GEOLOGY OF ASIA

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Contents

Summary

Asia is the largest of the continents occupying some 12% of the earth's surface. It has a complex geological evolution involving 7 major continental nuclei: The Angaran craton (Siberian platform), the Indian craton, the Arabian craton, the Kontum craton, the north and south China cratons and the North Tarim fragment. These continental fragments are welded together by a range of orogenic systems the most important of which are (from oldest to youngest) the Altaids, the Manchurides, Scythides, Chukotkalaskides, Tethysides, Verkhoyansk-Kolyma orogenic system and the Nipponides (the Asian part of the Circum-Pacific orogenic zone). The last major event in Asia has been the collision of the Indian subcontinent with Asia forming the highest and most spectacular topographic feature on earth: the Himalaya and the Tibetan plateau.

1. Introduction

Asia is the earth's largest continent, occupying an area of some 43,608,000 square kilometers, which is equivalent to about 12% of the earth's total and 30% of its land surface (Fig. 1). It has been assembled mostly in the last 500 million years. The intricate morphology of Asia masks an extremely complex geologic history that predates the active deformations largely responsible for the existing landforms varying from Arctic tundra to Central Asian deserts and from mountainous highlands to enormously high mountain ranges of the Himalaya. Tectonic units (regions identified by similarity of style and origin of geologic structures contained in them) that are defined on the basis of the active structures in Asia are not identical with those defined on the basis of its fossil structures. It is therefore convenient to discuss the tectonic framework of Asia in terms of two separate maps, one showing its palaeotectonic (e.g. older tectonic) units (Fig. 2) and the other displaying its neotectonic (new and presently active) units (Fig. 3).

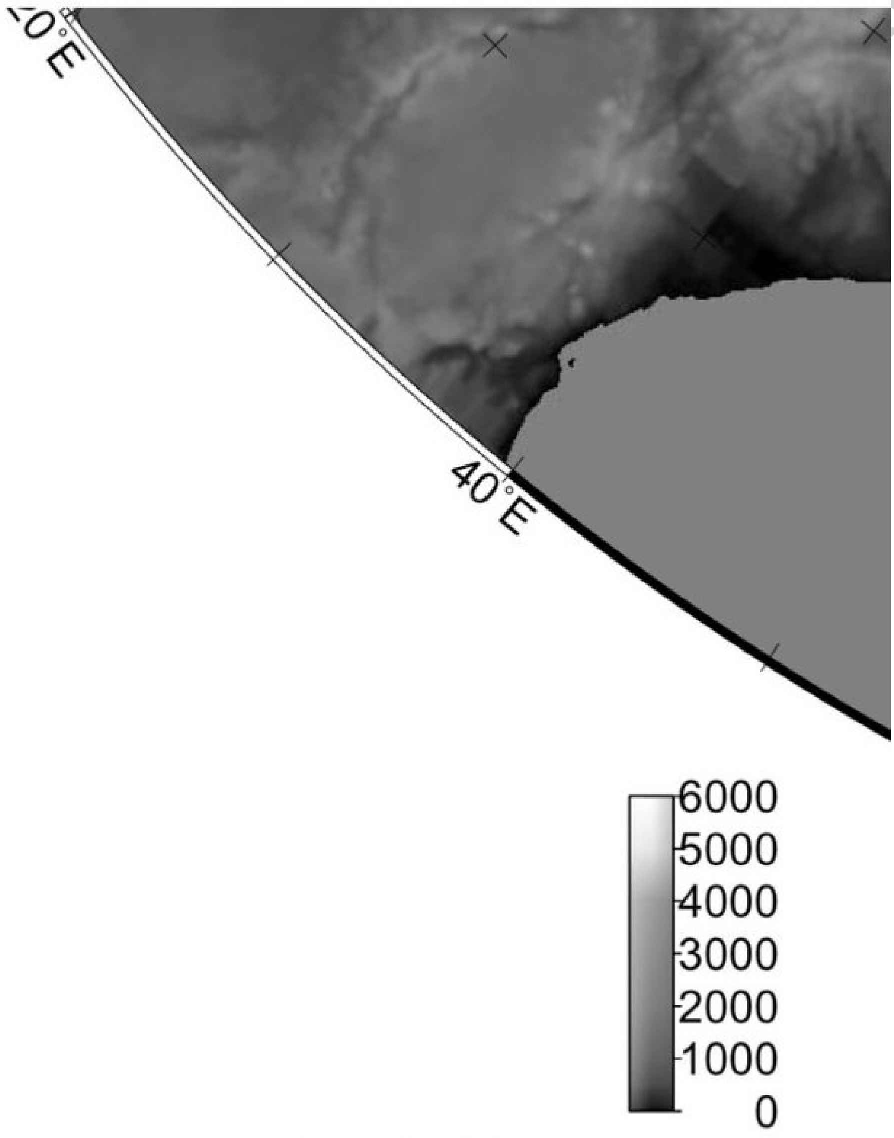

Figure 1: Physical map of Asia

The formation of continents is a consequence of the motion of tectonic plates – opening and closing of oceans (the Wilson Cycle), dispersal of continental fragments and their amalgamation in larger continental masses. Most continental material and structures owe their origin and development to plate boundary processes, i.e. to rifting, transform faulting, subduction, and collision. Identification of sutures containing oceanic material leads to the recognition of ancient oceans. The Tethyan Oceans (Palaeo- and Neo-Tethys) closed along sutures that extend from Spain to the Pacific shores. However, these two oceans, as many other ancient oceans of similar sizes, added little to the Asian continent. Asian tectonics has shown that continental crust originates mainly at subduction zones, where magmatic arcs (island arc chains topped with modern volcanoes on the Pacific side of Asia) and paired subduction-accretion complexes (mainly trench sediments bulldozed from subducting oceanic crust) are formed.

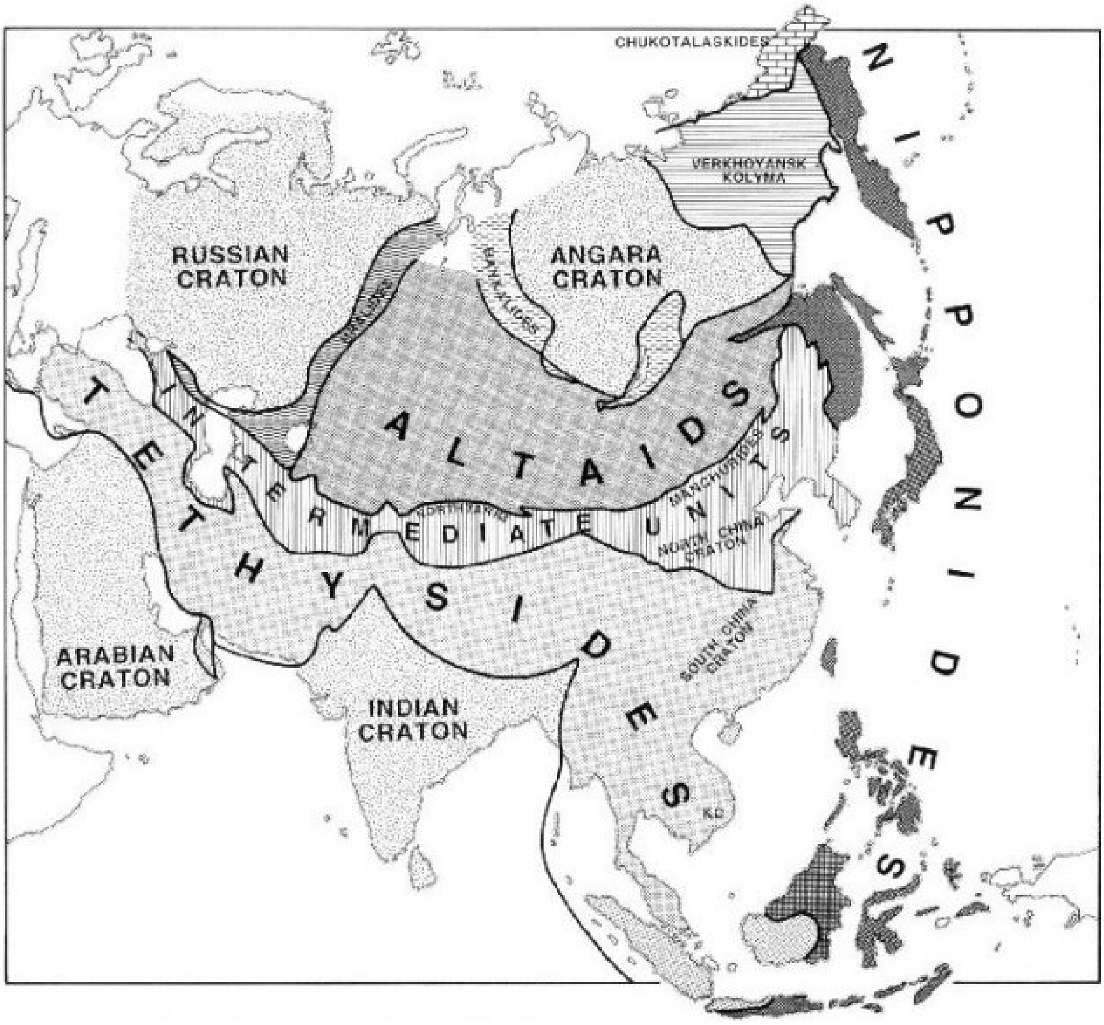

Figure 2: Major orogenic collages of Asia, forming its palaeotectonic subdivisions. *(These subdivisions largely, but not completely, correspond with orogenic zones, as defined in Şengör (1984), for they exclude the marginal fold-and-thrust belts that develop on cratons as the collages accrete. Not shown here, to avoid illegibility, are the orogenic systems, including both the orogenic zones and the associated fields of foreland and hinterland structures populated mainly by germanotype structures. KC is*

the Kontum Craton; Tethysides include both the Cimmerides and the Alpides.)

Continuous convergence in subduction zones is usually followed by collision with a continent on the opposite side of an ocean. When continental masses collide across a former subduction zone, the resulting region of high, semi-penetrative convergent strain is rarely wider than about 1000 km (cf. Tibet as the widest example). Such areas of elongate, linear/arcuate zones of high convergent strain, called orogens by Kober (1921) are located either between stable continental rafts, or between a continental craton and an oceanic plate, or, more rarely, between two oceanic plates. Regions combining several orogens of similar history, age and structure we call orogenic complexes including orogenic systems (see Şengör, Regional Geology, this chapter). An orogenic system usually grows alongside a continental nucleus. This refers to old, Precambrian continental blocks, which have remained stable during the last 1.8-1.5 billion years. In Asia, orogenic systems coincide with mountain areas while continental nuclei occupy lowland plains. Lowland plains are characteristic for yet another type of tectonic structures – rifts and taphrogens, which form by the stretching of previously formed continental crust.

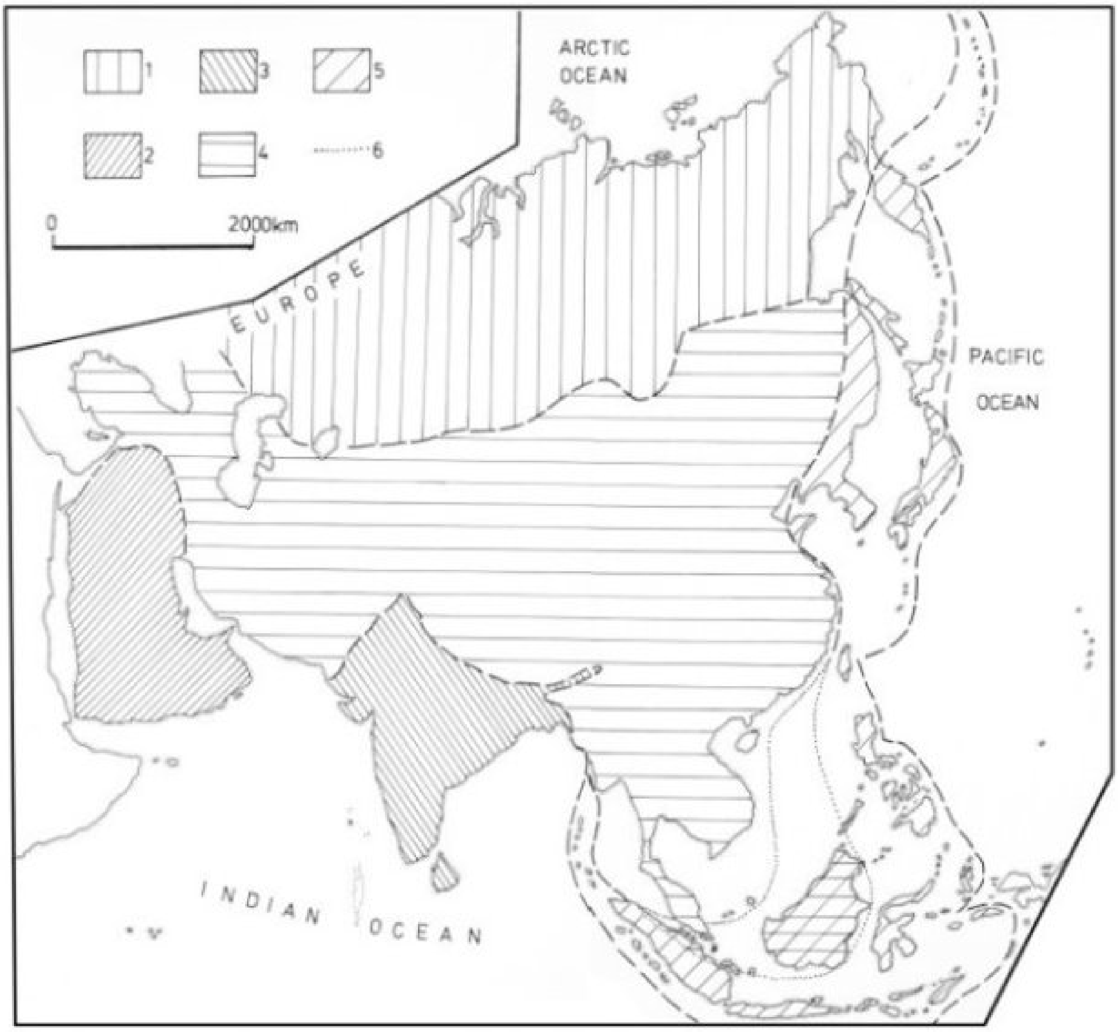

Figure 3: Neotectonc subdivisions or Asia

(I, stable Asia; 2, Arabian platform; 3, Indian subcontinent; 4, Alpide plate-boundary zone; 5, island-arcs and marginal basins; 6, boundaries of the zone of transition between the Alpide plate-boundary zone and the zone of Island-arcs and marginal basins.)

2. First-order Tectonic Units of Asia

Fig. 2 and Fig. 4 display respectively the palaeotectonic subdivisions of Asia and its suture distribution. In the palaeotectonic subdivisions, regions that functioned as continental nuclei to late Vendian-early Palaeozoic orogens are shown as cratons. The following continental nuclei have been recognized in the structure of Asia: Angaran craton, Indian craton, Arabian craton, Kontum craton, North China craton, South China craton, and North Tarim fragment. From oldest to youngest, the following orogenic systems are recognized in Asia: Altaids, Manchurides, Scythides, Chukotkalaskides, Tethysides, Verkhoyansk - Kolyma orogenic system, and Nipponides (i.e. the Asian part of the Circum-Pacific Orogenic Zone). The Scythides, extending from the northern shores of the Black Sea to the Pamirs, belong to the Intermediate units of Eurasia (Fig. 4).

3. Continental Nuclei

The Angaran craton (Fig. 2)—commonly known in the Russian literature as the Siberian Platform—consists of a metamorphic basement and Riphean and younger, undeformed or weakly deformed sedimentary cover. The basement is exposed in the Aldan and Anabar shields. The Aldan shield contains its own continental nucleus consisting of Archaean metamorphosed granitoids and mature metasedimentary rocks (quartzite, schists, and marbles). On the east and west, this nucleus is framed by younger, late Archaean, greenstone belts. Similar rocks are exposed in the Anabar Shield. The greenstone belts consist of rocks that are similar to the present day magmatic arcs and to rocks that may be considered primitive oceanic crust. Blocks of trondhjemite-granite composition are sandwiched between greenstones and this pattern is very similar to what we see in younger orogenic systems. All of these indicate that tectonic processes have experienced little change in the last 3 Ga. The N-S-striking Akitkan belt consisting of 1.9 - 1.7 Ga old island arc volcanic and intrusive rocks stretches for almost 800 km and separates the eastern and western parts of the Angaran craton. This belt marks the line of last amalgamation within the Angaran craton.

Following the mid-Proterozoic consolidation of the Angaran craton, platform type sedimentary rocks were laid down on it with oldest isotopic ages around 1.5 Ga. In the north, east, and south, these sediments pass into thick passive continental margin successions. Establishment of the passive margins was accompanied by the formation of large extensional structures – aulacogens – that extend into the craton interior. In the west and south, the Angaran craton is framed by the Baykalide orogenic system that evolved from 1.8 to 0. 57 Ga as it is shown by the amalgamation of poorly-outlined fragments of magmatic arcs, ophiolites and small continental blocks. The last of the most significant episodes of the Angaran craton tectonic evolution was the eruption of voluminous mafic lavas and tuffs at the Permo-Triassic transition. This eruption affected areas to the west of the Angaran Craton in the basement of the West Siberian

Basin and the Taymyr to the northwest. The origin of these mafic rocks is usually interpreted as related to mantle plume activity.

The basement of the Indian craton (Fig. 2) consists of rocks ranging in age from the Archaean to the Ordovician. The best-known Archaean terrain in the Indian craton is the Dharwar Craton, in the south-central part of the subcontinent (Fig. 4), where, as in the case of the Angaran craton, it consists of gneiss-greenstone associations. The major part of the Proterozoic rocks of the Indian craton is located in the northern part of the subcontinent. The middle to late Proterozoic Ghapuvalli orogeny lasted from about 1.7 Ga to almost 700 Ma ago. How much of this tectonism was collision-related, or, alternatively, how much Andean margin activity without much accretion or convergent margin tectonism with abundant subduction-accretion activity may have taken place is unclear. There is growing evidence for a peri-Gondwanian Pan-African orogen in northern India, north of the Ghapuvalli System and separated from it by the Proterozoic Bundelkhand Craton (Fig. 4), now largely involved in the Himalayan collisional deformation. Widespread granitic magmatism in the north-central part of the Indian subcontinent lasted until about 0.6 Ga ago. Farther north in the Himalaya, it even extended well into the medial Ordovician, as shown by the cordierite granites with ages between 511 and 466 Ma. We have been unable to identify in the Indian craton unequivocal Precambrian aulacogens. By contrast, numerous Permo-Carboniferous rifts crisscross the subcontinent, related to the opening of the Neo-Tethys.

The Arabian craton (Fig. 2) is the youngest of the major Asiatic continental nuclei. It has very sparse Archaean rocks (mainly in the extreme south) and its formation was almost entirely a result of the Pan-African evolution roughly between 0.9 and 0.5 Ga. This evolution was governed by the development of a large orogenic collage consisting dominantly of ensimatic island arcs behind large subduction-accretion complexes. Arc axes later migrated into the growing accretionary complexes to create juvenile continental crust, much like the situation we are going to encounter in the evolution of the Altaids below. This accretionary collage gathered largely around the older parts of the same collage including some 2.0 Ga fragments. This immense Pan-African collage forms much of the Saharan Africa east of the 0° meridian. Its final collision with another continent in the Arabian area most likely took place during the earliest Cambrian.

The high-grade metamorphic terrains making up the original continental nucleus of Indochina are known as the Kontum Massif. Although the oldest widespread thermal event dated isotopically in this area falls into the medial Cambrian (530 Ma), it also contains isotopically dated Precambrian metamorphic rocks with minimum ages around 2.3 Ga. In this respect, the Precambrian-earliest Palaeozoic history of the Kontum craton resembles those of Arabia, India, and South China (see below) betraying an original Gondwana-Land affinity possibly governed by subduction-accretion and later arc/collision events. The latest thermal event may signify the latest Pan-African collision(s) characteristic of the Gondwana-Land margins. This thus might place the Kontum craton on the margins of the supercontinent.

Archaean rocks in the North China craton (Fig. 4) are generally divided into two sequences or "stages": The Qianxian stage (3.5 - 3.0 Ga) and the Fupingian stage (3.0 -

2.5 Ga). The older stage is characterized by the existence of greenstone belts with mafic-ultramafic rocks and siliceous sedimentary rocks. High-grade amphibolite to granulite facies metamorphism affected the associated granitic gneisses. During the course of the Qianxian stage, a number of local palaeonuclei formed, which coalesced into larger protocontinents by the end of the Fupingian stage. All these Achaean rocks of the North China Block constitute a part of the pre-Changcheng metamorphic basement. The actual consolidation of the North China craton took place during the Zhongtiao "orogenic cycle" (approximately 1.7 Ga). Stable sedimentation was almost continuous across the craton during the late Proterozoic to Ordovician interval. It was interrupted in the Late Ordovician and resumed in the Carboniferous. This is the well-known northern Gondwana-Land Palaeoozoic gap known from many Gondwana-Land fragments. Mesozoic and Cainozoic extensional and compressional deformations within the craton are confined to narrow, mainly N-S striking zones of crustal thinning.

The South China craton is variously known in the literature as the South China block, the Yangtze platform, or the Sichuan block. Six "periods" of tectonism nave been established in it on the basis of the character of sedimentation, metamorphism, magmatism, structural style, and isotopic ages. They are named, from the oldest to youngest, as follows: 1) Kangding (=Dabie) Period (2.5 Ga); 2) Dahong Shan Period (2.5 - 1.8 Ga); 3) Manyingou Period (1.8 -1.4 Ma); 4) Jinning Period (1.4 -0.85 Ma); 5) Chengjiang Period (0.85 - 0.7 Ga); and 6) Tongwan Period (0.7 - 0.57 Ga). As in most cratonic nuclei in Asia, the end of the Archaean (i.e. the Kangding Period) marked the initial emergence of a continental nucleus. During the Jinningian orogeny (± 1.0 Ga) the Sichuan block basement became more or less consolidated, although final stabilization occurred until after the Chengjiang orogeny (± 0.8 Ga). The position of the South China craton somewhere directly north of Australia during the earliest Palaeozoic, and the role the Manyingou to Tongwan cycles played in its cratonisation, invite comparison of these orogenies with the long-lived Ghapuvalli orogeny in India. We tentatively interpret the South China craton as a part of the Ghapuvalli orogen. The Tongwan period, characterized by the Xingkaian movements, probably represented the post-Pan-African collision tectonism in South China.

4. North Tarim Craton

Argand (1924) was the first to suggest the presence of a cratonic basement beneath the Tarim basin, which he termed "Serindia". This was followed by Huang (1945) and Sinitzin (1957), although Huang called the hypothetical craton "Tarim". The pioneering work of Norin along the northern (Norin, 1937, 1941) and along the southwestern (Norin, 1946) margins of the Tarim basin seemed to justify Argand's interpretation, although the discovery of a very thick (>15 km) sedimentary cover of essentially entirely Phanerozoic age has since made the assumption of a normal-thickness continental crust under the isostatically compensated Tarim basin suspect. Hsü (1988) recently has argued that the Tarim basin might be a Black-Sea like, land-locked remnant marginal basin of dominantly late Palaeozoic age. Only in the north is a well-established Precambrian cratonic sliver with a geology very reminiscent of the South China craton (NT in Fig. 4). The presence of ~800 Ma-old blueschists near Aksu in the northwestern part of the Tarim suggests that the Chengjiang orogeny here involved subduction.

Şengör and Okuroğulları (1991) presented arguments from the regional geology of the frame of the Tarim basin to support Hsü's contention, but the one definite piece of evidence in favor of Hsü's arguments they thought was a widespread Permian plateau basalt event that clearly had affected not only the margins of the Tarim basin, but also its internal parts (see sep. Norin, 1941). Although we do not necessarily contend for the presence of "normal" oceanic crust under the Tarim, it is clear that whatever underlies it is not normal continental crust. Şengör et al. (1996) contend that the northern Tarim basin—at least—may be underlain by a pre-Sinian oceanic plateau, but we now think that the southern part of the basin, south of the Bachu and the Da Zhong uplifts may be a Permian pull-apart that had formed along a major right-lateral shear zone that connected the Caucasus (even beyond the Tornquist-Teisseyre Lineament in Europe? Natal'in and Şengör, 2001), the Turkmenian basement and the Tarim/Kuen-Lun system. The Permian basalts observed on the Bachu and the Da Zhong uplifts may be indications of this episode (cf. especially Norin, 1941).

The continental nuclei listed above reveal both differences and similarities in their Precambrian history. For example, the Angaran craton and North China being separated by several Paleozoic oceans are nevertheless characterized by similar timing of events in Achaean and Proterozoic, similar styles of tectonic evolution, age of consolidation, and initiation of the platformal cover. The same evolutionary aspects of the Angaran craton are almost identical to those of the Russian craton though in the present day structure they appear as entirely isolated by orogenic systems bearing traces of former Paleozoic oceans. This shows that some of our Asiatic nuclei were combined in other continental configurations before the Phanerozoic, although we do not attempt their reconstruction here.

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Biographical Sketches

Celal Sengor received his PhD at Albany University in the US in 1982. He is now a full professor in the geology department of Istanbul Technical University in Turkey. He has worked in a wide range of disciplines of the earth sciences and is well known as one of the best experts on regional geology of the world today. He has a reputation in the field of history and philosophy of the earth sciences about which he has recently published a textbook. His current research comprises tectonics of Asia, extensional tectonics with emphasis on the Aegean region and evolution of orogenic belts in general.

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