The accretionary compley was intruded by tonalites (525 and 524 Ma), a 'plagiogranite' (520 Ma), a syenite of 506 Ma and a gabbro diorite (494) (all in loc. 12-1, Table I). The medial Cambrian (Epoch 3, Age 5) syenite may be a product of the localisation of the subduction zone here on a possible former fracture zone as in some modern examples (e.g. De Long et al., 1975; Karson and Dewey, 1978).

13. Boshchekul-Tarbagatay (Altaid early Palaeozoic-Silurian ensimatic magmatic arc and accretionary complex). The unit is formed from a double arc system (13.1 - Boshchekul-Tarbagatay and 13.2 - Bayanaul-Akbastau) separated by the Maikain-Balkybek suture (Yakubchuk and Degtyarev, 1991). Later Degtyarev (2011, 2012) redescribed the unit, but we

prefer Yakubchuk and Degtyarev (1991), because the later description is less precise and introduces no corrections to the old one. Schists, marble, migmatized amphibolites, garnet amphibolites, Vendian-early Cambrian ophiolites yielding isotopic ages of 525-568 Ma comprise the basement of the Boschekul-Tarbagatay arc (13.1), which was originally an ophiolite that nucleated an ensimatic arc (Şengör and Natal'in, 2004). Clearly a 43 Ma spreading history may be implied or the unit may have brought together ophiolite fragments of diverse spreading ages (across one or more former transform faults?). Parts of the ophiolite are metamorphosed giving rise to garnet amphibolites. This basement is overlain by Lower Cambrian rhyolites and dacites grading up into Lower-Middle Cambrian calc-alkalic volcanics and island arc tholeiite basalts (Khromykh 1986; Borisenok et al., 1989). The mafic basement and the Early Cambrian island arc volcanics are here interpreted in terms of a primary ensimatic magmatic arc which gave rise to the double arc system in the middle Cambrian to Ordovician, much like the Mariana arcs today. Island arc volcanics intercalated with tuffs, volcanoclastic rocks, cherts, conglomerates, reef limestones, comagmatic intrusions of gabbro and diorite formed as a result of continuous extensional magmatic activity from the early Cambrian to late Ordovician (Esenov and Shlygin 1972; Chakobaev 1981; Peive and Mossakovsky 1982; Yakubchuk and Degtyarev 1991). A gabbro of 478 Ma is in the Kujibai 'ophiolite' here forming a part of the ensimatic arc (Loc. 13.1-1).

A short break of the activity corresponds with an Arenigian-Llanvirnian episode of chert, tuff, and limestone accumulation. Also in loc. 13.1-1, we have three Carboniferous ages on a granodiorite (332 Ma), a monzonitic granite (also 332 Ma) and a granodiorite (325 Ma). These are the last gasps of the subduction zone there, which was to be soon deactivated by the strike-slip emplacement of units 14 and 15 in front of it. The Vendian-Early Cambrian rocks of the Bayanaul-Akbastau arc (13.2) are similar to those in subunit 13.1. Here a tonalite dyke of 494 Ma represents the Furongian basement of the dominantly ensimatic arc (loc. 13.2-1, Table I). Along the northern side of subunit 13.2, the pre-Middle Floian ophiolites form the basement of the magmatic arc (Yakubchuk et al., 1988) which is represented by the early (Tremadoc) to late (Caradoc; now corresponding to Sandbian and partly to Katian) Ordovician island arc volcanics and late Ordovician granodiorites.

Between the arcs are early Ordovician ophiolites (Maikain-Balkybek suture) generated in a supra-subduction zone tectonic environment, where there is a dated 'plagiogranite' of 448 Ma age (i.e. Katian) in loc. 13.2-2 (Table I). Lower to Middle Ordovician cherts, Middle-Upper Ordovician flysch and debris flow deposits, and Lower Silurian clastics (Esenov and Shlygin 1972; Chakabaev 1981a; Peive and Mossakovsky 1982; Yakubchuk and Degtyarev 1991) formed during the opening and closing of a marginal sea between two arcs. Early-Middle Llandoverian collisional flysch grades up into the medial-late Silurian island arc volcanics and coeval diorite and granodiorite. The Silurian volcanics as well as the younger Devonian and Carboniferous magmatic rocks (a granodiorite of 314 Ma is present at loc. 13.2-3 (Table I)) are common cover for units 10-13 (Chakabaev, 1981a; Karyayev, 1984; Mossakovskiy and Dergunov, 1985). They are related to subduction in the Tekturmas (14) and Junggar-Balkhash (15) units.

14. Tekturmas (Ordovician-medial Palaeozoic accretionary complex, medial Devonian-early Carboniferous magmatic arc): The accretionary complex of this arc unit becomes younger toward the center of the Junggar-Balkhash region. Along the northern and northwestern periphery of the unit are early Ordovician and medial Ordovician ophiolites and blueschists embedded into Upper Ordovician to Middle Silurian turbidites and debris flow deposits (Kuznetsov 1980; Gerasimova et al., 1992).

This accretionary complex of the Tekturmas unit is overlain by fore-arc deposits which start with unconformable early Silurian fossil-rich sandstones and mudstones grading up into late Silurian-early Devonian sandstones. Mudstones, and reef limestones; then there are early-medial Devonian varicolored conglomerates, sandstones, and mudstones (Velikovskaya et al. 1980). The Givetian-Frasnian magmatic fronts invaded the early Palaeozoic accretionary complex as well as the fore-arc basin and are represented by unconformable intermediate volcanics. But before this invasion, a Pragian/Emsian age (407 Ma) is provided by a quartz porphyry in loc. 14-1 (Table I).

To the south of this locality (Loc. 14-2, Table I) a granitoid gives a 381 Ma Frasnian age. This belt stitches together unit 5 to 13. The Silurian-early Devonian accretionary complex consists of a thick pile of sandstones and mudstones including as tectonic slivers of Middle Ordovician cherts, basalts, and gabbro (Chakabaev, 1981a; Gerasimova and Kurkovskaya 1992; Gerasimova et al., 1992). The Lower-Middle Devonian sandstones and shales probably also belong to the accretionary complex. Silurian-Lower Carboniferous varicolored conglomerates, and fossil-rich sandstones, mudstones, tuffaceous rocks, and reef limestones filled the fore-arc basin which is superimposed on the accretionary complex along its southwestern side.

Around the Junggar Basin are three fragments of the same arc disrupted during the early Permian, when the Junggar Basin was opening (Allen et al., 1995). In the northernmost of these fragments, where the famous Karamay ophiolite is exposed (loc. 14-3, Table I; ophiolites p, q and s in Fig. 6), we have leucogabbros, gabbros and one pyroxenite age grouping around numbers from 531 (earliest Cambrian: Fortunian) to 409 (early Devonian: Pragian). The Mayila ophirags are from here and are of MORB-type, but they are enriched by a plume source and are probably pieces of former ocean islands (cf. Şengör and Natal'in, 2004). Arc rocks go from 422 to 305, i.e., from Pridoli to Kasimovian. Within this suite, charnokites have been reported by Geng et al. (2009), but their descriptions and published photomicrographs clearly show that these hornblende- and biotite-bearing rocks with ages from Kasimovian to Asselian (305 to 296 Ma ages) are simply granodiorites and not charnokites, thus finding a ready place for themselves within our arc suite of intrusions. Therefore, there is no need to invoke here a ridge subduction model. We are surprised that the charnokite designation passed the reviewers and the editors in view of the clear photomicrographs.

Another interesting suite within the arc rocks is the K- and SiO_2-rich rocks such as granites and rhyolites with ages ranging from 420 to 417MA. Again, because the geological descriptions provided together with the dates are so poor that we cannot constrain the tectonic interpretation. It is possible that these rocks may have formed during a ridge subduction that melted the bottom of the accretionary complex.

Loc. 14-4 (Table I) is an isolated arc fragment left stranded in its present place when the Junggar Basin was opening and rotating in an anti-clockwise fashion in the Permian as a large extensinal basin (Allen et al., 1995). This isolated fragment has 'plagiogranites' from its ophiolitic basement giving ages of 503 Ma (Drumian), 497 Ma (Paibian), 403 Ma (Emsian) and 373 Ma (Frasnian) . In addition, there are two gabbros (489 and 406 Ma) and an anorthosite (481 Ma). These ages are related to ocean-opening, but the 'plagiogranites' may have continued forming in a Troodos- or Oman-type supra-subduction zone ophiolite that became basement to an ensimatic arc located in an exterior part of the subduction-accretion complex, to where the magmatic front moved. But the nearby Karameili ophirags give a pure MORB signature and they are clearly just plucked off pieces of the downgoing oceanic crust (Şengör and Natal'in, 2005). From the same locality we have arc gabbros with ages of 342 and 336 Ma. They are younger than the 'plagiogranites' and sugest the evolution of the magmatic arc.

As in the fragment of the Tekturmas arc earlier described, here too we have high K-granites with three reported ages: 310, 306 and 302 Ma (Loc. 14-4, Table I). These are young and may be related to the beginning disruption of the Altaid collage here. Some detailed structural mapping here is now necessary to provide a geological frame for the reported ages.

Along the southern and southwestern boundary of the Junggar Basin, i.e., along the mighty Bogdo Shan range, there is yet another fragment of the Tekturmas arc. We group the available ages in a single locality here, namely 14-5 (Table I). There are five of them: a 344 Ma gabbro, a 325 Ma trondjhemite (called 'plagiogranite' in the papers reporting the age: Xu et al., 2005 and 2006), a 315 Ma granodiorite, a 297 Ma rhyolite and a 288 Ma gabbro porphyrite. These rocks nicely line up as arc-related gabbro, trondjhemite and granodiorite and rift-related rhyolite and gabbro porphyrite. These assignments to tectonic environments are done not only on rock types, but manily on the basis of our own work on the large-scale structural geology of the area reported in Allen et al. (1995).

A final fragment of the Tekturmas arc is located south of the Turfan Basin (Allen et al., 1995). In this locality 14-6 (Table I), there are three gabbro ages, all from the early Permian, namely 285 (hornblende gabbro), 279 and 269 Ma. These are the last recorded magmatic events of the Tekturmas arc as an arc system. Three Cu-Ni-sulfide ores have been dated by the Re-Os method yielding 283, 282 and 265 Ma, in agreement with the ages on the magmatic rocks.

Thus the Tekturmas unit records the activity of a continuous arc segment that developed from the Devonian to the Carboniferous and then became disrupted in the Permian opening within it the large Central Asian basins of Alakol, Junggar and Turfan. This entire evolution can be reconstructed as a movie within the same Altaid model with great predictive power. So far, all the reported studies (ninety percent of those are isotopic age dates with little geological background) since the publication of the final form of the Altaid model by Şengör and Natal'in (1996a, b) necessitated no major revision of this model, except renaming the southeastern parts of the former unit 15 as parts of unit 14 (which changes nothing in the basic model, except a local restacking of the arc fragments 14 and 15: see our reconstructions in Part II: Şengör et al., in press), despite the great complexities of the model evolving in a long time interval from the latest Precambrian to the end of the Palaeozoic in its western half.

Two ophirags to the southeast of the Junggar-Balkhash unit have been recently studied from the viewpoint of their regional geology, petrology and geochemistry: these are the Dabut (p in Fig. 6) and the Honguleleng (q) ophirags.

Dabut has a Sm-Nd age of 395 Ma (Emsian) and is closely associated with Ordovician radiolarian cherts in the subduction mélange of the Tekturmas unit. The geochemical discrimination diagrams indicate that the Dabut ophiolite represents a MORB- type ophiolite later enriched in an ocean island setting by plume contribution. It may be that the original ocean floor was of Ordovician age onto which the later hot-spot edifice was built. It is clear that the Dabut ocean island was clipped off the downgoing plate and added as an ophirag into the subduction mélange.

The Honggueleng opiholite also has MORB signatures, but also island arc signatures. If one considers our reconstruction (see the reconstructions in Part II: Şengör et al., in press) the reason for this becomes readily apparent. Pieces of unit 18 (Zharma-Saur) representing an ensimatic Ordovician island arc were fed laterally into the accretionary complex of unit 14 by arc-shaving strike-slip faults to become ophirags within it.

Thus, ocean floor ophirags and island arc ophirags were brought into close proximity within an accretionary complex by means of arc-shaving strike-slip faults.

15. Junggar-Balkhash (early Palaeozoic and late Palaeozoic magmatic arc, medial and late Palaeozoic accretionary complex): The Itmurudy subunit consists of subduction mélange characterized by fragments of an early Ordovician complete ophiolite succession, medial-late Ordovician cherts embedded into medial-late Ordovician turbidites and debris flow deposits. Unconformably overlying are late Ordovician andesites, dacites, and sandstones (island arc) (Abdulin and Patalakha 1981; Chakabaev, 1981a; Novikova et al., 1983). The Itmurudy subunit is enlarged by the Silurian-Devonian turbidites associated with tectonic slivers of Middle-Late Ordovician cherts and basalts (Novikova et al., 1983) and then by the medial Devonian-Early Carboniferous part of accretionary complex consisting of

serpentinite mélange formed upon medial-late Devonian ophiolites (Degtyarev et al., 1993), Middle-Late Devonian cherts, siltstones, sandstones, and tuffs, early Carboniferous shales, sandstones, limestone lenses, and conglomerates (Afonichev and Vlasov, 1984).

17. Tar-Muromtsev (Essentially identical with the Tar-Muromtsev unit of Şengör et al., 1993a, 1994; early Palaeozoic magmatic arc and accretionary complex): concealed beneath the cover of the West Siberian Basin. Previously (Şengör et al., 1993a, 1994) it was interpreted as a fragment of the Zharma Saur unit, but due to fault truncation in the unit 13 and the removal of a major part of primary structures of the arc massif (they are now found incorported into unit 17) we assume that the Tar-Muromtsev unit consists of a displaced fragment of the unit 13. The shape of the unit is outlined according to aeromagnetic data. Subduction-related rock assamblages in this area are assumed after Surkov and Jero (1981).

18. Zharma-Saur (Essentially identical with the Zharma-Saur unit of Şengör et al., 1993a, 1994; early to late Palaeozoic magmatic arc and early Palaeozoic accretionary complex): Late Ordovician mélange with a flysch matrix and tectonic lenses of serpentinites, Middle-Upper Cambrian limestones, and Lower Ordovician cherts (Surkov and Jero, 1981) belonging to the accretionary complex (southwestern side of the unit). Stratigraphic record of the magmatic arc starts with medial-late Cambrian and medial-late Ordovician calc-alkalic volcanics and late Ordovician granodiorite intrusions. They grade up into: Silurian basalts, andesitic basalts, andesites, tuffs, sandstones, conglomerates, mudstones, and rare limestones, coeval granodiorites, diorites, and granites; early Devonian-Eifelian andesites, basalts, rhyolites, trachyrhyolites, dacites, tuffs and ignimbrites, coeval granites and granodiorites; unconformable middle-late Devonian andesites, basalts, tuffs, trachyandesites, dacites in the south and southeast, and quartz sandstones, siltstones, conglomerates, rare black shales in the northeast, coeval granodiorites and granites; unconformable early Carboniferous tuffs and agglomerates of andesites and andesitic basalts, intruded by late-early Carboniferous gabbrodiorites, diorites, granodiorites and plagiogranites (Afonichev and Vlasov, 1984, plates 65-69). Early Carboniferous terrigenious rocks along the northeastern side of the unit might represent a back-arc sedimentary filling. K-rich early Permian rocks here most likely record the disruption of the Altaid collage.

We have two ages indicating this activity: a 294 Ma K-rich granite and a 291 Ma granitoid (Loc. 18-1, Table I). To the south of these granites, in loc. 18-2 (Table I), we have a 344 Ma granite, two adamellites (328 and 313 Ma), a K-granite (321 Ma), a granite porphyry (303 Ma), an ivernite (this is an obsolete term for a rock transitional between a granodiorite and a granite, here reported by Zhou et al, 2008 to be 302 Ma old) and finally a K-granite 298 Ma. All these rocks are of Carboniferous to earliest Permian age and may reflect the last gasps of subduction and transition to strike-slip dominated disruption of the Altaid collage.

19. Ob-Zaisan-Surgut (Essentially identical with the Surgut unit of Şengör et al., 1993a, 1994; late Devonian-early Carboniferous accretionary complex, strike-slip fault-bounded fragments of the late Devonian-early Carboniferous magmatic arc, late Palaeozoic volcanic arc): the main corpus of this large unit is concealed beneath the West Siberian basin.

In the Kalba-Narym region: ophiolites, serpentinitic mélange, debris flow deposits, HP/LT schists, eclogites, and garnet amphibolites (545-470 Ma). These are collectivly known as the Chara Mélange. Katian ages, obtained from arc intrusions consisting of tonalites, orthogneisses and deformed granites giving isotopic ages between 451 and 448 Ma (loc. 19-1, Table I). Lower Silurian to Upper Devonian cherty deep-water carbonate rocks, Middle-Upper Devonian and early Carboniferous cherts, Upper Devonian-Lower Carboniferous reef limestones, fault-bounded blocks of late Devonian and early Carboniferous island arc volcanics. These rocks occur as tectonic inclusions in subduction and strike-slip faulting-related mélange. The mélange matrix is formed from turbidites and debris flow deposits that are Upper Visean-Serpukhovian in the west and Upper Devonian-Lower Carboniferous in the east. The main unconformity is at the base of the Middle Carboniferous. Above, are Middle Carboniferous sandstones, siltstones, black shales, rare coal seams, Middle and Upper Carboniferous terrestrial coarse-grained clastics, intermediate and felsic volcanics. Early Carboniferous and late Carboniferous-Permian granites intrude the accretionary complex. The same rocks were traced beneath the West Siberian Basin where their width was considerably enlarged by Triassic east-west stretching in the north. Indicators of transtension in the latest Palaeozoic-earliest Mesozoic in the Ob-Zaisan region are mafic and alkalic PermoTriassic plutons, volcanics, and dykes (Dobretsov and Panomareva 1969, Rotarash et al. 1982; Ermolov et al. 1981, 1983; Surkov and Jero 1981, Surkov 1986).

In locality 19-1 (Table I) we have early Permian, collage-disruption-related granites giving ages of 286 and 264 Ma. In locality 19-2 (Table I), we have two granite ages giving 362 and 338 Ma representing a late arc activity here during the late Devonian and early Carboniferous.

Loc. 19-3 (Table I) is located farther north. There are subduction-related granitoids grouping between 324 and 307 Ma ages. In the same area we have granitoids during the early Permian to early Triassic interval. These rocks, very close to the major Irtysh and Gornostaev shear zones (see Şengör et al., 1993 and Şengör and Natal'in, 1996a) and most likely represent the extension associated with the major keirogenic activity along these giant shear zones. One amphibole-biotite rock (age 242 Ma) in the same assemblage represents wet melting during the earliest Triassic. There are two possibilities to interpret such a rock at this time within this part of the Altaids: it results either from a hidden subduction of the kind described by Şengör (1984) from the Songpan-Ganzi System in China or it represents the remelting of wet subduction-accretion material. Because so far it is a singularity in our area, we lean towards the latter interpretation.

West of loc. 19-3 is the location loc. 19-4 (Table I), from where two ages are reported: A trachyte of 248 Ma and a similar rock, called vitrophyre (i.e. a vitrophyrite) by Lyons et al. (2002) giving the same age. The 'vitrophyre' is most likely also of felsic composition.

Loc. 19-5 (Table I), also west of loc. 19-3 and to the south-southwest of loc. 19-4 is the Chara Mélange. New observations have reported four blueschist ages from it ranging from 450 to 449 Ma, i.e., Katian.

In loc. 19-1 (Table I), there are epidote-amphibolite facies metamorphic rocks with Ar/Ar ages scattering from 278 to 252 Ma. In loc. 19-3 we have Ar-Ar ages from 282 to 267 Ma. These are related to the disruption of the Altaid collage. The greatest structure of the Altaid collage is the Irtysh Shear zone, a zone of intense mylonitisation and other shear-related deformation that is kilometres wide: width estimates range from 3 to 15 km. From this zone of intense strike-slip deformation, we have eight Ar-Ar ages on a wide variety of gneissose and mylonitic rocks ranging from mafic 'gneiss' through sheared granites to schists. These ages spread from 275 to 262 Ma (Briggs et al., 2007), i. e., later early Permian to late Permian, and here date the activity of the Irtysh shear zone. Briggs et al. (2007) did structural work and concluded, on the basis of their measurements on fold axes that here a north-south shortening existed and that this indicated a continental collision as favoured by Zonenshain et al. (1990), Dobretsov et al. (1995) and Badarch et al. (2002). However, the only S-C fabric in a mylonitic zone that they measured is parallel with the fold axes, not perpendicular to it, suggesting motion not across but close to parallel with the folds favouring the strike-slip interpretation suggested by Şengör et al. (1993) and Şengör and Natal'in (1996a).

20. Kolyvan-Rudny Altay (Identical with the Kolyvan-Rudny Altay unit of Şengör et al., 1993a, 1994; early Palaeozoic accretionary wedge and early and medial-late Palaeozoic magmatic arc): In the extreme south (Rudny Altay) medial Devonian-early Carboniferous volcanic arc atop early Palaeozoic clastics and carbonate rocks intruded by Ordovician, Carboniferous and Permian granitoids; to the west and north, these rocks are replaced by Middle Devonian-Carboniferous (Visean rocks are the youngest) turbidites and medial Devonian island arc volcanics intruded by late Palaeozoic granites; its northern part in the Kolyvan range is thrust onto the Salair-Kuzbas unit (unit 23 in Fig. 6) in the Permian.

The isotopic ages recently measured in loc. 20-1 (Table I) are mainly late Devonian and early Carboniferous. On the granitoids, ages scatter from 379 to 336 Ma. There is an isolated age of 308 Ma also on a granitoid. The so-called amphibole 'plagiogranites' (i.e., trondjhemites) here are not in ophiolites and their ages are as follows: two Ar-Ar ages of 322 and 321 Ma and a SHRIMP age of 319, which is essentially the same as with the other two. A biotite 'plagiogranite' has here yielded an age of 318. To the immediate south-southwest of loc. 20-1, is our locality 20-2 (Table I) which has two granitoids of 236 and 197 Ma, a synkinematic granite of 226 Ma and a granite of 225 Ma. These rocks are all within the Irtysh shear zone and represent crustal melts along this complex keirogen. To the north, in the Kolyvan Range, the Kolyvan-Rudny Altay unit becomes much wider, but this widening is clearly because of the post-Altaid extension that also created the late Permian Nurol Basin here (Şengör et al., 1993a, 1994; Şengör and Natal'in, 1996a).

In the Kolyvan range we have our locality 20-3 (Table I), in which there are two Zr ages on granitoids yielding 255 and 250 Ma. Ar-Ar ages from seven granitoids range from 253 to 232 Ma. Three dykes are 252 to 238, related to the rifting of the Nurol basin as a result of the large strike-slip along the Irtysh Keirogen. Beneath the West Siberian basin the northern continuation of the unit is a belt of Devonian - early Carboniferous slates tectonically juxtaposed against the Baykalides (Nekhoroshev 1967, Matvievskaya 1969; Rotarash et al. 1982; Surkov and Jero 1981, Surkov 1986, Grigorev 1988).

21. Gorny Altay (Identical with the Gorny Altay unit of Şengör et al., 1993a, 1994; Early Palaeozoic accretionary wedge and magmatic arc overlain by a middle Palaeozoic magmatic arc; farther west in the 'South Altay' middle Palaeozoic accretionary wedge with forearc basin): in the northeastern part of the unit, Vendian-early Cambrian ophiolites and HP/LT schists are tectonically juxtaposed with Vendian-early Cambrian andesites, basalts, tuffs and sandstones (Buslov 1992); Middle Cambrian-Lower Ordovician turbidites (sandstones are mainly quartzo-feldspathic, especially in the lower part of the stratigraphic succession) and debris flows intruded by Ordovician and Devonian granitoids and unconformably overlain by Silurian sandstones, and reef limestones.

In Loc. 21-1 (Table I), we have only 3 ages: 2 Zr ages of 264 to 251 and one Ar-Ar age of 241. These are the latest products of the Altaid subduction here and also the beginning disruption of the collage by extensive strike-slip movement. The oldest intrusion we have from the older part of the accretionary complex is a 505 Ma gneiss which is Drumian, i.e., early part of the Epoch 3 of the late Cambrian (Loc. 21-2, Table I). Ordovician and Silurian granites and diorites range in age from 470 to 417 Ma (Loc. 21-2, Table I). A felsic tuff from the same place provided a 406 Ma age. In the same locality five ages on granites (granitoids) range from 257 to 241 and are clearly products of the strike-slip related extension here. Palaeontologically constrained Ordovician, early-medial Devonian and early Carboniferous calc-alkalic volcanics and Upper Devonian non-marine clastics have given the following ages in the loc. 21-3 (Table I): Granites and granodiorites range from 420 to 370 Ma with one diorite having provided an age of 379 Ma. In this locality, the Permo-Triassic strike-slip-related extension and later continuing Jurassic extension are associated with dykes (248 and 245 Ma Ar-Ar ages), a granite (240 Ma) and granitoids ranging from 192 to 182 Ma (Sinemurian). Loc. 21-4 (Table 1) has granodiorites (five ages ranging from 439 to 318), two biotite granites (404 and 368 Ma), two peraluminous granites (412 to 393 Ma) and a gneissic granite (479 Ma), all representing the activity of a magmatic arc here. A 267 Ma granitoid is associated with the later strike-slip-related extension.

Loc. 21-5 (Table I) is still farther to the southeast in the Gorny Altay. It has two groups of arc-related magmatic rocks: an older group is highly deformed, gneissified and, in migmatites, its ages are reset: gneissic granites range from 462 to 382 Ma (nine ages: Table I). In the same group, gneissified rhyolites range from 412 to 406 Ma. Two migmatite ages are 373 and 362 Ma. It is interesting that the undeformed plutonic rocks are grouped into three separate areas. Two ages seem isolated by themselves, but a group is located in a northwest-southeast trending narrow zone. This zone contains the youngest of the group ranging from 400 to 371 Ma, i.e. from medial to late Devonian. This is the beginning of the intense 'transpressional regime' in this area (see our reconstructions in Part II: Şengör et al., in press) and it seems that the intrusion sites of younger subduction-related magmatics seem controlled by subordinate, intra-arc strike-slip zones, intrusions possibly being located by mini pull-apart 'holes'! A 267 Ma granite and a migmatite of 226 Ma here were probably related to the strike-slip regime. A mapping campaign to check this suggestion here may be very fruitful.

Still farther to the southeast is locality 21-6 (Table I). Here we have an abundance of arc rocks of various ages as expected from the model of Şengör et al. (1993a, 1994) and Şengör and Natal'in (1996a). A rhyodacite here gave 505 Ma with the Pb-Pb method. Five granitoids range in age from 416 to 399, i.e., early Devonian. A peraluminous granite gave 419 Ma. Three granites have ages going from 409 to 399 Ma. Finally, a granodiorite and a biotite granodiorite have yielded ages of 404 and 359 Ma, respectively. In places, arc rocks have been deformed and gneissified. Of these, we have three intrusion ages: a granitic orthogneiss (415 Ma), a tonalitic gneiss (411 Ma) and a gneiss of two-mica-granite parentage (381 Ma). The shear-related younger metamorphic and intrusive rocks are two 'biotite-granites' (212 and 210 Ma) and four pagmatites (220 to 198 Ma age range). Ar-Ar ages on a micaschist are 261 and 249 Ma, on an orthogneiss 265 Ma, on a cordierite-garnet-orthogneiss 245 Ma, on a garnet-bearing-orthogneiss 244 Ma and, finally, on mylonites, 249 and 244 Ma.

The 'South Altay' subunit includes Silurian-Lower Devonian limestones, sandstones, and shales, Middle-Upper Devonian turbidites and siliceous shales, Lower Carboniferous sandstone, shale, limestone, lenticular bodies of Devonian? diabases (Nekhoroshev 1967, Dergunov et al. 1980; Rotorash et al.1982; Dergunov 1989; Windley 1993; Berzin and Dobretsov, 1994). The Kuerti ophiolite in the accretionary complex has yielded an age of 372 on its 'plagiogranite' (loc. 21-6, Table I). Early Carboniferous (Visean) island arc volcanics and late Palaeozoic granites stitch together the Gornyi Altai, Kobdin (40), and Kolyvan-Rudnyi Altay (20) units.

At the southernmost tip of the Gorny Altay unit (loc. 21-7, Table I), we have two ages on synmetamorphic granites of 371 to 365 Ma, probably originally located deep in the arc core.

22. Charysh-Chuya-Barnaul (Pre-Altaid continental crust, early Palaeozoic magmatic arc and accretionary complex, medial Palaeozoic fore-arc basin and magmatic arc): Pre-Altaid continental crust is inferred from gravity, magnetic and drillhole data. The inferred Precambrian crust and the overlying early Palaeozoic magmatic arc are concealed beneath Mesozoic and Cainozoic rocks. According to drillhole data, the latter consists of early-medial Cambrian andesites, basalts, and clastic rocks as well as Cambrian granites. The accretionary complex is made up of Vendian-Lower Ordovician turbidites, rare tectonic slivers of basalt and chert (Surkov et al. 1988). Early Ordovician, early Silurian shales, thinly-bedded turbidites, cherts and siliceous shale cropping out along the southwestern side of the unit (Elkin et al. 1994) might indicate the youngest part of the accretionary wedge.

23. Salair-Kuzbas (Essentially identical with the Salair and Tomsk units of Şengör et al., 1993a, 1994 but interpretation of the tectonic nature of the subunit and polarity of the magmatic arc are different; Pre-Altaid continental crust, Vendian-early Palaeozoic magmatic arc and accretionary complex, Ordovician-Silurian fore-arc basin, Devonian pull-apart basin, late Palaeozoic foredeep basin): Neoproterozoic (Riphean-Vendian)-early Cambrian ophiolites, metabasalts, greywackes, cherts, shales, and schists, Cambrian-early Ordovician turbidites, (both belong to accretionary complexes); Cambrian-early Ordovician andesites and basalts, tuffs, limestones, and clastic rocks resting atop the early Cambrian limestones which might represent a carbonate platform overlying the Vendian-early Cambrian accretionary complex. These relationships indicate a migration of the Cambrian magmatic front. Ordovician-Silurian reef limestones and shallow-marine clastics overlie a forearc region.

The back-arc region of the Salair arc experienced extension in the Devonian. The indicators of this extension are early-medial Devonian bimodal volcanics, terrestrial red beds, shallow-marine and lagoonal Devonian and early Carboniferous clastics, limestones, tuffs, and, rare mafic volcanic rocks. In the late Palaeozoic this region turned into a foredeep basin filled up with Middle Carboniferous-Permian terrestrial coal-bearing deposits, and Triassic trap basalts.

On the arc of the Salair-Kuzbas unit, three of the young, extension-related granitoids have yielded a 251 Ma age and two Ar-Ar ages of 258 and 250 Ma (loc. 23-1, Table I). On the accretionary complex of the Salair-Kuzbas, the same event generated a 250 Ma granitoid and a 246 Ma one, dated with the Ar-Ar method (loc. 23-2, Table I). Pre-Altaid continental crust makes up a narrow band of amphibolites, gneisses, migmatites, marbles and quartzites yielding 1800, 780, and 610 Ma isotopic ages along the eastern side of the unit (Matvievskaya 1969; Volkov 1988; Surkov et al. 1988; Amantov et al.1988; Grigorev, 1988; Elkin et al., 1994).

24. Anuy-Chuya (Diffrent from the unit with the same name of Şengör et al., 1993a, 1994; early Palaeozoic magmatic arc and accretionary complex): Cambrian turbidites with tectonic slivers of chert and basalt; early-medial Cambrian island arc volcanics; Ordovician and Silurian sandstones, shales and limestones, thick horizons of reef limestones in the Upper Or-

dovician and middle and Upper Silurian; (Surkov et al. 1988; Amantov et al. 1988; Elkin et al.,1994). The arc basement ages have been reported by Rudnev et al., 2004 and Rudnev et al., 2013 and they range from Ediacaran (570 Ma) to Katian (450) and are in perfect agreement with the older palaeontologically made estimates.

The arc here recently yielded granite and granodioite ages ranging from 411 to 375, i.e., entirely Devonian rocks (in loc. 24-1, Table I). However, it is difficult to separate these according to tectonic environments, because, at this time the Kuznetsk pull-apart basin opened along the transpressional systems of the Altay Mountains (Şengör and Natal'in, 1996a). What part of the magmatism belongs to the arc and what part to the opening basin located to the present-day northeast in the unit, not dissimilar to the Taupa volcanic region today in the North Island of New Zealand, is hard to tell.

In loc. 24-2 (Table I), to the immediate north-northwest of the previous locality, we have a leucogranite with an age of 392 Ma and a somewhat younger granite of 379 Ma. Loc. 24-3 (Table I) is farther to the north, where we have clearly younger, extension-related rocks, one granite and four granitoids with ages ranging from 250 to 233 Ma. A 257 Ma Ar-Ar age was obtained from a foliated sandstone.

25. Eastern Altay (Pre-Altaid continental crust, early Palaeozoic magmatic arc and accretionary complex, including huge, highly deformed seamount fragments): the pre-Altaid basement is assumed to be present beneath the shallow-marine sedimentary cover of the Riphean dolomites, limestones, shales, sandstones, phosphorites, and Lower-Middle Cambrian rocks of the same lithology. This basement was intensely deformed by strike-slip when Kolyvan-Rudny Altay unit overtook it in the early Carboniferous. A mylonitized granite (Ar-Ar age of 365 Ma), a migmatite (350 Ma) and a mylonitic gabbro (331 Ma) are witnesses of these events in loc. 25-1 (Table I). The Vendian-medial Cambrian magmatic arc started its evolution as a primitive ensimatic arc as it is indicated by boninites forming the lowest rock type; in early-medial Cambrian time, it turned into a mature arc consisting of calc-alkalic volcanics, tuffs, lava breccias and limestones. Island arc volcanics commonly rest upon carbonates which might indicate a progradation of the magmatic front on a carbonate platform. Medial-late Cambrian granites intrude the island arc complex.

On the pre-Altaid crust, felsic dykes yield 511 Ma (loc. 25-2, Table I) and orthogneisses 419 Ma in the same locality. Muscovite-chlorite schists here have yielded a 346 Ar-Ar age. The disruption of Altaid collage by late strike-slip and extensional events is here recorded by a xenolith found in a younger flow (245 Ma) and a 225 Ma granite. In locality 25-3 (Table I), a gabbro yielded an age of 528 Ma. A quartz porphyry has an age of 462 Ma. The rest of the available new ages are all on highly deformed rocks ranging from a 410 blastomylonite, 397 granitic gneiss, an Ar-Ar age of 319 Ma on a biotite schist and finally a diorite is 295 Ma old. All these ages, beginning with the 410 blastomylonite and ending with the 295 Ma diorite, are products of the intense deformation first in the forearc region, but then, with the Devonian onwards, of the increasing strike-slip displacements. Permo-Trissic ages, witnesses of the large strike-slip and extensional deformations within the jostling Altaid collage, are known from the northernmost tip of the accretionary complex belonging to the Eastern Altay unit: one granitoid here gave an Ar-Ar age of 249 Ma and two Zr ages are also from granitoids: 220 and 211 Ma (Loc. 25-4, Table I).

The accretionary complex consists of Vendian-early Cambrian ophiolites (in loc. 25-2, Table I, a gabbro of 529 Ma may belong to these ophiolites), high-pressure schists, eclogites, turbidites, and debris flow deposits. It includes large fragments of the Vendian-early Cambrian seamounts consisting of tholeiite and subalkalic basalts, diabases, chert, siliceous shale, carbonates and shales which are overlain by a thick succession of the shallow-marine cherty dolomites and limestones, quartzites and shales. Ordovician and Silurian sandstone, shales, and limestones are interpreted as molasse (Buslov et al 1993; Berzin and Dobretsov 1994) or shelf sediments but during a field excursion in 1993 we have found that the Ordovician and Silurian rocks are mainly thinly-bedded turbidites which contain limestone blocks. We assume that these rocks might very well belong to the accretionary complex. (Grigorev et al. 1988; Surkov et al, 1988; Buslov et al 1993).

Loc. 25-5 (Table I) is located in the middle part of accretionary complex of the Eastern Altay unit. A granodiorite here provided a Frasnian age: 378 Ma. A granitoid (244 Ma) and an Ar-Ar age of 306 Ma on a basalt flow seem more related to the strike-slip events and to associated extension here.

The southernmost tip of the accretionary complex of the Eastern Altay unit is our loc. 25-6 (Table I). Here during the Cambrian an arc had already started being constructed on the growing accretionary complex producing first tonalites (there are three reported Zr ages on these: 540, 534 and 510Ma). There are no Ordovician or Siluran magmatic rocks that are recently dated by isotopic methods here. The next younger rocks are a biotite gneiss of 485 Ma age (Tremadocian) and an alkali gabbro (seamount?) of 415 Ma. A diorite yielded 413 Ma and two orthgneisses are dated at 422 and 410 Ma. A 397 Ma old granodiorite is also clearly a product of the arc. There is a 380 Ma granite and 373 Ma diorite, which, may be produced during the time when the arc here was being affected by major strike-slip.

26. Kozhykhov (early Palaeozoic magmatic arc and accretionary complex) Vendian-Early Cambrian clastic rocks containing greenstones in the west (accretionary complex) and acidic and intermediate volcanics, tuffs, tuffaceous clastics, and limestones in the east, early Cambrian reef limestones and overlying them medial Cambrian andesites, basalts, lava breccies, tuffs, sandstones and siltstones (Volkov 1988; Grigorev, 1988).

27. Kuznetskii Alatau (Pre-Altaid continental crust, early Palaeozoic magmatic arc and accretionary complex): the pre-Altaid continental crust is represented by the same rocks as in the unit 26 but it crops out in a more extensive area. The magmatic arc is made up of the Vendian-early Cambrian is-

land arc volcanics, clastic rocks and limestones. As in many other units of the Altay region, early Cambrian reefal limestones separate the Vendian-early Cambrian island arc assemblages into two parts, namely, an earlier Vendian-lowermost Cambrian section and a later upper Lower to Middle Cambrian sections. The arc has an ophiolite basement on which supposedly the best-known ensimatic arc of the entire Altaid edifice was constructed (Dr. Alexander V. Vladimirov, pers. comm., 2002). Medial Cambrian-early Ordovician island arc volcanics are andesites and basalts intercalated with shallow-marine coarse-grained clastics and limestones. Numerous intrusions of medial Cambrian-early Ordovician granites. The Vendian-early Cambrian accretionary complex in the east is similar to the one in the unit 26, but includes large lenses of ophiolites. Lower-Middle Devonian alkalic volcanics and nepheline-bearing intrusions (Volkov 1988; Grigorev 1988; Kungurtsev 1993).

In locality 27-1 (Table I), two late Devonian and early Carboniferus mylonites are related to the Altaid strike-slip events: a mylonitised granite of 370 and a mylonitised gabbro of 332 Ma (Şengör and Natal'in, 1996a).

28. Belyk (Vendian-medial Cambrian magmatic arc and accretionary complex) The magmatic arc is essentially identical with that in unit 29. The accretionary complex consists of the Vendian-Early Cambrian sandstones, shales, tuffs, spilites, diabases, quartz keratophyres, limestones (Volkov 1988; Surkov et al 1988).

29. Kizir-Kazyr (Vendian-middle Cambrian magmatic arc and accretionary complex): the magmatic arc consists of early Cambrian island arc volcanics intercalated with limestones; early Cambrian limestones, marls, calcareous shales, rare cherts and siliceous shales; Middle-Upper? Cambrian calc-alkalic basalts, andesites, dacites, rhyolites varicolored clastics; Cambrian-early Ordovician granites. The accretionary complex is similar to that in unit 28 (Volkov 1988, Surkov et al 1988). Loc. 29-1 (Table I) yielded an age of 327 Ma. This is probably the cooling of a micaschist, from which the age was obtained, caught up in the early Carboniferous strike-slip dragging of the entire west Altaid collage against the Siberian Craton (Şengör and Natal'in, 1996a).

30. North Sayan unit (Vendian-early Palaeozoic magmatic arc and accretionary complex) Vendian?-early Cambrian calc-alkalic andesites, basalts, and dacites, hyaloclastites, tuffs, cherts, reef limestones, calcareous shales, tuffaceous sandstones, latest early Cambrian reef limestones; medial Cambrian tuffs, calc-alkaline volcanics, vocanoclastic rocks (Samygin and Karyakin 1991). The accretionary complex consists of ophiolites, serpentinite mélange, high-pressure schists, metapelites, metacherts, marbles, and greenschist yielding isotopic ages between 400 and 450 Ma (Dobretsov and Sklyarov 1989, Surkov et al. 1988). In the accretionary wedge, is the Boruss mélange belt, from which Dobretsov et al. (1995) report ophiolites with geochemical signatures indicating island arc boninites and back-arc basin basalts. These ophiolites are bereft of a sheeted dyke complex. We interpret these sequences as parts of an ophiolitic forearc in front of which an accretionary complex had developed.

The only new age we have from the first locality in this unit (loc. 30-1, Table I) is again an age of deformation of 374 Ma K-Ar age indicating the final cooling of the system. In locality 30-2 (Table I), we have two arc products, both of late Silurian age: a 420 Ma diorite and a 419 granite. In the same locality, essentially within the Irtysh Keirogen, there is an abundance of deformation ages, all Ar-Ar and related to strike-slip activity! These are: a myonitised granite (366 Ma), a deformed granite (365 Ma), a blastomylonite (360 Ma), a 'schist' (341 Ma) another blastomylonite with a gabbro parent (332 Ma), a 'muscovite-quartz zone' (323 Ma) and a biotite schist (318 Ma). All these ages scatter from latest Devonian to well into the Triassic and are in agreement with the activity of the Irtysh Keirogen.

31. Utkhum-Oka (Pre-Altaid continental crust, early Palaeozoic magmatic arc, and accretionary complex): Pre-Cambrian basement is inferred below Vendian-early Cambrian shelf limestones, dolomites and shales. Above them are Vendian-early Cambrian basalts, andesites, tuffs, sandstones and reef limestones. These rocks as well as vast plutons of medial-late Cambrian tonalites, granodiorites and granites constitute the magmatic arc. The accretionary complex consists of high-pressure schists formed upon ophiolites and yielding an Rb-Sr age 640 Ma, a thick pile of Upper Cambrian-Silurian turbidites, island arc volcanics and tuffs, debris flow deposits containing inclusions of ophiolites, limestones, and dolomites (Dobretsov, 1985, Gordienko 1987, Dobretsov and Ignatovich 1988, 1989). Here (Loc. 31-1, Table I) we have another K-Ar age of 473 Ma on a granulite. If it is indeed an age of migmatisation, it may belong to the arc, but the instability of the K-Ar system in such a continuously active environment behooves us to be cautious.

32. Ulugoi (Vendian-early Cambrian magmatic arc and accretionary complex): Vendian-early Cambrian magmatic arc consists of basalts, dacites, rhyolites andesites, tuffs, tuffaceous clastics, limestones, cherts, siltstones and shales; the accretionary complex is made up of metasandstones and siltstones, black shales, cherts and oceanic basalts (Zaikov 1976; Zaikova 1978; Volkov 1988; Surkov et al. 1988).

33. Gargan (Pre-Altaid continental crust, Early Palaeozoic magmatic arc, Vendian-early Paeozoic accretionary complex): high-grade metamorphic rocks yielding K-Ar ages ranging between 700 and 2370 Ma (as old as 3200 Ma according Sklyarov, 1993) reveal a dome-like structure. The deepest level is composed of granulitic gneisses and granitic gneisses which grade up into various schists and then gneisses, amphibolites, and greenstones. Unconformably overlying are late Precambrian shallow-marine marbles, dolomites and quartzites. The metamorphic basement and sedimentary cover are intruded by 390-500 Ma-old tonalites and diorites. The older rocks, those younger than about 400 Ma belong to the magmatic arc; those that are younger may have formed during the formation of an extensional metamorphic core complex here, as suggested by the structure, related to the beginning activity of the Irtysh shear zone and the associated pull-apart sectors ripping

parts of the just assembled collage.

To the south and southeast are Ordovician-Silurian? basalts, andesites, sandstones, shales, olistostromes with inclusions of limestones and ophiolites. According to geochemical data, the ophiolites are subdivided into the island arc and mid-ocean ridge types (Dobretsov 1985, Dobretsov and Ignatovich 1988, 1989). Here, in loc. 33-1 (Table I), we have a good Zr U-Pb age of 481 on a granulite. This is probably the core of the arc during the Tremadocian, thus corroborating the earlier phase of the arc as it had been interpreted by Şengör et al. (1993, 1994) and Şengör and Natal'in (1996a).

34. Kitoy (early Palaeozoic magmatic arc): Cambrian-Silurian sandstones, shales, conglomerates, basalt, and andesites in the lower part and cherty limestones, dolomites, rare basalts, and andesites in the upper part. Sedimentary and volcanic rocks of island arc affinity are thrust on top of the Vendian arkosic sandstones, siltstones and conglomerates grading upwards into the Vendian-Silurian dolomites, quartz sandstones, limestones, and carbonate breccias. Upper Devonian-Carboniferous red beds (conglomerates, sandstones) and felsic volcanics and tuffs are unconformable above the underlying units (Dobretsov and Ignatovich 1989, Boos 1991).

35. Dzhida (Early Palaeozoic magmatic arc and accretionary complex): Island arc basalts and boninites overlying ophiolites are at the base of the Vendian-early Cambrian magmatic arc. Above are basalts, andesites, rhyolites, tuffs, sandstones, and archaeocyathid limestones. The accretionary complex consists of numerous tectonic lenses of main ocean ophiolites, turbidites, cherts, olistostromes, and reef limestones. A Cambrian-Silurian age is estimated for these rocks on the basis of regional relationships (Kheraskova et al. 1987, Gordienko 1987, Kepezhinskas et al. 1987, Belichenko et al. 1988, Luvsandanzan et al. 1990).

36. Darkhat (Pre-Baykalide continental crust, Riphean magmatic arc and accretionary complex): Early Precambrian gneisses and shists (basement), Riphean continental varicolored sandstones, conglomerates, siltstones, basalts, rhyolites, and tuffs (magmatic arc). Volcanic rocks have yielded a 718 Ma Rb-Sr age. Unconformable are shallow-marine Vendian-Lower Cambrian limestones, dolomites, diamictites, phosphorites, and bauxites, middle-Upper Cambrian calcareous flysch. Riphean basalts and various clastic rocks metamorphosed in the greenschist facies, rare marble and ophiolites streching along the eastern side of the unit are interpreted as a subduction-accretion complex. The Darkhat unit and the Sangilen unit are fragments of the Baykalide edifice involved in the Altaid evolution (Kheraskova et al, 1987; Dobretsov and Ignatovich 1988, 1989; Luvsandanzan et al 1990; Berzin and Dobretsov 1994).

37. Sangilen (Baykalide microcontinent collided in the Riphean with the Darkhat unit (36) and the Tuva-Mongol Massif (43.1) and experienced strike-slip displacement during the early Palaeozoic Altaid evolution): early Archean? gneisses, schists, marbles metamorphosed in granulite facies yielding a 3100 Ma U-Th-Pb isotopic age, late Archean? gneisses, schists and quartzites intruded by 1800-2000 Ma granites, Early Proterozoic? graphitic marbles, quartzites and micaschists which are interpreted as the cover of the Archaean basement (Surkov et al. 1988). Older isotopic age determinations reveal that the age of the Sangilen metamorphic rocks is Riphaean (1080 Ma Sm-Nd; 1100 Ma U-Pb) and that they underwent additional metamorphic events in the Ordovician (442 Ma U-Pb age) (Gibsher et al. 1991; Lebedev et al. 1993).

A tectonic sliver of the Vendian-early Cambrian accretionary complex including ophirags (Agardag: e in Fig. 6) and mélange with inclusions of the early Cambrian limestones separates the Sangilen block into two subunits: 37.1 - North Sangilen and 37.2 - South Sangilen. From the North Sangilen unit we have only one new locality (37-1, Table I) with the following isotopically dated rocks types: As would be expected, the oldest age, 569 Ma, comes from an ophiolite within the accretionary complex and obtained by the Pb-Pb method.

The oldest dated arc rocks are a granodiorite with much biotite (521 Ma ID-TIMS age) and a tonalite of 536 Ma obtained by the same method. An orthopyroxene-diorite yielded a 497 Ma age, a garnet-hypersthene trondjhemite 494 Ma, two 'granosyenites' (i.e. simply granites with variable amounts of K-feldspar ranging from 40 to 70%, plagioclase between 15 to 25% and quartz from 15 to 35%; as Tomkeieff {1983} says, this is a rock that can be between a granite and a syenite, but it is so unspecific that the term is best avoided) with ages 490 and 480 Ma a granite dyke of 489 Ma. All these rocks have been dated by the ID-TIMS method except the SHRIMP dating of the trondhjemite.

The ophiolites to the north, which now consist of small and dismembered ophirags, have been dated as 579 Ma by Sm-Nd and is believed to have formed in an island arc and back arc setting (Pfänder et al., 2002). The ophirags include gabbros of different mineralogical composition and major element geochemistry and may in fact represent different bits of the subducting Ediacaran oceanic crust. The close association of the island arc and back arc lavas now separating the accretionary complex from the continental nucleus of the Sangilen unit lead us to interpret this scenario in terms of our large-scale Altaid tectonic model (Şengör and Natal'in, 1996) as a pre-arc spreading event in front of the continental nucleus and now forming a backstop to the accretionary complex, whose age ranges from Vendian to the early Cambrian. It is thus similar to the Coast Range ophiolite in California and it is, like the Coast Range ophiolite south of San Francisco, in places highly disrupted.

38. Eastern Tannuola (Early Palaeozoic magmatic arc and accretionary complex): Basalts, tuffs, varicolored sandstones and siltstones, limestones, and minor acidic volcanics are in the lower part of an island arc succession. The upper part consists of basalts, andesites, dacite, rhyolites, limestone bearing an early and medial Cambrian fauna and clastic rocks. The magmatic arc activity was terminated with the emplacement of the medial-late Cambrian granitic plutons.

In locality 38-1 (Table I) a 511 Ma gabbronorite is reported. Two 'biotite-plagioclase peridotites' dated by Ar-Ar method yielded 342 and 335 Ma ages, but these rocks are clearly affected by metasomatism in the subduction zone. A 319 Ma teschenite with Ar-Ar method here indicates a high degree of partial melting in a hot environment below the arc. This may be because of fracture zone subduction. The accretionary complex is represented by Vendian-early Cambrian basalts, cherts, siliceous shale, and limestones with subordinate sandstones and shales; Middle-Upper Cambrian turbidites, breccias, and debris flows. Shallow-marine Ordovician and Silurian sandstones and shales (fore-arc basin) have an unconformity at the base and several unconformities throughout the stratigraphic succession. Together with the rocks of the accretionary complex they are involved in pre-late Silurian thrusting (Zaikov 1976, Volkov 1988, Berzin 1987, Zonenshain et al 1990, Berzin and Dobretsov 1994). The arc that grew on the accretionary complex has a 406 Ma high temperture dolerite ('picrodolerite') in loc. 38-2 (Table I). In loc. 38-3, there is a granite deformed by strike-slip with an age of 354 Ma.

39. Western Sayan (early Palaeozoic ensimatic magmatic arc and accretionary complex): The arc basement is exposed to the west of the unit and consists of island arc-boninite-bearing Kurtushiba ophiolite (g in Fig. 6). The ophiolite consists of a package of nappes thrust onto glaucophane-bearing accretionary complex rocks. The lower part of the package consists of three nappes each of which being represented by volcanic and sedimentary rocks. Their thicknesses individually range from 1.5 to 3 km. It is clear that with such thicknesses, if they are indeed stratigraphic, we cannot have a normal oceanic crustal succession. The ophiolite is probably some sort of a pre-arc spreading product. Above it is an ultramafic/gabbro/diabase thrust sheet that is 7 km thick. Its internal structure is said to be 'weakly disturbed'. The nappe includes metamorphic peridotites, cumulates ultramafics and gabbros followed by isotropic gabbros and diabases and volcanic rocks. The diabase section contains sheeted dykes in the central part of the ophiolite outcrop and by sills in its northeastern sector. The entire succession is terminated by Lower Cambrian volcanic rocks of island arc type forming a small area in the central and southern part of the ophiolite belt (Berzin and Kungurtsev, 1996). Farther east are coeval arc magmatic rocks including basalts, andesites, felsic volcanics, tuffs and conglomerates and reef limestones. Westwards, shallow-marine rocks of the forarc basin appear. Within the forearc area are MORB-type ophirags that probably represent offscraping from the downgoing slab.

The Kurtushiba ophiolite exposed along the western margin of the arc massif thus resembles, in its tectonic position, to the ophiolite believed to underlie the Great Valley Sequence in California.

The magmatic arc is preserved only in the western side of the unit. It consists of Vendian-Middle Cambrian basalts, andesites, felsic volcanics, tuffs, conglomerates, and reef limestones which are replaced in the west by shallow-marine clastic rocks of the fore-arc basin. Comagmatic with these volcanics are Cambrian granites, granodiorites and diorites indicating the evolution of the magmatic arc.

In loc. 39-1 (Table I) a granitic gneiss of 501 Ma is among these rocks. The youngest magmatic products in the arc are medial-late Ordovician dacites and rhyolites intercalated with coarse-grained shallow-marine clastics. A 460 Ma diorite and 402 Ma gneiss seem to be among them (loc. 39-2, Table I), but this last rock is probably related to the Emsian redeformation of the collage here while the units 19, 20 and 21 were overtaking it. This deformation lasted at least into the Frasnian as indicated by a K-Ar age of 374 Ma reported to be a 'deformation-age-related to strike-slip'.

In loc. 39-1 (Table I), a 367 Ma gabbro diorite and a 236 Ma granitoid are here interpreted to be the continuation of internal deformation of the Altaid collage well into the Mesozoic. To the west and northwest of the arc, is a thick pile of Upper Cambrian-Silurian shallow-marine and terrestrial sandstones, siltstones, shales, limestones, and conglomerates. The Kurtushiba forearc ophiolite (Şengör and Natal'in, 2004), has below it high-pressure schists yielding a 469 to 464 Ma age-range (Darriwilian) by the Ar-Ar method (loc. 39-3, Table I), Lower-Middle Cambrian cherts, basalts, reef limestones, Middle-Upper Cambrian turbidites and debris flow deposits, Ordovician-Lower Silurian turbidites. An ophiolitic sliver, an ophirag, in the Karatesh Pass (Kara tash=black rock), a gabbro dolerite yielded a 535 Ma Zr age (loc. 39-1, Table I). Early Silurian granites in the accretionary complex are the result of the migration of the subduction-related magmatic front. Unconformable are Upper Silurian red beds and Devonian clastics. Felsic and intermediate volcanics form a post-accretion cover (Volkov 1988, Amantov et al 1988, Zonenshain et al 1990).

40. Kobdin (Early and medial Palaeozoic magmatic arc and accretionary complex) Middle Cambrian-Lower Ordovician turbidites (accretionary complex), unconformably overlain by Ordovician-Silurian andesites, sandstones, mudstones, and limestones. Silurian and Devonian granitoids. The early Palaeozoic arc may have been constructed in loc. 40-1 (Table I) on an ophiolite consisting of troctolites (511 Ma) and biotite and amphibole trondjhemites with ages of 535 and 524 Ma. The trondjhemites gave further ages of 573, 571 and 511 Ma. There is a wide spread of 'granitoid' ages from 535 to 505 Ma. Among them a single, much younger age than the rest, of 468 Ma, is notable, but not in contradiction with the earlier stratigraphic studies. They are said to be a calc-alkalic suite and may indicate here supra-subduction zone activity. A variety of diorites all gave 507 Ma.

Loc. 40-2 (Table I) has a 546 Ma ophiolite. This is older than all the 'arc' rocks and older than the troctolite of the locality 40-1. It is possible that in the Kobdin unit, the arc may have been constructed across the age stripes of an ocean floor, parallel with a fracture zone. The troctolite of loc. 40-1 is probably a remnant of the axial magma chamber of the oceanic spreading centre.

In this arc, we have 5 granitoid ages spreading from 514 to 391, i.e., from the Cambrian to the Eifelian, entirely in agreement with earlier reported stratigraphic ages and tectonic interpretations (see Şengör and Natal'in, 1996a). Arc rocks, Middle and Upper Devonian sandstones, shales, subordinate cherts occuring along the southwestern side of the unit might be interpreted as an accretionary complex or fore-arc basin fill (Dergunov et al. 1980, Tumortogoo 1989, Dergunov 1989, Kravtsev et al. 1989).

Loc. 40-3 (Table I) is located in the forearc area: Here there are three rocks dated and all are from an ophiolite: a picrite (512 Ma), a picritic dyke (513 Ma) and a monzodiorite (512Ma). In the arc is a granite of 413 Ma age. Loc. 40-4 is to the southeast of this locality and has a gabbro with a cooling age of 391 Ma based on Ar-Ar dating. In loc. 40-5 there is a picrodolerite with an Ar-Ar age of 359 Ma. In loc. 40-6 (Table I), we have an andesitic tuff of 512 Ma, a tonalite of 365 Ma and a post-metamorphic granite of 259 monazite U-Pb age.

41. Ozernaya (Vendian-early Cambrian magmatic arc and accretionary complex): Vendian-early Cambrian ophirags, serpentinite mélange, tholeiite and alcalic basalts, tuffs, turbidites, cherts, limestones, and debris flow deposits compose the accretionary complex. The ophiolite, that seems already to have localised a magmatic arc, yielded in loc. 41-1 (Table I) an age of 570 Ma. Unconformable are Middle Cambrian shallow-marine sandstones, conglomerates, siltstones, and sandy limestones. These rocks may represent a fore-arc basin, but in the extreme northwestern part of the unit a medial Cambrian fauna have been found in a rock assemblage which is very much the same as that of the subduction-accretion complex. To the east and northwest of the accretionary complex are island arc basalts, andesites, agglomerates, tuffs, minor felsic volcanics, limestones and clastic rocks which are interpreted as producs of a magmatic arc. Numerous intrusions of tonalite, granodiorite, granite, diorite, and gabbro are known. Granitoids in loc. 41-2 (Table I) give ages of 531 and 529 Ma indicating early Cambrian arc activity falling into the Fortunian. In loc. 40-3 (Table I), similar rocks have yielded younger ages: 519 (Epoch 2, Age 3 of the Cambrian) and 495 Ma (i.e., Paibian), i.e. medial and late Cambrian. In both localities we also have younger intrusions of granitoids that have given Paibian ages: 465 (loc.41-3) and 459 Ma (loc. 41-2, Table I). Overlap assemblages are unconformable on older rocks: 1) Silurian coarse-grained sandstones, siltstones. and limestones, 2) Middle-Upper Devonian felsic volcanics, clastic rocks, and limestones, Lower Carboniferous coal-bearing rocks (Dergunov et al. 1980, Tumortogoo 1989, Dergunov 1989, Kravtsev et al. 1989).

42. Han-Taishir (Pre-Altaid continental crust, Vendian-early Cambrian accretionary complex and magmatic arc): Riphaean island arc volcanics metamorphosed in amphibolite facies and unconformable Vendian-Lower Cambrian shallow-marine carbonate rocks that are similar to those of the pre-Altaid rock assamblages of the Tuva-Mongol unit (43). The pre-Altaid piece of continental crust was dated by single zircon evaporation ages on a xenocryst as 1715 Ma. The granite carrying the xenocryst was emplaced at 1127 Ma (Kröner et al., 2001). To this basement is attached a complete ophiolite with boninites occurring in the sheeted dykes. The plagiogranites from the ophiolite give a zircon age of 568 Ma (Khain et al, 2003). Khain et al. (2003) interpret this as forearc spreading, whereas Zonenshain had originally considered the ophiolites to have formed in a back-arc basin. We consider them to have formed in an Andaman Sea-type situation with spreading next to the continent which shortly later nucleated on top of an ensimatic arc. At the boundary of the ophiolite is an accretionary complex. The latter consists of dismembered lenses of ophiolites, cherts, turbidites, shales, limestones, debris flow deposits and seamount type basalts. Island arc basalts and andesites intercalate with sandstones and carbonates of the same age as that of the accretionary complex, and medial Cambrian granites represent the magmatic arc located to the south (Zonenshain and Kuzmin, 1978, Tomurtogoo 1989, Kepizhiskas et al. 1990).

The following ages have been obtained from the Pre-Altaid arc massif (loc. 42-1, Table I): a garnet-hypersthene-granulite gave 510 Ma and a gneissose biotite hornblende tonalite 490 Ma. The locality 42-2 is within the accretionary complex, with a sliver of the pre-Altaid arc massif caught up in it resulting from strike-slip duplication, which gave a 950 Ma SHRIMP age on a granite gneiss. The rest of the rocks belong to the arc and to the strike-slip disruption regime: The oldest granites are medial Cambrian and their ages range from 511 to 506 Ma. A granitic gneiss yielded 500 Ma. Associated is a felsic pyroclastic rock with an age of 501 Ma. One pegmatite here yielded an age of 485 Ma, right at the Cambrian/Tremadocian boundary. The next age group is Devonian to early Carboniferous and comprise an Emsian metagranite (397 Ma) and a granodiorite (396 Ma). The early Carboniferous rocks are a felsic volcanoclastic rock (358 Ma), a granodiorite being 345 Ma.

Within the accretionary complex are high pressure/low temperature metamorphic rocks, witnesses of subduction here (loc. 42-2): an eclogite yielded 543 Ma and a quartz mica schist 536 Ma. There are older cooling ages (a 573 Ma on a mylonitised orthogneiss and a 540 Ma on a quartzite-micaschist). The oldest deformation here is the early Cambrian thrusting of the eclogitic mélange of the Tsakhir Uul Formation of the Han-Taishir ophiolite over the Zamtyn basement of the Lake Zone (Lehmann et al., 2010). This happened when the coastwise transport and shaving of arc rocks had already started along the present-day southern margin of the Tuva-Mongol Fragment. The bivergent structures in this zone (Lehmann et al., 2010, fig. 7) is compatible with this interpretation.

Dijkstra et al. (2006) criticised the Şengör and Natal'in (1996a) model and suggested instead a south-dipping subduction zone. They noted a steeply south-dipping foliation in the pre-Altaid basement, but its age is uncertain. The associated lineation is subparallel with the strike. They argue that the granulite-facies metamorphism was caused by intra-arc spreading leading to the metamorphism of large volume of siliciclastic rocks and carbonates. Inherited zircons in a diorite cutting the basement have yielded 2462 and 795 Ma ages. Unfortunatly there is no evidence whatever in their paper showing extension and rock-types they report have no diagnostic value for tectonic environment. The structures are undated, but the lineation they measured would be compatible with strike-slip, not dip-slip. In the light of the data Dijksra et al. (2006) provide, we see no justification for altering the model presented in Şengör and Natal'in (1996a).

43. Tuva-Mongol (same as the Tuva-Mongol *s.l.* in Şengör et al., 1993a, 1994; Pre-Altaid continental crust and Vendian-Permian magmatic arc (43.1), Vendian-Triassic accretionary complex (43.2) and Ordovician-early Carboniferous accretionary complex (43.3)).

43.1. Tuva-Mongol Arc Massif (same as the Tuva-Mongol s. s. unit of Şengör et al., 1993a, 1994; Early Precambrian high-grade metamorphic rocks, locally separated along later strike-slip faults by bands of Vendian-early Cambrian ophiolites {Kerulen region}). In the western part of the hairpin-shaped unit are Riphean island arc volcanics. The basement is unconformably overlain by Vendian-Cambrian shelf carbonates. Early, medial and late Palaeozoic granites are widespread. Subordinate Devonian and Permian syenites. Middle and late Palaeozoic clastic rocks in diverse types of superimposed basins. Devonian calc-alkalic and abundant Permian calc-alkalic and alkalic volcanic rocks are present. (Marinov et al. 1973, Zonenshain 1973, Kovalenko and Yarmoluk 1990). In this unit we have defined nine localities. They go around the tight hairpin of the Tuva-Mongol arc massif and we begin in the easternmost end of the southern leg of the pin.

In locality 43.1-1 (Table 1), we have three Precambrian ages: a gneiss was dated at 843 Ma, an alkali feldspar granite at 795 and a granodiorite at 792. The ages of the Palaeozoic arc rocks spread from 501 Ma to 328 Ma. However, this arc remained active all the way into the early Cretaceous, especially at its easternmost end, as the Tuva-Mongol hairpin was gradually closing. The ages on granodiorites, monzogranites, granites and associated other arc rocks spread from 236 Ma to 131 Ma in agreement with the tightening of the Tuva-Mongol orocline.

Locality 43.1-2 (Table 1) has two Precambrian ages: an alkali feldspar granite of 927 Ma and a monzogranite of 817 Ma. The Altaid arc products are monzogranites, syenogranites and monzogranites with six ages obtained ranging from 482 to 416 Ma. Younger, Mesozoic arc products are similar and 18 ages were measured on them ranging from 249 to 125 Ma (see Table I).

Loc. 43.1-3 (Table I) Here a sliver of Altaid accretionary complex has been caught up between two Tuva-Mongol slivers. The Adatsag ophiolite, located in the accretionary complex, has yielded an age of 325 Ma representing the younger part of the accretionary complex caught within the hairpin of the Tuva-Mongol massif. The sliver lying north of the ophiolite has yielded a pegmatite and two orthogneiss ages ranging from 285 to 282.

Loc. 43.1-4 (Table I) Behind, i.e., arcward, that is west of the Bayankhongor ophiolite (u in Fig. 6), there are ten measured Altaid-related ages from the arc magmatic rocks that have intruded into the Precambrian basement of the Tuva-Mongol Massif, whose ages range from 579 to 514 Ma. In the southernmost part of this locality, there are two leucogranitic gneisses. The finer-grained one yielded 502 and the other 501 Ma age. A granodiorite gneiss and a biotite-rich gneiss provided 499 and 498 Ma, respectively. All of these show the Ediacaran to late Cambrian activity of the arc here.

Loc. 43.1-5 (Table I) immediately west of the previous locality, we have two monzogabbros yielding 269 and 262 Ma ages, the latter being an Ar-Ar age. The closeness of these rocks to the strike-slip margin of Permo- Carboniferous age suggests that they may be related to the extension associated with the southern tail of the giant Irtysh Keirogen.

Loc. 43. 1-6 (Table I). This is an area affected by broad sinistral strike-slip deformation already pointed out by Natal'in (1991, 1993), where shearing of the Tuva-Mongol fragment against the Siberian craton took place. The basement contains a mylonitic granite of 553 Ma and a rhyolite eruption has been dated here as being of 461 Ma (Darriwilian). These two rocks probably reflect the activity of the Altaid magmatic arc perched on the Tuva-Mongol pre-Altaid basement. The rocks are all peralkaline granites, syenites, rhyolites and their sheared and in places even mylonitised equivalents. Their ages range from 286 to 211 Ma as established by 22 age determinations (Table I). Strike-slip-related basins here contain mainly Jurassic coal-bearing rocks and another pulse of magmatic activity, probably related also to strike-slip deformation. Similar events took place during the early Cretaceous farther east.

Loc. 43.1-7 (Table I). In this locality, the Cambrian arc is represented by four age measurements on two felsic volcanic rocks (534 and 529 Ma), a 'rhyolite' reported to have plagioclase (529 Ma) and a quartz porphyry (516 Ma). The later arc activity has been attested by late Carboniferous to early Permian intrusives and volcanic rocks: a hypabbyssal felsite porphyry yielded 290 Ma with the Ar-Ar method. Another Ar-Ar measurment on 'mafic and intermediate composition volcanic rocks' gave an age of 310 Ma. Finally a trachyrhyolite provided an age also of 290 Ma. The intrusive rocks here range from 296 to 278 and consist of biotite granites, granodiorites and quartz monzogranites.

43.2. Khangay-Khantey (same as the Khangay-Khantey unit of Şengör et al., 1993a, 1994; accretionary complex and magmatic arc: Upper Riphean?-Vendian-early Cambrian ophiolites, serpentinite mélange, cherts, limestones, and shales; lower Palaeozoic to Carboniferous turbidites, mafic and intermediate volcanic rocks, tuffs, subordinate cherts; Carboniferous-Permian-Triassic turbidite, ophiolitic gabbro and basalts in the northeastern part of the subunit is the youngest part of the accretionary complex. All of the above were intruded by Permian, Triassic and Jurassic granitic rocks {Marinov et al. 1973, Zonenshain 1972, Rutshtein and Starchenko 1975, Kopteva et al. 1984, Gordienko 1987, Tumortogoo 1989, 2005}).

There is a large number of new isotopic age determinations on the magmatic rocks here that represent the magmatic arc of the Tuva-Mongol unit which migrated out onto its forearc within the Khangay-Khantey accretionary complex. This accretionary complex was trapped within the Tuva-Mongol hairpin. In the inner parts of the accretionary complex, its thickening caused its top to rise above sea-level already during the Triassic, similar to the situation now encountered in Makran in Iran and Pakistan. While the hairpin was closing during the Mesozoic, the outer parts of the subduction-accretion complex were expelled from the interior of the closing hairpin. As a result no Mesozoic marine deposits are seen in the Khangai-Khantey unit. This led to numerous misinterpretations in terms of pre-Triassic ocean closure here. The continuation of the arc magmatism all the way into the early Cretaceous shows otherwise as already was pointed out by Şengör et al. (1993a) and Şengör and Natal'in (1996a).

The locality 43.2-1 is the oldest part of the accretionary complex of the Kangay-Khantey Mountains. The oldest rock from here is from the Archaean to the Palaeoproterozoic ages (2650 to 1825 Ma) reported by Demoux et al. (2009) and most likely represents a sliver of the Tuva-Mongol unit. A felsic schist of volcanoclastic parentage gives a SHRIMP age of 606±39 Ma, i.e., either in the very latest Cryogenian or already in the early Vendian. On the basis of the surrounding rocks we would think the age is more likely to be Vendian than top Cryogenian. A nearby granite gneiss has an age of 569 Ma. A felsic metavolcanic rock yielded 472 Ma. Finally two granites have 241 and 219 Ma.

Loc. 43.2-2 (Table I) contains the Bayanhongor ophiolite. This is a peculiar ophiolite with a large alkalic component and an anorthosite lens within gabbros (Jian et al., 2010). It extends for 300 km in a NW-SE orientation exhibiting a serpentinitic mélange that includes a complete ophiolite suite (Buchan et al., 2001, 2002). A 569±21 Ma Sm-Nd age on pyroxene and whole rock from ophiolitic gabbro (Kepezhinskas et al., 1991) indicates a late Precambrian (Vendian) age for this ophiolite. Khain et al. (2003) reported a similar age (571±4 Ma). The ophiolite is interpreted as result of sea-floor spreading on the basis of enriched MORB signatures (Kepezhinkas et al., 1991; Badarch et al., 2002; Buchan et al., 2001, 2002). The shallow water sedimentary rocks covering it may indeed indicate a plume environment for its original production and may be a clue to its preservation. The presence of extensive serpentinitic mélanges in it, however, are very similar to the Kings-Kaweah ophiolite in California and may suggest a fracture zone origin that originally may have localised an ocean island similar to the Coastal Complex in Newfoundland (Karson and Dewey, 1978).

Moreover, it is very unlikely that the anorthosite and the gabbros are within their original positions with respect to one another and we here suggest that the anorthosite suite is a tectonic slice within the gabbros. Boris A. Natal'in and A. M. C. Şengör have seen this 'ophiolite' in the field and noted its extreme disruption and thought it would be better described as a mélange (Natal'in, 2007).

Loc. 43.2-3 (Table I) is just to the northwest of the previous locality, but located in a more 'external' position with respect to the Tuva-Mongol arc massif. The ages from here are accordingly younger as a result of the movesent of the magmatic axis 'outward'. There is here also a 252 Ma monzogranite.

Loc. 43.2-4 (Table I) is in a fragment formed from medial Cambrian to Silurian accretionary complexes which became invaded by the arc axis until the early Carboniferous. This fragment was later displaced from its original locality with respect to the arc massif by means of strike-slip faulting during the tightening of the Tuva-Mongol orocline in the Mesozoic. Here a quartz porphyry was dated at 493 Ma. Two occurrences of rhyolite yielded 348 and 334 Ma ages.

In Loc. 43.2-5 (Table I), there is a dated granite giving 458 Ma and a granite dyke which yielded 435 Ma. These are Ordovician-Silurian ages showing that the arc axis shifted away from the main Tuva-Mongol pre-Altaid massif. Rhyolitic volcanics and tuffs have four samples dated giving a range of 465 to 403 Ma carrying the arc activity all the way into the late early Devonian (Emsian).

In loc. 43.2-6 there are only two age measurements, both giving younger ages than the accrtionary complex that form their host rock: a porphyritic granite of 441 Ma and a feldspar porphyry with an age of 443 Ma.

Loc. 43.2-7 (Table I) here we have only three Ar-Ar ages on three granites: 211, 209 and 201 Ma. Similarly in loc. 43.2-8 two Ar-Ar ages are on a porphyry copper housed in granites, granodiorites and gabbro diorites, namely 222 and 219 Ma. A biotite granodiorite here has yielded 222 Ma. All these rocks indicate the continuation of subduction in the Khangay-Khantey Mountains during the late Triassic.

43.3. South Mongolian unit (Accretionary complex and magmatic arc): the accretionary complex reveals the southward rejuvenation of the rock ages. The oldest part of it stretches along the south margin of the Tuva-Mongol Massif (43.1) and consists of a sliver of pre-Altaid basement, Upper Ordovician-Silurian turbidites containing lenses of ophiolites and debris flow deposits. These rocks are intruded by Silurian granites and unconformably overlain by Lower-Middle Devonian reef limestones or Middle-Upper Devonian turbidites, early-late Devonian andesites, dacites, rhyolites, tuffs and clastic rocks (magmatic arc migrated from Tuva-Mongol Massif!), and unconformable Lower-Carboniferous conglomerate and sandstones. In this part of the pre-Altaid sliver and the accretionary complex, we have the following ages (loc. 43.3-1, Table I): The pre-Altaid fragment, already identified as such by Marinov et al. (1973), gave a single Ar-Ar age of 738 Ma on a micaschist. A metamorphic rock gave a U-Pb age of 384 Ma. Another was dated at 359 Ma. Arc rocks dated here are a tonalitic gneiss (363 Ma), a granitoid gneiss (360 Ma) and a granitic gneiss (360 Ma). An upper 'metamorphic' age was reported from here without further specification of the rock type: it is 385 Ma. Five foliated granites have an age range of 295 to 289 Ma. A foliated diorite gave an age of 289 Ma. A cataclastic granite yielded 286 Ma.

To the east-northeast of locality 43.3-1 is our locality 43.3-2 (Table I). Here the oldest magmatic rocks are porphyritic rhyolites and rhyolites with 397 and 396 Ma respectively. A leucocratic orthogneiss (363 Ma), melanogabbros (337 and 332 Ma), a granitic gneiss (350 Ma), a granitoid (340 Ma), a migmatite

(330 Ma with Ar-Ar method), and a granite (279 Ma) here represent the younger arc rocks. To the east of the last locality is our locality 43. 3-3 (Table I), which has a single metamorphic age reported: a red alkalic metagranite of 231 Ma. The last locality on the medial Cambrian-Silurian subduction-accretion prism is 43.3-4 (Table I). Here the following arc magmatic rocks have been dated: a gabbro (322 Ma), 3 monzogranites (318, 304, 220 Ma) and a granodiorite which is medial Cretaceous (Aptian) in age (118 Ma).

Early-late Devonian island arc volcanics tectonically juxtaposed with the coeval rocks of the accretionary complex which is interpreted as result of strike-slip repetition (Marinov et al. 1973, Zonenshain 1972, Ruzhentsev et al. 1987 1992).

On this younger part of the accretionary complex is our locality 43.3-5 (Table I). Here is a single age from the basement itself, which is an ophiolite fragment, which yielded a 352 Ma (Tournaisian) age on a tholeiitic basalt. East of loc. 43.3-5 is the next locality, namely 43.3-6 (Table I): A gabbro norite gave a Zr age of 316 and an Ar-Ar age of 330 Ma. This rock is very near a major straight fault zone and is probably related to strike-slip-related extension. Farther east is the large locality 43.3-7 (Table I), from which arc rocks consisting of granites, biotite-hornblende monzonites and migmatites gave ages in an interval of 433 to 331 Ma. Metamorphic igneous rocks and the leucosomes of the mimatites gave ages from 308 to 277 Ma. These younger ages are related to the late strike-slip deformation in the area. A post-kinematic emplacement age of a red alkalic granite here is 230 Ma. This intrusion dates the cessation of the strike-slip deformation in this locality.

Loc. 43.3-8 (Table I) lies farther east than the previous locality. A suite of arc rocks ranging in composition from a trachydacite through tonalites, quartz diorites, porphyritic quartz monzonites, granodiorites and granites have yielded 12 ages spanning an age interval from 330 Ma to 290 Ma. Some of the granites are cataclasised. A granodiorite pegmatoid has given an age of 288 Ma. An alkali granite is 292 Ma old. Two Ar-Ar ages on a pegmatite and an alkali granite are 285 and 283 Ma respectively. The alkali granite and these two last ages are probably related to the strike-slip deformation in the Permian.

Loc. 43.3-9 (Table I) lies to the northeast of the last locality as the unit curves to the northeast. Here the oldest arc-related rock is a granodiorite associated with syenites and granosyenites with an age of 364 Ma (Famennian). We have here a suite of younger arc rocks including monzonites, quartz monzonites, monzonite porphyries, granodiorites, andesites and rhyolites formed in an interval of time from 333 Ma to 292 Ma.

Loc. 43.3-10 (Table I) forms the easternmost tip of unit 43.3. Here the oldest arc rock is a monzogranite with an age of 300 Ma. Two trondjhemites have yielded 226 and 122 Ma. Two granodiorites have 170 and 165 Ma. Finally two syenogranites are each 125 Ma old. These last ages probably are related to the last gasps of the Khangai-Khantey subduction zone to the north.

Loc. 43.3-11 (Table I) is a fault-separated bit of the unit 43. 3. It contains two ages of 421 and 417 from metavolcanoclastics plus a quartz monzonite giving an age of 307 Ma.

44. South Gobi. As defined by Şengör and Natal'in (1996), on the basis of the classical, regrettably now almost forgotten, studies (Marinov et al., 1973; Yarmolyuk 1983; Ruzhentsev and Badarch, 1987; Ruzhentzev et al., 1989; Byamba et al., 1990; Ruzhentsevet al. 1989, 1992; Hsü et al. 1991; Wang, 1991; Liu, 1991; Anonymous, 1991; Guo, 1991), the core of the unit consists of late Proterozoic rocks (unit 44.1a), which both from the north and south are overlain and enlarged by Palaeozoic arc systems (44.2 and 44.3, respectively). Precambrian rocks of the unit have a similar stratigraphy all over the region: Neoproterozoic ortho- and paragneiss, biotite- and hornblende-bearing schist with minor quartzites, amphibolites, and marbles are intruded by granites of 950 and 916 Ma (Wang et al., 2001; Wang et al., 2004; Yarmolyuk, 2005). These rocks are covered by Cryogenian and Ediacaran carbonates and quartzites allowing correlation across wide stretches where scattered exposures of Palaeozoic arc volcanic rocks and ophiolites lead some researches to the identification of individual sutures. The arc system of unit 44 indeed has an intricate structure. In the early Carboniferous, it was obliquely cut by a dextral strike-slip fault zone, which was active at least until in the Permian. This rather wide zone of brittle-ductile inhomogeneous shearing runs along the southern boundary of the unit 43.3, and is recorded by steeply- plunging asymmetric folds, in places of kilometer scale, separated by narrow zones of ductile faults (Natal'in et al., 2009). In the central segment of the unit 44, this zone is overprinted by the sinistral NE-striking East Gobi fault zone active in the latest Triassic (~207 Ma) and has a total displacement on the order of ~200-400 km (Webb and Johnson, 2006). In western Mongolia, the Carboniferous-Permian dextral shearing between units 44.2 and 43 can be traced to the Trans-Altay dextral shear zone (Hanzl et. al., 2008), where relationships with unmetamorphosed surrounding rocks suggest its pre-late Carboniferous age. Farther west, it joins the Irtysh shear zone, which had the sinistral sense of shear during most of the Permian and dextral shearing in earlier times (Şengör et al., 1993; Şengör Natal'in, 1996; Natal'in and Şengör, 2005). The oldest arc-related rock appears in the easternmost part of the unit: it is a gneiss with an intrusion age of 437 Ma (Llandovery). Late Carboniferous-early Permian magmatic activity along the northern and southern margins of unit 43.3 (Southern Mongolia), as well as along the northern boundary of unit 44, is characterized by bimodal magmatism (basalt–comendite volcanic rocks) that are confined to narrow linear zones and are interpreted as evidence for rifting (Yarmolyuk et al., 2008 a, b). We further refine this interpretation and ascribe the formation of alkaline rocks to transtensional, lithospheric scale dextral shearing, along these continental-scale fault boundaries.

To the south, in the Mongolian sector of unit 44, the Precambrian core (unit 44.1a) reveals a strike-slip repetition. Loc. 44.1a-1 (Table I) is located in this unit. Only a granite of 308 Ma has been reported from it. Loc. 44.1a-2 (Table I) has two Carboniferous arc rocks and one rock related to shear deformation during the late Triassic (Norian): an augen gneiss of 331 Ma, a granodiorite of 328 Ma and a quartzo-feldspathic gneiss of 220 Ma. Farther to the northeast of this unit is loc. 44.1a-3 (Table I). A late Carboniferous quartz diorite-granodiorite was dated in it yielding an age of 313 Ma. Two monzogranites gave early Permian ages: 296 and 288 Ma. Our final locality in this sub-unit is 44.1a-4 (Table I). It has two monzogranites of 157 and 129 M and one syenogranite of 120 Ma.

The pre-Altaid continental crust reappears father to the south, which we denote as the unit 44.1b. In the literature, it is known as the Hutag Uul terranes (Badarch et al., 2002), a designation which says nothing of their tectonic nature. Along the northern boundary, crystalline rocks of unit 44.1b is framed by deep-marine Permian clastic rocks (Lugingol flysch), that increase their width to the east. This steeply-dipping flysch is subjected to dextral strike-slip affecting also in various degrees the crystalline rocks of the unit 44.1b (Natal'in et al. 2009). To the east, the Lugingol flysch continues as unit 44.3 (Lugingol-Hegenshan). The main lithological component of this unit is represented by the Devonian-Lower Permian flysch including tectonic slivers of middle-Upper Devonian cherts, other oceanic sediments, and ophiolites, the largest of which is mapped as the Hegenshan ophiolite (xy in Fig. 6; Robinson et al., 1999; Nozaka and Liu, 2004; Miao et al., 2007, 2008). The 'flysch' here is thus in reality a mélange. Following the initial modern interpretations of the tectonic structure of this part of the Altaids (Hsü et al. 1991; Wang, 1991; Liu, 1991, Şengör et al. 1993, Şengör and Natalin, 1996; Natal'in, 1996; Natal'in et al., 2009), unit 43.3 is interpreted as a south-facing accretionary wedge. Synsedimentary structures of the Lugingol part of this unit indicate south-directed thrusting overprinted by strike-slip deformations (Natal'in et al. 2009). To the west, the accretionary wedge becomes narrower and finally it wedges out bringing units 44.1a and 44.1b into direct contact with one another (Natal'in et al. 2009). The age of the outlined strike-slip duplication in the South Gobi units is believed to be early Permian, as it follows from distribution of the Permian carbonate massifs (see below) and alkaline rocks (alleged indicators of 'rifting': Yarmolyuk et al., 2008 a, b). We believe that the carbonate 'massifs' are coral reefs growing at the outer non-volcanic high of then accretionary complex which later localised the strike-slip boundary. To the south and west of the unit 44.1b stratigraphic and igneous activity records the continuous growth of the accretionary prism and migration onto it magmatic arc from Ordovician to early Permian times (Şengör and Natalin, 1996a).

In the east, the distribution of the Precambrian basement and Palaeozoic arc/accretionary wedge complexes is more complicated because of the early Palaeozoic sliver of chert, limestone, dolomite, sandstone, dunite, harzburgite, lherzolite, low-Ti tholeiitic basalt and rare gabbro and blueschists (383 ± 13, Ma, Miao et al., 2008;) which are set in a matrix of foliated tuffaceous sandstone and schist (Wang and Liu, 1986; Tang, 1990), and which is known as the Erdaojing mélange. Upper Devonian conglomerate of the Serobao Formation unconformably covers the mélange. Mélange structures indicate a southerly vergence and they are overprinted by the dextral deformation along E-W striking surfaces. Thus, Erdaojing mélange was a part of the South Gobi microcontinent that was emplaced because of the arc-shaving faulting (Şengör and Natal'in, 2004) in front of the younger part of subduction-accretion complex of unit 44.3.

Exposed farther south of the Erdaojing mélange, is the Xelinhot metamorphic complex represented by chlorite schist, kyanite and staurolite gneiss, quartzite, and marble (Hsu et al., 1991). Age of a migmatite leucosome of this complex is 437 Ma (Shi et al., 2003; Jian et al., 2007; Jian et al., 2008), and the ages of detrital zircons span intervals of 963-780 Ma, and 2933-1524 Ma, having ben derived from various sources (Shi et al. 2003). The presence of quartzite and marbles coupled with geochronology, which are characteristic for other Neoproterozoic rocks of the unit 44, implies another strike-slip repetition. We designate this unit as 44.1c. The extent of this unit to the east is not known because of the overlying Mesozoic and Cainozoic rocks, but we do know that it has the oldest Altaid-related rock in unit 44.1a. It is a gneiss with an intrusion age of 437 Ma (Llandovery) (loc. 44.1c-1, Table I). In this subunit (loc. 44.1c-1, Table I) are three quartz diorite ages of 325, 303 and 301 Ma. A gabbro yielded 323 Ma. A quartzdiorite-granodiorite gave 323 Ma and a granite 316 Ma. The only Permian age here belongs to an alkali-feldspar granite yielding 276 Ma.

Along the southern boundary of this unit, the Pennsylvanian to early Permian accretionary wedge is known as the Solonker suture (Şengör and Natal'in, 2004). It is made mainly of turbidites containing tectonic slivers of shallow-marine carbonates (seamount caps?)—missing in the Hegenshan accretionary wedge of the same age—ophiolites, as well as small blocks of Devonian to Carboniferous basalt, andesite, dacite, rhyolite, tuff and marine clastic rocks together with Vendian-Cambrian marbles and quartzites. Thus, the Mongolian-Chinese sector of the Solonker suture represents a mega-mélange created by strike-slip movement. In places in the west, the accretionary wedge/mélange zone wedges out and Devonian-Carboniferous parts of accretionary wedges abut against the Manchurides.

Subunits 44.2 and 44.3 comprise the accretionary complexes of unit 44. The former contain the medial Cambrian to Silurian accretionary complexes and the latter the Devonian to Carboniferous ones. The former unit has mainly arc magmatic rocks: Four granodiorites yielded 326, 309, 299 and 293 Ma ages. Two granitic gneisses have intrusion ages of 301 Ma each. An andesite dyke is the oldest Permian arc-related rock here: 295 Ma. Into the Permian, the rocks become more alkali-rich: a syanogranitic sheet gave 292 Ma and a rhyolite 290 Ma. An Ar-Ar age on a leucogranitic gneiss gave an age of 228 Ma, i. e. early Carnian (loc. 44.2-1, Table I). Loc. 44.2-2 has a single age reported from it: a granite porphyry of 319 Ma belonging to the arc magmatic suite. Locality 44.2-3 (Table I) has three Carboniferous ages: a syenogranite (337 Ma), a granodiorite (320 Ma) and a monzogranite (313 Ma). The other batch of arc rocks here are early Cretaceous in age and represent the last gasps of the arc activity: five ages span an interval from

143 to 129 Ma. From here on, we shall see much Jurassic and Cretaceous activity of the arc, as the Khangay-Khantey accretionary complex within the closing jaws of the Tuva-Mongol continental fragment was being expelled east-northeastward.

Loc. 44.2-4 (Table I) is an excellent instance of documenting continuous arc activity in the Mongolian wing of the Altaids within the scale of the present-day sparse sampling from the medial Ordovician (Darriwilian) to the early Cretaceous (early Berriasian)! Here we have a 466 Ma-old gneiss, a quartz diorite (446Ma), a diorite (381 Ma), an alkali feldspar granite (359 Ma), two monzogranites (309 and 267 Ma), a syenogranite (301 Ma) and a diorite 249 Ma in the Palaeozoic. The arc continued its activity into the late Mesozoic as indicated by five Monzogranites with an age span from 179 to 142 Ma. The subduction-related magmatic rocks may appear to be very far away from their associated subduction zones in the Khangai-Khantey unit; the distance, however, is about half as much as the distance of the Laramide arc rocks from their subduction zone in California in the United States.

Loc. 44.2-5 (Table I) has only early Cretaceous ages between 142 and 129 Ma obtained from five monzogranites.

The last locality from this subunit is 44.2-6 (Table I). The oldest rock in this locality is a granodiorite intruded at the Cambrian/Ordovician boundary: it has an age of 485 Ma. All the other arc rocks range from early Permian to early late Cretaceous: 292 to 106 Ma! The available ages are 292, 282, 264, 176, 167, 164, 106. Given the immense areal extent of the locality (8500 km2) and the sparsity of the sampling in it this is essentially continuous activity at least from the Permian to the Cretaceous and only in this locality. Even this locality, tiny on the scale of the entire Tuva-Mongol unit (about 2.5 million km^2; this locality is 1/342 of the entire Tuva-Mongol/Khangai-Khantey units!), has yielded a Cambrian/Ordovician granodiorite.

The Devonian to Permian accretionary complex, subunit 44.3, has nine localities from which reliable isotopic ages have been obtained. From west to east these are:

Loc. 44.3-1 (Table I) In this locality, the arc activity was essentially continuous from the late Cambrian (Jiangshanian) to the Pridoli with quartz diorites, a gabbro, three tonalites, and two granites being among the rocks dated. Eight ages span an interval from 490 to 422 Ma. A single quarz diorite gave a late Carboniferous age of 309 Ma.

Loc. 44.3-2 (Table I) has two ages: one on a trondjhemite (‘plagiogranite’) from an ophiolite giving a Visean age: 343 Ma. The other, an Ar-Ar age, is a blueschist from the accretionary complex: 383 Ma.

Loc. 44.3-3 (Table I), to the east of the last locality, also displays essentially continuous arc activity from the Permian into the early Cretaceous, but also has one age from the early Silurian (biotite gneiss: 437 Ma) and another from the later early Carboniferous (quartz diorite: 322 Ma). The Permian to early Cretaceous rocks are more diverse ranging from gabbros through monzogranites, granodiorites to real granites and even syenogranites. 12 ages from these range from 287 Ma to 132 Ma.

In locality 44.3-4 (Table I) we have the Hegenshan ophiolite xy in Fig. 6. The diverse rock types of this ophiolite suite range from the late Devonian to early Cretaceous and clearly represent tectonic additions to an accretionary complex. The ophiolite is cut by a quartz diorite-granodiorite with an age of 323 Ma and there is a volcanic breccia dated at 300 Ma. These two last ages indicate not only arc activity on top of an accretionary complex, but also active, possibly explosive, volcanicity.

Loc. 44.3-5 (Table I), farther to the northeast, has alkali feldspar granites, monzogranites and syenogranites. From these, 17 ages were established ranging from 236 Ma (Carnian) to 119 Ma (Aptian).

Loc. 44.3-6 (Table I) again shows a wide spread of ages: They begin with a 483 Ma gabbro, 333 Ma gneiss, 319 Ma granodiorite. We have two groups of monzogranites: a group has ages from 316 to 301 and the other from 187 to 169. Another granodiorite was intruded in the late Jurassic: 160 Ma. Two Permian ages both belong to more alkaline rocks: an alkali feldspar granite has 285 Ma and a syenogranite 260 Ma.

Loc. 44.3-7 (Table I) is near the Solonker suture: we again go from west to east. In this locality there are two Permian granodiorites of 299 and 288 Ma, in perfect agrement with the latest Permian closure of the Solonker Ocean.

Loc. 44.3-8 (Table I) is to the east of the previous locality: It seems to house more deformed rocks than those in the last locality, although all ages are emplacement ages of arc-type igneous rocks. A mylonite has yielded 373 Ma, a gneiss has 368 Ma and two augen gneisses each have 367 and 248 Ma. Intermediate composition dyke has here yielded an Ar-Ar age of 245 Ma.

Loc. 44.3-9 (Table I) is the Solonker ophiolite. The dated rocks here are gabbros and diabases. Six ages range from 297 to 248 Ma.

In the following section we discuss some implications of the data displayed in Table I. These implications are critical to assess the value of the reconstructions that follow.

9. Temporal and spatial evolution of magmatism and metamorphism in the Altaids

Figs. 11 A-F show histograms illustrating the temporal evolution of the magmatism in the Altaids and our reconstructions in the second part of this paper (Şengör et al., in press) its spatial evolution.

Magmatism in Altaid magmatic arcs: Under 'arc rocks' we collected all rocks of the calc-alkalic suite as reported in the literature and on the basis of our assessment of our field observations made during excursions with experts who had actually mapped them, with their maps in our hands. The first remark that we believe is important to make in connexion with the magmatic arc rocks is the fact that arc magmatism in the Altaids began during the medial Ediacaran with subdued activity, picking up during the Cambrian, with a peak during the late Cambrian, keeping a fairly steady rate of activity until the early Carboniferous when there was a lull and then peaking again during the late Carboniferous from which it declined steadily, with a local peak during the earlier late Permian, until almost the end of the early Cretaceous. Given the sparse sampling in an immense area (602 ages in about an area of some 8,745,000 km²) this is an impressive demostration of real continuity in the entire system, because of the wide geographic distribution of the samples and their random pattern of collection. This continuity is in agreement with what had been done earlier only on the basis of field geological evidence as reported by Şengör et al. (1993a, 1994) and Şengör and Natal'in (1996a).

The two peaks during the late Carboniferous and the late Permian are difficult to interpret in view of the lack of detailed rock descriptions, geochemistry and the structural environment into which the rocks were injected. Many of these rocks may be considered to be related to the final shortening during the collisional consolidation of the western part of the Altaids between Mongolia and the Ural Mountains. However, their spatial distribution belies this interpretation, because the ages concentrate along the still active subduction zones along the southern parts of the Djezkazgan-Kirgiz and the Tekturmas units and along the recently closed suture delimiting the Ob-Zaisan-Surgut unit in the west and the long Tuva-Mongol and the South Gobi arc massifs in the east. Along the Djezkazgan-Kirgiz unit, the large, gold-bearing shear zone containing Permian granites indicates here the activity of a strike-slip fault zone probably active above a subduction zone during the final stage of its activity, which seems to have lasted even into the later early Triassic (Xiao et al., 2009), which is consistent with the presence of Permian ophiolites, reported both from Russia and China, as we indicated above. Along the southern parts of the Tekturmas unit, both rhyolites and hornblende gabbros of early to medial Permian age seem subduction-related, but clearly influenced by the ongoing strike-slip related deformation in the aera (Allen et al., 1995).

High pressure and ultrahigh pressure and low temperature metamorphic rocks along the Altaid magmatic arcs: Unequivocal indicators of subduction are high- and ultra-high pressure metamorphic rocs formed in environments much colder than is usual at the depths implied. What is really surprising is that they too show a continuity in time from the latest Ediacaran to early Jurassic in the Altaids, strongly corroborating the similar inference made above on the basis of the arc magmatic rocks. What is remarkable is that all maxima in the production of high and ultrahigh pressure metamorphic rocks along Altaid subduction zones correspond with minima in the magmatic production along the arcs.

Alkalic rocks: With the small number of observations in an immense area, no meaningful correlation between the alkalic and the calc-alkalic rocks is expected and none is actually seen, except an interesting point at the two alkalic maxima: The medial Permian maximum coincides with a climb in the calc alkalic activity, whereas the medial Triassic maximum in alkalic activity coincides with a waning in the calc-alkalic activity. However, no meaning can be attached to these until many more observations are made.

Magmatic and metamorphic rocks associated with the Irtysh/Gornostaev Shear Zones: Despite the limited number of observations, the distribution of the ages, in this case both of magmatic and metamorphic rocks, here look significant in that they peak at times when our reconstructions (Part II: Şengör et al., in press) show a surge in strike-slip activity along the two shear zones. The first peak is at 420 Ma. This is the time when the Sayan orocline (units 30 through 38) is shut close and the first activity along the Irtysh compressional keirogen at its full length begins (see our reconstructions in Part II: Şengör et al., in press). The second maximum, 360 Ma ago, is at the time of the beginning motion of the immense Ob-Zaisan-Surgut unit northwards past the units of the Altay proper. Finally there is a large concentration of ages between 320 Ma and 220 Ma. This is the time of the maximum amount of strike-slip deformation first left-lateral along the Irtysh Zone (until the Permian) and then right-lateral (Permian to the earliest Jurassic) along a broad zone following the Gornostaev, during which the pull-apart basins of Alakol, Junggar and Turfan opened (Allen et al., 1995). In some of the pull-apart segments along the Irtysh-Gornostaev Keirogen elsewhere, it may even have come to the generation of small ophiolite-floored basins, similar to that behind the Andaman arc (Hamilton, 1979) or to those housing Lake Baykal (Thybo and Nielsen, 2009) or the Salton Sea trough (Parsons and McCarthy, 1996) today (see below).

The peak during the early Cretaceous is interesting, because it is an indication of the rejuvenation of the strike-slip systems in Mongolia (right-lateral; along the former continuation of the Irtysh transpressional zone) and along the former Irtysh-Gornostaev Keirogen (now only left-lateral) as a consequence of the Cimmeride collisions to the south (Şengör, 1984, 1985; Şengör et al., 1988; Şengör and Natal'in, 1996a). Along these systems, the magmatic rocks are commonly, almost exclusively, confined to small pull-apart sagments.

Altaid ophiolites: As Şengör and Natal'in (2005) have pointed out, there is a vast variety of ophiolites and ophirags within the Altaids, although we see no need to expand the definition of ophiolite (Anonymous, 1972) to include also oceanic plateaux and oceanic island arcs in the way done by Furnes et al. (2014, especially fig. 1.2). Such a lumper's expansion will not only violate the historical usage of the term since Brongniart (1813), but simply muddle the concept and make it less useful in tectonic discussions. Imagine considering the entire Kohistan-Ladakh oceanic arc system an ophiolite: would one not call it an oceanic arc simply because it produced felsic igneous rocks in great quantities? What about the rhyolitic calderas in the forearc region of the Marianas? Are they too parts of ophiolites? Or the andesites and rhyolites of Iceland? This would be like expanding the definition of human to all primates.

In our mapping, we only took those rock associations fitting the ophiolite definition of the Penrose Conference (Anonymaus, 1972) and those that can be inferred with some degree of confidence to have once been a part of an ophiolite. As one can see on Fig. 6, we mapped ensimatic arcs separately.

As one would expect, there is no correlation of ophiolite generation (i.e., spreading) ages with any other kind of magmatic or metamorphic activity within the Altaids. After a peak in the Cambrian, ophiolite generation ages continuously decline until the end of the Triassic, which is entirely compatible with the final closure of all the Altaid oceans. Only the Khangai-Khantey ocean had remained not terminally sutured until the earliest Cretaceous (although all marine environments in its preserved portions in the Khangai-Khantey unit had disappeared by the Triassic and the ocean continued its existence and subduction under large subduction-accretion complexes), but by that time the Tuva-Mongol orocline had tightened so much that most of the generated ophiolites had already been subducted or expelled eastward.

General remarks concerning the magmatic and metamorphic evolution of the Altaids: The above discussion, when combined with the histograms in Fig. 11 and with our reconstructions (Şengör et al., in press) show that the Altaids behaved as a single super orogenic complex from the Ediacaran to the early Cretaceous. The spatial and the temporal distribution of the new isotopic ages of magmatic and metamorphic rocks agree very well with reconstructions made before they were available. The uniformity in the timing of the entire Altaid magmatism we think opposes the terrane models positing numerous collisions, because the evolution in magmatism does not show the implied stops and goes. The same is true in a much more surprising fashion with the high pressure-low temperature metamorphic rocks. They too indicate continuous subduction activity and their spatial distribution agrees with the reconstructions presented in Şengör et al. (1993a) and Şengör and Natal'in (1996a).

Because the newly available isotopic ages can be fitted into our reconstructions so seamlessly, we see no need to resort to the motion of independent terranes in the middle of a vast ocean, for which there is no present analogue. As Suess had foreseen more than a century ago, the Altaids are a single system, albeit immense.

10. Conclusions of part I

The Altaids constitute one of the largest superorogenic complexes in the world. They are shown to consist of two genetically closely related orogenic complexes that ended up forming much of northern Asia to the south and east of the Siberian Table Land of Eduard Suess (Suess, 1901) during the latest Proterozoic, Palaeozoic and the early and medial Mesozoic. This vast superorogenic complex, covering almost 9 million square kilometres, evolved as a consequence of the creation and development of two large island arc systems called the Kipchak and the Tuva-Mongol (Şengör et al., 1993a; Şengör and Natal'in, 1996a). They both have rifted from the Siberian Table Land during the Neoproterozoic following the late Proterozoic Baykalide/Uralide collisional orogeny. The Baykalide/Preuralide collisions were entirely independent of the succeeding Altaid events, simply because they formed a continuous girdle of collided continental pieces with the Siberian and the Russian cratons. Some of the girdle later rifted off these two cratons to give rise to some of the pre-Altaid massifs forming the basement of a part of the Kipchak Arc. That is why the Altaid/Baykalide distinction is so clear in Asia and there is no justification for reviving Yanshin's (1964) vague and uninformed designation of 'Central Asian Orogenic Belt' except as an attempt to steal Suess' priority (without his understanding, however).

As a consequence of this rifting, the Khanty-Mansy Ocean opened behind both the Kipchak and the Tuva-Mongol magmatic arc systems and they respectively faced the Turkestan and the Khangai-Khantey Oceans. It is at the expense of these oceans that these two arc systems generated large subduction-accretion complexes. The Kipchak Arc was completely detached from the Siberian craton during the Neoproterozoic and it was reconnected with it by means of ensimatic arc systems forming the first order tectonic units 10-13, 15-18, 26-25, 32, 34-38, 40 that formed along its strike. These ensimatic arcs also accumulated large volumes of subduction-accretion complexes in front of them, as seen in Fig. 6. As the accretionary complexes grew, magmatic fronts of the arcs migrated into them from the Cambrian to the Triassic, even into the latest Cretaceous in the extreme east of the system (see especially Şengör and Natal'in, 1996a, figs. 21.53A-F), turning them into arc massifs by magmatism and HT/LP metamorphism in arc cores. Especially near the Siberian Craton and in the Khangai-Khantey ocean, the subduction-accretion complexes were fed by turbidites shed from old continental crustal pieces represented by these two entities. When arc magmatic axes migrated into such accretionary complexes they in places exhibit Proterozoic crustal zircon ages and isotopic signatures inherited from their ancient source terrains, but now erupting through mostly juvenile material leading to the mistaken conclusion of pre-existing continental crust under such arcs. This is precisely similar to the case reported from the Japanese Cretaceous Sanbagawa and Shimanto accretionary complexes by Aoki et al. (2012). The geology of the Altaid arc complexes from which Proterozoic zircons have been reported, like the similar Japanese subduction-accretion complexes, simply precludes having ancient crust under them. It would be like looking for Precambrian crust under the Sanbagawa or the Shimanto Zone in Japan. Sensibly, Aoki et al. (2012) thought that such zircons were probably not punched through from pre-existing hypothetical old continents underlying Japan, but recycled through a complex erosion/subduction sequence from the North China craton, probably similar to the Altaid cases that were most likely fed from the Siberian Craton or from the old Tuva-Mongol massif. That is why it seems imperative to document proper field geological data together with the isotopic work, as exemplifed by the meticulous work by Aoki et al. (2012), to derive any reliable conclusions concerning crustal growth rates and not just list laboratory conclusions of samples collected without proper geological mapping, as exemplified by the most recent assessment by Kröner et al. (2014). Their handling of the local geology is not only non-existent on a field-scale (let us say 1:10,000 or larger), but their presentation of the large scale geology of the area they deal with is internally inconsistent. Their fig. 1, for example, excludes the Aldan Shield from the Siberian Craton, which is an integral part of the Siberian Craton, yet their fig. 2 includes it! They treat the Stanovoy Massif as a microcontinent with no justification whatever, yet they write 'Rytsk et al. (2011) concluded that the popular model of simple arc accretion, from S to N, onto the Siberian craton is inconsistent with their isotopic data.' They also show that what they call the CAOB terranes unrelated to the Siberian craton evolving far away from it, presumably in the 'widening Palaeo-Asian oceanic archipelago'. The two assertions negate one another, unless they can show continental assemblies forming away from Siberia and then colliding with it. No such events can be seen in the geological record! One also wanders, where the simple model they refer to has been published, except in their own and their co-authors' papers describing numerous terranes stampeding towards Siberia, examples of which we cited in the introduction, although van der Voo (2004) had earlier shown that the terrane models were flatly contradicted by palaeomagnetic observations, as well as by geology.

As Şengör (2014) pointed out, such geochronological/geochemical conclusions look impressive, because of the quantitative data they provide, but they are as reliable as their geological field basis.

In this study, we compiled 1090 new, mostly zircon ages of magmatic and some metamorphic rocks from the literature and plotted them on our geological base maps, finally transferring them to our tectonic map seen in Figs 6. and 10. These ages show a continuous arc activity from the Ediacaran into the early Cretaceous in the Altaids (within the range of the continuity observed in active arcs as seen in our Fig. 9), although arc magmatism turned off already in the Triassic in the western Altaids. The arc magmatism marched from the innermost parts of the units toward the outermost parts represented by younger subduction-accretion complexes. We have not encountered a single age that plotted on what was not previously established as older subduction-accretion material or a pre-Altaid arc crust in our earlier papers (Şengör et al., 1993a, Şengör and Natal'in, 1996a). That shows that the geological basis of those maps is very likely to be correct.

Much of the succeeding alkalic magmatism in the western part of the Altaids was related to strike-slip activity opening the West Siberian basins such as the Nurol and Nadym and the large pull-apart basins of Alakol, Junggar and Turfan. There are numerous other smaller areas of extension related to the late Altaid strike-slip activity and they too have alkalic magmatism associated with them. Some of the alkalic granites not related to the late strike-slip activity may have been related to slab fall-off as is now seen in eastern Turkey (Şengör et al., 2008), although this is now difficult to document with any confidence in the Altaids, because they are so old.

On the basis of the existing geological, geochronological, geochemical and palaeomagnetic data (the palaeomagnetic data are to be displayed and discussed in the second part of this paper: Şengör et al., in press) nowhere in the entire Altaid orogenic collage can one show independent movements of numerous 'terranes' tied to individual subduction zones. Only two major subduction zones were responsible for the entire Altaid evolution from the beginning to the end and this is consistent not only with the most recent and the present tectonics of the earth, where major subduction zones display great spatial continuity and temporal persistence, but also with the tomographic observations on well-imaged former subduction zones such as those associated with the Tethyan and the North American Cordilleran chains.

The entire Altaid collage occupies some 8,745,000 km². At least half of this area represents juvenile addition to the continental crust during the Ediacaran to the earliest Cretaceous interval on the basis of the existing geochemical observations. Older age Zr data collected from large turbidite complexes, many now metamorphosed to various degrees, cannot refute this (as the exemplary study by Aoki et al., 2012, in Japan shows), unless they can be shown to come from geologically existing provenances beneath the accretionary complexes mapped in the field. This can only be done by detailed seismic reflexion surveys such as those done in the Yilgarn Craton of Australia (see Şengör and Natal'in, 1996b). No such data are now in existence.

Half of the Altaid area is more than 10% of the entire land area of the Asian continent. Similar events are now going on in the Nipponides in eastern Asia and in the Oceanian arc systems in the southwestern Pacific Ocean. Altaids were one of the main factories—if not the main factory—of continental crustal generation during the Phanerozoic on our earth. This was not because the growth rate of the crust was unusual (by pointing this out without referring to earlier work, Kröner et al., 2014, say nothing not known earlier: it has been often pointed out that the Altaids were similar to the mostly juvenile Cordilleran areas or to the Nipponides in eastern Asia: Şengör and Natal'in, 1996b; 2004b), but because so much of it was produced in such a huge area and in some half a billion years.

Acknowledgements

We are immensely grateful for the invitation by Michael Wagreich and Franz Neubauer to write this paper. We are greatly honoured by being able to say something about one of the most important contributions of Eduard Suess in a volume dedicated to his memory. Werner Piller was also instrumental in getting this paper into this volume. We would like to thank our Russian, Kazakh, Kyrgyz, Uzbek, Mongol and Chinese colleagues who have helped us with our Altaid research for over two decades now. They are so many that it would be quite impossible to fit them all individually into this acknowledgement. The paper was reviewed by Wolfgang Frisch and Franz Neubauer and their comments have greatly improved its presentation. Finally, we are grateful to Eduard Suess, who has illuminated our path from a century ago, in every phase of our Altaid research.

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Received: 24 February 2014
Accepted: 4 June 2014

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Appendix

B. F. Hermann on thrusting in the Altay (translated by A. M. C. Şengör from the German original)

From the landing place mentioned above onwards, and still a little beyond the mouth of the Buchtarma downstream, all is *granite* of the *grey* kind, like for example, [*the ones*] that so frequently occur around *Yekatarinenburg* etc. and which consists of greyish white quartz, yellow feldspar, and blakish fine mica flakes and is fairly finely-grained. It here occurs mostly in thick *horizontal* layers, although some of which is split into thin foliae. One part stands in *strange groups* similar to the the granite crags around the Lake Kolyvan.

Immediately below the mouth of the Buchtarma those schists appear, which I had driven over so often on the land journey from Ustkamenogorsk, which consist of similar variations, with the exception that here much bluish *micaschist* occurs, with and next to *siliceous schists* [Hornschiefer *in the original*[45]]. The schist moreover crops out at steep and high cliffs, often cut very straight where the layers are mostly *vertical*. The schist outcrops continue on both sides of the Irtysh as far as a place above the mouth of the Kozlovka, where on the right shore the layered granite again is seen along many craggy and bald cliffs that look like old and ruined battlements [Ringmauer *in original*], for its many thin and horizontal layers are in numerous places *vertically* jointed, whereby the whole acquires the appearance of having been constructed of *bricks*. At this place, a little farther down, is seen that peculiar feature that *granite* overlies, or at least *appears* to overlie, the schists, for the former, itself in large wedges and woolsacks [Wollsack *in original, used here to evoke the image of sacks thrown on top of each other to visualise in the reader's mind the pillow-like exfoliation of the granites*], hangs high above the the schists, such that almost no doubt exists that the granite not really lie *on* the schists[46]. But still the latter was probably only *shoved towards* the former, because the entire left shore of the river consists here of nothing but high and steep schist walls, the *right* one of disrupted *granite domes*[47]. Only higher above these latter does one see a mountain range of high and thick schist crags stretch away above the granite.

Somewhat farther down bluish black slates [Thonschiefer *in original*] crop out on the left shore along extraordinarily high and vertically sculpted walls. Its thin beds are cut *across* numerous times entirely *horizonally*, whereby it acquires a great similarity to a *basalt wall*. A dyke [stehender Gang *in the original*] of *dense*, *whitish-grey limestone*, which is up to 8 fathoms thick, occurs in one of these walls, not far above the so-called *Silver Island* (of which nobody could tell me the right reason why it carries this name). The said island is covered with a bunch of small and large pebbles, among which are granite, various kinds of *porphyry*, *quartz*, dense and granular limestone, jasper and many *types of schists*, among which also the *Lapis lidius*[48].

From here on the rocky places along the right bank (for now and then the Irtysh has a few narrow grassy banks) consist of strong and high granite walls, which are here much less well-bedded however, but instead the rock appears in wedges irregularly fitted on top of each other. Then follows the siliceous schists, but micaschist is exposed on the left side. Then one comes to a fairly broad valley on both sides, and farther on the left bank to a few soft clay hills, but on the right soon again follow extremely wild and lacerated rocks disposed in high and steep peaks. Among those one, the Sharp Peak (*ostrii kamen* [= *sharp rock*]), is especially noteworthy. This terrible rocky range begins first to rise below the mouth of the *Pikhtovka*. But it consists only in part, and in the more lowly cupolas, many of which have been truncated along the banks into steep walls, of *granite*. Its highest and most disrupted peaks are formed, however, as one can very clearly see, from *schist*. In a few localities it crops out very near both the riverbanks, where its large hills are covered partly with enormous blocks of granite and other rock types. In narrow and deep canyons,

[45] Ospovat (1971, pp. 72-73 and 113, note 22) translated Werner's Hornschiefer in his *Kurze Klassifikation* (Werner, 1786, p. 287) as hornslate, but noted that shortly after the publication of the *Kurze Klassifikation* the term *Kieselschiefer* (= siliceous schist) was substituted for this *Honschiefer* and put into a separate category containing two common varieties of that rock: common *Kieselschiefer* and lydite.

[46] This is a complicated sentence that to Şengör at least seems to say the opposite of what we think Hermann was trying to say. We here give also the German original, with the antiquated spelling and emphasis by bold-face type: 'so daß beynahe kein Zweifel statt findet, daß der Granit nicht im eigentlichen Sinne **auf** Schiefer liege.' Hermann was probably trying to say that the granite does not in a stratigraphic sense (this is how we interpret the words im eigentlichen Sinne, i.e. "in the real sense") overlie the schists, yet it seems to have ben shoved on top of it, as the next sentence underlines.

[47] This last sentence is of the greatest importance, but it is exceedingly difficult to translate felicitously, without assuming what Hermann was trying to say. Not every reader may share our interpretation of what he was here trying to say, so we give the German original also, again retaining his archaic spelling: 'und doch ist letzterer wol nur auf jenen **angeschoben**, weil das ganze **linke** Ufer des Flusses hier auf eine grosse Sterecke aus nichts als aus lauter hohen und steilen **Schieferwänden** besteht; das **rechte** aber aus zerrissenen **Granitkuppen**' (Hermann, 1801, p. 109; we retained again here also Hermann's way of putting emphasis by writing in bold-face type). Here the important thing is the translation of the verb **anschieben**, which variously may mean push, shove, give a push. We should here recall that Hermann was writing at a time when compressional origin of mountains has not yet been seriously considered, the only suggestion having been published in the last year of his travels in Siberia, namely in 1796, by de Saussure in the fourth volume of his *Voyages* dans les Alpes (de Saussure, 1796, p. 181 and 183) on the basis of his *misinterpretation* of the vertical structures on the top of Mont Blanc as granite 'beds' that had been upturned by horizontal shortening, which de Saussure expressed with the term *refoulement*, meaning, in this context, pushing to shorten. Hermann had thus no codified terminology at his disposal, intelligible to a professional community at large, to describe and interpret what he was seeing and thinking, exactly as de Saussure in the Alps at the same time. Both saw (or thought they saw) structures that indicated a crowding together of rock masses, both, luckily, depicted them in panoramic pictures, and both tried to find the most appropriate words to describe them.

[48] *Lapis lidius*, literally Lydian stone, from ancient Lydia in Asia Minor, now called lydite or basanite. Used as a touchstone, it is a compact, extremely fine-grained, velvet or grey-black variety of siliceous schist or jasper consisting more than of 75% silica, first mentioned in antiquity in Theophrastus' book Περί Λίθον (*Peri Lithon* = on stones; see Schmieder, 1807, § 4). See also Ospovat (1971, p. 113, note 22 and p. 152) for Werner's usage.

some of these are in places covered by many-fathom-thick beds of alluvium. Most are fairly rounded, from the smallest grain to the many-pounds-heavy ones. It should be mentioned as a rarity in this region that this wild and disrupted piece of rocky terrain is covered considerably with pine trees, but only with thin ones.

But a little farther down one sees clearly again that here the granite makes up the higher rocky cupolas, while the schist the lower ones. The schist leans against the granite for a considerable strech along the right bank of the Irtysh and forms ist foothills [Vormauern *in the original*]. But soon one loses the granite ridges completely from sight and between the mouths of the two Krestovkas one sees on both banks nothing but schists, in which are a few rare quarz veins exposed, in one of which I saw small sticks of shorlite [Stangenschoerl *in the original*] in an aggregate of quartz and grey mica.

In the region of *Ognevka*, which on the left joins the *Irtysh*, *granite* is seen again, but it is partly very *flasery* and passes into *gneiss*. Between [*parts of*] this granite one sees very thick layers of a kind of *micaschist*, exposed in thick and *vertical* beds. It consists of a blakish-grey clay body, intimately mixed with very small mica leaves, and richly sprinkled with four-cornered leaves of hornblende that shine like polished steel. In this schist another yellowish fossil[49] is mixed, which looks like small not fully crystallised *garnets* or almost like *olivine*.

In a similar vertical schist bed, close up to the former, but in a kind of schist that shows a transition from the finely flaked micaschist to *clay slate*, *natural alum* weathers out, which the locals here call *stone butter* and which the wild rams [Steinwidder *in the original*] are supposed to visit often. It occurs actually on a very high and steep schist wall, which is dangeruos to reach, and was sweated out both in cracks and crevices and on the surface of the rock in stalactitic forms.

A little bit farther down on the Kirgizian side is a huge, steeply sculpted rocky wall of black schist beds, whose high edges are near the river. It is truncated by the river in such a way that one bed sticks out much farther than the others and resembles from a distance to the shadow of a rooster and that is why it is called the rooster, *petukh,* by the Irtysh travellers. Its beds are so straight, so distinct, and so thinly-leaved that at a distance it looks like a book of papers of colossal dimensions. Close by they reach, however, a thickness of 10 or more inches. These vertical beds are also cut across by horizontal lines, whereby the whole acquires an *articulated* appearance.

Similar steep schist walls are encountered farther down as far as the region of Maslovka. There granite reappears on both banks, which is here especially fine-grained, dense and very grey. Higher up along the said stream one sees a large, lacerated granite mountain, richly covered with pine trees and called *Shivera*. It has a very pictoresque appearance and is studded with ruin-like crags, which are in no way inferior to those around the Kolyvan Lake etc. Especially prominent is a natural wall made up of horizontal granite layers on the right bank of the Irtysh, which is cut by vertical joints so closely that one gets the impression of being in front of a real ruined city wall or in front of the rudera of a temple.

But one sees here too the schists above these granite rocks. The schists reappear soon as the only rocks on both banks of the Irtysh as far as a nameless stream that empties into the *Irtysh* from the *Kirgizian* side. Then once again the granite appears on both sides, however now in massive, high rock masses, which in two places display an interesting feature along vertically cut walls: half of these walls is formed from a *clay slate* passing into a blakish grey siliceous schist, and the other from whitish grey, fine-grained *granite*.

The contact of the two rock types here is extremely sharp and with no intermediary material. One sees not the slightest salvedge, such that one can chip off a piece that would consist half of granite and half of schist. It is moreover remarkable that the schist occurs in vertical, but the granite in *flat* or at least in *gently* inclined beds and layers, and that in a few places the schist so crept under the *irregularly* rising granite, that should a person see only a section of this bit and not the entire wall, which rises at least 50 fathoms, he would believe that the granite really lies on the schist, instead of the opposite proved by the observation which shows that both were only pushed towards one another." (Hermann, 1801, pp. 108-113, emphases Hermann's).

[49] Fossil is here used in its pre-19th century meaning as 'mineral'."