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Magmatism and Metallogeny of the Altai and Adjacent Large Igneous Provinces
With an Introductory Essay on the Altaids

PART C

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EDUARD SUESS AND THE ALTAIDS: WHAT IS IN A NAME?

An Essay by

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Essay "Eduard Suess and the Altaids: What is in a Name?"

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Abstract:

The name *Altaids*, proposed by Eduard Suess in 1901, signifies not only a specific orogenic belt but carries the implication that here is a kind of mountain-bulding (now called *Turkic-type* to dissociate the type of mountain-building from a specific orogenic system) very different from the one that habitually creates the classically conceived linear/arcuate, narrow orogens fashionable since the days of Eratosthenes in the second century BC. The difference lies not in a difference in processes, but in the extent to which they operate. In the Altaids, immense subduction-accretion complexes, belonging essentially to only three arc systems, dominate the orogenic architecture. In the first decades of the twentieth century, geologists tried to force this unusual mountain system into the classical geosynclinal/phase-bound orogenic models and the result has been total failure. After the Russian revolution, Soviet geologists attempted to come to grips with the Altaids by improvising on the geosynclinal model within a strict non-uniformitarian/deterministic-regularistic Kober-Stillean tectonic world view. They proposed a vast array of models and each time the models failed to account for some new observation. Model-testing in the Soviet Union was slower than it could have been because of the compartmentalised and hierarchichal nature of the scientific establishment and the ideological underpinnings of some of the models. Despite this, there has been a remarkable success in shedding successive models in the light of observations and a convergence towards a view that acknowledged the unity of the Altaid system, its continuous evolution between the Vendian and the later Mesozoic and the progressive generation of the continental crust within it from immense terrigenous deposits, invaded by felsic/intermediate magmas. It was further acknowledged that orogenic evolution migrated in waves from certain centres in a stocky-shaped, unusual orogenic system. When plate tectonics came to the Soviet Union, some suggestions had already been made to seek actualistic analogues of what one saw in the Altaids and the modern subduction systems in Indonesia had been offerend as one possible analogue. However, after the fall of the Soviet Union, the flood of western geologists coming into the country have brought with them ready-made models to apply to parts of Altaids. This carries the great danger of repeating the mistakes of the twentieth century, when Soviet geologists regarded the geosynclinal model as sacrosanct. The geologists who have long been working on the Altaids have accumulated a vast array of observations that finally killed the simplistic open-and-shut scenario of the geosynclinal model. There is little need to reintroduce that model in the new guise of non-descript terrane collisions that have little predictive power. That is why we recommend that the various names attached to the Altaid system while they were being forced into the geosynclinal model, such as the 'Ural-Amurian' or the 'Ural-Mongolian', or the 'Central Asian' orogenic belt that are now being revived in the framework of simplistic and local plate tectonic/terrane models be not used for them, lest they give the impression that the Altaids or parts thereof resemble other much simpler collisional orogenic belts in Eurasia. Altaids are more like the North American Cordillera, except that they are a sort of cordillera bent back onto itself, and that their designation ought to set them apart from the usual simpler collisional orogenic 'belts'.

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EDUARD SUESS AND THE ALTAIDS: WHAT IS IN A NAME?

To Eduard Suess (20th August 1831-26th April 1914) for his recognition that the Altaids of Central Asia are a united orogenic complex formed essentially from sedimentary and igneous rocks contemporaneous with the orogenic development, thus creating a piece of continental crust coeval and coextensive with the Altaids.

> *'Twelve years have passed, Gentlemen, since the writing of the last pages of the great work of Suess, twelve years during which numerous distinguished works on diverse regions of the Earth have been published providing a priceless amount of new facts and occasionally bold interpretations. If the master were to return among us, he might perhaps be inclined to retouch a few details of the plan, to complete a given sketch, or to account for a given episode in a different arrangement. However, I am sure that he would not consider changing the major lines of the monument, because its arrangement has, to a great extent, remained correct.'*
> Émile ARGAND (1924, p. 171).

INTRODUCTION

The purpose of this paper may be considered indigent. What can be so squalid in science as to defend a name? However, our purpose is not so much to defend a mere name than to fortify a concept that has significant implications for our understanding of the behaviour and history of our planet. An entire history of interpretation of a certain type of mountain-building is behind the name *Altaids*, first proposed by the father of modern geology, Eduard Suess, in his immortal book *Das Antlitz der Erde* (*The Face of the Earth*), in 1901. Suess' interpretation, although conceived in a fixist, contractionist framework, actually burst that framework and, because of that, found little sympathy from his contemporaries. After Suess they tried to put the straightjacket of the geosynclinal theory onto the Altaids and rendered the comprehension of their structure and history impossible. Their vision was inherited by some modern geologists and continues the threat of rendering them obscure. With a view to forestalling such a development, we first briefly review below the outlines of continental structure and present a classification of orogenic belts taken mostly from an earlier work by one of us (Şengör, 1990a). This is done so as to make a comparative anatomy of mountain belts possible. It is only by understanding how such a comparative anatomy can be done, can we undestand what sets the Altaids apart.

We then show where the Altaids and, with them, all other Turkic-type orogens (cf. Şengör and Okuroğulları, 1991; Şengör and Natal'in 1996b, 2004b) fit in this scheme. The purpose of this exercise is to underline simply the significance of the Turkic-type orogens in continent-construction and why calling the Altaids simply another Asian foldbelt, such as Central Asian Orogenic Belt or, Ural-Mongolian Foldbelt, or Ural-Amurian Foldbelt or even worse, for the sake of a foppish acronym, the Central Asian Orogenic System (CAOS), might hide their peculiarity and the actual elegance of their internal structure and mislead the geological community not closely familiar with them.

Turkic-type orogeny is important, because much of the Archaean orogeny appers to have been of that kind. The continental crust that we have today, has been constructed largely through Turkic-type orogeny. On the other hand, to come to grips with Turkic-type orogeny as a process, minute attention to regional geology is necessary. Therefore, in what follows, we first present a brief review of the outlines of orogenic structure in its multifarious forms.

In dedicating this paper on how to name, i.e., *how to express the peculiarities of,* orogenic systems to the memory of Eduard Suess (1831-1914), we wish to underline the relevance and significance, for ideas on mountain-building and associated continent-generation, of his recognition of the difference in composition and structure of what he called the *Altaids* from those of such 'classical' mountain belts as the Alps, the Caucasus, the Himalaya or the Appalachians. In the distinction he recognised lies the key to understanding of how continents are made.

In the following when the word 'figure' is spelled with a lower case f, it refers to a Figure in the literature cited; when it is spelled with an upper case F it refers to our own Figure in the present paper. Some Russian names appear in more than one transliteration below, such as Sheinmann-Schönmann or Obruchev-Obrutschew. This is because when we cite a source, we use its transliteration or transcription. When we mention the name, we use the usual Russian transliteration. But the few cases here are too obvious to cause confusion.

CONTINENTAL TECTONICS

Regional geology is not restricted to continents. It embraces the entire surface of the planet (or any other ‘rocky’ space object of interest). The reason why our discussion is here restricted to continental tectonics is because when orogens finish their evolution they end up as parts of continents and we are here concerned with defining and naming dead orogenic systems, i.e. those that no longer need to change their names.

Even if there are very few orogens that die in the middle of oceans, such as the one in Palawan (e.g., Hamilton, 1979, esp. the impressive seismic reflexion profile in his figure 105), they do not stay there long, but are transported sooner or later by the eventual destruction of intervening oceans to some continental margin, get plastered against it and thus become incorporated into continental structure. For instance, although the Emba part of the Uralides never smashed against the Obshy Syrt and thus preserved the Devonian oceanic crust between itself and the Russian Craton in the Pre-Caspian Depression (see Burke, 1977; Şengör and Natal'in, 1996a), it still was juxtaposed against the Turanian continental units across the Ust-Yurt and became part of a large continent (Natal'in and Şengör, 2005).

From the viewpoint of the regional geologist, two major dichotomies seen on the surface of the earth are fundamental: (1) the difference between continental and oceanic regions (chemical difference) and (2) that between plate boundaries and plate interiors (mechanical difference).

Continent/ocean distinction results from the different ways the continental and oceanic crust and lithosphere are produced. The ocean floors are ephemeral features of the surface of the earth. The mean age of the oceanic crust is 0.1 Ga. The earth may have entirely renewed its oceanic surface anywhere between 20 to 34 times since 4.5 Ga ago (including at least one complete recycling of the continental crust). Although the oceanic crust covers 60% of the present surface of the planet, it makes up only 20% of the total volume of the crust and some 0.00099% of the total mass of the earth.

By contrast, the continents have a mean age of *ca.* 2 Ga and in places the oldest rocks are dated to be older than 3.8 Ga. Some individual zircons recovered from continents in a few places are older than 4 Ga (e.g. Maas et al., 1992; Wilde et al., 2001); some have yielded evidence for wet mantle melting (Watson and Harrison, 2005) and reworked continental crust as far back as 4,370 million years ago (Mojzsis et al., 2001; Harrison et al., 2005). In fact, Harrison et al. (2005) have produced ^{176}Hf/^{177}Hf evidence consistent with the view that a volume of continental crust close to the present one may have formed by 4.4. to 4.5. Ga, but then entirely mixed back into the mantle by the beginning of the Archaean! The present *rock record* on continents began to be kept since about 3.8 Ga ago, i.e., since the end of the heavy meteorite bombardment (Koeberl, 2006). The total Hadean recycling may have been at least in part (see Grieve et al., 2006) a result of the heavy bombardment forcefully mixing the lighter continental crust back into the mantle (Nutman et al., 2001) and only after its essential cessation, the buoyancy of the continental crust may have managed to preserve a good percentage of its produced morcels.

Owing to the simplicity of their structure and history, the regional geology of the ocean floors is much better understood than that of the continents. The problem in the continents is the repeated overwriting of the record, because, as just mentioned, in a normal plate tectonic regime, the continental crust resists large-scale recycling owing to its buoyancy and successive events get written on it in palimpsest. Thus, the older record gets partially, and, in many cases, largely, destroyed. The older are the events affecting the continents, the less of their record survives. That is why it is of the greatest importance for the regional geologist to have general models of the first-order continental structures, in the framework of which testable working hypotheses can be erected to interpret the usually very fragmentary data field areas present. It is like doing comparative anatomy: For it to be possible, one must have complete organisms and functional hypotheses enabling correlations of their parts at hand.

Orogenic belts are among the most fundamental structures of the continents and it is actually they that by and large construct the continental crust (see Şengör and Natal'in, 1996b and Brown and Rushmer, 2006, for discussion and references) at least since the Hadean (for non-plate tectonic impact processes capable of making continental crust, see Grieve et al., 2006).

The second dichotomy the large-scale tectonics of the earth presents to the regional geologist is the *plate boundary* and *plate interior* environments and the corresponding tectonic events (Figs. C1 and C2). However, from the viewpont of regional geology, it seems, for certain purposes at least, more useful to divide the geodynamic deformations of the lithosphere into two other main categories: *structures of small wavelength* and *structures of large wavelength*—'wavelength of structure' being defined as the distance between two amplitude crests of cogenetic structures within a field of deformation (Figure C3; Şengör, 2003).

Plate boundaries generally comprise structures of small wavelength, or *copeogenic structures* (Şengör, 2003: from the Greek κοπή, to cut). These structures have spatial repeat distances ranging from below a millimetre-scale to ten-kilometre-scale. In many, the amplitude exceeds the wavelength. They are commonly associated with *fracture* or other kinds of *structural discontinuities* (such as shear belts {Ramsay and Graham, 1970} and tectonic slides {Baley, 1910; Fleuty, 1964}, for example) on a scale similar to the size of the main structure; in some, such discontinuities constitute the only evidence of deformation. The plate boundary processes, or copeogenic events, consist mainly of horizontal phenomena and readily divide into the events taking place on the three principal types of plate boundaries (Figure C2). *Orogens* (Kober, 1921), bundling together structures resulting from shortening; *taphrogens* (Şengör, 1995), grouping into one large domain structures of extension; and *keirogens* (Şengör and Natal'in, 1996a), belts along which wrench faults crowd, are the three dominant families of small wavelength structures on earth (Figure C4). Orogens, taphrogens and keirogens have map dimensions that range within similar limits and the dominant type of strain along them corresponds to the character of the deformation along the three types of lithospheric plate boundaries. In fact, if an orogen, a taphrogen or a keirogen itself is not the expression of a present or a past plate boundary, or a plate boundary zone, it must at least be now, or have been in the past, part of a deformation field associated with one. That is why it is wholly inappropriate to speak of 'intraplate' tectonism in places where rates of displacement exceed a cm/yr and where a considerable family of structures of small wavelength take up the deformation (e.g., Davis, 1980).

Plate interiors, by contrast, are characterised by the dominance of large wavelength, or *falcogenic structures* (from the Greek φάλκηs bent rib of a ship) with wavelengths from hundreds to thousands of kilometres (i.e., mostly megascopic structures: e.g., Bally et al., 1980; Hinze et al., 1980; Brown and Reilinger, 1986; Park, 1988, pp. 188-209). Amplitudes of such structures are *always* only a small fraction of their wavelength (Figure C3). In these structures, fracturing is *always* subordinate to the bending of the lithosphere (cf. Şengör 2001), despite some persistent claims to the contrary (Cloos, 1939; Burke and Whiteman, 1973; Burke and Dewey,

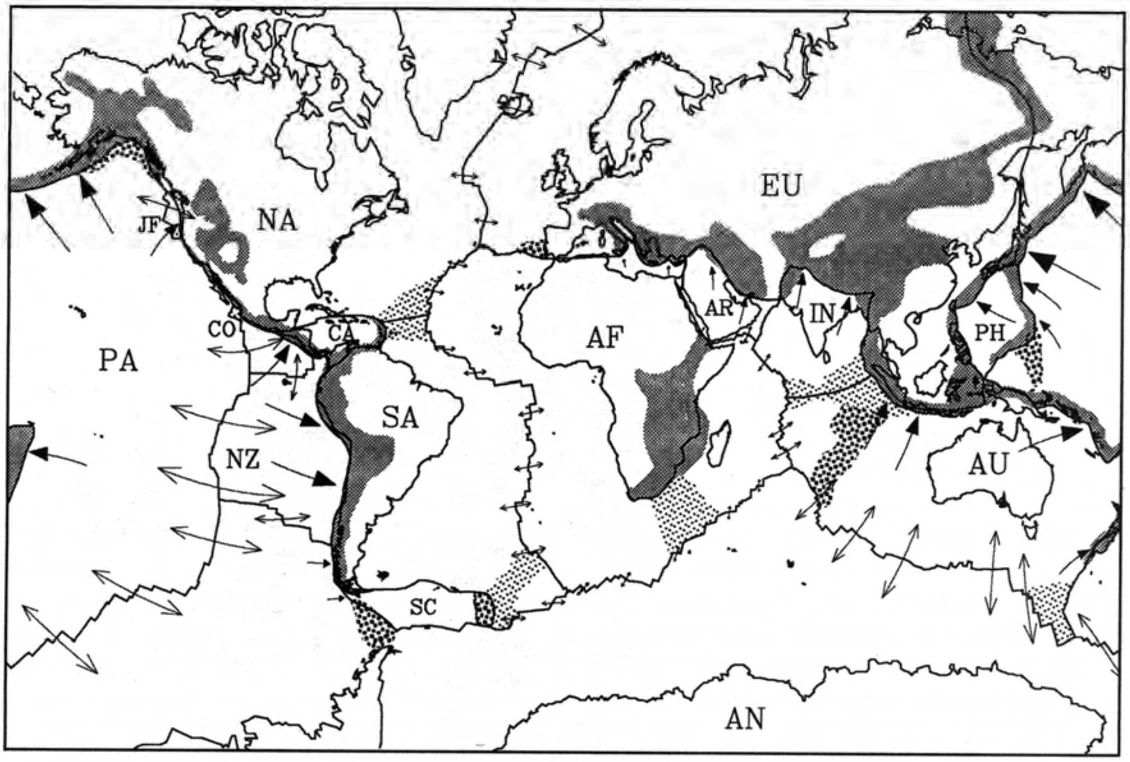


Fig. C1. Plate boundaries and plate boundary zones and relative motions across them according to the NUVEL-1 global plate motion model.

Arrow lengths are proportional to the displacement across the boundary if plates maintain their present relative motion for 25 Ma. Divergence across mid-ocean ridges is shown by diverging arrows. Convergence is shown by single arrows on the underriding plate. Plate boundary zones are depicted as broad zones implied by seismicity, topography or other evidence of faulting. Fine stipple shows mainly subaerial regions, where the deformation has been inferred from seismicity, topography or other evidence of faulting, or some combination of these. Medium stipple shows mainly submarine regions where the nonclosure of plate circuits indicates measurable deformation; in most cases, these zones are also marked by earthquakes. Coarse stipple shows mainly submarine regions where the deformation is inferred mostly from seismicity (from Stein and Sella, figure 1, with permission). The plate boundary zone deformation in Europe is actually very much broader than shown here.

1973; Ernst et al., 1995a, b; Şengör and Burke, 1978; Şengör, 1995; Baragar et al., 1996; Ernst et al., 1996; Ernst and Buchan, 1997), at least on earth (cf. McKenzie, 1994). They are all ultimately isostasy-related vertical phenomena (as Dutton recognised more than a century ago: Dutton, 1880, pp. 20-21; see figure 2). These fall into five groups, namely (1) those processes related to the heating or cooling of the lithosphere or the mantle below the lithosphere (*thermal isostasy*: Crough, 1979, 1983; McGetchin et al., 1980; Heestand and Crough 1981; Turcotte and Angevine, 1982; McKenzie, 1984; White and McKenzie, 1989; McKenzie, 1994), (2) those processes related to the loading of the lithosphere by sediments—e.g., at deltas (*sedimentary isostasy*; e.g., Fisk and McFarlan, 1955, esp. figure 11; Doust and Omatsola, 1989; Driscoll and Karner, 1994), (3) those processes related to the loading or unloading of the lithosphere through structural processes—e.g., thrusting or extensional detachment faulting (*structural isostasy*: e.g., Beaumont et al., 1982; Wernicke, 1985; Wernicke and Axen, 1988), (4) those processes triggered by the formation of continental ice-caps (*glacio-isostasy*, which is really a part of sedimentary isostasy, if one remembers that ice is first, when it is still snow, a sedimentary, then a metamorphic rock;

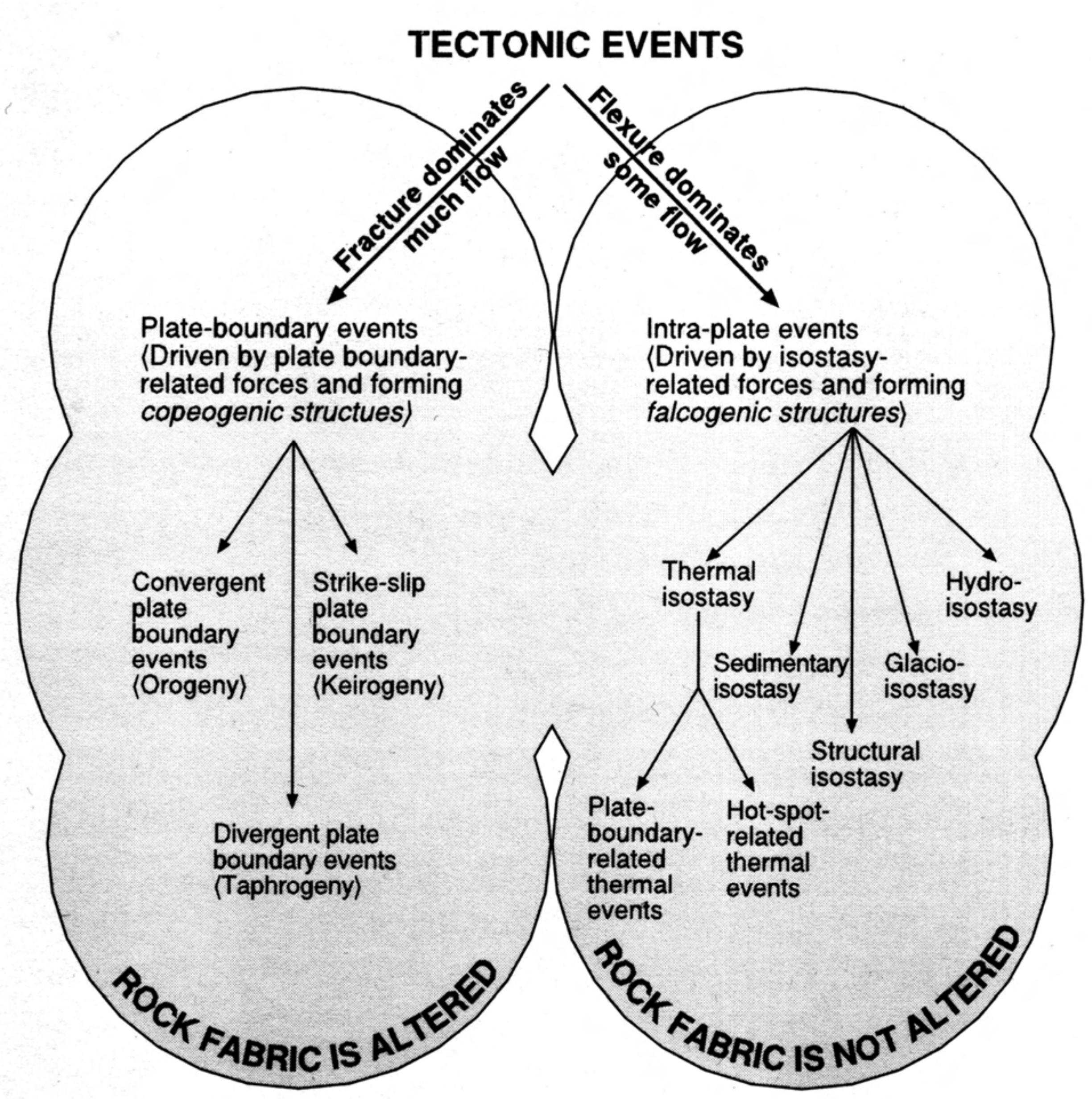


Fig. C2. The main classes of earth-sourced tectonic events on our planet.

Impact of major bolides are capable of generating tectonic edifices as spectacular as those formed by the indigenous processes (endogenous and exogenous) of the rocky planets—or more, but the classification shown here does not include them. Fracture and flow are meant to imply those only within the lithosphere. Although the plate boundary events are divided into three end-member types, it is clear that only short stretches of the world-wide plate boundary network (see Figure C1) can be fitted into one or other of these end-member types (e.g., 44% of all plate boundaries are hybrid, showing some component of strike-slip: Woodcock, 1986, figure 1; also, after him, Şengör, 1990, figure 27; also see Figure C2 herein). Of the intraplate events only the isostasy-driven ones are shown, as all others are fairly unimportant (for example, stress-induced elastic thinning or thickening of the lithosphere). Of the isostasy-driven events, varieties are shown only for thermal isostatic processes. Note also that plate boundary events are indicated to alter the fabric of rocks, whereas plate interior processes are claimed not to. These must be qualified with the word 'dominantly.' For instance, any fracture or fault atop a falcogenic dome does alter the local rock fabric there (let us say 150,000 km^3 in volume for a fault zone 500 km long, 1 km wide and 30 km deep) yet the doming itself, affecting volumes—within the lithosphere only—on the order of 50 to 100 million km^3, does not, at least not visibly (From Şengör, 2003, figure 3, with permission).

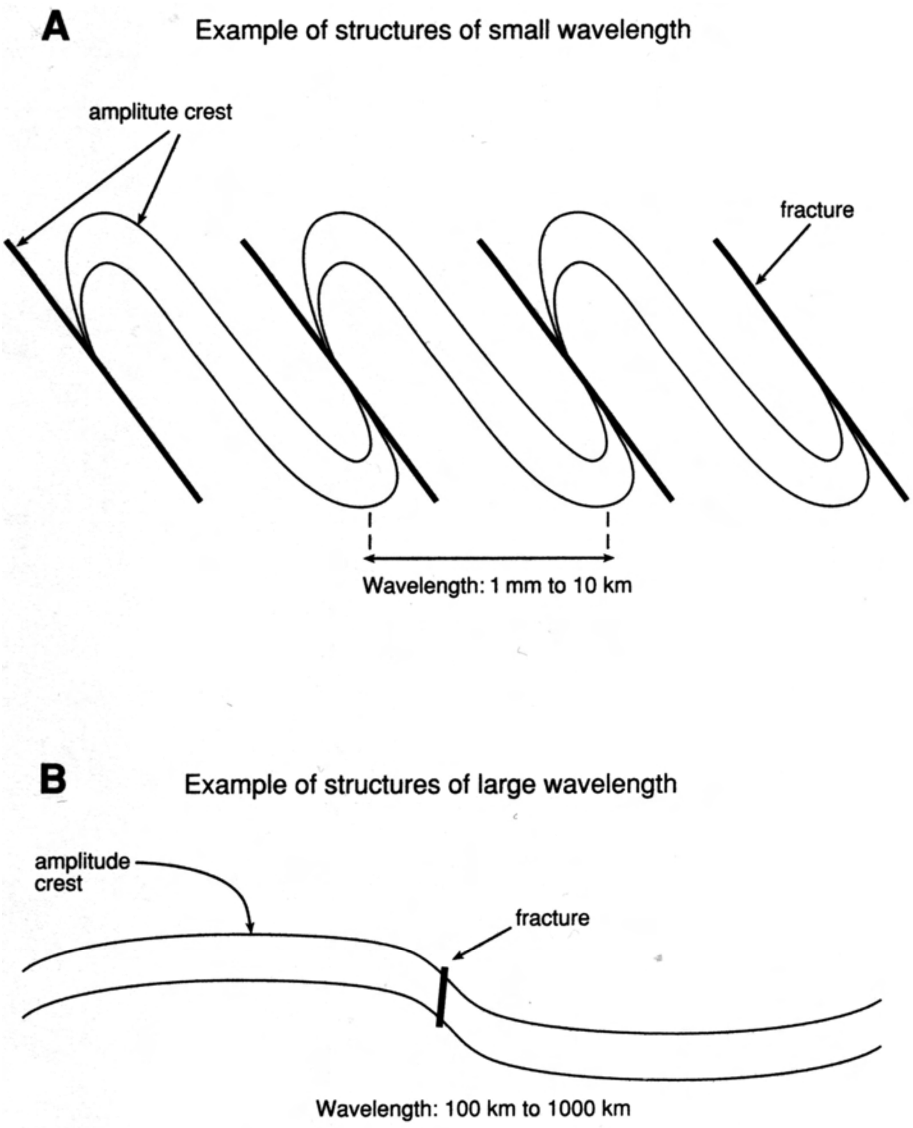


Fig. C3. Concept of ‘wavelength of structure.’

In A, a folded and regularly imbricated bed illustrates a structure of small wavelength. This picture could apply to crenulation cleavage as well as to a series of imbricated folds of mountain-size. Even if no folds were present, the imbricated structure would still define a group of cogenetic structures disposed with small repeat distances between them. Here the designation ‘wavelength’ naturally presupposes no sameness of distances between consecutive structures. It is employed only to call to mind an image of repeated recurrence with no necessary regularity of period being assumed. B illustrates a structure of large wavelength, which is *necessarily* of lithospheric dimensions (From Şengör, 2003, figure 1, with permission).

see Wegmann and Burri, 1972, for an excellent discussion of the transformations of ice and Chappell, 1974; Peltier, 1980; Sabadini et al., 1991, Aber and Ber, 2007, esp. ch. 9, for glacio-isostasy) and finally (5) those processes brought about by the formation and disappearance or waxing and waning of water bodies (*hydro-isostasy*: Gilbert, 1890; Chappell, 1974); all of these isostatic mechanisms involve a flexing of the lithosphere (Forsyth, 1979) that does not alter the fabric of the rocks at outcrop. Influencing all of these also is the state of stress within the lithospere (Gay, 1980; Cloetingh, 1988; Cloetingh et al., 1985, 1989; Etheridge et al., 1991; Zoback and Zoback, 1989, 1997; Zoback et al., 1989).

As pointed out above, copeogenic and falcogenic structures correspond *generally* to plate boundary and plate interior structures, respectively. Because copeogenic structures cut the lithosphere, they are, by definition, plate boundary structures. But falcogenic structures only gently bend the lithosphere. In places, they bend a whole plate boundary, as illustrated by the depression of the Antarctic/Indian plate boundary south of Australia creating the Australian-Antarctic Depression (Veevers, 1984), which is a falcogenic event affecting an active plate boundary. Alternation of normal mid-oceanic ridge segments with segments having no magmatism at all (the ‘ultra-slow’ amagmatic spreading centres: Dick et al., 2003) also creates strong bathymetry fluctuations along spreading centers, betraying the presence of falcogenic structures affecting the plate boundary. Trench-depth variations, generally resulting from variations in the age of subducting slabs, create bathymetry variations along subduction zones indicating the presence of falcogenic structures along the strike of the subduction zone (Dewey, 1980, figure 1: note esp. in the legend ‘trench with depth and longitudinal slope’). Therefore, falcogenic events do not *just* create plate interior structures.

Using the labels 'plate boundary' and 'plate interior' to distinguish copeogenic and falcogenic structures often leads to another kind of trouble, because many structures form thousands of kilometres away from the *usually depicted* plate boundaries (e.g. Lake Baikal from the Himalaya), yet they are within the *plate boundary zone* of the same plate boundary (Şengör, 1987; Şengör and Natal'in, 1996b; Stein and Freymueller, 2002). Plate boundary zones are difficult to draw accurately (note the error in Figure C1 in Europe), because their boundaries against cratons are commonly marked, not necessarily by individual structures of significant strain and/or displacement, but by a zone of strain and/or displacement gradient that in places may be hundreds of kilometres wide (e.g., consider the whole of the British Isles as the *edge* of an Alpide plate boundary zone: Dewey and Windley, 1988).

A regional geologist must also distinguish the presently active tectonic regime in his region of interest from those regimes that preceded it. In defining tectonic units in a region, it is generally convenient to group those structures that formed through *fossil strain systems* (‘tectonic regimes’: Harland and Bayly, 1958) under *palaeotectonic* units and those that have formed and are now forming by *active strain systems* under *neotectonic* units (Şengör, 1980). When making the neo- and palaeotectonic distinction, it is important to specify the scale at which the distinction is made (in the scale of an orogen, or a country, or a continent, etc.). In Turkic-type orogens, it is very common to confuse presently-active tectonic regimes with tectonic regimes that long ceased to be active. This sort of confusion, for instance, leads to the conflation of the Baykalide structures with those of the Altaids (see, for example, Kröner et al., 2005, for a recent example of just such a confusion).

PLATE BOUNDARY STRUCTURES WITHIN CONTINENTS

Plate boundary structures have three categories, corresponding to the three types of plate boundaries: 1) Orogens, 2) Taphrogens, 3) Keirogens (Figures C2 and C4). Figure C4 is a ternary diagram for copeogenic structures (inspired by figure 5 in Harland and Bayly, 1958). Its three corners represent pure shortening, strike-slip and stretching events. The geometric centre of the triangle is a point of no horizontal strain. If, in a region of no horizontal strain, vertical falcogenic displacement takes place, it will generate an increasing amount of extensional strain and move the region in the direction of the stretching corner of the copeogenic ternary diagram, i.e., it will start generating copeogenic structures of extensional origin.

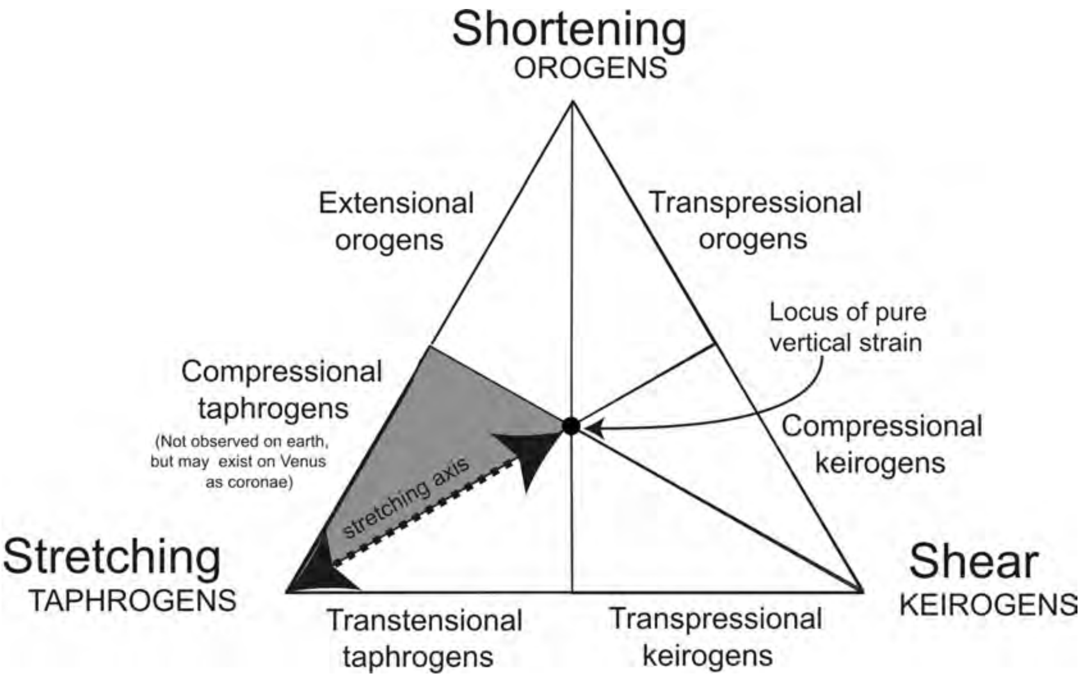


Fig. C4. Ternary diagram illustrating the strain associated with three principal plate boundaries and their hybrids.

The black dot in the centre of the triangle is a point of no horizontal strain. If vertical strain is applied here to create a dome, it will drive the strain towards the extensional corner along the 'stretching axis'. As Şengör (2001) has shown, however, this is nowhere nearly sufficient to create taphrogens given the tectonic processes on earth.

Orogens are products of convergent plate boundary events, taphrogens result from the activity of divergent plate boundaries and the keirogens are the products of major strike-slip boundaries. All three have been called orogens in the past, the latter two with qualifications indicating the dominant type of strain: Wernicke (1981, 1985) called the Basin and Range taphrogen an 'extending orogen' and Agar (1986) called the Najd keirogen in Saudi Arabia a 'strike-slip orogen.' It seems, however, more helpful and less confusing to attach different descriptive terms to each of the three different structures (Şengör, 1995; Şengör and Natal'in, 1996b).

Within an orogen, the geologist encounters structures resulting from shortening, stretching and strike-slip events. Similarly all three kinds of structures are seen also along taphrogens and keirogens. However, in orogens shortening, in taphrogens stretching, and in keirogens strike-slip dominate (Figure C4). Their genetic association with each of the three kinds of plate boundaries forms a part of the definition of the major structure families forming the orogens, keirogens and taphrogens. In the following paragraphs, the basic characteristics and types of orogens are outlined with a view to placing the Altaids into a proper perspective. Most of what is said below has been taken from Şengör (1990a), to which the reader is referred for further details.

CLASSIFICATION OF OROGENS

1) Orogens (For detailed references, see Şengör, 1990a, 1991a, 1991b, 1993, 1998, 2006; Şengör and Natal'in, 1996a, b; 2004a, b; Şengör and Okuroğulları, 1991)

Definition: An *orogen* (Kober, 1921, p. 21) *is a structure produced by the collective work of convergent margin processes* (Şengör, 1990a, p. 11). It can be wholly contained in continents (e.g., Alps, Himalaya, Altaids, Transverse Ranges in California), or in the ocean (e.g., the Marianas), or a part may be on the continent and a part in the ocean (e.g., Andes). A wholly intracontinental orogen (e.g., the Himalaya) may pass laterally into an entirely oceanic orogen (e.g., the Banda arc) via an Andean-type orogen with both continental and oceanic parts (e.g., the Indo-Burman ranges and Sumatra). As most convergent plate boundaries eventually lead to continental collision, most dead orogens lie within continents, although some convergent boundaries are known to die without being converted to another type of plate boundary mostly owing to continental collision somewhere near along the strike (e.g. Palawan trench: Hamilton, 1979, esp. figure 105).

Owing to advances in our understanding of the structure and evolution of *orogenic zones* (Şengör, 1987, p. 367), the term ‘orogen’ alone is no longer adequate to describe many major orogenic areas which are formed as a result of the activity of a large number of convergent plate boundaries in space and in time, such as the Tethysides (Şengör, 1987, 1990a), Altaids (Şengör et al., 1993; Şengör and Natal'in, 1996a, 2004a), Nipponides (Şengör and Natal'in, 1996a, b) or the North American Cordillera (Monger and Davis, 1982; Dickinson, 2004). An excellent active example of such a major orogenic area now in construction by the simultaneous growth of numerous orogens is the Indonesian/Philippine archipelagos (Hamilton, 1979; Hutchison, 1989; Hall and Blundell, 1996; Hall, 2002; Golonka et al., 2006). For such orogenic zones consisting of more than one orogen Helwig's (1974) apposite term orogenic collage has been in use. Terrane methodology proposed for tectonic analysis of orogenic collages has been criticised in detail by Şengör (1990b) and Şengör and Dewey (1990), which should be consulted for detailed literature references to 'terranology' and why it should be avoided.

Orogenic collages and the belts of *alpinotype deformation* (i.e., orogenic deformation generating penetrative strain at the scale of the orogen, forming folds, nappes, foliations etc. and commonly accompanied by various degrees of metamorphism and, in the case of the internides of the orogens, by dominantly calc-alkalic magmatism: Stille, 1920, 1924) are grouped into *orogenic zones*. Areas of *germanotype deformation* (i.e., orogenic deformation that creates non-penetrative, blocky structures, in places with some alkalic magmatism, such as the US Rockies or the post-Hercynian Central Europe) commonly accompany orogenic zones in their neighbouring cratons and result from orogenic stresses affecting the craton. *Orogenic systems* include both regions of alpinotype and germanotype deformation resulting from one orogeny; in other words, from the completion of one major Wilson Cycle, with all its attendant phenomena of opening and closing of multiple back-arc basins, coastwise strike-slip transport also including both secondary extensional (e.g. Gulf of California) and shortening phenomena (e.g. Transverse Ranges: Dickinson, 1996) (Şengör, 1984, 1990a; Şengör and Natal'in, 1996a). This definition of an *orogenic system* is important, as it relates the orogenic system as a concept to the final closure of an ocean that essentially eliminates one or more subduction zones and thus refers us back to *the* fundamental nature of the subduction zone as the defining feature of an orogen. Orogens complete their construction when their creative subduction zone ceases its activity. A number of subduction zones without intervening major continental rafts create orogenic collages, essentially bundles of orogens, and a final continental collision, apposing two major continental rafts across such a bundle, essentially creates an orogenic system.

A somewhat arbitrary category, but a useful one, is formed by the superorogenic systems. Both the Tethysides and the Altaids are examples of such superorogenic systems. They were constructed by two major Wilson Cycles without being separated by any major continental raft (i.e., no continental pieces bearing one or more major cratons) and which were genetically related. For instance, the Tethyside superorogenic system consists of the Cimmerides, products of the Palaeo-Tethyan ocean and the Alpides, products of the Neo-Tethyan ocean (Şengör, 1984). Along much of the length of the Tethysides, one can show that Neo-Tethys opened as a back arc basin to Palaeo-Tethys: hence the genetic connexion between the two orogenic systems that combines them into a single superorogenic system (Şengör, 1984, 1985, 1986). In fact, the major deformations of the Cimmerides and the Alpides look coaxial if viewed on a sufficiently small scale and in fact many of the germanotype structures of the Alpides are either resurrected or replaced structures with respect to the Cimmeride germanotype structures (Şengör, 1984, 1985; Şengör et al., 1988).

Altaids also consist essentially of two major orogens, one embodied in the Kipchak arc and its associated subduction zone and the other in the Tuva-Mongol continental fragment and its associated subduction zone. However, the Kipchak arc subduction zone also continued for a long time in front of the Tuva-Mongol fragment and as yet it is not possible to resolve whether one may have triggered the onset of the other. It is thus convenient to combine the two orogens into one superorogenic system, the Altaids. Şengör et al. (1993) and Şengör and Natal'in (1996a) document the fertility of this approach

Such considerations make a rapid overview of orogenic systems possible and allow powerful insights into the historical geology of continents.

Outline anatomy of orogens: The fundamental orogenic structure is the subduction zone and the entire orogenic architecture is best described with reference to it. This is shown by the ease with which the classical orogenic terminology, as developed by such authors as Ferdinand von Richthofen, Eduard Suess, Leopold Kober, Hans Stille and Emile Argand, can be applied to orogens in a plate tectonic framework, once the subduction zone is taken as the structure of reference.

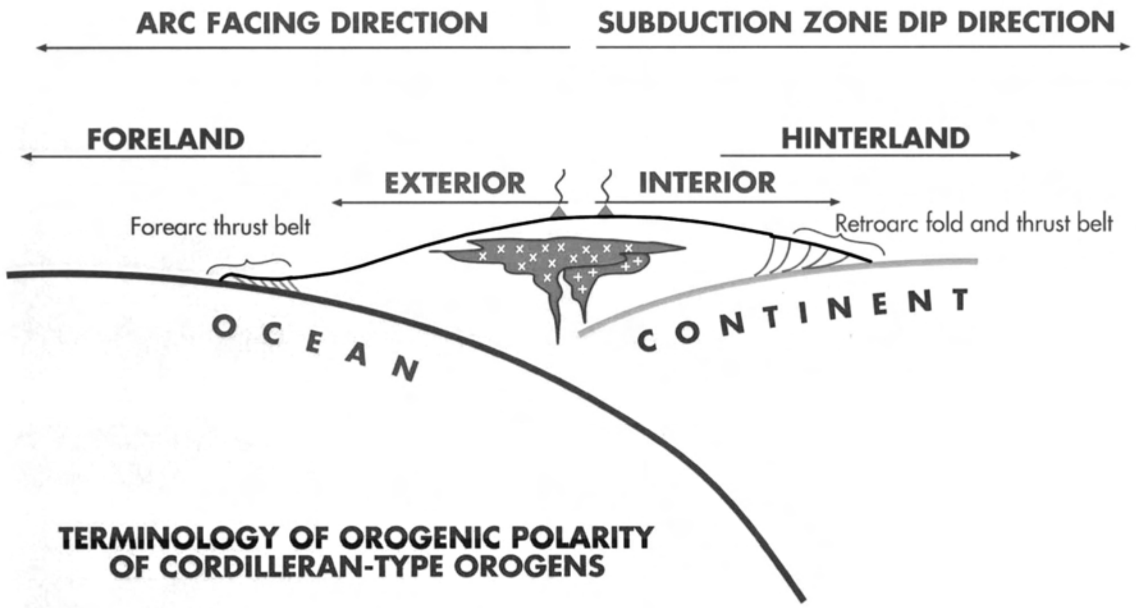


Fig. C5. The fundamental orogenic terminology of a single orogen, which is a structure produced by the collective work of the tectonic processes along a convergent margin.

Orogens have a *foreland* defined by the downgoing plate and a *hinterland* formed by the overlying plate (Figure C5). Only with plate tectonics, a clear, generally accepted distinction between a foreland and a hinterland of an orogen has become possible, namely that subducting plate (regardless of its composition) always carries the foreland and the overlying plate (regardless of its composition) always constitutes the hinterland. Before plate tectonics, the distinction was based on diverse, sometimes mutually contradictory criteria such as structural vergence, migration direction of orogenic deformation, polarity of eugeosyncline/miogeosyncline couples, character and volume of magmatism, ‘dominant direction of movement’ in an orogenic belt (e.g., Lees, 1952, p. 4) and the like. Even the man who introduced the foreland/hinterland distinction himself became confused about how to use them where a mountain belt displayed a structural symmetry at the crustal level. (See Suess, 1885, p. 775, where the Andean foreland and the foreland of the ‘Asiatic structure’ was identified to be the Pacific and in agreement with that the Rocky Mountains—considered a part of the ‘Asiatic structure’ and transitional to the Andes—were considered an area of backfolding in Suess, 1909, p. 717; then in Suess, 1909, p. 535, there is talk of the Brasilian foreland of the Andes! Although Suess considered the Andean structure as separate from the Asiatic structure, to which he attached the Rockies, the parallelisms he drew between the structure of the Cordillera of the North and South Americas make clear that he considered both to be similar. In the last volume of the *Antlitz* only, he emphasised that the west-vergent part of the Andes was not exposed. That is why Kober later assumed a sunken west wing of the Andean orogen: Kober, 1921, pp. 164-165, esp. figure 29).

In the Americas, misuse of the term foreland has been universal and, in large part, because of James D. Dana's and Hans Stille's cumulative influence. See, for example, the inappropriate, incorrect and obviously second-hand historical references in Dorobek and Ross (1995). Johnson and Beaumont (1995), clearly aware of the importance of the fore- and hinterland distinction, went so far as to invent the internally inconsistent terms *pro-foreland basin* vs. *retro-foreland basin*. They seem to think that foreland basin is a term for any asymmetric flexural basin adjacent to an orogen! In pre-plate tectonic days in the 20th century, only Stille developed an internally consistent set of criteria for separating forelands from hinterlands, which, when viewed in retrospect with plate tectonic spectacles, appears generally sound (see esp. Stille, 1940, pp. 614-616; Stille, 1948, pp. 26-31). He insisted that structural vergence is unreliable to indicate where the foreland lies. He instead pointed out that migration of folding within one *folding era* (such as Caledonian, Variscan or Alpine according to his theory of episodic and simultaneous world-wide orogeny: Stille, 1940, p. 653) and within one geosynclinal system almost always occurred in the direction of foreland. However, his claim that miogeosynclines always lie on the foreland side of a major orthogeosynclinal system was wrong as the North and South American Cordilleras so nicely illustrate. Where Stille did go wrong was his advocacy of the two-sidedness of all geosynclinal systems and nearly all orogenic belts. That is why he commonly too readily identified a legitimate area of backfolding as one of forefolding against a different foreland (e.g., the southerly backfolding of the South Alpine molasse between Como and Varese: Stille, 1924, pp. 270f. Suess had interpreted the Southern Alps already in 1875, pp. 86-95, as an exceptional thrust in the opposite direction—to the generally north-vergent structure of the Alps—and as backfolding and backthrusting in 1885, p. 352; modern tectonic interpretations of the region between Como and Varese follow Suess: e.g., Roeder, 1992, with minor and insignificant complications, e.g., Bernoulli et al., 1989, 1993; but, again, see Hsü and Briegel, 1991, pp. 148ff; Hsü, 1995, pp. 119 ff.)

Parts of the orogen close to the foreland and made up of deformed, unmetamorphosed to slightly metamorphosed foreland rocks without (or negligibly little) magmatism constitute the *external* part (Suess, 1875, 1883) of an orogen, or its *externides* (Kober, 1921). By contrast, parts showing a high degree of deformation and high-grade metamorphism plus abundant magmatism behind the externides constitute its *internal* parts (Suess, 1875, 1883) or *internides* (Kober, 1921). Internides are usually made up of oceanic and hinterland rocks, but in some orogens, the distal parts of the foreland may be underthrust for very considerable distances and become highly metamorphosed and later exposed in erosional and tectonic windows (e.g., in the Himalaya, the Guntschu and Gurla Mandata Highs: Gansser, 1964; the Tso Morari Gneiss Dome: Yin, 2006; Kangmar Dome: Lee et al., 2000). These are also counted by some as parts of the internides, especially in pre-plate tectonic days, when the origin of orogenic belts was much less clearly understood. In subduction-controlled orogens, the externides will be made up of oceanic rocks, piled up in accretionary mélange wedges or frontal folds and thrust belts, as in front of the Makran accretionary wedge (White, 1982). Following a continental collision, they fall into an internal position and the imbricated continental foreland rocks become the externides. Hence in the Alps, the basement massifs under the Helvetic Nappes, none to little metamorphosed during the Alpine orogeny, are called the external massifs, because they belong to the European foreland.

Also, behind well-developed Andean-type orogens extensive marginal fold and thrust belts develop that show relatively simple deformation and none to slight metamorphism (e.g. Allmendinger et al., 1983; Roeder, 1988; Sheffels, 1995; McQuarrie, 2002). In their stratigraphic content and architecture, involving some degree of inconsistent vergence (e.g. Roeder, 1988; Sheffels, 1995; McQuarrie and DeCelles, 2001), they are no different from the foreland marginal fold and thrust belts in terms of their structural geology. However, tectonically, such hinterland fold and thrust belts belong to the internal parts of an orogen, whereas the foreland fold and thrust belts belong to their external parts. They are thus analogous, but not homologous, structures. It is of great importance not to confuse them. A regional geologist studying a marginal fold and thrust belt must establish where that belt is located with respect to the fundamental polarity of the orogen to arrive at a correct interpretation.

Orogens thus have an *asymmetric structure* as first recognised by Suess (1875) and as Sir Edward Bailey so memorably summarised: ‘the principle that has been most fruitful has been the *one-way rule for mountain traffic*’ (Bailey, 1930, p. 25, italics his). Orogens (and magmatic arcs that are parts of orogens) are said to *face* their forelands (Figure C5). Orogenic events *migrate forwards* towards the foreland and *backwards* towards the hinterland (cf. Stille, 1909). Thus, for example, one speaks of *forefolding*, when folding marches forward, and *backfolding*, when it marches backward. Similarly, the term *retrocharriage* (=backthrusting) expresses thrusting towards the hinterland. *Rückfaltung* (=backfolding) signifies folding verging towards the hinterland. All hinterland marginal fold and thrust belts are nothing more than giant retrocharriage/backfolding structures.

All structures developing on both sides of an orogen can be simply described as being a foreland structure or a hinterland structure, depending on which side they are located. Deep-sea trenches, such as the Mariana or the Peru-Chile, are thus foredeeps (Figure C5, in which fore- and hinterland basins are indicated as flexural spaces not filled with sediment) that develop, following continental collision into foreland molasse basins on top of the incoming and underthrusting Atlantic-type continental margins and, if underthrusting goes on sufficiently far, eventually on the continental platforms, such as those north of the Alps or the Indo-Gangetic Plain south of the Himalaya. Back-arc basins that form by splitting the arc, such as the Mariana Trough, or the Japan Sea, are extensional hinterland basins. They can be eventually floored by oceanic crust, as in the examples just cited, or they may remain continental as in the case of the Eocene-Oligocene Basin-and-Range (Coney, 1980). Some basins behind arcs are shortening structures. The best-developed examples, the basins underlying the Llanos and the Pampas of the northern and central Andes, or those north of Tibet, are hinterland molasse basins, or backdeeps (Figure C5), contained entirely in a continent. Some hinterland basins developing on oceanic crust are found in the back of the Japan arc (Okamura et al., 1995) along the Okushiri Ridge (Okamura et al., 2005) and farther southwest of the Sado Ridge, where a more complex pattern of active thrusting and folding is seen (Okamura, 2003). Foredeeps and backdeeps are collectively referred to as marginal deeps (=*Saumsenken*) of an orogen (Stille, 1919a).

Continental collision disrupts both forelands and hinterlands by germanotype deformation. A complex array of compressional, extensional and strike-slip related structures may form on them. All of these can be related to the orogenic polarity by simply pointing out whether they are located on forelands or hinterlands.

In some cases two orogens facing each other may collide by eliminating their intervening common foreland. Such orogens, e.g., the Caledonides in Europe and Greenland (Figure C6A; Haller, 1985, Pickering et al., 1988, 1989; Pickering and Smith, 1995; van Staal et al., 1998), the Southeast Asian Cimmerides (Şengör 1990a), or possibly the western part of the Palaeozoic Lachlan orogenic zone (e.g., Soesoo et al., 1997, 1998; but see O'Holloran and Bryan, 1998 and Cayley and Taylor, 1998) have no forelands. Their 'externides' are found, in the *middle* of the orogenic zone, whereas their 'internides' are found along the margins of the orogenic zone, i.e., towards the outside of the orogenic zone. Their marginal deeps consist entirely of backdeeps. All of this sounds paradoxical, until one remembers that *an orogenic zone* consisting of two independent orogens facing each other is *not* itself *an independent orogen* and thus does not obey the same rules. Its constituent orogens individually do, however. To facilitate understanding all this, consider Figure C6B, and compare it with Figure C6A.

Types of orogenic belts: Having obtained the basic terminology useful in describing orogenic structures, let us now see how many different kinds of orogens there are. Şengör (1990a, 1991b) proposed a hierarchical classification of orogenic belts (including some basic types of orogenic zones) on the basis of their cross-sectional aspects (Table C1). He chose the cross-sectional aspects as the defining basis of the kinds of orogenic belts, because subduction is the single dominant aspect of orogeny (even in collisional orogenic belts) as we have just seen. In Şengör's classification, single orogens and orogenic zones consisting of more than one orogen are grouped into genera, families, superfamilies and orders, emphasising genetic relationships. The genera are the basic orogenic types and all larger orogenic collages form from the genera Şengör (1990a) has listed. Şengör's classification is a sort of check-list for the regional geologist working in an orogenic belt to see into which slot his area falls. He can start at the order level and by iterative questioning of his terrain he can gradually descend down the categories to specify more narrowly the type of the orogen he has under investigation.

Şengör's classification begins by specifying that a belt or area of tectonism has been formed dominantly through the activity of a convergent plate boundary. The class of plate boundary being convergent specifies the object of investigation as an orogenic belt (or an orogen: Table C1). Then the dominant process of convergence (transpression, subduction, obduction, collision) specifies the order, of which there are four. Orders are divided into families on the basis of the structural symmetry of the orogen and the nature of the associated magmatic arc (collisional orogens have two superfamilies). Families are subdivided into genera on the basis of the nature of the first-order tectonic entities involved (e.g., arcs, continents: Şengör, 1985, 1990a) and the symmetry of the orogenic polarity. Orogenic species are determined by arc, trench and obduction mechanism types, such as accreting vs. non-accreting trenches (von Huene and Scholl, 1991), or the various obduction mechanisms analysed by Dewey (1976). Even races may be distinguished within individual species determined by orogenic architecture, such as the two races of the Andean-type continental margin compressional arcs defined by the presence of an Altiplano-type high plateau or its absence, and the presence instead, of a wide area of cold basement thrusting, as in the Sierras Pampeanas (Dickinson and Snyder, 1978; Allmendinger et al., 1983).

Table C1 illustrates all of the first-order tectonic elements of the various orogenic taxa. Figure C7 shows representative cross-sections across some of the better-known ones representing the most widespread types. It is not possible to discuss their details in this article and for them we refer the reader to Şengör (1990a, 1990b, 1991a, 1993), Şengör and Okuroğulları (1991) and Şengör and Natal'in (1996a, b). In the following we summarise some of the salient points of the main four orders (Table C1) mainly after Şengör (1990a, pp. 170-173).

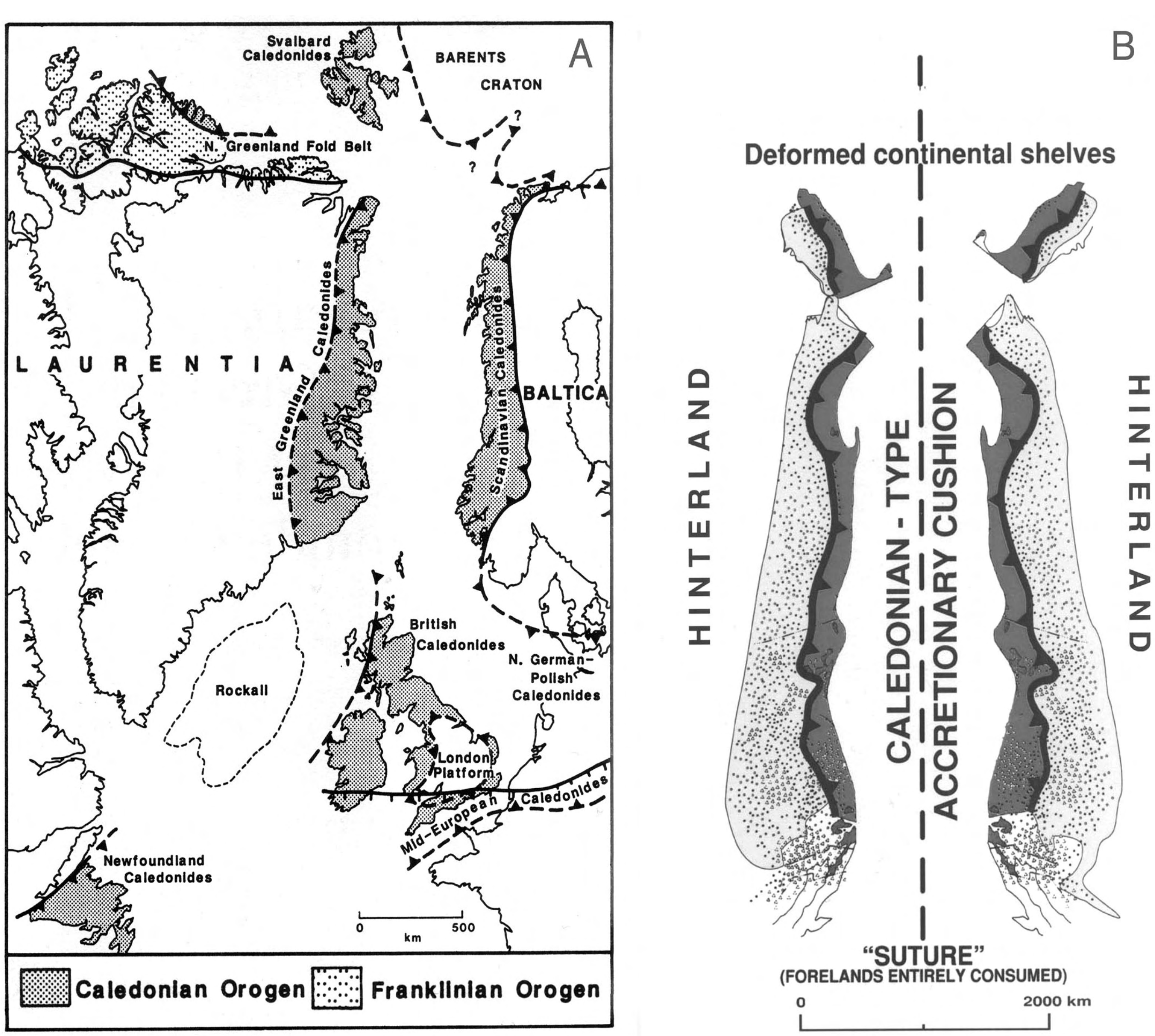


Fig. C6. The type double-sided orogen, the Caledonides (A; from Hambrey, 1989, figure 1; simplified on the cover of Gayer, 1989) and the North American Cordillera, together with its mirror image, reflected along an axis parallel with the orogen to its west-southwest (B), drawn to the same scale.

If two such cordilleras collided in the way shown, a Caledonian-type double-sided orogen *with no forelands* would result. Note that the Caledonides and the North American Cordillera between Alaska and Mexico have about the same length. Naturally, the Caledonides extended farther south than here shown, into the central and southern Appalachians. The hypothetical collisional orogen composed of the North American Cordillera and its twin would be somewhat wider than the Caledonides, but one must take into account the post-collisional shortening in the Caledonides that has not yet happened in the North American Cordillera. True, the Caledonides, especially in Norway and Greenland, underwent much extension after their collision had been completed; but so has the North American Cordillera in the Numic subtaphrogen (see Şengör and Natal'in, 2001).

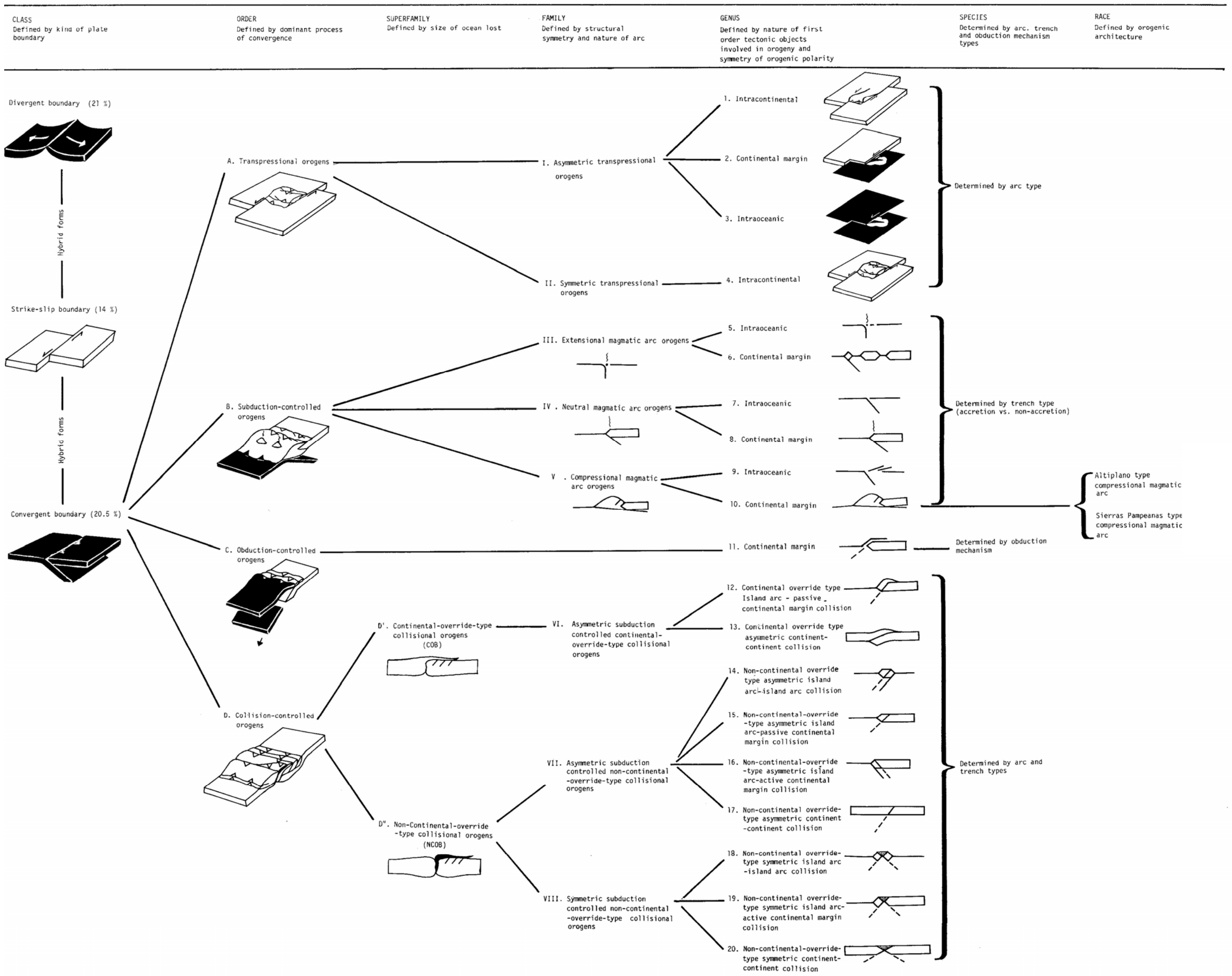
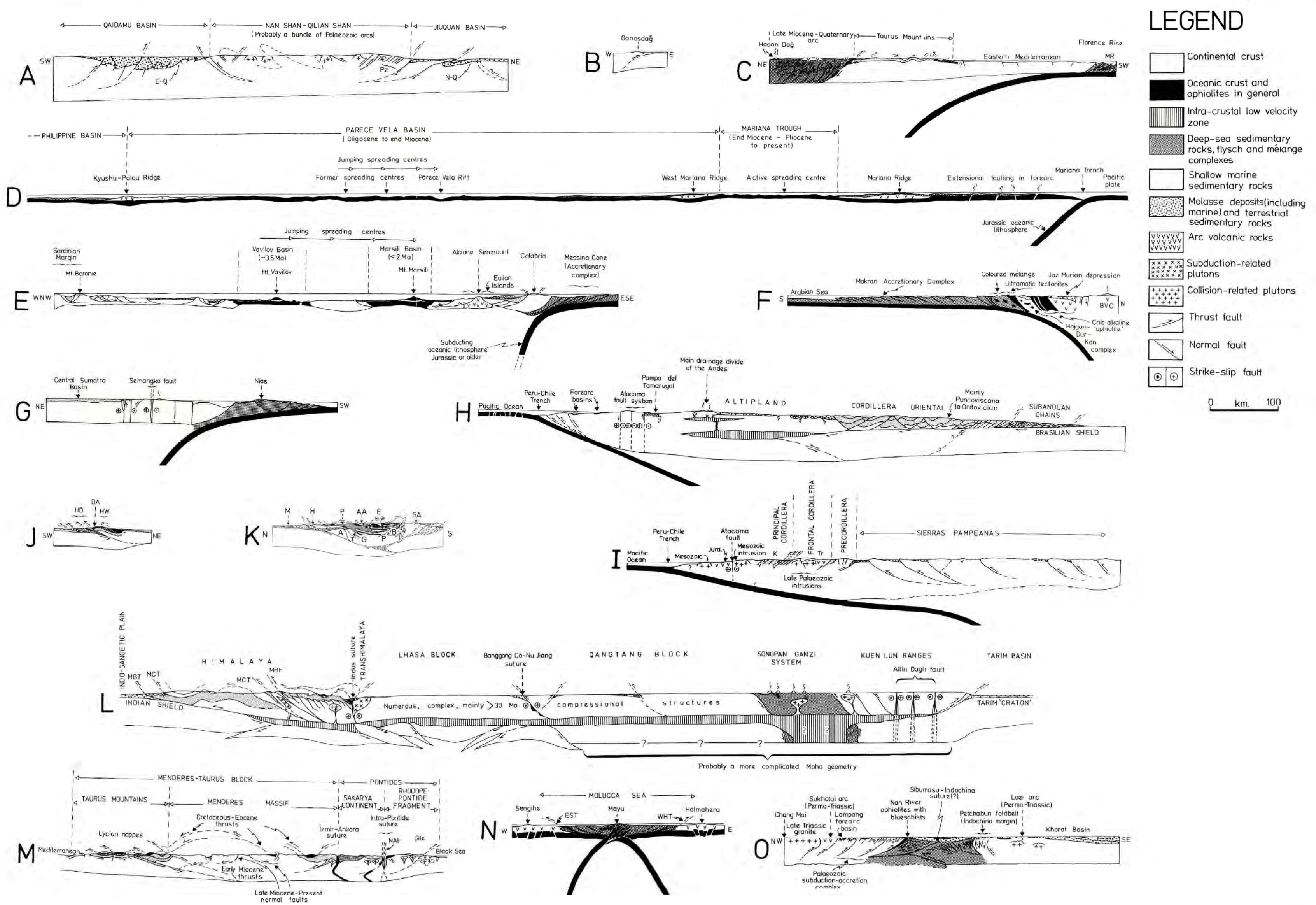


Table C1. Types of orogenic belts
(from Şengör, 1990a, reproduced with permission from ©Elsevier)

Fig. C7 (next page). True-scale cross-sections of various types of orogens (from Şengör, 1990a, reproduced with permission from ©Elsevier).

All of the cross-sections have been drawn to the same scale to enable comparison. Key to abbreviations: A: Aar massif; AA: Austroalpine nappes; B: Bergell pluton; DA: Djebel Akhdar; E: Eocene (in section A) and Engadine (in section K); EST: East Sengihe thrust; G: Gotthardt massif; H: Helvetic nappes; HD: Hamrat Duru ranges; HW: Hawasina window; M: Molasse basin; MBT: Main Boundary Thrust; MCT: Main Central Thrust; MHF: Main Himadri Fault; MR: Mediterranean Ridge; N: Neogene; NAF: North Anatolian Fault; P: Pennine Nappes; PZ: Palaeozoic; SA: Southern Alps; T: Tavetsch Massif; Tr: Triassic.


LEGEND
Continental crust
Oceanic crust and ophiolites in general
Intra-crustal low velocity zone
Deep-sea sedimentary rocks, flysch and mélange complexes
Shallow marine sedimentary rocks
Molasse deposits(including marine) and terrestrial sedimentary rocks
Arc volcanic rocks
Subduction-related plutons
Collision-related plutons
Thrust fault
Normal fault
Strike-slip fault
0 km 100
A
SW
NE
QAIDAMU BASIN
NAN SHAN-QILIAN SHAN
(Probably a bundle of Palaeozoic arcs)
JIUQUAN BASIN
E-Q
Pz
N-Q
B
W
E
Ganosdağ
C
NE
SW
Late Miocene-Quaternary arc
Hasan Dağ
Taurus Mountains
Eastern Mediterranean
Florence Rise
MR
D
PHILIPPINE BASIN
PARECE VELA BASIN
(Oligocene to end Miocene)
MARIANA TROUGH
(End Miocene - Pliocene to present)
Jumping spreading centres
Kyushu-Palau Ridge
Former spreading centres
Parece Vela Rift
West Mariana Ridge
Active spreading centre
Mariana Ridge
Extensional faulting in forearc
Mariana Trench
Pacific plate
Jurassic oceanic lithosphere
E
WNW
ESE
Sardinian Margin
Mt.Baronie
Jumping spreading centres
Vavilov Basin
(~3.5 Ma)
Mt.Vavilov
Marsili Basin
(<2 Ma)
Mt.Marsili
Alcione Seamount
Eolian Islands
Calabria
Messina Cone
(Accretionary complex)
Subducting oceanic lithosphere Jurassic or older
F
S
N
Arabian Sea
Makran Accretionary Complex
Coloured mélange
Ultramafic tectonites
Jaz Murian depression
BVC
Calc-alkaline 'ophiolite'
Bajgan-Dur-Kan complex
G
NE
SW
Central Sumatra Basin
Semangko fault
Nias
H
Pacific Ocean
Peru-Chile Trench
Forearc basins
Atacama fault system
Pampa del Tamarugal
Main drainage divide of the Andes
ALTIPLANO
CORDILLERA ORIENTAL
Mainly Puncoviscana to Ordovician
SUBANDEAN CHAINS
BRASILIAN SHIELD
I
Pacific Ocean
Peru-Chile Trench
Mesozoic
Jura.
Atacama fault
Mesozoic intrusion
K
Tr
PRINCIPAL CORDILLERA
FRONTAL CORDILLERA
PRECORDILLERA
SIERRAS PAMPEANAS
Late Palaeozoic intrusions
J
SW
NE
HD
DA
HW
K
N
S
M
H
P
AA
E
SA
A
G
P
B
L
INDO-GANGETIC PLAIN
MBT
MCT
HIMALAYA
MCT
MHF
INDIAN SHIELD
Indus suture
TRANSHIMALAYA
LHASA BLOCK
Banggong Co-Nu Jiang suture
QANGTANG BLOCK
Numerous, complex, mainly >30 Ma compressional structures
SONGPAN GANZI SYSTEM
KUEN LUN RANGES
Altin Dugh fault
TARIM BASIN
TARIM 'CRATON'
Probably a more complicated Moho geometry
M
MENDERES-TAURUS BLOCK
TAURUS MOUNTAINS
MENDERES MASSIF
PONTIDES
SAKARYA CONTINENT
RHODOPE-PONTIDE FRAGMENT
Mediterranean
Lycian nappes
Cretaceous-Eocene thrusts
İzmir-Ankara suture
Intra-Pontide suture
NAF
Şile
Black Sea
Early Miocene thrusts
Late Miocene-Present normal faults
N
W
E
MOLUCCA SEA
Sangihe
EST
Mayu
WHT
Halmahera
O
NW
SE
Chang Mai
Late Triassic granite
Sukhotai arc
(Permo-Triassic)
Lampang forearc basin
Palaeozoic subduction-accretion complex
Nan River ophiolites with blueschists
Sibumasu-Indochina suture(?)
Petchabun foldbelt
(Indochina margin)
Loei arc
(Permo-Triassic)
Kharat Basin

A. Transpressional orogenic belts commonly display uniform sense of rotation about vertical axes, in agreement with their sense of the strike-slip component, of blocks and panels of various sizes and thicknesses (for an excellent discussion on the example of the California Transverse Ranges, see Dickinson, 1996). They have a colder-than-normal thermal evolution and, partly as a consequence, alkalic magmas preponderate in the magmatic arcs associated with them (see Şengör, 1990a, for references).

A number of transpressional orogenic segments exist within the Altaids, as, for example in the Kolyvan Range during the Permian (Şengör and Natal'in, 1996a).

B. Subduction-related orogenic belts have three families determined by whether the associated magmatic arc is extensional, neutral or compressional (Dewey, 1980). Of the six genera each family has two depending on whether the arcs are intra oceanic or continental margin types. If extensional arcs form within the oceanic lithosphere, their forearcs are usually made up of ophiolites showing a complex history of extensional and strike-slip deformation. If preserved, such forearcs may be confused with fossil fracture zones or even oceanic metamorphic core-complexes and the presence of the associated arc magmatism may be the only criterion by which to tell them apart. Some may even nucleate on former fracture zones that further complicates the issue to a point where it may not be resolvable on the basis of few preserved remnants in the fossil record. Extensional arcs formed at continental margins may have forearcs reaching thicknesses of some 40 km, as in Calabria. Such arcs generally grow on the floor of their own marginal basins close to the detached continental sliver making up the fore-arc. If formed on existing arcs, they split the arc along the magmatic axis. Neutral arcs may be particularly difficult to identify in the geological record, because they may have substantial strike-slip faults along their axes, as, for example in Sumatra, along the strike sinuosities of which both extensional and shortening structures may develop (Sieh and Natawidjaja, 2000). Compressional arcs develop mainly along continental margins. Even if they evolve within oceans (one may be evolving in the Gorringe Bank on the Azores Fracture Zone: Auzende et al., 1984), they are rapidly driven onto a continental margin, where they initially may cause ophiolite obduction (see Dewey, 1976, figure 8).

All these arc types are known from the Altaids, despite our very rudimentary knowledge of their details. They can only be properly studied if mapped in sufficient detail to illuminate their strain histories and the stratigraphic/structural contact relations of their constituent rock types. Calling individual arc segments 'terranes' is no more informative than if one attempted to describe the anatomy of an animal or a plant by saying it had 'organs' without specifying the functions of those organs. One should specify what the constituant elements of an orogenic zone are (i.e., whole arc segment, or accretionary complex of an arc, or only the arc massif, etc., coupled with one or more representative geographic names, thus, e.g.: 'Rhodope-Pontide continental arc fragment').

C. Obduction-related orogenic belts generally form when a large ophiolite nappe is obducted onto a continental margin, which usually happens when a continent attempts to tuck its Atlantic-type continental margin into an intra-oceanic subduction zone, or beneath any magmatic arc that has an ophiolitic fore-arc. It is in such cases that the most extensive and coherent blueschist terrains are produced (e.g., Okay, 1989; Şengör, 1990a, figure 17). Supra-subduction zone ophiolites, commonly displaying primitive arc petrological/geochemical signatures (Pearce et al., 1984), indeed dominate the world's obduction-related orogenic belts. Ophiolites in fore-arc positions are also often obducted as parts of accretionary prisms, such as the ones detected by high seismic velocities within the Guatemalan prism (Aubouin et al., 1986). In such cases it may be exceedingly difficult to distinguish an accretionary prism that formed under an ophiolitic fore-arc basement (e.g. Constenius et al., 2000) from one that just happens to underlie a stray ophiolite slab caught up within the accretionary complex (such as the so-called Coast Range Ophiolite south of San Francisco, misinterpreted as an ophiolitic backstop to the Franciscan mélange wedge: Evarts, 1977; for reinterpretation, see Dickinson, in press).

So far, no obduction-type orogens have been recognised in the Altaids, despite claims to the contrary (see esp. Şengör and Natal'in, 2004b). Neither any Atlantic-type continental margins, nor any foreland molasse basins have been identified except along the outermost periphery of the orogenic system (Şengör and Natal’in, 1996a).

What often confuses the regional geologist is the separation of an obduction-related orogenic belt from a following collision-related one that superimposes the earlier one. Cretaceous ophiolite obduction onto the Arabian Platform in the Zagros Mountains, for example, has been frequently misinterpreted to have resulted from terminal continental collision (e.g. Berberian and King, 1981), regardless of the fact that in Oman, an across-strike continuation of the same obduction front is present and where no collision has since followed it (Lippard et al., 1986). Ophiolites obducted across transpressive fracture zones (Saleeby, 1977; Karson and Dewey, 1978) and the obduction of old oceanic lithosphere through a number of mechanisms (cf. Dewey, 1976) may also generate obduction-related orogenic belts of various sizes, most of which later become incorporated into collisional orogens.

D. Collision-related orogenic belts form a large order. They are divided into two superfamilies: Those with a high overriding continental nappe and those without. This criterion marks a fundamental difference between those orogens that grew out of oceans that had never been wider than about 1000 km, measured perpendicular to the subduction direction, such as the Alps with the high Austroalpine continental nappe complex, and those that resulted from the disappearance of a large ocean (minimum perpendicular-to-convergence width >> 1000 km), such as the Himalaya whose highest tectonic units are formed from the ophiolite nappes (Şengör, 1991c). Şengör (1990a) called the former type Alpine and the latter Himalayan.

Turkic-type orogenic belts, our special focus in this paper, forms a species group of the Himalayan-type superfamily, where, because of the dominantly accreting nature of the associated trenches, the accretionary complexes grow to such large sizes, such as the ones in the present Makran (McCall and Kidd, 1982; Arthurton et al., 1982) or Alaska (Moore et al., 1991; Plafker et al., 1994), that they actually arrest continental convergence before the original continental nuclei of the converging continents can come into contact. The Altaids form the most extreme case of this species so far known (Şengör et al., 1993; Şengör and Natal'in, 1996a, 1996b), but the Kuen-Lun (Şengör and Okuroğulları, 1991), the Lachlan (Gray, 1997; Gray et al., 1997, 1998; Gray and Foster, 1998; Foster and Gray, 2000; Glen, 2005) and the Songpan-Ganzi Sytem in China (Şengör, 1984; Zhou and Graham, 1993; Nie et al., 1994) are further Phanerozoic examples, whereas the Pan-African System of the northern Afro-Arabia is the best known latest Proterozoic-earliest Palaeozoic example (see Şengör and Natal’in, 1996b; Kröner et al., 2005). Older Proterozoic examples include the Svecofennides in Finland and Sweden (see esp. Wegmann, 1961; Patchett and Kouvo, 1986; BABEL Working Group, 1990;) and the early Proterozoic crustal provinces in the United States (Van Schmus et al., 1993, esp. figure 38; but see Bickford and Hill, 2007). In fact, most Archaean greenstone belts are probably remnants of Archaean Turkic-type orogens (cf. Şengör and Natal'in, 1996b, 2004; Burke, 1997).

When accretionary complexes are caught up between two or more converging continents, they gradually thicken, while their underlying oceanic lithosphere continues to be subducted 'subcutaneously' under them. This 'hidden subduction' gives rise to apparently enigmatic, entirely land-bound magmatic arcs, as in the late Triassic to early Cretaceous history of the northeastern and western margins of the Songpan-Ganzi System (Şengör, 1984). When the subcutaneous oceanic lithosphere eventually falls out, asthenosphere fills its place and, while rising to do so, it undergoes decompression melting (Soesoo et al., 1997; Şengör et al., 2003), produces basalts which further melt the overlying accretionary complex rocks and give rise to widespread vulcanicity ranging from calc-alkalic close to the former arc to alkalic away from it (Şengör et al., in press). Some of the extensive A-type granites and the associated Permian vulcanicity in the Altaids may have been of this origin. Similar post-collisional igneous rocks are known from the Pan-African of Arabia (see Şengör et al., in press, for references).

Turkic-type orogens are most readily recognised by the presence of extensive terrains of dominantly flysch deposits, associated with fragments of ophiolites, cherts and various types of knockers swept from diverse oceanic environments (basaltic ocean islands, oceanic plateaux, stray—but rare— Seychelles-type continental fragments). These rocks are often multiply-deformed, generally metamorphosed at most to higher greenschist grade, intruded by arcuate belts of arc magmatics and covered by their volcanic products. Such arcuate belts of arc magmatic rocks poking through vast terrains of subduction-accretion material as a rule young in the direction of the growth of the accretionary complex. Şengör (1993), Şengör et al. (1993) and Şengör and Natal'in (1996a, 1996b, 2004) have discussed at some length the regional/field aspects of Turkic-type orogens. See Wegmann (1961) for the description of deeper levels in a Turkic-type orogen on the basis of the Svecofennides in Finland. Wegmann's outstanding paper reads like a guide for the recognition of old Turkic-type orogens and must be recommended reading for anybody wishing to work on such orogenic belts.

Alpine-type orogens have only two genera: arc-passive margin and continent-continent collision genera (Table C1). By contrast, the Himalayan type is very rich both in genera and species and the Himalayan-type orogens clearly dominate the orogenic history of the earth. The Turkic-type orogenic complexes are nothing but a species of the Himalayan type (e.g., Şengör, 1998, figure 95).

The evolution of Turkic-type orogens generally follow and in part coincide with times of major continental glaciation, low global sea-level and high ^{87}Sr/^{86}Sr ratio in the oceans (Şengör, 2006a), whereas the other kinds of accretionary-complex-poor or even -free Himalayan- and Alpine-type orogens commonly form after and in part during times of continental glacier-free earth, high sea-level, and low oceanic ^{87}Sr/^{86}Sr. This reflects the availability of clastic material delivered into the oceans (clastic input into the oceans has increased four-fold since the Cretaceous, for example: Southam and Hay, 1981, figure 5) to be scraped off into accretionary complexes. ε_{Nd} values can be used to see whether the clastics represent juvenile (+values) or reworked (-values) material (see Şengör and Natal'in, 1996b).

Germanotype areas of orogenic systems: As mentioned above, outside the Alpinotype zones of the orogenic systems, the flanking continents commonly get deformed during both collisional and compressional magmatic arc-related orogeny. In these areas, deformation is characterised by blocky structures that do not create penetrative structures. These blocky structures take the shape of chains of thrust-bound basement uplifts within cratons marginal to orogenic belts (Rodgers, 1987), similar to the U.S. Rockies and the Sierras Pampaenas in compressional arc orogens or the Mangyshlak/Kyzyl Kum uplifts and the Cainozoic Tien Shan mountains in collisional orogens (cf. Şengör, 1990a). In addition to such uplifts, impactogens (rifts at high angles to orogenic belts produced by point collisions: Şengör, 1976, 1995; Şengör et al., 1978), rift clusters resulting from orogen-parallel extension and conjugate strike-slip faults resulting from an overall orogen-normal shortening of the fore- and hinterlands accompany orogeny in the germanotype fore- and hinterland fields of collisional and compressional arc-type orogens (Şengör, 1995).

In the next section, we present the original definition of the Altaids as given by Eduard Suess, who defined them as a kind of mountain-building different from the classically-known ones in the Alps, in the Himalaya, in the Caucasus and in the Appalachians. Suess' descriptions are still very relevant to an understanding of the Altaid structure.

ALTAIDS

In 1901, in the third volume of his immortal *Das Antlitz der Erde* (The Face of the Earth), Suess noticed that mountain ranges built to the south and west of the East Siberian table-land during much of the Palaeozoic—which he collectively called the *Altaids* after the Altay Mountains—were formed mostly from schists, slates and clastic sedimentary rocks, intruded by granites of various ages and overlain by diverse types of mainly intermediate and felsic volcanic rocks. Following Alexander von Humboldt (1843), he pointed out that this was surprising, because until that time most mountain ranges that had become geologically known were seen to contain a large proportion of gneisses in their structure (particularly along their 'axial' parts).

Suess further noticed that mountains with a significant proportion of older gneisses in their structure possessed well-defined fore- and hinterlands; in other words, they were long and narrow, linear/arcuate, structures. That orogenic belts are long and narrow objects is a recognition dating back to Eratosthenes of Cyrene (284 or 274 to 202 or 194 BC) is known to few geologists today (see Şengör, 1998). Eratosthenes' recognition had long been assumed to be a universal property of mountain belts and thus led to much confusion when the mountains of Central Asia were seen not to have that property. Suess saw that if every range in Central Asia were assumed to be an independent orogenic belt (as some 'terrane' enthusiasts claim in our day), no sense could be made of its tectonic evolution. Every range possessed an internal structure that was a direct continuation of the neighbouring ranges and only when all of them were considered together it became possible to reconstruct an intelligible architecture and history.

However, 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—the prevailing global tectonic theory of the day, and the one Suess was known to support. 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)[1]. This annoyed many of his contemporaries and successors, who henceforth chose to adhere to the theory and to repudiate his interpretation of the tectonics of Central Asia (see esp. Şengör, 1998, p. 79 for quotations and discussion; also see below, the next section). However, it has remained fashionable to admire and to cite him—but not to understand him. The reason for this became obvious only after the emergence of plate tectonics: Suess had correctly recognised both the structure and major elements of the history of the Altaids, but neither could be explained in any detail without a knowledge of the processes and the environments in deep sea trenches and island arcs[2], which become possible only through plate

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[1] In the English edition: Suess (1909, p. 626). In the French edition: Suess (1918, pp. 1616-1617). However, he was not ready to let it die completely. See Suess (1913).

[2] Suess clearly implied that the orogenic events within Asia and those now shaping the margins of the Pacific were the same sorts of events in sketches he sent to Prof. W. J. Sollas, the editor of the English translation of the *Antlitz* (Suess, 1924, foldout titled 'Explanatory diagrams supplied by Prof. Suess': see Fig. C8A herein). Argand, who saw himself as the heir to Suess' throne, put it poetically thus: '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

tectonics. Shortly after he died, both Russia and China became essentially inaccessible to western geologists and his large database[3] has long remained the only source of reliable information about vast areas in Asia. It is *still* a valuable source for the more remote areas of this immense continent. Although this repository of regional information was frequently cited, what it meant was not undestood until plate tectonics made it intelligible to the majority of geologists.

The modern recognition that much of Central Asia consists mainly of Palaeozoic subduction-accretion complexes and is mostly juvenile has grown out of a re-evaluation of Suess' interpretation of its geology, especially from his emphasis on the paucity of older gneisses in its structure, on the dominance of schists, slates and clastic rocks in places interleaved with mafic and ultramafic igneous rocks, the disposition of granites in long and narrow, 'arc-like' structures, the ubiquitous steepness of the bedding and schistosity, and the apparent absence of a foreland. However, today his book is unfortunately inaccessible to most geologists, although it has been translated both into English and French (only its first volume was translated into Italian in 1894 by P. E.Vinassa de Regny). It has long become a 'rare book' fetching prices upwards of a thousand Euros in the cheapest dealers. It is concerned with the entire world and those few geologists with access to it hardly have the time to search for its relevant chapters to read to get the gist of his ideas on Central Asia. Even if they did, the antiquity of the concepts, the geological terminology, even toponymy, and Suess' style of almost hiding his interpretations in the long descriptive passages, would bar most of them from understanding it. Because of that, we decided to reproduce below the text where he defines the Altaids, with some explantory notes and Figures to aid comprehension.

Note: When Suess says 'Archaean,' he simply means Precambrian rocks (most commonly crystalline) bereft of fossils. Also, Suess considered the Altaids as a much broader concept than we do today, including even the youngest ranges of Asia that seem broadly concentric around the Angaran nucleus (see Figures C8B, C8C and C8D). He therefore discusses, in the text below, the Kuen-Lun and its easterly continuations into the Qilian Shan, Qinghai Nan Shan, Anyemaqen Shan and even Tanggula Shan, as parts of it. Although we today consider the Kuen-Lun *sensulato*

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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). The importance of 'arcs' in mountain-building was a popular topic in the beginning of the twentieth century mainly because of Suess' influence. See, for example Kayser (1905, 1912), Sacco (1906), Ogawa (1907), Andrée (1914), Taylor (1910, 1921), 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 continued to be prominent (e.g., Lake, 1931; Russo, 1933, 1950; Kay, 1942, 1944, 1947, 1951, 1952; Lee, 1952; Umbgrove,1947; Wilson, 1950, 1954, 1957; Benioff,1954) and one of their authors, J. Tuzo Wilson, ended up inventing plate tectonics in 1965.

[3] Especially as enlarged in the French edition by Emmanuel de Margerie by the publication of the figures from sources that Suess had used but could not publish owing to high cost of reproduction. Some figures were expressly drawn for the French edition. De Margerie also augmented Suess' bibliography mostly by adding references to sources 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 this augmentation, 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.

a part of the Tethysides, its structure is like that of the Altaids and unlike most of the rest of the Tethysides (Şengör and Okuroğulları, 1991). In that regard, Suess' grouping has some justification. What makes the Kuen-Lun Tethyside in our minds is not its style, but its history and tectonic connexions (cf. Stille, 1928a, esp. figure 1; Şengör and Okuroğulları, 1991, figure 10; Natal'in and Şengör, 2005), which Suess could not have known in a fixist world.

In the footnotes below, we have explained those terms likely to be unfamiliar to an average geological reader not working on Central Asian geology, including some geographical names. Italic comments and footnote numbers, given in square brackets [ ], are our additions. Wherever it was necessary to use parentheses within parentheses, we have set pointed brackets { }. All Figures are our additions to Suess' text, made with a view to enable a reader unfamiliar with his ideas (and the geography) to follow the description and the argument. That is why we were careful to choose the illustrations from the publications of his correspondents and sources. We always gave page numbers of the passages we cite in all three editions of Suess' book to enable readers familiar with any one of these languages to be able to locate the passages without further trouble. Those wishing more comprehensive accounts of Suess' tectonic concepts and his general outlook in geology should read Greene (1982, chs. 6 and 7) and Şengör (1982a, 1998, 2000 and 2006). For various facets of Suess' life in general, see Suess' own memoires (Suess, 1916; devoted, however, almost entirely to his political life and very little to his geological work), Obruchev and Zotina (1937)[4], Wegmann (1981), Hamann (1983), Pinneker (1989), Tollmann (1990) and Cernajsek et al. (1999; with a fine bibliography on Suess). We do not recommend Tietze (1917), the only long critical monograph on Suess' work, for those not closely familiar with Suess' work, because it is so full of misunderstandings and misrepresentations as to render it essentially useless. Here, then, is Suess' text:

'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 [*Figure C9*] 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

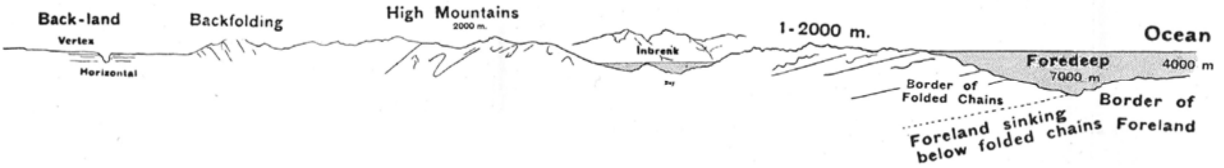

Fig. C8A. Cross-section across Asia from the East Siberian table-land to the high ranges close to the Pacific Ocean (from Suess, 1924).

We combined it from a section he provided across the Pacific trenches. The section across Asia and the section across the trench are found on the same page, one below the other, and seem to be parts of a single cross-section, separated only by the exigencies of space. We simply restored them to a single section giving a faithful idea of Suess' view of the structure of the Altaids from his own hand.

By contrast, Suess never provided a map of the Altaids. His coloured plate VII in the third volume of the Antlitz is only a partial map. Because of this deficiency, we reproduce below, as Figures C8B and C8C two maps showing the distribution of the Altaid structures according to Suess, drawn by two contemporaries of his, the physical geographer Emmanuel de Martonne and the geologist John Walter Gregory.

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[4] This book is by far the best biography of Suess. Obruchev himself was a great geologist and geographer and a friend of Eduard Suess. It is now being translated into German in Austria by Barbara Steininger as part of a Collège de France, Chaire Internationale project on the history of tectonics initiated by A. M. C. Şengör (*titulaire*: 2004-2005)

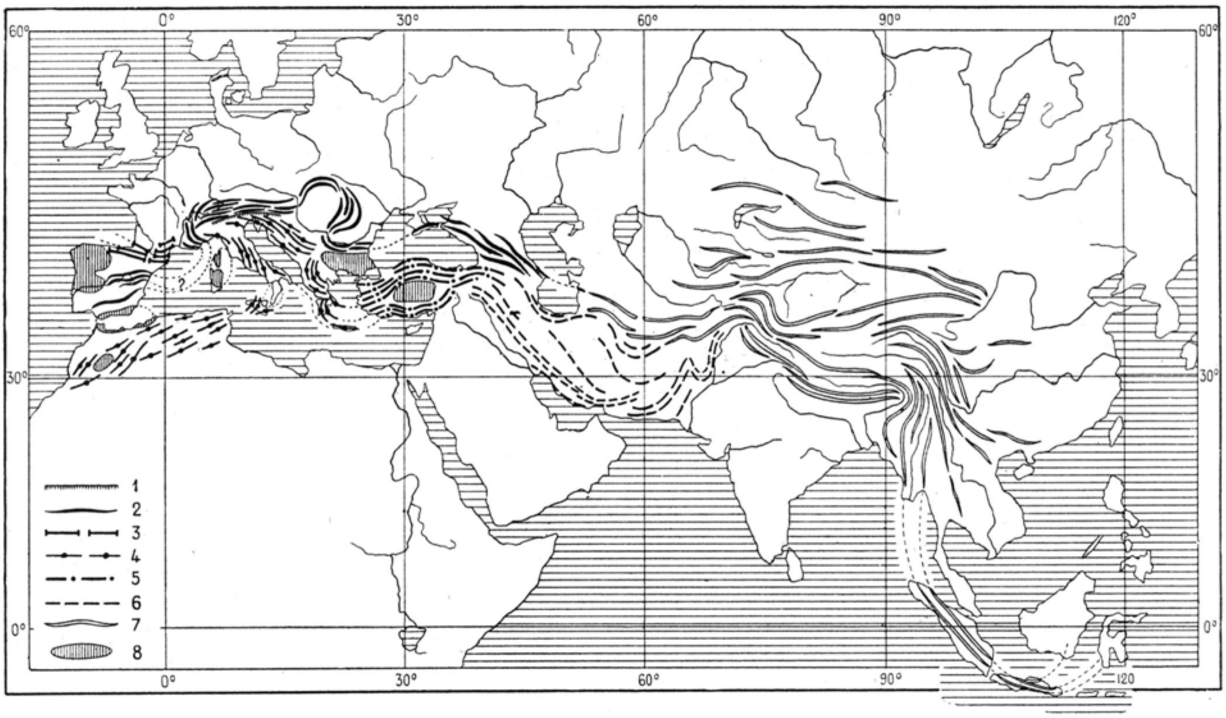

Fig. C8B. Emmanuel de Martonne's rendition of Suess' Altaids.
Key to legend: 1. Tonalitic scar; 2. Alpine folds *sensu stricto*; 3. Pyrenean folds; 4. Dinaric folds; 5. Tauric folds; 6. Iranian arcs; 7. Altaids; 8. Hercynian massifs included in the Alpine zone (from de Martonne, 1909, figure 273).

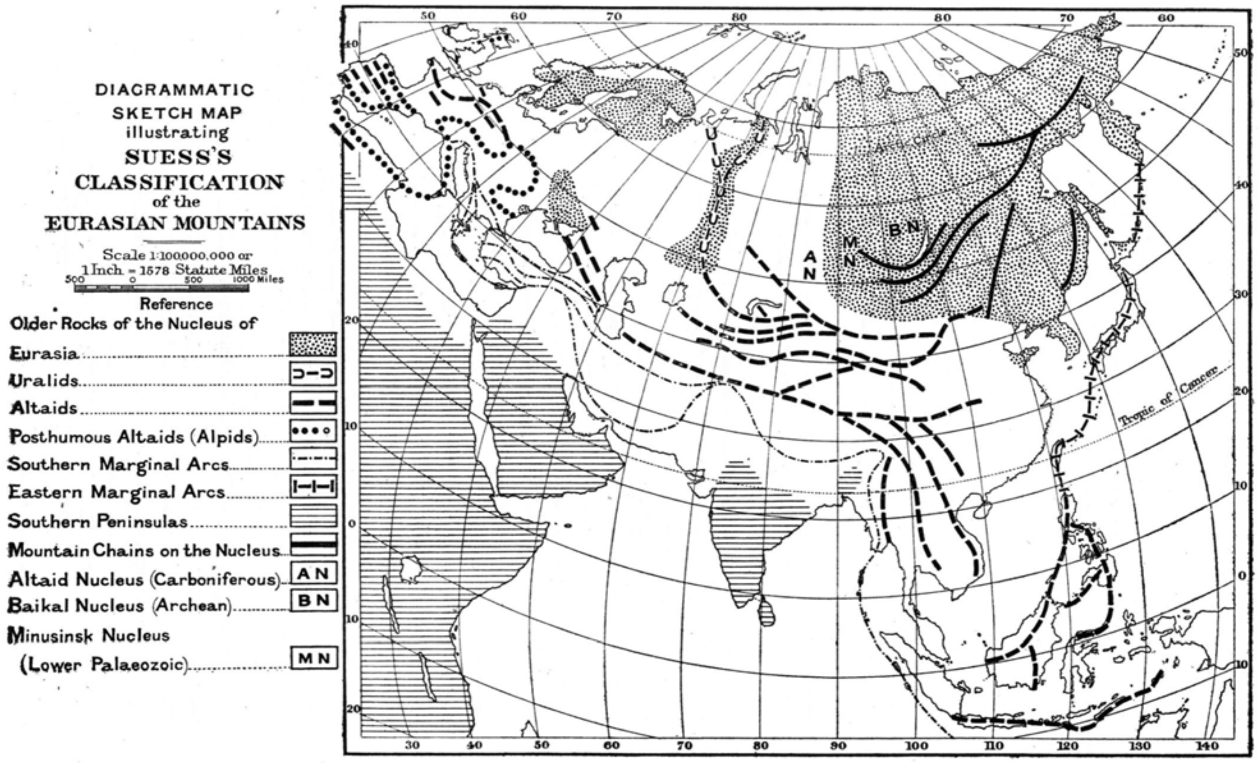

Fig. C8C. John W. Gregory's rendition of Suess' Altaids. From Gregory (1915, unnumbered figure on his p. 499).

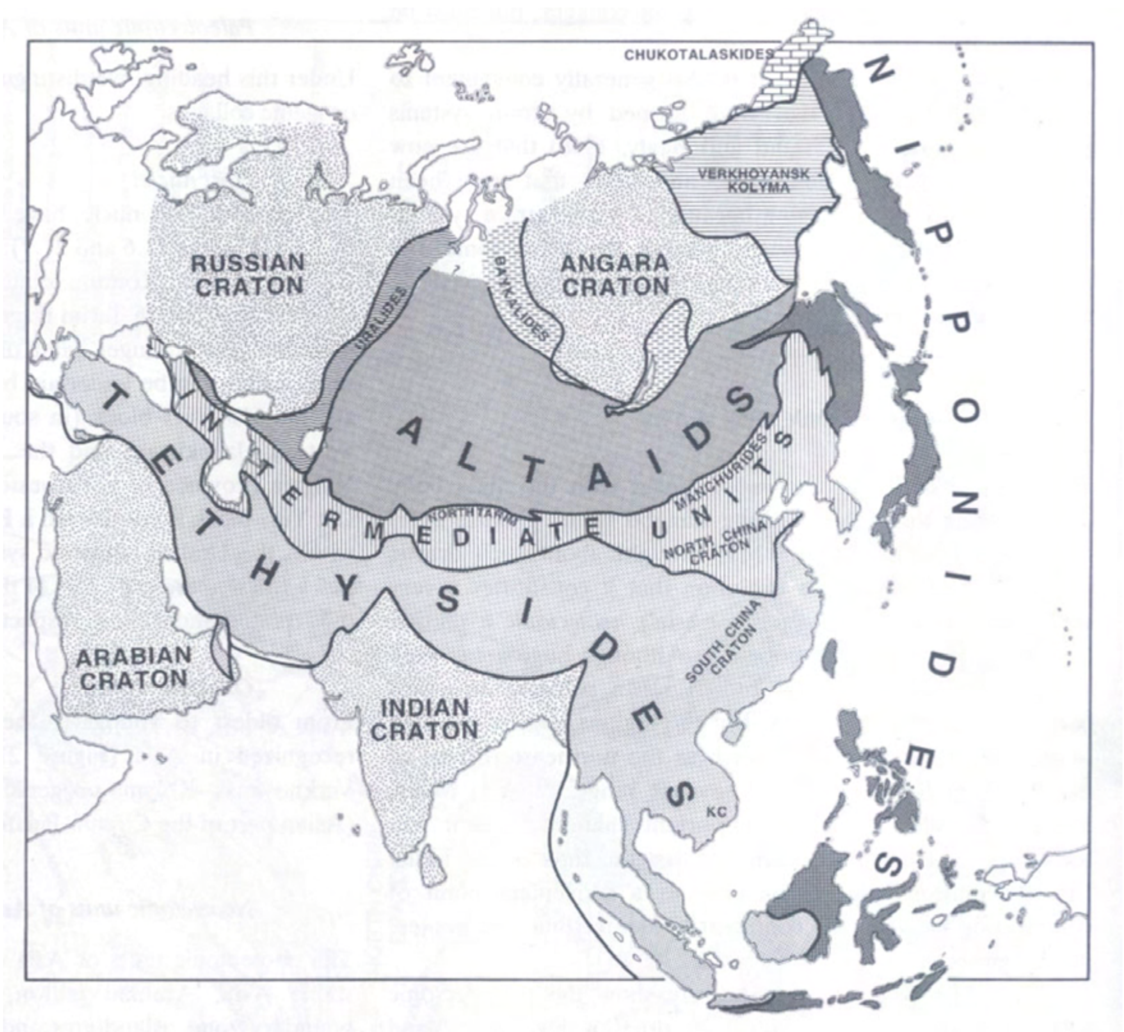

Fig. C8.D. Current understanding of the extent of the Altaids.
From Şengör and Natal'in (1996a, figure 21.7)

dislocation[5], and perhaps also in isolated cases to particularly long granite trains which reveal themselves in the relief of the country.

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[5] 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; in the English edition: Suess, 1908, p. 41; in the French edition: Suess, 1902, pp. 55-56). 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.

Fig. C9. Tectonic map of a part of Central Asia showing the ancient vertex of Asia and associated units after Obrutschew (1926, plate 11). Suess never presented a map of the ancient vertex. Obrutschew was one of his most loyal followers in the definition of it[6]. For a description of the ancient vertex of Asia, see Suess (1901, ch. 3) and Obrutschew (1926, pp. 15-17).

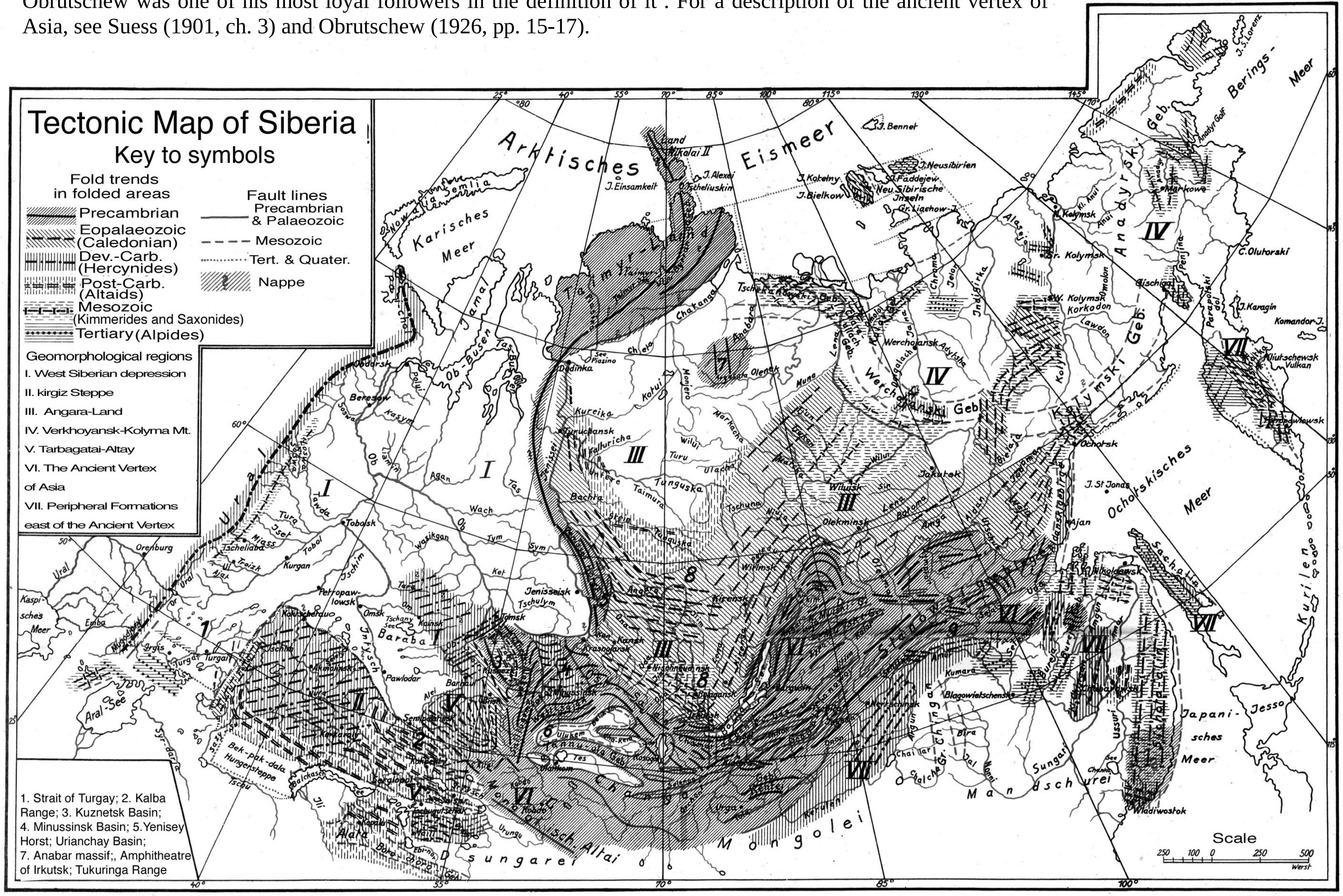
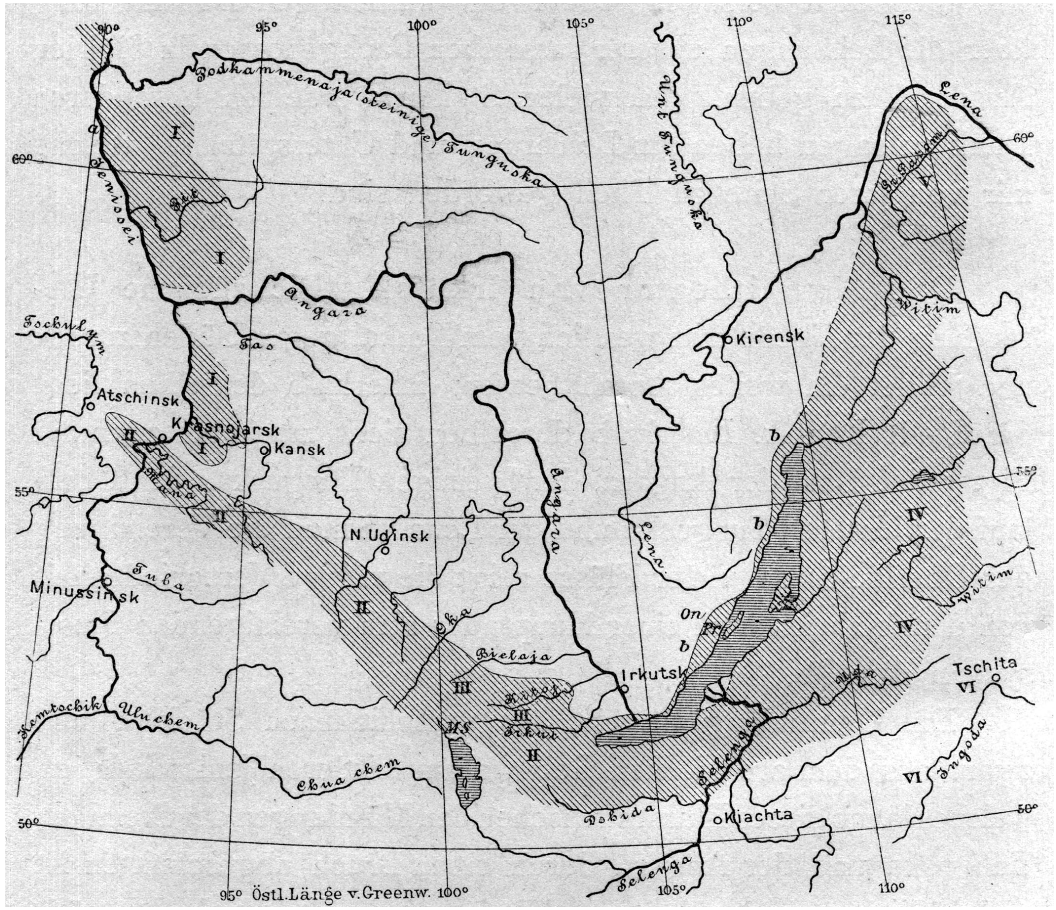


Fig. C10. The Amphitheatre of Irkutsk: the core region of the ancient vertex of Asia (I-V; from Suess, 1901, figure 2; this Figure is copied from the English edition).



The backfolding mentioned by Suess is towards the concave side of the amphitheatre, i.e. towards the internal side of the Asiatic structure. It took place at different times with varying intensities well into Jurassic times. 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 (cf. Şengör and Natal'in, 1996a, for the modern interpretations of Suess' units).

In the east, as on the Gazimur[6], for example, where the discordant Devonian is folded, it is possible that posthumous folding[7] 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 independence is much smaller. There are signs of back-folding towards the amphitheatre [*Figure C10*], 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.

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 [*Figure C9, the early Palaeozoic folds north of the ancient vertex];* the same feature is repeated in Minussinsk [*see Figure C10 for location*]; but even outside the vertex, in the basin of the upper Amur[8] and in Manchuria[9] [*north of areas where it says* Mandschurei *in Figure C9*], 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[10] [*Figure C11*].

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[6] 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).

[7] 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 of 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.

...

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 west-north-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. 112-114; in the English edition: Suess, 1906, pp. 93-96; in the French edition: Suess, 1900, pp. 142-145; 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 esp. Stille (1924, p. 41; Bucher, 1933, pp. 374-377, with criticism of Suess' view; Murawski, 1971; Şengör, 1995, pp. 207-209).

[8] 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.

[9] 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).

[10] The Gobi deposits are the Gobi Series of Obruchev (1900, p. 69) and correspond with the Han Hai Beds of von Richthofen (1877, p. 25: Han Hai means 'dry sea' in Chinese. On his p. 25, von Richthofen cites Ritter as quoting 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. 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 Tertiary. 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

Fig. C11. Flat-lying Cretaceous sandstones belonging to the Gobi Series in the Nemegt Valley, Southern Mongolia (from Kielan-Jaworowska, 1969, photograph facing p. 65).
Suess was aware that even equivalents of these and younger Gobi deposits were in places folded and also otherwise deformed.

With so extensive a movement it only remains, in tracing out the trend-lines[11], 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

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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 freshwater deposits are of middle or late Tertiary age.' (Suess, 1901, p. 131; in the English edition: Suess, 1908, p. 104-105; in the French edition: Suess, 1902, p. 136).
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). For a modern assessment of these deposits, see Bureau of Geology and Mineral Resources of Gansu Province (1989, chs. 14 through 16) and Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region (1991, esp. chs. 11 through 13).

[11] By trend-lines (*Leitlinien* in the German original, translated as *lignes directrices* into French), 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., 1993; Şengör and Natal'in, 1996a).

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 [*Figure C9*][12].

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 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[*Figure C12*]. But wherever these mighty mountain masses are cut into by deep transverse valleys, as between Min-tschou[13] and the "Red Basin,"[14] 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 [*Figure C13*].

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[15], 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[16]; 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[17].

When he had fully recognised the convergence of the folded ranges of the Baikal and the Sayan towards the region of the southern Baikal [*Figure C9*], 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

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[12] In Figure C9, *West. Sajan* is Western Sayan Mountains and *Ost. Sajan* is Eastern Sayan Mountains. By the Baykal and Sayan directions, Suess here means NE and NW respectively; i.e., the 'Sayan direction' refers to the northwesterly direction.

[13] 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 esp. Lóczy (1893, pp. 619-667 and figure 111; herein Figure C12). 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).

[14] This is another name of the Sichuan Basin as indicated in the French translation: 'le «Bassin Rouge» du Sé-tchouen' (Suess, 1902, p. 248).

[15] Nan Shan simply means 'South Mountain'. There are many Nan Shans in what we today think as the eastern termination of the Kuen-Lun, but in Suess' time was considered 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). What Suess means under Nan Shan is located in Figure C12, which 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.)

[16] See esp. Şengör and Okuroğulları (1991, figure 14, cross-section B).

[17] 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 titled (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 lecture is not titled. See Cherskiy (1886).

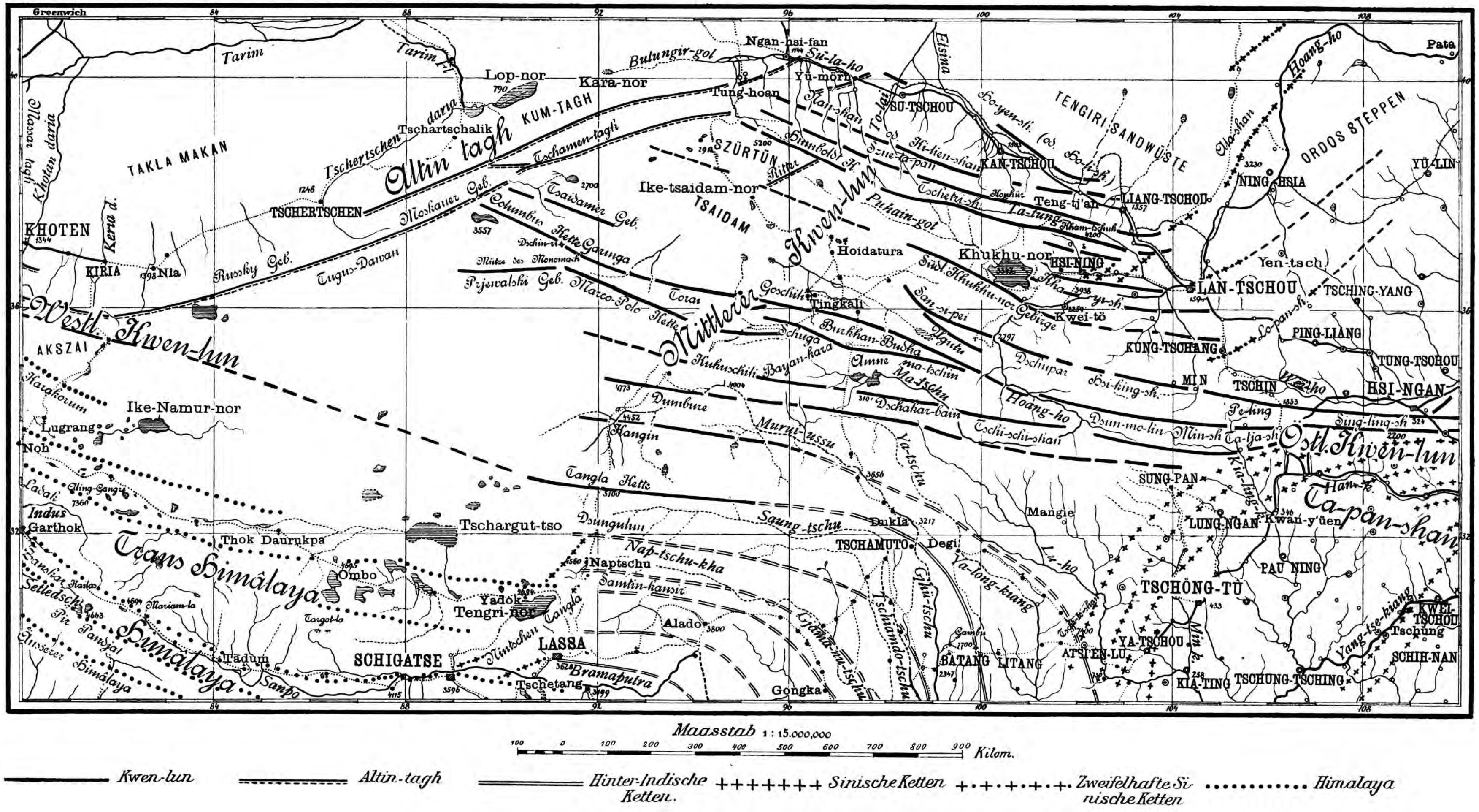

Fig. C12. ‘Mountain ranges of the Tibetan Highland’ from Lóczy (1893, Figure 111).
Translation of the legend: *Kwen-Lun*=Kuen-Lun, *Hinter-Indische Ketten*=Ranges of Farther India (i.e. Southeast Asia), *Sinische Ketten*=Sinian Ranges (Sinian is here taken in von Richthofen’s sense, i.e., as the NE-SW trending ranges east and northeast of Tibet), *Zweifelhafte Sinische Ketten*=Doubtful Sinian Ranges. *Maasstab* is scale. On the map, *Westl. Kwen-Lun* is western Kuen-Lun (thought by Lóczy to extend as far south as the Tanggula {‘Tangla’ on the map} Mountains of central Tibet, i.e. to the Banggong Co-Nu Jiang suture: see Şengör and Natal’in, 1996a), *Östl. Kwen-Lun* is eastern Kuen Lun in von Richthofen’s sense, i.e. the westernmost Qin Ling. The ‘central Kuen-Lun Suess refers to is the sector labeled ‘*Mittleres Kwen-Lun.*’

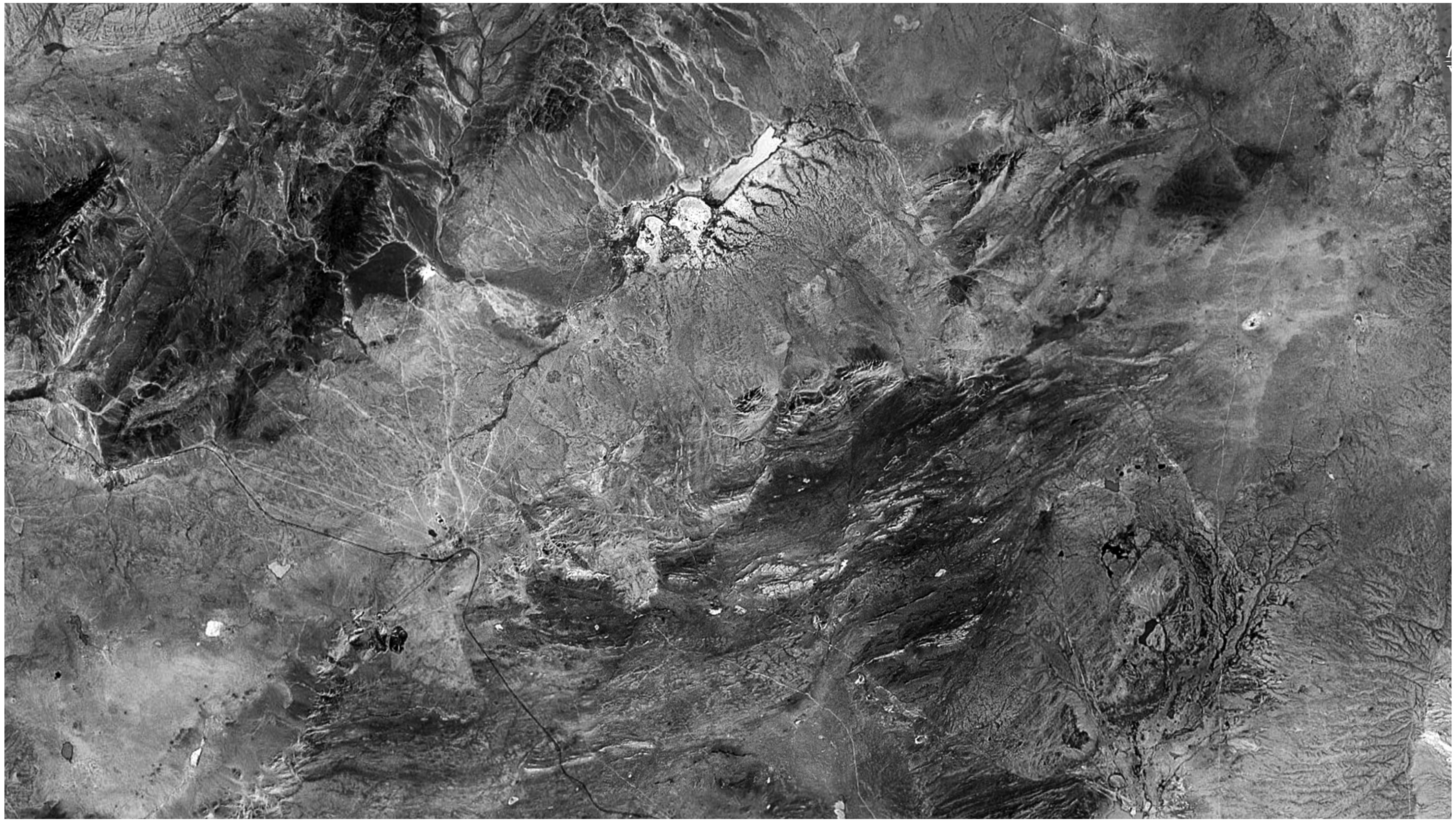

Fig. C13. The ‘sea of more or less denuded folds’ of the Gobi. Mosaic of images from Google Earth.

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 Natal’in, 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.

about lat. 54ºN, on the upper Kan[18], that is at the boundary between the east and west Sayan [*Figure C9*]. From here onwards we again meet with a dominant direction opposed to that of the Sayan, or to the west-south-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[19] and Salair[20]. On the Bukhtarma[21] and on the Irtysh[22] [*Figure C9*], 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[23] [*Figure C14*], and he at once recognised that the Tarbagatai[24], Boro-Khoro[25], 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 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[26], 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.

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[18] One of the right-hand tributaries of the Yenisey (the river between Kansk and Krasnoyarsk in Figure C10). It joins the Yenisey at Ust Kan (i.e., 'Mouth of the Kan': 56º 32'N, 93º 47'E).

[19] 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, 90º31'E) where the Kuznetskii Alatau abuts against the Western Sayan across the upper course of the Yenisey.

[20] 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).

[21] 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.

[22] 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 (Figure C9).

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

[24] 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.

[25] 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.

[26] Urga (also Niislel Khureheh) is the former name of Ulan Bator (Ulaanbaatar=Red Hero), the capital of Mongolia (at 47º 54'N and 106º 52'E). 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.

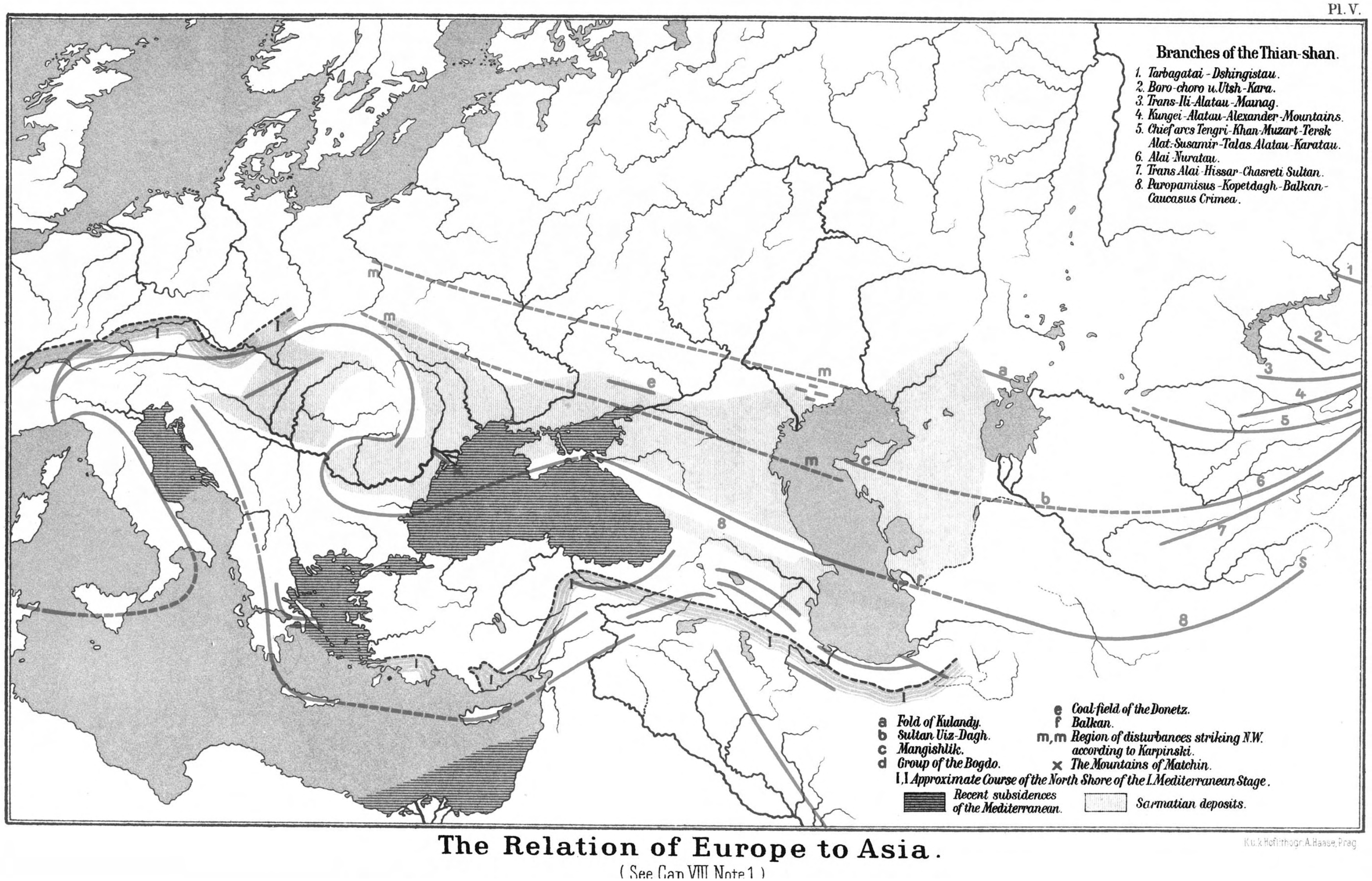

Fig. C14. The connexion of Asiatic to European structure according to Eduard Suess’ conception in 1885, following the great Russian geologist A. P. Karpinsky’s ideas, published in Karpinsky (1883).

The part of this Figure Cwest of the Caspian Sea in southern Russian Platform, Suess took from Karpinsky’s Figure C (Karpinsky, 1883, figure 1). The lines of dislocation continuing from the Tien-Shan into Europe, Suess called the Karpinsky Lines (see esp. 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 complex in Europe ‘European Altaids.’

The hypothetical axis of the constriction of the Archaean folds within the overfolded syncline of Olkhon [*Figure C15*] lies in the Primorskiy Khrebet[27], 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[28], follows the meridian of 91º.

If we include the bend of the Altay in the Belukha[29] 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'[30]: 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[31] and the Izykh[32], 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[33] and the Ili[34]. 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)[35]

Suess had thus recognised a very wide area of mountain-building extending from the shores of Lake Baykal and Yenisey to the Iranian and Tibetan highlands. Folding towards the exterior of this large region had been, in many places, followed by steep faulting. In wide areas, granite trains characterised the overall aspect. Within this immense area, he was unable to isolate any one range from the rest and underlined that only when viewed in its entirety did its structural

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[27] 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 *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).

[28] A right-hand tributary of the Yenisey, joining it just north of the town of Minussinsk (see Figure C9).

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

[30] 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.

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

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

[33] 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.

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

[35] In the English edition: Suess (1908, pp. 193-197). In the French edition: Suess (1902, pp. 246-251).

evolution make sense. Suess recognised an hitherto unsuspected unity in the whole of this vast region of Asia and decided that this unity had to be expressed with its own appellation. He appropriately chose the Altay to lend its name to characterise the entire ensemble and called it the Altaids.

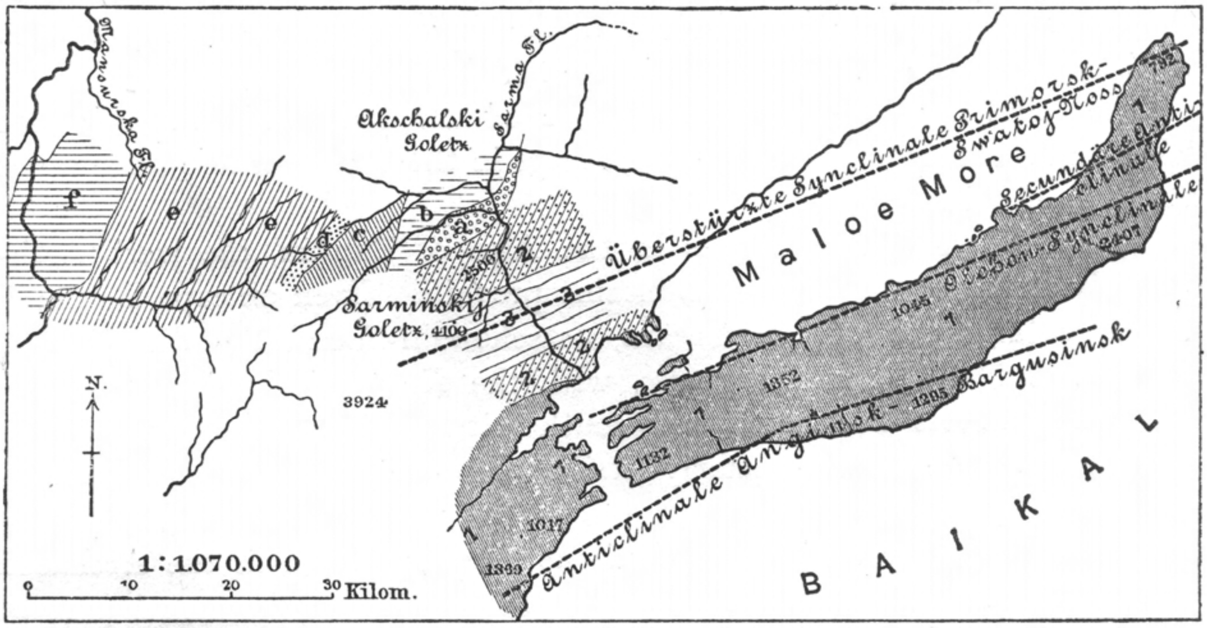

Fig. C15. The syncline of Olkhon. 1, 2, 3, Archaean rocks (sensu Suess); a to e, metamorphic schists; f, Cambrian limestone.

The heights are given in English feet above the level of the lake. *Überstürzte Synclinale* means inclined syncline. From Suess (1901, figure 4). The Olkhon syncline is overturned to the northwest.

DEVELOPING IDEAS ON AND CHANGING APPELLATIONS OF THE ALTAIDS AFTER SUESS

Just a year before Suess published the third volume of *Das Antlitz der Erde*, the great French stratigrapher Émile Haug (1861-1927) brought out his influential paper on geosynclines and continental areas (Haug, 1900). This paper, plus Haug's widely used treatise (Haug, 1907-1911; translated into Russian under as high an authority as Academician A. P. Pavlov {1854-1916}, see esp. v. 1, pp. 131-142[36]: Haug, 1933), brought back to Europe the idea of geosynclines, but in its original Beaumontian form (cf. Şengör, 2003, pp. 93-97 and 123), i.e., as deep water[37] troughs between stable jaws that are as a rule considered continental. Despite their (unacknowledged) Beaumontian form, Haug's ideas were presented in the terminology of James Dwight Dana (1873, 1895[38]) and as such they exercised a profound influence on the development of tectonics in Europe, including Russia, until the rise of plate tectonics in the mid-sixties. The most important aspect of these ideas from the viewpoint of the tectonic interpretation of the Altaids was the image of the geosynclines as long, curvilinear troughs between stable continental platforms. Very rapidly, people began attempts to put the Altaids into the straightjacket of geosynclines with little regard to whether they would fit. And when it was finally realised that they did not, such extraordinary notions as 'areal-' or 'mosaic-type geosynclines' were invented with a view to salvaging the geosyncline theory. Even the later early plate tectonics models were nothing more than simple adaptations of the geosynclinal interpretations (with the remarkable exception of the first plate tectonic interpretation of the Altaids together with the Uralides by the great American geologist Warren B. Hamilton, 1970). Even now, the attempt to force the terranology onto the Altaids is another expression of reviving the geosynclines: this time by subdividing the Altaid area into innumerable little collision belts, i.e., little geosynclines, with two jaws on both sides, to avoid dealing with the great geological complexity expressed in the evolution of large accretionary wedges developing in front of arc systems that display large-scale strike-slip displacements and oroclinal bendings, because the tectonics of such terrains can only be sorted out by careful and painstaking geological mapping and not by sample grabbing during geological touristic excursions, as Eugen Wegmann so sharply and tersely expressed nearly half a century ago (Wegmann, 1961).

Haug on the Altaids: Haug's (1861-1927) view of the world was one of a palaeontologist and a stratigrapher, in a way very similar to that of his great American contemporary Charles Schuchert (1858-1942). Tectonics interested him only as it influenced the distribution of lands and seas and the animals that inhabited them and this is reflected in his influential treatise, which,

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[36] Significantly, Haug's literature reference list at the end of his chapter 12, titled: 'geosynclines and continental areas' was greatly shortened in the Russian translation, but the second edition of Kober's *Der Bau der Erde* (Kober, 1928) was added to it (Haug, 1933,p. 143). This is important in showing Kober's influence in Russia. We should here also note that Pavlov was one of the leading geologists responsible for making geosynclines popular in Russia (Markov et al., 1974). For a history of the 'Pavlov school of geology' in Russia, see Starodubtseva et al. (2004).

[37] Haug introduced the adjective 'bathyal' to describe the bathymetric conditions of geosynclines (Haug, 1907, p. 160; for the definition of the bathyal zone, see: Haug, 1907, p. 88, figure 23; for description of its characteristics, see p. 89). Haug has conceived the bathyal zone as a sort of equivalent to the zones, where 'pelagic sediments' in the sense of Eduard Suess accumulate, i.e., sediments free of continental intercalations and of frequent lacunae and are now found commonly in a highly dislocated state (see Haug, 1907, p. 158, footnote 1). However, it is of great importance not to confuse the senses in which Suess used pelagic and we do it now. The great sedimentologist Kenneth J. Hsü once criticised Suess for not being a sedimentologist, precisely because Hsü himself had failed to see that what Suess had called pelagic and what we today call pelagic are not the same things (see Hsü, 1973, p. 67).

[38] Haug had used the fourth edition of Dana's *Manual* while preparing his treatise (see Haug, 1907, p. 5). In that edition Dana had changed his old term geosynclinal to geosyncline (Dana, 1895, p. 106), but Haug continued to use the adjectival form. This is also the form used in Russian.

in scope, was more restricted than its great predecessor, the treatise of geology by Albert de Lapparent. That great book had gone through five editions between 1883 and 1906 (a, b, c) and greatly influenced Haug through its palaeogeographical maps (for an assessment of their importance in the history of palaeogeographical map-making see Dacqué, 1915, pp. 17-19; also see de Lapparent, 1906d) constructed in the way recommended by Loewinson-Lessing's scathing criticism to keep the intervals limited at most by ages (Loewinson-Lessing, 1899), which unfortunately Haug later ignored.

The term Altaids occurs only in the geographical name index of Haug's treatise (Haug, 1911, p. 1940) and signifies the *late* Palaeozoic chains of northern Asia around the East Siberian Platform of Suess. In his first volume, Haug defines the Altaids as a 'homologue of the Hercynian foldings of Europe. They surround the Archaean[39] nucleus of Siberia' (Haug, 1907, p. 528). He regarded the Archaean continental nuclei, as being separated by 'very large geosynclines, where the rock packages [=*terrains* here used in the old sense of Brongniart, 1829, and Dufrenoy and Élie de Beaumont, 1841, p. 35] of the Archaean and the Algonkian are conformable with one another and with the first rock packages [=*terrains*] of the Palaeozoic. On the sites of these geosynclines ... were born all the post-Huronian zones of folding' (Haug, 1907, pp. 526-527). It is thus clear that, according to Haug, the Altaids too were born in a geosyncline.

Haug was also inclined to follow his countryman Auguste Michel-Lévy (1898) in considering mountain belts symmetric, in fact 'double chains' arising from a single geosyncline, which early becomes divided into two partial geosynclines by a median geanticline (Figure C16). Later, each partial geosyncline gives rise to an asymmetric folded chain, verging away from the central geanticline. The total picture of a mountain chain, arising from a main geosyncline, was thus one of a symmetric mountain chain. Although Haug clearly saw this picture around the Mediterranean, he confessed that it was not easy to see it everywhere outside the Mediterranean region (Haug, 1907, p. 529). Especially in the Altaids, he acknowledged that Suess had pointed out that the vergence was mainly away from the East Siberian table-land: 'In general, in Asia, as shown by Eduard Suess, the foldings verge not towards the continental nucleus, towards the Sino-Siberian continent, but in a reverse sense, towards the deep depressions of the Indian and the Pacific oceans. One could ask oneself whether, *in the beginning* of the orogenic movements that gave rise to the fold festoons that surround Asia, continents were not present where there are now these two oceans' (Haug, 1907, p. 529, italics his). This was, of course, Haug's long-maintained position that geosynclines always are placed between two continents. That is why he had felt compelled to reconstruct a hypothetical Pacific Continent to account for the circum-Pacific geosyncline in the Mesozoic (Haug, 1900). In the place of the Indian Ocean he had placed the Australo-Indo-Malagasy continent, although he was unsure whether between Antarctica and this hypothetical continent a deep ocean had not already existed in the earlier times of earth history (Haug, 1907, pp. 532-533).

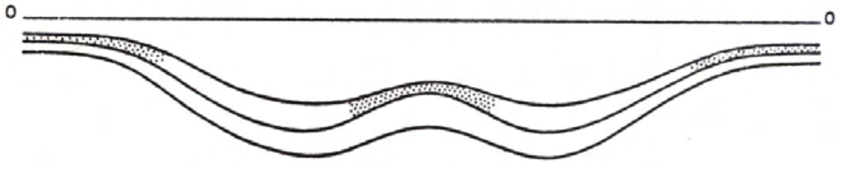

Fig. C16. Schematic cross-section across a geosyncline that has just begun to be shortened according to Haug (1907, figure 38).

A rising central geanticline divides the geosyncline into two partial or secondary or subordinate geosynclines. Stippled: regions of neritic sedimentation; white, regions of bathyal sedimentation.

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[39] The Archaean was used by Haug as the earlier division of the Precambrian, the later in those days being known under the name Algonkian introduced in the *Tenth Annual Report (for 1889-1890) of the United States Geological Survey*, p. 66. However, in Asia he carelessly uses Archaean also in Suess' sense to refer to any Precambrian strongly folded and metamorphosed.

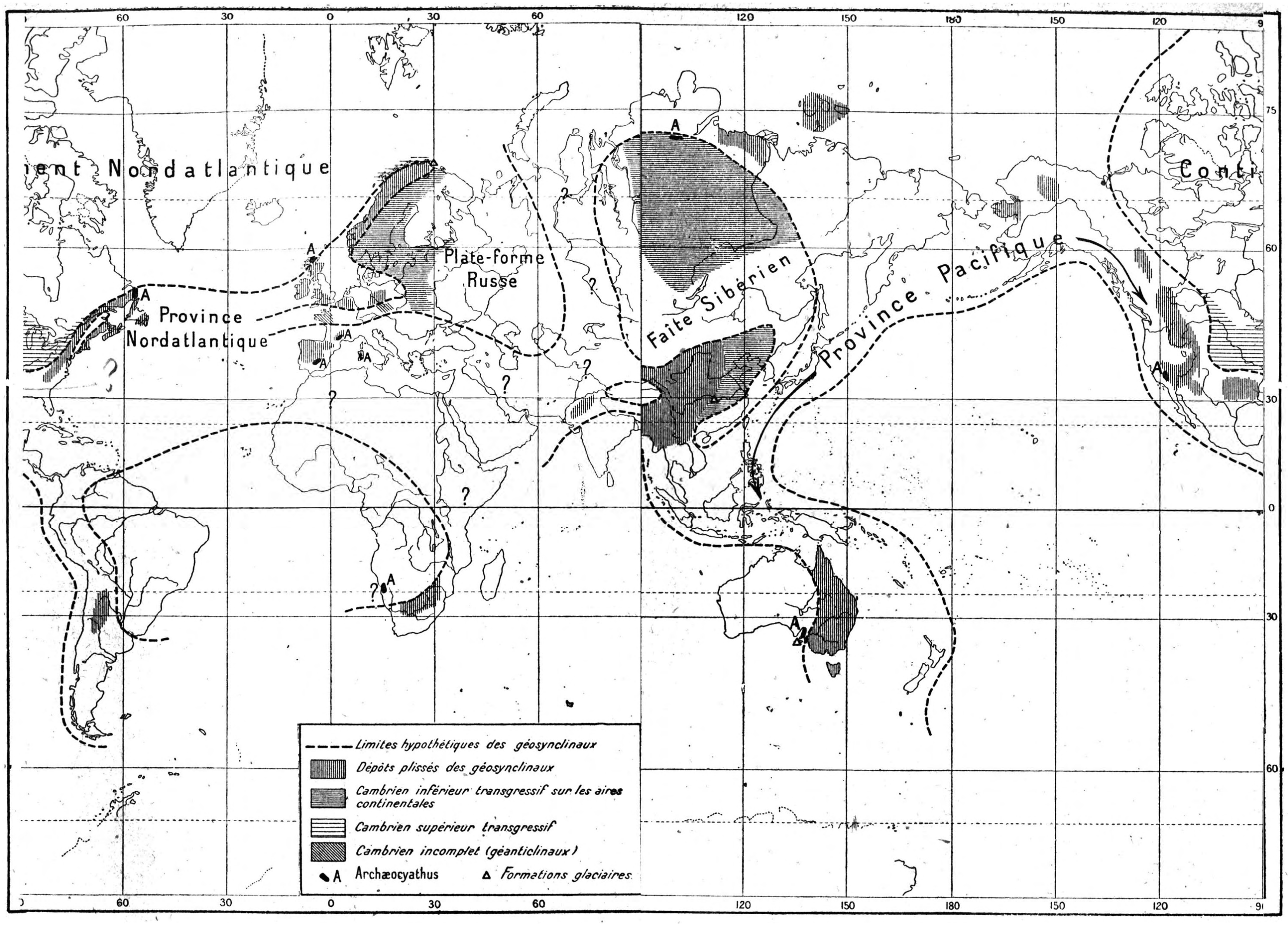

Fig. C17. The palaeogeography of the Cambrian world according to Haug (1908-1911, figure 215; rearranged to bring Asia to the middle of the map).

The arrows indicate the migration of marine faunas. Translation of the legend: *Limites hypothétiques des géosynclinaux*=hypothetical limits of geosynclines; *Dépôts plissés des géosynclinaux*=folded deposits of geosynclines; *Cambrien inférieur transgressif sur les aires continentales*= Transgressive Lower Cambrian on continental areas; *Cambrien supérieur transgressif*=Transgressive Upper Cambrian; *Cambrien incomplet (géanticlinaux)*=Incomplete Cambrian (geanticlines); *Formations glaciaires*=glacial formations. As a result of our rearrangement, some serious discrepancies arose in this and in Figures C19 and C20. This shows the degree of Haug's sloppiness in handling his data, in sharp contrast to Suess and his students. It is reflected in Haug's conclusions.

When did the Altaid history begin according to Haug? And where? And how? In northern and Central Asia, Haug was informed of the Precambrian tectonics ony through the third volume of Suess' *Das Antlitz der Erde*: He repeated the existence of the Ancient Vertex, the southern border of the vast East Siberian table-land, where the Cambrian was seen to be transgressive on folded crystalline series and that he regarded 'certainly of an age anterior to the Cambrian' and agreed that it consisted of two main directions of folds: a western *Sayanic* direction of southeast or east-southeast and an eastern *Baykalic* direction of southwest or west-southwest.

Figure C17 shows the world of the Cambrian according to Haug (1908-1911). In Asia we see the Lower Cambrian transgressive over the East Siberian nucleus and the ancient Vertex to the south and west of it. A corridor separates the Ancient Vertex from the Russian Platform to the west. This is where roughly the future Ural orogenic belt will form and Haug thought that the corridor was a geosyncline, formed by the epeirogenic downbending (= *dépression transversale*) of the post-Archaean foldings that had formed earlier a structural connexion between Europe and the central nucleus of Siberia (Haug, 1907, p. 530). This is based on Suess' interpretation of the origin of the Urals: Suess considered the Urals as a posthumous fold bundle belonging to the folds of the Ancient Vertex and viewed them as a couterpart of the east-verging folds of eastern Asia and the south-verging folds of the Tien Shan (Suess, 1901, p. 499). This implies a continuous Ancient Vertex from the East Siberian table-land to the Russian table-land and in the middle the Urals filling a depression that later became compressed and created a posthumous mountain belt. But, as Haug did not consider Suess' unity of plan of the Asiatic structure, his interpretation of the Uralian geosyncline became *ad hoc*.

South of the Ancient Vertex, in most of what is today's China, Haug showed geosynclinal deposits. The way he depicted the palaeogeography of Asia, there was not much place left to put the Altaid mother geosyncline. His Ordovician-Silurian (Haug did not consider the Ordovician as a separate period) palaeogeography shows pretty much the same thing, except that the marine realm in China had now enlarged its area towards the northeast almost into the Sikhote Alin (Figure C18). He thought that 'palaeontological characteristics' united the northerly seas with those of Asia and even Australia (Haug, 1908-1911, p. 661). Again more than half the area of the future Altaids, he thought, had been occupied by land!

It was in the Devonian that Haug was able at last to draw the Altaid geosyncline proper (Figure C19). It was shown to embrace from the south what he called the Siberian Vertex (=Suess' East Siberian table-land) and unite to the east with the Ural geosyncline. Also, through the Tien-Shan, the Altaid geosycline connected with the irregular geosynclinal realm of the Tibetan/Himalayan area. Inappropriately, Haug declared this southerly geosyncline as the '*Central Mediterranean* of Neumayr, the *Thetys* [*sic!*] of Suess, the *Mesogea* of H. Douvillé, but with a much larger width than during the Mesozoic' (Haug, 1908-1911, p. 726; italics his), thus contributing to the subsequet confusion in the Tethys concept (see Şengör, 1990c and 1998). Haug pointed out that in all of northern and central Asia, marine Devonian was exclusively confined to regions that were to be a theatre of folding at the end of the Palaeozoic, which Suess had called the *Altaids* (Haug, 1908-1911, p. 710).

About the nature of the Altaid geosyncline Haug was extremely vague, except to say that its Devonian deposits everywhere seemed neritic and only rarely bathyal (Haug, 1908-1911, p. 710). It was clear that he had insufficient data: 'In Asia, the present state of our knowledge does not permit us to delineate the location and the direction of the pre-Devonian folding, but it also seems that these were posthumous folds that gave rise to the meso-Devonian transgression reported from diverse places. Here also the maximum extent of the sea was reached in the Givetian and the Frasnian. But the geosynclines lost in depth what they gained in extent.' (Haug, 1908-1911, p. 733).

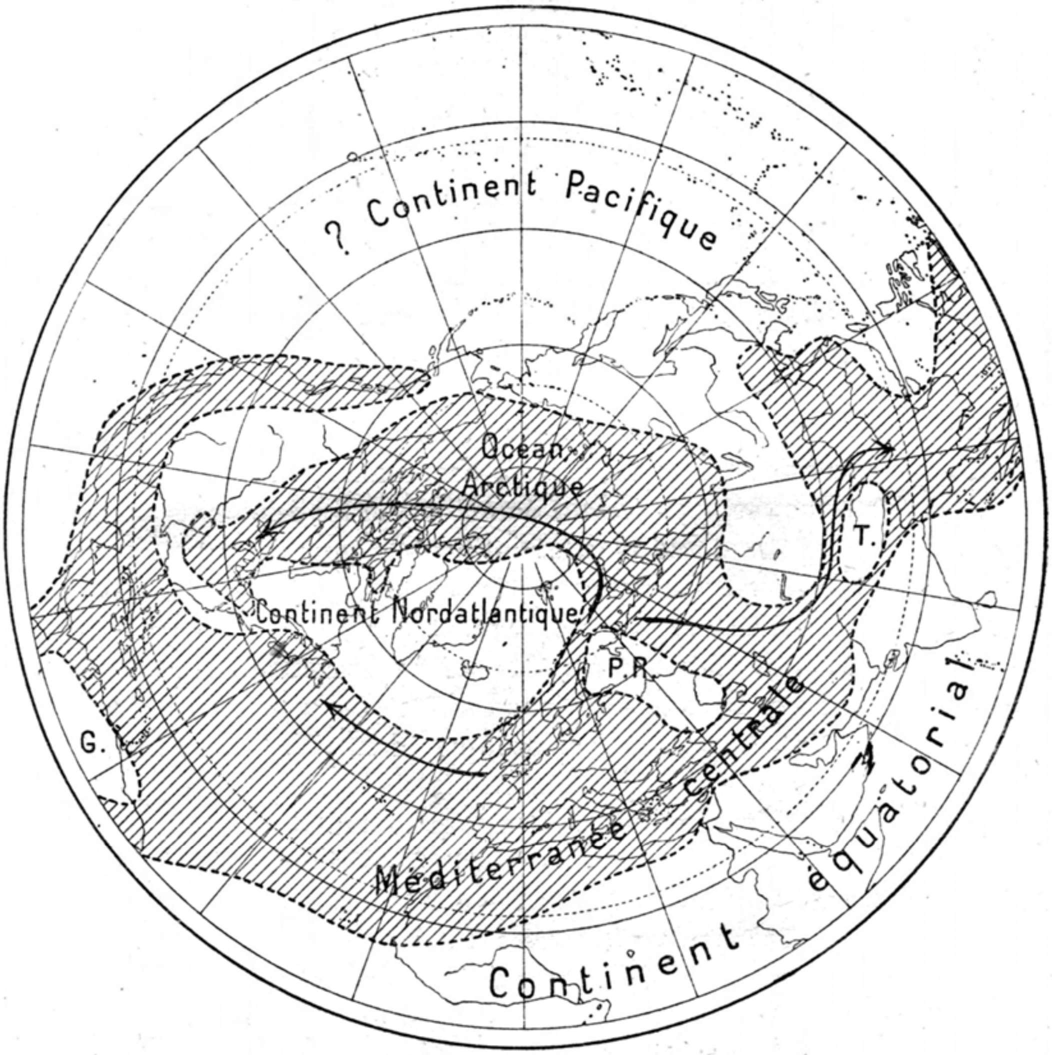

Fig. C18. The 'Gotlandian' (=Llandovery+Wenlock+Ludlow=what we today call Silurian) reconstruction of the northern hemisphere according to Haug (1908-1911, figure 226).
The arrows indicate the migration of marine faunas. P. R.=Russian platform; T= island of Tibet; G=ancient nucleus of Guyana.

He obviously did not have access to Suess' (1885, 1901) sources, which Suess had used to delineate mainly the structure. Haug's interests being more stratigraphical/palaeogeographic, he was unable to make use of Suess' own descriptions that generally gave types and ages of rocks and their attitude, but not their depositional environment.

Figure C19 shows that with Haug, we see, for the first time, the Altaids being confined into a geosyncline. Suess' view of the Altaid folds, being analogous to the ‘waves of an open sea’ with no borders, had already been replaced by marine deposits confined between two continental jaws. The distinction Suess had made between the type of mountain building in the Altaids and that in the more widely-known mountain belts, such as the Alps, the Appalachians, the Caucasus and the Himalaya, had vanished. It seems that the reason for this switch in interpretation was that the authors after Suess had lost touch with the details of the field geology of the Altaids. They took the ages and the crude inferences about the depositional environments of the rocks, gleaned from a few review papers they could find, and forced them into a global geosynclinal model. In a very analogous way, this is precisely what is again becoming fashionable in the Altaid studies today.

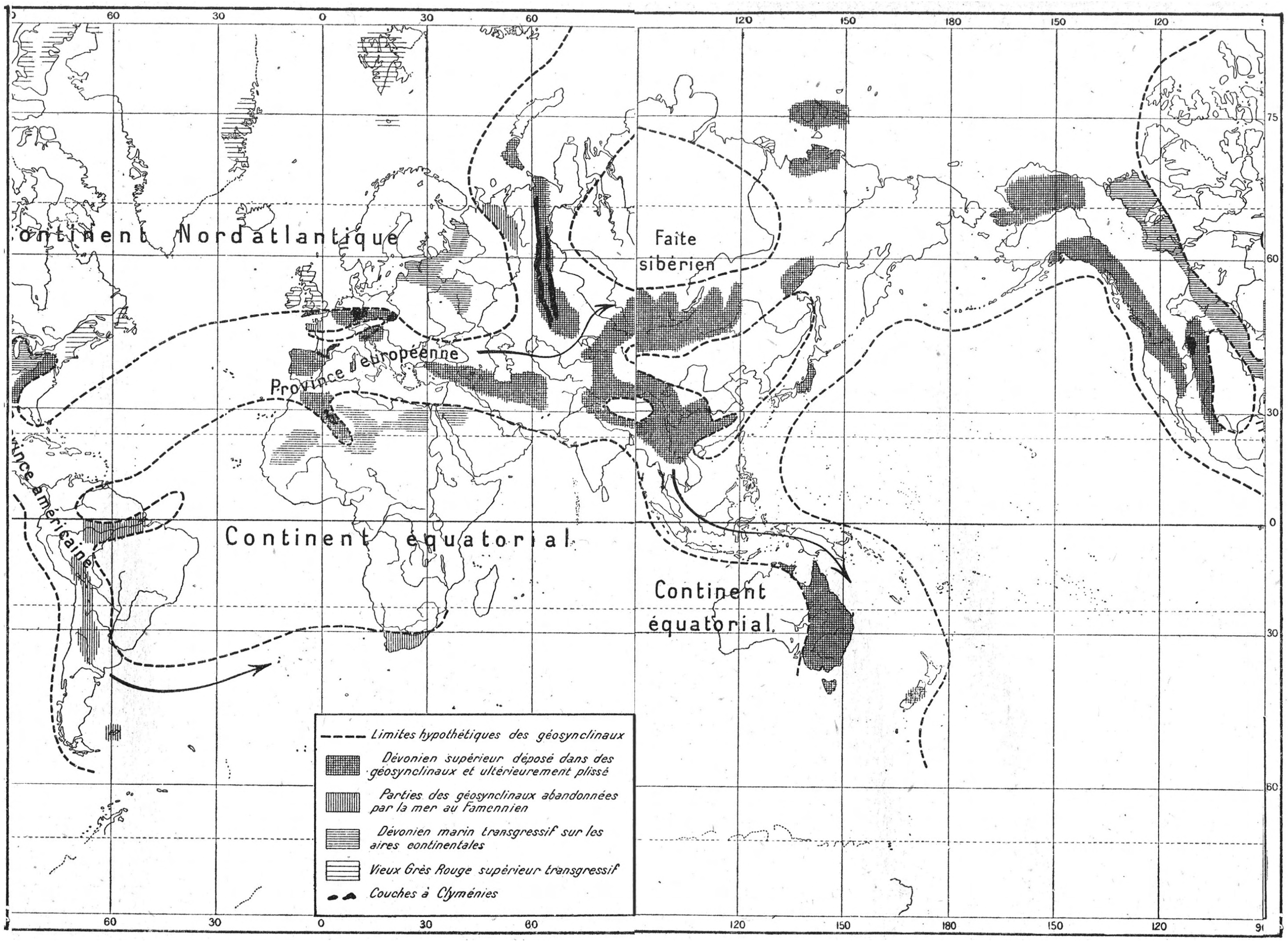

Fig. C19. The palaeogeography of the Devonian world according to Haug (1908-1911, figure 250; rearranged to bring Asia to the middle of the map).

The arrows indicate the migration of marine faunas. Translation of the legend: *Limites hypothétiques des géosynclinaux*=hypothetical limits of geosynclines; *Dévonien supérieur déposé dans des géosynclinaux et ultérieurement plissé*=Upper Devonian deposited in geosynclines and later folded; *Parties des géosynclinaux abandonées par la mer au Famennien*=Parts of geosynclines abandoned by the seas during the Fammenian; *Dévonien marin transgressif sur les aires continentales*= Transgressive marine Devonian on continental areas*; Vieux Grès Rouge supérieur transgressif*=Transgressive Old Red Sandstone; *Couches a Clyménies*=Clymenia-bearing beds.

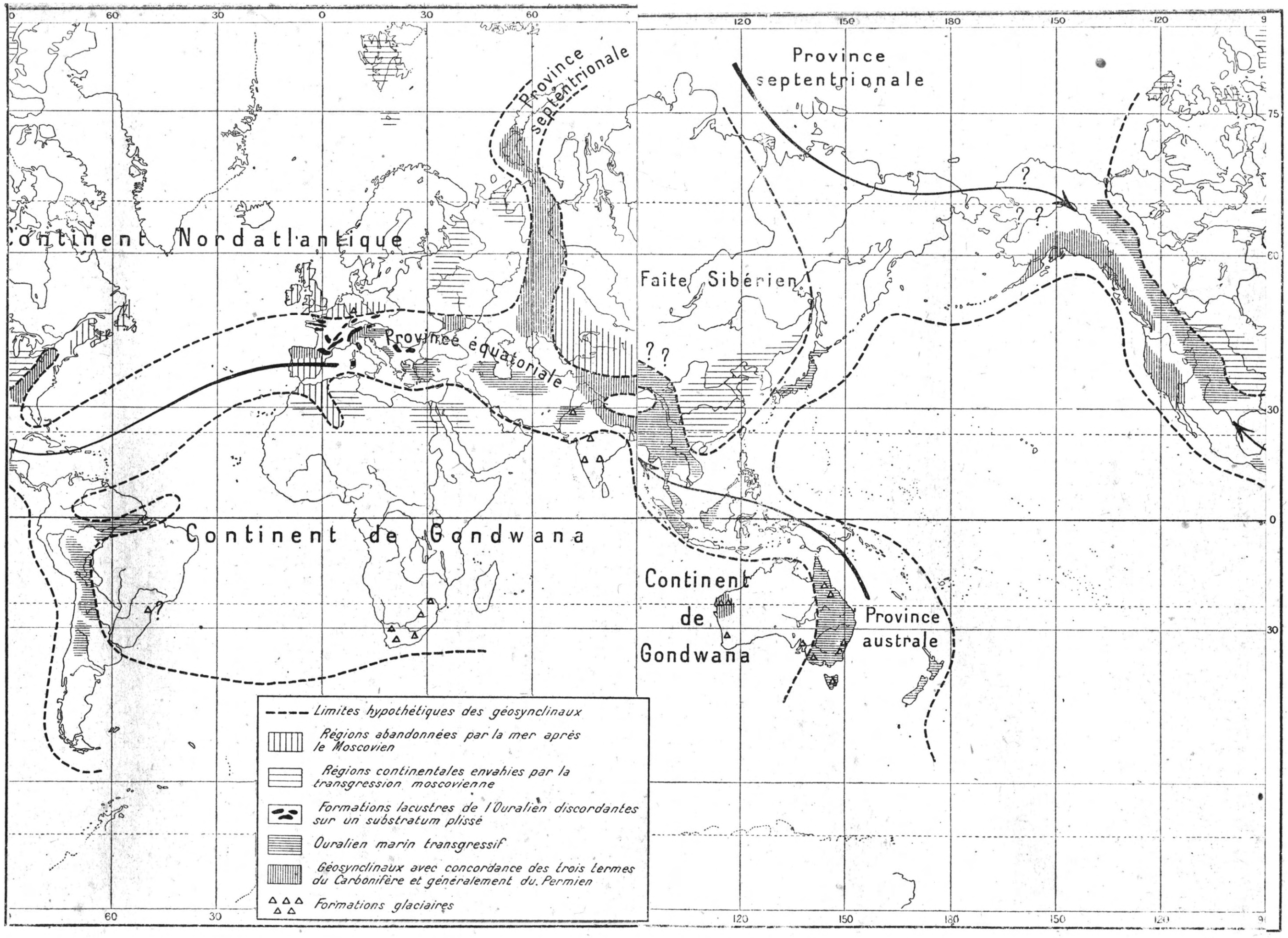

Fig. C20. The palaeogeography of the Anthracolithic world according to Haug (1908-1911, figure 272; rearranged to bring Asia to the middle of the map).

The arrows indicate the migration of marine faunas. Translation of the legend: *Limites hypothétiques des géosynclinaux*=hypothetical limits of geosynclines; *Régions abandonées par la mer aprés le Moscovien*=Regions abandoned by the seas after the Moscovian; *Régions continentales envahies par la transgression moscovienne*=Continental regions invaded by Moscovian seas; *Formations lacustres de l'Ouralien discordantes sur un substratum plissé*=Uralian lacustrine formations unconformable on a folded substratum; *Ouralien marin transgressif*=Transgressive marine Uralian; *Géosynclinaux avec concordance des trois termes de Carbonifère et généralement du Permien*=Geosynclines with the three parts of the Carboniferous concordant with one another and generally also the Permian; *Formation glaciaires*=Glacial formations.

Only in our times, the few review papers are replaced by the few samples gathered during geological touristic excursions, made possible by the facilities of modern travel and their interpretations, divorced from the details of the field geology, are fashioned in terms of plate-tectonics-based cartoon models of 'terrane' collisions—the modern version of the geosynclinal straightjacket.

In the Carboniferous and the Permian, which Haug considered to be a single period under Suess' great student Wilhelm Waagen's designation Anthracolithic (Waagen, 1891, p. 241), the Altaid geosyncline disappeared by folding (Figure C20). Haug wrote: 'In Asia, the large mountainous zone between the Ancient Vertex of Central Siberia and the Tertiary chains to the south is mainly formed from chains, the main episode of folding of which dates from the middle of the Anthracolithic Period and consequently must be envisaged as homologues of the Armorican and the Variscan chains. They are the *Altaids* of Suess. Without entering into any detail, it should suffice for us to say that the two principle bundles that constitute this system of folds are, in one part, those of the Altay and the chains of Trans-Baykalia following the contours of the Ancient Vertex, and in another part, those of the Kuen-Lun, which open up eastward giving rise to Nan Shan and the chains north of China, then to Qin-Ling and finally to the chains of Sichuan and Yunnan. All these divergent branches embrace in their arms the much older massifs of eastern China. Between the two bundles, the Tien-Shan is intercalated which is probably much younger, like the Ural.' (Haug, 1908-1911, p. 834). These lines are the source of much of the widespread confusion that plagued a good part of twentieth century geological liturature concerning the mountain ranges of China and southeast Asia. It is true that Suess considered his Altaids even to include the young ranges of Indonesia as we pointed out above (cf. Figures 8B and C above). However, his definition of the Altaids was clear: those mountain ranges that formed in waves away from the Ancient Vertex and thus *genetically* related to them. That is why Şengör (1987) restricted the term Altaids to those mountain ranges that formed around the Baykalides and the East Siberian table-land before the formation of Laurasia. Because after Laurasia had formed in the latest Palaeozoic, the new chains in Eurasia formed against the combined landmasses of Europe and Asia. The only exception to these was the Altaids in eastern Asia, in Mongolia and in the Russian Far East, as they are nothing more than a direct continuation of the tectonic regime established in the Palaeozoic. The early Cretaceous consolidation of the easternmost Altaids in the region of the lower Shilka and beyond eastward towards the Pacific was the end of the Altaid evolution (see esp. Şengör and Natal'in, 1996a).

Kober on the Altaids: The next great influence on the twentieth century tectonics after Haug was that of the Viennese tectonician Leopold Kober (1883-1970). A student of Viktor Uhlig (1857-1911), who was one of the Viennese giants and the successor of Eduard Suess in the chair of geology in the University of Vienna, Kober became a faithful follower of Haug's ideas probably under the influence of the dissenting views that had long begun to arise against Suess' ideas in his own institute (e.g., Bittner, 1887; Neumayr, 1895). In a short abstract published in 1911, the year in which the final instalments of Haug's treatise came out, Kober advertised his ideas on the two-sidedness of all mountain chains and their rise out of geosynclines (Kober, 1911). Such a two-sided mountain belt he called an *orogen* and supposed that its two flanks would be separated either by what he called a *Narbe* (=cicatrix {Longwell, 1923, p. 234}) or a *Zwischengebirge* (=intermontane space or middle zone {Longwell, 1923, p. 234}, betwixt mountains {Collet, 1935, p. 24} or median masses {de Böckh et al., 1929, pp. 60-61[40]}). Kober assumed that all mountain chains in the world were built according to this schema. (For an English summary of Kober's theory as outlined in his 1921 book, see Longwell, 1923).

What Kober wrote of the Altaids gives such an excellent example of how opinions on the Altaids have changed in the course of the twentieth century from Suess' richly documented initial

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[40] Boswell, in the glossary he appended to the translation of Heritsch, 1929, p. xxvii, points out that the translation 'median mass' is due to Professor Hugo de Böckh, one-time geologist of the Anglo-Persian Oil Co.Ltd. and the director of the Hungarian Royal Geological Survey.

interpretation to the schematic geosynclinal straightjackets with a nearly total neglect of actual observations that we feel compelled to translate here the entire section from Kober's influential 1921 textbook *Der Bau der Erde* (=Structure of the Earth). Reading Kober's dogmatic, repetitive, internally inconsistent prose would no doubt be tedious for the reader and we apologise for citing it at such length (see also Figure C21). However, without such a thorough documentation, it is impossible to grasp the nature of the change in the tectonic interpretation of the Altaids as also their name itself gradually disappeared from the literature together with Suess' model of their tectonics. We intersperse the following long quotation with our commentary set in italics in square brackets or in footnotes:

'**The Palaeoides**[41]

Hereto belong the great block mountains of Central Asia that begin with the Altay in the north and reach the Tien Shan System in the south. According to our view the Nan-Shan System in the east also belongs here with its easterly continuation (Qin-Ling Shan?). These Palaeozoic chains have been gathered together as the Altaids by E. Suess.

They constitute large regions of the earth that stand out morphologically. They have been studied in detail, especially in recent times, by the Russian researchers and others. However, there is no other region on earth that has been so variously interpreted as this one. It is indeed as yet little known and thus it is understandable that such differing interpretations on the structure of these regions exist, although, to a certain extent, the outline of the origin of these mountains was early recognised by Russian researchers. This origin culminates in the view that in these places the earth's crust has been deformed in relatively recent times by disjunctive dislocations atop the former Palaeozoic foldbelts. [*This information is entirely out of Suess'* Antlitz.] Thus the block mountains formed with the intervening basins.

Naturally, in detail, the structure is indeed much more complicated. Thus form different pictures and these lead to different views.

So it was thought as if the structure of Asia were entirely different from that of Europe [*This sentence and the whole paragraph is a criticism of Suess' interpretations in the* Antlitz]. The separation of the young chains from the old Palaeozoic Alps was not undertaken with sufficient clarity, foreland and orogens were not distinguished [*Let us remember what Suess had said: '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 do not lend themselves to such an inquiry.'*]. Old and young dislocations were not separated [*This is a criticism of the following view of Suess: '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.']. Morphological and tectonic trends were mixed-up [*See Tietze, 1917, pp. 426-440, for a criticism of Suess' employment of geomorphology in deducing tectonic consequences; Tietze's criticism was later echoed not only by Kober and Stille, but by many of their followers in the twentieth century*]. And thus it came to the various views on the structure of the Asiatic continent.

If we wish to judge the relationships correctly, we must bear in mind the European relationships. In Europe we were able to separate the Palaeoides from the Mesoides clearly. We have to undertake the same separation in Asia [*An extraordinarily dogmatic statement of forcing the European tectonic picture onto Asia with no justification; this had been precisely what Haug had done*].

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[41] The suffix -ide (plural -ides) comes from the Greek word ειδος meaning what is seen, form, shape, kind, genus, class, state and it has been introduced into tectonics to indicate genetic connexions of montain ranges (e.g. Suess, 1901, p. 250; this is the earliest usage of the suffix '-ides' for an orogenic system that we are aware of and it looks as if Suess introduced it first for the Altaids) and organisms. For example Altaids means the mountain ranges that are like the Altay, that have a genetic connexion with the Altay, that belong in the same class with the Altay. This suffix entered palaeontology from biology where it had been borrowed from the neo-Latin suffix *-ida* (=having the form of; see McLoughlin, 1980, p. x). Kober, however used it to indicate age of formation: 'We would like to designate with the name of the period plus the suffix 'ides' (ειδον = shape) those genetic units that originate in the same geological epoch.' (Kober, 1921,p. 21). Hence the Palaeoides, indicating mountain systems formed during the Palaeozoic. We think this is an inappropriate usage of the suffix that primarily ought to denote shape and affiliation on the basis of spatial, not temporal relations.

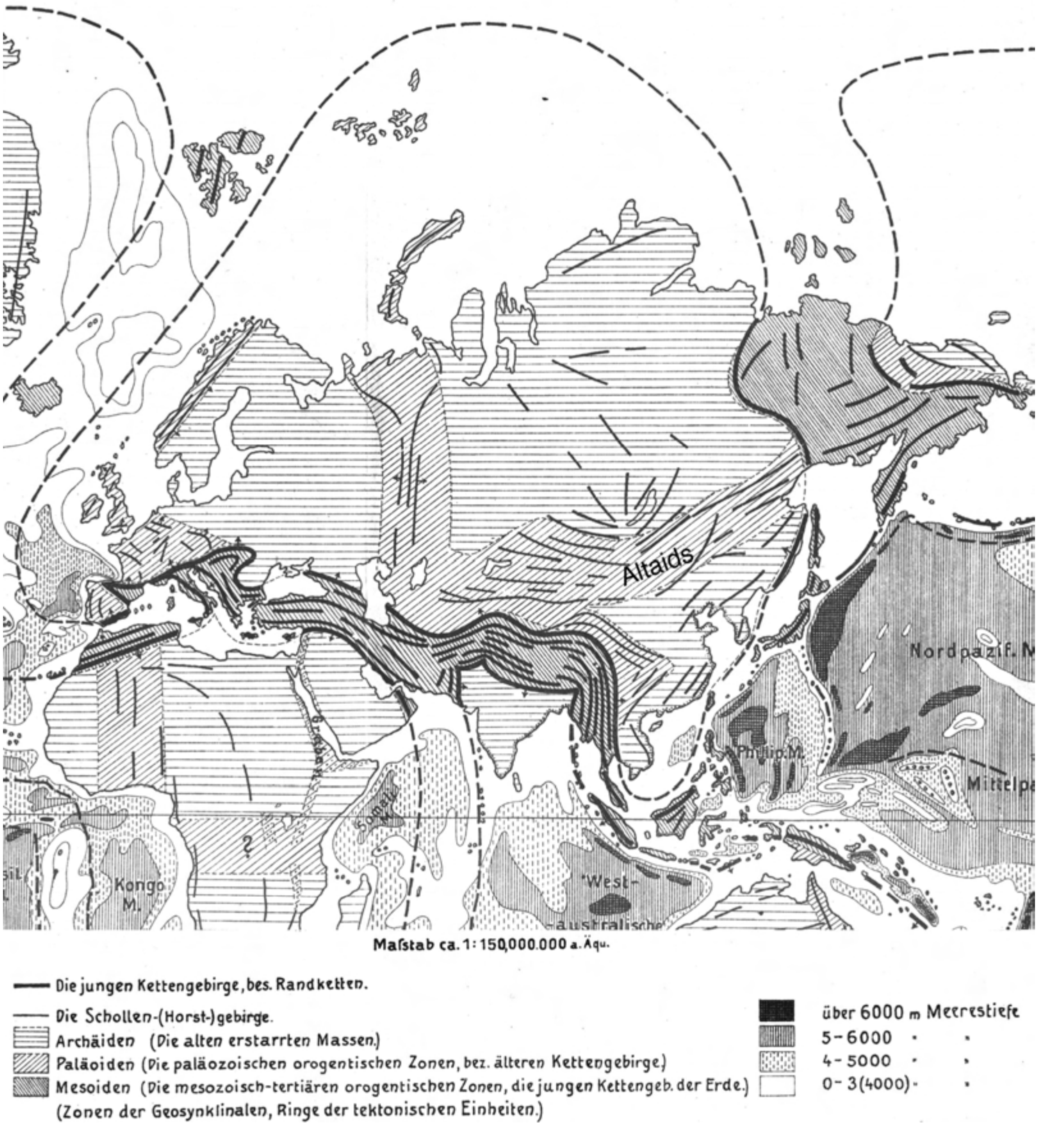

Fig. C21. A part of the tectonic map of the world according to Kober (1921; foldout).

We have added the word Altaids to show where they are in Kober's view of the structure of Asia. Translation of Kober's legend: *Die jungen Kettengebirge, bes. Randketten*=The young mountain chains, esp. marginal chains; *Die Schollen- (Horst-) gebirge*=Block (horst) mountains; *Archäiden (Die alten erstarrten Massen)*=Archaeides (The ancient consolidated Masses; *Paläoiden (Die paläozoischen orogenetischen Zonen, bes. älteren Kettengebirge)*=Palaeoides (The Palaeozoic orogenetic zones, esp. old mountain chains); *Mesoiden (Die mesozoisch-tertiären orogenetischen Zonen, die jungen kettengeb. der Erde)*=Mesoides (The Mesozoic-Tertiary orogenetic zones, the young mountain ranges of the earth); *(Zonen der Geosynklinalen, Ringe der tektonischen Einheiten)*=(Zones of geosynclines, rings of tectonic units).

Palaeoides are the Central Asian block mountains, the Altaids in the sense of E. Suess. [*This is an incorrect assertion! The block mountains in Central Asia, which disrupt the older orogenic structure do not constitute the Altaids. It is the orogenic structures that make up the Altaids, as Suess so clearly enunciated: 'It is these folds or waves that we group together as the* Altaids.'] They are the equivalents of the Hercynian, the Variscan, the Armorican Alps in Europe [*Compare with Haug: 'In Asia, the large mountainous zone between the Ancient Vertex of Central Siberia and the Tertiary chains to the south is mainly formed from chaines, the main episode of folding of which dates from the middle of the Anthracolithic Period and consequently must be envisaged as homologues of the Armorican and the Variscan chains. They are the* Altaids *of Suess'*]. As these, the various central Asian mountains probably also did not form at the same time. So for some of the mountains a pre-Devonian age is given, for others Carboniferous. Although these reports might well be right, we cannot pass a final judgement in view of the limited knowledge about these mountains. [*Notice the hint to separate the Altaids into separate orogenic entities, which Kober himself never attempted.*]

The Palaeoides of Central Asia belong to one orogen that trends approximately east-west across Central Asia, including plus or minus Mongolia. This orogen was recently rejuvenated along a strech between Lake Balkhash and the Amur. It is an orogen that lies between the *Siberian* and the *Sinian* Masses [*compare Figs. C19 and C21 to note Haug's direct influence*]. Its more detailed outlines are unknown. This orogen must be connected to the Uralian orogen in the west. This *Mongolian* or *Altaic* orogen is a descendant of a *Palaeozoic geosyncline*, which was connected to the Uralian in the west and to the Japanese (Pacific) in the east. Palaeozoic geosynclinal beds have become known from all the mountains of the Ob, of the Amur, of the Syr Darya. This Palaeozoic geosyncline of Mongolia has not been well understood until now. But it can now be distinguished and as the knowledge about these mountain regions progresses the geosynclinal character of these regions in the Palaeozoic will be better recognised.

As the Mongolian geosyncline is not yet recognised, it is understandable that the orogen-tectonics is much less comprehended. If we assume an east-west trending orogen [*from here on, see Figure C21 to be able to follow Kober's text better*], we have to separate an old north-flank and a south-flank. The first was moved onto the Siberian table-land and the latter over the foreland in the south, thus onto the Sinian Mass or its western continuation (Tarim Basin?). Then we would expect regional movement northwards, thus onto the Siberian table-land (Siberian stem [*or flank*]), but in the south, southward motion. [*This totally hypothetical picture was based entirely on Kober's expectations from his orogen-theory, which was nothing more than a paraphrase of Haug's ideas on mountain-building put in much stronger structural terms, and from his acceptance of Haug's geosynclines. The only observations at Kober's command at the time was the retrocharriage onto the East Siberian table-land and the southerly vergence onto the Tarim Basin of the Tien Shan, both of which made accessible to western European geologists by Suess after Russian publications. It is quite shocking how little data Kober commanded to come up with such detailed deductions and how seriously he was taken subsequently. See the summary of his database in Kober, 1921, pp. 210-215*] The younger tectonics, that has led to the rejuvenation of parts of the orogen, has to be separated from this older tectonics (stem-tectonics). It is this that today determines the morphology of Inner-Asia, making up the young disjunctive tectonics. And it is this tectonics that has mainly been recognised. The older orogen-tectonics, i.e. the old Palaeozoic structure, has not been recognised. Only the first steps have been taken.' (Kober, 1921, pp. 208-210, emphases his).

With Kober we finally have a two-sided, narrow, long and sinuous orogen that grew out of a 'Mongolian' geosyncline. Since he incorrectly ascribed Suess' designation Altaids to the brittle and semi-brittle block structures that divide up central Asia today, the hypothetical two-sided Palaeozoic orogen he created was left nameless except that it was thought a part of the Palaeoides of Asia. This prepared the ground for the renaming of the Altaids. Kober gave a first hint as to what sort of a name he thought might be appropriate by naming the mother geosyncline as Mongolian.

Stille on the Altaids: Kober's intellectual twin, but his superior in the rigour of thinking was his contemporary Hans Stille (1876-1966). His and Kober's thinking were almost exactly parallel and for half a century they dominated the classical fixist thinking in Europe and in the United States (see Şengör, 1982a, 1991a, 1999). Initially they also had great influence in the Soviet Union (e.g., Arkhangelsky, 1939; Bogdanov and Khain, 1964, esp. the introduction titled 'Hans Stille and his scientific work,' pp. 5-12; Şengör, 1996), but, as we shall see below, the developments in Central Asia soon forced the Russians to deviate from the classical geosynclinal models of the western European fixists.

When Stille's influential book, the *Grundfragen der Vergleichenden Tektonik* (=Fundamental Questions of Comparative Tectonics) came out in 1924, there was as yet no mention of any orogenic system as such in Asia, except to say that in Central Asia he was able to recognise, on the basis of the data presented in Suess (1901) and Leuchs (1916), the Bretonic (between late Devonian and the Visean) and the Sudetic (end of the early Carboniferous), orogenic phases. In the Kuen-Lun and the Chinese mountain ranges, Stille was further able to propose the existence of the Asturic (post-Moscovian-pre Uralian) and the Saalic (intra-Permian) phases (see Stille, 1924, pp. 118-121). However, these alleged episodes were not as yet tied to any large-scale structures in the structure of the continent.

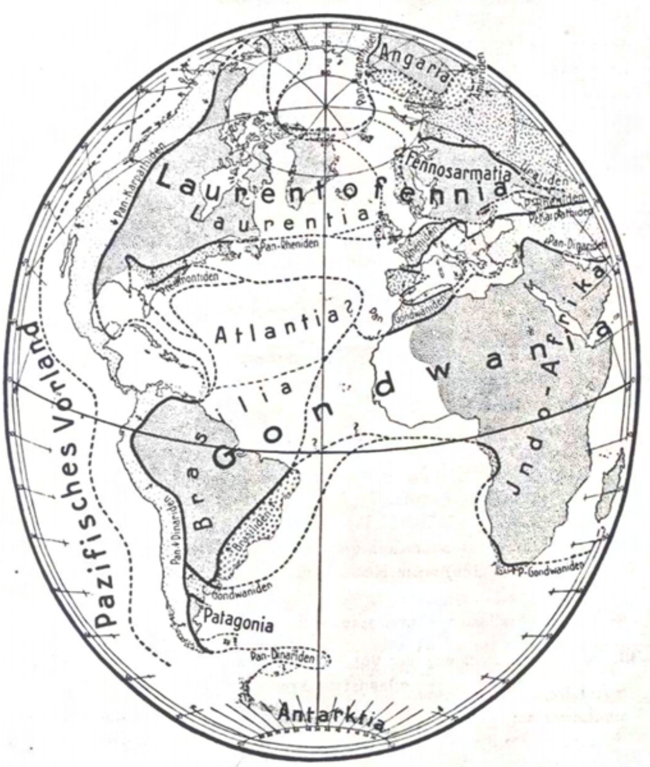

Fig. C22. Stille's tectonic sketch of the Atlantic hemisphere (from Stille, 1928, figure 2).
Key to symbols: dense stippling: regions of Precambrian consolidation; small circles: regions of Caledonian consolidation; irregular short lines: regions of Variscan consolidation; sparse stippling: regions of alpidic folding.

Stille addressed the spatial relations of orogenic structures in Central and northern Asia in a paper on the family tree of mountain ranges and forelands, which he read to the 14th International Geological Congress in Madrid in 1926. In that paper, he took Kober's hypothetical Palaeozoic orogen in central Asia, connected it with the Urals and named it the Ural-Amurian orogen (Stille, 1928b):

> 'A further Variscan orogen, one which was consolidated almost in its entire great extent already through the Variscan folding, lies between the Fennosinian foreland zone (Laurentofennia-Serindia-Sinia) in the south and Angaria in the north and northeast. It is divided into a 'Uralian' ('Uralian-Tien-Shanian') flank, the 'Uralides', the folding of which is directed towards the Fennosinian Foreland zone, and a northerly or northeasterly 'Amurian' ('Altaic-Amurian') [flank], the 'Amurides', whose folding is directed towards Angaria.

Fig. C23. Part of Leopold Kober's 'morphotectonic' world map from the second edition of his *Bau der Erde* (=Structure of the Earth), plate II (Kober, 1928).

Key to symbols: Heavy horizontal ruling: regions of Precambrian orogeny and the present-day cratons (*Kratogene* in Kober's terminology); black on white stippling: regions of Caledonian orogeny; Heavy vertical ruling: regions of Variscan (=Hercynian) orogeny; black: regions of Alpide orogeny; light vertical ruling: continental slopes (3000-4000 m depth range); light horizontal ruling: ocean floors (5000-6000 depth range); grey colouring: deep abyssal basins (same depth range as before, but in the shape of sag basins); white stippling on black: regions deeper than 6000 m, i.e. trenches); continuous dashed lines are the orogenic rings. Key to symbols: Ä: Ethiopian table-land; A'=Australian table-land; C: Congo sag-basin; C': Chinese table-land; Ca: Caledonides (stippled); J: Indian table-land; M: Madagascar sag-basin; Me: Alpides-Mesozoides (black); MP: Middle Pacific sag-basin; NP: North Pacific sag-basin; O: Orange sag-basin; Pa: Variscides (vertical thick ruling); R: Russian table-land; S: Somali sag-basin; S': Siberian table-land; S": West African table-land; U: Karroo table-land; WA: West Australian sag-basin. Arrows indicate vergence directions (shown only for Alpides-Mesozoides of Kober).
Both this and the previous map shown in Figure C21 illustrate also sloppiness in Kober's handling of the data similar to Haug. This attitude is reflected also in Kober's conclusions.

For example, the folds of the Altay and those in the Amur region, directed towards Angaraland [*the folds of the Altay as a whole are southwest-vergent, so what Stille says about them is just plain wrong and this was known at the time: see Suess, 1901*] belong to the Amurian flank and, according to Kober, on the eastern side of the Urals near Yekaterinburg the east-vergent folding recognised there expresses one directed towards Angaria. This is perhaps also so for the locally seen southeast-vergent folding in the Novaya Zemlya, whereas the rest of the island displays the Uralian west-vergent folding. To the east and southeast, the continuation of the Uralian flank of the Uralamurian orogen is found in the old folds southeast and east of the Aral Sea, in those of the Tien-Shan verging southwards towards Serindia and farther in the Huang-Ho chains directed towards Sinia' (Stille, 1928b, p. 1762).

As is seen in Figure C22, Stille sketched a wide area of ‘Caledonian’ consolidation between what he called Angaria (Suess' East Siberian table-land) and his Uralamurian orogen.

Stille thus finally invested Kober's unnamed, double-sided, hypothetical late Palaeozoic orogen in central Asia with a name, the Uralamurian orogen, and adduced additional evidence, albeit very fragmentary and some of it spurious, to support its symmetry. In the second edition of his *Bau der Erde* in 1928, Kober had resketched this orogen, but this time a narrow ‘Caledonian’ margin had appeared in the north, just around Lake Baykal (Figure C23), just as it had done in Stille's sketch (Figure C22). Subdivisions within the Altaids had begun to appear!

Fig. C24. Argand's ‘very ancient Asiatic drifts’ (Argand, 1924, figure 7), showing the convergence of the East Siberian, Sinian and the Serindian continental pieces and the creation of the Altaids.

Argand on the Altaids: Émile Argand (1879-1940) is the greatest tectonician in the history of geology after Suess, a multi-faceted polyglot genius who commanded no less than seventeen languages. In most of his structural thinking he was a direct heir to Suess. However, in his interpretation of the stratigraphy, in his adherence to the image of geosynclines (despite the fact that he said his thinking had somewhat neglected the notion of geosynclines: Argand, 1924, p. 299) and in his almost rigid application of the so-called folding eras in the history of the earth, namely the Caledonian, Hercynian and Alpine[42], he was under the strong influence of his namesake Haug. His analysis of the history of the Altaids is very reminiscent of that of Haug and no doubt had Haug's treatise as its basis. As such, his prophetically mobilist view was cast in a fixist framework: His oceans had the aspect of geosynclines and it was within this ‘geosynclinal’ framework that he interpreted the Altaid ocean (Figure C24). In the following, we quote and annotate Argand in the same way we did Kober and Stille above:

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[42] In this matter, Argand was most likely strongly influenced by another Francophone genius in geology: Marcel Bertrand. In the famous preface he wrote to the French translation of Suess' *Antlitz*, Bertrand had written that the grandeur of Suess' work was also reflected in the history of the earth he had presented. Bertrand wrote, among others, that ‘it should be recalled what could have been said about the general traits of this history thirty years ago: the complexity of the mountain chains reduced to three grand units ordered from north to south towards the Mediterranean region; the enormous massifs of Asia and the small massifs scattered about in Europe are equally attached to these three ensembles.’ (Bertrand, 1897, p. XIII). The inclusion of Asia in the three units (the Caledonian, Hecynian and Alpine) had never been done by Suess, so, what Bertrand said about it, was simply untrue. Suess in fact later protested against Bertrand's generalisation of what he had done in Europe to the world (Suess, 1909,p. 40, note 1), but somehow Argand did not pay attention to Suess' protest.

> ‘The Hercynian folding of the Urals is also responsible for the massif of the Kirgiz steppes, a portion of the Russian Altay, the Tarbagatai, the Dzungarian Alatau, the Tien Shan, and most of the Kuen-Lun with its branches: The Yarkand arc, Altyn Tagh and Nan Shan, with their rear chains, and Qin-Ling Shan [*cf. Haug: ‘Without entering into any detail, it should suffice for us to say that the two principle bundles that constitute this system of folds are, in one part, those of the Altay and the chains of Trans-Baykalia following the contours of the Ancient Vertex, and in another part, those of the Kuen-Lun which open up eastward giving rise to Nan Shan and the chains north of China, then to Qin-Ling and finally the chains of Sichuan and Yunnan. All these divergent branches embrace in their arms the much older massifs of eastern China. Between the two bundles the Tien-Shan is intercalated which is probably much younger, like the Ural.’*]. The different branches of the Kuen-Lun contain fragments of pre-Devonian folded frames brought to the surface. Precursor movements were active in many places during the Devonian [*see footnote 44 below*]. A very important phase of folding occurs in the Kuen-Lun and the Tien Shan at the end of the Devonian and at the beginning of the Dinantian; a second paroxysm, which probably corresponds to the intense and most frequent phase in Hercynian lands, affects these two chains during the Late Carboniferous. Later, smaller episodes of shortening occur at places during the Permian. [*Haug: ‘In Asia, the present state of our knowledge does not permit us to delineate the location and the direction of the pre-Devonian folding, but it also seems that these were posthumous*[43] *folds that gave rise to the meso-Devonian transgression reported from diverse places.’ ‘In Asia, the large mountainous zone between the Ancient Vertex of Central Siberia and the Tertiary chains to the south is mainly formed from chains, the main episode of folding of which dates from the middle of the Anthracolithic Period and consequently must be envisaged as homologues of the Armorican and the Variscan chains.’*] The Qin-Ling Shan, between the 104th and the 106th meridian, displays a typical Hercynian structure with pre-Devonian enclaves. At one location of the Ngan-Hoey, the Permian rests unconformably on Upper Carboniferous: the Hercynian frame reaches the shores of the Pacific. From there to the regions of western Europe, it stretches over more than 11,000 km; belonging to this trend are the 3,500 km of the American segment.’ (Argand, 1924, pp. 192-193).

The geosynclinal precursor of these ‘Hercynian’ ranges Argand traced well into the Precambrian, into Algonkian times and therein differed significantly from Haug. Where Haug had depicted just seas and lands, Argand clearly recognised a geosyncline, which he was aware, actually had been an ocean:

> ‘The fact that the Caledonian foldings had in Asia a much greater importance than shown at present by the most direct pieces of evidence is indicated by their action ...
>
> Assuming that the marginal folds of the Amphitheatre, which are identified or followed from the bend of the Lena, near the 118th meridian, toward Irkutsk, then along the Yenisey and across the lower part of the three Tunguskas, are really Caledonian, then there would be no difficulty in connecting them westward, underneath the Hercynian Novaya Zemlya, with the Caledonides of Svalbard and Greenland, as well as with those of Scandinavia and the British Isles; a Cambrian and Silurian geosyncline would have snaked between the Fennoscandian massif and the Siberian shield and would have been filled with folds; it would have been the precursor of the Hercynian geosyncline from which were generated the Urals, the massif of the Kirgiz steppes, and the major part of the Russian Altay.’ (Argand, 1924, pp. 190-191).

Figure C24 shows this geosynclinal system. Significantly it was placed on the same page as the map of the Tethyan geosyncline (Figure C25). Argand thought of geosynclines really as oceans that stopped evolving *in statu nascendi* (Argand, 1924, p. 299). But the way he depicted the Altaid geosyncline shows that he regarded it as an ocean or at least more of an ocean than the Tethys. Also the tremendous complexity he depicted within the Altaids by sketching their trend-lines (Figure C28), showed that he did not subscribe to the simple, double-sided orogen schema of Kober and Stille for the Altaid internal structure.

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[43] What Haug calls in this context posthumous folds refers to the previous folding in the Altaid geosyncline that the could not reconstruct (Haug, 1908-1911, p. 733). This is in a similar sense to Suess' calling the Alps ‘posthumous Altaids’ (see Suess, 1909, p. 219). Argand called the initial preparation of the Alpine embryonic nappes in the latest Palaeozoic and the Mesozoic precursor movements (Argand, 1916, 1920; with a fundamental modification to introduce intercalated episodes of extension, in 1934). So the posthumous movements of Suess, became the precursor movements of Argand. It is in this sense that Argand turns the posthumous movements of Haug within the Altaid geosyncline into the precursor movements of the Hercynian chains of Asia.

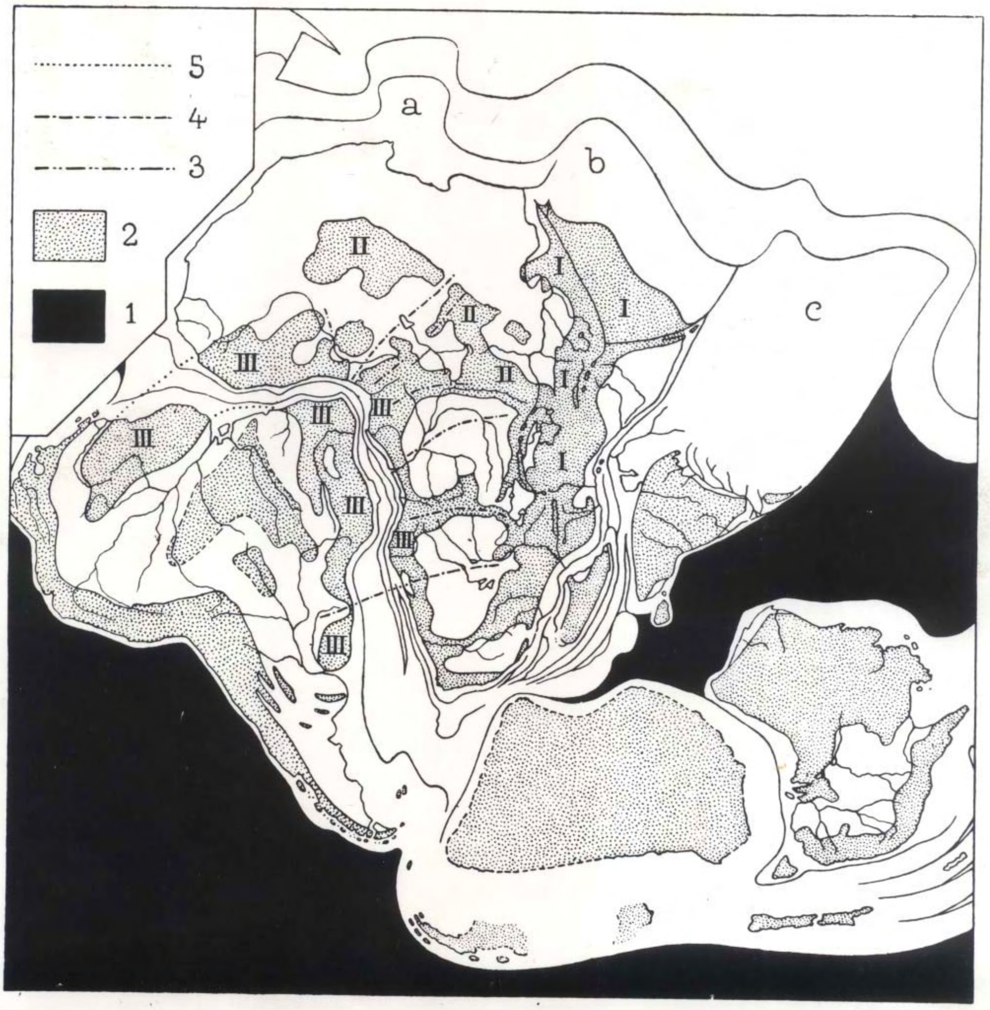

Fig. C25. Argand's Gondwana-Land and the Tethys.

Key to legend: 1, Sima dominant; 2. Regions in which anticlinal basement folds dominate; 3. Culmination of the basement folds; 4. Depressions of the axes of the basement folds.
I, II, III, first, second and the third branches of the interior virgation [of basement folds] of Gondwana-Land.
a, b, c, promontories, which Gondwana-Land turned towards the Tethys: a: African promontory, b: Arabian promontory, c: Indian promontory.
Note the entirely geosynclinal form of the Tethys and how Argand did not give it an entirely simatic basement. To be able to do that, he added an unrealistically long appendage to India. Also note, because of the geosynclinal form, the promontories of Gondwana-Land correspond exactly with the reentrants of Eurasia.

Let us now see how Argand imagined this Altaid geosyncline to have originated and when:

‘Let us draw a great circle passing approximately through Bodunö[44], Qiqihar[45], and crossing the Amur at 122° longitude, passing east of Teptorgo [46]and crossing the Lena near the 114th meridian. This line displays on the globe a slight convexity to the east-northeast like that other great circle, which not very far away is the terminator of the segment of central Asia. The new great circle divides into two halves the great reentrant that is occupied by the

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[44] A Chinese town now called Fuyu in the Jilin Province at 45°10'N, 124°40'E.

[45] A Chinese city in the Heilongjiang Province at 47°23N, 124°E.

[46] Within the Patom highland, where the Teptorgo metamorphic formation extends. See the next footnote.

loop of the old folds of the Patom region[[47]], folds that are strongly reworked into Alpine basement folds. The concavity of this loop opens in the same direction as the conformations of the north of Manchuria. Therefore, one can think that a nucleus or a spur of the Sinian massif is facing the Siberian reentrant on the same great circle, and not without a certain degree of congruence. This congruence could well be, just to mention it briefly, the indication of a very old Precambrian continental displacement that could have led to the separation of the oldest nuclei of the Serindian [[48]], Sinian,and Siberian massifs [*see Figure C24 herein*] and created the huge geosyncline with partially Algonkian deposits, from which the vertexes[[49]] was to rise and a portion of which was to survive until the end of the Hercynian cycle, in the vicinity of the Tien Shan. This displacement, if it ever ocurred, has been less important in the Sino-Siberian space than in the Serindo-Siberian space.

The nuclear parts of the Sinian and Siberian massifs could therefore have formed a single tectonically homogeneous mass in very remote times. Whether this was the case during all ante-Alpine times is doubtful on account of the polycyclic history of the Sinian massif and the enormous geosynclinal accumulations in the region of the vertexes. A Sino-Siberian welding was once again accomplished by the closing of this huge geosyncline, itself polycyclic. The welding became permanent only at the end of the Hercynian cycle.' (Argand, 1924, pp. 250-251).

Thus far Argand's published work. But the great master did not stop thinking about the Altaids and he sketched out an evolutionary scheme for them too, which shows his geosynclinal bias very clearly. Strangely, he annotated his unpublished (and unfortunately undated) figures in German[50]! In Figure C26, Argand showed what he called the early Caledonian situation: Notice that he recognised early Palaeozoic folding along the western and southern margins of what he called the Siberian Shield (Sb) and along the northern margin of Sinia (Si). Also he noted one locality north of Serindia (Se). Here, he divided Haug's Sinian continent into two and indicated South Sinia by Ssi, showing that it was separated from north Sinia (Si) by the Qin Ling, which he depicted with an alternation of CHCH, indicating 'Hercynian' folding with 'Caledonian' inliers. The Kuen-Lun south of Serindia, he indicated to be an entirely 'Hercynian' range, going down into Sichuan and Yunnan (a series of H's and two C's ranged along the western side of SSi, Ca {Cambodia} and Bo {Borneo}).

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[47] This region is the great reentrant of the east Siberian craton between Lake Baykal and the Aldan Shield, so roughly delimited by the 110°E and 120°E meridians and the 52°N and 60°N parallels.

[48] The term 'Serindia' was used by Argand to denote the allegedly continental fragment forming the basement of the Tarim Basin. Herrmann (1923), however, had suggested that Serindia was a misspelt form of 'Serinda,' which might be synonymous with the Arabic *Serendib*, and presented arguments to show that it was probably Ceylon! Using the same historical data as Herrmann, however, Baron von Richthofen (1877, pp. 528-529, 550-551) had come to the conclusion that Serinda must be identical with Khotan (today Hotan: 37°07'N, 79°57'E). The late dean of the Chinese geologists Prof. Huang Jiqing (T. K. Huang, a doctoral student of Argand) thought that the term might have been a sort of shorthand for the expression 'Silk roads to India', although a literal transliteration in Chinese would be *Shi Indu*, meaning 'silky India'. Prof. Huang was unfamiliar with such a usage in Chinese. Serindia was also used after Argand in the geological literature as late as 1958 by Stille.

[49] The plural term vertexes (*faîtes*) is Argand's reference to what Suess had called the Ancient Vertex (Suess, 1901, ch. 3) and to the surrounding younger vertexes mentioned by Suess (e.g., Suess, 1901, p. 249 and 498). Suess had regarded the vertexes as sort of central points of the Altaid structure, from where concentric waves of folds radiate away. They were viewed as the oldest parts of the folded edifice. Argand wrote: 'I think it is wise to abandon the adjective "primitive", which prejudges the folds to which it is applied to be exclusively Precambrian, and I shall use the word "vertex" or "vertexes", excluding any hydrographic implication, to designate a large region with incompletely sorted out fold trains that includes among others, the Alatau of Kuznetsk, the western Sayan, the eastern Sayan, Transbaykalia, and a portion of the Amur lands, the Khangay and the chainlets of northern Gobi, the Tannu-Ola, the horsts of the Valley of the Lakes, and the Mongolian Altay—all objects that, except for the Alpine movements that reinvolved them later, display within their old frames foldings of different ages, not defined everywhere, and whose extent could not be established without numerous new observations.' (Argand, 1924, p. 185).

[50] Could it be because he had Staub (1928) open before him, and what he sketched was a sort of improvement on what Staub had done? Compare the Figures C26 and C27 herein with figures 26 and 42 in Staub (1928).

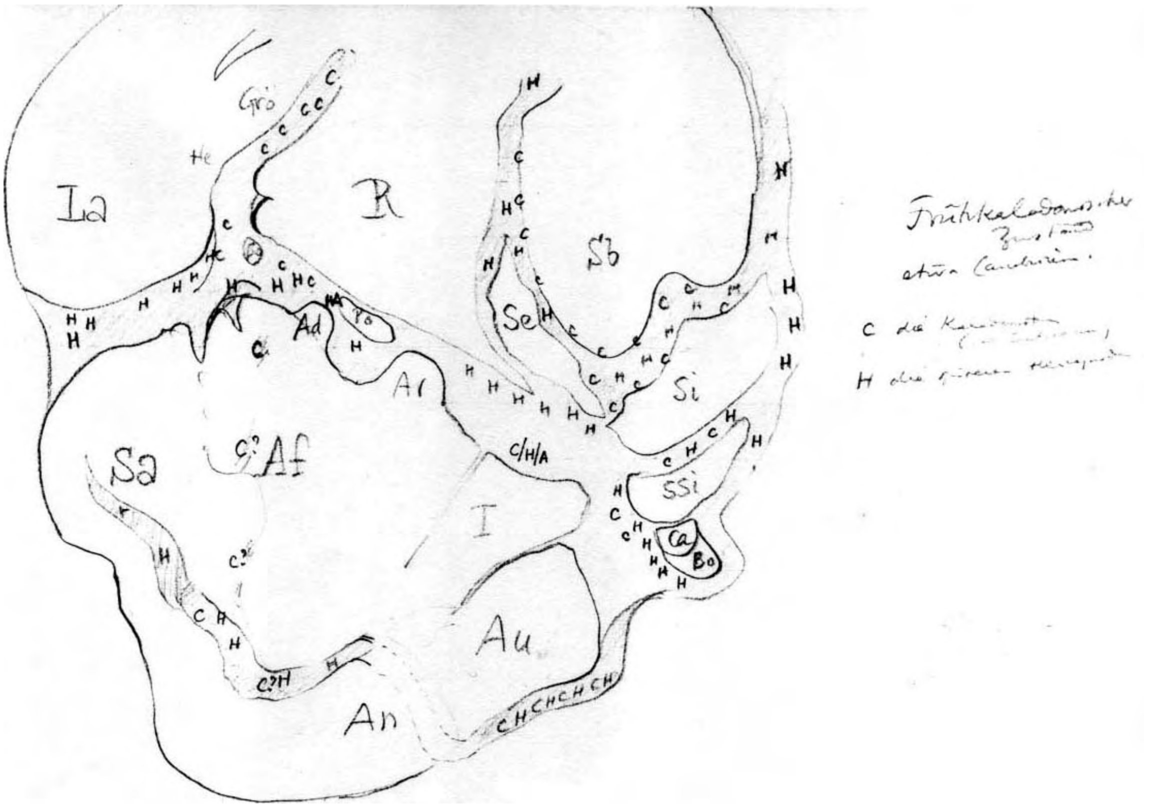

Fig. C26. Argand's manuscript sketch showing the 'early Caledonian' (i.e., very early Palaeozoic) situation of the Pangaea.

This sketch and the one in the subsequent Figure C27 were shown to Şengör by Professor Jean-Paul Schaer of the Institute of Geology of the University of Neuchâtel. We are deeply grateful to him and to the Institute for the permission to publish these never-before published figures. They are preserved in the archives of the Institute. Unfortunately the sketches are not dated.

Argand thought that after the 'Caledonian' orogeny, the ocean (had reopened and?[51]) created the 'Hercynian' chains (Figure C27). He thought that the situation of Pangaea, shown in Figure C27, depicted the geometry of the supercontinent during the early Carboniferous. By this time, the 'Caledonian' strip had been fully acrreted to the Eastern Siberian craton (Sb). The H's show the embryonic folds, according to Argand's theory of embryotectonics, growing out of the mother ocean (=geosyncline)! Today he might have called them island arcs.

Argand's vision of the Altaid evolution was decades ahead of its time. That is probably why he did not bother to publish them. He had little confidence in the geological community's ability to comprehend what he was getting at. With what was available to him, he did the best that could have possibly been done. At the time no major strike-slip faults had yet been recognised, despite the fact that Argand himself had noticed their necessity in the Alps and in his depiction of the tectonic evolution of the Mediterranean. However, the data at his command (whatever was available to Suess plus more, because Argand was able to read the languages in which the totality of the geological literature had been published until his time and he had the undivided support of Emmanuel de Margerie to find out what was being published) would not have allowed him to create an evolutionary scheme more complicated than a concertina-style tectonic evolution.

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[51] It is unclear whether Argand contemplated a closing and reopening of the Altaid mother ocean. His figures certainly imply so.

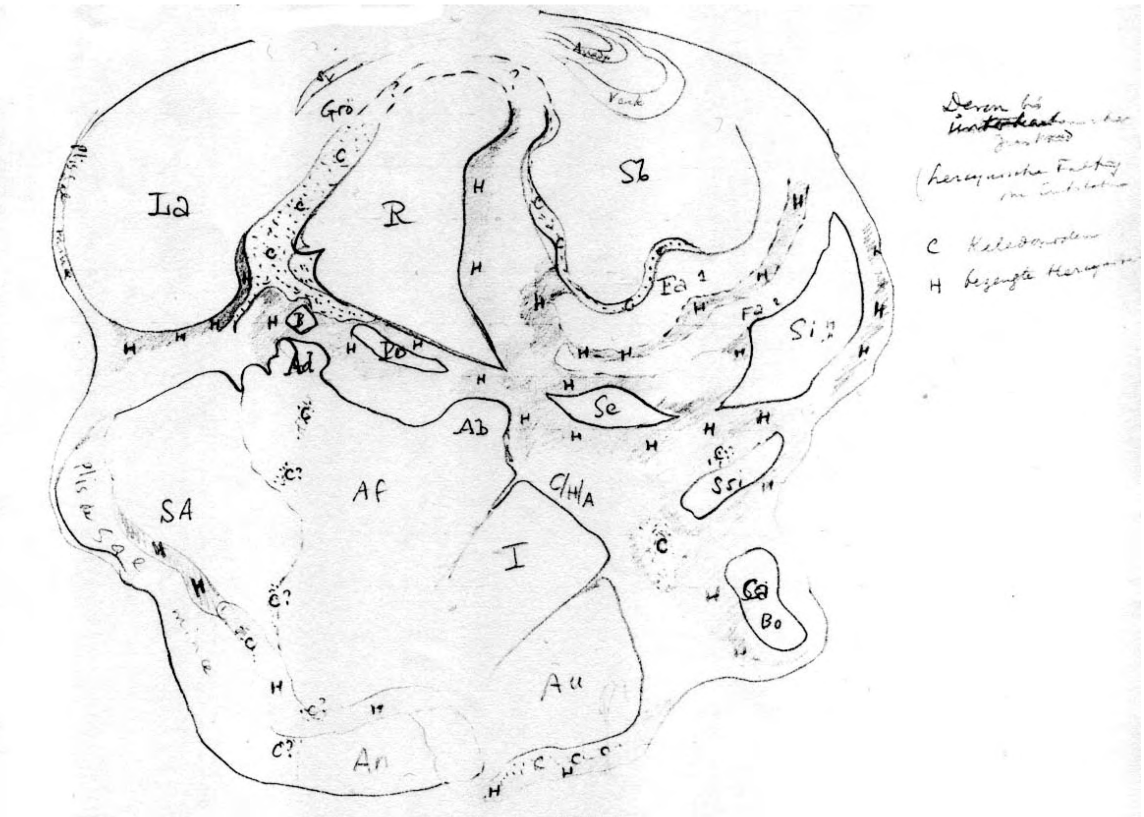

Fig. C27. Argand's manuscript sketch showing the early Carboniferous situation of the Pangaea.

We have little doubt that he must have appreciated that the situation had been more complex (otherwise he would not have drawn the trend-lines in Kazakhstan, in the Altay and in Mongolia in the way he did), and that the scheme he sketched out for his private studies was only a first step in the right direction. As has been usual with him, he turned out to be largely right.

Ironically, despite the great insight Argand sowed into the Altaid evolution, what he published (except his great 1928 coloured tectonic map of Eurasia: Figure C28) seemed to reinforce what Kober and Stille had been saying. Clearly, more data were needed.

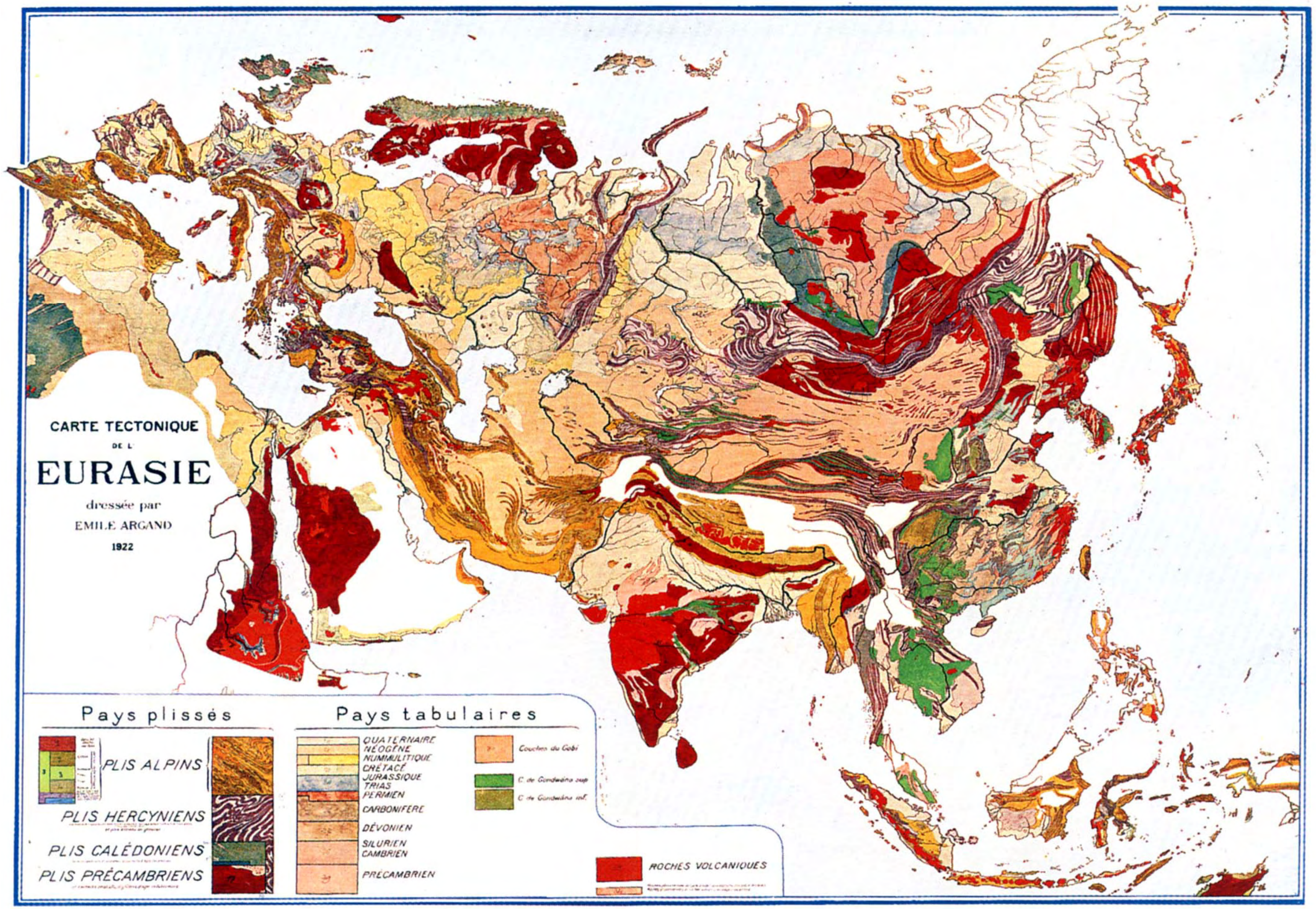

Fig. C28. Tectonic map of Eurasia by Émile Argand (1928).

ALTAIDS IN THE SOVIET UNION[52]

Developments after the death of Eduard Suess: After the end of the twenties of the twentieth century, there were no significant developments on understanding the Altaid tectonics in western Europe and in the United States until the seventies, despite the important expeditions to the individual Altaid chains (such as the expeditions of Sven Hedin to the Tien Shan or the expeditions of the American Museum of Natural History to Mongolia, or the 1928 German Alay-Pamir expedition, etc.). The reasons for this are varied, but the growing economic depression and consequent political instability in countries traditionally involved in Altaid research (Germany, Austria, France) and the severed scientific ties between eastern and western Europe after the Russian Revolution in 1917 are the main ones. Before that time, there were no great differences in thinking on tectonics beween the western scientists and the Russians, because they continuously influenced each other, exchanged ideas, and there were no ideological barriers to filter the mutual influence.

As we noted above, Marcel Bertrand (1897) extended Suess' tri-partite division of Europe into Caledonian, Armorican-Variscan (Bertrand, 1887, had called this ‘Hercynian’) and Alpine folding regions into Asia. This lead was quickly followed by Haug, as we saw, and the French geologist de Launay (1911) mapped out the regions of folding of different ages in Asia according to Bertrand's remark (Figure C29). Feodosy Nikolayevich Chernyshev (1856-1914) continued in the same vein in his posthumously published book (Chernyshev, 1915).

The great Russian geologist Alexander Petrovich Karpinsky (1847-1936), a friend and correspondent of Suess, included the Urals into the Altaid edifice in 1919 despite the fact that the Urals have the ‘wrong’ vergence if one accepts Suess’ view that the Russian craton is the western continuation of the Ancient Vertex[53] (Suess, 1901, p. 498; for further discussion of this problem see Natal’in, 2006). According to Suess, the Altaids must verge away from the Ancient Vertex, not towards it. Karpinsky considered that in the Silurian and Devonian times the Urals must have resembled the island arc systems of eastern Asia and that the Uralian geosyncline was first established in the early Carboniferous. Here it must be remembered that much of the ‘original geosyncline’ of James Hall was rightly viewed as only the Appalachian foredeep (e.g., see F. E. Suess, 1937, p. V; Şengör, 2003, p. 125). Karpinsky's reference to the Uralian geosyncline was actually to its foredeep and, in his dating of it, he was perfectly right. Karpinsky interpreted the large wavelength folds on the Russian platform as results of the Altaid shortening: Figure C30), Altaid ‘waves’ of Suess propogating into a crystalline basement material of much greater resistance than the dominantly sedimentary material surronding the East Siberian table-land. Karpinsky’s ‘Altaid waves’ propagating into the resistant material of the Russian platform were in the spirit of the times, as Abendanon had only a few years earlier published his *Großfalten der Erdrinde* (1914; ‘Megafolds of the earth’s crust’), an idea quickly adopted by such influential researchers as Walther Penck (1918, 1920) and Hans Stille (1919a, b), and may also have been influential in the creation of the *plis de fonds* (=basement folds) by Argand (1924).

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[52] It is unfortunate that there is no comprehensive history of Russian tectonics or geology as a whole in any western European language. For those who can read Russian, we recommend as background reading for the following discussions the following books: Tikhomirov (1953), Tikhomirov and Khain (1956), Burde et al. (2000), and Khain and Ryabukhin (2004). Short biographies, with portraits, of Arkhangelsky, Mazarovich and Shatsky are contained in Starodubtseva et al. (2004).

[53] Suess could only avoid this conclusion byconsidering the Ural as a posthumous fold bundle belonging to the folds of the Ancient Vertex (Suess, 1901, p. 499; also Natal’in, 2006, figure 13).

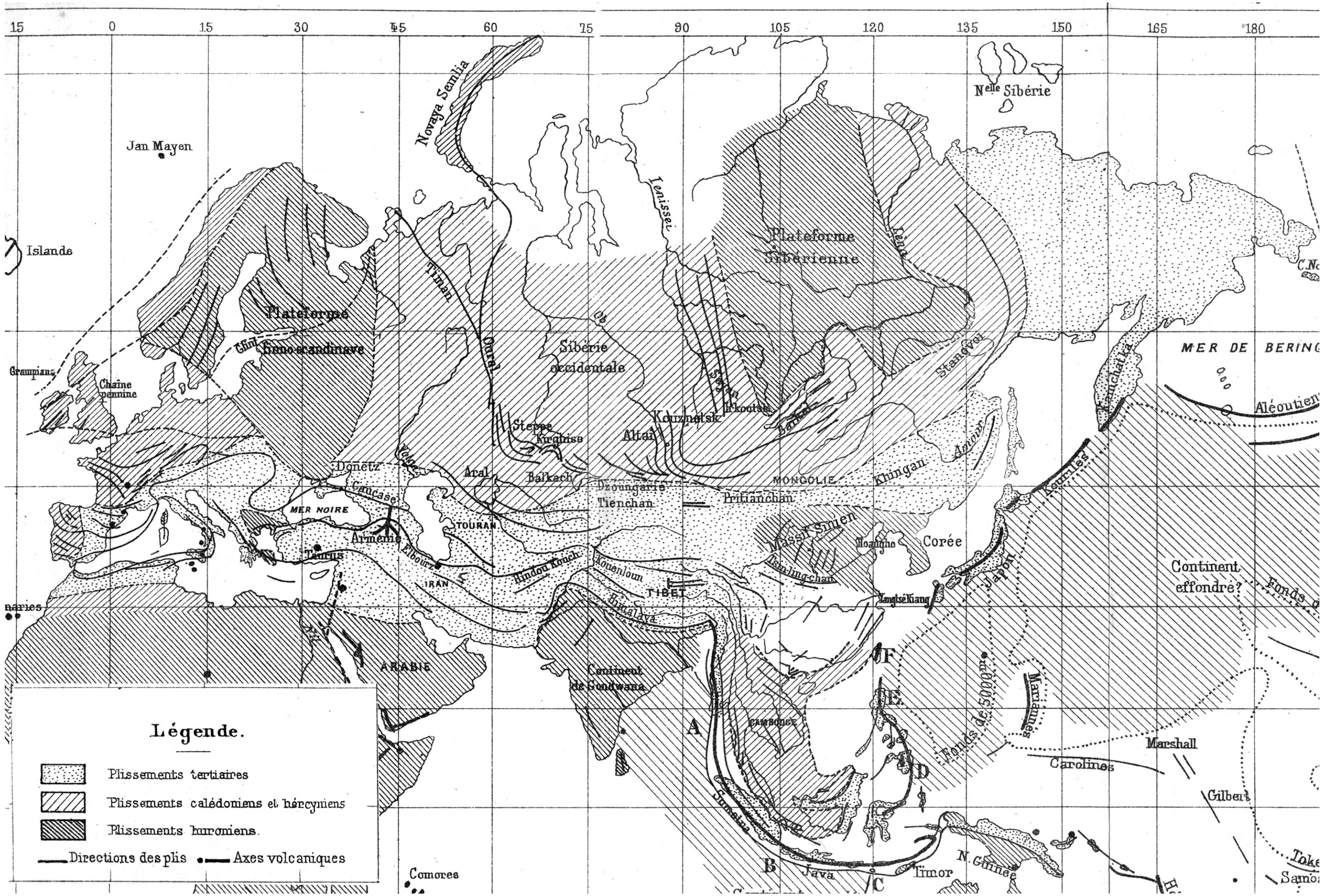

Fig. C29. Tectonic map of Asia and surrounding regions according to the age of orogeny drawn by de Launay (1911, plate I).

Translation of the legend: *Plissements tertiaires*: Tetriary foldings; *Plissements calédoniens et hércyniens*: Caledonian and Hercynian foldings; *Plissements huroniens*: Huronian foldings; *Directions des plis*: [Axial] trends of folds; *Axes volcaniques*: volcanic axes. This map had a profound influence on Russian thinking on the Altaids.

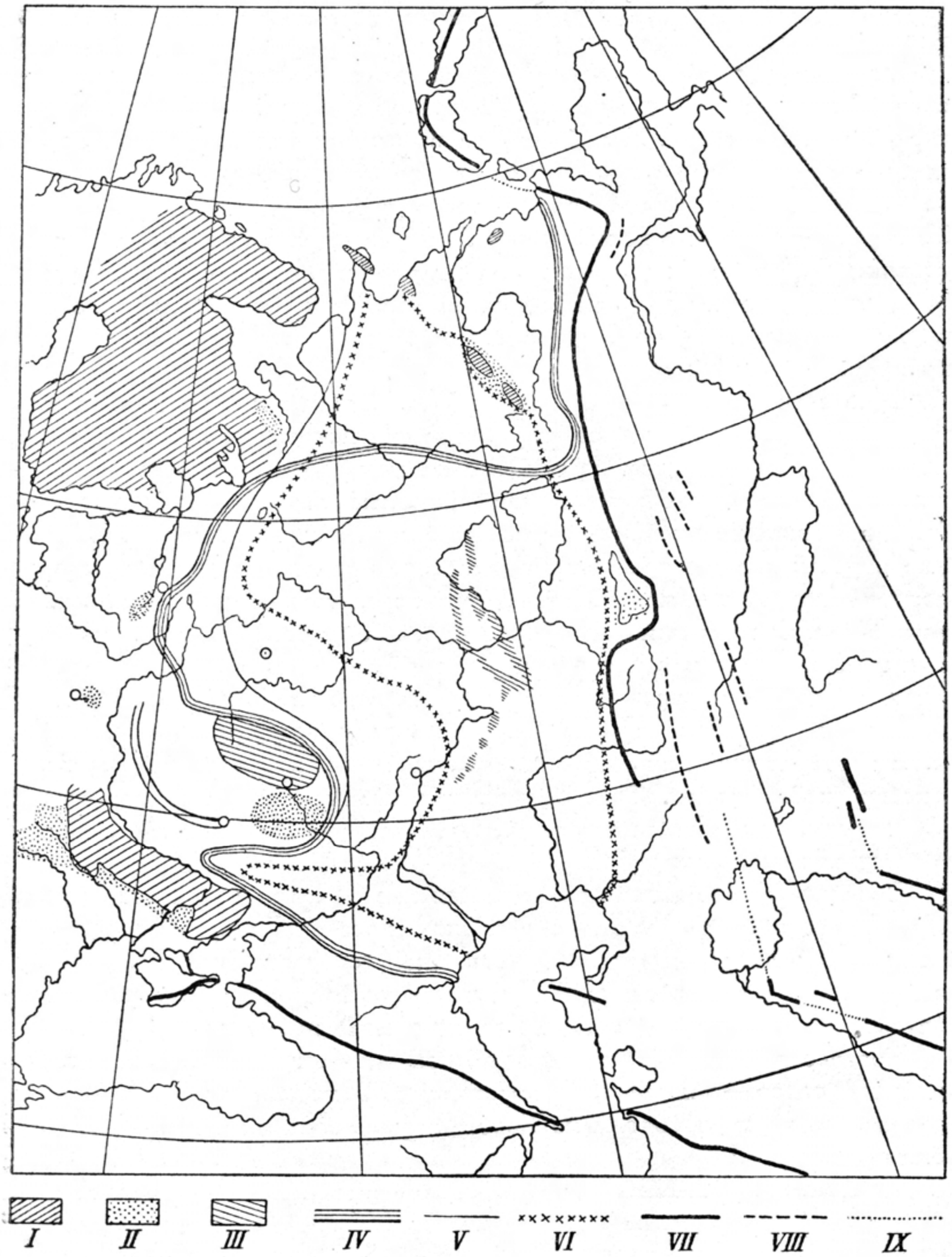

Fig. C30. Some elements of the tectonic structure of the European part of Russia after Karpinsky (1919[1939] figure 42) showing the conformity of the development of the platform structures wth the structures of the Urals.

Key to legend: I: Crystalline horsts (shields), II: Subterranean ‘horts’ (what are today referred to as basement uplifts), III: Gentle, ‘thick-skinned’ anticlines; IV: Western boundary of the early Carboniferous basin; V: Western boundary of the late Carboniferous basin; VI: Boundaries of the Permian marine basin; VII: Ural (western Carboniferous externides of the Urals) and the Crimean-Caucasian and Asiatic ‘kryazh’ (=uplands with resemblance to foldbelts; for a discussion, see Natal'in, 2006); VIII: Mugodzhar and other dislocation trends in the eastern Urals; IX: Suggested connexion between the Asiatic and Uralian dislocations.

The anti-Suess reaction in the Soviet Union: The anti-Suess reaction that had commenced with Haug in western Europe (cf. Şengör, 1998) was not long in coming to Russia. A younger generation of geologists began to be influenced by the authors of what Şengör (1982a, b) had called the Kober-Stille school (cf. Arkhangelsky, 1939) and Aleksei Alekseyevich Borisyak (1872-1944) accepted Stille's concept of the tectonic evolution of the earth, with some modification for the earliest periods of the Earth's evolution. He inferred an Archaean separation of continents and oceans. Then, the continental crust underwent universal penetrative folding and led to the formation of the platforms. The first geosynclines appeared as late as the late Proterozoic. With time, geosynclines diminished their sizes, making additions to cratons (Borisyak, 1924, 1931). This was precisely what was being taught in western Europe at the time concerning the Altaid evolution, as we saw above.

Tetyayev and Scheinmann on the Mesozoic development of Central Asia and the Soviet Far East: It was in the twenties that Mikhail Mikhailovich Tetyayev (1882-1956) came forth with the idea of the presence of strong, alpinotype orogenic events associated with large-distance, north-vergent nappe transport in the Transbaykal region, i.e., in a region about which there had been nearly universal agreement since Haug that the major orogeny there had been late Palaeozoic in age ('Hercynian' or 'Variscan' in the various writings of different authors). Tetyayev, by contrast sought to show that important orogenic events had continued in the Transbaykal region well into the Mesozoic and he further argued that the numerous granite intrusions in this area were supplementary indications of orogeny (see Gundlach, 1942, for a summary and literature list).

Later Yuri Mikhailovich Scheinmann used these Mesozoic movements plus the locally great thicknesses of Mesozoic deposits, all the way from western Tien Shan, through Mongolia, into the lower reaches of the Shilka river and beyond, following the southern edge of the East Siberian platform in the Soviet Far East, to reconstruct a hypothetical geosynclinal system, called the South Asian geosyncline, and subsequent orogen of Mesozoic age, which he termed the Mongol-Amurian foldbelt (Schönmann, 1929). This hypothetical structure comprised what we today consider the southern and eastern parts of the Altaids, excluding their extensions in Kazakhstan and in the Altay regions of the Russian Federation. In it were deposited not only the thick Mesozoic terrestrial sequences of Central Asia, but also the marine Triassic and Jurassic of the Transbaykal regions. Folds in the northern part of this geosyncline were overturned to the north. In the south, they were thrust onto the Ordos block thus showing classical divergent structure in accord with Kober's model.

However, Stille was asked by Emmanuel Kayser, the editor of the *Centralblatt*, where Scheinmann's article was published upon Stille's request, to discuss the significance of the contents of Scheinmann's paper. In his detailed discussion Stille (1929a) summarily rejected Scheinmann's interpretation of the existence of a large geosynclinal/orogenic system across Central Asia as far east as the Pacific shores. He pointed out that the sedimentary sections Scheinmann used were mostly continental and, notwithstanding their local great thicknesses, they did not amount to a unified mother trough of an orogenic belt. Moreover, the structures described were more germanotype in character than alpinotype, although Stille admitted that the Central Asian germanotype structures were more 'chain-like' than their equant-shaped European cousins (also see Stille, 1929b). They still, however, did not amount to an alpinotype orogen. As to the granites in the Transbaykal regions, Stille thought it prudent to await their geochemical study, lest they all turn out to be 'Atlantic-type', i.e., alkalic in character (Stille, 1929a).

What Stille could not deny, however, was the presence of very strong Mesozoic alpinotype deformations in the Transbaykal region and in the Soviet Far East. Although he doubted the transport distances reported by Tetyayev, he admitted that strong shortening must have taken place there. These were the first indications that the deformations of the eastern Altaids refused to be fitted into the Caledonian/Hercynian/Alpine schemata to which Marcel Bertrand and, following his lead, Haug had tried to confine them. Soon the developments in Kazakhstan were to force the Soviet geologists to begin deviating from the simplistic Kober-Stille schema of geosyncline⇒orogen⇒craton.

Mazarovich on the Altaids and the polycyclic nature of the Altaid 'geosyncline': In 1933, Aleksandr Nikolaevich Mazarovich (1886-1950), a student of the great Alexandr Petrovich Pavlov, under whose direction Haug's *Traité* had been translated, defined in the USSR regions of Precambrian, Caledonian, Pacific and Alpine folding (cf. Figure C31). Later, he recognized two first order units in the structure of the Earth: platforms and geosynclines (Mazarovich, 1938). In many aspects, his understanding of these structures was similar to the German tectonician Serge von Bubnoff's (1923, 1936), who in turn had been deeply influenced by Kober and Stille. The most important deviation of Mazarovich's division from his German forerunners was, however, the permanency he ascribed to geosynclinal development in certain regions because of manifest absence of transformation to cratonic state after episodes of folding. To support this statement, he pointed out the presence of large basins in cratonic domains that experienced a long history of subsidence and accumulation of rocks of great thickness. However, such zones of subsidence never experienced magmatic activity of geosynclinal extent. Subsidence on platforms evidently did not create geosynclines. On the contrary, he indicated that the 'Caledonian' structures of Kazakhstan had been later involved in subsidences accompanied by other earmarks of true geosynclinal activity, so no platforms were built by the Caledonian folding in Kazakhstan (cf. Figures C32 and C33), despite the Devonian redbeds seen in various parts of them (Figure C33). After the end of the early Devonian, there was renewed transgression and subsidence accompanied by volcanic activity. In the Carboniferous (Figure C34), Mazarovich saw a wide variety of facies development with islands dotting the sea surface. At the end of the Visean, he thought, the beginning of the Sudetic phase of folding was seen. Mazarovich emphasised that the distribution of the Sudetic structures, which were particularly strong within older massifs and accompanied by granitic intrusions, was largely controlled by the location of earlier consolidated blocks. Deformation eventually led to regional uplift and lacustrine formations began covering the uplifted land surface by the end of the Visean. By Moscovian time, Kazakhstan had no more marine waters; the regression progressed from east to west. By this time Kazakhstan had acquired considerable rigidity brought about by folding and intrusions. However, vulcanicity continued and in the medial Permian we again see folding, faulting and granite intrusions. In the Triassic there was yet another episode of folding and thrusting and Mazarovich says even the Cimmerian phase (earliest Jurassic-earliest Cretaceous) left some traces in Kazakhstan (Mazarovich, 1938, p. 359). Thus, cratonic areas grew in time by being welded by intervening polycyclic geosynclines and geosynclines developed not atop disrupted cratons but in regions of higher ductility of the Earth crust. For instance, the early Palaeozoic geosynclines developed atop the Algonkian geosynclines of the Proterozoic.

In Central Asia, Mazarovich defined the Ural-Tien Shan folded edifice (Figure C31; he did not use the terms geosyncline, fold belt, fold system etc.). In the east, near Ulaanbaatar, these edifices join the Mongol-Okhotsk folded edifice (Figure C31); the term Mongol-Okhotsk folded edifice thus makes its first appearance in Mazarovich's book. The Ural-Tien Shan folded edifice had been established already in the Proterozoic. Along the margins of the Siberian craton, one could see that some tectonic blocks of transitional nature (i.e., transitional in nature between fully consolidated cratons and geosynclines) had remained, whereas farther west, in the Ural-Tien Shan folded edifice, all ancient history of the region was thought to have resulted in the reworking of all parts of the ancient crust. The Salairian folding (late Cambrian) created archipelagos, but *not* stable and consolidated blocks.

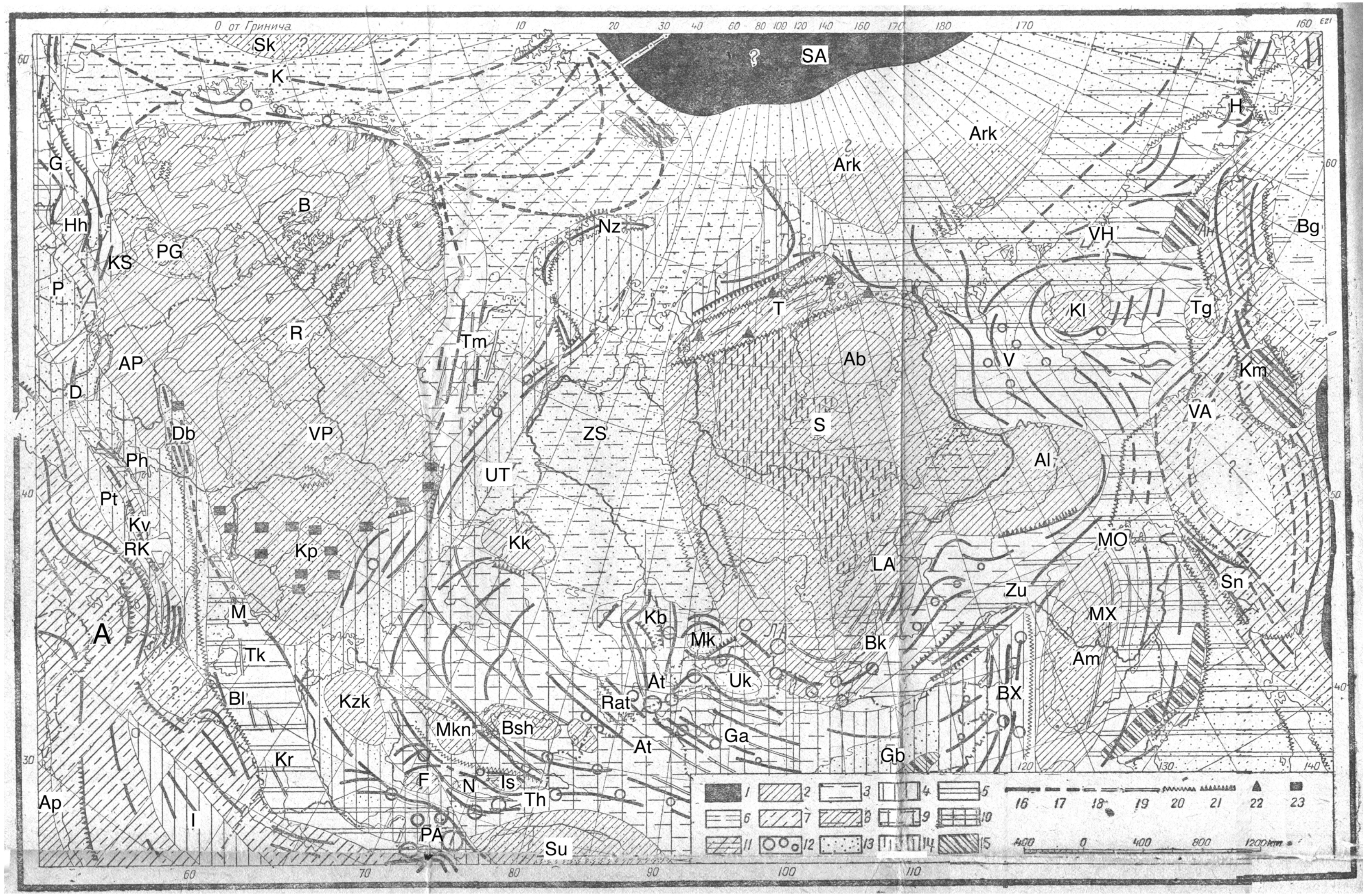

Fig. C31. Structural map of the USSR and surrounding regions (From Mazarovich, 1938, plate 32), explanation of legend on next page.

Fig. C31. continued. Structural regions (1-7): 1. Oceanic floor; 2. Precambrian folding; 3. Caledonian folding; 4. Hercynian folding; 5: Pacific folding; 6. Suggested extent of the Pacific folding; 7. Alpine folding. Combination of structural complexes (8-15): 8. Post-orogenic Caledonian folding superimposed on Precambrian folding, (i.e., Caledonian rejuvenation of Precambrian orogenic structures; in other words, posthumous Precambrian folds of Caledonian age); 9. Post-orogenic Hercynian folding on Caledonian folding (i.e., Hercynian rejuvenation of Caledonian orogenic structures; in other words, posthumous Caledonian folds of Hercynian age); 10. Post-orogenic Pacific folding on the Hercynian folding (i.e., Pacific rejuvenation of Hercynian orogenic structures; in other words, posthumous Hercynian folds of Pacific age, i.e., Mesozoic); 11. Post-orogenic Alpine folding superimposed on Pacific folding (i.e., Alpine rejuvenation of Pacific orogenic structures; in other words, posthumous Pacific folds of Alpine age, i.e., Cainozoic); 12. Alpine block uplifts (diameters of circles correspond with the magnitude of uplift); 13. Thick, flat-lying or weakly-deformed sedimentary rocks on folded basement; 14. Palaeozoic basaltic eruptions; 15. Meso-Cainozoic basaltic eruptions. Tectonic elements (16-23): 16. Observed trends of main folding; 17. Inferred trends of main folding directions; 18. Observed post-orogenic [posthumous] trends; 19. Inferred post-orogenic [posthumous] trends; 20. Normal faults and faults in general; 21. Thrust faults [hachures in the direction of thrusting]; 22. Early Palaeozoic salt structures; 23. Upper Palaeozoic salt structures. Key to abbreviations: A. Alpine geosyncline; Ab. Anabar block; Al. Aldan block; Am. Amur massif; AP. Azov-Podolian block; Ap. Arabian Platform; Apk. Arctic massifs; At. Altay; B. Baltic Shield; Bg. Bering massif; Bk. Baykal subsidence; Bl. Balkhan; BX. Great Khingan; Bsh. Balkhash massif; V. Verkhoyansk zone; VA. East Asian geosyncline; VP. East European basin; VH. Verkhoyansk-Chukotka geosyncline; G. Hercynian zone of central Europe; Ga. Gobi Altay (Mongolian Altay); Gb. Gobi massif; D. Dobrudja; Db. Donetz basin; ZS. West Siberian depression; Zu. Transbaykalian Uda geosyncline; I. Iranian massif; Is. Issyk Kul massif; K. Caledonian geosyncline; Kb. Kuznetsk basin; Kv. Caucasus; Kek. Kyzyl Kum massif; Kk. Kokchetav massif; Kl. Kolyma block; Km. Kamchatka; Kt. Caspian depression; Kp. Karakum; KS. Keletz-Sandomir highland; LA. Lena-Angara folded zone; M. Mangyshlak; Mk. Minusa basin; Mkn. Muyun Kum massif; MO. Mongol-Okhotsk edifice; MX. Lesser Khingan; N. Naryn massif; Nz. Novaya Zemlya arc; P. Pannonian massif; PA. Pamir-Alay; PG. Polish-German basin; Pt. Pontides; Ph. Pre-Black Sea basin; R. Russian platform; RAm. Rudny-Altay [Ore Altay]; RK. Rioni-Khoura block; S. Siberian platform; SA. Simatic region of the arctic; Su. Serindia; Sk. Scandic [massif]; Sn. Sakhalin; T. Taymyr arc; Tg. Taigonos massif; Tk. Tuarkyr; Tm. Timan; Th. Tien Shan; Uk. Uryan high basin; UT; Ural-Tien Shan geosyncline; F. Fergana massif; H. Chukotka massif; Hh. Czech [i.e., Bohemian] Massif

The stronger Taconic orogeny (late Ordovician) created some stable blocks, but the most efficient folding happened at the end of the Silurian, when most part of the Ural-Tien Shan belt was converted to a sort of quasi-platform, except the Ural-Alay zone, Salair and its neighboring regions. However, the early Palaeozoic quasi-platform then again became a geosyncline and fell prey to the Hercynian folding (Figure C34). These ideas were repeated almost unchanged in his posthumously-published 1951 text-book on regional geology (Mazarovich, 1951).

These aspects of Mazorovich's writings were the first Soviet indications of a long-lived tectonic evolution of the Altaids, and the absence of pre-existing cratonic basement in this area. Suess' and Haug's idea of an initial downbending of the fold axes of a hypothetical western extension of the Ancient Vertex connecting the East Siberian and the Russian platforms were gradually disappearing from the Soviet literature.

No western geologist at the time had as much data at his disposal concerning inter-cratonic connexions as the Soviet geologists. Not only the North American craton sat isolated, surrounded by younger foldbelts and beyond them oceans, the Russian craton in Europe was only partly accessible to the western European geologists and its relations to the American and the African cratons were hidden under oceans. Although the Russian and the Siberian cratons were also separated by wide expanses of younger deposits, their relationships were easier studied by their greater proximity, location in the same country, and the presence of trains of outcrops in the south, along the Tien Shan-Ural connexion.

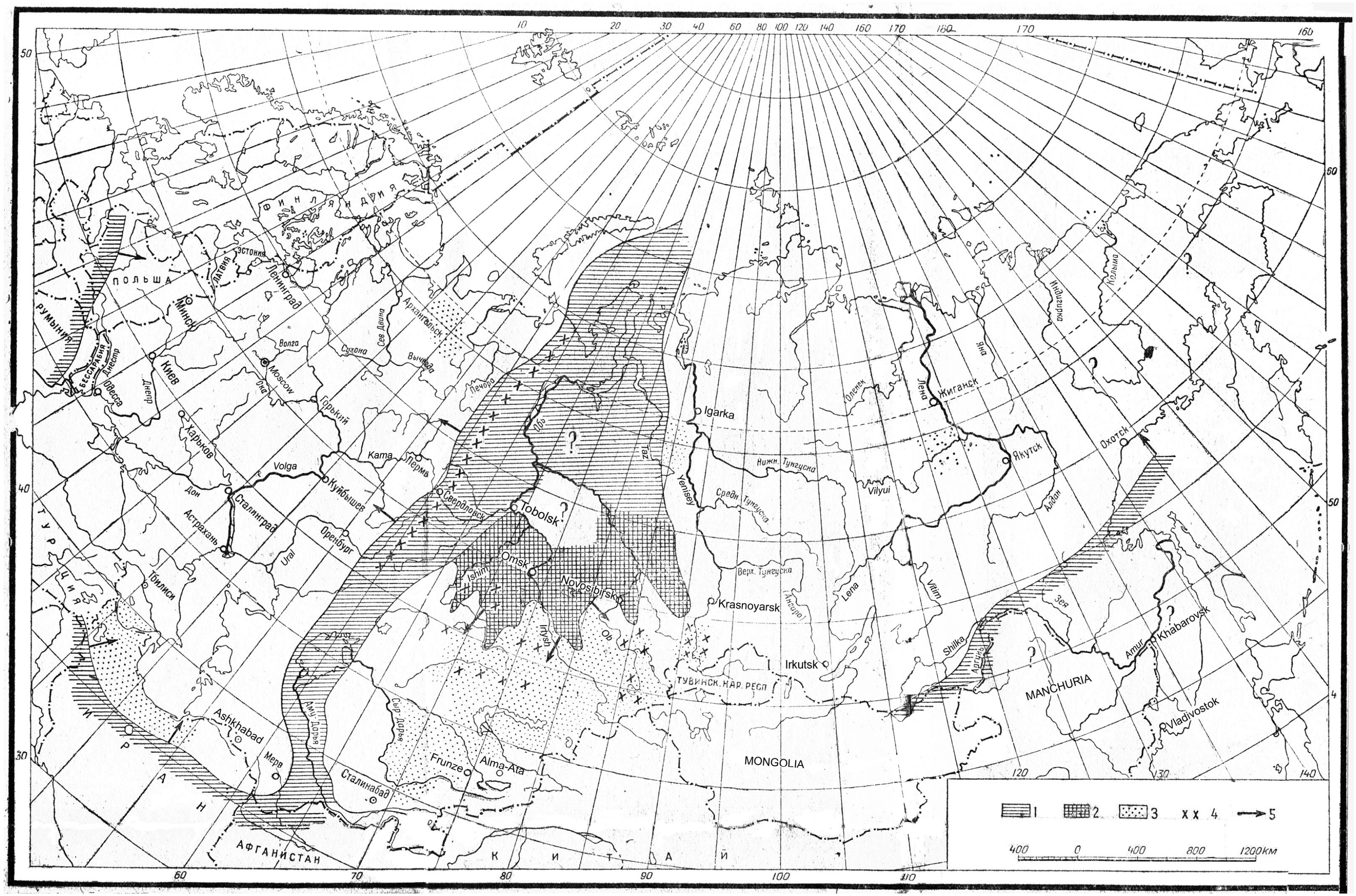

Fig. C32. Palaeotectonics of the USSR in the late Silurian according to Mazarovich (1938, plate 33).

Key to legend: 1. First order blocks (Precambrian platforms and massifs); 2. Regions of subsidence (mobile plates); 3. Regions of conjugate uplift and subsidence in the mobile plates and parageosynclines (taphrogeosynclines); 4. Platforms formed through ultimate orogeny (second-order blocks); 5. Geosynclines

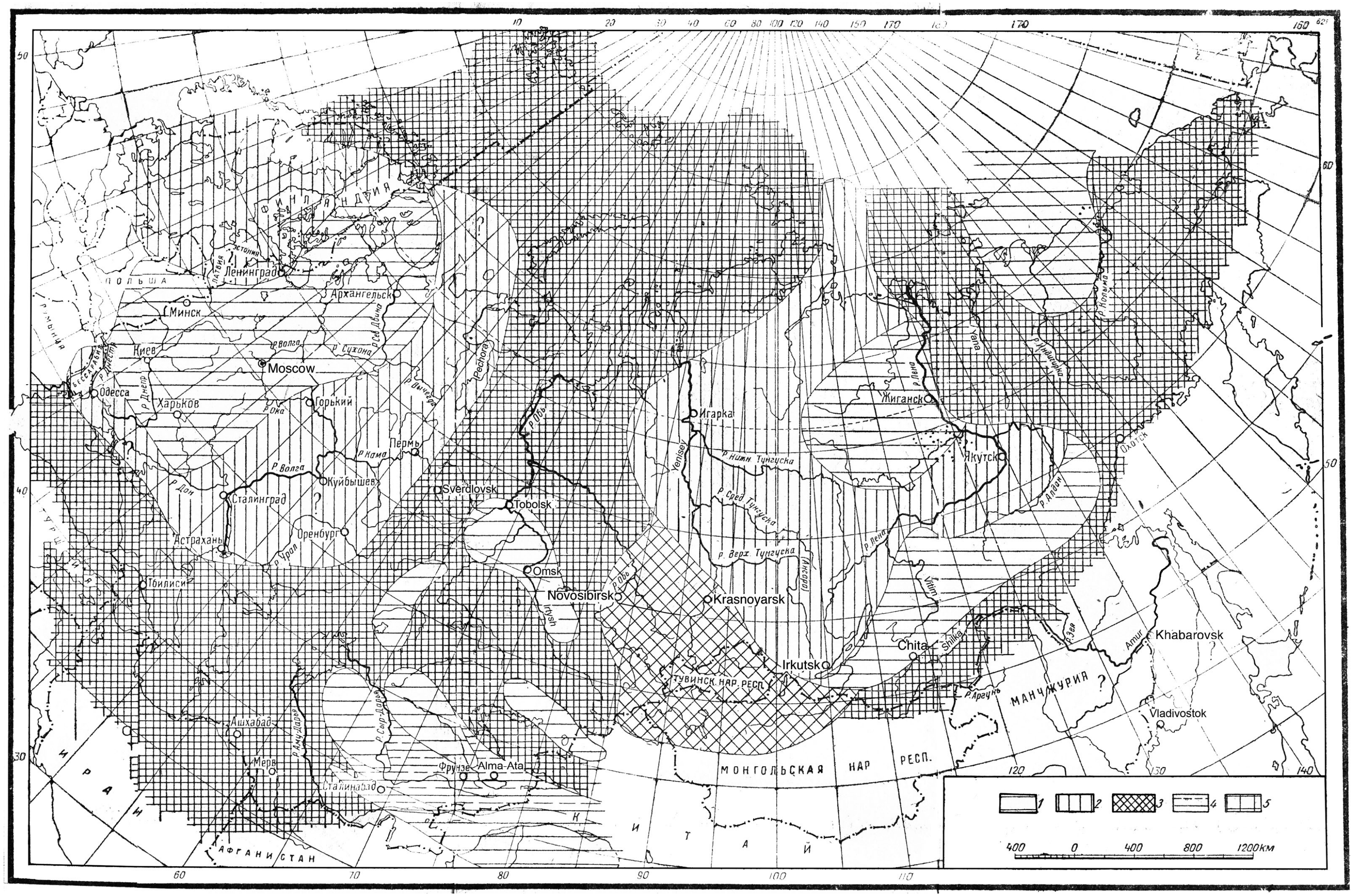

Fig. C33. Palaeogeographic map of the USSR in the early Devonian according to Mazarovich (1938, plate 34).

Key to legend: 1.Geosynclinal basins; 2. Transgressions on Caledonian platforms; 3. Continental deposits formed in arid climate; 4. Volcanoes; 5. Direction of transgression.

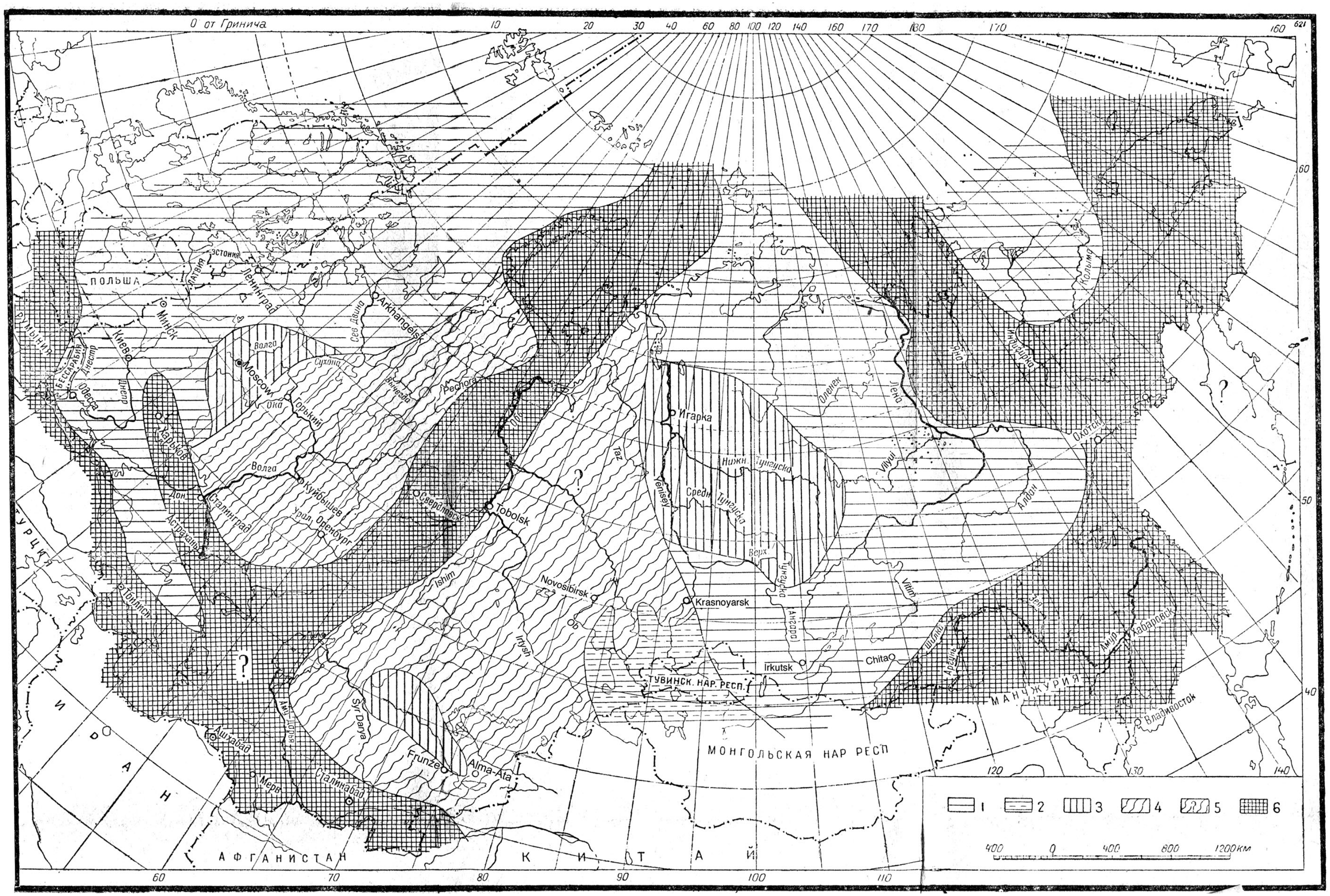

Fig. C34. Paleotectonics of the USSR in the early Carboniferous according to Mazarovich (1938, plate 35).

Key to legend: 1. Platforms; 2. Regions consolidated during Telbes folding (Devonian; these regions form second-order blocks); 3. regions of large-scale subsidence of Precambrian and Caledonian platforms (marginal plates); 4. Regions of small-scale subsidence (mobile plates); 5. Regions of inferred geosynclinal regimes (western Siberia); 6. Geosynclines.

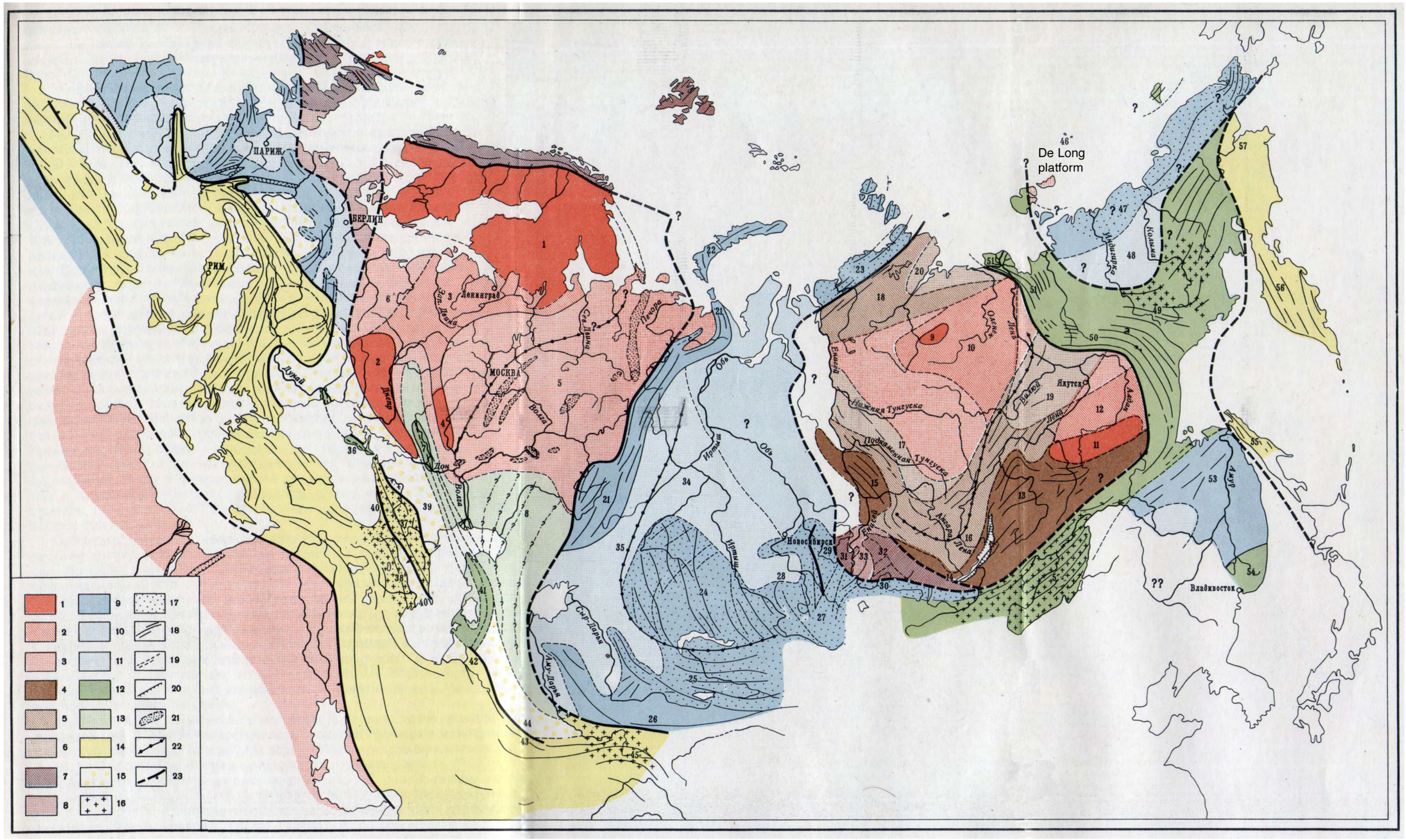

Fig. C35. Schematic tectonic map of the USSR by Arkhangelsky and Shatsky (1933, figure 1), key to legend on next page.

Fig. C35, continued.

Key to legend: Precambrian platforms: 1. Regions, in which Precambrian rocks are exposed or are readily accessed by drilling (shields); 2. Regions of relatively shallow depths to the Precambrian basement (subsurface slopes of shields, subsurface Precambrian uplifts and 'bridges'; 3. Regions with great depths to Precambrian basement (basins). Boxes 4 to 6 inclusive refer to Siberia where the basement is of Baykalian age, i.e., latest Proterozoic. 4. Regions where Baykalian rocks are exposed; 5. regions with shallow depths to Baykalian basement; 6. Regions with great depth to Baykalian basement. Palaeozoic platforms: 7. Regions where Caledonian basement is exposed; 8. Regions with shallow depths to Caledonian basement; 9. Regions where Variscan basement is exposed; 10. Regions with shallow depths to Variscan basement; 11. Regions with great depths to Variscan basement. Regions of Mesozoic (Cimmerian and Laramian) folding: 12. Regions where Mesozoic folds are exposed; 13. Regions with great depth to Mesozoic folded basement; Alpine geosynclinal region: 14. Regions of Alpine folding (Tertiary); 15. Foredeeps basins belonging to Alpine ranges. Structural symbols: 16. Hercynian folding known among the younger folded edifices of the USSR; 17. Caledonian folding known among the younger folded edifices of the USSR; 18. Trend-lines in post-Cambrian folded edifices; 19. Trend-lines of Caledonian folding in Kazakhstan [this identification is inaccurate, because the authors show the same trends in the Tien Shan, in the Altay and in the Soviet Far East]; 20. Normal faults; 21. Swells in east European Precambrian platform; 22. Boundaries of weak Mesozoic and Tertiary deformations in the Precambrian and Palaeozoic platforms; 23. Boundaries of geosynclinal folding of various tectonic eras with indication of vergence of folding.

Key to numbers on the map:

East European Precambrian Platform: 1. Baltic Shield; 2. Azov-Podolian Shield; 3. Subsurface slopes of the Baltic Shield; 4. Voronezh uplift of the Precambrian basement; 5. East Russian basin and Moscovian kettle; 6. Polish-German basin; 7. Donetz basin and its subsurface continuation; 8. Regions of inferred Cimmerian folding (in Precaspian depression, Emba region and Ust-Yurt).

Siberian Precambrian Platform: 9. Anabar (North Siberian) gneissic uplift; 10. Subsurface continuation of the north Siberian Uplift; 11. Aldan gneissic massif; 12. Subsurface continuation of the Aldan massif; 13. Baykalian crystalline massif; 14. East Sayan; 15. Yenisey Kryazh; 16. Lena-Yenisey older Palaeozoic strip; 17. Southern part of the Tunguz depression; 18. Northern part of the Tunguz depression; 19. Lena-Vilyuy Mesozoic basin; 20. Khatanga Mesozoic basin

Ural-Siberian Palaeozoic platform: 21. Ural, Pai-Khoy; 22. Novaya Zemlya; 23. Folded edifices of the Taymyr and Severnaya Zemlya; 24. Kazakh folded area; 25. Northern Tien Shan ranges; 26. southern Tien Shan ranges; 27. Altay; 28. Salair; 29. Kuznetsk Basin; 30. Western Sayan; 31. Kuznetskii Alatau; 32. Eastern Sayan; 33. Minusa Basin; 34. Irtysh basin; 35. Turgay basin (strait);

Alpine folded edifices: 36. Crimean mountains; 37. The main Caucasus range; 38. Lesser Caucasus; 39. Foredeep basin of the Carpathians, Crimea and the Caucasus; 40. Khoura-Rioni basin; 41. mangyshlak-Tuarkyr folds; 42. Great Balkhan; 43. Kopet Dagh; 44. Kopet Dagh foredeeep basin; 45. Pamir-Alay system

Eastern Siberia: 46. Precambrian platform of the De Long Archipelago (The name of this De Long Platform we added to the map to make it easier to find, as it is otherwise very inconspicuous); 47. Kolyma-Chukotka folds; 48. Yukagir plateau; 49. System of the Chersky Range; 50. System of the Verkhoyansk Range; 51. System of Kharaulakh mountains and Pronchischeff Range; 52. Eastern Transbaykal foldbelt; 53. Amur-Amgun folded region; 54. Area of Mesozoic and Alpine deformation in Primorye; 55. Sakhalin; 56. Kamchatka; 57. Anadyr region.

Shatsky on the Altaids: In the thirties of the twentieth century, the term Altaids became very infrequent in the Russian and in the western geological literature. Together with this decline in its frequency of usage, the understanding of the unity it expressed of the Central Asian mountain ranges also began to fade.

Andrei Dimitrievich Arkhangelsky (1879-1940) and Nikolai Sergeyevich Shatsky (1895-1960), two other students of Pavlov and whose influence on Russian pre-plate tectonic studies is difficult to overestimate, divided, in their tectonic map (Arkhangelsky and Shatsky, 1933; figure 35), the territory of the USSR into regions 'differing from each other by age of folding, after which the corresponding segment of the Earth's crust lost geosynclinal features and acquired the features of platforms' (p. 324)[54]. The Russian[55], Siberian and the De Long platforms appeared on this map as three

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[54] Although their ideas suggest strong influence of Stille's writings, Arkhangelsky and Shatsky gave no reference to them. This is all the more strange, because as Şengör once heard from Academician Viktor E. Khain, the present dean of Russian tectonicians, that in 1956, during the celebrations for the publication of the first tectonic map of the

principle old nuclei for surrounding geosynclines (Figure C35). They depicted younger (i.e., Palaeozoic) platforms with various ages of basement adjacent to the older nuclei. The map contains regions of Mesozoic folding (divided by Arkhangelsky and Shatsky into 'Cimmerian' and 'Laramian' folding phases) and the 'Alpine' geosynclinal region (being confined to regions of Cainozoic folding and their foreland basins) as the only tectonic objects contrasting with platforms. For instance, the Central Asian region, coincident with much of the Altaids, was interpreted as the Palaeozoic Ural-Siberian platform (=*plita*, i.e.,'plate' in Russian). The 'Caledonian' and the 'Hercynian' zones were the two components of its basement (Figure C35). According to the map, Southern Siberia and northeastern Russia enlarged the platform of northern Asia after the Mesozoic folding. Only Kamchatka, Koryak Highlands and Sakhalin were regarded to be still in the geosynclinal stage of their evolution. The same viewpoint was adopted by Nalivkin (1933) and Tetyaev (1933) as it follows from the description of their maps, provided by Arkhangelsky and Shatsky (1933) and Spizharsky (1973).

The map by Arkhangelsky and Shatsky was decorated by various structural elements, such as trends of folds, large normal faults, shields, depressions, swells, troughs and zones of superimposed Mesozoic and Tertiary deformation within the Precambrian and Palaeozoic platforms, (particularly within the better known Russian craton), etc. (Figure C35). Special attention was paid to falcogenic structures in platforms caused by vertical movements.

In the introduction to their paper, Arkhangelsky and Shatsky (1933) repeated Stille's statement that platforms are always forelands to the surrounding geosynclinal regions (Stille, 1924, p. 261). This is a very important statement. First, importance of forelands was well-known to Arkhangelsky and Shatsky as well as to all their followers. Secondly, their Kober-Stillean understanding of vergence of orogenic structures around large platforms was the very opposite of what Chersky and Suess had suggested for the Altaids in Asia.

Strangely, the first appearance of an explicit citation to Stille's work in Arkangelsky and Shatky was related to their disagreement with Stille's claim about concentric growth of cratons by orogens. Referring to the Russian craton, they indicated its contact with the Caledonian structures in the northwest and with the Variscan structures in the west and southwest. The absence of complete ring structures around cratonic nuclei could be explained, they argued, by the reworking of older Caledonian structures by the Variscan regeneration or by the primary absence of the Caledonian folding in the west and southwest. But, this had already been pointed out by Stille himself in the paper he read to the 14th International Geological congress in Spain (Stille, 1928b).

Concerning Central Asia, Arkhangelsky and Shatsky saw no growth of the Siberian craton by orogeny except along its southern side. They also saw the formation of some stable blocks in the centre of the basement of the Ural-Siberian platform created by the early 'Caledonian' folding. They further noted a migration of folding away from these blocks towards the south and to the west. They then turned around and warned their readers that the application of the concept of continental growth to this region may lead to a serious mistake, because the growth models had been developed in western Europe, where the tectonic picture is so complicated that von Bubnoff was moved to call it, following Wilhelm Deecke, a mega-fault breccia (von Bubnoff, 1930, p. 1). Their comment is not easy to understand, because it seems that what they were doing was simply taking Stille's concepts and using them without credit and then criticising some of them in an internally inconsistent manner!

Soviet Union, edited by Shatsky, somebody called Shatsky the greatest living tectonician, to which Shatsky immediately objected: 'No! Stille is still alive' (see Şengör, 1996).

[55] For some unjustified reason, Arkhangelsky and Shatsky began to call it 'East European': for details see Natal'in (2006).

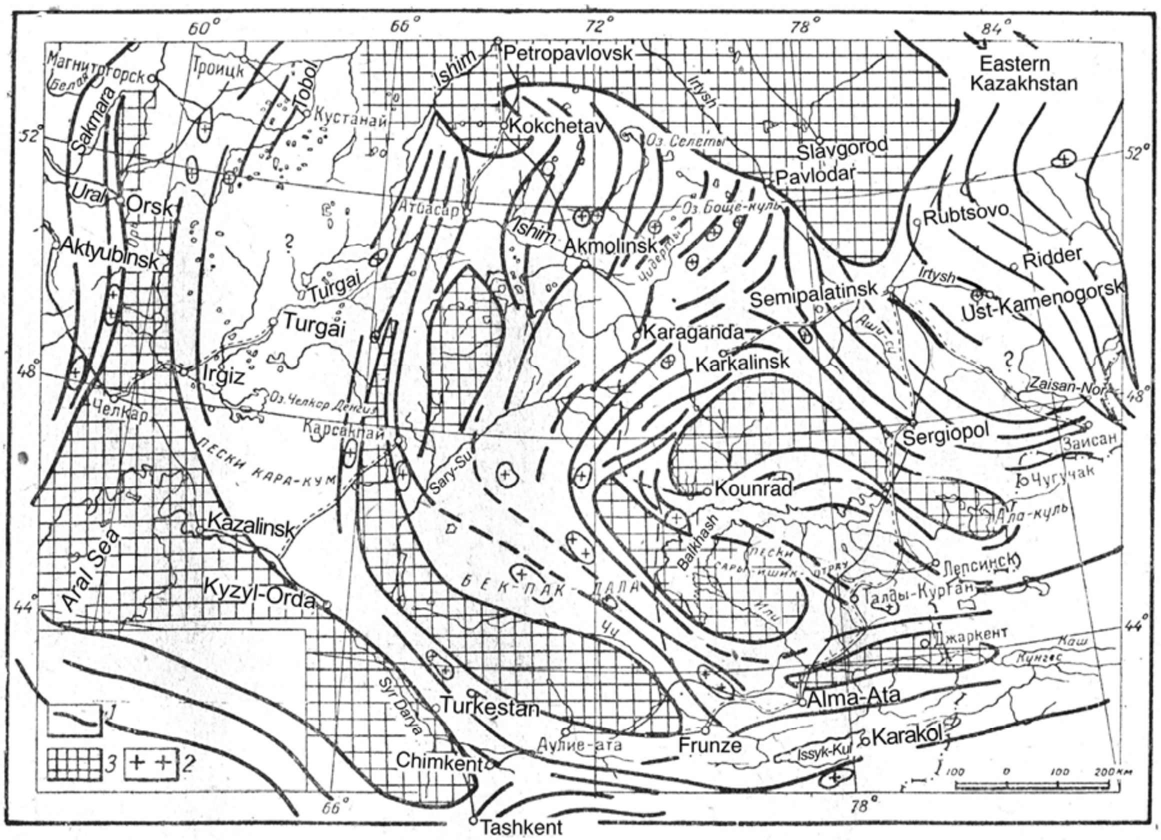

Fig. C36. Disposition of Precambrian massifs and Caledonian trend-lines in the western Altaids according to Kassin (1934) copied from Mazarovich (1938, figure 96).
Key to legend: 1. Trends of Caledonian folds and faults; 2. Caledonian intrusions; 3. Precambrian massifs.

Arkhangelsky and Shatsky disagreed with those who thought that geosynclines disappeared in the modern world. They claimed that their study clearly showed the development of new geosynclines atop a basement that just passed the main folding and was on the way to the transformation to platform. In this, they had a real disagreement with Stille.

Kassin on the Kazakhstan Altaids: Just a year after Arkhangelsky and Shatsky's influential paper came out, Nikolai Grigoriyevich Kassin (1885-1949) developed the concept of crosscutting relationships between ‘Caledonian’ and ‘Hercynian’ fold trends in Kazakhstan (Kassin, 1934; Figs. C36 and C37 herein). His remarkable map (Figure C36) showing intricate ‘Caledonian’ trends almost exactly follow the framework of the early Paleozoic structures recognized during detailed geological mapping by the end of the twentieth century and summarised by Zaitsev (1990) for his model of areageosynclines and Şengör et al. (1993) and Şengör and Natal’in (1996a) for their Altaid model. In the Chingiz-Tarbagatai region (just to the east of the intersection of 78°E and 48°N), the early Palaeozoic trends form an arc convex to the southwest. In the west, the early Palaeozoic trends form a much larger arc, showing a tighter convexity to the west. To the contrary, the so-called ‘Hercynian’ structures (Figure C37) are shown to have more or less consistent northwestern trends. In places, these trends are parallel with the Caledonian ones (compare with Figure C36), but in other places they crosscut them. Besides, Kassin established in Kazakhstan a number of continental blocks and platforms, some of which had formed in the Precambrian (Figure C36), others during the Caledonian and Hercynian orogenies (Figure C36).

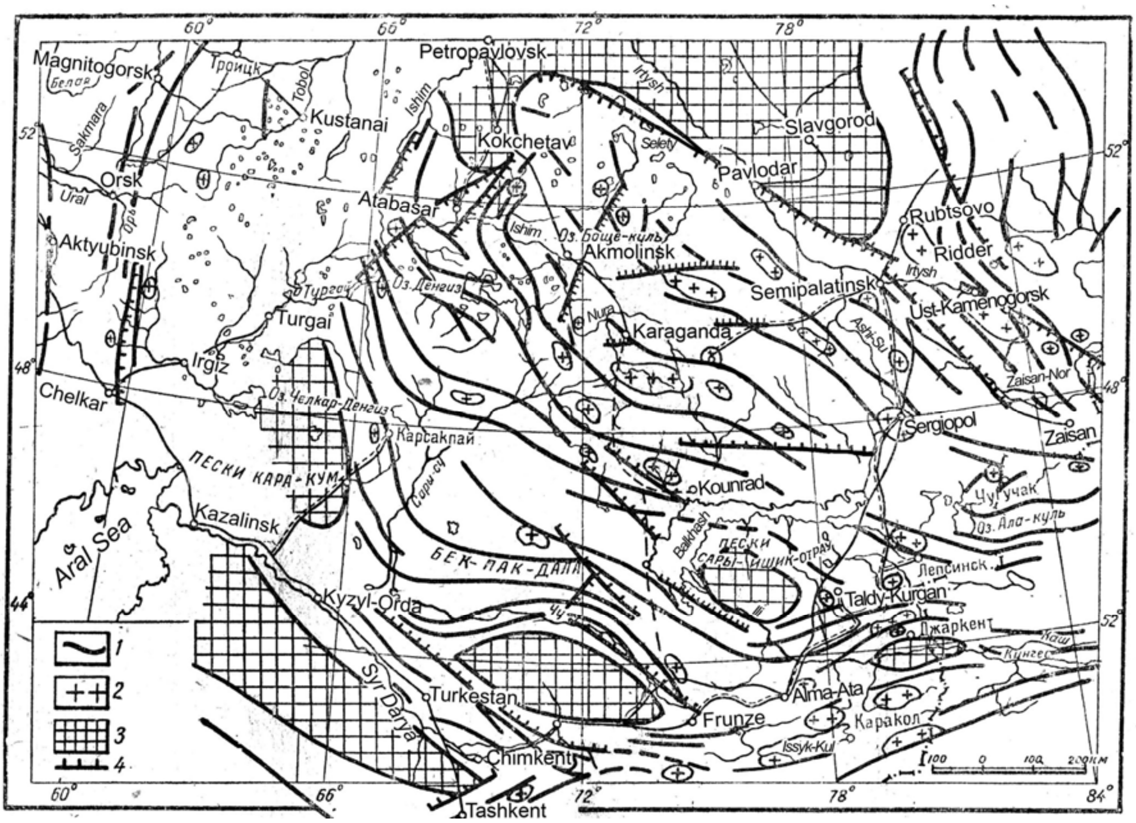

Fig. C37. Disposition of Precambrian massifs and Hercynian trend-lines in the western Altaids according to Kassin (1934) copied from Mazarovich (1938, figure 98).

Key to legend: 1. Trends of Hercynian folds; 2. Caledonian intrusions; 3. Ancient massifs, 4. Main faults of the earliest Mesozoic

This finding also has great significance for the modern understanding of Kazakhstan geology (compare with Şengör and Natal'in, 1996a, figure 21.19 reproduced here as Figure C38[56]).

Intersection of two structural trends allowed that Caledonian tectonic units be separated into blocks to permit Hercynian folding between them. Blocky structure of the ancient cratons was well-known since Karpinsky's studies of the Russian craton and his ideas were fully accepted by Arkhangelsky and Shatsky. Geosynclinal regions that were viewed as linear features should not have had such a structure. Moreover, subsidence during the initiation of geosynclines because of falcogenic movements did not imply faulting (in fact, Stille, 1910, 1924, vehemently denied that there was any significant faulting during geosynclinal subsidence). According to Kassin, however, initiation of the Hercynian geosynclines in Kazakhstan required faulting from the very beginning. Association of faulting with the origin of narrow troughs is a truism for modern geology, but at the beginning of the twentieth century, faulting, accompanying the subsidence, was either an important corroboration of a certain theory or a serious mistake in interpretation of nature from the viewpoint of some other. It is not surprising that these crosscutting relationships provoked discussions clustering about two issues: 1) development of geosynclines across

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[56] When we produced an earlier version of this Figure in 1992 in Şengör et al. (1993) and this particular one in 1995, we had no knowledge of Kassin's paper or Mazarovich's book. We see that the only major divergence between Kassin's and our schemes pertains to areas now covered by the younger deposits of the West Siberian Basin. There, we were able to use extensive geophysical and bore-hole data, which, of course, Kassin could not. We here wish to note our deep admiration for Kassin's great intuition as to the nature of the tectonics of eastern Kazakhstan.

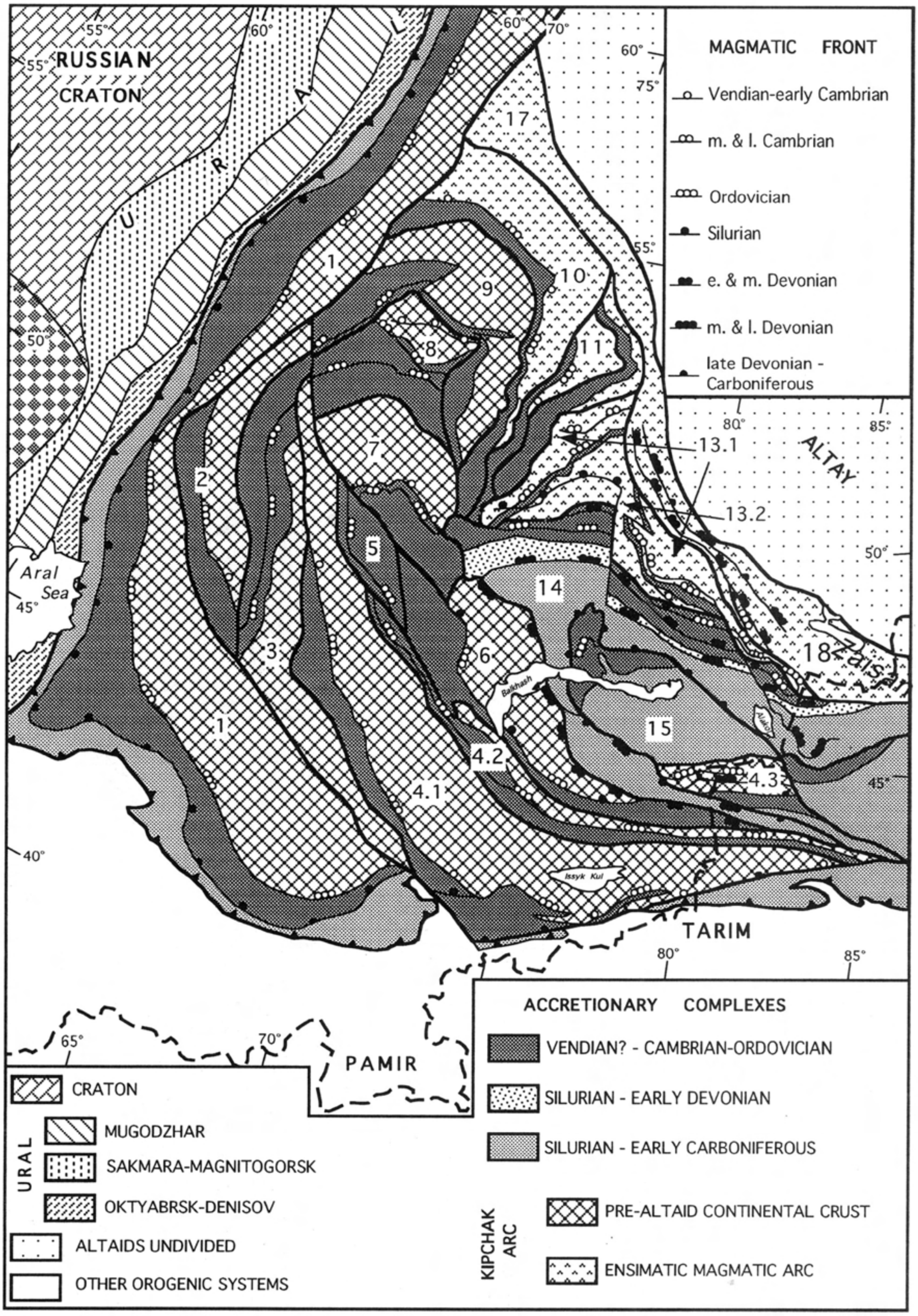

Fig. C38. Generalised map showing the main palaeotectonic elements of the Kazakhstan-Tien Shan sector of the Altaids, showing the Altaid magmatic fronts, key to legend on next page.

Fig. C38, continued**.**
Numbers on the Altaid units correspond to the numbers given to these units by Şengör and Natal'in (1996a). The open circles and the filled circles show facing of magmatic fronts (fronts face away from the circles). The unit names and compositions are as follows: 1. Valerianov-Chatkal (pre-Altaid continental basement+Altaid accretionary complex+magmatic arc); 2. Turgay (continental basement+Altaid accretionary complex+magmatic arc); 3. Baykonur-Talas (continental basement+early Palaeozoic accretionary complex & magmatic arc); 4.1. Djezkazgan-Kirgiz (continental basement+Palaeozoic Altaid accretionary complex & magmatic arc); 4.2; Jalair-Nayman (continental basement+early Palaeozoic marginal basin complex & magmatic arc+accretionarycomplex); 4.3 (16) Borotala (continental basement+early Palaeozoic magmatic arc & accretionary complex); 5. Sarysu (Altaid accretionary complex & magmatic arc); 6. Atasu-Mointy (continental basement+early Palaeozoic accretionary complex & magmatic arc); 7. Tengiz (pre-Altaid continental basement+Vendian-early Palaeozoic accretionary complex & magmatic arc); 8. Kalmyk Köl-Kökchetav (pre-Altaid continental basement+Vendian-early Palaeozoic accretionary complex & magmatic arc); 9. Ishim-Stepnyak (pre-Altaid continental basement+Vendian-early Palaeozoic accretionary complex & magmatic arc); 10. Ishkeolmes (early Palaeozoic accretionary complex & magmatic arc); 11. Selety (pre-Altaid continental basement+early Palaeozoic accretionary complex & magmatic arc); 12. Akdym (pre-Altaid continental basement+Vendian-early Palaeozoic accretionary complex & magmatic arc); 13. Boshchekul-Tarbagatay (early Palaeozoic accretionary complex & magmatic arc); 14. Tekturmas (Ordovician-medial Palaeozoic accretionarycomplex+medial Devonian-early Carboniferous magmatic arc); 15. Junggar-Balkhash (early to late Palaeozoic magmatic arc+late Palaeozoic accretionary complex); 17. Tar-Muromtsev (early Palaeozoic accretionary complex & magmatic arc); 18. Zharma-Saur (early to late Palaeozoic magmatic arc+early Palaeozoic accretionary complex).

structures of a recently formed platformal basement; and 2) the problem of inheritance of structural frame in tectonics.

Shatsky (1938) criticized Kassin’s structural model and suggested that there was no intersection between the Caledonian and Hercynian structures in Kazakhstan. Both of them were supposed to be conformable and trended northwest (Figure C39). At the same time, the geometry of structural trends was intricate with virgations, but not around rigid blocks as was usually thought but around large brachy-synclines, filled with thick Devonian and Carboniferous rocks (Figure C39). These synclines revealed only a mild folding. Despite that, their great sediment thickness was thought not to allow an interpretation of their basement in terms of rigid blocks, because, in those days, sediment thickness was thought to be directly proportional to basement ‘mobility’ (see Stille, 1924, pp. 37-39).

Moreover, Shatsky rejected all platforms, continental blocks, and shelves that Kassin had recognized in Kazakhstan (cf. Figures C36, C38 and C39). He inferred a continuous development of Kazakhstan through the Caledonian and Hercynian cycles stating that deformations and unconformities are characteristic only for geanticlines, but they were absent in the neighboring basins of long subsidence. Mesozoic basins further showed a conformity with the Paleozoic structures. Thus, the main message of Shatsky's 1938 paper was that inheritance of structures is a significant phenomenon that should be taken into account in tectonic studies. Interestingly, in this paper, Shatsky denounced, although not explicitly, his former theoretical basis of platforms and geosynclines and their transformation into each other. Here, he used only a method introduced into tectonics by Suess, namely a mapping of trend-lines and in those days used in the Soviet Union only by Dimitri Ivanovich Mushketov (1882-1938 on his way to the Gulag!), the talented son of the great Ivan Vasilievich Mushketov (1850-1902), Suess' friend and correspondant.

In that paper Shatsky totally neglected the historical development of the western Altaids and assumed inheritances, where none could really be demonstrated. In our days, terrane theorists follow Shatsky's footsteps with similar unfortunate results (e.g., Windley et al., 2007) by essentially claiming that, as Alex Du Toit once said of fixist theories of earth behaviour, ‘that things are *there*, because they *are* there’ (Du Toit, 1937, p vii, italics his).

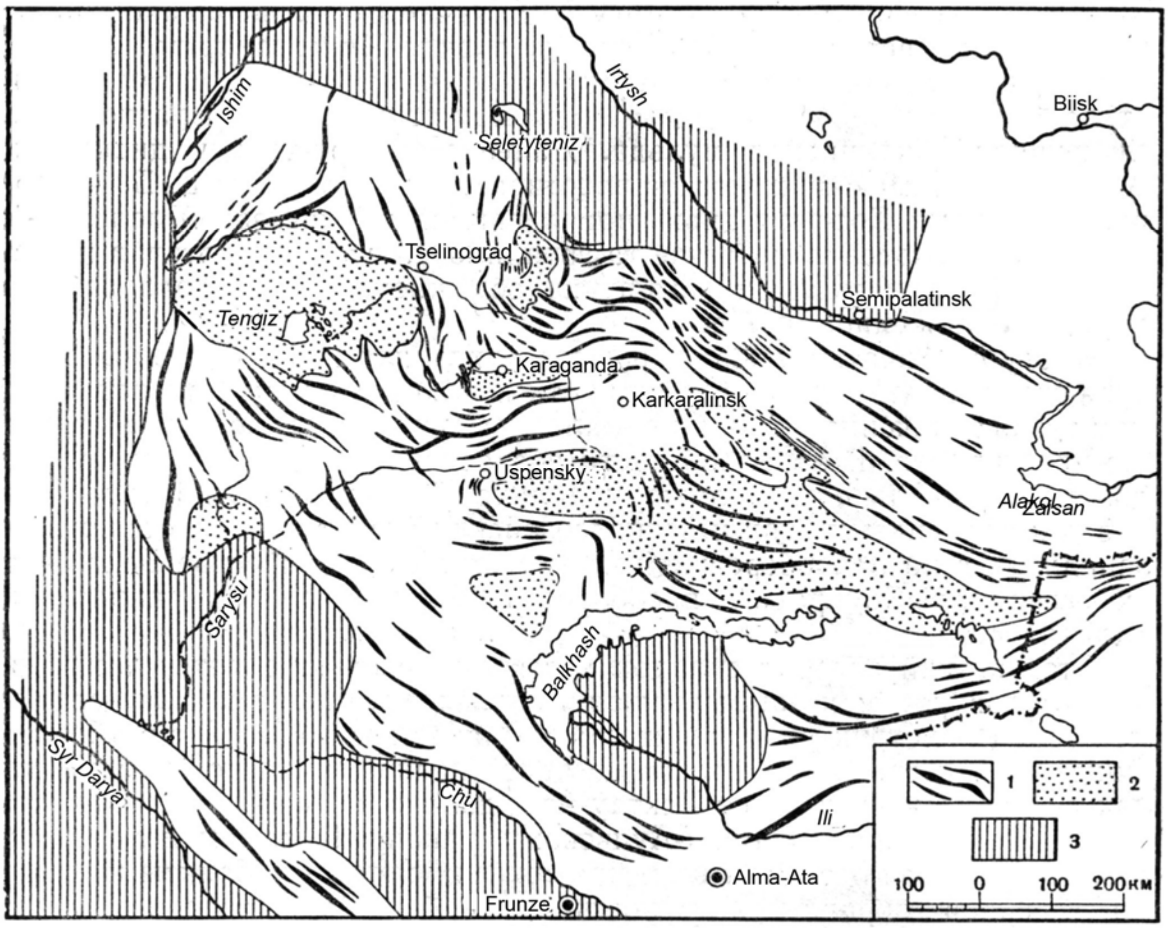

Fig. C39. Schematic tectonic map of central Kazakhstan after Shatsky (1938).
Key to legend: 1. Trends of Palaeozoic folds; 2. Basins and synclinoria; 3. Cainozoic basins. Note the great difference of this map from those by Kassin and by Şengör and Natal'in (1996a), reproduced here as Figure C37.

Tectonic structure of the western Altaids thus began posing a serious problem for Soviet geologists in the years to come. It could not be fitted into the simple western European and eastern North American scheme of Caledonian/Hercynian/Alpine foldings, neatly separated from one another and each followed by a degree of cratonisation after their paroxysmal phases. The Kazakhstan Altaids showed a continuity of folding from the late Precambrian well into the Permian. In the east, in the Transbaykal domains and in the Soviet Far East, Tetyayev's Mesozoic deformations looked as if they were there to stay; they sprung the Hercynian/Alpine boundary.

Despite all these, Shatsky’s simplistic model was accepted by his and Arkhangelsky’s student Alexei Alexeyevich Bogdanov (1907-1971) who clearly stated it in the introduction of his paper (Bogdanov, 1948) that ‘N.G. Kassin’s ideas on the intersection of the Caledonian and the Hercynian folding trends contradict all observations made by the members of the Central Kazakhstan Expedition of the Academy of Sciences of the USSR. We should add that these ideas also contradict the observations of Kassin’s own pupils’ (p. 81). At the end of his long paper, Bogdanov says something very different, however. According to his studies, the northern Kazakstan was characterized by an inextricable pattern of fold trends and a similar distribution of uplifts, each of which was unique in its structure and geological history. Any hypothesis of the jaws-of-the-vise type would fail in the explanation of this structure that showed ‘perpendicular intersections of fan-shape folds, inconsistency and bends in their trends, and the absence in the conformity of structures’ (p. 141) that was, incidentally, precisely what Kasssin had said in 1934 and what Shatsky had denied in 1938. Bogdanov agreed with Shatsky in denying any possibility of tangential compression for Kazakhstan folds and especially Argand's model of deep-rooted folds, because of complex fold trends at high angles to one another. He thought that the only possible explanation lay in vertical movements.

In contrast to Shatsky, Sapozhnikov (1948) found out that the Caledonian structures of the western Kazakhstan evolved in accord with a geosynclinal scenario that terminated with folding at the Silurian/Devonian boundary. The following medial to late Palaeozoic development of the region was thought similar to a platform or quasi-platform. Sapozhnikov (1948) suggested that the growth of the platform was directed to the west and to the east.

Beloussov: Tetyayev's student Vladimir Vladimirovich Beloussov (1907-1995) recognized three types of tectonic movements (oscillations, folding, and faulting), among which large-scale oscillations or falcogenic movements had priority in terms of importance (Beloussov, 1948). He suggested a model of geosyncline evolution in the framework of his ideas on oscillatory movements. Beloussov accepted Stille's phases of folding, though in 1962 he made an attempt to criticize Stille for these phases. It seems that this attempt was a tribute to fashion because his table of strong phases of folding is identical to Stille's. Beloussov favoured a cyclic development of the earth, although he let its history commence with a pan-geosyncline. First zones of cratonisation in the Archean and in the early Proterozoic were supposed to be destroyed, but from about 1.5 Ga onwards, the stabilised parts of the continental crust had become preserved as our ancient cratons. Geosynclinal cycles led to cratonic growth. Beloussov denied the possibility of geosynclinal development within a craton. That is the essence of his concept of the unidirectional evolution of the Earth, i.e., from geosynclines to cratons, much in the spirit of Stille minus Stille's horizontal motions. Beloussov also followed Stille's concept of destruction, i.e., the invasion of continental cratonic areas by mafic intrusions leading to their irreversible subsidence. He renamed this concept oceanization in 1964.

Beloussov's own field-work had been in the Greater Caucasus, so he did not have anything special to say about the Altaids. But the questions he posed in part led to the following developments:

Peive and his school on the Altaids: Peive and Sinitsyn (1950) tried to answer the following questions:

1) Can we assign Archaean and Proterozoic rocks in Central Asia to the geosynclinal stage of evolution? (i.e., is Beloussov right?)

2) Can we consider the modern deformation in Central Asia as geosynclinal and at the same time suggest the same settings for the Precambrian and Palaeozoic rocks of the same region? (i.e., is Mazarovich right?

3) Do we have the right to consider zones of 'Caledonian,' 'Hercynian,' and 'Alpine' folding as platforms? (i.e., is Shatsky right?)

4) Is the theory of continuous growth of platforms and the progressive stabilisation of the Earth correct? (i.e., is Stille right?)

The last question had been of great theoretical importance since the time of Suess, who had first introduced the concept of stabilistion under the designation *Erstarrung*, i.e., stiffening, and ascribed it to the removal of contraction-caused tangential stresses brought about by oceanic subsidences (Suess, 1875, p. 160; 1909, p. 720-721; see Şengör, 1982b). Kober (1928, p. 19) and Stille (1924, pp. 35-37) had long thought that folding and intrusions brought about stabilisation. Earlier, von Bubnoff (1923) had suggested that ancient sialic basement must have been absent beneath geosynclines and he ascribed the greater mobility of the geosynclines to this absence and in this he found agreement from Stille, who cited him on this issue (Stille, 1924, p. 36). The fill of any geosyncline was thus either in immediate contact with older geosynclines or directly with the underlying sima. Similar to Stille, Peive and Sinitsyn (1950) were convinced that, by the beginning of the Riphean, a pan-platform had been created as a basement for all future geosynclines[57]. They strongly supported this inference providing examples of occurrences of ancient rocks in all known foldbelts and arguing for their similarity with rocks exposed in the shield regions of the modern cratons. They disagreed with Beloussov, however, that in the Archaean and in the early Proterozoic, the Earth was evolving as a pan-geosyncline that had been converted to a pan-platform before the Riphean. They believed that the Archean-early Proterozoic regime was peculiar – there were neither cratons nor geosynclines.

Peive and Sinitsyn (1950) recognized three types of geosynclines in Central Asia and in the Urals, representing three stages of geosynclinal development. The primary geosynclines were linear and narrow features controlled by so-called ‘deep faults.’ This control was a new development of the geosynclinal theory in the USSR (inherited from a similar idea of Ver Wiebe, 1936, which in itself was a steep-fault-variant of Argand's geosyncline-bounding thrusts that also acted as ophiolite effusion channels: Argand, 1916, plate II, figure 1), because previous models from Dana (1873) onwards had related subsidence to large wavelength, reversible movements and thus without faulting. These primary geosynclines were magmatically active and contained deep-water sediments, lavas, and ophiolites. Being separated by geanticlinal uplifts, the secondary geosynclines had more or less equidimensional shape (brachy-geosynclines). They were filled with shallow marine rocks containing felsic volcanics that were later cut by voluminous granitoids. The third type was represented by remnant geosynclines. These types were separated from each other by an episode of folding.

It was common knowledge that the ultimate closure of primary geosynclines, which corresponded to eugeosynclines, led to the creation of a mountain belt (collision in the plate tectonic model). Peive and Sinitsyn (1950), again following Stille (1924, pp. 23-25), held that this opinion is wrong and claimed that folding, i.e., orogenic deformation, did not create uplift. Can this view be reconciled with data from the Kazakhstan Altaids, for example? There, strongly deformed Lower Palaeozoic rocks are covered by gently-dipping Devonian and Carboniferous rocks. Lower Middle Devonian volcanic rocks (400-500 m) are the first rocks above the unconformity (e.g. Sapozhnikov, 1948). They grade up into Upper Devonian conglomerates that are only locally 300-400 m thick. To our opinion, Peive and Sinitsyn’s (1950) inference was one of the most significant deductions made in the Altaid regions. We can understand it much more readily now: The evolution of the Altaids was controlled by large-scale arc-parallel tectonic transport, both syn- and post-subduction (Şengör et al., 1993; Şengör and Natal'in, 1996a). Thus, the capture of accretionary wedges (already highly deformed by folding, thrust-stacking and homogeneous bulk shortening) between older arc massifs by strike-slip duplication of the arc does not require much across-strike shortening and consequent thickening.

The elliptical secondary geosynclines of Peive and Sinitsyn (1950) implied the creation of a differentiated topography. Their designation as a separate type of geosyncline is somewhat confusing, although their rock types and structures can now be interpreted as various arc-related basins (fore-arc basins, intra-arc basins, rear-arc basins). Peive and Sinitsyn (1950) included in this class also what they thought were foredeep basins, however, and structures that are now considered as successor basins. Both overridden forearc basins and intra-arc basins comfortably fit into this class, as typical, collision-related, foredeeps are commonly bereft of any magmatism.

The third type, the remnant geosynclines, was simply the cover of young, just-assembled platforms that have a greater mobility compared with the ancient cratons, not dissimilar to that now seen in the Sunda Shelf in Indonesia. This kind of geosynclines were thus of more equant in shape than the previous two classes.

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[57] Stille called this late Proterozoic (in our present terminology) total consolidation of the earth's crust the ‘Algonkian consolidation’ and the subsequent world-wide regeneration of orthogeogsynclines the *Algonkischer Umbruch* (Stille, 1944, p. 62), translated into English as ‘Algonkian major regeneration’ (Stille, 1955, p. 189).

Bogdanov on the Altaids: By the time we come into the sixties it had become clear to Soviet geologists that there was something profoundly wrong with the classical geosynclinal models and with their multifarious variants till then proposed in the Soviet Union. Bogdanov (1965), for instance, found significant differences between classic geosynclines and the Palaeozoic structures of Kazakhstan: 1) Miogeosynclines were not necessarily placed in the external positions of foldbelts; 2) Folding in miogeosynclines could start earlier than in eugeosynclines; 3) Miogeosynclines could have andesitic magmatism. He distinguished a Devonian marginal volcanic belt that separated the 'Caledonian' and the 'Hercynian' structures of Kazakhstan.

This volcanic belt, around the Junggar-Balkhash unit (Şengör and Natal'in, 1996a; also see Zonenshain et al., 1990; Windley et al., 2007 and references therein), now interpreted as an Andean-type continental margin, is one of the most important components of all present plate tectonic reconstructions.

Altaids and plate tectonics in the USSR: Creation of the first plate tectonic models for orogenic belts could not help but affect the Soviet tectonic thinking. Although Hamilton (1970) interpreted the evolution of the Urals in plate tectonic terms and indicated how the Altaids of Kazakhstan might be drawn into the same picture by delineating their trend-lines using the Soviet magnetic data (Figure C40), he was unable to say anything specific concerning the whereabouts of the former plate boundaries and the specific plate tectonic environments east of the Urals. Three years later, the Yale structural geologist John Rodgers paid a second visit to Central Asia (see Rodgers, 2001, pp. 179-180) and Şengör remembers him, in 1977, comparing the Central Asia of Palaeozoic times with the Indonesia of today. We do not know whether Rodgers had been of that opinion already in 1973 and, if so, whether he had shared his thoughts with his Soviet colleagues.

The Soviet geologists, however, could not simply borrow available models, mainly because they had been created for fold belts stretching along modern margins of continents, where relationships created during subduction had been only slightly modified (including Indonesia), or for fold belts that have a simple tectonic history of open-and-shut case (mainly the Alps). The immensely more complicated Central Asia could not provide such objects for interpretation.

The well-known Russian geologist Alexander Valdemarovich Peive (1909-1985) was one of the first who recognized the similarity between the structure of oceanic crust and the structure of ophiolites (Peive, 1969). This recognition implied existence of large oceans during the early stages of geosynclinal development. The eugeosynclines, thus, could not have had ancient continental basements as it had been suggested earlier (e.g., Peive and Sinitsyn, 1950). Analysis of data on the geology of the USSR led Peive and his co-authors (1972) to the recognition of three stages in geosyncline development that were correlated with the process of the formation of the continental crust. In fact, the three stages thus recognised were nothing more than modernised versions of the three geosyncline types earlier discussed by Peive and Sinitsyn (1950).

The first stage was thought to be oceanic. It is represented by ophiolites and related rocks in foldbelts. The second stage was called transitional. During this stage, rock assemblages, similar to those of volcanic arcs and marginal seas, were formed. The third stage was called continental. It corresponds to the orogenic stage of the development of orogens that is characterized by molasses in foredeeps and intermountain basins, as well as by anatectic granitic magmatism and metamorphism[58].

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[58] What is called 'orogenic stage' in Russian terminology reflects the meaning of 'orogenic' literally, i.e., mountain-making. It really corresponds to what a western geologist would call post-orogenic or late orogenic, as it postdates the main deformation and coincides in time with molasse deposition and uplift of the mountain edifice.

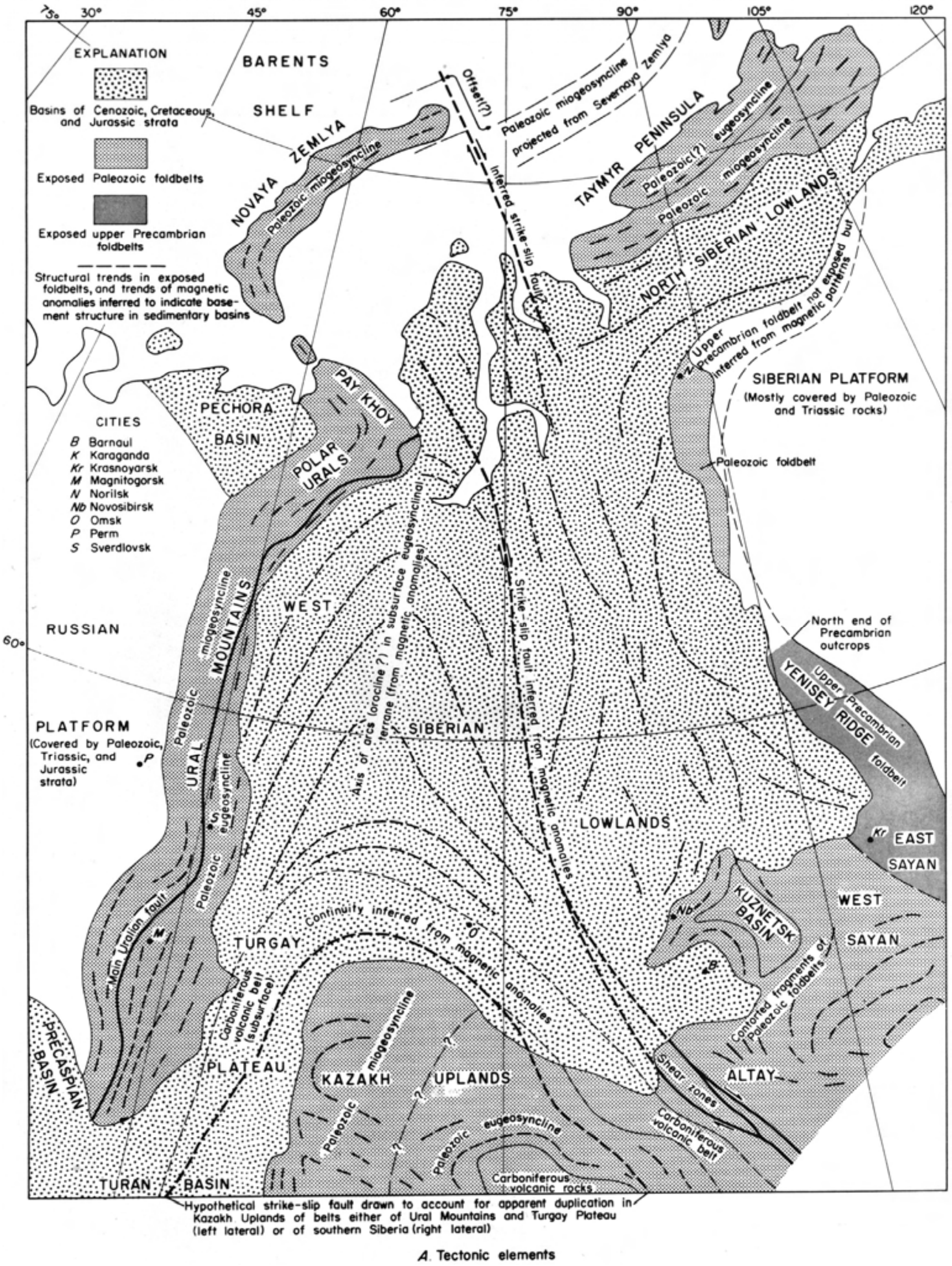

Fig. C40. 'Tectonic elements and magnetic anomalies of the central part of the Soviet Union' by Warren Hamilton (1970, figure 3).

Hamilton interpreted the magnetic anomaly trends as reflecting the trend lines of an orogenic system essentially connecting the Urals with the mountain ranges of Central and northern Asia. Compare this with Figure C38 herein to see the great insight Hamilton showed into the structure of the Altaids, just when plate tectonic interpretations of mountain belts had gone underway. Reproduced with permission.

Interestingly, that stage of initial rifting for the formation of the oceanic basins was not included into this model, although much earlier Peive and Sinitsyn (1950) had related the primary geosynclines to deep faults.

Peive and his co-authors (1972b) distinguished two types of folded regions: mosaic-type folded areas and linear fold belts. In Central Asia, the mosaic-type folded area includes the

Palaeozoic structures of Kazakhstan, the Altay-Sayan region and the Mongolian Altay plus Tuva. Ulutau and Kokchetav in the west, and the Tuva-Mongol massif and the Baykalides of southern Siberia were not included in the Palaeozoic mosaic-type folded areas. On their map (Figure C41), they are shown as regions with Precambrian continental crust that continued its growth into the Palaeozoic.

The Urals, Tien Shan, Southern Mongolia, Kuen-Lun, Northern Pamirs, and the Greater Caucasus belong to the linear fold belt type. On the map (Figure C41), the Urals, Tien Shan, and southern Mongolia are shown as a single continuous belt, similar to that first sketched by Mazarovich framing the mosaic fold belt of Kazakhstan and Altay-Sayan in the south. The mosaic-type folded area has a concentric structure with regions where continental crust was formed by the early Cambrian around its periphery and regions with younger crust in the middle in the Balkhash and Ob-Zaisan areas. The continental crust in the centre was formed by the beginning of the late Palaeozoic. Thus, the general conclusion Peive reached about the evolution of this mosaic-like folded area was continental crustal growth occurring from the periphery to the centre. Later, Zaitsev (1990) called this kind of a mosaic-type evolution, one in a centrifugal areageosyncline (Zaitsev, 1990, p. 59). Peive et al. (1972a, b) concluded that there was slow continental growth in the mosaic-type folded areas and fast growth of the crust in the linear fold belts.

The linear fold belts revealed asymmetric continental growth. In the Urals, for example, it proceeded from the west to the east. In the Tien Shan and Southern Mongolia, the younging direction was from the north to the south. The reason for the switching of polarity of continental growth (not structural vergence!) in a single orogenic belt was not discussed.

Peive et al. (1972) further inferred from their mapping of numerous nappes, large-scale horizontal movements and elimination of wide oceans in the linear fold belts and small-scale horizontal motions in the mosaic-type folded areas. In 1976, Peive et al. interpreted the earliest stage of ocean opening as rifting and distinguished an autochthonous continental growth (believed typical for the mosaic-type folded areas) from an allochthonous one (for the linear fold belts).

Zonenshain and the beginning of the modern plate tectonic interpretations of the Altaids: Being in a transition stage from geosynclinal thinking to plate tectonics, Lev Pavlovich Zonenshain (1929-1992) used for the structures, located between the East Siberian and Russian cratons in the north and North China and Tarim in the south, the designation ‘Central Asian Fold Belt’ (Zonenshain, 1972), following the synthesis of Alexander Leonidovich Yanshin (1911-1999), published in 1964. In contrast to Yanshin, Zonenshain included into the Central Asian Fold Belt both the late Proterozoic and the early Palaeozoic structures. The Urals, however, were excluded. Just as Bogdanov before him, Zonenshain stressed the differences between the ‘classic geosynclines’ and the geosynclinal structures of Central Asia. Although the evolution of a classic geosyncline normally occurs during one geotectonic cycle[59], in Central Asia rock assemblages of several tectonic cycles seemed to be jumbled with one another in a way not typical for ordinary geosynclines. This feature was mentioned, as our review shows, in one way or another, in all geosynclinal interpretations of Central Asia, starting with Argand (1924), Arkhangelsky and Shatsky (1933), Kassin (1934) and Mazarovich (1938). Concerning the general framework of evolution, Zonenshain stressed, as did Peive and his collaborators before him, the migration of the ‘geosynclinal processes’ from the periphery of the system toward its centre, where, according to him, the Main Variscan Geosyncline was located (Southern Mongolia, Zaisan-Irtysh).

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[59] For the best summary of the geotectonic cycle, see Stille (1940, pp. 4-23); from the viewpoint of plate tectonics, see Coney's assessment of the geotectonic cycle (Coney, 1970).

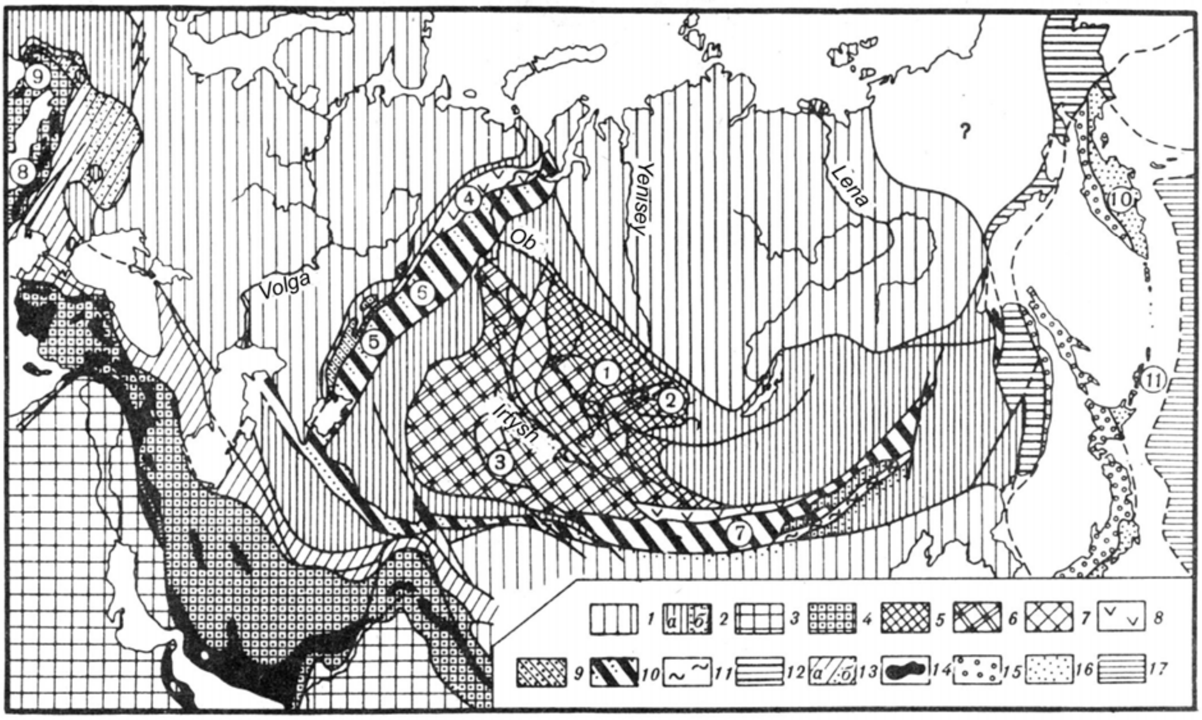

Fig. C41. Age of the continental crust in Eurasia according to Peive et al. (1972a).
1. Ancient platforms of Eurasia; 2. Continental crust that continued its growth during the Palaeozoic (a. in authochthonous, b. in allochthonous occurrence); 3. Ancient Gondwanian platforms; 4. The same, but in allochthonous position; 5. Continental crust formed by the end of the Cambrian (early Cambrian is the temporal boundary between oceanic and transitional types of crust); 6. Continental crust formed by the beginning of the Devonian (end of the early Cambrian is the temporal boundary between oceanic and transitional types of crust). Middle Carboniferous continental crust: 7. End-Ordovician is the temporal boundary between oceanic and transitional types of crust; 8. Early Silurian is the temporal boundary between oceanic and transitional types of crust; 9. Late Silurian is the temporal boundary between oceanic and transitional types of crust; 10. Middle Devonian is the temporal boundary between oceanic and transitional types of crust; 11. Early Carboniferous is the temporal boundary between oceanic and transitional types of crust; 12. Mesozoic continental crust; 13. Continental crust various ages continuing to grow in the Cainozoic (a. autochthonous, b. allochthonous); 14. Continental crust formed in the Neogene (Early Cretaceous is the temporal boundary between oceanic and transitional types of crust); 15 and 16. Regions where continental crust does not exist (Palaeogene is the temporal boundary between oceanic and transitional types of crust for 15 and Neogene is the temporal boundary between oceanic and transitional types of crust); 17. Modern oceanic crust.

According to Zonenshain, four discernable stages[60] of evolution had formed the structure of the Central Asian Fold Belt: Baykalian (800-750 Ma), Salairian (late Cambrian-beginning of the Ordovician), ‘Caledonian’ (Silurian-early Devonian), and ‘Variscan’ (medial Carboniferous-late Palaeozoic). In the east, there was a fifth, a medial Jurassic episode of folding (which Tetyayev had already brought to the world's attention in 1927 and which Mazarovich also mentioned: Mazarovich, 1938, p. 359). Zonenshain used certain rock bodies, believed to have certain tectonic connotations, to define his units within these stages. He thus introduced, sensibly, a genetic and, therefore, explanatory, description into the study of the Altaids.

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[60] The term ‘stage’ as used here is a translation of the Russian word *etazh*, borrowed from the French *étage* meaning stage or storey. In the Russian geological literature this word is used as an equivalent of the ‘folding eras’ of Hans Stille, such as the ‘Caledonian Era’ (=*etazh*), ‘Variscan Era’ (=*etazh*) or Alpine era (=*etazh*). For the time period corresponding with such a stage (=*etazh*), Russians use the term stadium. So, for example, one can say that the rocks of the Hercynian *etazh* were deposited during the Hercynian stadium. For the equivalent of the west European term ‘stage,’ as used in stratigraphy, Russians employ the term *otdel*.

According to Zonenshain (1972), the specific feature of Central Asia is the presence of what he called ‘terrigenous geosynclines.’ Similar to Central Asian ‘miogeosynclines,’ they did not, however, occupy the external sides of orogens as noted by Bogdanov (1965). Besides, they contained products of initial (ophiolitic) magmatism in small quantities (in that respect being somewhat similar to eugeosynclines). In places they followed ophiolitic belts. Composition of their sedimentary rocks showed derivation from the erosion of ‘internal volcanic uplifts and granites’ and their marginal parts might pass into volcanic zones of intermediate and felsic composition. Granitic intrusions were abundant, appearing after the folding in the ‘terrigenous geosynclines.’

This type of geosynclines had bothered Russian geologists for a long time. They kept coming up with specific names for them such as half-eugeosyncline, hemi-eugeosyncline, crypto-eugeosyncline (Knipper, 1963) or mictogeosyncline (Puscharovsky, 1987), with the hope of catching their essence. However, Zonenshain’s careful and conscientious descriptions clearly reveal them today to be former forearc-basin/accretionary wedge couples, invaded by magmatic arc fronts. It also clearly shows why the Altaids are something fundamentally different from the classic ‘geosynclines’ (i.e.collisional belts without large subduction-accretion complexes caught up between the colliding continental margins) of the Alps, the Urals, or the Himalaya. Unfortunately, Zonenshain did not put forward this interpretation in his figure, summarizing the essential elements of the structure of the geosynclines of Central Asian type (Zonenshain, 1972, his figure 44; reproduced herein as Figure C42). However, he interpreted the terrigenous geosynclines to have been in back-arc positions, following the common fashion of his day (e.g., Mitchell and Reading, 1969; Dewey and Bird, 1970; Dickinson, 1971).

As did many other researchers, Zonenshain also noted the frequent changes of strike directions, inconsistency of vergence, mosaic and blocky structure in vast areas of Central Asia. Concerning the structure of Central Asia, he pointed out the absence of any order in the distribution of folded zones that reveal a mosaic structure determined by bounding faults. As a whole, the Central Asian Folded Belt revealed no regular vergence; it seemed to vary even within its small segments. In terms of composition and tectonic significance (e.g., the distribution of mio- and eugeosynclines) the units of CAFB were not comparable with those of the Alps. However, the mosaic structure of the CAFB seemed somewhat similar to the Paleozoic units of Europe. In general the CAFB had two structural trends: northwesterly, but in places deviating to north-south and to northeast. Trying to explain the origin of this mosaic structure Zonenshain suggested a simultaneous deformation partitioned in two directions rejecting a possibility of a later reorientation of structures of their rotation. From this he came to the conclusion that the specific feature of the Central Asian geosynclines is motion in two directions. Without giving additional details of such a strange kinematics, Zonenshain nevertheless mentioned that strike-slip faulting or mid-oceanic spreading could produce structures having two separate directions.

Finally, Zonenshain rightly concluded that, in Central Asia, it is not possible to make a clear distinction between structures of different tectonic cycles such as ‘Assyntian,’ ‘Caledonian’ and ‘Variscan,’ although they were faintly discernible. He saw the Central Asian belt continuously evolving during the whole of the Palaeozoic and partly during the late Precambrian, notwithstanding the different stages he only loosely correlated with the so-called tectonic eras or cycles. Notwithstanding the vexation that pervades his attempts at interpretation, his work, marks a great breakthrough. He, in many respects, broke loose from the influence of the anti-Suess reaction. Had he been able to shed the pernicious influence of the geosyncline idea (which he eventually did do shortly before his untimely death in 1992), he might have entirely returned to Suess' free waves of mountain building.

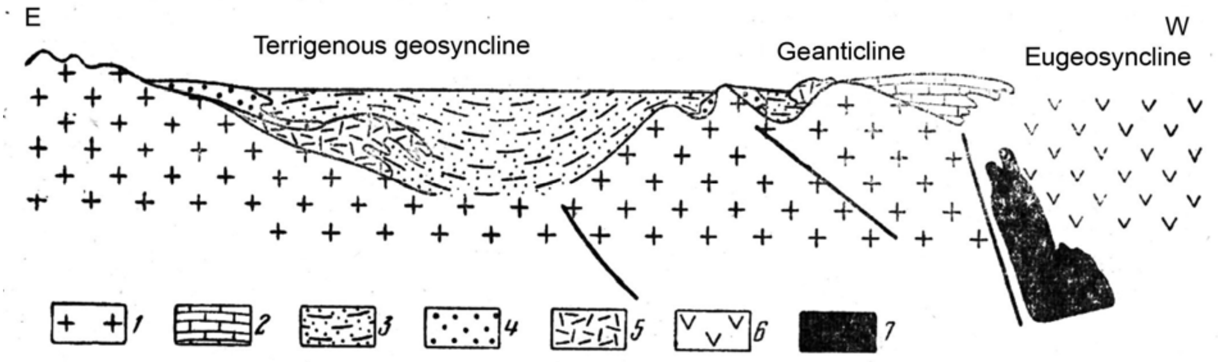

Figure C42. Zonenshain's (1972) figure 44 to illustrate his concept of 'terrigenous geosynclines'. Key to legend: 1. consolidated basement; 2. carbonates; 3. clastic rocks (turbidites); 4. deep-water sediments; 5. andesites; 6. initial magmatism; 7. ophiolites. From the position of andesites it is clear that we are not here looking at an ordinary Himalayan-type mountain belt. We read this cross-section as illustrating an arc (=eugeosyncline), an outer non-volcanic ridge (possibly with some older volcanics) (=geanticline) and accretionary complex with swept in volcanics ('terrigenous geosyncline')

The great Russian geologist M. V. Muratov introduced in 1965 the concept of 'Ural-Mongolian Foldbelt' for what Schönmann (1929) earlier had called the Ural-Amurian, although
Muratov understood under this term mainly the Palaeozoic chains in the same geographical area as Scheinmann's Ural-Amurian (Muratov, 1965). Others have widely used Muratov's designation since (e.g., Volochkovich et al., 1971; Karaulov, 1981; Koronovsky, 1984). Koronovsky (1984) used it, for example, for the ensemble of foldbelts located between the Russian and Siberian cratons. In the south, he included the Southern Tien Shan together with the Ghissar Range and even the Northern Pamirs into this orogenic complex. As we know now, since the time of Dimitri Ivanovich Mushketov and Stille (Stille, 1928a and the references to Russian work in it), and have repeatedly corroborated since, both the Ghissar and the Pamirs continue into the Kuen-Lun (e.g., Şengör, 1984; Şengör and Okuroğulları, 1991; Mattern et al., 1996; Schwab et al., 2004; Natal'in and Sengor, 2005) and belong to the Tethysides, so it is difficult to understand Koronovsky's grouping of them with the Altaid chains. According to him, the Ural-Mongol belt was formed because of the early Riphean disruption of a giant early Proterozoic craton, the largest fragments of which now exist as the Russian and the Siberian cratons. Koronovsky interpreted the crosscutting relationships between Riphean/Baykalian structures of the Ural-Mongol belt and Archaean and early Proterozoic structures of the neighboring cratons as evidence of superposition of the younger orogenic belt on the older basement. He doubted whether the Riphean and the Palaeozoic geosynclines in the belt had any similarity with the modern oceans. An interesting point in his synthesis is the discovery of only a slight manifestation of orogeny at the end of the 'Caledonian' cycle, hardly producing Silurian molasses, and those molasses that have formed showed conformable relationships with underlying geosynclinal rocks. At the same time, he stressed, largely following the earlier works by Bogdanov and Zaitsev, that the Caledonian orogeny supposedly had created the Central Kazakhstan-North Tien Shan massif, thus playing a significant role in the structural control on the surrounding 'Hercynian' geosynclines. We thus see no evidence of a serious geosynclinal closure at the end of his purported 'Caledonian' cycle! The closure of the 'Hercynian' geosynclines, on the other hand, indeed caused the formation of well-documented classic foredeep basins and fold-and-thrust belts that are known both in the Urals and in the southern Tien Shan. All this indicates, in present plate tectonic terms, incidence of continental collisions with major sialic rafts only towards the end of the Palaeozoic, not earlier.

E. E. Milanovsky (1987, 1996) defined three principal continental tectonic units: 1) Ancient platforms, 2) mobile belts that developed during the Riphean and the Phanerozoic, including the modern geosynclines, and 3) regions intermediate in their tectonic regimes between geosynclines and platforms (metaplatforms). The second of these first order structures has only two tectonic regimes – geosynclinal and post-geosynclinal. In contrast to the early works of Arkhangelsky and Shatsky, we do not see in Milanovsky's scheme the transformation of geosynclines into platforms after the phase of the main folding. Considering the Ural-Mongol belt, Milanovsky infers that, already in the early Proterozoic, the region evolved differently when compared with the synchronous stages of the ancient cratons. This comparison suggests the perennial existence of the geosynclinal regime in the belt. Around 1-1.1 Ga, the boundaries of the Ural-Mongol belt appeared during an episode of global earth-expansion (which Milanovsky calls 'destruction,' meaning the destruction of pre-existing platforms), although true oceanic troughs in these geosynclines appeared only in the Cambrian. The tectonic history of the belt consisted of alternation of episodes of destruction (extension resulting from earth-expansion) and shortening (resulting from earth-contraction). Similarly to Koronovsky, Milanovsky suggests that the Salairian (late Cambrian-early Ordovician) and the 'Caledonian' cycles were not terminated with strong orogenies, as it is shown by rare appearance of molasses and post-orogenic magmatism. On the contrary, the 'Hercynian' cycle is supposed to have terminated with a short, but powerful, orogeny that created mountains, molasses and the Uralian foredeep basin.

Summary of the developments of opinions on the tectonics of the Altaids in the Soviet Union: In the Russian Empire, there was a lively exchange of ideas concerning global tectonics with western European geologists. In fact, the greatest-ever synthesis of global tectonics, the immortal *Das Antlitz der Erde* (1883-1909) of Eduard Suess, largely centred around what he called the 'Asiatic structure' and Suess' understanding of the geology of Asia had been made possible largely through his friendly contacts with Russian geologists, Vladimir Afanasievich Obrutschev being the most important among them (see esp. Natal'in, 2006).

The unfortunate revolution of 1917 in Russia dealt a severe blow to such contacts. As the westerners were cut off from newer sources of data, they lost interest in the tectonics of the Altaids. Russian geologists were also cut off. In addition, they were now saddled with an ideological baggage that greatly restricted their freedom of thought. On the plus side, however, the new socialist regime laid great emphasis on practical science, which, in geology, translated into mapping on an hitherto unimaginable scale.

Russian geologists, working in the vast region of the Altaids, initially inherited the western European geosynclinal models of the twenties. Even the mobilist texts they translated (Argand, 1935; Staub, 1938) had been largely conceived in terms of geosynclines or at least with a strong geosynclinal bias (naturally, with the remarkable exception of Wegener himself, who strongly repudiated the idea of geosynclines: Wegener, 1925). It soon transpired, however, that the Altaids refused to fit into the 'classical' geosynclinal models, imported from western Europe. Then, the Russians began to improvise. However, these improvisations were done strictly in what Şengör (1982a, b) calls the Kober-Stille school of thinking, combininig a non-actualistic approach with a strong predilection to deterministic-regularistic models. However, notwithstanding the inhibiting influence of the Kober-Stillean schemata, including geosynclines, programmed orogeny and orogenic eras and phases, continuing accumulation of observations, made in the framework of numerous models, finally eliminated most of them and it was realised that what characterised the Altaids were 1) continuous tectonic evolution from the late Precambrian to the Jurassic or even, in the Soviet Far East, into the early Cretaceous; 2) dominance of richly clastic environments with long-lived magmatic associations of all types: ophiolites, tectonically incorporated into the continuously deforming clastic packages and intermediate to felsic volcanics initially contributing to the clastic sources and then invading the already-deformed clastic packages themselves; 3) alternation of long and narrow, consolidated continental slivers of Precambrian, early and even late Palaeozoic age with intervening younger flysch troughs; 4) lack of classic foredeeps within the system and also paucity of episodes of strong relief-building; 5) a tendency to go from oceanic to continental type of crust from the late Precambrian to the late Palaeozoic.

None of these characteristics were explicable with any geosynclinal model that had been developed in western Europe on the Caledonides, the Hercynides or the Alps, or the North American chains. There were some compositional similarities with the North American Cordillera, but the North American Cordillera was a long, linear belt, unlike the stocky outlines of the Altaids. Despite their great insights into the nature of the Altaids, Russian geologists got stuck in the geosynclinal interpretations and never managed a complete return to Suess' way of looking at them. One partial reason for this maybe that Suess' great classic had never been translated into Russian and it is still not readily available in most Russian geological libraries. That is why, the first comprehensive plate tectonics interpretation of the geology of the Soviet Union (Zonenshain et al., 1990) presented the interpretation of the Altaids in terms of the collision of independent mini continents that were at best *ad hoc*. It was as successful as the geosynclinal models it only eponymously replaced.

CONCLUSIONS

This paper was written ostensibly to defend the name of an orogenic system, namely the Altaids. If the defense of the name only really constituted its entire purpose, the effort in producing it would have been totally wasted. However, the real purpose of it is to shed light on how tectonic research is undertaken on the example of a large geological object that has attracted the attention of large scientific societies, profoundly divided politically and philosophically. Vastly differing patterns of thinking, paths of historical development, research tools and traditions and personalities have come to bear on understanding the structure and evolution of the Altaids since they were first defined in the beginning of the twentieth century. Our understanding concerning them has drawn wild zig-zags since then. However, amidst the confusion, there has been a general progress towards an ever-improving knowledge concerning the properties of the Altaids. Appreciating why the zig-zags were and how the knowledge actually progressed has immense potential in influencing our future research strategies and creating mutual understanding between scientific communities isolated from each other for more than three quarters of a century. Telling the history of the tectonic research on the Altaids, by emphasising what the critical observations were in influencing opinions and how scientific communication has affected evaluation of theories, has been the real purpose of this paper. In the name Altaids, an entire manner of looking at tectonic evolution is encapsulated.

That has been our sole reason for insisting that the Altaids are called by their proper names, first given to them by Eduard Suess in 1901.

When Eduard Suess began looking at them with a view to understanding their structure, mountain architecture had long been established as one of a long and narrow edifice created at the expense of a pre-existing basin of more-or-less similar plan. This view had been born in the 1820’s in the Alps, still the most intensively studied mountain range. The Alps had been learnt quickly because they are tiny, compared with the most major mountain ranges of the globe. Their small size is a function of the mode of their formation: they were 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 and why at all it 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 belongs to the predecessors of our French colleagues (see Şengör, 2003, pp. 93-97 and 123)! As luck would have it, the next mountain range similarly studied, the New York Appalachians, rendered a similar picture to its Yankee students. Squashing basins to make mountains became a dogma as soon as it was thought that thermal contraction was a good *vera causa*. Such a simple way of mountain-making was also easy to imagine. Even Suess in his 1875 book found the idea attractive and thought that his patrimonial Alps fitted the picture rather well. That, he thought, they had an asymmetric structure compared with the symmetric models of his predecessors was a small detail amidst the general agreement.

Suess was in fact somewhat bothered that not all chains seemed to have been squeezed out of basins, but this appeared not too troublesome: if one squeezed any part of the crust it would inevitably create a bump on it, either by breaking or buckling. The basins may have been more susceptible to being squashed by their walls and that seemed to explain why there were more mountains squeezed out of basins than not.

When Suess later began looking at the mountains of Central Asia, he was shocked to find mountains not squeezed between anything! They had the same sort of structures as any other mountain belt, such as folds and faults, but he could not find what squeezed them. The more he searched, the more he realised that they were 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 Suess thought populated Central Asia could possibly have formed.

In the meantime, Suess had become fond of another metaphor: He was saying that he could not find a better likeness 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 to allow some bleeding. The blood represented 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). His 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*) could create a similar wound in the crust of the earth (e.g. Löwl, 1906,p. 173). Evidently, these learned adversaries had remained ignorant of some physicists, contemplating convection currents in the interior of the earth 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 1895, see England et al., 2007).

This ignorance cost tectonics dearly. Suess died in 1914 and the geological community promptly threw away his model. He continued to be immensely admired for his erudition, but not for what he had discovered. The world of tectonics went back to models of narrow and long mountain belts, squeezed out of former basins.

Only three years after Suess' death, the mountains of Central Asia were convulsed not by any tectonic crisis, but by a human revolution that rendered them remote to most of humanity, so, for three quarters of a century, Suess' Altaids ceased to haunt the majority of the world's geologists.

The western Europeans, however, did continue thinking of them, but now in a platonic way, and the models they came up with to explain them reflected this: 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, rather than what they were really like. And the Soviet geologists, recovering from the ravages of a savage revolution and labouring under a new religion, began also adopting foreign faiths as had St. Augustine done with

Platonism. Western text-books with their imaginary Altaid pictures were read avidly, some even translated and those, 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 concept implicitly. His ideas were incorporated in university courses, in which many generations of Soviet geologists became trained (Spizharsky, 1973, p. 47). Indeed, the historicity of the geosynclinal model did appeal 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 gave 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 Marx on Feuerbach and they advised their scientists accordingly.

The result was a great proliferation of observations. Many new natural resources were indeed found thanks to the great competence of the empire-trained Russian geologists, but scientists are notoriously difficult to stop being also philosophers intent on understanding, notwithstanding the admonition of the Soviet state prophet. The more the observations accumulated, the less comfortably the Altaids seemed to fit the models imported from western Europe. The result was that the Soviet 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 it a new name. When that did not work, they thought of dividing it into smaller geosynclines by introducing all sorts of platforms, median massifs, blocks and uplifts into and between them and naming those either individually or uniting them into a system and giving that system yet a newer name. This would have given them smaller orogens, like the Alps, so readily explicable in terms of geosynclines and orogenic phases. When that attempt was in turn defeated by the uniformity of the Altaids, they then began inventing new sorts of geosynclines. Some of these were so bizzare 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 were not enough, the structure of the science in the new totalitarian country, 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 compartmentalised and totalitarian environment, the numerous models, generated on as large and as difficult an orogenic system as the Altaids, could hardly be fairly 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.

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 is everything and observations nothing. Such giants as Mushketov have died in the Gulag, such lone thinkers as Tetyayev paid by their freedom for their independent thinking. Many a modest brain was brought to dominate geniuses because of their apparent faith in the state religion and loyalty to its high priests. Yet, 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 a list of some of the small-scale Soviet maps, see Zhamoida, 1976; Petrov et al., 2000; for a history of geological cartography in Russia, see Burde et al., 2000)

It was finally realised 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. When plate tectonics reached the Soviet Union, such able geologists as Lev Zonenshain were on the verge of going back to Suess. 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 that 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 John Rodgers and Warren Hamilton, had begun making suggestions in that direction.

It was at this time that the plate tectonic models burst on the Russian geology, and, within a decade or so, the Soviet Union had become history. Soon, however, it looked as if the events of the twenties were repating themselves on a different stage: A new social upheaval in Russia coincided with a flood of new geological models into the country. What had come with text-boks in the twenties 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 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 measurements, however, soon outpaced the observations on field relations, making their interpretations *ad hoc*.

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 range in terms of imported models, long believed sacrosanct. It has managed to shed them gradually and at great intellectual (and human) cost on the basis of fine field observations. 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 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. However, 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 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.

That is why, we urge the Altaid researchers to refrain from calling them by names belonging to models deveoped on dissimilar mountain belts and now known to be obsolete. It will do little good to insist on calling the feathered dinosaurs *Caudipteryx zoui* or a *Sinosauropteryx prima* or a *Incisivosaurus gauthieri* mere reptiles; one would miss an entire new class of animals in doing so. Calling Altaids by names applicable to any old mountain range would have a similar effect.

ACKNOWLEDGEMENTS

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