Geology of the Beishan Mountains and the tectonic evolution of Northwest China

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Geology of the Beishan Mountains and the tectonic evolution of Northwest China

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ABSTRACT

The Beishan region is underlain by melanges. Remnants of deposits from ancient passive and active margins, as well as fragments of oceanic lithosphere are present as slabs, blocks and fragments in pervasively sheared matrix. A reconstruction of stratigraphical sequences is effected through the application of the principles of mélanges. Six map units have been recognized, i.e., four mélange units and two large exotic slabs, distinguished on the basis of the lithology and stratigraphy of mélange blocks. The Liuyuan and Hanshan slabs consist mainly of continental basement and its metamorphosed volcanic and sedimentary cover. The Niuquanzi mélange unit is made exclusively of remants of oceanic lithosphere and its sedimentary cover. Exotic blocks detached from continental-margin and from ocean basin, mixed in various proportions, constitute the other three mélange units: Huaniushan, Xichangjing and Dananshan.

Our reinterpretation of the geology of Beishan Mountains on the basis of using non-Smithian stratigraphy led us to postulate that the sedimentary and volcanic formations of the region were originally deposited on the southern margin of Laurasia and in the Paleotethys Ocean. A volcanic island-arc south of the continent may have existed as early as latest Precambrian or Early Cambrian time. The Laurasia margin was a passive margin which was changed into an active margin during the Ordovician, when active volcanism began. The Beishan mélanges were formed by subduction on Paleozoic active margins, and were subsequently squeezed into the suture zone of an arc-continent collision.

ZUSAMMENFASSUNG

Die Geologie der Region Beishan ist durch eine Serie von Mélanges gekennzeichnet. Überreste von einstigen passiven und aktiven Kontinentalrändern sowie Teile von ozeanischer Kruste liegen als Blöcke, Schuppen und Fetzen in der intensiv zerscherten Matrix vor. Anhand der Gesetzmässigkeiten in Mélanges konnte eine Rekonstruktion der verschiedenen stratigraphischen Abfolgen erstellt werden. Sechs kartierbare Einheiten, vier verschiedene Mélanges und zwei riesige exotische Schichtstapel, konnten mittels lithologischer und stratigraphischer Kriterien ausgeschieden werden. Die exotischen Liuyuan und Hanshan Einheiten bestehen vorwiegend aus kontinentaler Kruste und ihre metamorphen vulkanischen und sedimentären Bedeckung. Die Niuquanzi Mélange besteht nur aus ozeanischer Kruste und dazugehörenden Sedimenten. Die andern drei Mélanges, Huaniushan, Xichangjing und Dananshan, enthalten exotische Blöcke von Kontinentalrand und Tiefseebecken in unterschiedlicher Zusammensetzung.

Diese Befunde erlauben eine neue Interpretation der Beishanberge. Die sedimentären und vulkanischen Formationen stammen vom Südrand von Laurasia und der angrenzenden Paleotethys. Im späten Präkambrium oder frühen Kambrium exisitierte ein vulkanischer Inselbogen im Süden dieses Kontinentes. Der passive Kontinentalrand von Laurasia wurde während des Ordoviziums aktiviert, begleitet von vulkanischer Tätigkeit. Die Beishan Mélanges entstanden bei der Subduktion am paläozoischen Kontinentalrand und bilden heute die Suturzone der Inselbogen-Kontinent-Kollision.

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Introduction

Beishan is a WNW-ESE trending mountain chain in the Gansu province of northwest China, situated between Xinjiang on the west and the Badain Jaran Shamo (desert) on the east, and between Mongolia on the north and the Hexi corridor on the south (Figs. 1 & 2). Outcrops in the Beishan region were mapped as the Lower and Middle Palaeozoic, occuring in supposedly fault-bounded blocks. Field mapping and stratigraphical-paleontological researches have been carried out by geologists of the Gansu Provincial Geological Survey and by the Chinese Ministry of Geology. The observational data have been summarized in the explanation of the Geological Map of Gansu (Anonymous 1973), and in numerous unpublished reports.

Zuo et al., 1990 noted that the stratigraphy and lithology of rock units in adjacent fault-bounded blocks are grossly different and suggested an orogenic collage of 14 blocks, representing a dozen terranes or so, in an area of about 125,000 square kilometers (Fig. 2). Although their paper is entitled *Plate tectonics in Beishan region*, their interpretations were in fact a substitution of the new nomenclature form the plate-tectonic theory to replace the old terminology in the theory of geosynclinal sedimentation and episodic orogeny: Eugeosynclines were now called suture zones, volcanic rocks island-arc and metamorphic rocks are interpreted to represent continental basement. The extent of large-scale horizontal displacement by subduction and by overthrusting tectonics was not fully recognized. The result was a postulate of some 5 or 6 back-arc basins (or marginal seas) separated by almost an equal number of volcanic arcs and micro-conti-

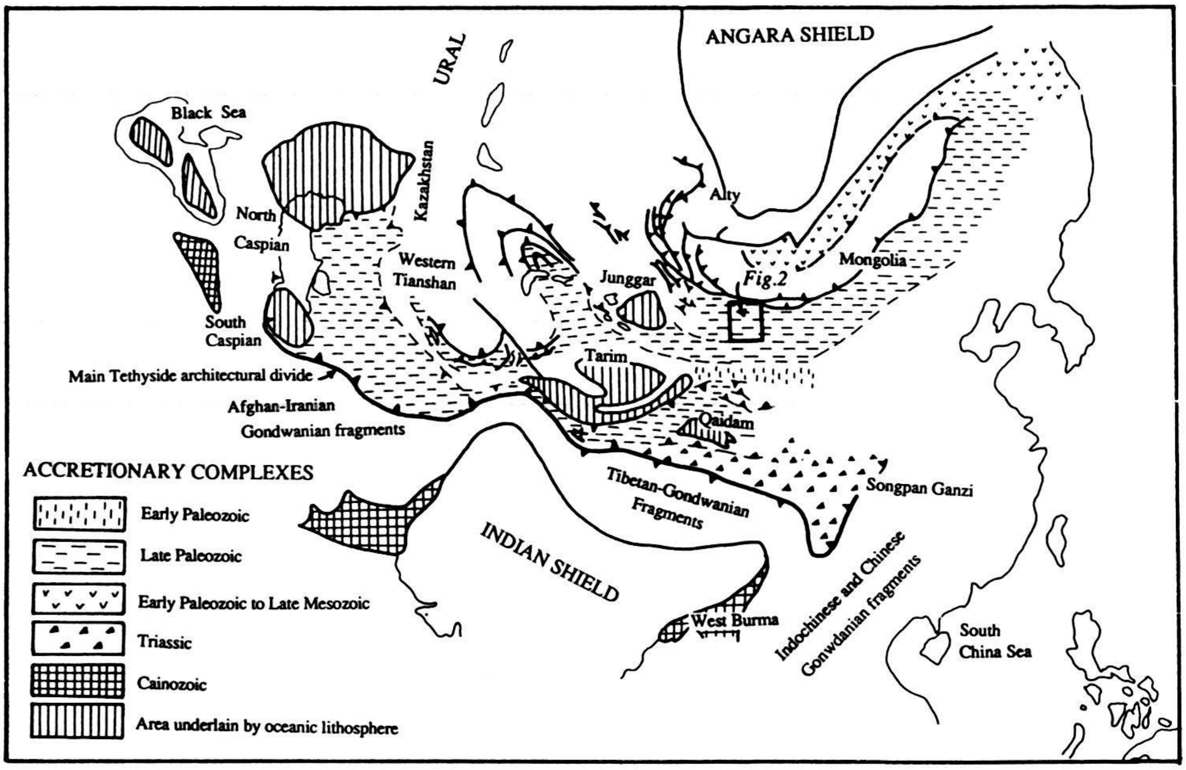

Fig. 1. Schematic tectonic map of central Asia (revised after Şengör et al. 1992), showing location of the Beishan Mountains with respect to other major tectonic units of central Asia.

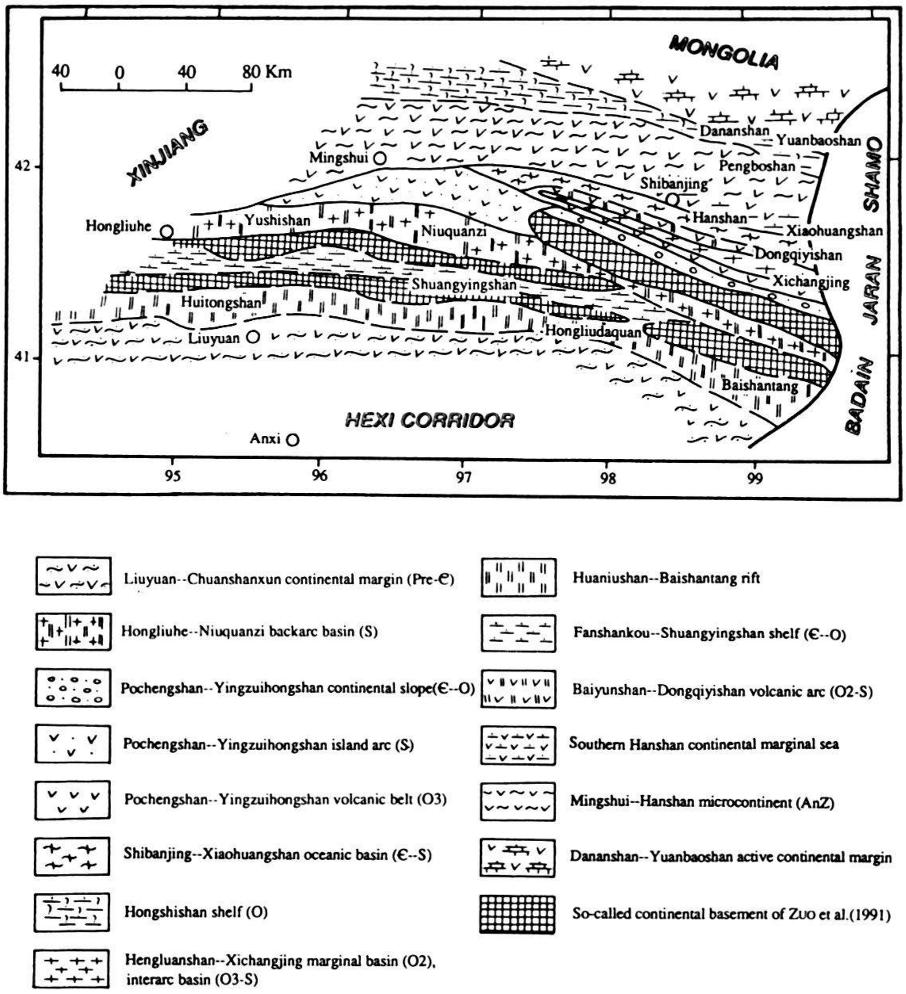

Fig. 2. Location map and interpretation by ZUO et al. (1990) of the Beishan region. Careful readers can locate small places through ZUO et al.'s geoprahical names of tectonic elements.
The interpretation of a collage of plates in the Beishan region is incorrect, see text for discussion.

nents. This unnecessarily complicated interpretion was based upon an unwarranted assumption that each fault-bounded block be the remnant of a lithospheric plate. Furthermore, the application of the Smithian stratigraphy to a region underlain by chaotic terranes has led to a grave misunderstanding of the geologic evolution of the region.

This article is a re-interpretation of published geological data of the Beishan region on the basis of a model that the region is underlain mainly by tectonic mélanges: Rocks detached from the southern plate-margin of the Siberian/Mongolia Plate as well as those fragmented from an ocean lithosphere were sheared and mixed to constitute several mélange units; their original tectonic framework is still recognizable and their stratigraphy has been reconstructed on the basis of principles of mélanges (Hsü 1958). Hsü, Wang, and Li visited Beishan in 1990 to calibrate the data presented in the *Geological Atlas of China* (Anonymous 1973) and those published by Zuo et al. 1990 in their latest article, and found that the descriptions of lithology, fossil ages, etc., in published literature are on the whole correct, even though their interpretation of Beishan geology was not accepted.

The Beishan Mélange

The Beishan region is underlain by rock formations which constitute exotic blocks embedded in the pervasively sheared pelitic matrix. The Smithian stratigraphy is thus not applicable (Hsü 1990). The Laws of Superposition and of Original Continuity are invalid because the blocks are separated by a matrix of innumerable shear surfaces. And the law of paleontological dating is only applicable to date individual blocks which are separated from other blocks by shear contact and thus uncertain stratigraphic relation. To apply the methodology of non-Smithian stratigraphy, the age, paleogeographic and paleo-tectonic significance of each exotic block are separately identified, and the relations of the varoius blocks are reconstructed on the basis of the tectonic facies concept proposed by Hsü et al. (1991) and Hsü (1991 b, in press).

Exotic Blocks Detached from Continental Crust (Liuyuan & Hanshan Slabs)

Granitic and gneiss rocks constituting originally continental basement are present in the Beishan Mélange. One exotic block cropped out in the Liuyuan area south of Beishan. The basement rocks include migmatitic gneiss, marbles and biotite-quartz schists. Metamorphic rocks, including metasandstones, quartzites, metamorphosed volcanic rocks, phyllitic siltstone and slates, have yielded Rb-Sr ages of 580 Ma. of amphibolites (Zuo et al. 1990). Those rocks are interpreted as remobilized continental crust and its sedimentary cover, having been underthrust along a Benioff zone and metamorphosed in early Cambrian times. The other exotic block is present in the central part of the mapped area (Fig. 2), and has been interpreted as a microcontinent, the Mingshui – Hanshan microcontinent, by Zuo et al. (1990). Those are, however, mainly metamorphosed volcanic rocks, quartz schists, marble, and hornblende-plagioclase gneiss, similar to those found in the Liuyuan area, and may have a similar origin.

Exotic Blocks Detached from Passive-Margin Formations

Shallow marine sedimentary rocks typically deposited on passive continental margin habe been found as exotic blocks in the Beishan Melange; they range from Sinian to Cambrian in age. Sinian strata are present in the Pochengshan – Yingzuihongshan area (Fig. 2). The tillite, conglomerate, and dropstones with a carbonate matrix were deposited in shallow marine environments during a glacial stage. These strata can thus be dated on the basis of event-stratigraphy to be correlative to the late Proterozoic rocks deposited during the continental glaciation in Eurasia. This interpretation is further verified by the fact that the glacial-marine deposits are conformably overlain by fossiliferous Cambrian strata. Shallow marine strata of Cambrian age crop out in the Fanshankou – Shuanyingshan (Fig. 2). These are mainly sandy slates, quartzites and quartz sandstones. Lenticles or phacoids of marbles are embodied in sandstones and slates, the loss of lateral continuity of the carbonate strata indicates extension as well as bedding-plane shearing during their deformation.

Exotic Blocks Detached from Active-Margin Formations

The presence of volcanic rocks, associated with continental basement, in the Beishan Mélange indicates the former existence of a magmatic-arc setting on an active plate margin. If the metamorphism of the Liuyuan volcanic rocks took place during a subduction process, their radiometric date suggests that this active margin may have existed in late Sinian or Early Cambrian. The presence of early Paleozoic active-margin sediments is further suggested by the occurrence of sandy limestones, radiolarian chert and turbidites in the Pochengshan – Yingzuihongshan area (Fig. 2). Those are dated Middle or Upper Cambrian by *Eoredlicha sp.* in sandy limestones and trilobites *Amphoton, sp., Kootenia, sp., Ptychopariidae sp.* in pelitic rocks.

The Ordovician strata were laid down in deep marine water. Lower and Middle Ordovician pelagic and hemipelagic deposits crop out in the Huaniushan – Baishantang, the Fanshankou – Shuanyingshan and the Hengluanshan – Xichangjing areas (Fig. 2). Slabs of radiolarian chert, basalt, marble and metasandstones are present in a slate matrix. Serpentinized ultramafic rocks and serpentine schists are also common in the area where Ordovician strata crop out. All those rocks are apparently exotic blocks, fragmented and mixed together with the Ordovician strata in a tectonic mélange. Ordovician fossils *Calymenae sp., Encrinrinae sp., Lichenaria sp.* have been found in marbles in Huaniushan, and *Maclurites sp., Plasmoporella convexotabulato var. maxima* in marbles in Hengluanshan. Those shallow marine corbonates are apparently blocks in slump deposits of the deep sea.

The existence of an Ordovician active plate margin is also evidenced by metamorphosed turbidites and intermediate-acidic volcanic rocks of the Huaniushan – Baishantang and Pochengshan – Yingzuihongshan areas. Their age is suggested by the Upper and Middle Ordovician fossils in limestone slump blocks. Geochemical analysis on the samples from the Pochengshan area indicates a calc-alkaline affinity (Fig. 3).

Silurian outcrops indicative of an active margin setting are widespread in the northern part od the Beishan region. They are mainly composed of terrigenous clastics, radiolarian chert and calc-alkaline volcanic rock, such as andesite, dacite, and rhyolite. Their Silurian age is suggested by the presence of *Eoptychia sp., Spyroceras sp., Maclurítites sp.* in exotic marble blocks of the Hanshan area and of *Palaeofavosites var. borealis, P. Cf. baltiucxus, Hexismia sp.* in exotic reef-limestone of the Dongqiyishan area. The radiolarite of the Pochengshan – Yingzuihongshan area has been metamorphosed and converted into quartzite, the turbidites into quartz schist and phyllite, and the limestone into marble.

Blocks Detached from Ocean Lithosphere

Ophiolite blocks, representing relics of former ocean lithosphere, are present in the Huaniushan – Baishantang, the Hongliuhe – Niuquanzi, the Hengluanshan – Xichangjing and the Shibanjing – Xiaohuangshan areas (Fig. 2). They include cumulative ultramafic and mafic rocks, such as peridotite, gabbro, diorite, serpentinite, as well as hypabyssal intrusive diabase and submarine pillow lava. Apparently in stratigraphic contact above the pillow lava is a deep-water depositional sequence of Ordovician age, including phyllite, slate, radiolarite and carbonate rocks. The ophiolites, metamorphosed in part,

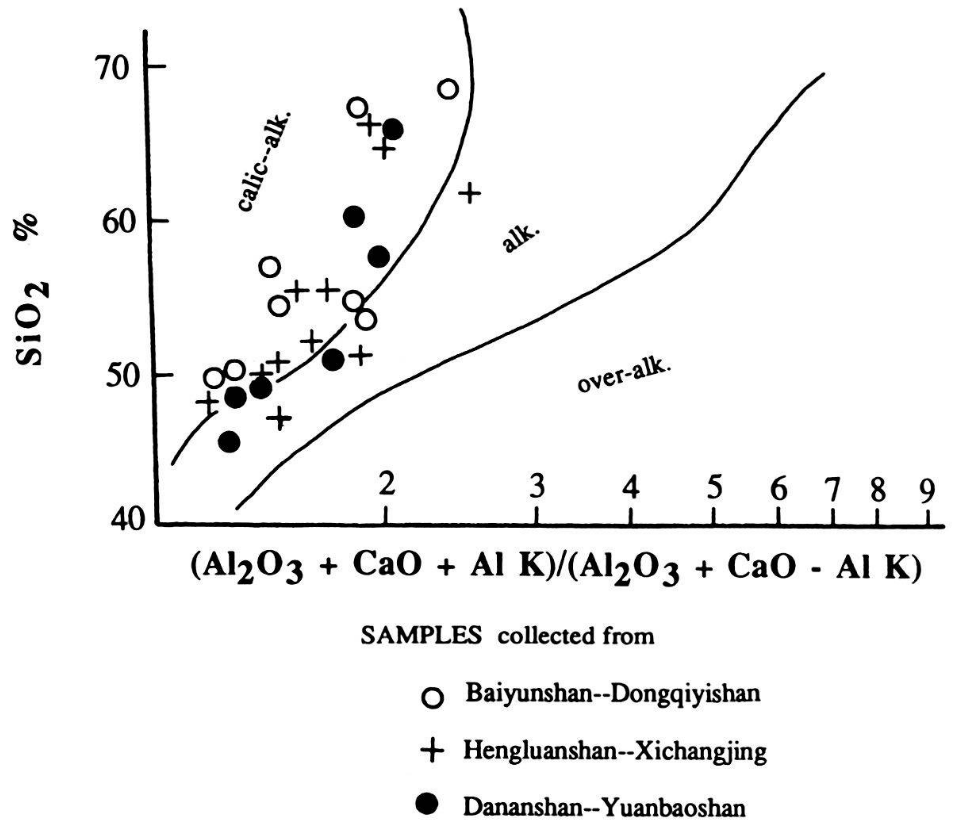

Fig. 3. Classification of volcanic rocks on the basis of alkalinity (after ZUO et al. 1991).

occur as exotic slabs, blocks, or as small fragments in pelitic matrix (Fig. 4). Chemical analyses show their affinity to the rocks of the tholeiitic suite (Zuo et al. 1990).

Mapping of the Beishan Mélange

The slabs and blocks of the Beishan mélange vary greatly in size. Small blocks and tectonic fragments cannot be mapped even on a very large-scale map. Thus a vast amount of important information on the stratigraphy and tectonics of small blocks cannot be communicated by normal (Smithian) geological mapping. We resort, therefore, to the technique of mapping of mélange units (see Hsü 1968; Hsü Ohrom 1969) to portray the tectonic evolution represented by the rocks of the Beishan region. Six map units have been recognized, namely four mélange units and two large exotic slabs (Fig. 5).

Slabs

Slabs in mélanges are those tectonic inclusions larger than 150 m long and could thus be mapped on a large scale (Hsü 1968). Slabs moved *en bloc* during mélange deformation so that the stratigraphic continuity of formations within a slab is essentially preserved. Although slabs are commonly bounded by shearing surfaces, individual formations within a slab are separated by stratigraphic contacts.

The two large slabs in the Liuyuan and Hanshan areas of Beishan seem to have been detached from the same continental basement, and the associated volcanic and sedimen-

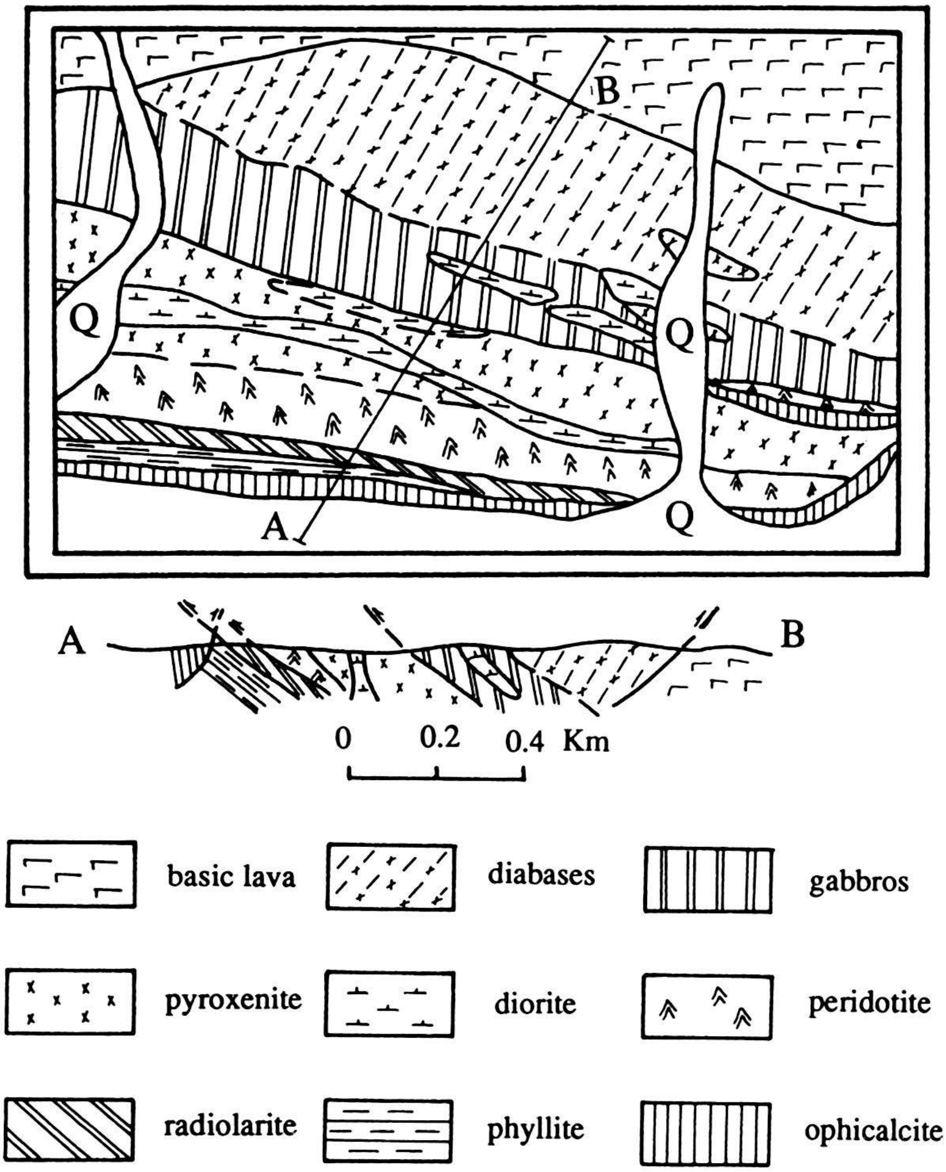

Fig. 4. An ophiolite slab, 2 km southeast of Yueyashan in Hengluanshan–Xichangjing area (after ZUO et al. 1991).

tary rocks may represent the original cover of the basement. Their stratigraphy, deformation and metamorphism suggest that they have been split off from an active continental margin, subducted and plunged tens of kilometers deep, into the Benioff zone, where they are metamorphosed.

An analogue model for the Liuyuan and Hanshan slabs in the Monta Rosa Nappe of the Swiss Alps, which represents subducted continental margin metamorphosed during an early stage of the Alpine active-margin development (Hsü 1991 a). However, the Alpine southern margin is atypical because of the absence of a magmatic arc there. A more comparable analogue is the Japan Arc or the central Andean Range, where older volcanic rocks have been subducted and younger volcanic rocks are erupted behind an active plate-margin. Unfortunately, those regions are not yet deeply enough eroded to have the highly metamorphosed subducted rocks exposed. A still more appropriate comparison can be made to the amphibolite-facies and granulite-facies rocks in San

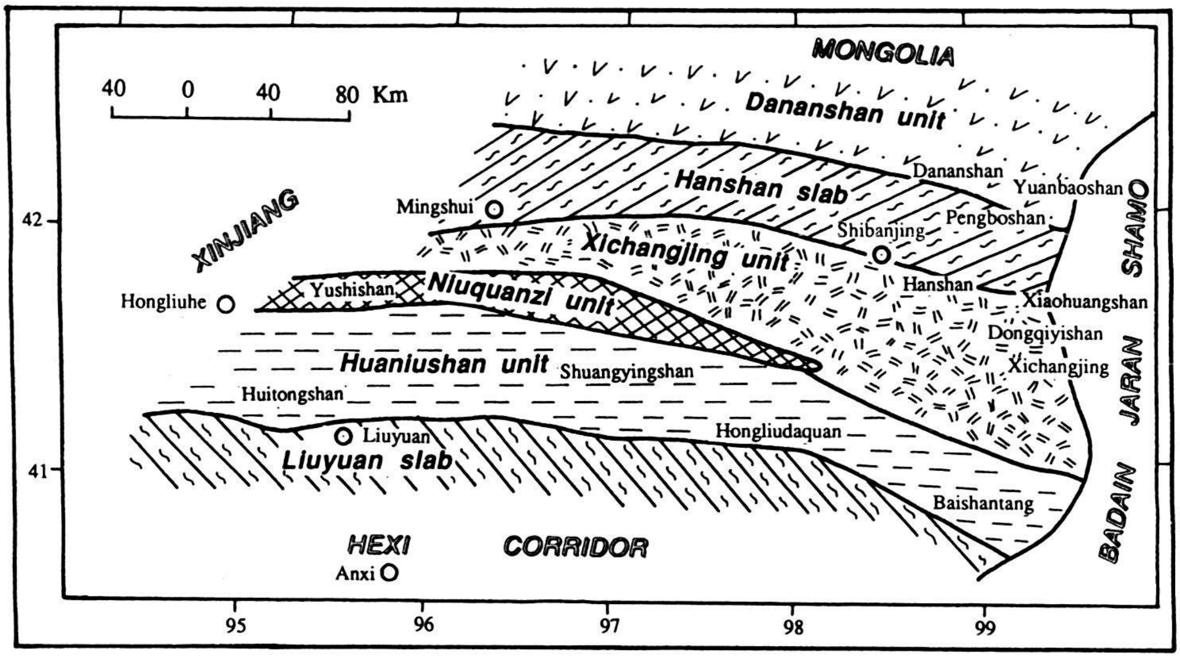

Fig. 5. Sketch geological map of the Beishan region, showing distribution of mélange units and large slabs.

Gabriel Mountains and in Mohave Desert of southern California (Hsü 1955; Silver, personnal communication). Those rocks include both the basement of western North American continental margin, and its volcanic/sedimentary cover. They were metamorphosed at 20–30 km depth during Cretaceous subduction, and were subsequently thrust above the ophiolite mélanges of California (e.g., Franciscan) which represent deformed ocean lithosphere. Both Liuyuan Slab and Hanshan Slab, in our opinion, have likewise been detached from an active continental margin, subducted, metamorphosed and subsequently uplifted and exhumed.

Mélange Units

The four mélange units are named after the places where they are best exposed, respectively. The Huaniushan unit is characterized by a matrix derived from hemipelagic and pelagic sediments of Early to Middle Ordovician ages. Exotic blocks include serpentinized ultramafic rocks and serpentine schists, metamorphosed sandstones and volcanic rocks, as well as marble lenses. (Tab. 1).

The Niuquanzi unit is similar to the Huaniushan unit except for the absence of metamorphosed sandstones and volcanic rocks.

The Xichangjing unit is characterized by a strong mixing of tectonic inclusions of vastly different origins. These include pieces of fragmented oceanic crust, such as those in the Hengluanshan–Xichangjing and the Shibanjing–Xiaohuangshan area, blocks of a volcanic arc, such as those in the Dongqiyishan and the Hengluanshan–Xichengjinh area, and numerous fragments detached from deposits on passive and active continental margins. The strong mixing of rocks of multiple origin suggests very intensive deformation of this unit.

The Dananshan unit is the northernmost unit of the Beishan region, close to the southern margin (Mongolia) of the Siberian Craton. The blocks and matrix are mainly

	Tectonic inclusions in melange units			
	Huaniushan	Niuquanzi	Xichanjing	Dananshan
passive continental-margin sediments				
Sinian			XX	
Cambrian			XX	
pelagic/hemipelagic deposits				
Ordovicain	XXX		XX	XX
Silurian		XX	XX	
volcanic rocks and sediments on active margin				
Ordovician	XX		XX	
Silurian			XX	XX
ophiolites	X	XXX	XX	

X : present XX : common XXX : predominant

Table 1: Composition of melange units

hemipelagic and pelagic sediments of Ordovician ages and volcanic flows of Silurian ages; the unit is characterized by the absence of ophiolite inclusions.

Geologic History of the Siberian/Mongolian Southern Margin

The classic Franciscan Mélange consists exclusively of rocks derived from ocean lithosphere. The upper Penninic mélanges of southeastern Switzerland include both ocean-lithosphere fragments and rocks derived from an active continental margin (see Hsü Briegel 1991). The Beishan Mélange is distinguished by the presence of components from a magmatic arc and from continental crust.

The presence of exotic blocks of Sinian and Early Cambrian shallow marine strata in the Beishan Mélange indicates that the Precambrian basement of the Siberian/Mongolian Craton was covered by shallow marine sediments on a passive margin until sometime in Cambrian.

The change from a passive to an active margin is signalled by the initiation of subduction of oceanic lithosphere. Three lines of evidence have been relied upon to determine the transition:

1. Age of subduction metamorphism. Subduction of an ocean plate could bring near-surface rocks to 50 km depth in 1 Ma at half seafloor-spreading rate of 10 cm/yr, or in 10 Ma at half-spreading rate of 1 cm/yr. The oldest age of metamorphism of rocks carried down a Benioff zone gives an approximate date for the initiation of subduction. This dating method has, for example, yielded a 130 Ma age of subduction at the southern margin of the Tethys ocean in the Alpine region, and the conclusion is verified by the

geological evidence. If the 580-Ma age of the metamorphic rocks of the Liuyuan area is reliable, subduction in the Beishan area could have started in late Precambrian or earliest Cambrian.

2. Age of deep-sea sedimentation. A change from the passive to an active margin is manifested by a change from shallow marine carbonate-orthoquartzite to deepwater hemipelagic or turbidite sedimentation. This dating method has, for example, yielded a Paleocene age for the initiation of subduction at the European (or northern Tethyan) margin in the Alpine region, and this conclusion is consistent with other lines of geologic evidence. If the first appearance of deep-water terrigenous clastics marks the genesis of a deep-sea trench, the beginning of the subduction at the southern Siberian/Mongolian margin could be Late Cambrian.

3. Age of volcanism. Calc-alkaline volcanism signifies partial melting of subducted lithosphere, and it should take place millions of years after the beginning of subduction. The volcanism on the European Tethyan margin started in middle or late Eocene, some 10 or 20 Ma after the postulated subduction. The calc-alkaline volcanic rocks of the Beishan region indicate that the subduction of ocean lithosphere started in Middle Ordovician time. The plate-subduction continued until, at least, the end of the Silurian.

Combining those three lines of evidence, we could postulate either (1) that the subduction began before the Cambrian, or (2) that the change from a passive to an active continental margin took place in Late Cambrian or Ordovician. Hsü, Wang et al. (1991) studied the Neimonides east of the Beishan region in recent years. Their research suggests that the southern margin of the Siberian plate had changed from a passive continental margin into an active continental margin sometime before the Middle Ordovician.

The existence of a Precambrian active plate-margin south of the Siberian/Mongolia craton is indicated by the presence of upper Proterozoic blue schists in Tianshan and Kunlun mountains (Liou et al., 1989; Hsü, in preparation). The recognition of a 580-Ma age of metamorphism in the Beishan region suggests Precambrian subduction along the Siberian margin, and that the Liuyuan slab was split off from the craton to form an island-arc in Cambrian time (Fig. 6). The shallow marine Cambrian–Ordovician deposits (Fanshangkou–Shuangyingshan shelf of Zuo et al. 1990) indicate passive-margin deposition on the north side of the island in a back-arc environment of extension. Lower Paleozoic sediments and ocean crust from the back-arc basin (Honliuhe–Niuquanzi back-arc basin, Shinbanjing–Xiaohuangshan ocean and the Pochengshan–Yingzuihongshan continental slope) are now the main constituents in the Beishan mélanges. The Hanshan Slab may be considered evidence for another island arc south of a back-arc basin in which the sediments constituting the Dananshan Mélange were deposited.

The Beishan mélanges were formed in one or more subduction zones. Was there a collision? A continent-continent collision is characterized by decollement deformation of a former passive margin (Hsü 1981). No foreland-defomation facies is recognizable, neither in Beishan nor in Qilian Mountains and Altun to the south, although Precambrian rocks indicative of continental derivation are present in both regions. This is the reason why we postulate an early Paleozoic arc-arc collision in the Beishan region (Fig. 6). The Huaniushan, Niuquannzi and Xichangjing mélanges owed their origin to subduction processes on active plate-margin and during back-arc basin collapse. They were squeezed into the suture zone of this arc-arc collision. Farther north was the Hanshan Arc and another back-arc basin south of the Siberian Craton.

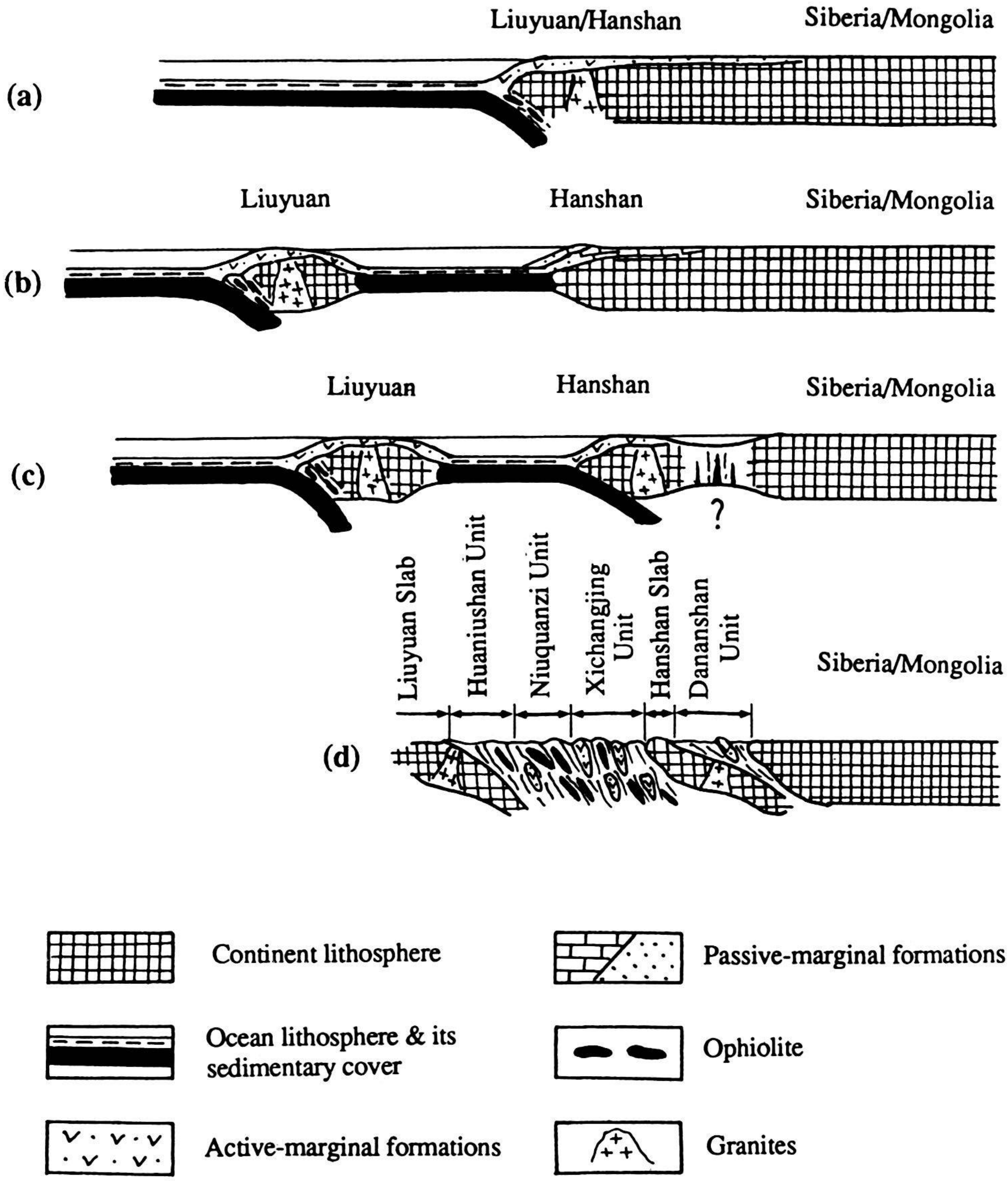

Fig. 6. Working hypothesis of geologic evolution of Beishan Mountains (a) Pre-Sinian: Deposition fo Precambrian – active-marginal formations on southern margin of Siberia/Mongolia (Liuyuan/Hanshan). (b) Sinian–Cambrian: Seafloor spreading of a back-arc basin, resulting in simultaneous deposition of active- and passive-marginal formations in Beishan region. (c) Ordovician: Back-arc basin collapse. (d) End of Silurian: Arc collision, final formation of Beishan Melange.

Our paleogeographic reconstructions suggest the presence of an island-arc setting during late Precambrian and early Paleozoic times south of the Siberian/Mongolia Craton, in contrast to the postulate by Zuo et al. 1990 of a mediterranean sea, with numerous ridges, basins and arcs between two continents. The Cenozoic West Pacific is the model for comparison. The Paleozoic southern margin of the Siberian/Mongolian Craton can be traced eastward from Beishan in Gansu, and from there northward to Ningxia and eastnortheastward across Inner Mongolia. The Beishan mélanges are thus the westward extension of those in the Neimonides; their Early Paleozoic age of deformation suggests a correlation to the Ondorsum Mélange in the Neimonides (Hsü, Wang et al. 1991).

To the west of the Beishan region, the orogenic belt bifurcates into the Altay and the northern Tianshan, enclosing the Junggar Basin between the two. The Altay Mélange marks the southern margin of the Siberian/Mongolian Craton. The ocean crust under the Junggar could be the western extension of a Beishan back-arc basin, except the Junggar basement is not everywhere subducted to form tectonic mélanges. A pair of early Paleozoic island arcs, Middle Tianshan and Serindia Arcs (Hsü et al., in preparation) are present in the Tianshan region. Whether those are correlative to the Liuyuan-Hanshan pair must await further work.

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REFERENCES CITED

ANONYMOUS. 1973: A geological map of the Gansu province. In: A collections of geological maps of the People's Republic of China, Beijing: Geology Press.

HSÜ, K.J. 1965: Francisan rocks of the Santa Luci Range, California and the argile Scagliose of the Apennines, Italy, A Comparison in style of deformation. Geol Soc. Amer. Spec. Pap. 87, abstracts for 1965, 210–211.

– 1967: Mesozoic geology of the California Coast Ranges – a new working hypothesis. In: Étages Tectoniques, 279–296; a la Baconniere, Neuchâtel, Suisse.

– 1968: The principles of melange and their bearing of the Franciscan-Knoxvill paradox. Geol. Soc. Amer. Bull. 79, 1063–1074.

– 1969: Preliminary report and geologic guide to Franciscan melange of the Morro Bay–San Simeon area, California. Publication 35 of the California Division of Mines and Geology.

– 1971: Franciscan melange as a model for geosynclinal sedimentation and underthrusting tectonics. J. Geophys. Res. 76, 1162–1170.

– 1981: Thin-skinned plate tectonic model for collision-type orogenesis. Scientia Sinica 24, 100–110.

– 1982: Geosynclines in plate-tectonic settings, sediments in mountains. In: Mountain Building Processes (Ed. by Hsü, K.J). London: Academic Press, 3–12.

– 1989: Time and place in Alpine orogenesis–the fermor lecture. In: Alpine Tectonics (Ed. by Coward, M.P., Dietrich, D. Park, P.G.) Geol. Soc. Spec. Publ. 45, 421–443.

– 1990: Melange and non-Smithian stratigrapy. Current Contents no. 26 for 1990, 24.

– 1991 a: Exhumation of high-pressure metamorphic rocks. Geology 19, 107–110.

– 1991 b: The concept of tectonic facies. In: The Ketin Festschrift (Ed. by ŞENGÖR, A.M.C.). Istanbul University Press (in press).

HSÜ, K.J. BRIEGEL, U. 1991: Geologie der Schweiz. Birkhauser Verlag, Basel.

Hsü, K.J. Ohrom, R. 1969: Melange of San Franciscan Peninsula-geological reinterpretation of type Franciscan. Amer. Assoc. Petroleum Geol. Bull. 53, 1348–1367.

Hsü, K.J. Wang, Q., Li, L. Hao, J. 1991: Geology of Neimonides : a working hypothesis. Eclogae geol. Helv. 84, 1–31.

Karig, D.E. 1982: Deformation in the forearc: implication for mountain belts. In: Mountain Building Processes (Ed. by Hsü, K.J.). London: Academic Press, 59–72.

Liou, J.G., Wang, X., Coleman, R.G., Zhang, Z.M. Maruyama, S. 1989: Blueschists in major suture zones of China. Tectonics 8, 609–619.

School, D.W., von Huene, R., Vallier, T.A. Howell, D.G. 1980: Sedimentary masses and concepts about tectonic processes at underthrust ocean margins. Geology 8, 564–568.

Şengör, A.M.C. Okurogullari, A.M. 1991: The role of accretionary wedges in the growth of continents: Asiatic examples from Argand to plate tectonics. Eclogae Geol. Helv. (in press).

Trommsdorff, V., Dietrich, V. Honegger, K. 1982: The Indus suture zone: palaeotectonic and igneous evolution in the Ladakh–Himalayas. In: Mountain Building Processes (Ed. by Hsü, K.J.). London: Academic Press, 213–220.

Wang, H. et al. 1985: Atlas of the palaeogeography of China. Cartographic Publishing House, Beijing, China.

Zuo, G., Zhang, S., He, G. Zhang. Y. 1990: Early Palaeozoic plate tectonics in Beishan area (in Chinese). Scientia Geologica Sinica for 1990, No. 4, 305–314.

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