GRANITOIDS OF THE CAOB AND CONTINENTAL GROWTH IN THE PHANEROZOIC

JAHN, Bor-ming, Géosciences Rennes, Université de Rennes 1, 35042 Rennes Cedex, France (e-mail : jahn@univ-rennes1.fr)

Abstract

The Central Asian Orogenic Belt (CAOB), also known as the Altaid Tectonic Collage, is characterized by vast distribution of Paleozoic and Mesozoic granitic intrusions as well as basaltic to rhyolitic volcanics. The granitoids have a wide range of compositions and roughly show a temporal evolution from calc-alkaline, alkaline to peralkaline series. The emplacement times for most granitic plutons fall between 500 to 120 Ma, but only a small proportion of plutons have been precisely dated. Most Phanerozoic granitoids of Central Asia are characterized by low initial Sr isotopic ratios, positive $\varepsilon_{Nd}(T)$ values and young Sm-Nd model ages (T_{DM}) of 300 to 1200 Ma. This is in strong contrast with the coeval granitoids emplaced in the European Caledonides and Hercynides, and in SE China and Korea. The isotope data indicate their "juvenile" character and suggest their derivation from source rocks or magmas separated shortly from the upper mantle. Granitoids with negative $\varepsilon_{Nd}(T)$ values also exist, but they occur in the environs of Precambrian microcontinental blocks and their isotope compositions may reflect contamination of the older crust in the magma generation processes.

The evolution of the CAOB is likely related to accretion of young arc complexes and old terranes (microcontinents). However, the emplacement of large volumes of post-tectonic granites requires another mechanism - probably through a series of processes including underplating of massive basaltic magma, intercalation of basaltic magma with lower crustal granulites, partial melting of the mixed lithologic assemblages leading to generation of granitic liquids, followed by extensive fractional crystallization. The proportions of the juvenile or mantle component for granitoids of Central Asia are high and for most of the studied samples they vary from 60 to 100%.

I. Introduction

The formation, growth and evolution of the continental crust have always been a fundamental and very interesting subject in earth science research. The growth of the continental crust is generally believed to have been essentially completed in the Precambrian, and the amount of juvenile crust produced in the Phanerozoic is considered insignificant. Such idea of negligible growth in the Phanerzoic may now be challenged by the revelation of very large volumes of juvenile crust produced in the period of 500 to 100 Ma in several orogenic belts. While appreciable volumes of juvenile terranes in North America (Canadian Cordillera, Sierra Nevada and Peninsular Range in the west, and Appalachians in the east) have been documented, the mass of new crust formed in Central Asia appears to be much greater than the above terranes combined.

In Central Asia, voluminous granitic rocks of late Paleozoic to Mesozoic ages were emplaced during the formation of the Central Asian Orogenic Belt (CAOB), otherwise known as the Altaid Tectonic Collage (Sengör et al., 1993). The CAOB, bounded by the Siberian and North China cratons, represents a complex evolution of Phanerozoic orogenic belts. The purposes of this talk are: (1) to demonstrate the dominantly juvenile nature of the Phanerozoic granitoids from Central Asia based on Sm-Nd isotopic data, and (2) to discuss the general implications on the global Phanerozoic crustal growth.

II. Nd isotopic data for Central Asian granitoids

(a) NE China & Inner Mongolia

In NE China, ≥ 350 granitic bodies were intruded (mainly during the Mesozoic) in the Great Xing'an (or Khinggan), Lesser Xing'an and Zhangguangcai Mountains. Some of the granites were emplaced within the domain of the Jiamusi Massif, a Preterozoic microcontinental block whose metamorphic age has been precisely dated at 500 Ma by SHRIMP zircon analyses (Wilde et al., 1997). The granites are composed mainly of I-type and subordinated A-type granites (Wu et al., 1999a). They are covered by extensive Mesozoic and Tertiary acid volcanic rocks. Petrographic examination of drilled cores revealed that the Songliao Basin in central NE China is underlain by vast granitic rocks. This suggests that the true volume of granitic rocks is much greater than what is observed in the present geologic map.

In Inner Mongolia, several periods of granitic intrusions took place from Devonian to Jurassic times. Our samples came from a Paleozoic anorogenic A-type suite (280 Ma ; Hong et al., 1996), an arc-related calc-alkaline magmatic belt composed of gabbroic diorite, quartz diorite, tonalite and granodiorite (SHRIMP zirocn age of 309 ± 8 Ma) and a Mesozoic collision-type granitic suite of mainly adamellite with subordinate granodiorite and leucogranite (Chen et al., 1999).

Sm-Nd isotope data including all derivative parameters (intrusive and model ages, $f_{Sm/Nd}$) for the Phanerozoic granitic rocks from NE China, Inner Mongolia and the Hida belt of Japan are presented in Figs. 1. In contrast to the European or SE China granites, the majority of the analyzed samples have positive $\varepsilon_{Nd}(T)$ values, indicating their relatively juvenile character. Note that most of the samples with negative $\varepsilon_{Nd}(T)$ values came from within the domain of the Precambrian Jiamusi Massif. Such a close relationship between the isotopic compositions of granitoids and the ages and nature of their intruded « basement » rocks is also demonstrated by the data from Xinjiang (Hu et al., 1999) and from the CAOB's northern belt of Mongolia-Transbaikalia (Kovalenko et al., 1996). The lowering of $\varepsilon_{Nd}(T)$ values of granitic intrusions was most probably effected by contamination of old crustal rocks.

Figs. 1b & 1c show that they have a wide range of single-stage model ages. Aberrant model ages (negative or ≥ 4000 Ma) are produced due to strong Sm/Nd fractionation through crystallisation and magma-hydrothermal interaction leading to the tetrad effect of REE distribution (Jahn et al., 1999b). We therefore consider model ages interpretable only when $f_{Sm/Nd}$ values are –0.4 ± 0.2. Consequently, the granites of NE China and Inner Mongolia have young model ages ranging from 500 to 1200 Ma except a few plutons emplaced in the Jiamusi Massif.

(b) Northern Xinjiang & East-central Kazakhstan

The geology of northern Xinjiang in NW China may be conveniently divided into five « terranes » (from north to south) : Altai, East and West Junggar, and East and West Tianshan (Hu et al., 1999). Within the CAOB, the Altai terrane is a composite terrane consisting of Proterozoic gneiss complexes and Phanerozoic sedimentary cover and intrusions. The Junggar Basin is covered by Cenozoic desert and thick continental basin sediments (≥ 10 km) as old as Permian.

Drilling records indicate little deformation within the basin, suggesting stable configuration of the basement at least since the Permian (Coleman, 1989). A variety of Phanerozoic granitoids occur throughout northen Xinjiang. As in NE China, the majority of granitoids have positive $\varepsilon_{Nd}(T)$ values (Figs. 1d,e,f) which suggest very large proportions of the mantle component in the generation of these rocks. This is particularly true for the granitoids from the Junggar terranes (Zhao, 1993; Han et al., 1997) and Alatau Mtns (Zhou et al., 1995). On the other hand, granitoids emplaced in the Altai composite terrane tend to show a wider range of isotopic compositions (Figs. 1d & e). Granites of negative $\varepsilon_{Nd}(T)$ values are most probably generated from mixed sources or due to contamination by Proterozoic gneisses during magma differentiation and emplacement.

Figs. 1e & 1f show that the Junggar granites have very young model ages ranging from 300 to 1000 Ma, whereas the granites from the Altai have more variable T_{DM} from 700 to 1700 Ma. A tight relationship between the isotopic compositions of granitoids and the nature of their basement rocks can be established. Hu et al. (1999) concluded from their Sm-Nd isotope data that the basement rocks of Altai and Tianshan were largely produced in the Proterozoic, but that of Junggar seem to represent very young accreted terrane with little Precambrian history. The parallel manifestation of isotopic compositions and model ages between basement rocks and intrusive granites argue for the significant role of crustal contamination in the genesis of the Phanerozoic granitoids. A tectonic implication is that the presence of old Precambrian microcontinents is important in the accretionary history in Central Asia.

Heinhorst et al. (1999) undertook a comprehensive study of mineralisation in association with a variety of magmatic rocks in east-central Kazakhstan. Although the types of mineralisation (Au, Cu, rare-metal, or REE) may be related to a particular magmatic suite or a lithological variety, most granitic rocks have positive $\varepsilon_{Nd}(T)$ values (Figs. 1d & 1e) irrespective of their compositions or rock types (Heinhorst et al., 1999). The granitoids were intruded in several episodes : 450 and 300 Ma for magmatic suites with gold mineralisation, about 300 Ma for granitoids of rare-metal mineralisation, and ca. 250 Ma for A-type granites of REE mineralisation. Single-stage model ages for all granites fall between 400 to 1400 Ma.

III. Discussion

The above data for the southern belt of the CAOB – from Kazakhstan, northern Xinjiang, Inner Mongolia to NE China, covering a distance of nearly 5000 km, indicate that most of the granitoids, despite of their highly differentiated nature and sometimes strong hydrothermal alteration leading to important mineralisations, possess a clear signature of high proportion of the mantle component in their petrogeneses. They are considered relatively juvenile and their massive intrusions suggest a significant addition of juvenile continental crust during the Phanerozoic. Likewise, the granitoids of the northern belt from central Mongolia to Transbaikalia have been extensively studied by Kovalenko et al. (1996), and a similar conclusion has been reached.

With regard to the massive generation of Phanerozoic juvenile crust, the best documented examples until now are those from the Mesozoic Sierra Nevada and Peninsular Range batholiths in the western U.S. (DePaolo, 1981), the Canadian Cordillera (Samson et al., 1989; Samson and Patchett, 1991), and the Appalachians (Whalen et al., 1996; Samson et al., 1995). While a significant mantle contribution to the generation of the CAOB granitoids is indicated by the Nd isotopic evidence, the precise mechanisms for the growth and evolution of the Phanerozoic continental crust remain debatable.

Windley (1995) distinguishes two types of orogens: (1) collisional orogens, formed by the collision of two or more large continental blocks (e.g., Himalayas, Alps, Grenville, etc.), and (2) accretionary orogens, formed by the growth and amalgamation of island arcs, intervening accretionary prisms, etc. (e.g., Altaids, North American Cordillera, Andes, Birimian, Nubian-Arabian, etc.). A depleted mantle isotopic character is unusual for granitic rocks of collisional orogens worldwide, but are more commonly observed for those in accretionary orogens. High $\varepsilon_{Nd}(T)$ values could reflect a direct contribution of mantle in subduction zones, but they could equally have no connection with subduction as well, as evidenced from the abundant Central Asian A-type granites which are post-orogenic and not generated in subduction zones. Thus, subduction processes alone could not have been responsible for the formation of all the juvenile crust in the CAOB.

Although many plutons and batholiths of the CAOB belong to the calc-alkaline series and have differentiated I-type characteristics, the emplacement of voluminous granites of the alkaline and peralkaline series is remarkable. Of these rocks, many are post-orogenic A-type granites (A/CNK $\leq$ 1), and whose origin is still much debated. It appears that the production of a huge amount of alkaline to peralkaline granites was initiated by extensive basalt underplating and accompanied by large-scale crustal extension. Intraplate magmatism was probably a significant process of continental growth in the Phanerozoic.

The available trace element and Nd-Sr isotopic data of A-type granites from Xinjiang and Inner Mongolia, and differentiated I-type granites from NE China indicate that the mixing model is the most probable process and the dominance of mantle component over crustal material. A mixing calculation using a fixed depleted mantle (ε_{Nd} = +8) and variable crustal end-members suggest that the proportion of the mantle component (or % juvenile crust) for positive $\varepsilon_{Nd}(T)$ granites varies from 60 to 100% depending on the compositions of the assumed crustal end-members, which are taken from the Jiamusi Massif for NE China (ε_{Nd} = -12), the Baidarik Block for Central Mongolia (-30), the basement gneisses for Altai (-15), and Junggar (-4), and the Kazak basement assumed to be the same as the Altai gneisses. This implies extensive mantle differentiation and rapid juvenile crustal addition during the Phanerozoic. However, significant proportions of recycled crust are also visible in the granitoids emplaced in the Jiamusi Massif and Altai composite terranes, and Pre-Riphean zones in Mongolia and Transbaikalia.

IV. Conclusions

(1) The vast orogenic belt (CAOB) that welded together the Siberian and Sino-Korean cratons is characterized by voluminous granitic rocks of Paleozoic to Mesozoic ages. Nd isotopic data show that the voluminous granitic rocks from Central Asia are very « juvenile », composed of high proportions of the depleted mantle component. Considering the immense geographic coverage, the Central Asian Orogenic Belt represents undoubtedly the most important site of crustal growth in the Phanerozoic.

(2) The origin of A-type granites has long been controversial, but most of the post-orogenic A-type granites from the CAOB are demonstratably of predominantly mantle origin based on their Nd-Sr isotopic data.

(3) The tectonic evolution of the CAOB (= Altaid Collage) is probably related to accretion of arc complexes and the emplacement of juvenile granitoids as suggested by Sengör et al. (1993). However, the granites with negative values require the existence of old Precambrian blocks, thus accretion of old terranes must be envisaged. Besides, the emplacement of voluminous post-orogenic A-type granites requires an additional process, probably involving basalt underplating, mixing of underplated magma and lower crustal rocks, melting of the mixed sources, and followed by extensive fractional crystallisation. Intraplate magmatism involving plume melting, basalt underplating, differentiation or remelting of a basaltic source, could be an important process, in addition to arc accretion, of continental growth in the Phanerozoic.

(4) For the entire Altaid Collage, Sengör et al. (1993) estimated that during the 400 Ma of crustal evolution, a total area of about two million km^2 of juvenile crust was added to Asia. This is translated into a growth rate of about 0.3 km^3/a. Combining this with the growth rate of the Canadian Cordillera (about 0.15 km^3/a, Samson et al., 1989; Samson and Patchett, 1991), the new rate would be at least 50% higher than the global growth rate of ca. 1.1 km^3/a deduced from arc magmatism only by Reymer and Schubert (1984, 1986). Consequently, the recent « discovery » of juvenile crust in several Phanerozoic orogenic belts, in particular the CAOB, may considerably change our views of the continental growth.

(Contribution to IGCP-420)

References :

Arakawa, Y. and Shimura, T., 1995. Nd-Sr isotopic and geochemical characteristics of two contrasting types of calc-alkaline plutons in the Hida belt, Japan. Chem. Geol., **124**, 217-232.

Chen, B., Jahn, B.M., Wilde, S., Xu, B., 1999. Two contrasting Paleozoic magmatic belts in northern Inner Mongolia, China : petrogenesis and tectonic implications. Tectonophysics (in press).

Coleman, R.G., 1989. Continental growth of northwest China. Tectonics, **8**, 621-635.

DePaolo, D.J., 1981. A neodynium and strontium isotopic study of the Mesozoic calc-alkaline granitic batholiths of the Sirra Nevada and Peninsular Ranges, California. J. Geophys. Res., **86**, 10470-10488.

Han, B. F., Wang, S. G., Jahn, B. M., Hong, D. W., Kagami, H. and Sun, Y. L., 1997. Depleted-mantle magma source for the Ulungur River A-type granites from north Xinjiang, China: geochemistry and Nd-Sr isotopic evidence, and implication for Phanerozoic crustal growth. Chem Geol., **138**, 135-159.

Heinhorst, J., Lehmann, B., Ermolov, P., Serykh, V., Zhurutin, S., 1999. Paleozoic crustal growth and metallogeny of Central Asia : evidence from magmatic-hydrothermal ore systems of Central Kazakhstan. Tectonophysics (in press).

Hong, D.W., Wang, S.G., Han, B.F. and Jin, M.Y., 1996. Post-orogenic alkaline granites from China and comparisons with anorogenic alkaline granites elsewhere. J. SE Asian Earth Sci., **13**, 13-27.

Hu, A.Q., Jahn, B.M., Zhang, G., Zhang, Q., **1999**. Crustal evolution and Phanerozoic crustal growth in Northern Xinjiang: Nd-Sr isotopic evidence. Part I: Isotopic characterization of basement rocks. (in preparation).

Jahn, B. M., Wu, F. Y. and Chen, B., 1999a. Granitoids of the Central Asian Orogenic Belt and continental growth in the Phanerozoic. Trans. Royal Soc. Edinburgh (submitted)

Jahn B. M., Wu F. Y., Capdevila, R., Wang, Y. X. and Zhao, Z. H., 1999b. Highly evolved juvenile granites with tetrad REE patterns: The Woduhe and Baerzhe granites from the Great Xing'an (Khingan) Mountain in NE China. Abstract of IGCP420 2nd Workshop in Ulaanbaator, ed. by G. Bardach and B. M. Jahn, 43-47.

Kovalenko, V.I., Yarmolyuk, V.V., Kovach, V.P., Kotov, A.B., Kozakov, I.K., Sal'nikova, E.B., 1996. Sources of Phanerozoic granitoids in Central Asia: Sm-Nd isotope data. Geochem. Int'l., **34**, 628-640.

Reymer, A. and Schubert, G., 1984. Phanerozoic addition rates to the continental crust and crustal growth. Tectonics, **3**, 63-77.

Reymer, A. and Schubert, G., 1986. Rapid growth of some major segments of continental crust. Geology, **14**, 299-302.

Samson, S.D. and Patchett, P.J., 1991. The Canadian Cordillera as a modern analogue of Proterozoic crustal growth. Aust. Jour. Earth Sci., **38**, 595-611.

Samson, S.D., McClelland, W.C., Patchett, P.J., Gehrels, G.E., Anderson, R.G., 1989. Evidence from neodymium isotopes for mantle contributions to Phanerozoic crustal genesis in the Canadian Cordillera. Nature, **337**, 705-709.

Samson, S. D., Hibbard, J. P. and Wortman, G. L., 1995. Nd isotopic evidence for juvenile crust in the Carolina terrane, southern Appalachians. Contrib. Mineral. Petrol., 121: 171-184.

Sengör, A.M.C., Natal'in, B.A. and Burtman, V.S., 1993. Evolution of the Altaid tectonic collage and Paleozoic crustal growth in Eurasia. Nature, **364**, 299-307, 1993.

Whalen, J.B., Jenner, G.A., Longstaff, F.J., Robert, F. and Galiépy, C., 1996. Geochemical and isotopic (O, Nd, Pb and Sr) constraints on A-type granite petrogenesis based on the Topsails igneous suite, Newfoundland Appalachians. J. Petrology, **37**, 1463-1489.

Wilde, S. A., Dorsett-Bain, H. L. and Liu, J. L.,. 1997. The identification of a Late Pan-African granulite facies event in Northeastern China: SHRIMP U-Pb zircon dating of the MashanGroup at Liu Mao, Heilongjiang Province, China. Proceedings of the 30th IGC: Precambrian Geol. Metamorphic Petrol., **17**, 59-74.

Wilde, S.A., Zhang, X.Z., Wu, F.Y., 1999. Extension of a newly-identified 500 Ma metamorphic terrain in NE China: further U-Pb SHRIMP dating of the Mashan Complex, Heilongjiang Province, China. Tectonophysics (in revision).

Windley, B., 1995. The Evolving Continent, 3rd edition. John Wiley & Sons, Chichester, 526 pp.

Wu, F.Y., Jahn, B.M., Lin, Q., Ge, W.C. and Sun, D.Y., 1999a. Highly fractionated I-type granites from NE China: geochemistry, petrogenesis and implications for continental growth. (to be submitted to J. Petrology).

Wu, F. Y., Jahn, B. M. and Sun D. Y., 1999b. Phanerozoic crustal growth: Sr-Nd isotopic evidence from the granites in northeastern China (to be submitted to Tectonophysics).

Zhao, Z.H., 1993. REE and O-Pb-Sr-Nd isotopic compositions and petrogenesis of the Altai granitoids. In: New Development of Solid Earth Science in Northern Xinjiang. Science Publishing Co., Beijing, 239-266.

Zhou, T.X., Chen, J.F., Chen, D.G. and Li, X.M., 1995. Geochemical characteristics and genesis of granitoids from Alataw Mountain, Xinjiang, China. Geochimica, **24**, 32-42 (in Chinese with English abstract).

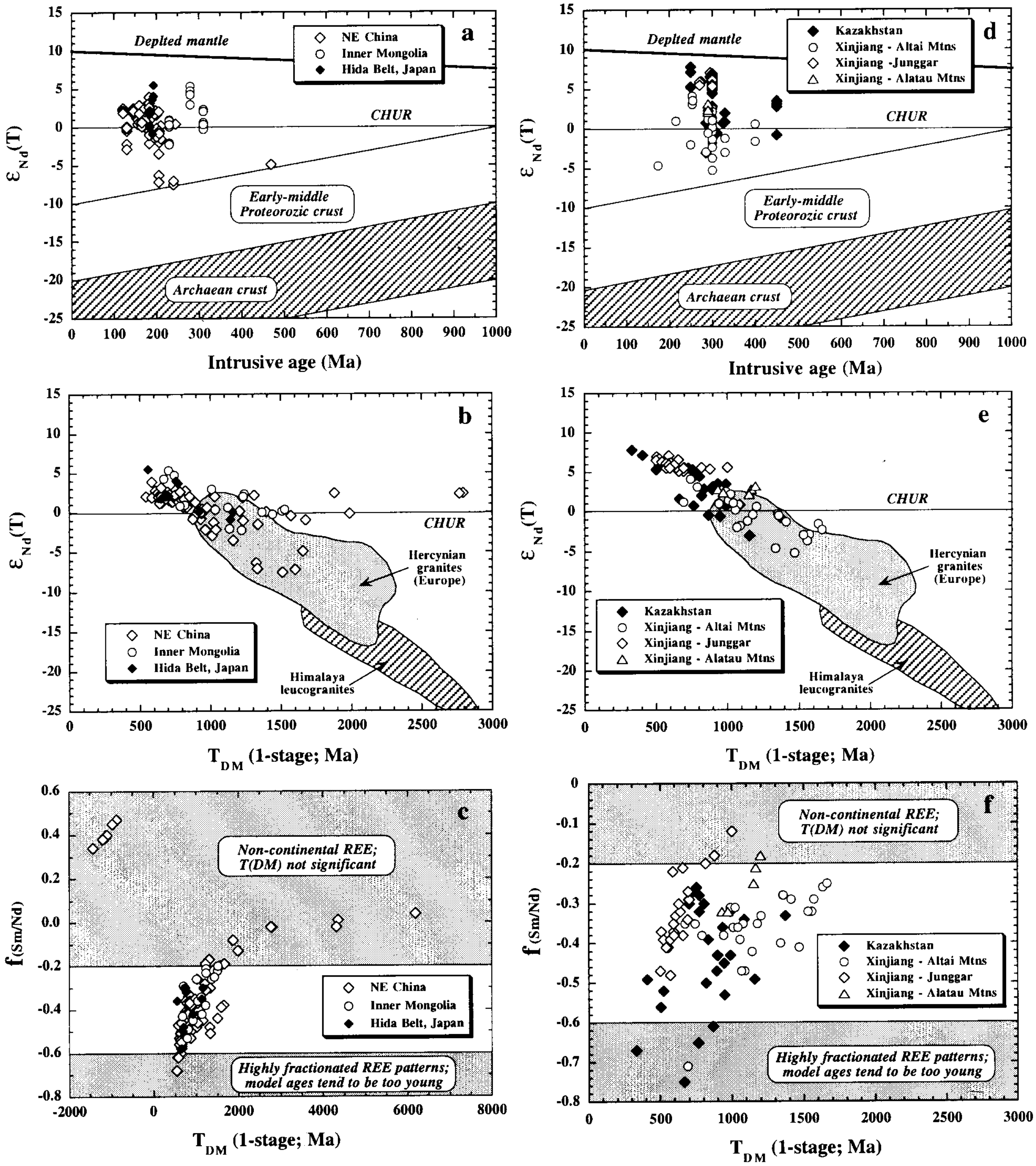

Fig. 1. Isotope diagrams for granitoids from Kazakhstan, northern Xinjiang, NE China and Inner Mongolia. Data sources : **NE China** : Wu et al. (1999a, 1999b) and Jahn et al. (1999b) ; **Inner Mongolia** : Jahn, unpublished ; **Hida belt** : Arakawa and Shimura, (1995) ; **Xinjiang** : Zhao et al. (1993), Zhou et al. (1995), Han et al. (1997), Jahn (unpublished) ; **Kazakhstan** : Heinhorst et al. (1999).