



# Emplacement ages, geochemical and Sr–Nd–Hf isotopic characterization of Mesozoic to early Cenozoic granitoids of the Sikhote–Alin Orogenic Belt, Russian Far East: Crustal growth and regional tectonic evolution



Bor-ming Jahn<sup>a,\*</sup>, Galina Valui<sup>b</sup>, Nikolai Kruk<sup>c,d</sup>, V. Gonevchuk<sup>b</sup>, Masako Usuki<sup>a</sup>, Jeremy T.J. Wu<sup>a</sup>

<sup>a</sup> Department of Geosciences, National Taiwan University, Taipei 106, Taiwan

<sup>b</sup> Far Eastern Geological Institute, Russian Academy of Sciences, Vladivostok, Russia

<sup>c</sup> Institute of Geology and Mineralogy of Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia

<sup>d</sup> Novosibirsk State University, Novosibirsk, Russia

## ARTICLE INFO

### Article history:

Received 18 May 2015

Received in revised form 10 August 2015

Accepted 10 August 2015

Available online 13 August 2015

### Keywords:

Sikhote–Alin

Accretionary orogen

Granitoids

Juvenile crust

Zircon age

Sr–Nd–Hf isotope compositions

Cretaceous magmatism

## ABSTRACT

The Sikhote–Alin Range of the Russian Far East is an important accretionary orogen of the Western Pacific Orogenic Belt. In order to study the formation and tectonic evolution of the orogen, we performed zircon U–Pb dating, as well as geochemical and Sr–Nd–Hf isotopic analyses on 24 granitoid samples from various massifs in the Primorye and Khabarovsk regions. The zircon dating revealed that the granitoids were emplaced from 131 to 56 Ma (Cretaceous to Paleogene). In the Primorye Region, granitoids in the coastal Sikhote–Alin intruded the Cretaceous Taukha Accretionary Terrane from ca. 90 to 56 Ma, whereas those along the Central Sikhote–Alin Fault zone intruded the Jurassic Samarka Accretionary Terrane during ca. 110–75 Ma. The “oldest” monzogranite (131 Ma) was emplaced in the Lermontovka area of the NW Primorye Region. Granitoid massifs along the Central Sikhote–Alin Fault zone in the Khabarovsk Region formed from 109 to 58 Ma. Thus, the most important tectonothermal events in the Sikhote–Alin orogen took place in the Cretaceous.

Geochemical analysis indicates that most samples are I-type granitoids. They have initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios ranging from 0.7040 to 0.7083, and initial Nd isotopic ratios, expressed as  $\epsilon_{\text{Nd}}(t)$  values, from +3.0 to –6.0 (mostly 0 to –5). The data suggest that the granitoid magmas were generated by partial melting of sources with mixed lithologies, including the subducted accretionary complex ± hidden Paleozoic–Proterozoic basement rocks. Based on whole-rock Nd isotopic data, we estimated variable proportions (36–77%) of juvenile component (=mantle-derived basaltic rocks) in the generation of the granitic magmas. Furthermore, zircon Hf isotopic data ( $\epsilon_{\text{Hf}}(t) = 0$  to +15) indicate that the zircon grains crystallized from melts of mixed sources and that crustal assimilation occurred during magmatic differentiation.

The quasi-continuous magmatism in the Sikhote–Alin orogen suggests that the Paleo-Pacific plate subduction was very active in the Late Cretaceous. The apparently regular progression of granitic intrusion ages from 80 to 56 Ma in the Taukha Terrane may reflect oblique underflow of the Paleo-Pacific plate beneath the Eurasian continental margin. Subduction was not only manifested by granitic intrusion, but also by abundant silicic volcanism. The Late Cretaceous Paleo-Pacific plate motion probably changed from parallel or sub-parallel to oblique relative to the continental margin of the Sikhote–Alin, leading to the change of magmatic source region and geochemical characteristics of the derived igneous rocks. Late Cretaceous rapid sea-floor spreading at ca. 100 Ma induced highly active subduction and led to voluminous magmatism in the entire Circum-Pacific realm. Finally, the present age and isotopic study lends support to the hypothesis of geologic and tectonic correlation between Sikhote–Alin and SW Japan.

© 2015 Elsevier Ltd. All rights reserved.

## 1. Introduction

The Asian continent is a complex mosaic composed of numerous tectonic blocks of various sizes. To simplify, the eastern part

of Asia consists of four to five Precambrian cratons which are welded together by younger orogenic belts. A gigantic belt, the Altaids (Sengor et al., 1993) or Central Asian Orogenic Belt (CAOB; Jahn, 2004; Jahn et al., 2000a,b) between the Russian, Siberian and Tarim–North China cratons was formed by the successive accretion of island arcs and rifted microcontinents. The evolution of the CAOB is generally regarded to be related to the birth and death

\* Corresponding author.

E-mail address: [bmjahn@ntu.edu.tw](mailto:bmjahn@ntu.edu.tw) (B.-m. Jahn).

of the Paleo-Asian Ocean, hence the CAOAB represents the Paleo-Asian Tectonic Realm. Similarly, the second gigantic belt, the Tethysides, between the Tarim-North China and India-Arabian cratons, was also formed by stacking of arc and micro-continental terranes, with a final stage of continental collision that produced the Himalayan Range and elevated the Tibetan Plateau. Thus, the Tethysides belongs to the Tethyan Tectonic Realm. The orogenic belts the eastern margin of Asia comprise Mesozoic and younger continental and oceanic arcs formed by subduction of the Pacific Plate and its marginal seas. Rifted microcontinental blocks make up a small component. Thus, the third group of orogenic belts constitute the Pacific Tectonic Realm. Sengor and Natal'in (1996) coined this tectonic realm as the "Nipponides".

Through extensive field investigations, zircon age dating and Nd–Sr–Hf isotopic tracer studies in the last two decades, the CAOAB is renowned for massive generation of juvenile continental crust (e.g., Sengor and Natal'in, 1996; Jahn, 2004; Jahn et al., 2000a,b). Isotopic studies on the crustal rocks of the Tethysides are comparatively rare; however, the available data and on-going research of S.L. Chung and co-workers have indicated that a significant proportion of these crustal rocks are also of juvenile characteristics (Chu et al., 2006; Lin et al., 2013). Though the orogenic belts of the Pacific Realm are known to comprise mainly accretionary orogens, the true crustal characteristics and evolution remain much debated. For example, the Japanese Islands have long been considered as the classic example of an accretionary orogen in which voluminous granitoids was transferred from the mantle to the crust via melting of subducted slabs (Isozaki, 1996, 1997; Maruyama, 1997; Maruyama et al., 1997). This model has not been supported by the available Nd–Sr isotopic data for SW Japan (Jahn, 2010), but probably is true for NE Japan and Hokkaido (Jahn et al., 2014).

The Sikhote-Alin Orogenic Belt of the Russian Far East is a part of the Pacific Tectonic Realm. Its geological and tectonic evolution has been correlated with that of SW Japan (Ishiwatari and Tsujimori, 2003; Khanchuk, 2001; Sato et al., 2004, 2006). In this work we carried out a comprehensive investigation on the

emplacement ages and geochemical-isotopic characteristics of the granitoids from the Sikhote-Alin Belt. These data are used to discuss the granitoid petrogenesis and implications for the crustal and tectonic evolution in the Sikhote-Alin accretionary orogen.

## 2. Geological setting of the Sikhote-Alin Orogenic Belt

The Sikhote-Alin Orogenic Belt is composed of Mesozoic tectonostratigraphic terranes lying to the east of the late-Precambrian crustal blocks – Bureya, Jiamusi and Khanka (Fig. 1). Structural nappes, ophiolite mélanges, and chaotic olistostromes occur widely in the belt (Geology of the USSR, 1971; Melnikov and Golozubov, 1980; Khanchuk et al., 1988; Zonenshain et al., 1990a,b). Parfenov (1984) was the first to interpret the Sikhote-Alin Belt as an accretionary orogen, and this interpretation was further elaborated by Natal'in (1991).

The Pre-Mesozoic tectonic units include (1) the Neoproterozoic Bureya, Jiamusi and Khanka Blocks (Wilde, in press), and (2) the Paleozoic Dzhagdy-Kerbinsky, Galamsky and Laelin-Grodekovo terranes (Fig. 1). The Laelin-Grodekovo terrane is the southern extension of the Zhangguangcai Range of NE China. The Khanka Block consists of Precambrian continental basement overlain by thick Paleozoic continental margin deposits, including Cambrian calcareous sediments and post-Silurian non-marine strata. It is probably part of a larger continental segment (=Amuria superterrane or microcontinent) that includes the Bureya and Jiamusi blocks to the north (Khanchuk, 2001; Khanchuk et al., 1996). A basic granulite (two-pyroxene-amphibole schist;  $\text{SiO}_2 = 47\%$ ,  $\text{Al}_2\text{O}_3 = 17.1\%$ ,  $\text{MgO} = 8.6\%$ ) from the Khanka Block near the Khanka Lake has been dated using SHRIMP analysis on zircon grains (Khanchuk et al., 2010). Type 1 zircon grains (inner cores) yielded  $757 \pm 4$  Ma, and type-2 zircon grains (structureless and rims of zoned zircons) gave  $507 \pm 3$  Ma. The age of 757 Ma probably represents the formation time of the protolith (basaltic) and 507 Ma the time of the granulite facies metamorphism. In NE China, the pre-Mesozoic basement (Jiamusi Block) is composed of the Mashan

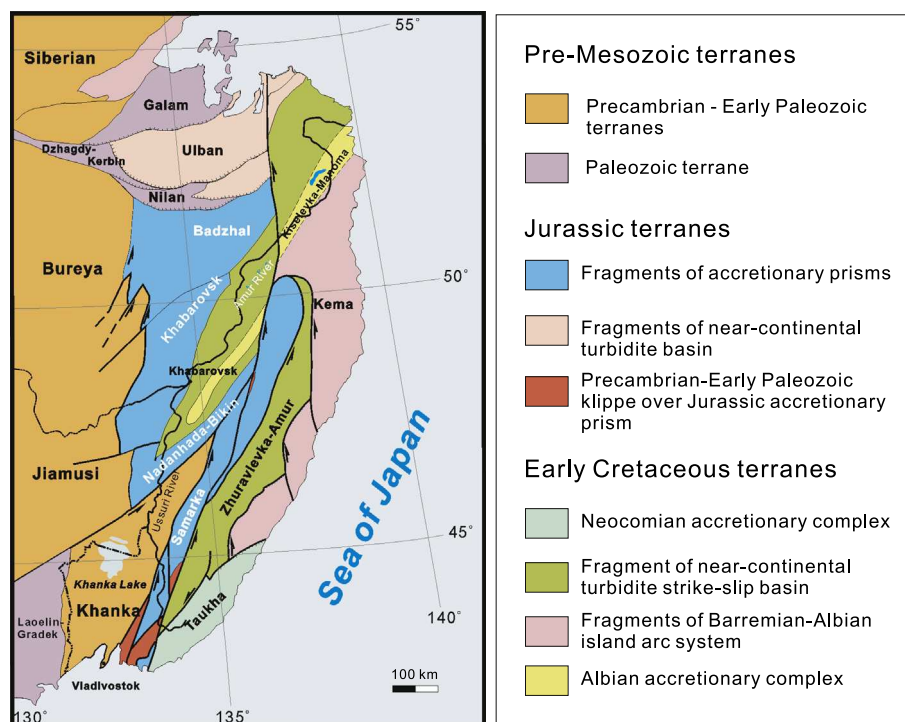


Fig. 1. Principal tectonostratigraphic terranes in the Sikhote-Alin Orogenic Belt, Russian Far East (after Golozubov, 2006).

and Heilongjiang Complexes and Permian granites (Wilde et al., 2003; Wilde, in press; Wu et al., 2011; Zhou et al., 2010; Zhou and Wilde, 2013). The high-grade metamorphic rocks of the Khanka Block are comparable to those of the Mashan Complex, whose metamorphic ages have been well determined at ca. 500 Ma (Wilde et al., 1997, 2000, 2003; Wilde, in press). In fact, a very important work in NE China has been the recognition of a huge khondalite belt along the China-Russia border. The khondalitic metasedimentary rocks and associated igneous rocks were metamorphosed to granulite facies at ca. 500 Ma. This event is registered in the northern parts of the Erguna and Xing'an Blocks (Zhou et al., 2011) as well as in the Jiamusi and Khanka Blocks (Wilde et al., 2000, 2003, 2010; Wilde, in press).

As shown in Fig. 1, the Sikhote-Alin Orogenic Belt proper is constituted by several Mesozoic terranes. The Jurassic terranes comprise four accretionary prisms (=Samarka, Nadanhada-Bikin, Khabarovsk and Badzhal terranes), a turbidite basin (=the Ulban terrane) and a Precambrian-Early Paleozoic klippe (=the Sergeevka terrane) overlying accretionary complexes. The Early Cretaceous terranes include: (1) the Taukha Terrane, an accretionary complex; (2) the Zhuravlevka Terrane, a fragment of near-continental turbidite basin; (3) the Kema Terrane, mainly composed of island arc assemblages; and (4) the Kiselevka-Manoma Terrane, another accretionary complex to the north and west of the Kema terrane. All the Mesozoic terranes are intruded by Late Cretaceous to Eocene granitic rocks or covered by vast contemporaneous volcanic and volcanisedimentary rocks (Kemkin and Khanchuk, 1994; Kojima et al., 2000).

The Jurassic Samarka accretionary prism consists mainly of terrigenous sediments (sandstones and siltstones). Fragments of oceanic basalts, mainly OIB, are often associated with clastic sediments. Blocks of limestone and chert also occur. The Cretaceous Zhuravlevka Terrane is a vast expanse of turbidite that mainly occurs to the east of the Central Sikhote-Alin Fault (Fig. 1; Golozoubov and Khanchuk, 1996). Kojima (1989) considered the Samarka Terrane to be equivalent to the Mino-Tamba belt in SW Japan and the Nadanhada Terrane in China, and they were fragments of the same Jurassic accretionary complex.

The Kema Terrane of eastern Sikhote-Alin is mainly composed of flysch deposits and volcanisedimentary sequences; the volcanic rocks are basalt, andesite and rhyolite of Cretaceous to Paleocene ages (e.g., Grebennikov and Popov, 2014). The youngest volcanic rocks are the Miocene-Pliocene plateau basalt that occurs in the northern Kema Terrane, in the Khabarovsk Region. Several researchers considered the Kema Terrane to be of island arc or back-arc origin (e.g., Malinovsky et al., 2006, 2008; Golozoubov, 2006; Grebennikov and Popov, 2014).

The Taukha Terrane in the southeastern part of the Primorye Region is mainly a Cretaceous accretionary complex, intruded by numerous granitoid plutons and stocks (e.g., Kemkin and Taketani, 2008). The nature of the basement is largely unknown, but some workers consider it to be composed predominantly of tholeiitic basalts, similar to that of the Kema Terrane.

A distinctive feature of the Sikhote-Alin Belt is that it is broken by a system of sinistral strike-slip faults, the most striking being the Central Sikhote-Alin Fault (Figs. 1 and 2) with a displacement of ca. 200 km. The Fault was most active during the Early Cretaceous, and the activity was terminated in the Late Cretaceous (Utkin, 1980).

Mesozoic-Cenozoic magmatic activity in Sikhote-Alin is mainly manifested in the Central Sikhote-Alin magmatic belt and the East Sikhote-Alin Volcanic-Plutonic Belt (ESAVPB). The "Central Sikhote-Alin magmatic belt" includes numerous granitoid plutons in the Zhuravlevka, Samarka and Nadanhada terranes. In addition, small volumes of basalt and andesite also occur (Simanenkov et al., 2002). The granitoid plutons and volcanic rocks were mostly

emplaced during the Early Cretaceous and rarely in the Late Cretaceous to early Cenozoic (Sakhno, 2001; Khanchuk, 2006).

The East Sikhote-Alin Volcanic-Plutonic Belt (ESAVPB) comprises a large volume of volcanic rocks overlying the Kema and Taukha terranes. These volcanic rocks, including basalt, andesite and rhyolite, were emplaced in the Late Cretaceous to Middle Paleogene. According to Khanchuk (2001) and Khanchuk and Kemkin (2003), during the period from Cenomanian (ca. 95 Ma) to Maestrichtian (70–65 Ma), the tectonic regime of the ESAVPB was of a supra-subduction nature, but it changed to a transform or strike-slip setting in the Paleocene-Eocene. Volcanic activity was accompanied by the emplacement of numerous granitoid plutons in the same areas.

A correlation between the tectonic units of Sikhote-Alin and the Japanese Islands has been proposed by Kojima (1989) and Khanchuk (2001), and further supported by Ishiwatari and Tsujimori (2003) based on their study of the distribution and emplacement of the ophiolite-blueschist complexes. Because the correlation will be further discussed in the last section, a brief description of the main features of SW Japan is given in the Appendix A.

### 3. Occurrences of granitic rocks in Sikhote-Alin and description of sampling localities

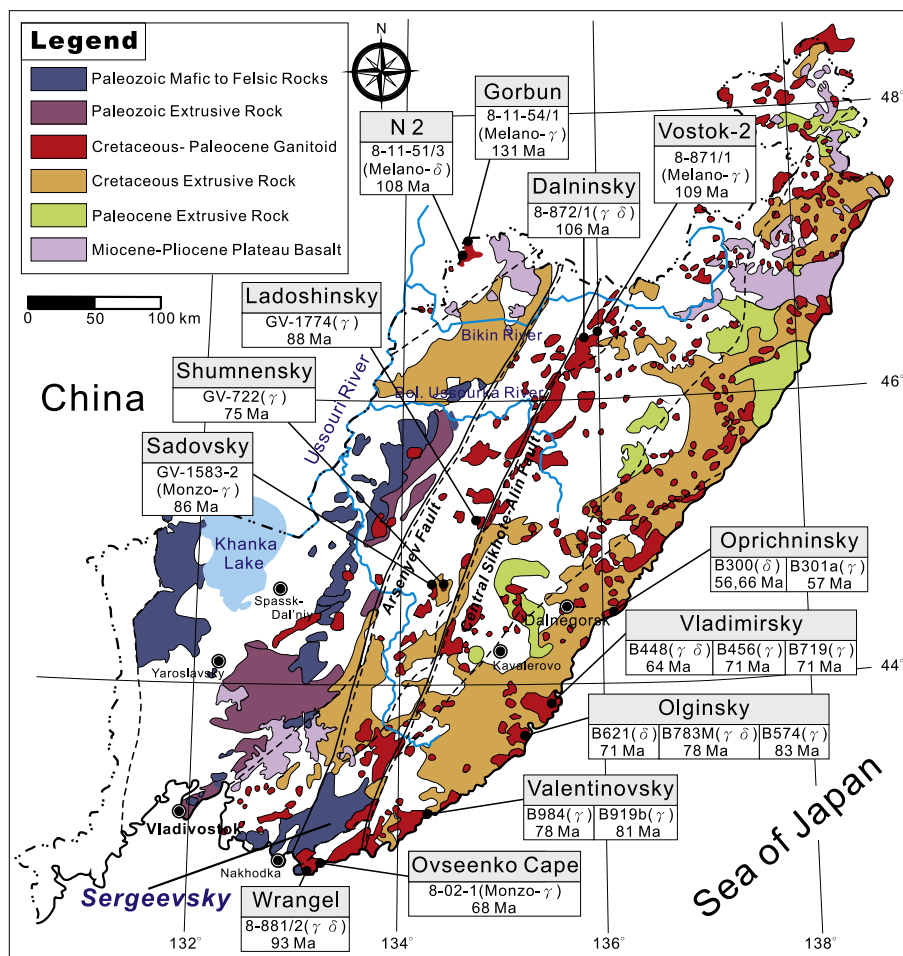
Fig. 2 shows the distribution of granitoid intrusions in the Primorye region. The granitoid samples were collected from four general areas: (1) the East Sikhote-Alin Volcanic-Plutonic Belt (ESAVPB), along the Japan Sea and south of 45°N (Valui samples; from the Oprichnensky, Vladimirsky, Olginsky and Valentinovsky massifs); (2) along the Central Sikhote-Alin Fault zone (Gonevchuk samples from the Shuminsky, Berezovsky, Sadovsky and Ladoshinsky massifs; Kruk samples from the Dalnensky area including the Dalnensky and Vostok-2 massifs; and also from the southernmost tip of Sikhote-Alin: the Ovseenko Cape and Vrangell massifs of the Uspensky area); (3) the Lermontovka area of the NW Primorye Region (Kruk samples, Gorbun and Chaplievsky massifs), and (4) to the north of Fig. 2 map area, in the Khabarovsk Region (N49°20' to 50°35'), including the Chalba and West-Anuy massifs and small unnamed stocks (Gonevchuk and Kruk samples). A description of the four areas is given below. This is done as a brief review for the international reader as the original Russian literature is hard to access or difficult to understand for non-Russian reader.

#### 3.1. The East Sikhote-Alin Volcanic-Plutonic Belt (ESAVPB)

According to Valui (2004, 2014) and Valui et al. (2008), the four plutons of the ESAVPB (Oprichninsky, Vladimirsky, Olginsky, and Valentinovsky) are mainly composed of diorite, granodiorite and granite. The plutons of the western part of the ESAVPB, within the Dalnegorsk district, are mono-phase granitic porphyry of the ilmenite series. K–Ar ages of 83, 69–72, and 60–63 Ma were obtained for the Dalnegorsk gabbro-diorites, granodiorites, and granites, respectively (Valui et al., 2008). Many plutons are accompanied by important mineralization, for example, borosilicate and base metal deposits in the Dalnegorsk district.

The granitoids of the coastal ESAVPB show various stages of differentiation and levels of emplacement (Valui et al., 2008). The lithological and petrographic characteristics of the plutons may be represented by two massifs – the Olginsky and Valentinovsky massifs.

The Olginsky massif is multi-phased, composed of diorite, granodiorite and coarse-grained granite. As a whole, coarse-grained



**Fig. 2.** Distribution of granitoids and extrusive (volcanic) rocks in the Primorye region, Sikhote-Alin (Khanchuk, 2006). The sampling localities and new zircon age data are also shown. At each sample locality, the sample number, rock-type and zircon age are given in a rectangular box. Symbols:  $\gamma$  = granite,  $\delta$  = diorite,  $\gamma\delta$  = granodiorite. The Sergeevsky Massif or Complex, located in the southern part of Sikhote-Alin and near Vladivostok, is a tectonic “klippe”, composed mainly of early Paleozoic metabasic to metagranitoid rocks.

granite is dominant, but diorite is the earliest phase. Granitic bodies are intruded by stocks of miarolitic granite and aplitic dikes. Diorite is generally massive, grey-green and fine-to-medium-grained. Granodiorite crops out only in the Manevsky Cape area. It is cut by granite in many places. Granite is generally massive, porphyritic and coarse-grained. Three samples from the Olginsky massif were selected for the present study – a diorite (B-621), a granodiorite (B-783M), and a granite (B-574).

The **Valentinovsky massif** in southern Sikhote-Alin extends along the Japan Sea coast for more than 50 km, with a total exposure of about 200 km<sup>2</sup>. The massif shows a complicated structure and comprises diorite, quartz diorite, granodiorite, granite, aplite and granite porphyry. As in the Olginsky massif, the earliest intrusive phase is diorite, which occurs as a small stock between the Bodisko and Tumannyi capes. The northern part of the massif is composed of uniform granodiorite. In the central part of the massif, a large block (0.5 × 2.5 km) of sedimentary rock is found in granodiorite. K–Ar dating suggests that the Valentinovsky massif was emplaced during a prolonged period from late Cretaceous (ca. 95 Ma; diorites) to Eocene–Oligocene (alkaline granites and granite-porphyrates of the Tasovaya Bay) (Valui, 2014). A granodiorite (B919-b) and a granite (B984) samples were chosen for the present study. In terms of mineralization, the intrusions of the coastal region host only very minor magnetite–skarn and molybdenum deposits.

### 3.2. The Central Sikhote-Alin Fault zone

Numerous granitoid intrusions were emplaced along the Central Sikhote-Alin Fault zone. Large granitoid massifs, such as Dalnensky and Biserny, occur in the **Dalnensky area** in the northern Primorye Region (Fig. 2). The granitoid intrusions are accompanied by small stocks and dikes of basic to silicic compositions (Soloviev and Krivoshchekov, 2011). The Dalnensky monzonite–granodiorite pluton is associated with the celebrated tungsten deposit “Vostok-2”. The granitoids in the Dalnensky area intruded into the Jurassic terrigenous siliceous-volcanic strata of the Samarka Terrane and early Paleozoic amphibolite of the **Sergeevsky** metamorphic complex.

The principal rock-types of the granitoid massifs are medium-grained biotite- and biotite-hornblende granodiorite and melanocratic granite. In the Dalnensky massif, amphibole-biotite ( $\pm$  pyroxene) diorite, quartz diorite and monzodiorite form the early phase. The granitoids were intruded by dikes and small bodies of biotite granite porphyry, leucocratic granite and aplite. **Samples 8-871/1** (Vostok-2 stock) and **8-872/1** (Dalnensky massif) are representative of the granitoids from the Dalnensky area.

In the middle segment of the Central Sikhote-Alin Fault zone, or in the geographic center of the Primorye Region (Fig. 2), granitoid samples were collected from four massifs – from north to south, Ladoshinsky (granite sample **GV-1774**), Sadovsky (granite sample

**GV-1583-2**, Shumnensky (granite sample **GV-722**) and Berezovsky (monzogranite sample **GV-1401**). The first two massifs intruded into clastic and volcanoclastic rocks of the Samarka terrane of the Jurassic accretionary prism; whereas the last two massifs intruded into the clastic sedimentary rocks of the Zhuravlevka turbidite basin.

The **Ladoshinsky** massif is characterized by medium-grained biotite and biotite-hornblende granites. These granites are often cut by small leucocratic granite porphyry and aplite, and are associated with minor gabbro and diorite bodies. They are also accompanied by tungsten mineralization, such as the Skrytoye deposit (Soloviev, 1995).

The **Sadovsky** massif is a large granite intrusion (>100 km<sup>2</sup>) with zonal structure. The central part of the massif is composed of medium- and coarse-grained biotite granite, often with schlieren texture and thin veins of muscovite pegmatite. The marginal part is characterized by fine-grained porphyritic granite. In addition, small bodies of melanocratic granite, granodiorite, and alkali gabbro are also associated with the Sadovsky massif.

The **Shumnensky** and **Berezovsky** massifs occur in the Kavalerovo magmatic area. The area has more than 10 massifs of different compositions and emplacement ages, many of them are accompanied by tin (Sn) mineralization. The rock-types include gabbro (Ararat massif), monzodiorite, syenite and monzogranite (Berezovsky massif), granodiorite and plagiogranite (Porubsky massif), granite and leucogranite (Shumnensky) (Rub et al., 1982; Sakhno et al., 2011; Gonevchuk et al., 2011; Kruk et al., 2014a). The Shumnensky massif is composed of medium-grained porphyritic biotite granite, and it was dated at 85–70 Ma by the K–Ar method on biotite (Gonevchuk, 2002). The Berezovsky massif was dated at 100–85 Ma by the K–Ar and Rb–Sr methods (Gonevchuk, 2002; Gonevchuk et al., 2011).

The **Uspensky area** is located in the southernmost part of Sikhote-Alin (Fig. 2). To the east of this area is the southern part of the ESAVPB and to the west the Khanka block. The area is bounded by two major faults – the Central Sikhote-Alin Fault in the east and the Arsenyev Fault in the west. It includes the Early Cretaceous Uspensky and Wrangel Massifs and Late Cretaceous Ovseenko Cape Massif and several small intrusive bodies. The granitoids intruded the Jurassic terrigenous siliceous volcanoclastic deposits of the Samarka Terrane and Early Paleozoic amphibolites of the **Sergeevsky** complex. Together with the overlying Permian volcanosedimentary sequences, the **Sergeevsky** complex forms a tectonic allochthon (klippe). The granitoid massifs were dated by the Rb–Sr and K–Ar methods at 112–98 Ma (Krimskii et al., 1998; Gvozdev, 2010). Metamorphic ages of metagabbro, metadiorite and amphibolites from the Sergeevsky complex have recently been dated at 480–490 Ma at National Taiwan University (zircon U–Pb; unpublished data).

The **Uspensky Massif** is a linear body of ca. 40 km long and 10 km wide. The western part of the massif is composed of coarse-grained garnet-bearing biotite and two-mica leucocratic granites; whereas the eastern and central parts are dominated by medium-grained biotite ( $\pm$ amphibole) granodiorite and melanocratic granite. Khanchuk et al. (2008) published two zircon U–Pb ages (103  $\pm$  2 and 99  $\pm$  2 Ma) for the Uspensky granitoids. Recently, Nd isotopic compositions were determined for a garnet-bearing leucogranite ( $\varepsilon_{\text{Nd}}(t) = -3.8$ ) by Moskalenko et al. (2011) and for biotite-amphibole granodiorites and granites ( $-0.7$  to  $-2.4$ ) by Kruk et al. (2014a).

The **Wrangel Massif** (about 50 km<sup>2</sup>) is mostly composed of medium-grained equigranular biotite-hornblende granodiorite and weakly porphyritic biotite granite. Mafic enclaves are frequently found in the granitoids. In places the massif was cut by dikes of granite porphyry and aplites.

The **Ovseenko Cape massif** is an isometric body with an exposure area of about 35 km<sup>2</sup>. The massif is homogeneous and composed of coarse-grained biotite granites. Two granitoid samples

from the Uspensky area were subject to analysis in this work – **sample 8-881/1** represents the Wrangel massif and **sample 8-02-1**, the Ovseenko Cape massif.

### 3.3. The Lermontovka area of the NW Primorye Region

In the **Lermontovka area** several Cretaceous granitoid massifs intruded and metamorphosed the Late Jurassic clastic and volcanoclastic rocks of the eastern part of the **Nadanhada Terrane**. The massifs also intruded sub-latitude mafic dikes (pyroxenite, gabbro and diorite). The granitoids belong to two associations. The first comprises large massifs (Shivka, Gorbun and Olimpiada) and small stocks, with one massif connected with the Lermontovka tungsten deposit. The predominant rock types of the massifs are coarse- to medium-grained biotite or two-mica cordierite-bearing granodiorites and melanocratic granites. In places, they are intruded by fine-grained leucogranitic dikes. **Sample 8-11-54/1** is a melanocratic monzogranite from the **Gorbun massif**.

The second association is represented by the Chaplievsky massif and several small satellite bodies. The association comprises fine-grained pyroxene-amphibole monzodiorite and quartz monzodiorite. Mafic enclaves (fine-grained monzogabbro) and fine-grained biotite-amphibole monzogranite veins also occur in the monzodiorites. **Sample 8-11-51/3** is representative of the monzodiorite.

### 3.4. Khabarovsk Region (N49°20' to 50°35')

A number of granitoid massifs of Early Cretaceous and Paleogene age occur in the basin of the Anuy River, a tributary of the Amur River. The largest massif is the **Gobilly intrusion** emplaced at 105  $\pm$  2 Ma (Natal'in et al., 1994). The granitoids intruded into deformed Jurassic strata of the Samarka Terrane and metamorphic rocks of the Anuy Dome, which is a Mesozoic core complex (Kruk et al., 2014b). Contact metamorphism produced aureoles of biotite- and cordierite-bearing hornfels up to 1 km wide.

Large intrusions (up to 100 km<sup>2</sup>) of Early Cretaceous granitoids occur in sub-meridional to NE orientation. They consist mainly of coarse-grained biotite granodiorite or porphyritic melanocratic granite. Dikes of fine-grained granite and aplite occur but rarely. A monzogranite sample (**AN-2-11**) was chosen for the present study.

Granitoids of Paleogene age usually make up small massifs or stocks (<15 km<sup>2</sup>). They are composed of medium- and fine-grained biotite and biotite-amphibole leucocratic granites. A leucocratic granite sample (**AN-3-11**) was selected for the present analysis.

Two more granitoid samples came from two complexes of the **Komsomolsk** magmatic area – a monzogranite of the **Silinka complex** ( $\Psi\Gamma$ -332) and a porphyritic granite of the **Chalba complex** ( $\Psi\Gamma$ -410). The granitoids intruded into the terrigenous rocks of the **Badzal Terrane** of the Jurassic accretionary prism.

The **Silinka complex** is composed of trachyandesite and a suite of intrusive rocks ranging from gabbro to leucogranite, with a predominance of quartz diorite and granodiorite. Quartz diorite and granodiorite often occur as small intrusive bodies and dikes. The Silinka complex was emplaced from 102 to 80 Ma based on the K–Ar and Rb–Sr geochronology (Gonevchuk, 2002; Gonevchuk et al., 2011).

The **Chalba complex** is characterized by granitic rocks (>80%) with coarse-grained biotite granite in the central part and biotite-hornblende-bearing granite porphyry in the border. K–Ar dating suggests that the complex was formed during 90–92 Ma.

A summary of rock types, intrusive age information, sample localities, pluton names, principal geological features, and mineral assemblages for all the granitoid samples analyzed in this work is presented in **Table 1**.

**Table 1**  
Brief description of the analyzed granitoid samples from Sikhote-Alin.

Sample No.	Rock type (original appellation in parentheses)	Literature age information (Ma)	Sample locality (Coordinates)	Name of Pluton or intrusive body	Geological and structural features; associated rocks	Petrographic texture	Mineral assemblage or characteristic phases <sup>a</sup>
B-300	Quartz monzodiorite (Diorite)	81 (K–Ar)	E 136°10'13", N 44°30'04"	Oprichnensky (central. Part.)	Located in the central part of pluton	Massive, medium-to-coarse-grained	Pl 64%, Hbl 9%, Px 1%, Bt 9%, Qz 10%, Kfs 5%. Accessory (2%): Mag, Ilm, Ap, Zrn, cassiterite, fergusonite
B-301a (=B-257)	Alkali feldspar granite (Granite)	57.5 (K–Ar)	E 136°07'29", N 44°29'17"	Oprichnensky (central. Part.)	Located in the south-central part of pluton	Coarse-grained, equigranular	Pl 27%, Qz 32%, Kfs 35%, Bt 5%. Accessory (1%): Mag, Ap, Zrn, Au, fergusonite
B-448 (=B433)	Granodiorite	68 (K–Ar)	E 135°28'01", N 43°55'36"	Vladimirsky	Located in the northern part of pluton	Medium-to-fine grained, heterogeneous	Pl 46%, Qz 21%, Kfs 18%, Bt 8%, Hbl 5%. Accessory (2%): Mag, Ap, Zrn, Aln
B-456 (=B-494)	Granodiorite (Granite)	68 (K–Ar)	E 135°28'10", N 43°55'02"	Vladimirsky	Located in the middle of the western coast of the Vladimir Bay	Coarse-grained, equigranular	Pl 28%, Qz 36%, Kfs 33%, Bt (2%). Accessory (1%): Mag, Ap, Zrn, Aln
B-719 (=B-720)	Granite	70 (K–Ar)	E 135°27'57", N 43°48'35"	Vladimirsky	Located in the southern part of pluton	Coarse-grained, equigranular	Pl 30%, Qz 36%, Kfs 30%, Bt 2%, Hbl 1%. Accessory (1%): Mag, Ap, Zrn, Aln
B-574	Granite	59 (K–Ar)	E 135°13'17", N 43°38'36"	Olginsky	Located in the southern part of pluton	Coarse-grained, equigranular	Pl 33%, Kfs 30%, Qz 32%, Bt 3%, Hbl 1%. Accessory (1%): Mag, Ap, Zrn, Aln, fergusonite, cassiterite
B-617a, B-621 (=B611)	Granodiorite (Diorite)		E 135°13'35", N 43°40'14"	Olginsky	Located in the central part of pluton	Fine-to-medium-grained, equigranular	Pl 60%, Px 15%, Hbl 10%, Qz 10%, Kfs 2%. Accessory (3%): Mag, Ilm, Ap, Zrn ± Aln ± cassiterite
B-783M (=B-781)	Granite (Granodiorite)	60, 65 (K–Ar)	E 135°13'03", N 43°37'59"	Olginsky	Located in the southern part of pluton	Medium-grained, heterogeneous	Pl 46%, Qz 26%, Kfs 20%, Hbl 4%, Bt 3%. Accessory (1%): Mag, Ap, Zrn, Aln, cassiterite
B-919b (=B909A)	Granite (Granodiorite)	69, 62 (K–Ar)	E 134°21'21", N 43°07'09"	Valentinovsky	Located in northern part of pluton	Coarse-to-medium-grained, equigranular	Pl 36%, Qz 34%, Kfs 12%, Hbl 3%, Bt 14%. Accessory (1%): Mag, Ap, Zrn, Aln, cassiterite, fergusonite
B-984 (=B-995)	Granite	57 (K–Ar)	E 134°10'01", N 43°01'49"	Valentinovsky	Located in the southern part of pluton	Coarse-grained, equigranular	Pl 23%, Qz 40%, Kfs 27%, Hbl 3%, Bt 6%. Accessory (1%): Mag, Ap, Zrn, fergusonite
GV-722	Granite	76 ± 2 (K–Ar)	E 134°20', N 44°15'	Shumny	Located within the Central Sikhote-Alin fault zone. Leucocratic granites with biotite and rarely hornblende.	Coarse-grained	Qz 40%, Kfs 35%, Pl 20%, Bt 4%, Hbl ≤ 1%
GV-1401	Granite (Monzogranite)	102–105 (K–Ar)	E 134°43', N 44°25'	Berezovsky	The intrusive body comprises gabbro and younger monzogranite	Coarse-grained	Qz 35%, Pl 30%, Kfs 25%, Bt 6%, Px 2%, Hb 2%
GV1583-2	Granite (Monzogranite)	90 ± 2 (K–Ar)	E. 134°15', N 44°33'	Bisersky complex, Sadovy intrusive body	Biotite granite prevails in the Sadovy body. Small pegmatite or leucogranite dikes are also present.	Coarse-grained	Qz 45%, Kfs 25%, Pl 25%, Bt 4%, Hbl ≤ 1%
GV1774	Granite	87 ± 2 (K–Ar)	E 134°50', N 45°10'	Ladoshin intrusive body	Located in the central part of the Malinovka area. Early granite stock (phase I) is intruded by biotite-muscovite granite, which is cut by dikes of fine-grained biotite granites (phase II).	Coarse-grained	Qz 40%, Kfs 30%, Pl 25%, Bt 4%, Hbl ≤ 1%
QG-332	Granite (Monzogranite)	94 ± 2 (K–Ar)	E 136°00', N 50°35'	Silinka Complex	Granite forms small intrusive body. Sharp contact with granite. K–Ar and Rb–Sr ages = 102–80 Ma		Qz 35%, Kfs 30%, Pl 25%, Bt 5%, Px 3%, Hbl 2%
QG-410	Granite	90 ± 2 (K–Ar)	E 136°10', N 50°35'	Chalba Complex	It occurs in the contact zone of the Chalba intrusive body (K–Ar age = 90–92 Ma).	Porphyritic	Qz 40%, Kfs 30%, Pl 25%, Bt 4%, Hbl 1%
8-11-54/1	Granite (Monzogranite)	120–127 (Rb–Sr)	E 134°35'24"; N 47°02'05"	Gorbun	It occurs in the northern part of massif, about 250 m from the border; melanocratic	Coarse-grained, equigranular	Qz 25%, Pl 28%, Kfs 35%, Bt 12%
8-11-51/3	Quartz monzodiorite (Monzodiorite)	K2 (?)	E 134°30'23"; N 47°02'53"	unnamed	Southern part of the massif, about 50 m from the contact.	Fine-grained, equigranular	Pl 45%, Kfs 15%, Qz 5%, Cpx 2–3%, Hbl 25%, Bt 5%

Table 1 (continued)

Sample No.	Rock type (original appellation in parentheses)	Literature age information (Ma)	Sample locality (Coordinates)	Name of Pluton or intrusive body	Geological and structural features; associated rocks	Petrographic texture	Mineral assemblage or characteristic phases <sup>a</sup>
8-871-1	Granodiorite (Melanogranite)	95–100 (Rb–Sr)	E 135°53'48"; N 46°30'03"	Vostok-II stock	Central part of the stock; melanocratic	Medium-grained, equigranular	Pl 45%, Kfs 20%, Qz 22%, Hbl 4%, Bt 9%
8-872-1	Granodiorite	100–102 (Rb–Sr)	E 135°49'38"; N 46°24'13"	Dalnensky	Central part of the massif; melanocratic	Medium-grained, equigranular	Pl 45%, Kfs 15%, Qz 5%, Hbl 9%, Bt 6%
8-02-01	Alkali feldspar granite (Monzogranite)	75 ± 3 (Ar/Ar)	E 133°02'18"; N 42°45'43"	Ovseenko Cape	Northern part of the massif, about 100 m from the border; leucocratic	Medium-grained, equigranular	Qz 50%, Pl 20%, Kfs 25%, Bt 5%
8-881-2	Granodiorite	91 ± 1 (Ar/Ar)	E 133°02'18"; N 42°41'04"	Wrangel	Central part of the massif; melanocratic	Medium-grained, equigranular	Pl 32%, Kfs 33%, Qz 25%, Bt 8–9%, Hbl 1–2%
AN-2-11	Granite (Melanogranite)	K1 (?)	E 137°48'11"; N 49°20'48"	Unnamed	Central part of the massif; melanocratic	Coarse-grained, porphyritic	Qz 25%, Pl 30%, Kfs 35%, Bt 10%
AN-3-11	Alkali feldspar granite (Leucogranite)	K2 (?)	E 137°37'26"; N 49°20'33"	Unnamed	Central part of the massif; leucocratic	Fine-grained, equigranular	Qz 45%, Pl 20%, Kfs 30%, Bt 5%

<sup>a</sup> Mineral name abbreviations (Whitney and Evans, 2010): Qz = quartz, Pl = plagioclase, Kfs = K-feldspar, Hbl = hornblende, Px = pyroxene, Cpx = clinopyroxene, Bt = biotite, Mag = magnetite, Ilm = ilmenite, Aln = allinite, Zrn = zircon, Ap = apatite.

## 4. Analytical methods

### 4.1. Zircon U–Pb geochronology and Lu–Hf isotope analysis

Zircon grains were separated from granitic samples using conventional techniques and final purification by hand-picking. They were mounted in epoxy resin bed and half-sectioned after the resin bed had dried. Cathodoluminescence (CL) images were taken at the Beijing SHRIMP Center, Chinese Academy of Geological Sciences, for examination of zircon internal structures and for selection of analytical spots. Zircon U–Pb isotopic analyses were performed using a New Wave UP213 laser ablation system combined with an Agilent 7500s quadrupole ICPMS (inductively coupled plasma mass spectrometer) at the Department of Geosciences, National Taiwan University (NTU-Geosciences). The LA-ICP-MS operating conditions and analytical procedures were the same as those reported in Chiu et al. (2009). Due to the small radiogenic growth of <sup>207</sup>Pb in the present zircon samples, only the weighted means of pooled <sup>206</sup>Pb/<sup>238</sup>U ages are given to represent the ages of the zircon crystallization.

In-situ Hf isotopic analysis of zircon was performed using a multi-collector ICP-MS (Neptune), also at NTU-Geosciences. A New Wave UP193FX laser ablation system was used for spot vaporization. The Hf isotope analysis was done on the same zircon grains that were previously analyzed for U–Pb dating. Ablation time was about 26 s for each measurement with a beam diameter of ca. 40 μm, an 8 Hz repetition rate, and energy of 100 mJ. A detailed description of the analytical techniques can be found in Wu et al. (2006) and Xie et al. (2008). Harvard reference zircon 91500 and Australian Mud Tank carbonatite zircon were used as secondary standards for data quality assessment. During the data acquisition, <sup>176</sup>Hf/<sup>177</sup>Hf ratios of 0.282293 ± 22 (2σ, n = 16) for Harvard 91500 and 0.282511 ± 25 (2σ, n = 39) for the Mud Tank standards were obtained. These values are in good agreement with those obtained by solution and ICP-MS methods reported in the literature (Goolaerts et al., 2004; Woodhead et al., 2004; Woodhead and Hergt, 2005; Griffin et al., 2006; Wu et al., 2006).

### 4.2. Major and trace element analyses

Samples were crushed in a stainless steel jaw crusher and then powdered in an agate mill. Major element contents were determined by X-ray fluorescence (XRF) spectroscopy on fused glass beads, using a Rigaku RIX-2000 spectrometer. For trace elements analysis, about 200 mg of powdered sample was dissolved in a mixture of HF and HNO<sub>3</sub> (2:1) in a screw-top Savillex Teflon beaker for 5–7 days at ~100 °C. This was followed by evaporation to dryness, refluxing in 6 N HCl and drying twice, and finally redissolution in 1 N HCl. The procedure was repeated until complete dissolution was achieved. The final solution was split in two parts; a small aliquot (about 10–20%) was used for subsequent trace element analysis by ICP-MS, and the rest for further chemical separation of Sr and Nd for isotopic analysis.

Trace element analysis was performed using an Agilent 7500s at NTU-Geosciences. The standard reference materials used for trace element analyses are AGV-2, BCR-2, BHVO-2, BIR9-1 and DNC-1. The details of analytical procedures may be found in Lin et al. (2012). Analytical errors are 0.5–3% for major elements and 1–10% for trace elements, depending on the concentrations.

### 4.3. Whole-rock Sr–Nd isotopic analyses

For Sr–Nd isotopic analysis, the chemical preparation and mass analysis were performed at Institute of Earth Sciences (IES), Academia Sinica, Taipei. Approximately 150–175 mg of rock powder was

dissolved using a HF-HNO<sub>3</sub> (2:1) mixture in a screw-top Teflon beaker for 5–7 days at ~100 °C. The same procedure was followed by evaporation to dryness, refluxing in 6 N HCl and drying twice, and then re-dissolution in 1 N HCl. The procedure was repeated until complete dissolution. The sample solution was split into two portions, a small portion (ca. 20%) for trace element analysis and the rest for further chemical separation of Sr and Nd using the conventional ion exchange technique. Sr and rare-earth elements (REEs) were separated in polyethylene columns with a 2.5 ml resin bed of AG 50W-X8, 100–200 mesh. Neodymium was separated from other REEs using 1 ml polyethylene columns packed with Eichrom Ln resin (Ln-B25-A) as a cation exchange medium. Sr and Nd isotope ratios were measured at IES using a Finnigan MAT 262 and a TRITON mass spectrometer, respectively. For the isotope measurement, Sr was loaded on a single Ta filament with H<sub>3</sub>PO<sub>4</sub>; whereas Nd was loaded on a Re filament with H<sub>3</sub>PO<sub>4</sub> and measured using a double-Re-filament configuration. The effect of mass fractionation in Sr and Nd isotopic measurements was corrected by normalizing to  $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$  and  $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ , respectively. Analyses of NBS-987 Sr and JMC Nd standard throughout the period of data acquisition yielded  $^{86}\text{Sr}/^{87}\text{Sr} = 0.710251 \pm 0.000020$  ( $2\sigma$  external precision) and  $^{143}\text{Nd}/^{144}\text{Nd} = 0.511818 \pm 0.000010$  ( $2\sigma$  external precision). Procedural blanks were ca. 330 pg Sr and 300 pg Nd. Within-run or internal precision, expressed as  $2\sigma_m$ , was better than 0.000010 for both Sr and Nd. The procedures of chemical separation and mass analysis can be found in Jahn et al. (2009, 2014).

## 5. Analytical results

The results of zircon U–Pb age determination, whole-rock chemical and Sr–Nd isotopic and zircon Hf isotopic analyses are presented in Tables 2, 4 and 5, respectively. A summary of the new zircon age data is given in Table 3.

### 5.1. Zircon U–Pb age data

As a whole, the majority of zircon grains from the granitoids of Sikhote-Alin have a rather simple morphology of magmatic origin. Five representative CL images of zircon from each sample are displayed in Fig. 3a and b. The magmatic zoning and prismatic habit are clearly shown. Round spots of ca. 40 μm diameter are the analytical positions on zircon grains. Uranium concentrations show a large range from <100 to 5600 ppm, but the majority of these are lower than 1000 ppm (Table 2). Th/U ratios are exclusively higher than 0.1, and the majority are between 0.4 and 4.0. Such high ratios suggest that all the zircon grains analyzed have magmatic origin. This is consistent with the information derived from the CL images.

The zircon age data are illustrated in the Concordia plots (Fig. 4A–X). The color code of each data ellipse represents the Th/U ratio of the analyzed spot. In most cases, the data points form a tight cluster, yielding a well-defined  $^{206}\text{Pb}/^{238}\text{U}$  age, which is interpreted as the time of magmatic intrusion. However, in rare cases, the zircon analyses revealed a more complicated thermal or zircon crystallization history. For example, the data of sample B-300 (Fig. 4A), a quartz monzodiorite (formerly misnamed as “diorite”) from Oprichnensky, show two clearly defined clusters, yielding an age of  $56.3 \pm 0.7$  Ma and another of  $65.6 \pm 0.9$  Ma (Fig. 4A). Interpretation of the two ages is not straightforward. The CL images indicate that all the zircon crystals are of magmatic origin. An apparent difference between the older (66 Ma) and younger (56 Ma) zircon grains lies in their Th/U ratios. The older crystals have an average ratio of 2.19 (16 grains), whereas the younger ones have a ratio of 1.70 (10 grains). However, this is insufficient to provide a clear explanation why this rock reflects

two distinct magmatic ages. Perhaps this rock was initially emplaced at 66 Ma, and some zircon grains lost some radiogenic Pb at 56 Ma when the associated granite (B-301a) intruded. Incidentally, the Hf isotopic compositions, which will be presented and discussed later, do not show any difference between the two zircon groups.

The second rare case is demonstrated by sample 8-11-54/1 (Fig. 4U, V). This is a granite (formerly named as biotite-bearing monzogranite) from the Gorbun locality near the China–Russia international border. The zircon crystals have complicated  $^{206}\text{Pb}/^{238}\text{U}$  ages from 129 to 1316 Ma (Table 2). A partial set of data with a string of quasi-concordant data points yielded ages from 130 to 140 Ma (Fig. 4V). The youngest group of 9 spots defined an age of  $131 \pm 2$  Ma. This is interpreted as the time of intrusion of the Gorbun granite. The older zircon grains with  $^{206}\text{Pb}/^{238}\text{U}$  ages from 150 to 1316 Ma are likely to be inherited zircon crystals. However, the CL images of these older grains cannot be distinguished from those of the 130 Ma crystals (Fig. 3).

The new zircon ages are summarized in Table 3 and displayed in two age maps (Figs. 2 and 5). The age data are arranged for three groups of granitoids. The first group was for samples collected by G. Valui from the southeastern coastal areas of Sikhote-Alin. All granitic bodies occur within the Taukha Zone (Cretaceous accretionary complex). The age data indicate that the granitic plutons were emplaced from the Late Cretaceous (83 Ma) to Early Eocene (56 Ma), and they appear to show a younging trend toward the north (Fig. 2).

The second group was collected by V. Gonevchuk from several ore districts. Four of these (GV-722, GV-1401, GV-1583-2, GV-1774) are located in or near the Central Sikhote-Alin Fault zone in the Kavalerovo and Malinovka ore districts and intruded the Samarka (Jurassic to Cretaceous accretionary complex) and Zhuravlevka-Amur (Early Cretaceous turbidite basin) terranes of the Primorye Region. Two other samples (YG-332 and YG-410; also designated in English letters as CHG-332 and CHG-410; Fig. 5) are located in the Komsomolsk ore district (E136°00', N50°35') within the Badzhal terrane (analogue of the Samarka terrane) of the Khabarovsk Region (Fig. 5).

The new zircon dating yielded  $74.4 \pm 0.9$  Ma for GV-722 (granite),  $102.8 \pm 1.7$  Ma for GV-1405 (equivalent to GV-1401; monzogranite) from the Kavalerovo ore district,  $86.0 \pm 0.8$  Ma for **GV-1583-2** (granite), and  $88.3 \pm 0.8$  Ma for **GV-1774** (granite) from the Malinovka ore district. The two granitoid samples from the Komsomolsk ore district yielded two identical ages:  $92.4 \pm 0.8$  Ma for YG-332 (monzogranite) and  $91.5 \pm 0.8$  Ma for YG-410 (granite) (Table 3). Note that the newly obtained zircon ages are quite similar to the published K–Ar ages, suggesting that the plutons were emplaced at shallow levels and cooled rapidly.

The third group of granitoids was collected by N. Kruk from three different areas. Two samples (**8-02-1** and **8-881/2**) came from the southernmost part of Primorye (Sergeevka Terrane), and they were emplaced at  $68 \pm 1$  Ma and  $93 \pm 1$  Ma, respectively (Table 3). Two samples (**AH-2-11** and **AH-3-11**; also in English letter as **AN-2-11** and **AN-3-11**) from the Anyi area (Figs. 2 and 5) yielded two contrasting ages of 108 and 58 Ma (Table 3, Fig. 5). The rest of four samples are from the northern Primorye Region (Fig. 2). Two of these (8-871/1 and 8-872/1) occur close to the Central Fault and have zircon ages of 109 and 106 Ma; whereas the other two (**8-11-54/1** and **8-11-51/3**), from the western part of the Samarka Zone, were dated at 131 and 108 Ma, respectively (Table 3, Fig. 2).

### 5.2. Whole-rock geochemical data

The result of whole-rock chemical analysis is presented in Table 4. The silica contents of the 24 granitoid samples vary from



**Table 2**  
Zircon U–Th–Pb isotopic data & calculated ages for granitoids from Sikhote-Alin.

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
<i>B-300 wt. mean</i>																			
= 65.6 ± 0.9 Ma (2σ)																			
B-300-01	570	205	2.78	0.05106	0.00123	0.06926	0.00301	0.00984	0.00024	0.00325	0.00010	244	56	68	3	63	2	66	2
B-300-02	1291	402	3.21	0.04676	0.00077	0.06388	0.00216	0.00991	0.00023	0.00321	0.00010	37	37	63	2	64	1	65	2
B-300-03	746	254	2.94	0.04523	0.00107	0.06223	0.00266	0.00998	0.00024	0.00330	0.00011	-8	44	61	3	64	2	67	2
B-300-04	1215	488	2.49	0.04886	0.00070	0.06825	0.00214	0.01013	0.00024	0.00332	0.00011	141	34	67	2	65	2	67	2
B-300-05	153	90	1.69	0.05202	0.00253	0.07415	0.00525	0.01034	0.00027	0.00333	0.00013	286	111	73	5	66	2	67	3
B-300-06	93	611	0.15	0.04863	0.00122	0.06740	0.00317	0.01005	0.00028	0.00320	0.00024	130	59	66	3	64	2	65	5
B-300-08	153	84	1.83	0.04919	0.00311	0.07162	0.00627	0.01056	0.00030	0.00328	0.00015	157	144	70	6	68	2	66	3
B-300-10	961	309	3.11	0.04697	0.00100	0.06874	0.00283	0.01062	0.00027	0.00325	0.00012	48	47	68	3	68	2	66	2
B-300-12	474	204	2.32	0.04862	0.00121	0.06774	0.00303	0.01011	0.00025	0.00336	0.00013	130	59	67	3	65	2	68	3
B-300-15	283	122	2.32	0.04459	0.00202	0.06427	0.00431	0.01046	0.00027	0.00340	0.00012	-40	94	63	4	67	2	70	2
B-300-18	319	139	2.29	0.05061	0.00182	0.07237	0.00411	0.01037	0.00026	0.00338	0.00012	223	84	71	4	67	2	68	2
B-300-19	357	254	1.41	0.04983	0.00107	0.07211	0.00290	0.01050	0.00025	0.00349	0.00012	187	49	71	3	67	2	70	2
B-300-20	128	176	0.73	0.04778	0.00226	0.06849	0.00463	0.01040	0.00027	0.00330	0.00011	88	104	67	4	67	2	67	2
B-300-21	227	99	2.30	0.04564	0.00251	0.06643	0.00515	0.01056	0.00028	0.00338	0.00014	-21	117	65	5	68	2	68	3
B-300-22	1443	454	3.18	0.05030	0.00085	0.07085	0.00248	0.01022	0.00025	0.00338	0.00013	209	39	70	2	66	2	68	3
B-300-23	1119	487	2.30	0.04607	0.00203	0.06493	0.00380	0.01022	0.00024	0.00336	0.00011	1	92	64	4	66	2	68	2
<i>B-300 wt. mean</i>																			
= 56.3 ± 0.7 Ma (2σ)																			
B-300-07	1136	395	2.88	0.05121	0.00089	0.06115	0.00213	0.00866	0.00020	0.00286	0.00010	250	40	60	2	56	1	58	2
B-300-072	557	273	2.04	0.04607	0.00138	0.05496	0.00249	0.00865	0.00020	0.00286	0.00008	1	61	54	2	56	1	58	2
B-300-09	312	189	1.65	0.05164	0.00158	0.06249	0.00319	0.00878	0.00022	0.00291	0.00011	270	70	62	3	56	1	59	2
B-300-112	311	170	1.83	0.04923	0.00352	0.06155	0.00564	0.00907	0.00023	0.00287	0.00006	159	157	61	5	58	1	58	1
B-300-13	162	113	1.44	0.05174	0.00257	0.06210	0.00448	0.00871	0.00023	0.00301	0.00012	274	114	61	4	56	1	61	2
B-300-14	261	194	1.35	0.04353	0.00210	0.05384	0.00387	0.00897	0.00025	0.00290	0.00012	-95	101	53	4	58	2	59	2
B-300-16	396	217	1.82	0.04607	0.00251	0.05559	0.00390	0.00875	0.00023	0.00295	0.00015	1	118	55	4	56	1	60	3
B-300-17	145	126	1.15	0.05127	0.00389	0.06168	0.00607	0.00872	0.00024	0.00275	0.00006	253	171	61	6	56	2	55	1
B-300-24	272	202	1.35	0.04641	0.00290	0.05650	0.00448	0.00883	0.00022	0.00281	0.00011	19	133	56	4	57	1	57	2
B-300-25	400	274	1.46	0.04682	0.00122	0.05500	0.00252	0.00852	0.00021	0.00278	0.00010	40	56	54	2	55	1	56	2
<i>B-301a wt. mean = 57.1 ± 0.4 Ma (2σ)</i>																			
B301A-01	312	196	1.59	0.04978	0.00082	0.06093	0.00204	0.00888	0.00020	0.00289	0.00007	185	39	60	2	57	1	58	1
B301A-02	104	82	1.27	0.04536	0.00172	0.05626	0.00324	0.00900	0.00021	0.00286	0.00008	-1	79	56	3	58	1	58	2
B301A-03	300	176	1.71	0.04863	0.00092	0.05984	0.00218	0.00893	0.00020	0.00294	0.00007	130	46	59	2	57	1	59	1
B301A-04	341	189	1.81	0.04786	0.00169	0.05931	0.00345	0.00899	0.00025	0.00243	0.00008	92	77	59	3	58	2	49	2
B301A-05	204	115	1.77	0.04571	0.00128	0.05594	0.00265	0.00888	0.00021	0.00291	0.00008	-17	53	55	3	57	1	59	2
B301A-06	265	184	1.44	0.04937	0.00086	0.06030	0.00209	0.00886	0.00020	0.00287	0.00007	165	43	59	2	57	1	58	1
B301A-07	234	179	1.31	0.04759	0.00088	0.05825	0.00210	0.00888	0.00020	0.00284	0.00008	79	40	57	2	57	1	57	2
B301A-08	402	223	1.80	0.05196	0.00082	0.06276	0.00206	0.00876	0.00020	0.00282	0.00007	284	36	62	2	56	1	57	1
B301A-09	199	138	1.44	0.05084	0.00366	0.06273	0.00568	0.00895	0.00022	0.00282	0.00005	234	159	62	5	57	1	57	1
B301A-11	227	141	1.61	0.04321	0.00116	0.05310	0.00244	0.00891	0.00021	0.00310	0.00009	-112	64	53	2	57	1	63	2
B301A-12	256	189	1.35	0.04656	0.00089	0.05683	0.00208	0.00885	0.00020	0.00295	0.00009	27	38	56	2	57	1	60	2
B301A-13	70	101	0.70	0.04974	0.00151	0.06095	0.00304	0.00889	0.00021	0.00318	0.00011	183	74	60	3	57	1	64	2
B301A-15	209	127	1.65	0.05159	0.00129	0.06255	0.00277	0.00879	0.00021	0.00338	0.00009	267	60	62	3	56	1	68	2
B301A-16	93	109	0.86	0.04565	0.00142	0.05572	0.00282	0.00885	0.00021	0.00310	0.00010	-20	60	55	3	57	1	63	2
B301A-17	738	313	2.36	0.04686	0.00068	0.05864	0.00184	0.00908	0.00021	0.00307	0.00008	42	35	58	2	58	1	62	2
B301A-18	112	84	1.33	0.04553	0.00205	0.05650	0.00371	0.00900	0.00022	0.00337	0.00012	-27	92	56	4	58	1	68	2
B301A-19	201	137	1.47	0.04529	0.00115	0.05467	0.00244	0.00876	0.00021	0.00291	0.00008	-5	54	54	2	56	1	59	2
B301A-20	187	162	1.15	0.04454	0.00100	0.05484	0.00225	0.00893	0.00021	0.00290	0.00008	-43	50	54	2	57	1	59	2
B301A-21	147	92	1.59	0.04841	0.00178	0.05877	0.00344	0.00880	0.00023	0.00308	0.00010	119	78	58	3	56	1	62	2
B301A-22	487	264	1.84	0.04403	0.00077	0.05444	0.00192	0.00897	0.00021	0.00289	0.00008	-69	40	54	2	58	1	58	2
B301A-23	178	126	1.42	0.04572	0.00140	0.05707	0.00293	0.00905	0.00023	0.00294	0.00010	-17	59	56	3	58	1	59	2
B301A-24	96	62	1.53	0.04734	0.00253	0.05795	0.00443	0.00888	0.00024	0.00288	0.00010	66	109	57	4	57	2	58	2

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
<i>B-448 wt. mean = 64.0 ± 0.7 Ma (2σ)</i>																			
B448-01	177	152	1.17	0.04248	0.00108	0.05717	0.00258	0.00976	0.00024	0.00326	0.00009	-151	56	56	2	63	2	66	2
B448-02	58	44	1.31	0.04183	0.00365	0.05709	0.00638	0.00990	0.00028	0.00341	0.00014	-186	163	56	6	64	2	69	3
B448-03	103	57	1.82	0.04514	0.00271	0.06267	0.00520	0.01007	0.00027	0.00358	0.00012	-12	135	62	5	65	2	72	2
B448-05	77	55	1.40	0.05109	0.00464	0.07105	0.00807	0.01009	0.00029	0.00318	0.00007	245	195	70	8	65	2	64	1
B448-06	116	66	1.76	0.04394	0.00227	0.06095	0.00449	0.01006	0.00026	0.00365	0.00012	-74	110	60	4	65	2	74	2
B448-07	286	235	1.22	0.05344	0.00081	0.07541	0.00244	0.01024	0.00024	0.00374	0.00010	348	33	74	2	66	2	75	2
B448-08	1197	980	1.22	0.04608	0.00104	0.06142	0.00243	0.00967	0.00023	0.00314	0.00009	2	44	61	2	62	1	63	2
B448-09	96	75	1.28	0.04516	0.00195	0.06243	0.00406	0.01003	0.00026	0.00331	0.00011	-11	87	61	4	64	2	67	2
B448-10	82	51	1.62	0.04607	0.00231	0.06205	0.00438	0.00977	0.00028	0.00332	0.00016	1	106	61	4	63	2	67	3
B448-11	247	186	1.33	0.04444	0.00091	0.06407	0.00255	0.01046	0.00026	0.00304	0.00009	-48	41	63	2	67	2	61	2
B448-12	128	78	1.63	0.04654	0.00183	0.06554	0.00398	0.01022	0.00026	0.00357	0.00012	26	86	64	4	66	2	72	2
B448-13	123	73	1.67	0.03230	0.00221	0.04495	0.00407	0.01009	0.00026	0.00327	0.00010	-185	97	45	4	65	2	66	2
B448-14	79	39	2.04	0.03831	0.00426	0.05212	0.00714	0.00987	0.00029	0.00336	0.00012	-390	229	52	7	63	2	68	2
B448-15	143	93	1.54	0.04917	0.00335	0.06675	0.00625	0.00985	0.00030	0.00311	0.00008	156	150	66	6	63	2	63	2
B448-16	511	470	1.09	0.04726	0.00060	0.06387	0.00184	0.00980	0.00023	0.00353	0.00010	62	32	63	2	63	1	71	2
B448-17	80	44	1.81	0.05124	0.00317	0.07122	0.00610	0.01008	0.00028	0.00354	0.00012	252	146	70	6	65	2	71	2
B448-18	178	113	1.58	0.04887	0.00141	0.06766	0.00332	0.01004	0.00025	0.00355	0.00011	142	67	66	3	64	2	72	2
B448-19	122	70	1.75	0.03811	0.00235	0.05301	0.00444	0.01009	0.00026	0.00332	0.00012	-403	224	52	4	65	2	67	2
B448-20	168	98	1.72	0.04320	0.00179	0.05993	0.00378	0.01006	0.00026	0.00343	0.00012	-112	87	59	4	65	2	69	2
B448-21	237	129	1.84	0.04421	0.00154	0.05976	0.00334	0.00980	0.00025	0.00356	0.00012	-60	75	59	3	63	2	72	2
B448-22	188	111	1.70	0.04761	0.00158	0.06684	0.00362	0.01018	0.00026	0.00347	0.00012	80	72	66	3	65	2	70	2
B448-23	70	39	1.81	0.04469	0.00444	0.06209	0.00783	0.01008	0.00031	0.00366	0.00015	-35	186	61	7	65	2	74	3
B448-24	220	105	2.09	0.03980	0.00179	0.05597	0.00377	0.01020	0.00027	0.00343	0.00012	-301	111	55	4	65	2	69	2
<i>B-456 wt. mean (one old core excepted) = 70.5 ± 0.9 Ma (2σ)</i>																			
B-456-01	259	180	1.44	0.05333	0.00137	0.08358	0.00381	0.01137	0.00028	0.00420	0.00015	343	57	82	4	73	2	85	3
B-456-02	226	183	1.24	0.04904	0.00284	0.07460	0.00586	0.01103	0.00029	0.00349	0.00008	150	131	73	6	71	2	70	2
B-456-03	240	164	1.47	0.04495	0.00153	0.06798	0.00370	0.01097	0.00027	0.00375	0.00014	-22	68	67	4	70	2	76	3
B-456-04	446	633	0.70	0.04821	0.00071	0.07221	0.00230	0.01086	0.00026	0.00364	0.00014	110	35	71	2	70	2	73	3
B-456-06	189	146	1.30	0.04916	0.00174	0.07535	0.00425	0.01112	0.00028	0.00367	0.00015	155	83	74	4	71	2	74	3
B-456-07	376	187	2.01	0.05113	0.00128	0.07853	0.00354	0.01114	0.00028	0.00348	0.00012	247	59	77	3	71	2	70	2
B-456-08	289	274	1.05	0.04871	0.00106	0.07512	0.00307	0.01118	0.00027	0.00368	0.00015	134	52	74	3	72	2	74	3
B-456-09	480	565	0.85	0.04971	0.00069	0.07547	0.00231	0.01101	0.00026	0.00343	0.00013	181	33	74	2	71	2	69	3
B-456-092	336	261	1.29	0.04767	0.00095	0.06979	0.00263	0.01062	0.00024	0.00364	0.00012	83	47	69	2	68	2	73	2
B-456-11	300	95	3.15	0.05685	0.00402	0.08436	0.00831	0.01076	0.00035	0.00311	0.00016	486	157	82	8	69	2	63	3
B-456-12	582	214	2.72	0.04684	0.00447	0.07225	0.00832	0.01119	0.00031	0.00356	0.00010	41	198	71	8	72	2	72	2
B-456-13	289	217	1.33	0.04922	0.00123	0.07265	0.00324	0.01071	0.00026	0.00329	0.00011	158	59	71	3	69	2	66	2
B-456-14	430	587	0.73	0.04729	0.00066	0.07144	0.00220	0.01096	0.00026	0.00350	0.00012	64	33	70	2	70	2	71	2
B-456-15	160	128	1.25	0.04607	0.00116	0.06778	0.00281	0.01067	0.00026	0.00366	0.00018	1	49	67	3	68	2	74	4
B-456-17	288	197	1.46	0.05462	0.00227	0.08301	0.00546	0.01103	0.00032	0.00326	0.00016	397	92	81	5	71	2	66	3
B-456-18	332	214	1.55	0.05031	0.00126	0.07588	0.00340	0.01094	0.00027	0.00353	0.00013	209	59	74	3	70	2	71	3
B-456-19	307	136	2.26	0.04851	0.00190	0.07366	0.00445	0.01101	0.00028	0.00363	0.00014	124	90	72	4	71	2	73	3
B-456-192	191	105	1.82	0.04663	0.00345	0.066871	0.00630	0.01069	0.00027	0.00340	0.00011	30	156	67	6	69	2	69	2
B-456-20	361	250	1.44	0.04987	0.00107	0.07779	0.00313	0.01131	0.00027	0.00364	0.00014	189	49	76	3	72	2	73	3
B-456-21	864	364	2.37	0.04672	0.00085	0.07090	0.00257	0.01101	0.00026	0.00347	0.00013	35	40	70	2	71	2	70	3
B-456-23	249	158	1.57	0.05331	0.00161	0.08117	0.00413	0.01104	0.00028	0.00360	0.00015	342	68	79	4	71	2	73	3
B-456-16	717	681	1.05	0.04844	0.00062	0.09095	0.00261	0.01362	0.00032	0.00447	0.00015	121	30	88	2	87	2	90	3
<i>(Core)</i>																			
<i>B-719 wt. mean = 70.7 ± 0.8 Ma (2σ)</i>																			
B-719-01	251	210	1.19	0.04676	0.00083	0.06952	0.00246	0.01078	0.00025	0.00343	0.00010	37	40	68	2	69	2	69	2
B-719-02	310	260	1.19	0.04710	0.00073	0.07231	0.00233	0.01114	0.00025	0.00361	0.00010	54	37	71	2	71	2	73	2
B-719-03	388	256	1.52	0.04769	0.00242	0.07194	0.00495	0.01094	0.00027	0.00347	0.00007	84	110	71	5	70	2	70	1
B-719-04	279	201	1.39	0.04583	0.00084	0.06957	0.00250	0.01101	0.00025	0.00352	0.00010	-11	34	68	2	71	2	71	2

B.-m. Jahn et al./Journal of Asian Earth Sciences 111 (2015) 872–918

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
B-719-05	156	153	1.03	0.04683	0.00102	0.07030	0.00285	0.01089	0.00026	0.00345	0.00011	41	47	69	3	70	2	70	2
B-719-06	228	220	1.04	0.04607	0.00112	0.07001	0.00285	0.01102	0.00026	0.00362	0.00011	1	47	69	3	71	2	73	2
B-719-07	345	283	1.22	0.04563	0.00073	0.06972	0.00233	0.01108	0.00026	0.00342	0.00011	-22	29	68	2	71	2	69	2
B-719-08	190	129	1.47	0.04536	0.00122	0.06777	0.00314	0.01084	0.00026	0.00360	0.00012	-1	54	67	3	70	2	73	2
B-719-09	838	426	1.97	0.05240	0.00064	0.08060	0.00224	0.01116	0.00026	0.00359	0.00011	303	28	79	2	72	2	72	2
B-719-10	320	271	1.18	0.04953	0.00077	0.07501	0.00248	0.01098	0.00026	0.00345	0.00012	173	37	73	2	70	2	70	2
B-719-11	294	168	1.75	0.04687	0.00100	0.07084	0.00283	0.01096	0.00026	0.00361	0.00013	43	46	69	3	70	2	73	3
B-719-12	211	159	1.33	0.04895	0.00106	0.07386	0.00299	0.01095	0.00026	0.00367	0.00013	145	52	72	3	70	2	74	3
B-719-14	261	213	1.23	0.04846	0.00114	0.07377	0.00321	0.01104	0.00028	0.00339	0.00011	122	55	72	3	71	2	68	2
B-719-15	477	660	0.72	0.04732	0.00057	0.07062	0.00194	0.01083	0.00025	0.00352	0.00010	65	29	69	2	69	2	71	2
B-719-16	408	299	1.36	0.04921	0.00087	0.07578	0.00273	0.01117	0.00027	0.00361	0.00012	158	42	74	3	72	2	73	2
B-719-17	363	299	1.21	0.04701	0.00104	0.07245	0.00303	0.01118	0.00028	0.00348	0.00013	50	49	71	3	72	2	70	3
B-719-18	199	152	1.31	0.05196	0.00120	0.07884	0.00336	0.01101	0.00027	0.00346	0.00012	284	54	77	3	71	2	70	2
B-719-19	169	157	1.08	0.04539	0.00119	0.06902	0.00317	0.01103	0.00027	0.00361	0.00013	-34	51	68	3	71	2	73	3
B-719-20	315	346	0.91	0.04807	0.00091	0.07386	0.00281	0.01114	0.00028	0.00359	0.00014	103	45	72	3	71	2	72	3
B-719-21	496	344	1.44	0.04652	0.00071	0.07130	0.00231	0.01112	0.00026	0.00356	0.00012	25	33	70	2	71	2	72	2
B-719-22	289	245	1.18	0.04646	0.00085	0.07016	0.00255	0.01095	0.00026	0.00351	0.00012	22	39	69	2	70	2	71	2
B-719-23	138	109	1.27	0.04923	0.00169	0.07630	0.00420	0.01124	0.00028	0.00367	0.00014	159	79	75	4	72	2	74	3
B-719-24	299	273	1.10	0.04668	0.00080	0.07072	0.00248	0.01099	0.00026	0.00337	0.00012	33	38	69	2	70	2	68	2
<i>B-574 wt. mean = 82.7 ± 0.8 Ma (2σ)</i>																			
B574-01	135	90	1.50	0.05592	0.00152	0.09956	0.00475	0.01291	0.00033	0.00519	0.00016	449	62	96	4	83	2	105	3
B574-02	103	84	1.22	0.04836	0.00150	0.08932	0.00458	0.01340	0.00033	0.00452	0.00015	117	70	87	4	86	2	91	3
B574-03	112	97	1.15	0.05672	0.00135	0.10167	0.00442	0.01300	0.00032	0.00520	0.00016	481	53	98	4	83	2	105	3
B574-04	218	144	1.51	0.04561	0.00098	0.07914	0.00318	0.01258	0.00030	0.00435	0.00013	-23	40	77	3	81	2	88	3
B574-05	172	119	1.45	0.04773	0.00146	0.08667	0.00452	0.01317	0.00035	0.00469	0.00016	86	64	84	4	84	2	95	3
B574-06	97	90	1.07	0.04886	0.00137	0.08583	0.00415	0.01274	0.00032	0.00451	0.00014	141	68	84	4	82	2	91	3
B574-07	170	108	1.57	0.04821	0.00121	0.08728	0.00390	0.01313	0.00032	0.00449	0.00014	110	53	85	4	84	2	91	3
B574-08	206	146	1.41	0.05782	0.00176	0.10629	0.00574	0.01333	0.00039	0.00477	0.00018	523	60	103	5	85	2	90	4
B574-10	127	80	1.60	0.06273	0.00210	0.11398	0.00630	0.01318	0.00035	0.00533	0.00022	699	76	110	6	84	2	107	4
B574-11	160	106	1.51	0.04530	0.00120	0.08069	0.00376	0.01292	0.00032	0.00451	0.00015	-4	50	79	4	83	2	91	3
B574-12	159	107	1.48	0.04695	0.00116	0.08394	0.00374	0.01297	0.00032	0.00448	0.00015	47	50	82	4	83	2	90	3
B574-13	172	113	1.52	0.04842	0.00120	0.08552	0.00379	0.01281	0.00031	0.00428	0.00013	120	63	83	4	82	2	86	3
B574-14	113	92	1.23	0.04277	0.00138	0.07660	0.00402	0.01299	0.00032	0.00447	0.00014	-135	73	75	4	83	2	90	3
B574-15	197	129	1.53	0.04740	0.00107	0.08250	0.00347	0.01262	0.00031	0.00447	0.00013	69	49	80	3	81	2	90	3
B574-16	177	137	1.29	0.04927	0.00108	0.08804	0.00368	0.01296	0.00033	0.00448	0.00014	161	51	86	3	83	2	90	3
B574-17	140	97	1.45	0.04759	0.00132	0.08379	0.00403	0.01277	0.00032	0.00432	0.00013	79	66	82	4	82	2	87	3
B574-18	188	121	1.56	0.04992	0.00109	0.08689	0.00358	0.01262	0.00031	0.00435	0.00013	191	54	85	3	81	2	88	3
B574-19	162	104	1.55	0.04913	0.00124	0.08634	0.00392	0.01275	0.00032	0.00435	0.00014	154	61	84	4	82	2	88	3
B574-20	156	114	1.37	0.04391	0.00113	0.07812	0.00357	0.01291	0.00032	0.00439	0.00014	-75	56	76	3	83	2	89	3
B574-21	146	98	1.49	0.04804	0.00129	0.08566	0.00402	0.01293	0.00032	0.00454	0.00015	101	60	83	4	83	2	92	3
B574-22	201	132	1.52	0.05050	0.00455	0.08818	0.00997	0.01267	0.00036	0.00399	0.00013	218	186	86	9	81	2	81	3
B574-23	168	131	1.28	0.04555	0.00100	0.08081	0.00335	0.01287	0.00032	0.00448	0.00015	-26	43	79	3	82	2	90	3
B574-24	210	150	1.40	0.04713	0.00106	0.08165	0.00347	0.01257	0.00032	0.00418	0.00014	56	49	80	3	81	2	84	3
<i>B-621 wt. mean (one old core excluded) = 70.8 ± 0.8 Ma (2σ)</i>																			
B621D-02	530	257	2.07	0.04753	0.00090	0.07254	0.00269	0.01107	0.00026	0.00381	0.00013	76	44	71	3	71	2	77	3
B621D-03	119	299	0.40	0.04556	0.00078	0.07042	0.00245	0.01121	0.00026	0.00363	0.00015	-25	32	69	2	72	2	73	3
B621D-04	337	210	1.60	0.04980	0.00151	0.07616	0.00393	0.01109	0.00029	0.00382	0.00016	186	70	75	4	71	2	77	3
B621D-05	762	268	2.85	0.05649	0.00121	0.08656	0.00356	0.01111	0.00028	0.00359	0.00014	472	47	84	3	71	2	72	3
B621D-06	529	181	2.93	0.04634	0.00436	0.06893	0.00764	0.01079	0.00028	0.00344	0.00010	16	196	68	7	69	2	69	2
B621D-07	736	267	2.75	0.04864	0.00088	0.07432	0.00267	0.01108	0.00026	0.00368	0.00013	131	43	73	3	71	2	74	3
B621D-08	1277	367	3.48	0.05576	0.00103	0.08623	0.00323	0.01122	0.00028	0.00384	0.00017	443	41	84	3	72	2	77	3
B621D-09	778	290	2.69	0.05099	0.00144	0.07646	0.00375	0.01088	0.00028	0.00363	0.00014	240	65	75	4	70	2	73	3
B621D-12	879	352	2.50	0.05181	0.00117	0.07738	0.00326	0.01083	0.00027	0.00359	0.00014	277	51	76	3	69	2	72	3
B621D-13	2409	685	3.52	0.04635	0.00095	0.06929	0.00279	0.01084	0.00028	0.00349	0.00016	16	42	68	3	70	2	70	3

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
B621D-14	1736	479	3.62	0.04512	0.00087	0.07093	0.00270	0.01140	0.00028	0.00357	0.00014	-13	35	70	3	73	2	72	3
B621D-15	829	281	2.95	0.05005	0.00165	0.07558	0.00418	0.01095	0.00030	0.00333	0.00016	197	77	74	4	70	2	67	3
B621D-16	376	437	0.86	0.04530	0.00080	0.06804	0.00240	0.01089	0.00025	0.00403	0.00017	-4	33	67	2	70	2	81	3
B621D-18	430	237	1.82	0.04607	0.00200	0.06938	0.00402	0.01092	0.00026	0.00360	0.00013	2	91	68	4	70	2	73	3
B621D-19	517	202	2.57	0.04533	0.00215	0.07078	0.00499	0.01132	0.00031	0.00372	0.00020	-3	101	69	5	73	2	75	4
B621D-20	615	300	2.05	0.04607	0.00198	0.07098	0.00402	0.01117	0.00026	0.00370	0.00015	1	89	70	4	72	2	75	3
B621D-21	341	174	1.95	0.04941	0.00191	0.07355	0.00439	0.01080	0.00027	0.00376	0.00014	167	88	72	4	69	2	76	3
B621D-22	490	176	2.78	0.04929	0.00237	0.07486	0.00532	0.01102	0.00030	0.00348	0.00014	162	108	73	5	71	2	70	3
B621D-23	977	414	2.36	0.04944	0.00088	0.07610	0.00270	0.01117	0.00026	0.00360	0.00013	169	42	74	3	72	2	73	3
B621D-24	611	227	2.69	0.04750	0.00145	0.07213	0.00366	0.01102	0.00027	0.00361	0.00014	74	68	71	3	71	2	73	3
B621D-25	1174	406	2.89	0.04491	0.00094	0.06758	0.00268	0.01091	0.00026	0.00368	0.00015	-24	39	66	3	70	2	74	3
B621D-26	1629	447	3.64	0.05492	0.00088	0.08399	0.00281	0.01109	0.00026	0.00369	0.00014	409	36	82	3	71	2	74	3
B621D-27	1208	441	2.74	0.04994	0.00206	0.07583	0.00496	0.01102	0.00032	0.00279	0.00016	192	95	74	5	71	2	56	3
B621D-28	1499	439	3.41	0.04847	0.00116	0.07170	0.00315	0.01073	0.00027	0.00335	0.00015	122	56	70	3	69	2	68	3
B621D-01 (Core)	977	289	3.39	0.44060	0.00488	1.34656	0.03418	0.02216	0.00050	0.01971	0.00089	4054	16	866	15	141	3	395	18
<i>B-783M wt. mean = 77.7 ± 0.9 Ma (2σ)</i>																			
B-783M01	588	216	2.72	0.04608	0.00216	0.07694	0.00485	0.01211	0.00029	0.00395	0.00010	2	97	75	5	78	2	80	2
B-783M02	678	201	3.38	0.04607	0.00209	0.07674	0.00475	0.01208	0.00029	0.00393	0.00009	1	95	75	4	77	2	79	2
B-783M03	353	149	2.36	0.04822	0.00093	0.08038	0.00300	0.01209	0.00028	0.00410	0.00010	110	45	79	3	77	2	83	2
B-783M04	504	198	2.55	0.05547	0.00103	0.09482	0.00352	0.01240	0.00030	0.00401	0.00011	431	42	92	3	79	2	81	2
B-783M06	335	140	2.40	0.04607	0.00226	0.07723	0.00518	0.01216	0.00031	0.00393	0.00010	1	103	76	5	78	2	79	2
B-783M08	885	271	3.26	0.04743	0.00067	0.08132	0.00247	0.01244	0.00028	0.00418	0.00011	71	33	79	2	80	2	84	2
B-783M09	471	201	2.34	0.04837	0.00078	0.08184	0.00271	0.01227	0.00028	0.00408	0.00011	117	37	80	3	79	2	82	2
B-783M10	1027	295	3.49	0.04826	0.00066	0.08229	0.00245	0.01237	0.00028	0.00404	0.00011	112	32	80	2	79	2	81	2
B-783M12	416	149	2.80	0.05471	0.00115	0.09442	0.00381	0.01252	0.00031	0.00400	0.00013	400	48	92	4	80	2	81	3
B-783M13	408	155	2.63	0.05360	0.00110	0.08892	0.00350	0.01203	0.00029	0.00390	0.00010	354	47	86	3	77	2	79	2
B-783M14	483	175	2.76	0.04620	0.00303	0.07677	0.00641	0.01205	0.00030	0.00384	0.00009	8	140	75	6	77	2	78	2
B-783M15	322	121	2.66	0.04608	0.00272	0.07741	0.00590	0.01218	0.00030	0.00391	0.00010	2	127	76	6	78	2	79	2
B-783M18	306	144	2.12	0.05128	0.00437	0.08638	0.00946	0.01222	0.00036	0.00384	0.00008	254	192	84	9	78	2	78	2
B-783M19	159	86	1.84	0.05404	0.00583	0.08884	0.01208	0.01192	0.00040	0.00373	0.00009	373	241	86	11	76	3	75	2
B-783M20	384	147	2.61	0.05013	0.00122	0.08060	0.00356	0.01166	0.00029	0.00379	0.00011	201	56	79	3	75	2	76	2
B-783M21	168	84	1.99	0.05188	0.00295	0.08482	0.00706	0.01186	0.00037	0.00368	0.00016	280	128	83	7	76	2	74	3
B-783M22	364	141	2.58	0.05743	0.00148	0.09405	0.00439	0.01188	0.00031	0.00357	0.00012	508	57	91	4	76	2	72	2
B-783M23	493	166	2.96	0.04719	0.00401	0.07911	0.00828	0.01216	0.00033	0.00387	0.00010	59	182	77	8	78	2	78	2
<i>B-919B wt. mean = 80.8 ± 0.8 Ma (2σ)</i>																			
B-919b-01	233	259	0.90	0.04972	0.00116	0.08524	0.00362	0.01243	0.00030	0.00400	0.00017	182	54	83	3	80	2	81	3
B-919b-02	568	527	1.08	0.04710	0.00217	0.08016	0.00496	0.01234	0.00029	0.00393	0.00012	54	100	78	5	79	2	79	2
B-919b-03	290	289	1.00	0.04472	0.00108	0.07785	0.00340	0.01263	0.00031	0.00391	0.00018	-34	47	76	3	81	2	79	4
B-919b-04	448	358	1.25	0.04811	0.00092	0.08234	0.00307	0.01242	0.00029	0.00410	0.00018	105	45	80	3	80	2	83	4
B-919b-05	368	409	0.90	0.04665	0.00089	0.08194	0.00305	0.01274	0.00030	0.00417	0.00016	31	41	80	3	82	2	84	3
B-919b-06	239	283	0.84	0.04311	0.00121	0.07603	0.00363	0.01279	0.00031	0.00427	0.00018	-117	62	74	3	82	2	86	4
B-919b-07	388	349	1.11	0.04553	0.00097	0.07866	0.00316	0.01253	0.00030	0.00392	0.00015	-27	41	77	3	80	2	79	3
B-919b-08	580	517	1.12	0.04429	0.00086	0.07594	0.00288	0.01244	0.00030	0.00427	0.00019	-56	40	74	3	80	2	86	4
B-919b-09	719	507	1.42	0.04770	0.00117	0.08482	0.00381	0.01290	0.00033	0.00412	0.00022	84	56	83	4	83	2	83	4
B-919b-10	965	564	1.71	0.05413	0.00104	0.09490	0.00365	0.01272	0.00032	0.00402	0.00019	376	43	92	3	81	2	81	4
B-919b-11	244	211	1.15	0.05109	0.00156	0.08841	0.00450	0.01255	0.00031	0.00454	0.00021	245	70	86	4	80	2	92	4
B-919b-12	287	296	0.97	0.04796	0.00123	0.08118	0.00367	0.01228	0.00030	0.00415	0.00020	97	58	79	3	79	2	84	4
B-919b-13	397	381	1.04	0.04445	0.00166	0.07714	0.00465	0.01259	0.00035	0.00380	0.00024	-47	76	75	4	81	2	77	5
B-919b-15	229	195	1.18	0.04730	0.00166	0.08255	0.00458	0.01266	0.00031	0.00386	0.00019	64	76	81	4	81	2	78	4
B-919b-19	273	333	0.82	0.04745	0.00109	0.08331	0.00353	0.01274	0.00031	0.00424	0.00019	72	53	81	3	82	2	86	4
B-919b-20	456	542	0.84	0.04709	0.00079	0.08174	0.00283	0.01259	0.00030	0.00421	0.00018	54	39	80	3	81	2	85	4
B-919b-21	224	252	0.89	0.04659	0.00145	0.08098	0.00416	0.01261	0.00031	0.00410	0.00019	28	64	79	4	81	2	83	4
B-919b-22	381	348	1.10	0.04662	0.00243	0.08174	0.00558	0.01272	0.00032	0.00405	0.00015	30	111	80	5	81	2	82	3

(continued on next page)

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
B-919b-23	270	283	0.95	0.04432	0.00131	0.07667	0.00382	0.01255	0.00031	0.00398	0.00020	-54	59	75	4	80	2	80	4
B-919b-24	334	328	1.02	0.05310	0.00120	0.09220	0.00383	0.01259	0.00030	0.00474	0.00023	333	52	90	4	81	2	96	5
B-919b-25	549	502	1.09	0.04530	0.00092	0.07679	0.00302	0.01230	0.00030	0.00410	0.00021	-4	38	75	3	79	2	83	4
B-919b-26	213	278	0.77	0.04708	0.00232	0.08166	0.00534	0.01258	0.00031	0.00400	0.00018	53	106	80	5	81	2	81	4
B-919b-27	368	381	0.97	0.04691	0.00112	0.08228	0.00357	0.01272	0.00031	0.00431	0.00024	45	52	80	3	81	2	87	5
B-919b-28	152	174	0.87	0.04509	0.00205	0.07959	0.00535	0.01280	0.00033	0.00422	0.00025	-15	94	78	5	82	2	85	5
<i>B-984 wt. mean = 78.1 ± 0.8 Ma (2σ)</i>																			
B984-01	294	217	1.36	0.04703	0.00181	0.07893	0.00466	0.01217	0.00030	0.00415	0.00018	51	82	77	4	78	2	84	4
B984-02	399	228	1.75	0.04597	0.00186	0.07606	0.00472	0.01200	0.00031	0.00406	0.00018	-4	81	74	4	77	2	82	4
B984-03	256	165	1.55	0.04293	0.00249	0.07039	0.00566	0.01189	0.00031	0.00403	0.00019	-127	125	69	5	76	2	81	4
B984-04	239	166	1.44	0.04691	0.00228	0.08053	0.00567	0.01245	0.00032	0.00387	0.00018	45	105	79	5	80	2	78	4
B984-05	190	126	1.51	0.05498	0.00306	0.09469	0.00740	0.01249	0.00033	0.00425	0.00021	411	126	92	7	80	2	86	4
B984-06	256	212	1.21	0.04537	0.00186	0.07599	0.00475	0.01215	0.00031	0.00391	0.00019	-1	85	74	4	78	2	79	4
B984-07	251	201	1.25	0.05065	0.00190	0.08633	0.00505	0.01236	0.00031	0.00425	0.00021	225	88	84	5	79	2	86	4
B984-08	104	129	0.81	0.04425	0.00310	0.07467	0.00692	0.01224	0.00032	0.00437	0.00026	-58	145	73	7	78	2	88	5
B984-09	471	428	1.10	0.04525	0.00100	0.07602	0.00312	0.01219	0.00029	0.00382	0.00019	-7	42	74	3	78	2	77	4
B984-10	137	116	1.19	0.04652	0.00342	0.07923	0.00766	0.01235	0.00033	0.00401	0.00023	25	159	77	7	79	2	81	5
B984-12	321	217	1.48	0.04686	0.00441	0.07815	0.00869	0.01210	0.00032	0.00385	0.00020	42	198	76	8	78	2	78	4
B-984-13	666	578	1.15	0.04846	0.00053	0.08455	0.00212	0.01266	0.00028	0.00400	0.00009	122	26	82	2	81	2	81	2
B-984-15	305	236	1.29	0.04880	0.00070	0.08069	0.00248	0.01199	0.00027	0.00383	0.00009	138	33	79	2	77	2	77	2
B-984-16	301	204	1.48	0.05107	0.00077	0.08539	0.00269	0.01213	0.00027	0.00390	0.00010	244	35	83	3	78	2	79	2
B-984-17	637	402	1.58	0.04889	0.00251	0.08554	0.00598	0.01269	0.00030	0.00402	0.00008	143	117	83	6	81	2	81	2
B-984-18	327	227	1.44	0.04855	0.00071	0.07967	0.00248	0.01190	0.00027	0.00378	0.00010	126	35	78	2	76	2	76	2
B-984-19	751	425	1.77	0.04754	0.00212	0.07818	0.00492	0.01193	0.00029	0.00379	0.00008	76	98	76	5	76	2	76	2
B-984-20	240	276	0.87	0.04559	0.00063	0.07697	0.00230	0.01225	0.00027	0.00404	0.00011	-24	26	75	2	78	2	81	2
B-984-21	678	763	0.89	0.04854	0.00053	0.07995	0.00200	0.01195	0.00026	0.00388	0.00010	126	26	78	2	77	2	78	2
B-984-22	612	379	1.61	0.05080	0.00061	0.08657	0.00237	0.01236	0.00028	0.00409	0.00011	232	27	84	2	79	2	82	2
B-984-23	673	618	1.09	0.04834	0.00054	0.08044	0.00207	0.01207	0.00027	0.00390	0.00011	116	27	79	2	77	2	79	2
B-984-24	622	563	1.10	0.04935	0.00057	0.08084	0.00212	0.01188	0.00026	0.00389	0.00011	164	27	79	2	76	2	78	2
<i>GV-722 wt. mean = 74.4 ± 0.9 Ma (2σ)</i>																			
GB72201	433	545	0.79	0.04753	0.00114	0.08160	0.00335	0.01245	0.00026	0.00396	0.00007	76	56	80	3	80	2	80	1
GB72202	271	456	0.60	0.04896	0.00051	0.08219	0.00196	0.01218	0.00025	0.00393	0.00009	146	24	80	2	78	2	79	2
GB72203	412	974	0.42	0.05668	0.00278	0.09032	0.00591	0.01156	0.00027	0.00359	0.00011	479	108	88	6	74	2	72	2
GB72204	430	1015	0.42	0.04870	0.00080	0.07774	0.00250	0.01158	0.00023	0.00367	0.00007	133	39	76	2	74	1	74	1
GB72205	328	313	1.05	0.04611	0.00119	0.07036	0.00289	0.01107	0.00024	0.00354	0.00008	3	52	69	3	71	2	71	2
GB72206	553	1979	0.28	0.04837	0.00045	0.07684	0.00163	0.01152	0.00023	0.00357	0.00008	117	22	75	2	74	1	72	2
GB72207	373	393	0.95	0.04828	0.00053	0.07869	0.00194	0.01182	0.00024	0.00379	0.00009	113	26	77	2	76	2	76	2
GB72208	494	493	1.00	0.04894	0.00059	0.07916	0.00209	0.01173	0.00024	0.00371	0.00010	145	28	77	2	75	2	75	2
GB72209	579	805	0.72	0.04752	0.00047	0.07782	0.00176	0.01188	0.00024	0.00379	0.00009	75	24	76	2	76	2	76	2
GB72210	397	845	0.47	0.04812	0.00047	0.07780	0.00175	0.01173	0.00023	0.00396	0.00010	105	23	76	2	75	1	80	2
GB72211	1197	2346	0.51	0.05410	0.00139	0.05316	0.00224	0.00713	0.00015	0.00223	0.00004	375	57	53	2	45.8	1	45	0.9
GB72212	1403	1908	0.74	0.05171	0.00049	0.08277	0.00180	0.01161	0.00023	0.00423	0.00011	273	22	81	2	74	1	85	2
GB72213	344	358	0.96	0.04830	0.00053	0.07950	0.00197	0.01194	0.00024	0.00391	0.00009	114	26	78	2	77	2	79	2
GB72214	194	158	1.23	0.04981	0.00072	0.08178	0.00246	0.01191	0.00025	0.00379	0.00009	186	34	80	2	76	2	76	2
GB72215	181	118	1.53	0.04789	0.00085	0.07818	0.00268	0.01184	0.00025	0.00386	0.00009	94	42	76	3	76	2	78	2
GB72216	588	837	0.70	0.04835	0.00047	0.07794	0.00175	0.01169	0.00023	0.00385	0.00009	116	23	76	2	75	1	78	2
GB72217	1253	1132	1.11	0.05274	0.00057	0.08368	0.00205	0.01151	0.00024	0.00364	0.00009	318	24	82	2	74	2	73	2
GB72218	1230	2761	0.45	0.04691	0.00153	0.05957	0.00276	0.00921	0.00019	0.00293	0.00012	45	69	59	3	59	1	59	2
GB72219	340	291	1.17	0.04892	0.00058	0.07980	0.00209	0.01183	0.00024	0.00385	0.00009	144	27	78	2	76	2	78	2
GB72220	1489	956	1.56	0.04609	0.00139	0.06992	0.00309	0.01100	0.00023	0.00354	0.00008	2	61	69	3	71	1	71	2
GB72221	885	1811	0.49	0.05212	0.00177	0.07777	0.00396	0.01082	0.00025	0.00340	0.00007	290	78	76	4	69	2	69	1
GB72222	560	780	0.72	0.04784	0.00048	0.07949	0.00183	0.01205	0.00024	0.00388	0.00009	91	24	78	2	77	2	78	2
GB72223	480	852	0.56	0.04781	0.00051	0.07791	0.00188	0.01182	0.00024	0.00382	0.00010	90	25	76	2	76	2	77	2
GB72224	852	1723	0.49	0.04973	0.00052	0.07787	0.00186	0.01136	0.00024	0.00358	0.00010	182	24	76	2	73	2	72	2

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
<i>GV-1583-2 wt. mean = 86.0 ± 0.8 Ma (2σ)</i>																			
GV158301	153	120	1.28	0.04860	0.00082	0.08973	0.00296	0.01339	0.00028	0.00440	0.00010	129	39	87	3	86	2	89	2
GV158302	527	607	0.87	0.04878	0.00048	0.08974	0.00202	0.01334	0.00026	0.00434	0.00009	137	23	87	2	85	2	88	2
GV158303	363	171	2.12	0.04613	0.00246	0.08486	0.00570	0.01334	0.00029	0.00426	0.00011	4	111	83	5	85	2	86	2
GV158304	202	226	0.90	0.04773	0.00061	0.08626	0.00235	0.01311	0.00026	0.00430	0.00010	86	31	84	2	84	2	87	2
GV158305	94	79	1.20	0.05167	0.00262	0.09383	0.00660	0.01317	0.00031	0.00414	0.00008	271	116	91	6	84	2	84	2
GV158306	343	263	1.30	0.05005	0.00059	0.08991	0.00233	0.01303	0.00026	0.00426	0.00010	197	27	87	2	83	2	86	2
GV158307	297	334	0.89	0.04763	0.00053	0.08644	0.00216	0.01316	0.00026	0.00414	0.00010	81	27	84	2	84	2	84	2
GV158308	154	132	1.16	0.04770	0.00075	0.08975	0.00281	0.01365	0.00028	0.00436	0.00011	84	37	87	3	87	2	88	2
GV158309	401	414	0.97	0.04997	0.00053	0.09246	0.00221	0.01342	0.00027	0.00434	0.00010	194	24	90	2	86	2	88	2
GV158310	570	560	1.02	0.04952	0.00050	0.09400	0.00217	0.01377	0.00027	0.00438	0.00011	173	24	91	2	88	2	88	2
GV158311	293	369	0.79	0.04926	0.00053	0.09361	0.00227	0.01378	0.00027	0.00435	0.00011	160	26	91	2	88	2	88	2
GV158312	170	130	1.31	0.05397	0.00080	0.10128	0.00308	0.01361	0.00028	0.00438	0.00011	370	33	98	3	87	2	88	2
GV158313	235	146	1.61	0.05125	0.00073	0.09446	0.00282	0.01337	0.00028	0.00418	0.00009	252	33	92	3	86	2	84	2
GV158314	568	476	1.19	0.04951	0.00050	0.09220	0.00212	0.01351	0.00027	0.00419	0.00009	172	23	90	2	87	2	85	2
GV158315	277	337	0.82	0.04788	0.00052	0.09150	0.00223	0.01386	0.00028	0.00431	0.00010	93	25	89	2	89	2	87	2
GV158316	360	272	1.33	0.05179	0.00059	0.09647	0.00243	0.01351	0.00027	0.00438	0.00010	276	26	94	2	87	2	88	2
GV158317	355	347	1.02	0.04837	0.00053	0.08915	0.00221	0.01337	0.00027	0.00420	0.00009	117	25	87	2	86	2	85	2
GV158318	725	698	1.04	0.04790	0.00047	0.08753	0.00196	0.01325	0.00026	0.00411	0.00009	94	24	85	2	85	2	83	2
GV158319	135	103	1.31	0.05582	0.00089	0.10439	0.00337	0.01356	0.00029	0.00489	0.00011	445	36	101	3	87	2	89	2
GV158320	91	65	1.40	0.05130	0.00119	0.09609	0.00393	0.01359	0.00030	0.00418	0.00011	254	53	93	4	87	2	84	2
GV158321	262	324	0.81	0.04848	0.00054	0.08965	0.00225	0.01341	0.00027	0.00420	0.00010	123	27	87	2	86	2	85	2
GV158323	225	337	0.67	0.04873	0.00055	0.08944	0.00225	0.01331	0.00027	0.00459	0.00012	135	26	87	2	85	2	93	2
GV158324	180	148	1.22	0.04826	0.00073	0.08977	0.00277	0.01349	0.00028	0.00421	0.00011	112	35	87	3	86	2	85	2
<i>GV-1774 wt. mean = 88.3 ± 0.8 Ma (2σ)</i>																			
GV177401	765	668	1.14	0.05010	0.00050	0.09614	0.00218	0.01392	0.00028	0.00452	0.00010	200	23	93	2	89	2	91	2
GV177402	369	364	1.01	0.04640	0.00158	0.08798	0.00424	0.01375	0.00029	0.00438	0.00012	18	70	86	4	88	2	88	2
GV177403	441	459	0.96	0.05314	0.00058	0.10139	0.00250	0.01384	0.00028	0.00515	0.00014	335	25	98	2	89	2	104	3
GV177404	452	371	1.22	0.04971	0.00054	0.09465	0.00232	0.01381	0.00028	0.00442	0.00011	181	26	92	2	88	2	89	2
GV177407	183	299	0.61	0.04876	0.00056	0.09568	0.00244	0.01423	0.00029	0.00462	0.00012	136	27	93	2	91	2	93	2
GV177408	345	293	1.18	0.04892	0.00057	0.09252	0.00241	0.01372	0.00028	0.00425	0.00011	144	28	90	2	88	2	86	2
GV177409	292	231	1.27	0.04881	0.00062	0.09105	0.00251	0.01353	0.00028	0.00426	0.00011	139	30	88	2	87	2	86	2
GV177410	282	277	1.02	0.04714	0.00056	0.09065	0.00240	0.01395	0.00029	0.00432	0.00012	56	28	88	2	89	2	87	2
GV177411	561	654	0.86	0.04867	0.00050	0.09098	0.00214	0.01356	0.00027	0.00436	0.00012	132	24	88	2	87	2	88	2
GV177412	308	336	0.92	0.05111	0.00058	0.09550	0.00244	0.01355	0.00028	0.00445	0.00012	246	26	93	2	87	2	90	2
GV177413	333	301	1.11	0.04878	0.00057	0.09147	0.00239	0.01360	0.00028	0.00449	0.00010	137	27	89	2	87	2	91	2
GV177414	333	297	1.12	0.04956	0.00058	0.09241	0.00241	0.01352	0.00028	0.00439	0.00010	174	27	90	2	87	2	89	2
GV177415	470	502	0.94	0.04975	0.00052	0.09496	0.00225	0.01384	0.00028	0.00438	0.00010	183	24	92	2	89	2	88	2
GV177416	363	343	1.06	0.04871	0.00055	0.09325	0.00236	0.01389	0.00029	0.00440	0.00010	134	26	91	2	89	2	89	2
GV177417	479	373	1.29	0.04939	0.00194	0.09319	0.00532	0.01368	0.00030	0.00433	0.00008	166	91	90	5	88	2	87	2
GV177418	263	252	1.04	0.04907	0.00175	0.09263	0.00500	0.01369	0.00031	0.00433	0.00008	151	82	90	5	88	2	87	2
GV177419	466	522	0.89	0.04830	0.00051	0.09114	0.00219	0.01369	0.00028	0.00427	0.00010	114	25	89	2	88	2	86	2
GV177420	395	337	1.17	0.04841	0.00055	0.09239	0.00238	0.01384	0.00029	0.00433	0.00011	119	27	90	2	89	2	87	2
GV177421	472	404	1.17	0.05128	0.00057	0.09814	0.00247	0.01388	0.00029	0.00453	0.00011	253	26	95	2	89	2	91	2
GV177422	355	269	1.32	0.05209	0.00063	0.10012	0.00267	0.01394	0.00029	0.00457	0.00012	289	28	97	2	89	2	92	2
GV177423	261	208	1.25	0.04956	0.00067	0.09355	0.00271	0.01369	0.00029	0.00427	0.00011	174	31	91	3	88	2	86	2
GV177424	159	102	1.56	0.05036	0.00096	0.09522	0.00345	0.01371	0.00030	0.00425	0.00012	212	43	92	3	88	2	86	2
<i>CG-332 wt. mean = 92.4 ± 0.8 Ma (2σ)</i>																			
CG332-01	230	149	1.54	0.04792	0.00076	0.09561	0.00302	0.01447	0.00030	0.00472	0.00011	95	37	93	3	93	2	95	2
CG332-02	257	146	1.76	0.04818	0.00078	0.09565	0.00307	0.01440	0.00030	0.00468	0.00011	108	38	93	3	92	2	94	2
CG332-03	331	187	1.77	0.05058	0.00070	0.09946	0.00288	0.01426	0.00029	0.00459	0.00011	222	32	96	3	91	2	93	2
CG332-04	493	254	1.94	0.05100	0.00078	0.10040	0.00318	0.01428	0.00031	0.00447	0.00012	241	36	97	3	91	2	90	2
CG332-05	292	171	1.71	0.04961	0.00282	0.09843	0.00731	0.01439	0.00032	0.00455	0.00008	177	128	95	7	92	2	92	2

(continued on next page)

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
CG332-06	402	213	1.89	0.04827	0.00063	0.09711	0.00272	0.01459	0.00030	0.00462	0.00011	113	30	94	3	93	2	93	2
CG332-07	123	113	1.09	0.04999	0.00253	0.09943	0.00699	0.01443	0.00035	0.00455	0.00009	194	115	96	6	92	2	92	2
CG332-08	325	236	1.38	0.04753	0.00061	0.09377	0.00259	0.01431	0.00029	0.00455	0.00012	76	31	91	2	92	2	92	2
CG332-09	133	117	1.13	0.04616	0.00089	0.09138	0.00327	0.01436	0.00030	0.00459	0.00013	6	38	89	3	92	2	93	3
CG332-10	235	185	1.27	0.04815	0.00218	0.09711	0.00602	0.01463	0.00032	0.00464	0.00009	107	99	94	6	94	2	94	2
CG332-11	402	226	1.78	0.04696	0.00066	0.09399	0.00277	0.01452	0.00030	0.00449	0.00012	47	33	91	3	93	2	91	2
CG332-12	329	229	1.44	0.04608	0.00062	0.09079	0.00257	0.01429	0.00029	0.00450	0.00012	2	27	88	2	91	2	91	2
CG332-13	379	222	1.71	0.04868	0.00062	0.09554	0.00263	0.01424	0.00029	0.00450	0.00010	132	31	93	2	91	2	91	2
CG332-14	155	127	1.22	0.05043	0.00085	0.10047	0.00330	0.01445	0.00030	0.00461	0.00012	215	39	97	3	92	2	93	2
CG332-15	484	298	1.62	0.04814	0.00056	0.09405	0.00242	0.01417	0.00029	0.00446	0.00010	106	27	91	2	91	2	90	2
CG332-16	253	174	1.45	0.04778	0.00213	0.09864	0.00607	0.01497	0.00033	0.00475	0.00009	89	98	96	6	96	2	96	2
CG332-18	285	188	1.52	0.05024	0.00069	0.09885	0.00285	0.01427	0.00029	0.00464	0.00012	206	31	96	3	91	2	94	2
CG332-19	368	219	1.68	0.04871	0.00063	0.09735	0.00272	0.01450	0.00030	0.00457	0.00011	134	31	94	3	93	2	92	2
CG332-20	417	230	1.81	0.04845	0.00062	0.09739	0.00270	0.01458	0.00030	0.00462	0.00012	121	31	94	2	93	2	93	2
CG332-21	213	147	1.45	0.04886	0.00076	0.09988	0.00314	0.01483	0.00031	0.00464	0.00012	141	37	97	3	95	2	94	2
CG332-22	196	124	1.58	0.04830	0.00083	0.09578	0.00319	0.01439	0.00030	0.00455	0.00012	114	41	93	3	92	2	92	2
CG332-23	566	265	2.13	0.04749	0.00058	0.09605	0.00258	0.01467	0.00030	0.00451	0.00012	74	29	93	2	94	2	91	2
CG332-24	235	151	1.55	0.04647	0.00076	0.09206	0.00298	0.01437	0.00030	0.00457	0.00013	22	35	89	3	92	2	92	3
<i>CG-410 wt. mean = 91.5 ± 0.8 Ma (2σ)</i>																			
CG410-01	227	179	1.27	0.04562	0.00065	0.09253	0.00276	0.01471	0.00031	0.00472	0.00011	-22	27	90	3	94	2	95	2
CG410-02	637	714	0.89	0.04793	0.00132	0.09537	0.00423	0.01443	0.00031	0.00458	0.00008	96	63	92	4	92	2	92	2
CG410-03	234	220	1.06	0.04722	0.00061	0.09395	0.00262	0.01443	0.00030	0.00454	0.00011	60	31	91	2	92	2	92	2
CG410-04	297	216	1.38	0.05000	0.00065	0.09820	0.00272	0.01425	0.00029	0.00453	0.00011	195	30	95	3	91	2	91	2
CG410-05	259	444	0.58	0.04816	0.00051	0.09549	0.00230	0.01438	0.00029	0.00473	0.00012	107	25	93	2	92	2	95	2
CG410-06	415	578	0.72	0.04798	0.00049	0.09319	0.00218	0.01409	0.00028	0.00452	0.00011	98	24	90	2	90	2	91	2
CG410-08	350	325	1.08	0.04877	0.00056	0.09382	0.00241	0.01395	0.00029	0.00462	0.00012	137	26	91	2	89	2	93	2
CG410-10	491	716	0.69	0.05096	0.00051	0.10275	0.00235	0.01462	0.00030	0.00479	0.00012	239	23	99	2	94	2	97	2
CG410-11	198	287	0.69	0.04862	0.00057	0.09961	0.00261	0.01486	0.00031	0.00475	0.00013	130	28	96	2	95	2	96	3
CG410-12	433	575	0.75	0.04837	0.00050	0.09532	0.00226	0.01429	0.00029	0.00470	0.00013	117	24	92	2	91	2	95	3
CG410-13	743	910	0.82	0.05118	0.00133	0.09540	0.00409	0.01352	0.00028	0.00426	0.00008	249	61	93	4	87	2	86	2
CG410-14	220	302	0.73	0.05012	0.00057	0.09967	0.00254	0.01443	0.00029	0.00459	0.00011	201	27	96	2	92	2	93	2
CG410-15	363	559	0.65	0.04955	0.00051	0.09764	0.00228	0.01429	0.00029	0.00467	0.00011	174	24	95	2	91	2	94	2
CG410-16	373	594	0.63	0.04755	0.00048	0.09311	0.00217	0.01420	0.00029	0.00455	0.00011	77	24	90	2	91	2	92	2
CG410-17	266	243	1.09	0.04671	0.00059	0.09064	0.00249	0.01408	0.00029	0.00443	0.00011	34	29	88	2	90	2	89	2
CG410-18	456	701	0.65	0.04753	0.00106	0.09108	0.00356	0.01390	0.00029	0.00441	0.00008	76	50	89	3	89	2	89	2
CG410-19	164	228	0.72	0.04745	0.00124	0.09307	0.00403	0.01422	0.00030	0.00452	0.00008	72	59	90	4	91	2	91	2
CG410-20	548	724	0.76	0.04836	0.00048	0.09425	0.00216	0.01414	0.00028	0.00443	0.00011	117	24	91	2	91	2	89	2
CG410-21	375	500	0.75	0.04857	0.00051	0.09832	0.00235	0.01468	0.00030	0.00459	0.00012	127	25	95	2	94	2	93	2
CG410-22	554	333	1.66	0.04937	0.00056	0.09949	0.00253	0.01462	0.00030	0.00440	0.00011	165	26	96	2	94	2	89	2
CG410-23	722	823	0.88	0.04786	0.00048	0.09427	0.00215	0.01429	0.00029	0.00444	0.00011	92	23	91	2	91	2	90	2
CG410-24	574	732	0.78	0.04729	0.00127	0.09312	0.00403	0.01428	0.00031	0.00454	0.00009	64	60	90	4	91	2	92	2
<i>8-02-1 wt. mean = 67.8 ± 0.8 Ma (2σ); Average calculation except the young 4 components</i>																			
8-02-1 01	202	142	1.43	0.04838	0.00153	0.07077	0.00352	0.01061	0.00023	0.00346	0.00010	118	72	69	3	68	1	70	2
8-02-1 02	92	82	1.12	0.04941	0.00323	0.07436	0.00642	0.01091	0.00027	0.00345	0.00008	167	147	73	6	70	2	70	2
8-02-1 04	432	381	1.13	0.04899	0.00072	0.07183	0.00218	0.01063	0.00022	0.00332	0.00008	147	35	70	2	68	1	67	2
8-02-1 05	385	201	1.91	0.04762	0.00110	0.07005	0.00279	0.01067	0.00022	0.00328	0.00008	80	53	69	3	68	1	66	2
8-02-1 07	567	355	1.60	0.05565	0.00577	0.08358	0.01030	0.01089	0.00027	0.00339	0.00008	438	232	82	10	70	2	68	2
8-02-1 08	1849	1456	1.27	0.05037	0.00052	0.07414	0.00174	0.01068	0.00021	0.00345	0.00008	212	24	73	2	68	1	70	2
8-02-1 09	1190	1226	0.97	0.04882	0.00060	0.07319	0.00198	0.01087	0.00023	0.00329	0.00008	139	29	72	2	70	1	66	2
8-02-1 10	557	324	1.72	0.05357	0.00387	0.07458	0.00711	0.01010	0.00027	0.00316	0.00006	353	159	73	7	65	2	64	1
8-02-1-11	622	396	1.57	0.05409	0.00115	0.07901	0.00309	0.01060	0.00024	0.00333	0.00011	375	48	77	3	68	2	67	2
8-02-1-12	891	1198	0.74	0.05428	0.00158	0.07932	0.00356	0.01060	0.00022	0.00331	0.00006	383	65	78	3	68	1	67	1
8-02-1-18	2196	2594	0.85	0.05549	0.00377	0.07712	0.00644	0.01008	0.00022	0.00314	0.00007	432	152	75	6	65	1	63	1
8-02-1-19	332	242	1.37	0.04908	0.00103	0.07009	0.00266	0.01036	0.00022	0.00327	0.00011	152	49	69	3	66	1	66	2

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
8-02-1-21	204	200	1.02	0.05022	0.00123	0.07218	0.00301	0.01042	0.00022	0.00334	0.00012	205	56	71	3	67	1	67	2
8-02-1-22	118	126	0.94	0.04926	0.00170	0.07388	0.00391	0.01088	0.00024	0.00331	0.00014	160	79	72	4	70	2	67	3
8-02-1-23	413	356	1.16	0.05720	0.00188	0.08290	0.00454	0.01052	0.00028	0.00327	0.00016	499	74	81	4	67	2	66	3
8-02-1-24	1692	1892	0.89	0.05139	0.00059	0.07581	0.00198	0.01070	0.00023	0.00335	0.00010	258	27	74	2	69	1	68	2
8-02-1-06 (young)	4630	1865	2.48	0.13443	0.00533	0.16200	0.00952	0.00874	0.00020	0.00248	0.00005	2157	69	152	8	56	1	50	1
8-02-1-14 (young)	1134	373	3.04	0.12056	0.00969	0.12162	0.01279	0.00732	0.00022	0.00210	0.00005	1964	146	117	12	47	1	42	1
8-02-1-15 (young)	1873	2163	0.87	0.05385	0.00833	0.05979	0.01029	0.00805	0.00020	0.00252	0.00020	365	326	59	10	52	1	51	4
8-02-1-16 (young)	819	822	1.00	0.07003	0.01060	0.07751	0.01346	0.00803	0.00023	0.00244	0.00012	929	325	76	13	52	1	49	2
8-881/2 wt. mean = 92.9 ± 0.9 Ma (2σ)																			
8-881/2 01	932	594	1.57	0.05320	0.00057	0.10300	0.00249	0.01404	0.00028	0.00464	0.00012	337	24	100	2	90	2	94	2
8-881/2 02	1435	616	2.33	0.04697	0.00051	0.09227	0.00225	0.01425	0.00028	0.00425	0.00011	48	26	90	2	91	2	86	2
8-881/2 03	769	391	1.96	0.04838	0.00060	0.09618	0.00259	0.01442	0.00029	0.00449	0.00012	118	29	93	2	92	2	91	2
8-881/2 04	428	306	1.40	0.05185	0.00069	0.10267	0.00288	0.01436	0.00029	0.00464	0.00013	279	30	99	3	92	2	94	3
8-881/2 05	990	706	1.40	0.04948	0.00052	0.09853	0.00234	0.01445	0.00029	0.00446	0.00012	171	24	95	2	92	2	90	2
8-881/2 06	1496	526	2.85	0.04985	0.00059	0.09724	0.00251	0.01415	0.00028	0.00449	0.00013	188	27	94	2	91	2	91	3
8-881/2 07	627	433	1.45	0.04840	0.00059	0.09542	0.00253	0.01430	0.00029	0.00448	0.00013	119	28	93	2	92	2	90	3
8-881/2 08	428	259	1.65	0.04793	0.00072	0.09612	0.00295	0.01455	0.00030	0.00451	0.00014	96	35	93	3	93	2	91	3
8-881/2 09	1216	807	1.51	0.04793	0.00054	0.09510	0.00238	0.01439	0.00029	0.00444	0.00014	96	26	92	2	92	2	90	3
8-881/2 10	2503	4558	0.55	0.05594	0.00109	0.11125	0.00425	0.01442	0.00035	0.00439	0.00032	450	44	107	4	92	2	89	6
8-881/2-11	1933	1216	1.59	0.04826	0.00045	0.10020	0.00213	0.01506	0.00029	0.00466	0.00011	112	22	97	2	96	2	94	2
8-881/2-12	1820	2168	0.84	0.05235	0.00176	0.10777	0.00544	0.01493	0.00033	0.00469	0.00009	301	78	104	5	96	2	94	2
8-881/2-13	1134	694	1.63	0.04787	0.00048	0.09587	0.00219	0.01453	0.00028	0.00452	0.00011	93	24	93	2	93	2	91	2
8-881/2-14	4662	1546	3.02	0.06237	0.00088	0.12820	0.00387	0.01491	0.00033	0.00461	0.00020	687	30	122	3	95	2	93	4
8-881/2-15	4123	1161	3.55	0.06841	0.00103	0.13347	0.00403	0.01415	0.00028	0.00459	0.00023	881	31	127	4	91	2	93	5
8-881/2-16	1745	816	2.14	0.04876	0.00048	0.10161	0.00228	0.01511	0.00029	0.00455	0.00012	136	23	98	2	97	2	92	2
8-881/2-17	666	572	1.16	0.04620	0.00146	0.09570	0.00422	0.01502	0.00029	0.00479	0.00012	8	65	93	4	96	2	97	2
8-881/2-18	1323	643	2.06	0.04853	0.00050	0.09638	0.00226	0.01440	0.00028	0.00450	0.00012	125	25	93	2	92	2	91	2
AH-2-11 wt. mean = 108.1 ± 1.3 Ma (2σ)																			
AH-2-11-01	250	238	1.05	0.05166	0.00067	0.12355	0.00337	0.01735	0.00034	0.00526	0.00015	270	30	118	3	111	2	106	3
AH-2-11-02	390	312	1.25	0.05495	0.00086	0.13328	0.00411	0.01759	0.00035	0.00592	0.00024	410	35	127	4	112	2	119	5
AH-2-11-03	86	135	0.64	0.05160	0.00089	0.12366	0.00408	0.01738	0.00035	0.00575	0.00020	268	39	118	4	111	2	116	4
AH-2-11-04	136	202	0.67	0.05162	0.00071	0.12349	0.00352	0.01735	0.00034	0.00572	0.00018	269	32	118	3	111	2	115	4
AH-2-11-05	627	448	1.40	0.05030	0.00054	0.12567	0.00301	0.01812	0.00035	0.00586	0.00014	209	25	120	3	116	2	118	3
AH-2-11-06	1225	1236	0.99	0.05700	0.00185	0.13313	0.00624	0.01694	0.00033	0.00526	0.00009	491	72	127	6	108	2	106	2
AH-2-11-07	380	363	1.05	0.05036	0.00057	0.12436	0.00313	0.01791	0.00035	0.00578	0.00015	212	26	119	3	114	2	116	3
AH-2-11-08	457	553	0.83	0.05006	0.00174	0.12489	0.00617	0.01809	0.00036	0.00571	0.00010	198	80	119	6	116	2	115	2
AH-2-11-09	606	736	0.82	0.04780	0.00049	0.11078	0.00258	0.01681	0.00032	0.00523	0.00015	89	24	107	2	107	2	105	3
AH-2-11-10	329	401	0.82	0.04938	0.00057	0.11287	0.00286	0.01658	0.00032	0.00525	0.00015	166	27	109	3	106	2	106	3
AH-2-11-11	335	883	0.38	0.04843	0.00093	0.10975	0.00386	0.01644	0.00034	0.00521	0.00010	120	45	106	4	105	2	105	2
AH-2-11-12	249	472	0.53	0.04811	0.00054	0.10659	0.00265	0.01607	0.00031	0.00519	0.00015	105	26	103	2	103	2	105	3
AH-2-11-13	343	782	0.44	0.04895	0.00049	0.10795	0.00247	0.01599	0.00031	0.00565	0.00016	145	24	104	2	102	2	114	3
AH-2-11-14	695	766	0.91	0.05029	0.00051	0.11454	0.00262	0.01652	0.00032	0.00527	0.00015	208	24	110	2	106	2	106	3
AH-2-11-15	653	1570	0.42	0.04980	0.00060	0.11574	0.00309	0.01686	0.00035	0.00561	0.00022	186	28	111	3	108	2	113	4
AH-2-11-16	514	849	0.61	0.05115	0.00057	0.12009	0.00303	0.01703	0.00035	0.00536	0.00019	248	26	115	3	109	2	108	4
AH-2-11-17	171	282	0.61	0.05029	0.00065	0.11716	0.00322	0.01690	0.00034	0.00564	0.00015	208	30	112	3	108	2	114	3
AH-2-11-18	122	409	0.30	0.04864	0.00055	0.11189	0.00282	0.01669	0.00033	0.00542	0.00016	131	26	108	3	107	2	109	3
AH-2-11-19	776	1618	0.48	0.04838	0.00104	0.11121	0.00418	0.01667	0.00035	0.00528	0.00010	118	50	107	4	107	2	107	2
AH-2-11-20	618	591	1.04	0.04970	0.00052	0.11634	0.00275	0.01698	0.00033	0.00532	0.00014	181	24	112	3	109	2	107	3
AH-2-11-21	368	662	0.56	0.04874	0.00051	0.11422	0.00270	0.01700	0.00033	0.00552	0.00015	135	24	110	2	109	2	111	3
AH-2-11-22	203	301	0.67	0.04898	0.00064	0.11300	0.00313	0.01674	0.00033	0.00535	0.00016	147	31	109	3	107	2	108	3

(continued on next page)



Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
AH-2-11-23	208	224	0.93	0.05534	0.00116	0.13288	0.00515	0.01742	0.00039	0.00550	0.00022	426	47	127	5	111	2	111	4
AH-2-11-24	273	299	0.91	0.04967	0.00185	0.11414	0.00611	0.01667	0.00035	0.00527	0.00009	179	85	110	6	107	2	106	2
<i>AH-3-11 wt. mean = 57.8 ± 1.1 Ma (2σ)</i>																			
AH-3-11-02	2596	1206	2.15	0.07034	0.00088	0.08762	0.00240	0.00904	0.00019	0.00176	0.00007	938	26	85	2	58	1	36	1
AH-3-11-03	337	280	1.20	0.06071	0.00115	0.07865	0.00280	0.00940	0.00020	0.00302	0.00011	629	41	77	3	60	1	61	2
AH-3-11-04	127	55	2.32	0.10227	0.00349	0.13253	0.00742	0.00940	0.00025	0.00286	0.00011	1666	63	126	7	60	2	58	2
AH-3-11-05	1906	925	2.06	0.06018	0.00068	0.07324	0.00183	0.00883	0.00017	0.00245	0.00008	610	25	72	2	57	1	49	2
AH-3-11-06	162	178	0.91	0.04773	0.00204	0.05957	0.00363	0.00905	0.00020	0.00287	0.00007	86	94	59	3	58	1	58	1
AH-3-11-07	2879	3519	0.82	0.05478	0.00057	0.06646	0.00158	0.00880	0.00018	0.00217	0.00006	403	23	65	2	56	1	44	1
AH-3-11-08	1343	4205	0.32	0.04695	0.00044	0.05744	0.00123	0.00887	0.00017	0.00288	0.00007	47	23	57	1	57	1	58	1
AH-3-11-09	4321	5606	0.77	0.04840	0.00056	0.06060	0.00151	0.00908	0.00017	0.00292	0.00013	119	27	60	1	58	1	59	3
<i>8-11-54/1 wt. mean of most concentrated part = 131.4 ± 2.0 Ma (2σ)</i>																			
8-11-54/1-01	121	91	1.33	0.05285	0.00105	0.19018	0.00692	0.02610	0.00054	0.00869	0.00026	322	45	177	6	166	3	175	5
8-11-54/1-02	98	261	0.37	0.05054	0.00066	0.14401	0.00397	0.02067	0.00041	0.00673	0.00022	220	31	137	4	132	3	136	4
8-11-54/1-03	135	264	0.51	0.05096	0.00067	0.14201	0.00394	0.02021	0.00040	0.00658	0.00020	239	30	135	4	129	3	133	4
8-11-54/1-04	58	51	1.14	0.04945	0.00246	0.16221	0.01154	0.02379	0.00060	0.00738	0.00038	169	113	153	10	152	4	149	8
8-11-54/1-05	175	88	1.98	0.05500	0.00083	0.41681	0.01259	0.05497	0.00109	0.01711	0.00058	412	34	354	9	345	7	343	12
8-11-54/1-06	76	331	0.23	0.05062	0.00092	0.14299	0.00486	0.02049	0.00042	0.00646	0.00013	223	43	136	4	131	3	130	3
8-11-54/1-07	195	175	1.12	0.05043	0.00074	0.17002	0.00508	0.02445	0.00049	0.00800	0.00025	215	34	159	4	156	3	161	5
8-11-54/1-08	219	291	0.75	0.05487	0.00071	0.46261	0.01285	0.06115	0.00124	0.02174	0.00098	407	29	386	9	383	8	435	19
8-11-54/1-09	90	157	0.57	0.10777	0.00121	2.93315	0.07236	0.19740	0.00366	0.05720	0.00104	1762	21	1391	19	1161	20	1124	20
8-11-54/1-10	200	325	0.62	0.05514	0.00050	0.49987	0.01046	0.06575	0.00126	0.02127	0.00050	418	20	412	7	410	8	425	10
8-11-54/1-11	46	180	0.26	0.05066	0.00061	0.14485	0.00384	0.02074	0.00042	0.00687	0.00021	225	28	137	3	132	3	138	4
8-11-54/1-12	94	403	0.23	0.05132	0.00072	0.14505	0.00435	0.02050	0.00045	0.00688	0.00026	255	33	138	4	131	3	139	5
8-11-54/1-13	47	343	0.14	0.04909	0.00057	0.15083	0.00393	0.02229	0.00046	0.01027	0.00034	152	28	143	3	142	3	207	7
8-11-54/1-14	170	227	0.75	0.05030	0.00134	0.14335	0.00623	0.02067	0.00043	0.00652	0.00012	209	61	136	6	132	3	131	2
8-11-54/1-15	116	189	0.61	0.04961	0.00060	0.14486	0.00380	0.02118	0.00042	0.00718	0.00019	177	28	137	3	135	3	145	4
8-11-54/1-16	113	504	0.22	0.04948	0.00078	0.13890	0.00420	0.02036	0.00040	0.00644	0.00013	171	36	132	4	130	3	130	3
8-11-54/1-17	208	315	0.66	0.05059	0.00051	0.20338	0.00468	0.02915	0.00057	0.01062	0.00028	222	24	188	4	185	4	214	6
8-11-54/1-18	123	137	0.90	0.05228	0.00070	0.23854	0.00670	0.03309	0.00066	0.01060	0.00035	298	31	217	5	210	4	213	7
8-11-54/1-19	104	242	0.43	0.05002	0.00057	0.14109	0.00358	0.02046	0.00041	0.00674	0.00020	196	27	134	3	131	3	136	4
8-11-54/1-20	108	349	0.31	0.10972	0.00107	3.42503	0.07664	0.22642	0.00455	0.06147	0.00212	1795	18	1510	18	1316	24	1206	40
<i>8-11-51/3 wt. mean = 108.1 ± 1.1 Ma (2σ)</i>																			
8-11-51/3 01	283	179	1.58	0.04829	0.00070	0.11069	0.00329	0.01663	0.00034	0.00514	0.00013	114	34	107	3	106	2	104	3
8-11-51/3 02	135	106	1.28	0.05103	0.00092	0.11941	0.00407	0.01697	0.00035	0.00531	0.00014	242	41	115	4	108	2	107	3
8-11-51/3 03	107	82	1.32	0.04943	0.00111	0.11680	0.00460	0.01714	0.00036	0.00541	0.00015	168	52	112	4	110	2	109	3
8-11-51/3 04	154	93	1.66	0.05051	0.00103	0.11626	0.00432	0.01670	0.00035	0.00540	0.00015	219	48	112	4	107	2	109	3
8-11-51/3 05	233	121	1.94	0.05076	0.00085	0.11875	0.00389	0.01697	0.00035	0.00536	0.00014	230	39	114	4	108	2	108	3
8-11-51/3 06	118	87	1.36	0.04899	0.00244	0.11455	0.00779	0.01696	0.00038	0.00537	0.00010	147	113	110	7	108	2	108	2
8-11-51/3 07	146	124	1.18	0.04903	0.00113	0.11571	0.00473	0.01712	0.00038	0.00555	0.00018	149	54	111	4	109	2	112	4
8-11-51/3 08	157	127	1.24	0.04922	0.00084	0.11861	0.00388	0.01748	0.00035	0.00553	0.00016	158	41	114	4	112	2	111	3
8-11-51/3 09	334	180	1.86	0.04915	0.00069	0.11595	0.00334	0.01711	0.00034	0.00544	0.00015	155	33	111	3	109	2	110	3
8-11-51/3 10	120	88	1.36	0.04805	0.00218	0.11578	0.00773	0.01748	0.00044	0.00623	0.00035	102	100	111	7	112	3	126	7
8-11-51/3 11	372	213	1.75	0.04856	0.00081	0.11417	0.00375	0.01705	0.00036	0.00521	0.00017	127	39	110	3	109	2	105	3
8-11-51/3 12	191	121	1.58	0.05304	0.00112	0.12355	0.00476	0.01690	0.00037	0.00526	0.00018	331	48	118	4	108	2	106	4
8-11-51/3 13	170	140	1.21	0.04873	0.00077	0.11681	0.00366	0.01739	0.00035	0.00542	0.00014	135	38	112	3	111	2	109	3
8-11-51/3 14	261	148	1.77	0.04893	0.00077	0.11718	0.00366	0.01737	0.00035	0.00542	0.00013	144	37	113	3	111	2	109	3
8-11-51/3 15	110	95	1.16	0.04812	0.00104	0.11130	0.00427	0.01678	0.00035	0.00549	0.00015	105	51	107	4	107	2	111	3
8-11-51/3 16	198	185	1.07	0.04974	0.00067	0.12152	0.00343	0.01772	0.00035	0.00564	0.00014	183	32	116	3	113	2	114	3
8-11-51/3 17	299	170	1.76	0.05236	0.00072	0.12186	0.00351	0.01688	0.00034	0.00528	0.00013	301	31	117	3	108	2	106	3
8-11-51/3 19	300	165	1.82	0.05037	0.00308	0.11494	0.00899	0.01655	0.00036	0.00522	0.00009	212	139	110	8	106	2	105	2
8-11-51/3 20	160	144	1.11	0.04984	0.00210	0.11311	0.00677	0.01646	0.00036	0.00520	0.00009	187	97	109	6	105	2	105	2
8-11-51/3 21	401	226	1.77	0.05016	0.00065	0.11311	0.00308	0.01636	0.00032	0.00514	0.00014	202	30	109	3	105	2	104	3

Table 2 (continued)

Analysis No.	Th (ppm)	U (ppm)	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	±1σ	<sup>207</sup> Pb/ <sup>235</sup> U	±1σ	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ	<sup>208</sup> Pb/ <sup>232</sup> Th	±1σ
8-11-51/3 22	133	100	1.32	0.05012	0.00107	0.11258	0.00429	0.01629	0.00034	0.00524	0.00016	201	50	108	4	104	2	106	3
8-11-51/3 23	183	177	1.04	0.04921	0.00073	0.11259	0.00337	0.01659	0.00033	0.00540	0.00016	158	35	108	3	106	2	109	3
8-11-51/3 24	229	198	1.16	0.05042	0.00069	0.11415	0.00326	0.01642	0.00033	0.00526	0.00015	214	31	110	3	105	2	106	3
<i>8-871/1 wt. mean = 108.8 ± 0.8 Ma (2σ)</i>																			
8-871-1 01	181	241	0.75	0.05109	0.00063	0.12032	0.00322	0.01708	0.00034	0.00540	0.00014	245	28	115	3	109	2	109	3
8-871-1 02	190	264	0.72	0.04813	0.00060	0.11245	0.00299	0.01695	0.00033	0.00516	0.00013	106	29	108	3	108	2	104	3
8-871-1 03	230	309	0.74	0.04804	0.00057	0.11219	0.00288	0.01694	0.00033	0.00523	0.00014	101	28	108	3	108	2	105	3
8-871-1 04	318	370	0.86	0.04966	0.00055	0.11607	0.00287	0.01695	0.00033	0.00534	0.00014	179	26	112	3	108	2	108	3
8-871-1 05	142	188	0.76	0.04846	0.00070	0.11319	0.00336	0.01694	0.00034	0.00528	0.00015	122	34	109	3	108	2	106	3
8-871-1 06	146	161	0.91	0.04951	0.00076	0.11478	0.00354	0.01682	0.00034	0.00536	0.00015	172	36	110	3	108	2	108	3
8-871-1 07	482	931	0.52	0.04983	0.00060	0.11643	0.00308	0.01695	0.00035	0.00519	0.00018	187	28	112	3	108	2	105	4
8-871-1 08	493	903	0.55	0.04853	0.00056	0.11544	0.00295	0.01725	0.00035	0.00468	0.00016	125	27	111	3	110	2	94	3
8-871-1 09	198	277	0.72	0.05192	0.00064	0.12413	0.00330	0.01734	0.00034	0.00539	0.00016	282	28	119	3	111	2	109	3
8-871-1 10	266	398	0.67	0.04924	0.00055	0.11764	0.00294	0.01733	0.00034	0.00541	0.00016	159	26	113	3	111	2	109	3
8-871-1 11	240	314	0.77	0.04908	0.00078	0.11338	0.00361	0.01676	0.00035	0.00546	0.00020	152	37	109	3	107	2	110	4
8-871-1 12	701	846	0.83	0.05068	0.00053	0.11829	0.00280	0.01693	0.00033	0.00542	0.00017	226	24	114	3	108	2	109	3
8-871-1 13	216	279	0.77	0.04938	0.00060	0.11553	0.00307	0.01697	0.00034	0.00552	0.00015	166	28	111	3	108	2	111	3
8-871-1 14	419	546	0.77	0.05091	0.00093	0.11834	0.00427	0.01686	0.00039	0.00479	0.00019	237	42	114	4	108	2	97	4
8-871-1 15	305	349	0.87	0.04958	0.00056	0.11889	0.00297	0.01739	0.00034	0.00545	0.00014	175	26	114	3	111	2	110	3
8-871-1 16	715	860	0.83	0.04943	0.00144	0.11739	0.00530	0.01722	0.00036	0.00544	0.00010	169	68	113	5	110	2	110	2
8-871-1 17	268	349	0.77	0.04953	0.00057	0.11482	0.00291	0.01681	0.00033	0.00550	0.00014	173	27	110	3	107	2	111	3
8-871-1 18	160	191	0.84	0.05171	0.00072	0.12175	0.00351	0.01708	0.00034	0.00555	0.00015	273	32	117	3	109	2	112	3
8-871-1 19	358	313	1.14	0.05743	0.00066	0.13468	0.00342	0.01701	0.00034	0.00504	0.00013	508	25	128	3	109	2	102	3
8-871-1 20	203	236	0.86	0.04850	0.00066	0.11479	0.00324	0.01717	0.00034	0.00562	0.00016	124	32	110	3	110	2	113	3
8-871-1 21	196	284	0.69	0.04814	0.00060	0.11228	0.00303	0.01692	0.00034	0.00528	0.00015	106	29	108	3	108	2	106	3
8-871-1 22	325	349	0.93	0.05829	0.00073	0.13749	0.00374	0.01711	0.00035	0.00559	0.00017	541	27	131	3	109	2	113	3
8-871-1 23	213	245	0.87	0.05421	0.00068	0.12954	0.00350	0.01733	0.00035	0.00549	0.00016	380	28	124	3	111	2	111	3
8-871-1 24	217	245	0.89	0.04994	0.00066	0.11591	0.00324	0.01684	0.00034	0.00511	0.00015	192	31	111	3	108	2	103	3
<i>8-872/1 wt. mean = 105.9 ± 1.0 Ma (2σ)</i>																			
8-872-1 01	196	163	1.20	0.05302	0.00079	0.12138	0.00363	0.01660	0.00033	0.00536	0.00014	330	33	116	3	106	2	108	3
8-872-1 02	134	120	1.12	0.04756	0.00092	0.11096	0.00391	0.01692	0.00034	0.00545	0.00015	77	45	107	4	108	2	110	3
8-872-1 03	297	198	1.50	0.05236	0.00098	0.12039	0.00423	0.01668	0.00035	0.00519	0.00017	301	42	115	4	107	2	105	3
8-872-1 04	214	179	1.20	0.05411	0.00075	0.12414	0.00357	0.01664	0.00033	0.00535	0.00014	376	31	119	3	106	2	108	3
8-872-1 05	110	107	1.03	0.04758	0.00231	0.10899	0.00718	0.01662	0.00038	0.00528	0.00014	78	105	105	7	106	2	106	3
8-872-1 06	290	206	1.41	0.05162	0.00248	0.11732	0.00764	0.01648	0.00035	0.00518	0.00009	269	110	113	7	105	2	104	2
8-872-1 07	493	462	1.07	0.05009	0.00062	0.11676	0.00313	0.01691	0.00034	0.00544	0.00018	199	29	112	3	108	2	110	4
8-872-1 08	183	146	1.26	0.05317	0.00086	0.12358	0.00393	0.01686	0.00034	0.00543	0.00016	336	37	118	4	108	2	109	3
8-872-1 09	186	159	1.17	0.05045	0.00230	0.11557	0.00719	0.01661	0.00036	0.00524	0.00009	216	103	111	7	106	2	106	2
8-872-1 10	251	203	1.24	0.05081	0.00076	0.12084	0.00366	0.01725	0.00035	0.00564	0.00018	232	35	116	3	110	2	114	4
8-872-1 11	346	259	1.34	0.05065	0.00123	0.12116	0.00519	0.01735	0.00040	0.00558	0.00027	225	56	116	5	111	3	112	5
8-872-1 12	274	193	1.42	0.04886	0.00265	0.11112	0.00786	0.01649	0.00037	0.00522	0.00011	141	123	107	7	105	2	105	2
8-872-1 13	142	138	1.03	0.05023	0.00099	0.11720	0.00423	0.01692	0.00035	0.00563	0.00016	206	44	113	4	108	2	113	3
8-872-1 14	245	167	1.47	0.04701	0.00099	0.10659	0.00401	0.01645	0.00034	0.00524	0.00015	50	47	103	4	105	2	106	3
8-872-1 15	987	933	1.06	0.04854	0.00053	0.10720	0.00263	0.01602	0.00032	0.00507	0.00014	126	26	103	2	102	2	102	3
8-872-1 16	257	194	1.33	0.05420	0.00105	0.12659	0.00457	0.01694	0.00036	0.00546	0.00018	379	43	121	4	108	2	110	4
8-872-1 17	140	104	1.34	0.05147	0.00125	0.11392	0.00473	0.01605	0.00034	0.00528	0.00016	262	55	110	4	103	2	106	3
8-872-1 18	151	140	1.08	0.05300	0.00100	0.11712	0.00412	0.01603	0.00033	0.00530	0.00016	329	44	112	4	103	2	107	3
8-872-1 19	159	120	1.32	0.05135	0.00113	0.11345	0.00439	0.01603	0.00033	0.00485	0.00016	257	51	109	4	103	2	98	3
8-872-1 20	262	200	1.31	0.05255	0.00079	0.11870	0.00360	0.01638	0.00033	0.00528	0.00016	309	34	114	3	105	2	106	3
8-872-1 21	173	153	1.14	0.04889	0.00095	0.10960	0.00389	0.01626	0.00033	0.00518	0.00017	143	45	106	4	104	2	104	3

**Table 3**  
Chemical data for Mesozoic and Early Cenozoic granitoids from Sikhote-Alin.

Sample No.	B-300	B-257	B-433	B-494	B-720	B-574	B-611	B-781	B-909A	B-995	GV-722	CV-1401	GV-1583-2	CV-1774	IG-332	IG-410	2/8/2001	8-881/2	AN-2-11	AN-3-11	8-11-54/1	8-11-51/3	8-871/1	8-872/1	
Rock-type	Quartz monzodiorite	Alkali feldspar granite	Granodiorite	Granodiorite	Granite	Granite	Granodiorite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Alkali feldspar granite	Granodiorite	Granite	Alkali feldspar granite	Granite	Qtz monzodiorite	Granodiorite	Granodiorite	
<i>Major element (in %)</i>																									
SiO <sub>2</sub>	59.74	74.06	68.96	70.16	72.57	71.49	64.54	69.87	65.66	72.45	69.35	67.48	74.41	73.07	69.90	72.86	78.32	68.17	68.55	76.07	69.48	56.54	69.63	67.49	
TiO <sub>2</sub>	0.77	0.22	0.46	0.34	0.25	0.28	0.59	0.36	0.63	0.22	0.33	0.42	0.19	0.25	0.32	0.25	0.03	0.52	0.44	0.09	0.47	1.08	0.42	0.51	
Al <sub>2</sub> O <sub>3</sub>	15.38	12.94	14.95	14.82	13.92	13.86	15.88	14.42	13.97	14.12	15.26	15.04	13.25	13.88	13.73	13.22	11.11	15.10	14.73	12.69	14.78	16.41	15.02	14.54	
Fe <sub>2</sub> O <sub>3</sub>	7.85	3.18	4.08	3.14	2.57	3.42	6.57	4.29	7.61	3.11	3.21	3.56	1.99	2.55	3.93	3.28	1.22	0.95	3.74	1.60	5.03	8.36	3.20	4.55	
MnO	0.12	0.13	0.07	0.07	0.06	0.11	0.13	0.11	0.13	0.04	0.12	0.08	0.05	0.06	0.07	0.04	0.02	2.85	0.06	0.04	0.06	0.13	0.04	0.07	
MgO	4.22	0.29	0.95	0.90	0.61	0.50	1.19	0.71	1.30	0.52	0.54	1.32	0.26	0.35	1.28	0.45	0.08	1.54	1.15	0.03	1.07	3.70	1.67	1.97	
CaO	6.12	0.53	2.87	2.71	2.22	2.00	3.87	2.47	3.29	2.30	1.58	2.37	0.91	1.46	2.36	1.50	0.59	3.67	2.19	0.57	1.37	6.43	2.65	3.68	
Na <sub>2</sub> O	2.95	4.61	3.86	3.85	3.68	3.63	3.93	3.55	3.43	3.05	4.21	3.12	3.79	4.05	2.74	2.81	3.62	3.70	3.69	3.82	3.13	3.15	3.32	2.71	
K <sub>2</sub> O	2.10	3.58	3.43	3.32	3.49	4.01	2.26	3.70	3.40	4.19	4.27	5.38	4.56	3.82	4.66	5.09	4.27	2.52	4.00	4.67	4.19	3.03	2.98	3.98	
P <sub>2</sub> O <sub>5</sub>	0.15	0.05	0.11	0.10	0.07	0.07	0.21	0.11	0.16	0.06	0.10	0.12	0.05	0.07	0.08	0.06	0.03	0.17	0.11	0.02	0.20	0.30	0.11	0.15	
LOI	0.33	0.45	0.22	0.38	0.30	0.32	0.87	0.51	0.22	0.25	0.76	0.91	0.44	无样	0.26	0.15	0.56	0.96	0.48	0.43	0.28	0.47	1.24	0.80	
Total	99.73	100.04	99.96	99.79	99.74	99.69	100.04	100.10	99.80	100.31	99.73	99.80	99.90	99.56	99.33	99.71	99.85	100.14	99.12	100.02	100.05	99.61	100.28	100.45	
Na <sub>2</sub> O/K <sub>2</sub> O	1.40	1.29	1.13	1.16	1.05	0.91	1.74	0.96	1.01	0.73	0.99	0.58	0.83	1.06	0.59	0.55	0.85	1.47	0.92	0.82	0.75	1.04	1.11	0.68	
<i>Trace element (in ppm)</i>																									
P	534	294	482	415	352	332	1052	448	711	280	415	574	235	342	345	257	103	827	537	88	1004	1570	550	748	
Sc	17.7	10.7	8.5	6.2	5.2	4.9	12.4	6.7	14.2	3.8	8.7	9.4	2.9	3	7.4	5.8	39.1	6.6	7.6	8.7	6	19	6.8	10.2	
Ti	4314	1662	2615	1965	1759	1562	3916	2060	3848	1284	1872	2588	1101	1565	1818	1391	431	2885	2445	405.9	2637	6024	2442	2857	
V	138	2	41	33	28	14	55	20	71	18	16	69	7	10	52	16	1.74	48	28	2	30	177	34	85	
Cr	91	292	12	8	9	10	20	12	23	10	4	99	2	58	39	9	16	38	63	25	136	54	59	48	
Mn	849	1261	484	506	529	827	1124	813	1060	306	862	637	369	423	479	310	151	491	435	281	425	994	344	571	
Co	20	1.5	4.9	4.5	3.8	3.5	9.4	4.5	10.4	3.7	2.4	7.6	1.4	1.8	6.7	2.7	0.6	7.9	6.5	0.7	7.3	21.3	7.1	9.8	
Ni	43.6	18.3	12.1	9.1	11.6	12.3	23.4	16.5	18.2	10.4	1.5	11.5	1.2	1.9	8.8	7.8	9.101	9.2	18.6	5.4	38.6	18.1	23.4	9.9	
Cu	34.6	17.6	7.6	12.0	5.6	9.5	29.3	12.4	20.6	16.3	5.0	17.4	2.6	2.5	12.3	6.3	13.79	7.0	15.3	5.9	34.8	80.9	6.9	11.3	
Zn	65	106	40	50	34	73	185	69	69	31	62	56	54	60	45	52	23.3	37	47	26	53	83	33	40	
Ga	16	24	17	16	18	16	23	16	19	15	24	19	21	21	16	15	17.3	18	19	25	20	20	20	15	
Rb	74	135	106	119	156	145	95	127	155	149	344	233	222	187	197	189	403.9	123	155	447	177	120	128	142	
Sr	357	107	250	231	230	159	376	189	222	197	76	312	95	140	170	128	20	389	153	18	155	508	344	356	
Y	19.9	59.2	26.6	20	20.5	24.6	35.3	25.7	27.9	12.5	110.5	24.2	27.1	26.2	21.5	20.9	36.5	14.7	24.6	62.3	17.5	25.7	15.3	15.6	
Zr	30	146	60	45	57	68	69	68	66	40	212	189	86	95	60	55	104	56	57	110	50	42	74	21	
Nb	7.1	21.2	11.6	11.6	13.3	10	15.6	11.3	16.3	7	42.6	16.6	21.8	17.6	10.5	14.6	16	9.7	13	33.3	13.2	13.5	10.6	8.1	
Cs	3.8	3.6	4.2	3.3	4.6	3.1	3.6	2.7	7.4	4.4	24.0	11.0	12.4	10.7	13.3	9.5	17.34	6.7	6.1	19.0	6.8	5.1	4.3	6.0	
Ba	400	1105	745	522	542	581	687	556	422	483	129	251	269	203	432	341	39	394	579	55	498	618	562	388	
La	18.1	53.4	38.7	26.6	24.4	34.3	36.3	26	49.4	33.7	48.6	39.8	26.3	33.7	31.4	36.9	31.8	31.7	21.4	23.2	27	30.8	27.8	32.6	
Ce	41.7	121.3	80.1	56.1	51.7	69.2	81.3	56.2	99.3	62.8	111.8	85.6	70.7	72.9	66.5	81.3	65.5	60.9	47.7	59.9	59.9	65.6	57.7	56.9	
Pr	4.51	14.01	8.56	5.57	5.19	7.04	8.99	5.91	10.11	5.77	12.93	8.99	6.61	7.82	6.83	7.61	8.175	6.08	5.03	7.10	6.66	7.55	5.92	5.37	
Nd	17.7	53.8	30.9	18.8	17.5	23.6	33.9	21.1	33.4	17.3	46.9	30.9	22.8	26.8	22.4	25.1	30.29	21.1	18.8	27.1	25.3	30.0	21.7	18.5	
Sm	3.87	11.33	5.99	3.53	3.41	4.42	7.11	4.44	5.92	2.73	12.08	5.8	4.94	5.37	4.17	4.59	7.35	3.5	4.07	7.43	5	5.83	3.89	3.18	
Eu	0.93	1.82	1.39	0.75	0.79	0.84	1.72	0.96	0.94	0.71	0.33	0.76	0.42	0.54	0.61	0.52	0.178	0.89	0.71	0.12	0.72	1.42	0.88	0.89	
Gd	3.71	10.11	5.24	3.13	3.06	3.96	6.46	4.22	4.83	2.1	12.4	4.64	4.3	4.53	3.51	3.76	6.37	2.75	3.95	7.34	3.95	4.94	3.02	2.69	
Tb	0.57	1.62	0.81	0.51	0.51	0.64	0.99	0.68	0.75	0.33	2.24	0.72	0.72	0.72	0.57	0.60	1.052	0.45	0.72	1.49	0.62	0.79	0.48	0.45	
Dy	3.43	9.81	4.73	3.14	3.12	3.96	5.93	4.2	4.41	1.89	14.97	4.18	4.35	4.27	3.42	3.6	6.33	2.38	4.13	9.41	3.11	4.31	2.52	2.55	
Ho	0.71	2.07	0.96	0.68	0.69	0.84	1.21	0.89	0.92	0.40	3.31	0.86	0.91	0.88	0.72	0.74	1.199	0.48	0.87	2.05	0.59	0.89	0.51	0.54	
Er	1.93	5.82	2.61	1.99	2.05	2.45	3.26	2.51	2.59	1.18	9.93	2.42	2.59	2.49	2.06	2.09	3.68	1.36	2.39	6.33	1.58	2.47	1.4	1.53	
Tm	0.295	0.894	0.386	0.327	0.341	0.392	0.479	0.394	0.410	0.192	1.666	0.375	0.426	0.400	0.329	0.329	0.6073	0.205	0.354	1.092	0.232	0.366	0.205	0.237	
Yb	1.93	5.77	2.46	2.25	2.36	2.63	3.04	2.59	2.75	1.36	11.17	2.48	2.88	2.65	2.21	2.15	4.36	1.3	2.17	7.24	1.4	2.26	1.3	1.49	
Lu	0.284	0.841	0.355	0.347	0.37	0.398	0.442	0.383	0.417	0.217	1.624	0.366	0.418	0.387	0.325	0.308	0.641	0.196	0.318	1.078	0.195	0.332	0.193	0.226	
Hf	1.13	5.05	2.08	1.76	2.21	2.47	2.3	2.41	2.24	1.44	6.37	5.61	3.18	3.61	2										

**Table 4**  
Sr–Nd isotopic compositions of granitoids from Sikhote-Alin.

Sample No.	Rock type	Age (Ma)	[Rb] (ppm)	[Sr] (ppm)	<sup>87</sup> Rb/ <sup>86</sup> Sr	<sup>87</sup> Sr/ <sup>86</sup> Sr	±2σ	l (Sr)	[Sm] (ppm)	[Nd] (ppm)	<sup>147</sup> Sm/ <sup>144</sup> Nd	<sup>143</sup> Nd/ <sup>144</sup> Nd	±2σ	ε <sub>Nd</sub> (0)	ε <sub>Nd</sub> (t)	f (Sm/Nd)	T <sub>DM-1</sub> (Ma)	T <sub>DM-2</sub> (Ma)
B-300	Quartz monzodiorite	66	74	357	0.60	0.705894	9	0.70533	3.87	17.69	0.1323	0.512543	4	-1.8	-1.3	-0.33	1135	980
B-301a (=B-257)	Alkali feldspar granite	57	135	107	3.64	0.708052	7	0.70511	11.33	53.82	0.1273	0.512568	6	-1.4	-0.9	-0.35	1027	937
B-448 (=B-433)	Granodiorite	64	106	250	1.22	0.706652	8	0.70554	5.99	30.91	0.1172	0.512516	6	-2.4	-1.7	-0.40	1000	1013
B-456 (=B-494)	Granodiorite	71	119	231	1.49	0.706831	7	0.70533	3.53	18.77	0.1137	0.512551	6	-1.7	-1.0	-0.42	914	956
B-719 (=B-720)	Granite	71	156	230	1.97	0.707364	7	0.70538	3.41	17.53	0.1176	0.512539	6	-1.9	-1.2	-0.40	969	976
B-574	Granite	83	145	159	2.63	0.708559	7	0.70546	4.42	23.62	0.1131	0.512510	6	-2.5	-1.6	-0.42	970	1019
B-621 (=B-611)	Granodiorite	71	95	376	0.73	0.706449	7	0.70571	7.11	33.92	0.1267	0.512509	6	-2.5	-1.9	-0.36	1123	1032
B-783M (=B-781)	Granite	78	127	189	1.94	0.707735	8	0.70559	4.44	21.13	0.1270	0.512502	8	-2.6	-2.0	-0.35	1138	1043
B-919B (=B-909A)	Granite	81	155	222	2.01	0.708111	9	0.70579	5.92	33.39	0.1072	0.512468	6	-3.3	-2.4	-0.46	976	1081
B-984 (=B-995)	Granite	78	149	197	2.19	0.708547	9	0.70612	2.73	17.34	0.0952	0.512459	6	-3.5	-2.5	-0.52	889	1087
GV-722	Granite	75	344	76	13.11	0.721149	10	0.70718	12.08	46.91	0.1557	0.512409	6	-4.5	-4.1	-0.21	1940	1214
GV-1401	Granite	75	233	312	2.16	0.708179	8	0.70588	5.80	30.89	0.1135	0.512450	6	-3.7	-2.9	-0.42	1064	1116
GV-1583-2	Granite	86	222	95	6.76	0.713472	7	0.70522	4.94	22.84	0.1308	0.512580	6	-1.1	-0.4	-0.34	1047	923
GV-1774	Granite	88	187	140	3.87	0.709852	7	0.70502	5.37	26.78	0.1212	0.512595	6	-0.8	0.0	-0.38	915	891
QG-332	Granite	92	197	170	3.35	0.710498	10	0.70611	4.17	22.36	0.1127	0.512391	6	-4.8	-3.8	-0.43	1145	1208
QG-410	Granite	92	189	128	4.28	0.711447	9	0.70586	4.59	25.14	0.1104	0.512423	6	-4.2	-3.2	-0.44	1073	1156
8-881/2	Granodiorite	93	123	389	0.915	0.706582	8	0.70537	3.50	21.11	0.1002	0.512564	6	-1.4	-0.3	-0.49	788	920
AN-2-11	Granite	108	155	153	2.93	0.710603	8	0.70611	4.07	18.84	0.1306	0.512548	6	-1.8	-0.8	-0.34	1104	978
AN-3-11	Alkali feldspar granite	58	447	18.0	72.2	0.767241	8	0.70796	7.43	27.13	0.1656	0.512651	6	0.3	0.5	-0.16	1576	827
8-11-54/1	Granite	131	177	155	3.31	0.714511	8	0.70832	5.00	25.31	0.1194	0.512361	4	-5.4	-4.1	-0.39	1275	1264
8-11-51/3	Qtz monzodiorite	108	120	508	0.684	0.705076	8	0.70403	5.83	29.95	0.1177	0.512738	6	1.9	3.0	-0.40	655	659
8-871/1	Granodiorite	109	128	344	1.08	0.708169	8	0.70650	3.89	21.73	0.1082	0.512358	6	-5.5	-4.2	-0.45	1144	1256
8-872/1	Granodiorite	106	142	356	1.16	0.706298	8	0.70456	3.18	18.50	0.1039	0.512563	6	-1.5	-0.2	-0.47	816	924

$$\varepsilon_{\text{Nd}}(0) = 10^4 * ((^{143}\text{Nd}/^{144}\text{Nd})_{\text{sample}(0)} / (^{143}\text{Nd}/^{144}\text{Nd})_{\text{CHUR}(0)} - 1).$$

$$\varepsilon_{\text{Nd}}(t) = \varepsilon_{\text{Nd}}(0) - Q_{\text{Nd}} * f_s * t \text{ (in Ga)}.$$

$$f_s = f_{\text{Sm}/\text{Nd}} / \text{sample}(0) = (^{147}\text{Sm}/^{144}\text{Nd})_{\text{sample}(0)} / (^{147}\text{Sm}/^{144}\text{Nd})_{\text{CHUR}(0)} - 1.$$

$$T_{\text{DM-1}} = (1/\lambda_{147}) * \log_e \{ 1 + [ (^{143}\text{Nd}/^{144}\text{Nd})_{\text{sample}(0)} - (^{143}\text{Nd}/^{144}\text{Nd})_{\text{DM}(0)} ] / [ (^{147}\text{Sm}/^{144}\text{Nd})_{\text{sample}(0)} - (^{147}\text{Sm}/^{144}\text{Nd})_{\text{DM}(0)} ] \}.$$

$$T_{\text{DM-2}} = ((\varepsilon_{\text{Nd}})_{\text{DM}(0)} - \varepsilon_{\text{Nd}})_{\text{sample}(0)} + Q * t * (f_s - f_{\text{cc}}) / (Q * (f_{\text{DM}} - f_{\text{cc}})) * 1000 \text{ (Ma)}.$$

$$Q = 10^4 * \lambda_{147} * (^{147}\text{Sm}/^{144}\text{Nd})_{\text{CHUR}(0)} / (^{143}\text{Nd}/^{144}\text{Nd})_{\text{CHUR}(0)} = 25.1 \text{ (/Ga)}.$$

$$\lambda_{147} = 6.54 * 10^{-6} / \text{Ma}.$$

$$(^{143}\text{Nd}/^{144}\text{Nd})_{\text{CHUR}(0)} = 0.512638.$$

$$(^{147}\text{Sm}/^{144}\text{Nd})_{\text{CHUR}(0)} = 0.1967.$$

$$(^{143}\text{Nd}/^{144}\text{Nd})_{\text{DM}(0)} = 0.51315; (^{147}\text{Sm}/^{144}\text{Nd})_{\text{DM}(0)} = 0.2137.$$

$$f_{\text{cc}} = (^{147}\text{Sm}/^{144}\text{Nd})_{\text{aver. cont. crust}} / (^{147}\text{Sm}/^{144}\text{Nd})_{\text{CHUR}} - 1 = -0.4.$$

**Table 5**  
Zircon Lu–Hf isotopic compositions of granitoids from Sikhote-Alin.

Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR( <i>t</i> )	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}^*$
B-300 01-1	63.0	4	65.6	0.283022	29	0.000519	8.8	0.019078	230	0.282745	8.4	9.8	370	612
B-300 02	64.0	2	65.6	0.282989	27	0.001925	11	0.075801	1600	0.282745	7.2	8.6	442	711
B-300 03-2	64.0	4	65.6	0.283003	36	0.000932	25	0.033451	1700	0.282745	7.7	9.1	406	667
B-300 04-2	65.0	4	65.6	0.282951	35	0.001830	39	0.061239	2000	0.282744	5.9	7.3	505	820
B-300 05	66.0	4	65.6	0.282912	35	0.000711	4.9	0.029377	240	0.282744	4.5	6.0	551	928
B-300 07-2	56.0	2	65.6	0.282981	29	0.002729	40	0.090135	1700	0.282750	6.9	8.2	468	742
B-300 07	56.0	2	65.6	0.283103	29	0.004402	170	0.155781	8400	0.282750	11.2	12.5	271	395
B-300 08	68.0	4	65.6	0.282959	36	0.000769	9.2	0.031410	650	0.282742	6.2	7.7	476	791
B-300 10	68.0	4	65.6	0.283093	23	0.001454	41	0.057242	2600	0.282742	10.9	12.4	263	406
B-300 11	58.0	2	65.6	0.283022	32	0.002014	81	0.081943	3200	0.282749	8.4	9.7	388	620
B-300 12	65.0	4	65.6	0.282994	19	0.001609	56	0.065508	1400	0.282744	7.4	8.8	430	695
B-300 13	56.0	2	65.6	0.283080	35	0.002665	78	0.083651	1300	0.282750	10.4	11.7	295	456
B-300 14	58.0	4	65.6	0.282990	29	0.001990	40	0.076908	1600	0.282749	7.2	8.5	442	713
B-300 15	67.0	4	65.6	0.283018	46	0.001230	51	0.047127	420	0.282743	8.2	9.7	385	623
B-300 16	56.0	2	65.6	0.282956	23	0.002863	78	0.114855	4300	0.282750	6.0	7.3	513	815
B-300 17	56.0	4	65.6	0.283059	24	0.002522	120	0.094330	3500	0.282750	9.7	10.9	330	516
B-300 18	67.0	4	65.6	0.282962	19	0.000871	15	0.035873	1100	0.282743	6.3	7.7	472	783
B-300 19	67.0	4	65.6	0.283090	17	0.001805	100	0.074971	3500	0.282743	10.8	12.3	271	417
B-300 20	67.0	4	65.6	0.282875	41	0.000532	5.6	0.020881	630	0.282743	3.2	4.7	608	1033
B-300 21	68.0	4	65.6	0.283103	30	0.001459	84	0.063996	2900	0.282742	11.2	12.8	246	377
B-300 22	66.0	4	65.6	0.282918	22	0.001367	40	0.060285	1100	0.282744	4.7	6.2	552	913
B-300 23	66.0	4	65.6	0.282908	24	0.000967	15	0.042830	480	0.282744	4.3	5.8	562	940
B-300 24	57.0	2	65.6	0.282997	34	0.001989	26	0.083453	1400	0.282749	7.5	8.8	430	693
B-301a 01	57.0	2	57.1	0.283032	22	0.002217	14	0.089297	1600	0.282749	8.7	10.0	373	593
B-301a 02	58.0	2	57.1	0.282919	19	0.001174	7.9	0.043224	830	0.282749	4.7	6.0	547	915
B-301a 03	57.0	2	57.1	0.283061	21	0.002327	71	0.090649	3400	0.282749	9.8	11.0	325	509
B-301a 04	58.0	4	57.1	0.283028	30	0.003087	170	0.112485	4400	0.282749	8.6	9.9	391	606
B-301a 05	57.0	2	57.1	0.283062	25	0.002299	53	0.093810	2200	0.282749	9.8	11.1	323	506
B-301a 06	57.0	2	57.1	0.283030	26	0.002430	85	0.086611	2300	0.282749	8.7	9.9	379	599
B-301a 07	57.0	2	57.1	0.283024	34	0.002102	160	0.072592	3800	0.282749	8.5	9.7	385	616
B-301a 09	57.0	2	57.1	0.283060	18	0.002619	33	0.096071	1600	0.282749	9.7	11.0	330	513
B-301a 10	58.0	2	57.1	0.282890	29	0.002607	100	0.100606	2700	0.282749	3.7	5.0	623	1003
B-301a 11	57.0	2	57.1	0.282955	37	0.002111	79	0.069048	1900	0.282749	6.0	7.3	503	815
B-301a 12	57.0	2	57.1	0.283109	20	0.002357	59	0.091370	1500	0.282749	11.5	12.7	243	370
B-301a 13	57.0	2	57.1	0.282992	22	0.001693	75	0.064472	2400	0.282749	7.3	8.6	434	707
B-301a 14	56.0	4	57.1	0.282974	21	0.001278	44	0.051526	2800	0.282750	6.7	7.9	458	758
B-301a 15	56.0	2	57.1	0.283055	27	0.002002	61	0.074212	1300	0.282750	9.5	10.8	332	526
B-301a 16	57.0	2	57.1	0.283074	23	0.001871	30	0.073796	600	0.282749	10.2	11.5	298	470
B-301a 17	58.0	2	57.1	0.283014	40	0.003686	150	0.130123	2100	0.282749	8.1	9.4	424	649
B-301a 18	58.0	2	57.1	0.282963	37	0.002258	100	0.099962	5800	0.282749	6.3	7.6	491	791
B-301a 19	56.0	2	57.1	0.283080	30	0.002295	48	0.101900	1400	0.282750	10.4	11.7	292	455
B-301a 20	57.0	2	57.1	0.282994	27	0.001391	7.3	0.060316	550	0.282749	7.4	8.7	427	700
B-301a 21	56.0	2	57.1	0.282954	36	0.002263	33	0.094012	1700	0.282750	6.0	7.2	507	819
B-301a 22	58.0	2	57.1	0.283091	23	0.003287	130	0.150549	3900	0.282749	10.8	12.1	282	425
B-301a 24	57.0	4	57.1	0.282954	27	0.001965	26	0.093454	2700	0.282749	6.0	7.2	502	817
B448 01	63.0	4	64.0	0.282950	23	0.001351	35	0.051359	1000	0.282745	5.8	7.2	499	822
B448 02	63.0	4	64.0	0.282886	26	0.000888	4.3	0.032100	630	0.282745	3.6	5.0	596	1005
B448 03	63.0	4	64.0	0.282886	20	0.001475	16	0.056406	1300	0.282745	3.6	5.0	607	1007
B448 04	63.0	4	64.0	0.282875	25	0.001126	46	0.040384	1300	0.282745	3.2	4.6	619	1038
B448 05	63.0	4	64.0	0.282894	26	0.001319	18	0.049125	500	0.282745	3.9	5.3	591	984
B448 06(near)	63.0	4	64.0	0.282893	24	0.001329	8.9	0.047996	970	0.282745	3.8	5.2	593	987
B448 07	63.0	4	64.0	0.282903	27	0.001484	30	0.054701	1700	0.282745	4.2	5.6	579	958
B448 08	63.0	4	64.0	0.282879	16	0.002174	69	0.077621	3700	0.282745	3.3	4.7	633	1030
B448 09	63.0	4	64.0	0.282904	27	0.000792	11	0.027067	740	0.282745	4.2	5.6	565	953

Table 5 (continued)

Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR(t)	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}^*$
B448 10	63.0	4	64.0	0.282838	31	0.001505	35	0.054671	870	0.282745	1.9	3.3	687	1145
B448 11	63.0	4	64.0	0.282848	29	0.001263	22	0.045459	1400	0.282745	2.2	3.6	666	1116
B448 12	63.0	4	64.0	0.282954	26	0.001426	29	0.050552	1200	0.282745	6.0	7.4	494	811
B448 13	63.0	4	64.0	0.282904	25	0.001328	24	0.054037	1200	0.282745	4.2	5.6	575	955
B448 14	63.0	4	64.0	0.283074	26	0.001857	90	0.077302	3100	0.282745	10.2	11.6	298	466
B448 15	63.0	4	64.0	0.282919	29	0.001676	67	0.065485	2700	0.282745	4.7	6.1	556	913
B448 16	63.0	4	64.0	0.282929	27	0.001414	19	0.058277	1500	0.282745	5.1	6.5	535	883
B448 17	63.0	4	64.0	0.282887	25	0.001084	13	0.043423	880	0.282745	3.6	5.0	598	1003
B448 18	64.0	4	64.0	0.282977	29	0.001686	20	0.071871	830	0.282745	6.8	8.2	459	745
B448 19	65.0	4	64.0	0.282920	24	0.001210	22	0.049246	800	0.282744	4.8	6.2	546	907
B448 20	65.0	4	64.0	0.282888	22	0.000985	21	0.040159	1300	0.282744	3.6	5.1	595	998
B-448 21	63.0	4	64.0	0.282945	15	0.001499	28	0.065401	1700	0.282745	5.7	7.1	510	837
B-448 22	65.0	4	64.0	0.282987	28	0.001500	43	0.064644	1300	0.282744	7.1	8.6	440	715
B-448 23	65.0	4	64.0	0.282915	20	0.001373	25	0.061341	440	0.282744	4.6	6.0	557	922
B-448 24	65.0	4	64.0	0.282920	16	0.001554	24	0.065570	1800	0.282744	4.8	6.2	552	908
B-456 01	73.0	4	70.5	0.282955	31	0.000808	5.6	0.032022	910	0.282739	6.0	7.6	483	799
B-456 02	71.0	4	70.5	0.282978	25	0.001142	51	0.047563	2500	0.282740	6.8	8.4	450	735
B-456 03	70.0	4	70.5	0.282898	27	0.000796	17	0.032591	1500	0.282741	4.0	5.6	575	965
B-456 04	70.0	4	70.5	0.282985	15	0.001815	23	0.080187	740	0.282741	7.1	8.6	448	718
B-456 06	71.0	4	70.5	0.282848	29	0.000853	21	0.034055	450	0.282740	2.2	3.8	658	1108
B-456 07	71.0	4	70.5	0.282948	22	0.001992	78	0.080558	2600	0.282740	5.8	7.3	513	825
B-456 08	72.0	4	70.5	0.282898	27	0.001212	8.4	0.047627	1100	0.282740	4.0	5.6	583	965
B-456 09	71.0	4	70.5	0.282976	19	0.001349	38	0.053723	1300	0.282740	6.8	8.3	456	742
B-456 09-2	68.0	4	70.5	0.282888	22	0.001493	42	0.060735	970	0.282742	3.6	5.2	604	998
B-456 11	69.0	4	70.5	0.282907	28	0.001105	15	0.043777	1100	0.282742	4.3	5.8	566	941
B-456 12	72.0	4	70.5	0.282970	22	0.001267	27	0.049986	1600	0.282740	6.5	8.1	465	758
B-456 13	69.0	4	70.5	0.282961	24	0.000853	42	0.031014	2200	0.282742	6.2	7.8	474	784
B-456 14	70.0	4	70.5	0.282981	22	0.001727	23	0.063829	670	0.282741	6.9	8.5	453	729
B-456 15	68.0	4	70.5	0.282830	29	0.000763	12	0.027289	85	0.282742	1.6	3.1	685	1162
B-456 16	87.0	4	70.5	0.282926	29	0.001282	73	0.047284	2800	0.282730	5.0	6.9	538	874
B-456 18	70.0	4	70.5	0.282957	19	0.001163	37	0.039698	1700	0.282741	6.1	7.6	485	796
B-456 19-1	71.0	4	70.5	0.282930	20	0.001377	40	0.049460	1200	0.282740	5.1	6.7	533	874
B-456 19-2	69.0	4	70.5	0.282887	35	0.001155	44	0.039805	2200	0.282742	3.6	5.1	600	999
B-456 20	72.0	4	70.5	0.282953	23	0.001294	31	0.046636	950	0.282740	5.9	7.5	493	807
B-456 21	71.0	4	70.5	0.282996	31	0.002041	81	0.068810	4200	0.282740	7.5	9.0	432	686
B-456 22	68.0	4	70.5	0.282929	22	0.002035	69	0.071007	3100	0.282742	5.1	6.6	545	882
B-456 23	71.0	4	70.5	0.282965	29	0.001447	36	0.047639	500	0.282740	6.4	7.9	476	774
B-719 01	69.0	4	70.7	0.282969	25	0.001356	11	0.044165	600	0.282742	6.5	8.0	468	763
B-719 02	71.0	4	70.7	0.282876	24	0.001692	30	0.054621	1400	0.282740	3.2	4.8	628	1031
B-719 03	70.0	4	70.7	0.282954	27	0.001420	19	0.045471	620	0.282741	6.0	7.5	493	806
B-719 04	71.0	4	70.7	0.282917	27	0.001616	65	0.049571	1500	0.282740	4.7	6.2	558	913
B-719 05	70.0	4	70.7	0.282898	25	0.000902	10	0.026950	290	0.282741	4.0	5.6	577	966
B-719 06	71.0	4	70.7	0.282942	28	0.001258	13	0.037360	850	0.282740	5.6	7.1	511	839
B-719 07	71.0	4	70.7	0.282806	29	0.001114	51	0.034993	1600	0.282740	0.7	2.3	732	1230
B-719 08	70.0	4	70.7	0.282974	27	0.001847	27	0.062392	1100	0.282741	6.7	8.2	466	750
B-719 09	72.0	4	70.7	0.282963	28	0.003441	110	0.116555	5100	0.282740	6.3	7.9	511	786
B-719 10	70.0	4	70.7	0.282966	21	0.001198	9.7	0.040112	870	0.282741	6.4	8.0	470	771
B-719 11	70.0	4	70.7	0.282987	22	0.001887	57	0.066419	2400	0.282741	7.1	8.7	445	713
B-719 12	70.0	4	70.7	0.282957	26	0.001580	40	0.057452	2700	0.282741	6.1	7.6	491	798
B-719 14	71.0	4	70.7	0.282922	21	0.001215	43	0.044343	1500	0.282740	4.8	6.4	543	897
B-719 15	69.0	4	70.7	0.282931	18	0.001683	25	0.066136	1500	0.282742	5.2	6.7	536	874
B-719 16	72.0	4	70.7	0.282954	22	0.002000	75	0.073205	1800	0.282740	6.0	7.6	503	807
B-719 17	72.0	4	70.7	0.282963	22	0.001212	23	0.045726	1100	0.282740	6.3	7.9	475	778
B-719 18	71.0	4	70.7	0.282922	23	0.001627	87	0.061487	3900	0.282740	4.8	6.4	550	898
B-719 19	71.0	4	70.7	0.282925	21	0.001330	24	0.047239	650	0.282740	5.0	6.5	540	889

Table 5 (continued)

Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR( $t$ )	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}$
B-719 20	71.0	4	70.7	0.282947	22	0.001911	61	0.070373	1100	0.282740	5.7	7.3	513	827
B-719 21	71.0	4	70.7	0.282900	25	0.001942	49	0.075610	1800	0.282740	4.1	5.6	593	963
B-719 22	70.0	4	70.7	0.282954	20	0.001072	30	0.038617	600	0.282741	6.0	7.5	488	805
B-719 23	72.0	4	70.7	0.283019	22	0.001115	50	0.042081	2600	0.282740	8.3	9.9	382	616
B-719 24	70.0	4	70.7	0.282988	29	0.001136	11	0.042549	790	0.282741	7.2	8.7	433	707
B-574 01	83.0	4	82.7	0.282937	32	0.001180	16	0.045464	1200	0.282733	5.4	7.2	518	844
B-574 02	86.0	4	82.7	0.282960	24	0.001189	34	0.042885	1200	0.282731	6.2	8.1	480	776
B-574 03	83.0	4	82.7	0.282878	32	0.001031	16	0.038083	240	0.282733	3.3	5.1	612	1014
B-574 04	81.0	4	82.7	0.282933	21	0.001565	23	0.053729	1400	0.282734	5.2	7.0	531	859
B-574 05	84.0	4	82.7	0.282807	20	0.001312	29	0.044971	550	0.282732	0.8	2.6	734	1218
B-574 06	82.0	4	82.7	0.282904	22	0.000921	34	0.031722	880	0.282734	4.2	6.0	568	939
B-574 07	84.0	4	82.7	0.282883	32	0.001356	22	0.049942	1200	0.282732	3.5	5.3	610	1000
B-574 08	85.0	4	82.7	0.282916	18	0.001320	16	0.049436	1300	0.282732	4.6	6.5	555	904
B-574 09	86.0	4	82.7	0.282956	24	0.001983	190	0.064575	4600	0.282731	6.0	8.0	499	791
B-574 10	84.0	4	82.7	0.282739	28	0.001335	37	0.050189	850	0.282732	-1.6	0.2	847	1413
B-574 11	83.0	4	82.7	0.283004	22	0.001470	22	0.054875	390	0.282733	7.7	9.6	411	652
B-574 12	83.0	4	82.7	0.282974	21	0.001023	24	0.039020	1500	0.282733	6.7	8.5	455	737
B-574 13	82.0	4	82.7	0.282901	22	0.001398	16	0.055121	1100	0.282734	4.1	5.9	581	950
B-574 14	83.0	4	82.7	0.282918	32	0.001358	29	0.055448	680	0.282733	4.7	6.5	552	900
B-574 15	81.0	4	82.7	0.282990	23	0.001596	24	0.064578	1600	0.282734	7.2	9.0	436	695
B-574 16	83.0	4	82.7	0.283003	22	0.001523	94	0.063286	3400	0.282733	7.7	9.6	413	655
B-574 17	82.0	4	82.7	0.282862	19	0.001250	12	0.052758	490	0.282734	2.7	4.5	643	1061
B-574 18	81.0	4	82.7	0.282847	20	0.001253	17	0.054294	1800	0.282734	2.2	4.0	667	1105
B-574 19	82.0	4	82.7	0.282969	22	0.001566	48	0.064918	560	0.282734	6.5	8.3	471	755
B-574 20	83.0	4	82.7	0.282928	18	0.001205	21	0.049641	1700	0.282733	5.1	6.9	533	870
B-574 21	83.0	4	82.7	0.282968	29	0.001412	13	0.060375	1000	0.282733	6.5	8.3	470	756
B-574 22	81.0	4	82.7	0.282847	31	0.001048	8	0.046166	1100	0.282734	2.2	4.0	663	1104
B-574 23	82.0	4	82.7	0.283047	24	0.001366	23	0.058001	1600	0.282734	9.3	11.1	338	528
B-574 24	81.0	4	82.7	0.282939	27	0.000959	24	0.038997	1400	0.282734	5.4	7.2	511	839
B-621d 02	71.0	4	70.8	0.282850	32	0.001778	65	0.074440	710	0.282740	2.3	3.9	673	1106
B-621d 03	72.0	4	70.8	0.282947	40	0.000547	36	0.020478	610	0.282740	5.7	7.3	492	821
B-621d 04	71.0	4	70.8	0.282967	51	0.001102	22	0.044112	890	0.282740	6.4	8.0	467	767
B-621d 05	71.0	4	70.8	0.283004	21	0.002076	42	0.098522	1500	0.282740	7.7	9.3	419	663
B-621d 06	69.0	4	70.8	0.282971	33	0.000968	21	0.045244	1400	0.282742	6.6	8.1	459	756
B-621d 07	71.0	4	70.8	0.283091	24	0.002183	44	0.102712	1900	0.282740	10.8	12.4	272	412
B-621d 08	72.0	4	70.8	0.282879	42	0.001716	90	0.080165	6600	0.282740	3.3	4.9	624	1022
B-621d 09	70.0	4	70.8	0.282978	35	0.001913	66	0.089446	3300	0.282741	6.8	8.4	461	739
B-621d 12	69.0	4	70.8	0.282963	30	0.001527	60	0.062229	1700	0.282742	6.3	7.8	480	781
B-621d 13	70.0	4	70.8	0.282905	33	0.001156	69	0.049926	3700	0.282741	4.2	5.8	570	946
B-621d 14	73.0	4	70.8	0.282918	22	0.001739	55	0.069724	1100	0.282739	4.7	6.3	559	909
B-621d 15	70.0	4	70.8	0.282869	33	0.001386	65	0.054181	1800	0.282741	3.0	4.5	634	1051
B-621d 16	70.0	4	70.8	0.283010	27	0.001909	120	0.074854	2500	0.282741	8.0	9.5	407	646
B-621d 18	70.0	4	70.8	0.282946	37	0.001169	60	0.044113	890	0.282741	5.7	7.2	503	828
B-621d 19	73.0	4	70.8	0.282968	23	0.001358	14	0.056832	1000	0.282739	6.5	8.1	469	763
B-621d 20	72.0	4	70.8	0.282940	41	0.001061	23	0.039542	910	0.282740	5.5	7.1	511	844
B-621d 21	69.0	4	70.8	0.282881	38	0.001018	18	0.040267	1600	0.282742	3.4	4.9	607	1016
B-621d 22	71.0	4	70.8	0.283005	21	0.001519	55	0.060828	870	0.282740	7.8	9.4	410	658
B-621d 23	72.0	4	70.8	0.282905	25	0.001410	26	0.056309	2600	0.282740	4.2	5.8	575	946
B-621d 24	71.0	4	70.8	0.282960	26	0.001254	34	0.048944	940	0.282740	6.2	7.8	481	787
B-621d 25	70.0	4	70.8	0.283030	15	0.002067	62	0.082775	2200	0.282741	8.7	10.2	375	589
B-621d 26	71.0	4	70.8	0.283014	23	0.001869	55	0.075742	3600	0.282740	8.1	9.7	399	634
B-621d 27	71.0	4	70.8	0.282794	39	0.001293	22	0.046630	240	0.282740	0.3	1.9	755	1265
B-621d 28	69.0	4	70.8	0.282988	27	0.001444	45	0.057770	3100	0.282742	7.2	8.7	437	709
B-783M 01	78.0	4	77.7	0.282988	28	0.002826	47	0.125259	5100	0.282736	7.2	8.9	457	708
B-783M 02	77.0	4	77.7	0.283188	31	0.003515	60	0.158930	6700	0.282737	14.3	16.0	111	132

Table 5 (continued)

Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR( <i>t</i> )	$\epsilon_{\text{Hf}}(0)$	$\epsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}^*$
B-783M 03	77.0	4	77.7	0.282981	23	0.002313	76	0.099093	4900	0.282737	6.9	8.6	461	727
B-783M 04	79.0	4	77.7	0.282929	34	0.002356	53	0.092809	3000	0.282735	5.1	6.8	551	875
B-783M 06	78.0	4	77.7	0.282980	30	0.001819	69	0.081862	4300	0.282736	6.9	8.6	456	727
B-783M 08	80.0	4	77.7	0.283068	29	0.003998	110	0.173601	8400	0.282735	10.0	11.8	331	480
B-783M 09	79.0	4	77.7	0.282964	32	0.002683	92	0.105543	1500	0.282735	6.3	8.1	496	776
B-783M 10	79.0	4	77.7	0.283171	33	0.005048	120	0.216789	8500	0.282735	13.6	15.4	149	187
B-783M 12	80.0	4	77.7	0.283046	24	0.002810	120	0.115046	6100	0.282735	9.2	11.0	356	539
B-783M 13	77.0	4	77.7	0.282975	26	0.003764	110	0.146863	2300	0.282737	6.7	8.4	495	750
B-783M 14	77.0	4	77.7	0.283026	23	0.003686	61	0.137283	4500	0.282737	8.5	10.2	402	602
B-783M 15	78.0	4	77.7	0.282965	19	0.001977	73	0.068015	2500	0.282736	6.4	8.1	484	771
B-783M 18	78.0	4	77.7	0.283035	35	0.002355	100	0.089281	3700	0.282736	8.8	10.6	370	570
B-783M 19	76.0	6	77.7	0.282907	110	0.001500	18	0.056466	700	0.282737	4.3	6.0	573	937
B-783M 20	75.0	4	77.7	0.282978	34	0.002622	66	0.104769	3300	0.282738	6.8	8.5	471	738
B-783M 21	76.0	4	77.7	0.283043	34	0.002896	210	0.117582	10000	0.282737	9.1	10.8	362	551
B-783M 23	78.0	4	77.7	0.283100	54	0.003432	170	0.134546	3800	0.282736	11.1	12.9	267	387
B-919b 01	80.0	4	80.8	0.282907	17	0.001001	25	0.038583	800	0.282735	4.3	6.1	564	932
B-919b 02	79.0	4	80.8	0.282844	21	0.001409	37	0.060001	2300	0.282735	2.1	3.8	675	1116
B-919b 03	81.0	4	80.8	0.282893	28	0.000794	12	0.033307	330	0.282734	3.8	5.6	583	971
B-919b 04	80.0	4	80.8	0.282864	24	0.001640	35	0.073601	1400	0.282735	2.8	4.6	647	1059
B-919b 05	82.0	4	80.8	0.282866	33	0.001133	7.2	0.049779	940	0.282734	2.9	4.7	634	1049
B-919b 06	82.0	4	80.8	0.282876	29	0.001452	61	0.067036	4200	0.282734	3.2	5.0	623	1022
B-919b 07	80.0	4	80.8	0.283000	21	0.001785	44	0.074224	930	0.282735	7.6	9.4	422	667
B-919b 08	80.0	4	80.8	0.282964	17	0.001657	37	0.069377	2500	0.282735	6.3	8.1	480	771
B-919b 09	83.0	4	80.8	0.282697	28	0.001648	39	0.067767	2700	0.282733	-3.1	-1.3	925	1536
B-919b 10	81.0	4	80.8	0.282911	27	0.001565	40	0.063309	2900	0.282734	4.5	6.3	567	922
B-919b 11	80.0	4	80.8	0.282839	32	0.000895	33	0.036098	1100	0.282735	1.9	3.7	673	1128
B-919b 12	79.0	4	80.8	0.282867	20	0.001481	26	0.061609	1100	0.282735	2.9	4.7	639	1050
B-919b 13	81.0	4	80.8	0.282990	30	0.000737	11	0.028689	860	0.282734	7.2	9.0	425	691
B-919b 14	78.0	4	80.8	0.282786	32	0.001115	18	0.047383	1500	0.282736	0.0	1.8	764	1282
B-919b 15	81.0	4	80.8	0.282730	26	0.001165	77	0.045019	2200	0.282734	-1.9	-0.1	857	1441
B-919b 17	65.0	4	80.8	0.282955	23	0.001358	39	0.056056	2100	0.282744	6.0	7.5	491	807
B-919b 18	69.0	4	80.8	0.282949	22	0.001588	61	0.059534	1800	0.282742	5.8	7.3	504	822
B-919b 19	82.0	4	80.8	0.282987	31	0.001315	60	0.055747	1700	0.282734	7.1	9.0	437	701
B-919b 20	81.0	4	80.8	0.282847	24	0.000873	22	0.035861	1300	0.282734	2.2	4.0	660	1104
B-919b 21	81.0	4	80.8	0.282851	29	0.000906	15	0.032056	540	0.282734	2.3	4.1	654	1092
B-919b 22	81.0	4	80.8	0.282823	18	0.001125	7.8	0.045303	730	0.282734	1.3	3.1	704	1174
B-919b 23	80.0	4	80.8	0.282802	22	0.001239	15	0.045701	240	0.282735	0.6	2.4	741	1235
B-919b 24	81.0	4	80.8	0.282805	23	0.001023	11	0.034534	670	0.282734	0.7	2.5	731	1225
B-919b 25	79.0	4	80.8	0.282875	23	0.001354	34	0.045564	860	0.282735	3.2	4.9	623	1027
B-919b 26	81.0	4	80.8	0.282847	100	0.001125	33	0.036708	830	0.282734	2.2	4.0	665	1105
B-919b 27	81.0	4	80.8	0.282997	25	0.001094	11	0.035941	710	0.282734	7.5	9.3	418	672
B-919b 28	82.0	4	80.8	0.282821	36	0.000805	4.5	0.027773	420	0.282734	1.3	3.1	700	1177
B984 01	78.0	4	78.1	0.283031	23	0.001054	20	0.044611	1100	0.282736	8.7	10.4	361	576
B984 02	77.0	4	78.1	0.283065	29	0.002085	46	0.088584	1500	0.282737	9.9	11.6	315	483
B984 03	76.0	4	78.1	0.282879	29	0.001910	21	0.080220	620	0.282737	3.3	5.0	627	1020
B984 04	80.0	4	78.1	0.282956	22	0.001611	26	0.070051	1500	0.282735	6.0	7.8	493	794
B984 05	80.0	4	78.1	0.282926	42	0.000895	35	0.037382	2200	0.282735	5.0	6.8	531	877
B984 06	78.0	4	78.1	0.282839	28	0.001526	37	0.062468	1100	0.282736	1.9	3.6	686	1132
B984 07	79.0	4	78.1	0.282972	23	0.001492	69	0.062195	2200	0.282735	6.6	8.4	465	748
B984 08	78.0	4	78.1	0.282876	27	0.000942	92	0.037813	3400	0.282736	3.2	5.0	614	1023
B984 09	78.0	4	78.1	0.283019	28	0.002494	91	0.112396	4800	0.282736	8.3	10.0	399	617
B984 10	79.0	4	78.1	0.283059	20	0.001686	100	0.069088	3600	0.282735	9.7	11.4	322	497
B984 12	78.0	4	78.1	0.282873	32	0.001270	34	0.049851	1100	0.282736	3.1	4.8	625	1033
B984 13	81.0	4	78.1	0.282945	30	0.001469	16	0.064241	950	0.282734	5.7	7.5	509	824
B984 15	77.0	4	78.1	0.283075	27	0.001470	31	0.059127	700	0.282737	10.3	12.0	293	451



Table 5 (continued)

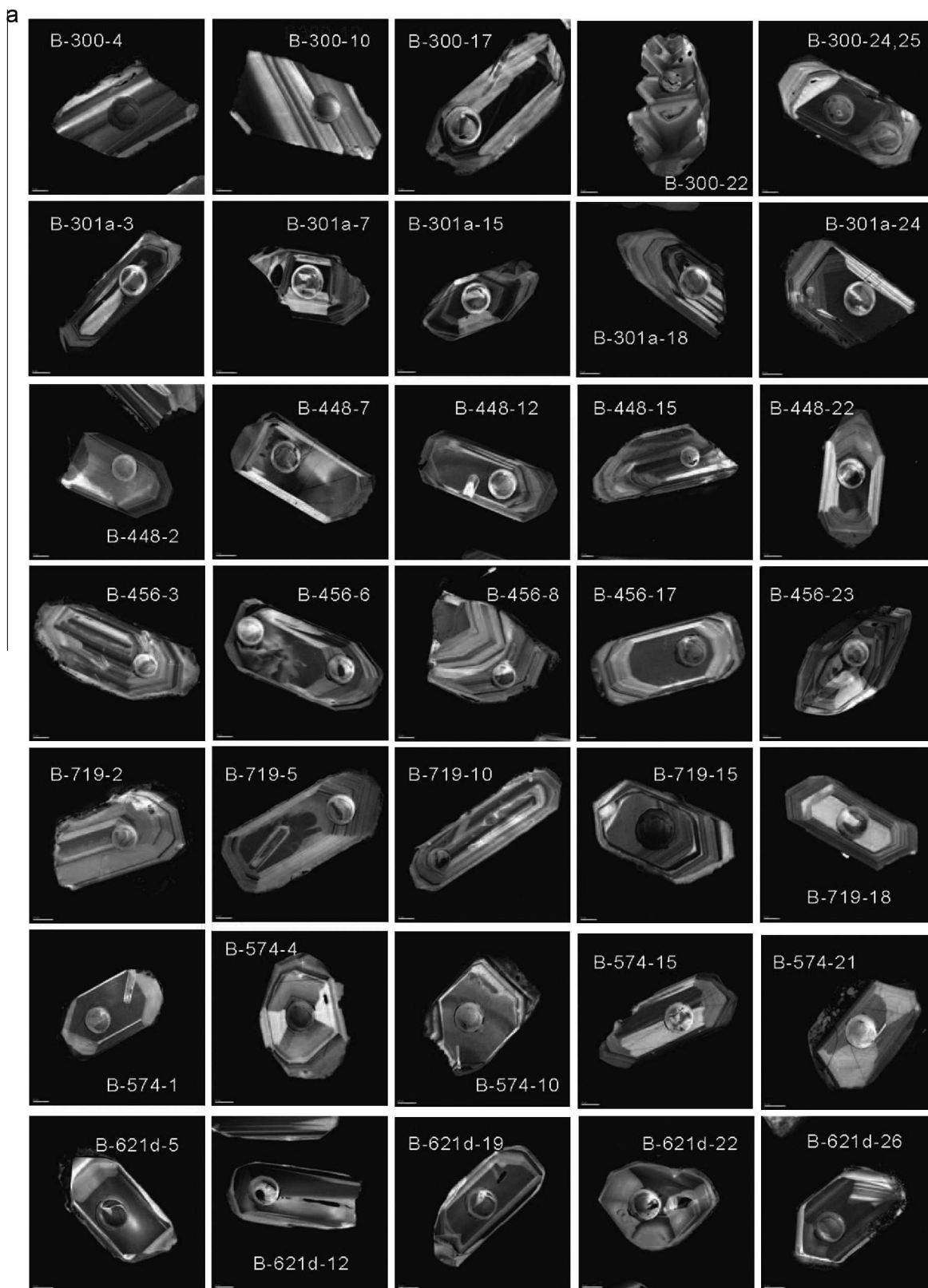
Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR( <i>t</i> )	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}^*$
B984 16	78.0	4	78.1	0.283025	30	0.001884	56	0.076523	1500	0.282736	8.5	10.2	381	597
B984 17	81.0	4	78.1	0.283021	28	0.002839	53	0.110594	2800	0.282734	8.3	10.1	400	611
B984 18	76.0	4	78.1	0.283043	35	0.001802	50	0.065343	600	0.282737	9.1	10.8	350	546
B984 19	76.0	4	78.1	0.282924	36	0.002221	92	0.081520	870	0.282737	4.9	6.6	557	891
B984 20	78.0	4	78.1	0.282868	31	0.001295	13	0.052802	1100	0.282736	2.9	4.7	634	1047
B984 21	77.0	4	78.1	0.282846	35	0.001876	32	0.075328	1100	0.282737	2.2	3.9	682	1114
B984 22	79.0	4	78.1	0.282993	25	0.001780	43	0.068885	1600	0.282735	7.4	9.1	434	688
B984 23	77.0	4	78.1	0.282927	23	0.001919	84	0.070206	1900	0.282737	5.0	6.7	547	881
B984 24	76.0	4	78.1	0.283176	120	0.002281	150	0.083552	4300	0.282737	13.8	15.5	127	163
GV-722 02	78.0	4	74.8	0.282836	27	0.002192	190	0.079225	6100	0.282736	1.8	3.5	706	1143
GV-722 03	74.0	4	74.8	0.282832	19	0.003335	270	0.148830	12000	0.282739	1.7	3.3	740	1161
GV-722 04	74.0	2	74.8	0.282770	22	0.001104	11	0.039173	620	0.282739	-0.5	1.1	790	1331
GV-722 05	71.0	4	74.8	0.282695	26	0.001587	91	0.061365	2600	0.282740	-3.2	-1.6	926	1550
GV-722 06	74.0	2	74.8	0.282786	24	0.002594	92	0.096472	2600	0.282739	0.0	1.7	801	1291
GV-722 07	76.0	4	74.8	0.282779	26	0.000994	13	0.035766	850	0.282737	-0.2	1.5	773	1303
GV-722 08	75.0	4	74.8	0.282754	36	0.000935	44	0.034422	2100	0.282738	-1.1	0.6	812	1376
GV-722 09	76.0	4	74.8	0.282748	26	0.001049	8	0.037428	510	0.282737	-1.3	0.4	825	1392
GV-722 10	75.0	2	74.8	0.282720	30	0.001848	100	0.067099	4500	0.282738	-2.3	-0.6	892	1476
GV-722 12	74.0	2	74.8	0.282779	27	0.001667	27	0.062919	1400	0.282739	-0.2	1.4	789	1307
GV-722 13	77.0	4	74.8	0.282749	20	0.000769	2.4	0.028216	470	0.282737	-1.3	0.4	816	1388
GV-722 14	76.0	4	74.8	0.282768	24	0.002555	250	0.090776	8600	0.282737	-0.6	1.1	831	1341
GV-722 15	76.0	4	74.8	0.282783	31	0.001662	86	0.058393	2800	0.282737	-0.1	1.6	782	1294
GV-722 16	75.0	2	74.8	0.282737	24	0.001088	58	0.036068	2400	0.282738	-1.7	0.0	844	1425
GV-722 17	74.0	4	74.8	0.282754	33	0.001487	140	0.055419	6200	0.282739	-1.1	0.5	826	1378
GV-722 19	76.0	4	74.8	0.282717	21	0.001138	63	0.040474	2600	0.282737	-2.4	-0.7	878	1482
GV-722 22	77.0	4	74.8	0.282892	31	0.001639	120	0.061254	4300	0.282737	3.8	5.5	600	980
GV-722 23	76.0	4	74.8	0.282867	25	0.001945	100	0.068926	3400	0.282737	2.9	4.6	648	1054
GV-722 24	73.0	4	74.8	0.282669	18	0.001216	80	0.045757	3400	0.282739	-4.1	-2.5	958	1621
GV-1583-2 01	86.0	4	86.0	0.282928	26	0.001058	21	0.038960	890	0.282731	5.1	7.0	531	868
GV-1583-2 02	85.0	4	86.0	0.282900	19	0.000906	19	0.032044	1200	0.282732	4.1	6.0	574	948
GV-1583-2 03	85.0	4	86.0	0.282829	29	0.001621	93	0.061377	4400	0.282732	1.6	3.4	705	1156
GV-1583-2 04	84.0	4	86.0	0.282839	23	0.000689	6.7	0.023752	180	0.282732	1.9	3.8	669	1124
GV-1583-2 05	84.0	4	86.0	0.282846	25	0.001263	25	0.044088	940	0.282732	2.2	4.0	669	1106
GV-1583-2 06	83.0	4	86.0	0.282893	24	0.000882	74	0.031073	3000	0.282733	3.8	5.7	585	970
GV-1583-2 07	84.0	4	86.0	0.282972	23	0.000854	33	0.034068	2000	0.282732	6.6	8.5	456	741
GV-1583-2 08	87.0	4	86.0	0.282870	15	0.001638	94	0.068116	3600	0.282730	3.0	4.9	637	1036
GV-1583-2 09	86.0	4	86.0	0.282947	28	0.001084	42	0.044514	2500	0.282731	5.7	7.6	500	813
GV-1583-2 10	88.0	4	86.0	0.282996	23	0.000872	46	0.035833	2400	0.282730	7.5	9.4	417	669
GV-1583-2 11	88.0	4	86.0	0.282960	18	0.001272	32	0.050947	1000	0.282730	6.2	8.1	481	775
GV-1583-2 12	87.0	4	86.0	0.283040	26	0.001644	86	0.060744	1400	0.282730	9.0	11.0	353	546
GV-1583-2 13	86.0	4	86.0	0.282805	31	0.001042	64	0.042387	2800	0.282731	0.7	2.6	732	1221
GV-1583-2 14	87.0	4	86.0	0.282908	19	0.001033	26	0.043725	1800	0.282730	4.3	6.3	563	924
GV-1583-2 15	89.0	4	86.0	0.282897	17	0.001061	33	0.047069	890	0.282729	4.0	5.9	581	955
GV-1583-2 16	87.0	4	86.0	0.282956	26	0.001939	50	0.088195	1900	0.282730	6.0	8.0	498	790
GV-1583-2 17	86.0	4	86.0	0.283017	22	0.001758	110	0.077484	3400	0.282731	8.2	10.1	393	614
GV-1583-2 18	85.0	4	86.0	0.282863	15	0.001898	54	0.085921	2100	0.282732	2.8	4.6	654	1059
GV-1583-2 19	87.0	4	86.0	0.282954	16	0.000948	39	0.039798	1200	0.282730	6.0	7.9	486	791
GV-1583-2 20	87.0	4	86.0	0.283065	25	0.000965	2.6	0.041022	590	0.282730	9.9	11.8	305	471
GV-1583-2 21	86.0	4	86.0	0.283035	19	0.000828	11	0.034219	980	0.282731	8.8	10.8	352	558
GV-1583-2 23	85.0	4	86.0	0.283062	17	0.001021	17	0.041053	510	0.282732	9.8	11.7	310	481
GV-1583-2 24	86.0	4	86.0	0.282974	30	0.001169	46	0.049295	1100	0.282731	6.7	8.6	457	735
GV-1774 01	89.0	4	88.3	0.283021	35	0.000935	8.7	0.033055	730	0.282729	8.3	10.3	376	596
GV-1774 02	88.0	4	88.3	0.282912	29	0.000711	46	0.025340	2300	0.282730	4.5	6.4	551	911
GV-1774 03	89.0	4	88.3	0.282900	20	0.000895	8.7	0.032169	900	0.282729	4.1	6.0	574	945
GV-1774 04	88.0	4	88.3	0.282929	24	0.001788	52	0.062370	2700	0.282730	5.1	7.0	541	867

Table 5 (continued)

Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR( $t$ )	$\epsilon_{\text{Hf}}(0)$	$\epsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}^*$
GV-1774 07	91.0	4	88.3	0.283067	23	0.001578	83	0.056968	3600	0.282728	10.0	12.0	307	465
GV-1774 08	88.0	4	88.3	0.282983	28	0.001238	67	0.049255	3500	0.282730	7.0	9.0	443	708
GV-1774 09	87.0	4	88.3	0.282895	25	0.002055	37	0.078404	980	0.282730	3.9	5.8	603	966
GV-1774 10	89.0	4	88.3	0.282895	18	0.001172	21	0.042218	740	0.282729	3.9	5.9	587	961
GV-1774 11	87.0	4	88.3	0.282931	31	0.000838	28	0.029862	1300	0.282730	5.2	7.1	522	857
GV-1774 12	87.0	4	88.3	0.282884	23	0.001124	37	0.041837	1700	0.282730	3.5	5.4	604	994
GV-1774 13	87.0	4	88.3	0.282909	32	0.000740	26	0.030225	1400	0.282730	4.4	6.3	556	920
GV-1774 14	87.0	4	88.3	0.282960	29	0.001652	12	0.067773	1000	0.282730	6.2	8.1	487	777
GV-1774 15	89.0	4	88.3	0.282985	23	0.001143	16	0.045187	1100	0.282729	7.1	9.1	438	701
GV-1774 16	89.0	4	88.3	0.282883	18	0.001286	19	0.050336	930	0.282729	3.5	5.4	609	996
GV-1774 17	88.0	4	88.3	0.282844	25	0.000872	13	0.035676	900	0.282730	2.1	4.0	664	1107
GV-1774 18	88.0	4	88.3	0.282989	23	0.001357	69	0.050975	2700	0.282730	7.2	9.2	435	691
GV-1774 19	88.0	4	88.3	0.282965	22	0.001516	17	0.063901	1500	0.282730	6.4	8.3	477	761
GV-1774 20	89.0	4	88.3	0.283094	31	0.001584	40	0.068746	3400	0.282729	10.9	12.9	262	388
GV-1774 21	89.0	4	88.3	0.282999	22	0.001071	21	0.046128	1500	0.282729	7.6	9.5	414	660
GV-1774 22	89.0	4	88.3	0.282974	26	0.001413	22	0.058629	1500	0.282729	6.7	8.7	460	734
GV-1774 23	88.0	4	88.3	0.282955	22	0.000976	42	0.038162	2300	0.282730	6.0	8.0	485	788
GV-1774 24	88.0	4	88.3	0.282923	27	0.001654	15	0.068683	650	0.282730	4.9	6.8	549	883
QG-332 01	93.0	4	92.4	0.282763	27	0.000683	21	0.023970	1100	0.282727	-0.8	1.3	791	1335
QG-332 02	92.0	4	92.4	0.282821	28	0.001229	74	0.044466	2300	0.282727	1.3	3.3	710	1172
QG-332 03	91.0	4	92.4	0.282786	22	0.001144	16	0.040974	570	0.282728	0.0	2.1	765	1273
QG-332 04	91.0	4	92.4	0.282836	27	0.001473	18	0.054241	1300	0.282728	1.8	3.8	690	1130
QG-332 05	92.0	4	92.4	0.282749	29	0.000864	14	0.031724	1200	0.282727	-1.3	0.8	818	1377
QG-332 06	93.0	4	92.4	0.282783	29	0.000974	17	0.035756	1500	0.282727	-0.1	2.0	766	1279
QG-332 07	92.0	4	92.4	0.282753	24	0.000687	35	0.023289	1100	0.282727	-1.1	0.9	808	1364
QG-332 08	92.0	4	92.4	0.282662	22	0.000669	10	0.024423	780	0.282727	-4.3	-2.3	954	1625
QG-332 09	92.0	4	92.4	0.282775	33	0.000596	7.2	0.021292	160	0.282727	-0.4	1.7	770	1301
QG-332 10	94.0	4	92.4	0.282808	25	0.000679	9.4	0.025831	610	0.282726	0.8	2.9	719	1205
QG-332 11	93.0	4	92.4	0.282713	29	0.001021	43	0.037906	1700	0.282727	-2.5	-0.5	881	1480
QG-332 12	91.0	4	92.4	0.282725	26	0.000887	4.4	0.031750	340	0.282728	-2.1	-0.1	858	1446
QG-332 13	91.0	4	92.4	0.282734	25	0.000830	14	0.030520	1100	0.282728	-1.8	0.2	842	1420
QG-332 14	92.0	4	92.4	0.282757	29	0.000525	7.7	0.019160	230	0.282727	-1.0	1.1	797	1352
QG-332 15	91.0	4	92.4	0.282819	19	0.000939	26	0.035849	1100	0.282728	1.2	3.2	706	1177
QG-332 16	96.0	4	92.4	0.282775	27	0.000898	32	0.035336	1100	0.282725	-0.4	1.8	777	1299
QG-332 18	91.0	4	92.4	0.282697	17	0.000661	18	0.025329	920	0.282728	-3.1	-1.1	897	1525
QG-332 19	93.0	4	92.4	0.282833	21	0.000800	20	0.030593	940	0.282727	1.7	3.8	681	1134
QG-332 20	93.0	4	92.4	0.282678	19	0.000957	8.5	0.038190	780	0.282727	-3.8	-1.7	936	1580
QG-332 21	95.0	4	92.4	0.282832	17	0.000874	11	0.033722	710	0.282725	1.7	3.8	684	1136
QG-332 22	92.0	4	92.4	0.282835	26	0.000771	24	0.032908	1500	0.282727	1.8	3.8	677	1129
QG-332 23	94.0	4	92.4	0.282763	25	0.001289	30	0.052989	2400	0.282726	-0.8	1.3	806	1337
QG-332 24	92.0	4	92.4	0.282732	34	0.000533	11	0.021710	880	0.282727	-1.9	0.2	838	1424
QG-410 01	94.0	4	91.5	0.282855	24	0.001115	29	0.042387	1300	0.282726	2.5	4.6	651	1072
QG-410 02	92.0	4	91.5	0.282787	24	0.001075	36	0.038887	1300	0.282727	0.1	2.1	762	1269
QG-410 03	92.0	4	91.5	0.282769	25	0.000952	24	0.032872	1300	0.282727	-0.6	1.5	788	1320
QG-410 04	91.0	4	91.5	0.282810	16	0.001423	45	0.050260	1100	0.282728	0.9	2.9	732	1205
QG-410 05	92.0	4	91.5	0.282831	33	0.000862	33	0.028466	1000	0.282727	1.6	3.7	685	1141
QG-410 06	90.0	4	91.5	0.282823	29	0.000948	39	0.033231	1200	0.282728	1.3	3.3	700	1166
QG-410 08	89.0	4	91.5	0.282888	20	0.001301	23	0.045756	210	0.282729	3.6	5.6	601	982
QG-410 11	95.0	4	91.5	0.282701	24	0.000597	17	0.021430	1100	0.282725	-3.0	-0.9	889	1511
QG-410 10	94.0	4	91.5	0.282747	24	0.000696	8.4	0.023961	610	0.282726	-1.3	0.7	818	1380
QG-410 12	91.0	4	91.5	0.282780	24	0.000707	18	0.024133	980	0.282728	-0.2	1.8	765	1288
QG-410 13	87.0	4	91.5	0.282778	19	0.000813	16	0.028032	770	0.282730	-0.2	1.7	770	1297
QG-410 14	92.0	4	91.5	0.282822	28	0.001135	35	0.039052	1200	0.282727	1.3	3.4	706	1168
QG-410 15	91.0	4	91.5	0.282803	28	0.000699	12	0.023671	250	0.282728	0.6	2.7	727	1222

Table 5 (continued)

Spot	Individual spot age (Ma)	$\pm 2\sigma$	Sample mean age (Ma)	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm 2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$ CHUR( $t$ )	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	$T_{\text{DM}}$	$T_{\text{DM}}^*$
4G-410 16	91.0	4	91.5	0.282818	20	0.000517	3.6	0.018146	220	0.282728	1.2	3.2	699	1178
4G-410 17	90.0	4	91.5	0.282789	20	0.000901	8.1	0.035206	600	0.282728	0.1	2.1	754	1264
4G-410 18	89.0	4	91.5	0.282765	15	0.000772	25	0.027525	1100	0.282729	-0.7	1.3	790	1333
4G-410 19	91.0	4	91.5	0.282839	19	0.000611	12	0.024051	730	0.282728	1.9	3.9	667	1118
4G-410 20	91.0	4	91.5	0.282809	18	0.000866	2.3	0.034978	430	0.282728	0.8	2.9	721	1205
4G-410 21	94.0	4	91.5	0.282736	19	0.000647	16	0.025833	1100	0.282726	-1.7	0.4	834	1411
4G-410 22	94.0	4	91.5	0.282817	17	0.000974	57	0.038927	2700	0.282726	1.1	3.2	711	1180
4G-410 23	91.0	4	91.5	0.282837	18	0.000827	2.2	0.033439	410	0.282728	1.8	3.9	675	1125
4G-410 24	91.0	4	91.5	0.282862	16	0.001082	14	0.043353	640	0.282728	2.7	4.7	639	1054
8-871-1 01	109.0	4	108.8	0.282913	22	0.001318	33	0.052022	960	0.282717	4.5	6.9	560	895
8-871-1 02	108.0	4	108.8	0.282786	27	0.001312	26	0.052050	1400	0.282717	0.0	2.4	769	1261
8-871-1 03	108.0	4	108.8	0.282876	16	0.000834	23	0.028814	1300	0.282717	3.2	5.6	612	999
8-871-1 04	108.0	4	108.8	0.282786	17	0.001466	3.7	0.054774	840	0.282717	0.0	2.4	773	1262
8-871-1 05	108.0	4	108.8	0.282800	23	0.001143	32	0.041301	910	0.282717	0.5	2.9	742	1220
8-871-1 06	108.0	4	108.8	0.282822	28	0.001005	16	0.042411	560	0.282717	1.3	3.7	703	1156
8-871-1 07	108.0	4	108.8	0.282527	28	0.001536	36	0.063802	1300	0.282717	-9.1	-6.7	1202	2002
8-871-1 08	110.0	4	108.8	0.282598	26	0.001253	51	0.047562	1800	0.282716	-6.6	-4.2	1075	1797
8-871-1 09	111.0	4	108.8	0.282615	20	0.000672	7	0.028387	540	0.282715	-6.0	-3.5	1029	1744
8-871-1 10	111.0	4	108.8	0.282821	23	0.001215	16	0.050844	460	0.282715	1.3	3.7	709	1157
8-871-1 11	107.0	4	108.8	0.282831	18	0.001087	19	0.042458	1000	0.282718	1.6	4.0	690	1131
8-871-1 12	108.0	4	108.8	0.282825	22	0.001376	51	0.049292	900	0.282717	1.4	3.8	706	1149
8-871-1 13	108.0	4	108.8	0.282900	25	0.001668	76	0.058928	1200	0.282717	4.1	6.5	588	935
8-871-1 14	108.0	4	108.8	0.282849	30	0.001537	58	0.059389	1900	0.282717	2.3	4.7	670	1081
8-871-1 15	111.0	4	108.8	0.282863	21	0.001559	23	0.057889	260	0.282715	2.8	5.2	647	1039
8-871-1 16	110.0	4	108.8	0.282792	23	0.001253	16	0.045914	1400	0.282716	0.2	2.7	758	1242
8-871-1 17	107.0	4	108.8	0.282769	25	0.001149	55	0.039679	1700	0.282718	-0.6	1.8	793	1309
8-871-1 18	109.0	4	108.8	0.282818	19	0.000677	16	0.024698	1000	0.282717	1.2	3.6	702	1164
8-871-1 19	109.0	4	108.8	0.282833	29	0.001084	17	0.040836	1100	0.282717	1.7	4.1	687	1124
8-871-1 20	110.0	4	108.8	0.282774	26	0.001360	65	0.045460	750	0.282716	-0.4	2.1	790	1294
8-871-1 21	108.0	4	108.8	0.282837	22	0.001632	38	0.064229	680	0.282717	1.8	4.2	692	1116
8-871-1 23	111.0	4	108.8	0.282816	20	0.001550	68	0.059606	2300	0.282715	1.1	3.6	725	1174
8-871-1 22-2	109.0	4	108.8	0.282886	21	0.001251	82	0.051312	4300	0.282717	3.6	6.0	603	972
8-871-1 24	108.0	4	108.8	0.282784	22	0.001322	25	0.054167	1100	0.282717	0.0	2.4	772	1266



**Fig. 3.** Cathodoluminescence (CL) images of zircon samples. The CL images were taken at the Beijing SHRIMP Center, Beijing. The rounded spot sizes after U–Pb isotopic analyses by ICP–MS are about 40  $\mu\text{m}$ .

57% to 78%, whereas the potash contents from 2.1% to 5.4%. Based on their normative compositions and the  $Q'$  vs ANOR classification (Streckeisen and Le Maitre, 1979), the granitoid samples fall into 4 rock types: quartz monzodiorite (2 samples), granodiorite (6),

granite (13) and alkali feldspar granite (3; Fig. 6A). In the A/CNK vs A/NK diagram (Fig. 6B), about half of the granitoids are metaluminous and the rest slightly peraluminous except for two. All of them may be considered as I-type granitoids except for the two samples

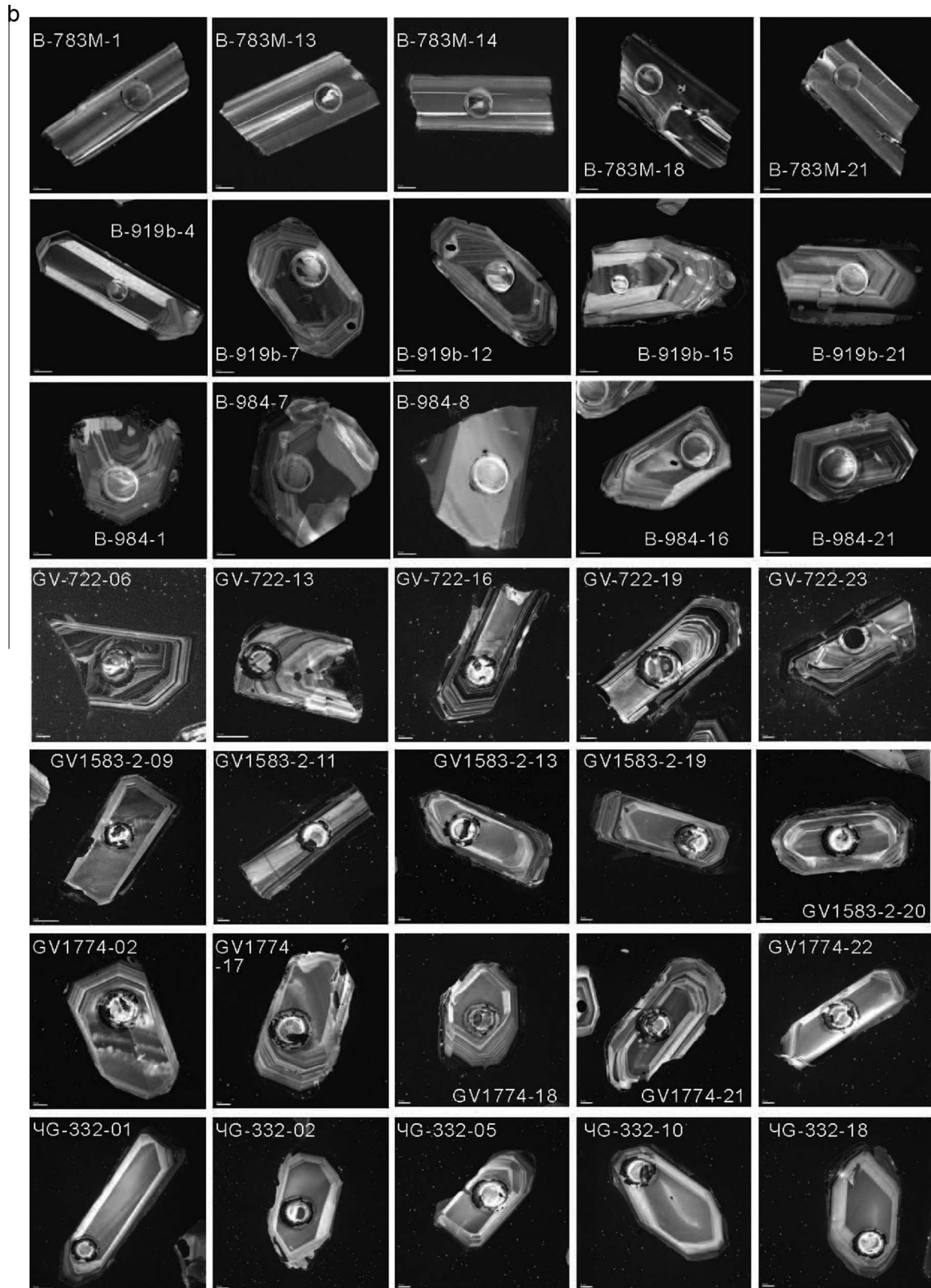


Fig. 3 (continued)

which fall in the category of “S-type”. In the  $\text{FeO}^*/\text{MgO}$  vs  $(\text{Zr} + \text{Nb} + \text{Ce} + \text{Y})$  plot of Whalen et al. (1987), most samples show variable degrees of fractional crystallization, and a few belong to A-type granitoids (Fig. 6C). Based on the  $\text{FeO}_{\text{total}}/(\text{FeO}_{\text{total}} + \text{MgO})$  vs  $\text{SiO}_2$  plot of

Frost et al. (2001), most granitic samples fall in the “magnesian” or “Cordilleran-type” granites (Fig. 6E). Samples in the “ferroan” field include some A-type granitoids or alkali feldspar granites. In the “modified alkali-lime index” ( $\text{MALI} = \text{Na}_2\text{O} + \text{K}_2\text{O} - \text{CaO}$ ) vs  $\text{SiO}_2$

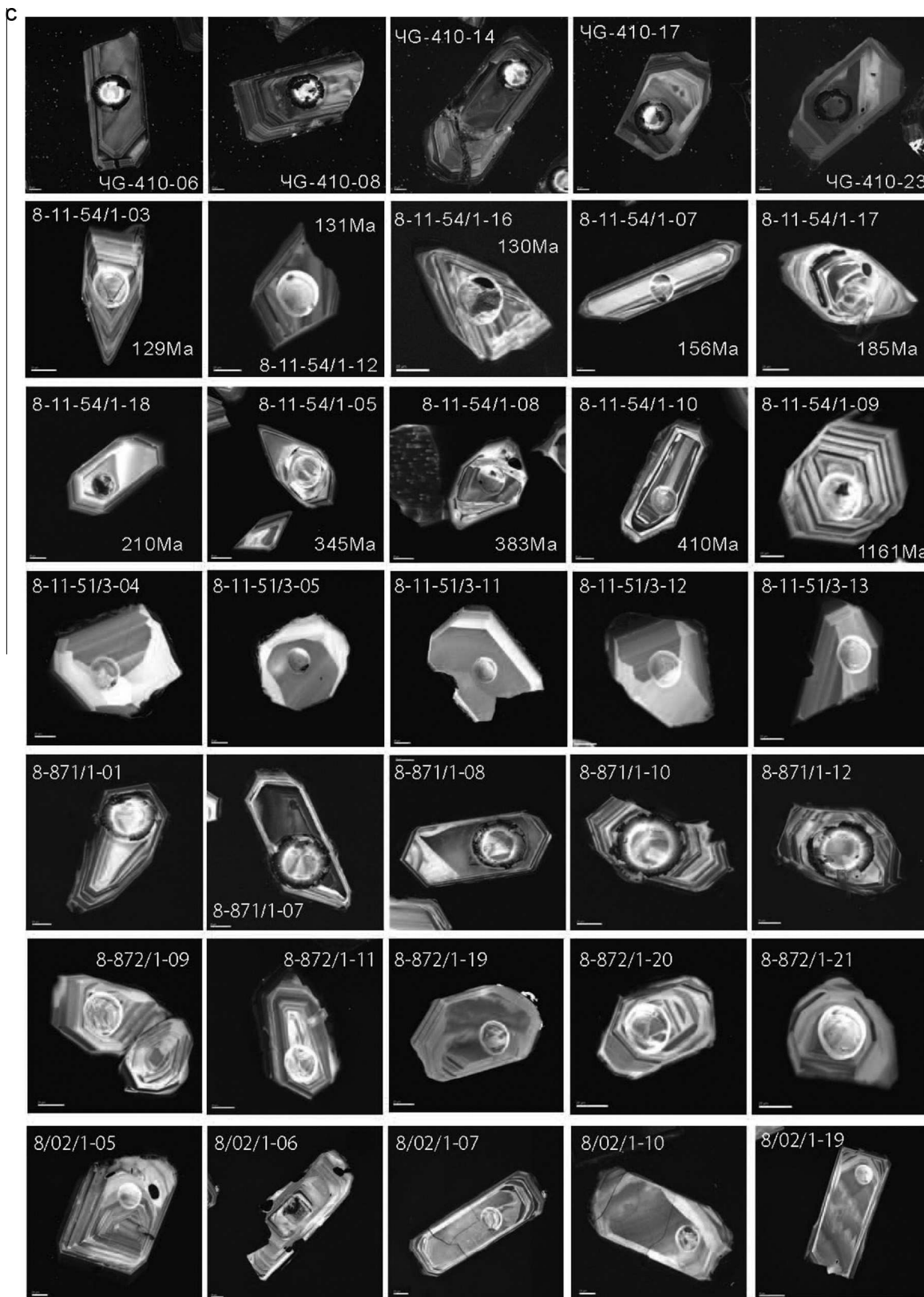


Fig. 3 (continued)

diagram of Frost et al. (2001), most samples are found in the “calc-alkalic” field, and only three in the “alkali-calcic” field (Fig. 6F). According to a tectonic discrimination diagram of Pearce et al. (1984), most of the rocks plot in volcanic arc setting except for three A-type granites in within-plate environment (Fig. 6D).

Chondrite-normalized REE patterns are shown in Fig. 7A–E. Most of these have “typical granitic patterns” with light REE enrichment ( $La_N = 100\text{--}200X$ ,  $Lu_N = 10\text{--}20X$ ), conspicuous negative Eu anomaly and 10–20 times chondritic abundance for heavy REE. However, a few exceptional patterns are also noticed. Samples

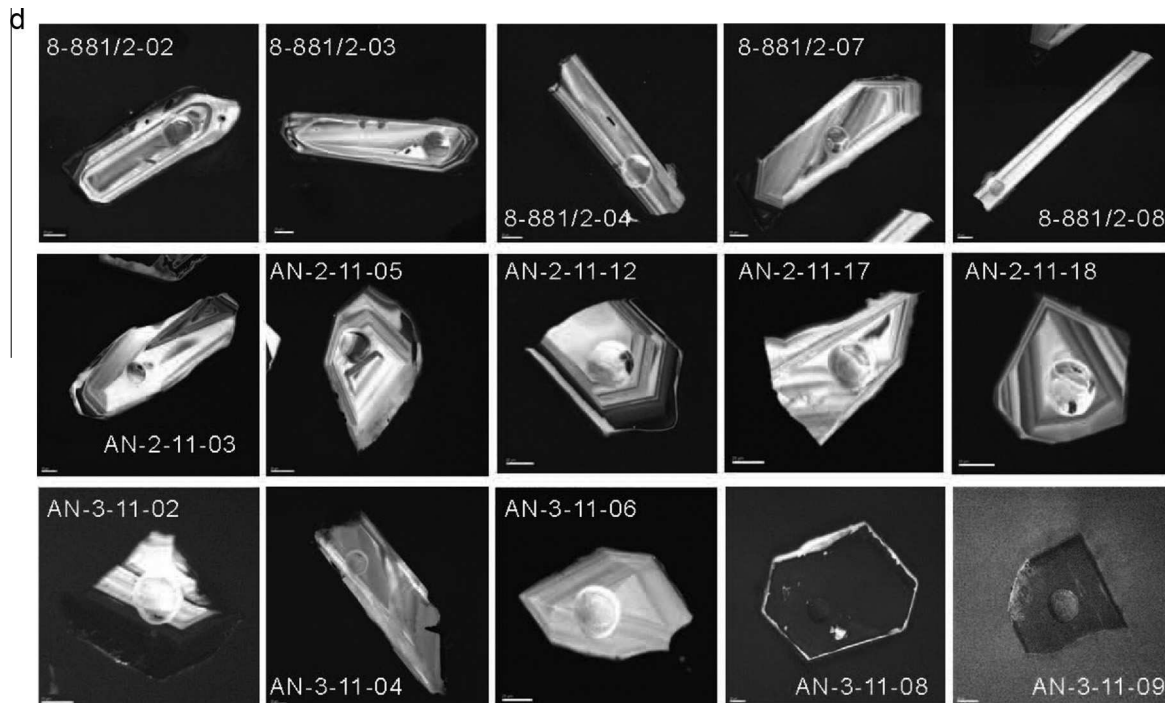


Fig. 3 (continued)

B-995 (Fig. 7B; a granite, equivalent to zircon sample B-984; 78 Ma; 73% SiO<sub>2</sub>), 8-02-1 (Fig. 7D; an alkali feldspar granite; 68 Ma; 78% SiO<sub>2</sub>), 8-881-2 (Fig. 7D; a granodiorite; 93 Ma; 68% SiO<sub>2</sub>), and 8-872/1 (Fig. 7E; a granodiorite; 106 Ma; 67% SiO<sub>2</sub>) do not display any Eu anomalies. All the four patterns are similarly fractionated, but they do not show any correlation with the emplacement ages nor the silica contents. In addition, two samples, GV-722 (Fig. 7B; a granite; 78 Ma; 69% SiO<sub>2</sub>) and AH-3-11 (Fig. 7D; an alkali feldspar granite; 58 Ma; 76% SiO<sub>2</sub>) show REE patterns of highly differentiated granites with high and near-flat heavy REE patterns (40–60X chondritic abundances) and extremely large negative Eu anomalies. Such REE patterns appear to have a faint feature of the “lanthanide tetrad effect” as shown in many highly evolved A-type granites (e.g., Jahn et al., 2001, 2004; Wu et al., 2004). In addition, these granites are often characterized by high Rb and low Sr concentrations, hence very high Rb/Sr ratios. Their Zr/Hf (33–21) and Nb/Ta (6.0–5.4) ratios are lower than the average crustal rocks (average crustal rocks have ratios of 35–40 and 14–20, respectively).

Primitive-mantle-normalized spidergrams of the granitoids are shown in Fig. 8A–E. In principle, trace elements in the spidergrams are arranged in the ascending order, from left to right, of their compatibilities with N-MORB basaltic liquid (Sun and McDonough, 1989). The application of such diagrams to granitic rocks also serves to identify fractionation of particular mineral phases during the generation and differentiation of granitic liquids. The present spidergrams show depletion or negative anomalies in Nb–Ta, Sr, P, Zr and Ti. Such a feature of “negative TNT (Ti–Nb–Ta) anomaly” is most characteristic of granitic rocks, island arc volcanic rocks and the continental crust in general. The significance of such anomalies and other features will be discussed later.

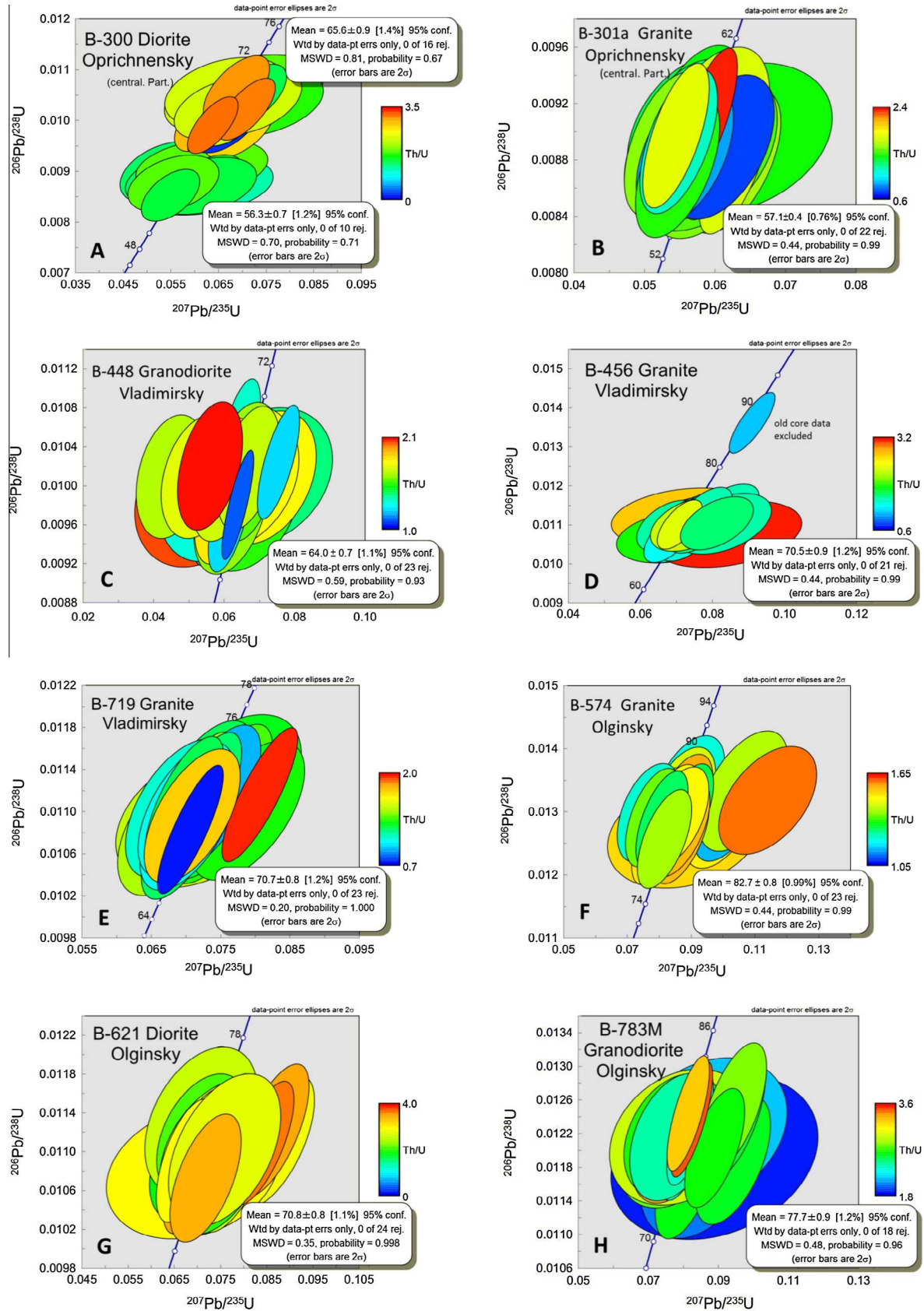
### 5.3. Whole-rock Sr–Nd isotopic data

The data of whole-rock Sr and Nd isotopic analyses are given in Table 5, and further illustrated in Fig. 9. The Rb concentrations range from 22 to 447 ppm, whereas Sr from 18 to 790 ppm. The

calculated initial <sup>87</sup>Sr/<sup>86</sup>Sr ratios (*I*<sub>Sr</sub> values) range from 0.7040 to 0.7083; and the age-corrected initial <sup>143</sup>Nd/<sup>144</sup>Nd ratios, expressed as  $\epsilon_{Nd}(t)$  values, vary from +3.0 to –6.0, but in most cases they are near zero or slightly negative (Fig. 9A). In Fig. 9A the only available coupled Sr–Nd isotopic data from the literature (Valui and Moskalenko, 2010) are also shown for comparison.

The present new analyses yielded single-stage Sm–Nd model ages between 655 and 1940 Ma and two-stage model ages from 650 to 1370 Ma (Table 5; Fig. 9). In Fig. 9B–D, the literature Nd isotopic data (Valui and Moskalenko, 2010; Khanchuk et al., 2013; Kruk et al., 2014a) are also shown for comparison. In all cases, the published and new data are quite comparable.

Correct use of single-stage and two-stage model ages may not be easy for many readers. Single-stage model assumes that the protolith (source rocks) of a rock, regardless of its composition, has evolved in a milieu with Sm/Nd ratio similar to that of the analyzed sample. That is, during the partial melting of a source rock, Sm/Nd ratio was not fractionated between the melt produced and the source rock. However, Sm/Nd fractionation frequently occurred during subsequent magma differentiation, leading to a ratio different from that of the initial melt or the average source rock. In this case, calculated single-stage model ages could be very different from the “true time” of the source separation from the depleted mantle reservoir. The most dramatic case is shown by highly differentiated granitic rocks with the “lanthanide tetrad effect” (Jahn et al., 2001; Jahn, 2010). The <sup>147</sup>Sm/<sup>144</sup>Nd ratios of these rocks often show values higher than the chondritic (0.1967) or even depleted mantle (0.2137) values, hence leading to negative or future model ages. To overcome this problem, a two-stage model was proposed (DePaolo et al., 1991), in which the protolith of a granitic rock is assumed to have evolved in a milieu with the average “continental” Sm/Nd ratio (<sup>147</sup>Sm/<sup>144</sup>Nd = 0.118, or *f*<sub>Sm/Nd</sub> = –0.4) for the period from its initial separation from the depleted mantle reservoir to the time of partial melting. As many granitic melts have undergone fractional crystallization, the two-stage model ages may be more meaningful than the single-stage ages. Therefore, two types of model ages are presented in Table 4.



**Fig. 4.** Zircon U–Pb Concordia plots for 24 granitoid samples from the Sikhote-Alin orogenic belt. The calculated ages are based on  $^{206}\text{Pb}/^{238}\text{U}$  ratios. The number of outliers (rejects) is indicated, but in most cases the number is zero. The color code represents Th/U ratios in individual spots of zircon analyses.



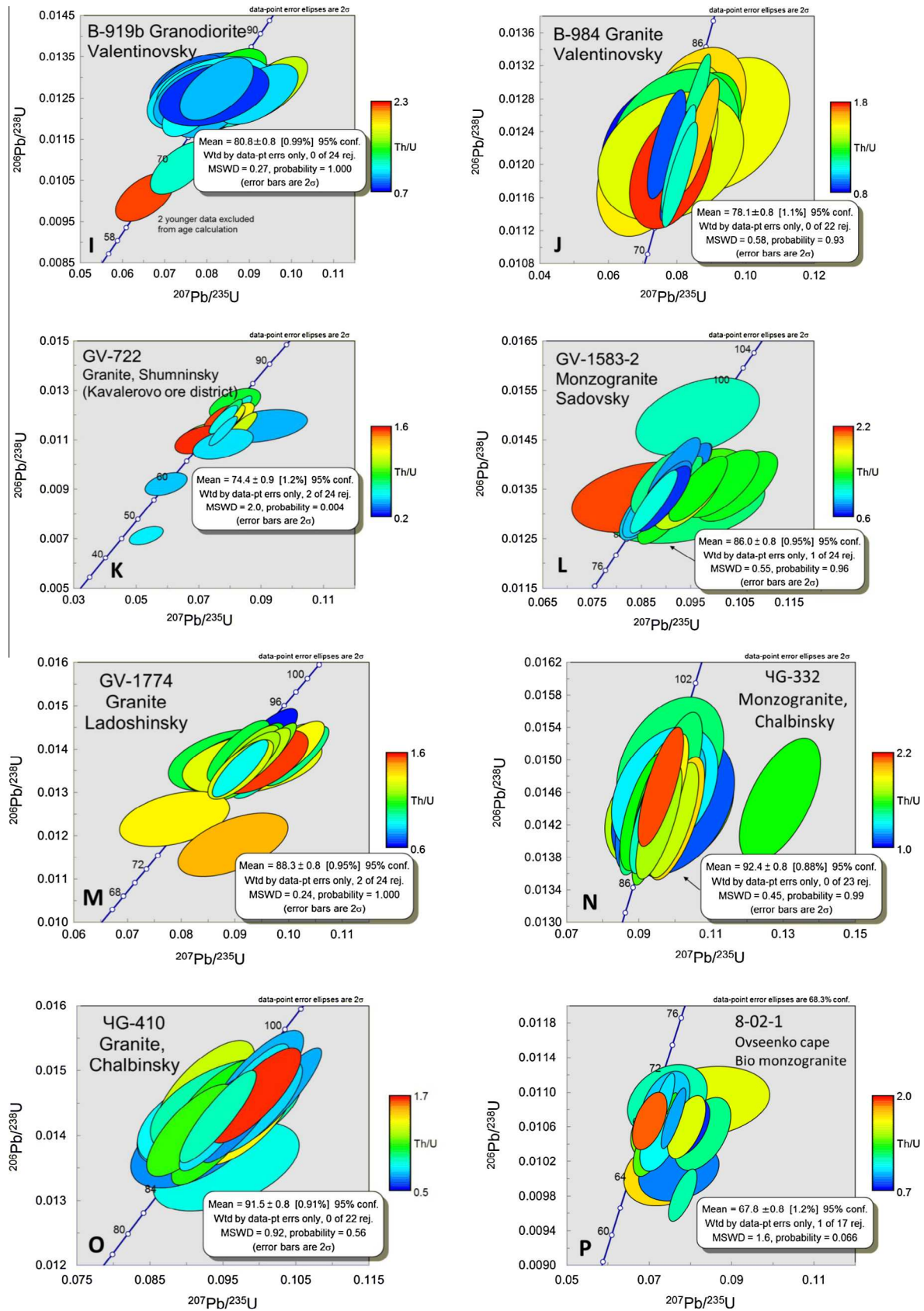


Fig. 4 (continued)

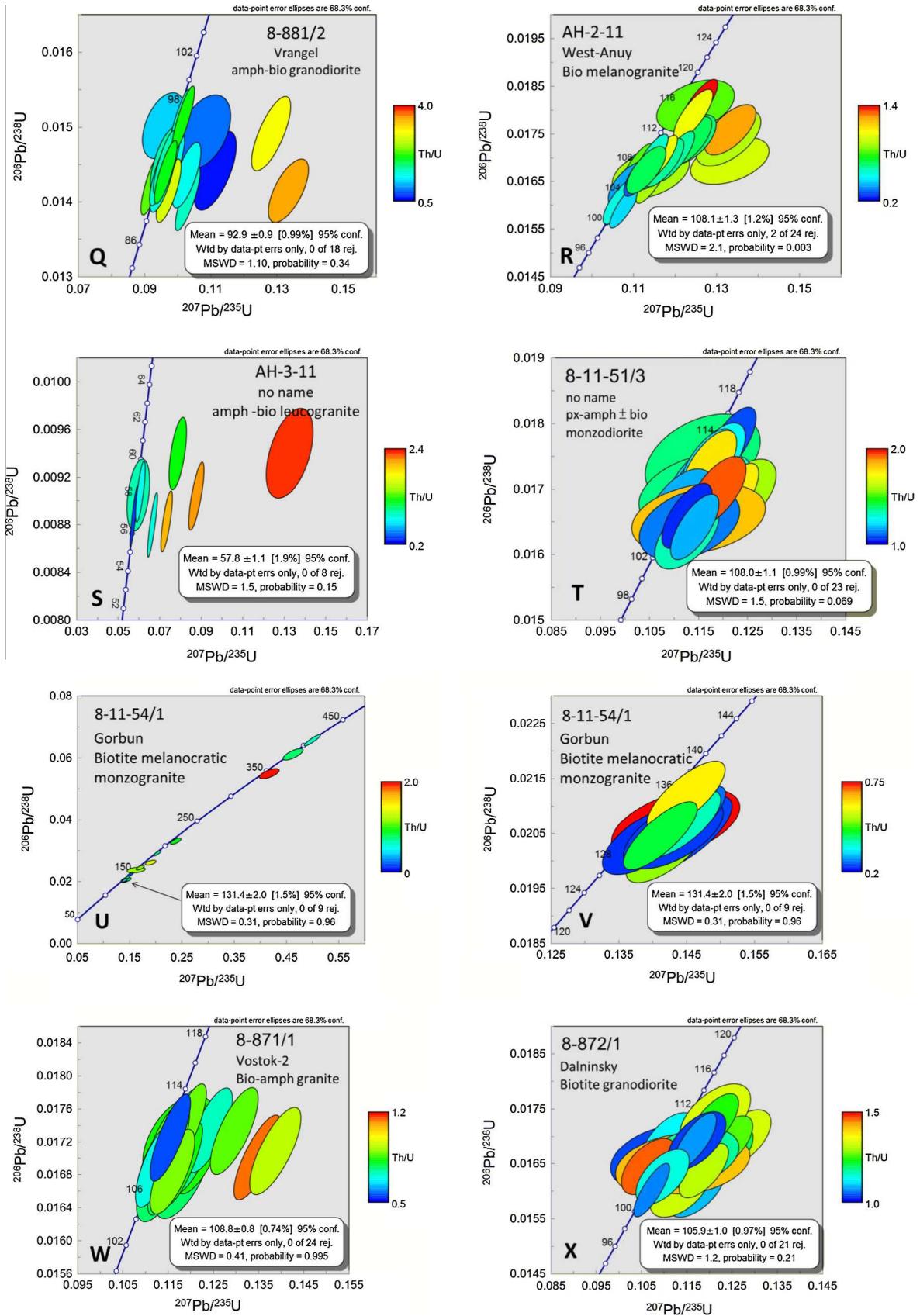


Fig. 4 (continued)

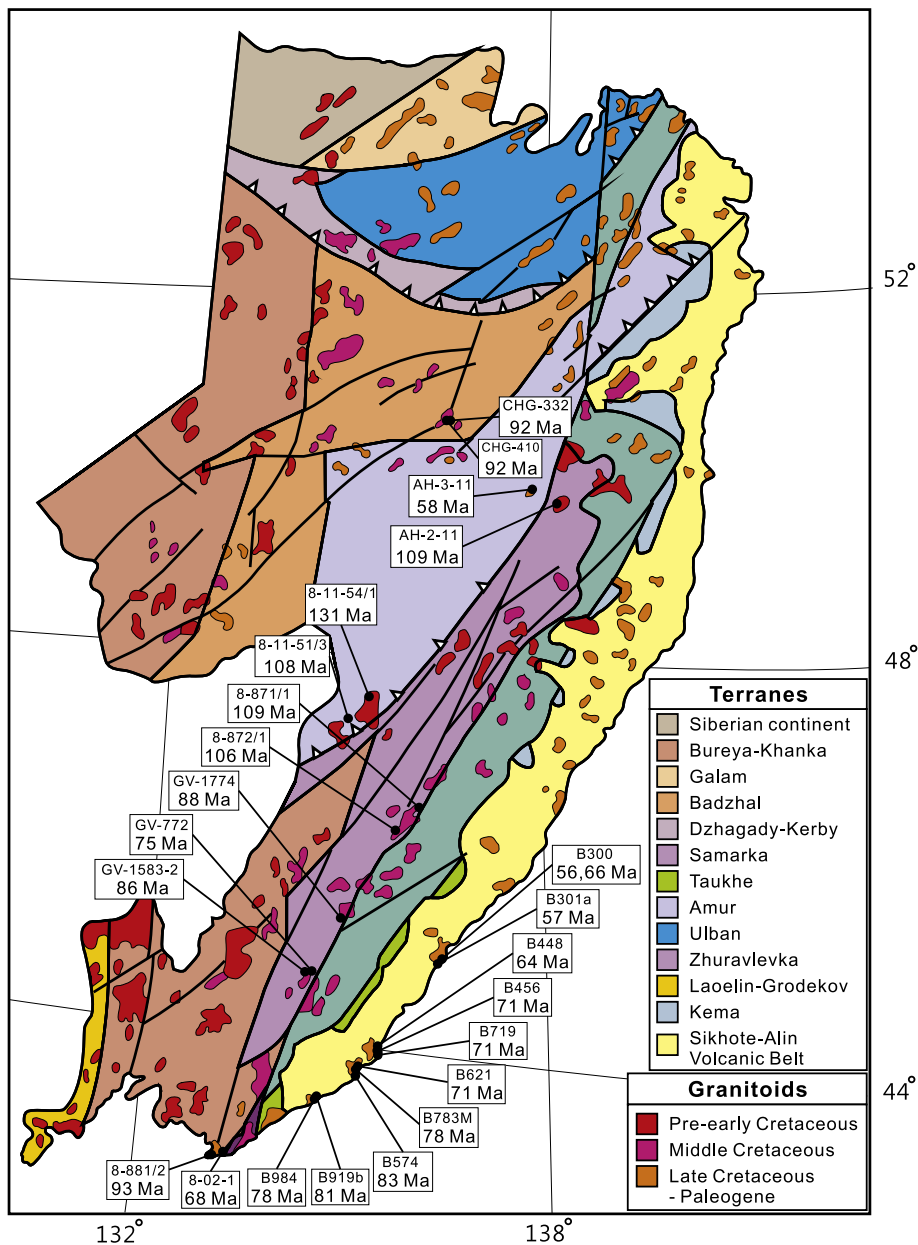


Fig. 5. Summary of zircon ages of all the 24 granitoid samples from the Primorye and Khabarovsk regions.

#### 5.4. Zircon Hf isotopic data

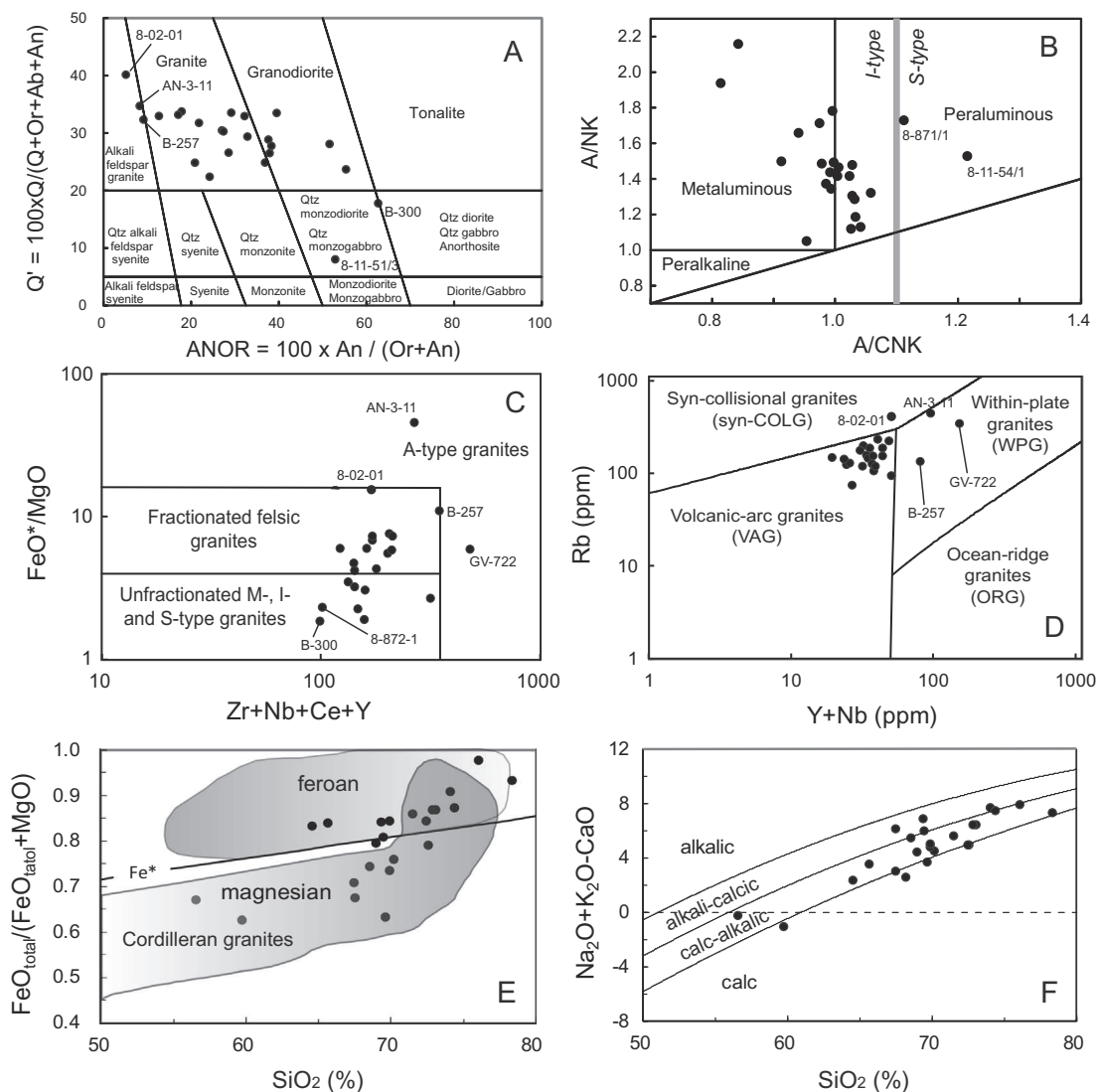
Zircon Hf isotopic compositions of the granitoids are given in Table 5, and further illustrated in Fig. 10. Fig. 10A shows that (1) the majority of the analyzed zircon domains are characterized by positive  $\varepsilon_{\text{Hf}}(t)$  values, and (2) all individual samples have a range of zircon  $\varepsilon_{\text{Hf}}(t)$  values, as commonly observed in granitic rocks. The range of values is beyond the analytical uncertainty of 0.5–1.0 epsilon unit. Note that the whole data set appear to suggest a faint trend of increasing  $\varepsilon_{\text{Hf}}(t)$  values as the emplacement age gets younger. However, such a trend is absent in the whole-rock  $\varepsilon_{\text{Nd}}(t)$  values (Fig. 10B). On the other hand, the Hf isotopic data of three granitoids occurring in the Central Sikhote-Alin Fault zone (GV-722, GV-1774, and GV-1583-2) appears to show an opposite trend; that is, the  $\varepsilon_{\text{Hf}}(t)$  values decrease with the younging of granitic intrusions.

## 6. Discussion

### 6.1. Significance of zircon ages and major thermal events in the Primorye region

As demonstrated earlier, the clear magmatic zoning, the range of Th/U ratios (>0.5) in zircon crystals and the clustering of concordant data points provide a strong argument for zircon crystallization in magmas. Thus, the zircon ages represent the emplacement time of the granitoid intrusions. The new age data indicate that the most important tectonothermal events of the Sikhote-Alin Orogenic Belt occurred in the Cretaceous. Note that the magmatic events are often accompanied by important mineralizations (e.g., Gonevchuk et al., 2010; Rodionov et al., 2010).

The granitic intrusive events in different tectonic units may be summarized as follows. The granitic rocks from the southeastern



**Fig. 6.** Geochemical characterization of the granitoid samples from Sikhote-Alin. (A) The normative Q'-ANOR plot of [Streckeisen and Le Maitre \(1979\)](#) shows that most samples fall in the fields of granite and granodiorite, with a few in alkali-feldspar granite and quartz monzogranite. (B) Most samples have A/NK values >1.0 and A/CNK less than 1.1, thus they may be classified into I-type granitoids. A, C, N, K = molecular proportion of  $\text{Al}_2\text{O}_3$ , CaO,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$ , respectively. (C) In the  $\text{FeO}^*/\text{MgO}$  vs  $(\text{Zr} + \text{Nb} + \text{Ce} + \text{Y})$  plot of [Whalen et al. \(1987\)](#), most samples are not A-type granitoids but show variable degrees of fractional crystallization. (D) A trace element discrimination diagram of [Pearce et al. \(1984\)](#) suggests that the majority of granitic samples formed in an arc setting except three samples which fall in the field of "within-plate granites". (E) In the  $\text{FeO}_{\text{total}}/(\text{FeO}_{\text{total}} + \text{MgO})$  vs  $\text{SiO}_2$  plot of [Frost et al. \(2001\)](#), most granitic samples fall in the "magnesian" or "Cordilleran-type" granites. Samples in the "ferroan" field include some A-type granitoids or alkali feldspar granites. The fit to the boundary line  $\text{Fe}^*$  is  $\text{FeO}_{\text{total}}/(\text{FeO}_{\text{total}} + \text{MgO}) = 0.486 + 0.0046 \times \text{SiO}_2(\%)$ . (F) In the MALI vs  $\text{SiO}_2$  diagram of [Frost et al. \(2001\)](#), the majority of granitic samples fall in the "calc-alkalic" field, and only three in the "alkali-calcic" field. MALI is the modified alkali-lime index and is equal to  $\text{Na}_2\text{O} + \text{K}_2\text{O} - \text{CaO}$ .

coastal areas were emplaced in the late Cretaceous to early Eocene (83–56 Ma), and they intruded into the early Cretaceous accretionary complex of the Tauka Terrane. The granitoids that occur along, or close to, the Central Sikhote-Alin Fault zone were emplaced in Middle to Late Cretaceous, from 109 to 75 Ma, and they intruded into the Jurassic to early Cretaceous accretionary complex of the Samarka Terrane. The other granitoids, including those occurring in the Khabarovsk Region, were emplaced from 131 to 58 Ma in the turbidite basin of the Amur Terrane (=Zhuravlevka Terrane). It may be concluded that the granitoids of Sikhote-Alin were mainly generated and emplaced in the Cretaceous, from 131 to 57 Ma.

Despite that the overall zircon geochronology is rather straightforward, sample 8-11-54/1 (biotite-bearing monzogranite) shows a more complicated age pattern (Fig. 4U and V). The presence of

inherited zircon grains suggests that the protolith of this rock contained a late Precambrian to early Paleozoic crustal component, or the granitoid magma has assimilated some crustal material during igneous differentiation. This seems to be corroborated by its negative  $\varepsilon_{\text{Nd}}(t)$  value of  $-4.1$  (Table 5).

The tectonothermal events are also recorded in the explosive eruptions of felsic magmas in the East Sikhote-Alin Volcanic-Plutonic Belt (ESAVPB). [Grebennikov and Popov \(2014\)](#) summarized that the "ignimbrite" or silicic volcanism occurs in two types – (1) voluminous plateau silicic volcanism filling large depressions, and (2) small caldera-type ignimbrites, formed by collapse of their roof into the magma generation zone. In fact, the two coastal terranes of accretionary complexes (Kema and Taukha) are extensively covered by felsic volcanic rocks. [Grebennikov and Popov \(2014\)](#) also noted that the voluminous plateau ignimbrites from

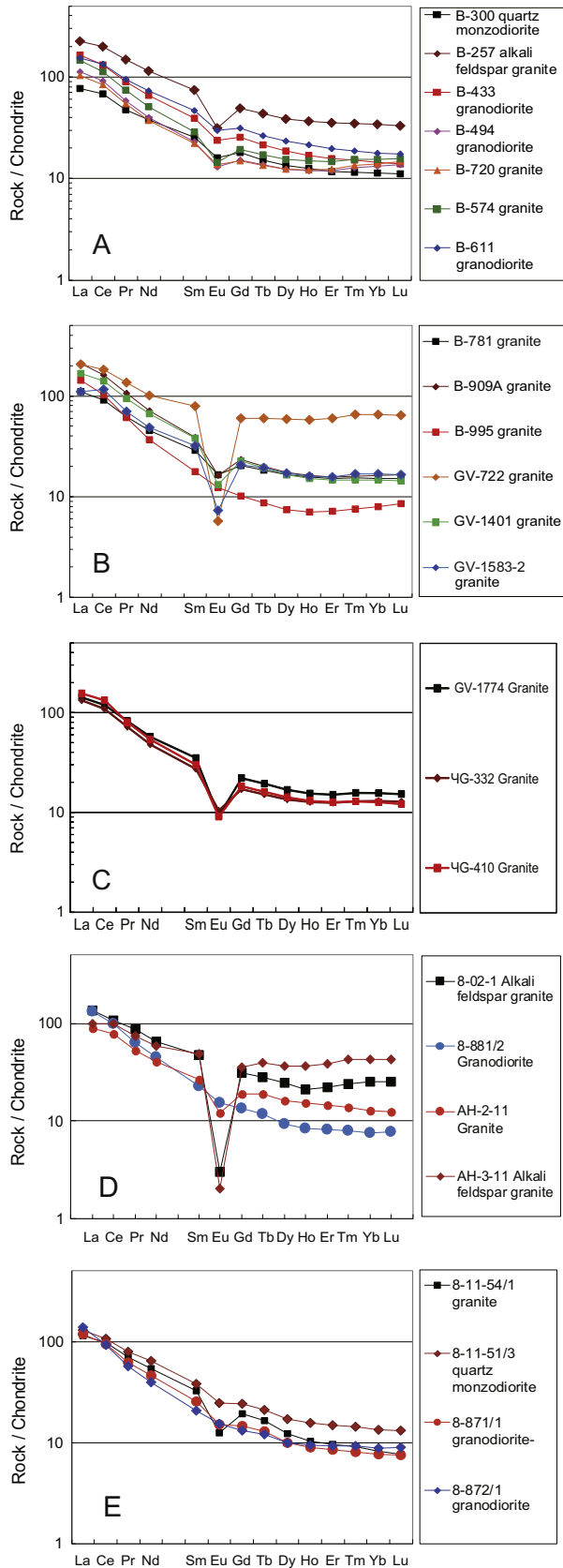


Fig. 7. Chondrite-normalized REE patterns of the granitoids from Sikhote-Alin. Chondrite values are from Sun and McDonough (1989).

the ESABV constitute a significant part of the Silicic Large Igneous Province (SLIP) that covers the Russian Far East along the coastal areas of the Japan and Okhotsk Seas.

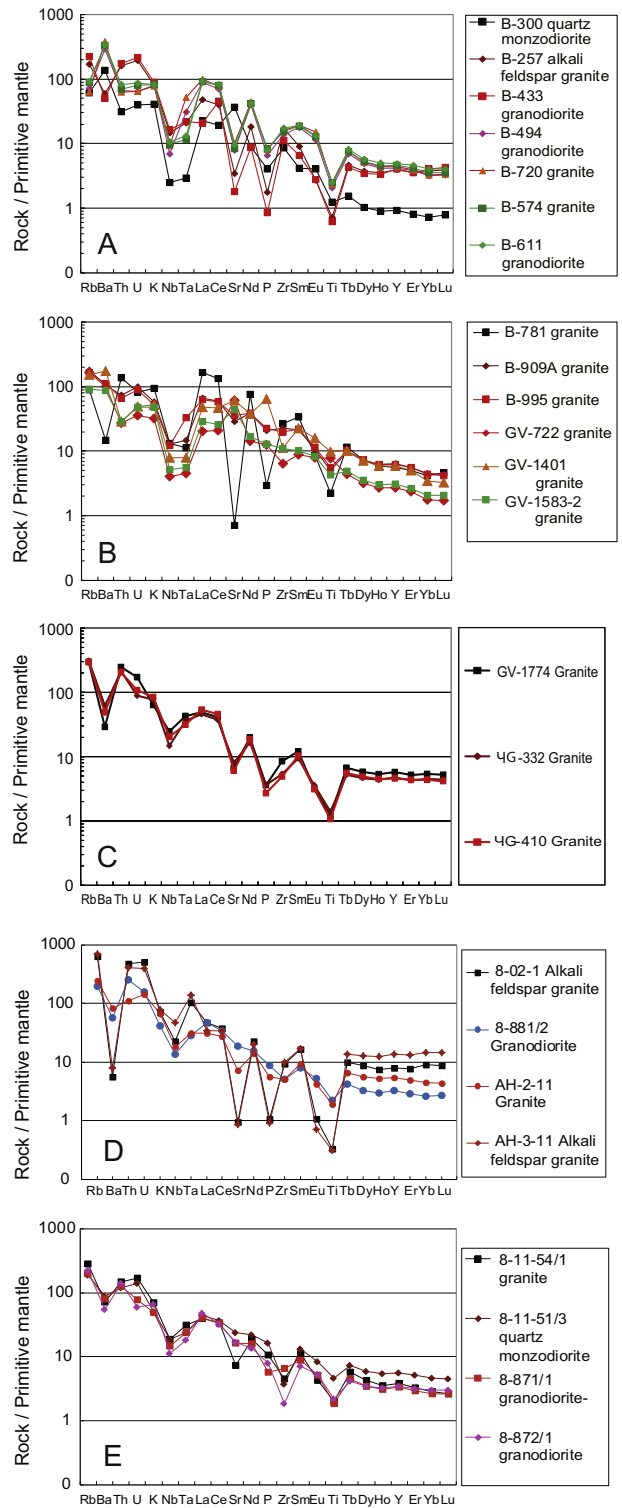
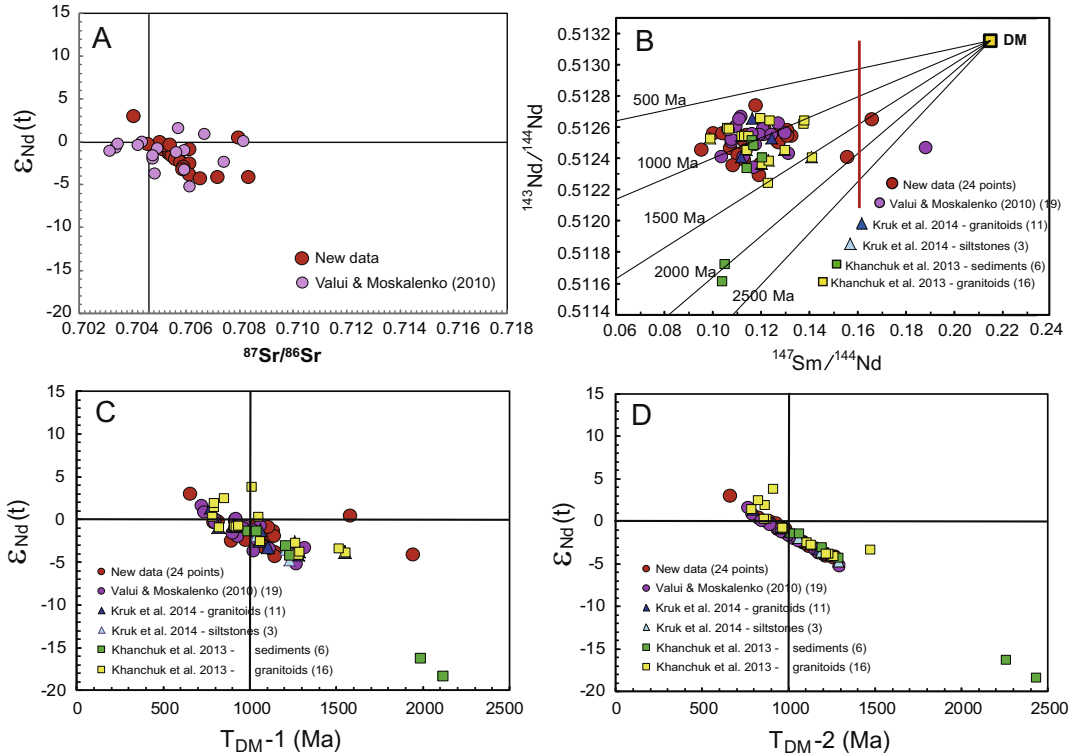
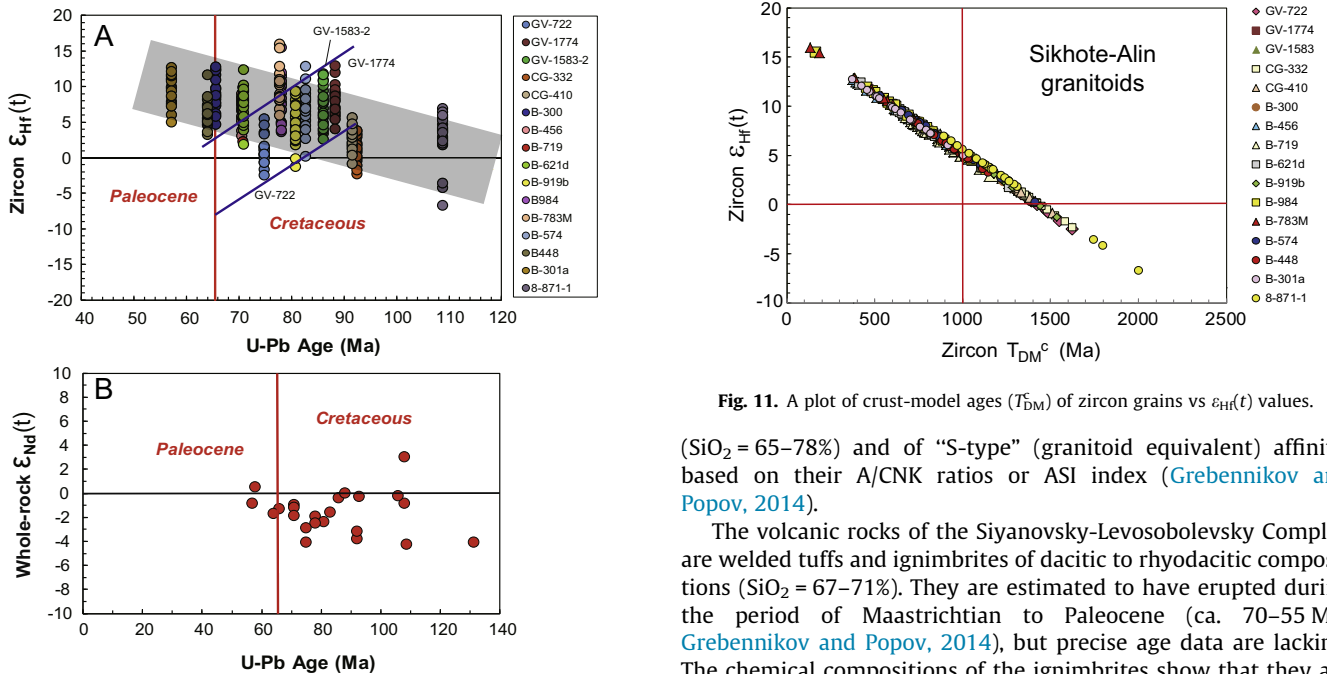


Fig. 8. Primitive mantle-normalized spidergrams of the granitoids from Sikhote-Alin. Primitive-mantle values are from Sun and McDonough (1989).

In the ESAPVB, three large ignimbrite complexes occur – (1) the Primorsky, (2) the Siyanovsky-Levosobolevsky, and (3) the Bogopolsky Complexes. These “complexes” have a wide areal distribution but are not restricted to small areas. Therefore, it might be more appropriate to call the complexes as “sequences”. The ignimbrites of the Primorye Region comprise mainly tuffs and ignimbrites, with subordinate rhyodacite and rhyolite lavas. The available age (Kurchavov, 1979; Mikhailov, 1989) and paleofloral



**Fig. 9.** Whole-rock Sr and Nd isotopic compositions of granitoids from Sikhote-Alin. The literature data (Valui and Moskalenko, 2010; Khanchuk et al., 2013; Kruk et al., 2014a) are used for comparison. (A)  $\epsilon_{Nd}(t)$  values vary from +3 to -6, with the majority from 0 to -5. Initial Sr isotopic ratios vary from 0.703 to 0.708. (B) Single-stage depleted-mantle model ages show a spread of values from 600 Ma to 1900 Ma, but (C) clustered around 1000 Ma. (D) Two-stage model ages vary from 600 to 1400 Ma.



**Fig. 10.** (A) Zircon initial Hf isotopic compositions seem to show a weak increasing trend of  $\epsilon_{Hf}(t)$  values with the younging of granite intrusions. However, this trend is not demonstrated in the whole-rock Nd isotopic compositions (B). On the other hand, the Hf isotopic data of three granitoids from the Central Sikhote-Alin Fault zone (GV-722, GV-1774, and GV-1583-2) appears to show an opposite trend (blue lines); that is, the  $\epsilon_{Hf}(t)$  values decrease with the younging of granitic intrusions.

data (Nevolina, 1960) suggest that the volcanic rocks were erupted during the period of 90–82 Ma (Turonian–Campanian). The volcanic rocks are mainly of rhyodacitic to rhyolite in compositions

**Fig. 11.** A plot of crust-model ages ( $T_{DM}^c$ ) of zircon grains vs  $\epsilon_{Hf}(t)$  values.

( $SiO_2 = 65\text{--}78\%$ ) and of “S-type” (granitoid equivalent) affinity, based on their A/CNK ratios or ASI index (Grebennikov and Popov, 2014).

The volcanic rocks of the Siyanovsky-Levosobolevsky Complex are welded tuffs and ignimbrites of dacitic to rhyodacitic compositions ( $SiO_2 = 67\text{--}71\%$ ). They are estimated to have erupted during the period of Maastrichtian to Paleocene (ca. 70–55 Ma; Grebennikov and Popov, 2014), but precise age data are lacking. The chemical compositions of the ignimbrites show that they are mainly of “S-type”. By contrast, the volcanic rocks of the Bogopol'sky Complex are characterized by two lithological facies; the early stage rocks are of S-type, whereas the late stage rocks are of A-type (Grebennikov and Popov, 2014). The volcanic rocks were erupted from the Paleocene to the early Eocene (ca. 60–50 Ma), based on Rb/Sr isochron ages of 60–53 Ma (Popov and Grebennikov, 2001) and K–Ar ages (Baskina and Favorskaya, 1969).

In conclusion, the three volcanic complexes or sequences have recorded three periods of volcanic eruptions: (1) 90–82 Ma, (2)

70–55 Ma, and (3) 60–50 Ma. In fact, these periods basically coincide with the intrusive episodes revealed by the present zircon U–Pb dating, even though the uncertainty of the volcanic chronology is higher.

### 6.2. Petrogenesis of the granitoids – geochemical and Sr–Nd–Hf isotopic constraints

The granitoids of the present study occur in different geologic terranes and were emplaced at different times. Therefore, they cannot be related by a differentiation process from a single parental magma, nor by different degrees of partial melting from a common source. However, their petrogenetic processes could be understood from, and constrained by, their geochemical and isotopic characteristics. The principal geochemical constraints are: (1) Based on the Q'–ANOR classification, the major rock types are granite and granodiorite, with three as alkali feldspar granite and two as quartz-monzodiorite (Fig. 6A). (2) The A/NK vs A/CNK plot (Fig. 6B) suggests that the majority (22/24) of granitoids are metaluminous to weakly peraluminous, thus they belong to the “I-type” genetic category; only two with A/CNK > 1.1 belong to the “S-type”. Surprisingly, this is in strong contrast with the chemical nature of the ignimbrites which are mainly “S-type” (Grebennikov and Popov, 2014). Note that peraluminous melts may form by melting of biotite-bearing metaluminous felsic rocks (Miller, 1985) or even by water-excess melting of mafic rocks (Ellis and Thompson, 1986), but not necessarily by melting of metasedimentary rocks. (3) The majority of the granitoids (21 out of 24) fall in the “volcanic-arc granites” (VAG) field (Fig. 6D), so they were most probably generated in a continental arc setting. (4) The  $FeO^*/MgO$  or  $FeO_{tot}/(FeO_{tot} + MgO)$  ratios indicate that many rocks have undergone significant fractional crystallization (Fig. 6C and E). (5) Three rocks (B-257, GV-722, AH-3-11) fall in the field of “within-plate granites”, but they are highly differentiated, show REE patterns with huge negative Eu anomalies and faint lanthanide tetrad effect (Figs. 7A and 8B, D). That is, they might not have been necessarily generated in a “within-plate” setting; their parental magmas could have been generated in a continental arc setting, like the other samples. Note that sample B-257 is equivalent to B-301a in the zircon age maps (Figs. 2 and 5), its occurrence in the coastal arc area cannot be related to an intraplate setting. (6) The spidergrams (Fig. 8A–E) show depletion or negative anomaly in Nb–Ta, Sr, P, Zr and Ti. The feature of “negative TNT (Ti–Nb–Ta) anomaly” is most characteristic of granitic rocks, island arc volcanic rocks and the continental crust in general. The anomaly is commonly attributed to the fractionation of accessory minerals, such as titanite and ilmenite (for Ti), magnetite, ilmenite and amphibole (for Nb–Ta), apatite (for P), zircon (for Zr), and some major phases, such as feldspars (for Sr). Fractionation of monazite, allanite and titanite could exert a huge effect in LREE depletion. Apparently, this did not occur as the REE patterns of the granitoids of interest do not show significant LREE depletion.

The whole-rock Sr–Nd and zircon Hf isotopic compositions provide the most stringent petrogenetic constraint. The calculated initial  $^{87}Sr/^{86}Sr$  ratios ( $I_{Sr}$  values) range from 0.7040 to 0.7083, and the initial  $\epsilon_{Nd}(t)$  values range from +3.0 to –6.0, but in most cases they are slightly negative (Fig. 9A). Single-stage Sm–Nd model ages vary between 655 and 1940 Ma and two-stage model ages range from 659 to 1370 Ma (Table 4; Fig. 9B and D). In comparison, zircon Hf isotopic data show that most analyzed zircon domains have positive  $\epsilon_{Hf}(t)$  values (Fig. 10A). Besides, the entire data-set appears to suggest an increasing trend of  $\epsilon_{Hf}(t)$  values as the emplacement age gets younger (Fig. 10A). Such a trend is lacking in the whole-rock Nd isotopic compositions (Fig. 10B). The zircon Lu–Hf model ages yielded a range of 200–2000 Ma, but the majority are from 500 to 1500 Ma (Fig. 11).

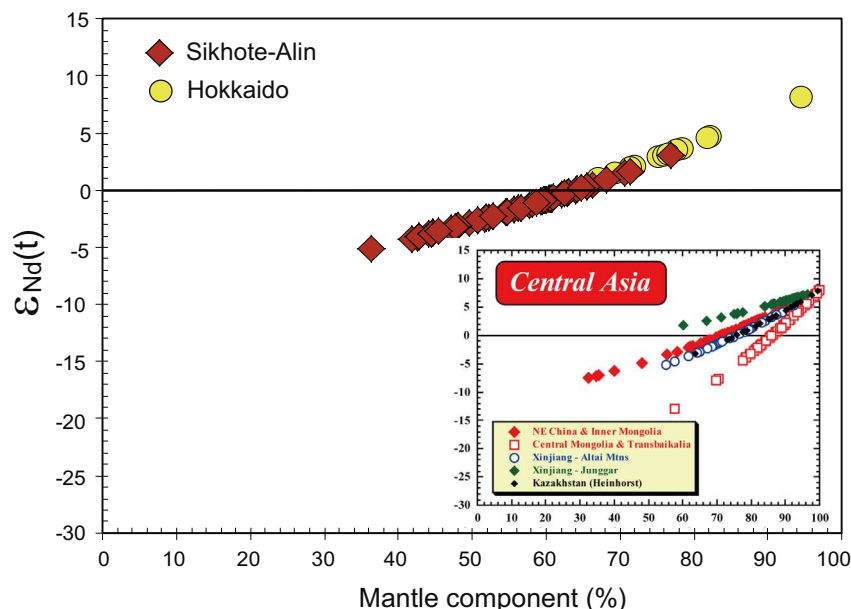
The display of a large range of  $\epsilon_{Hf}(t)$  values in zircon grains from the same sample is frequently observed in granitic rocks (e.g., Griffin et al., 2002; Jahn et al., 2014). A likely explanation is given as follows. Zircon crystallizes at a given time in an evolving granitic magma likely preserves its chemical and isotopic compositions in equilibrium with the magma at that time. The bulk composition of a magma chamber will change through fractional crystallization, but the crystallization process in a closed system will not modify the isotopic composition. A change of isotopic composition could only be achieved through an open-system behavior, such as influx of an external magma or assimilation of country rocks in the magma chamber. Zircon crystals formed at any given stage would register the Hf isotopic composition of the evolving magma at that stage. Since zircon crystals do not grow at the same time, the individual grains from a single rock might have recorded the Hf isotopic compositions of different stages of magma evolution.

Consequently, the Sr–Nd–Hf isotopic data suggest that the granitoid magmas of Sikhote-Alin were generated by partial melting of sources with significant proportions of mantle-derived materials intercalated with older continental crust components. The magma differentiation was probably accompanied by crustal assimilation as evidenced by the zircon Hf isotopic data. The mantle-derived materials could include the subducted oceanic basalt or underplated basaltic magma to the lower part of the Sikhote-Alin basement. In fact, fragments of the subducted oceanic plate are registered by seismic tomography at mantle depths as high-velocity objects (Bijwaard et al., 1998). The crustal component might be represented by the hidden older basement rocks and the accretionary complexes of terrigenous derivation. One might argue that “old basement rocks” do not exist in the Sikhote-Alin accretionary orogen; however, they are identifiable from the Nd–Hf isotopic point of view. Moreover, the crustal thickness beneath the Sikhote-Alin is 38 km (Rodnikov et al., 1996, 2008), and such a thick crust cannot be made up entirely of only accretionary complexes. Therefore, the existence of an old continental basement is hypothesized, as for the case of SW Japan (Jahn, 2010).

In a geochemical and Nd isotopic study of the Early Cretaceous granitoids of the Samarka terrane (130–98 Ma), Kruk et al. (2014a) found that the granitoids of the first stage (Khungari Group; 130–123 Ma) occur as a rather uniform melanogranite–granite association and are characterized by high K/Na, low Ca, and elevated  $Al_2O_3$ . They are akin to the S-type granites. Two Nd isotope analyses yielded  $\epsilon_{Nd}(t) = -4.1$  and  $-3.7$ , with Sm–Nd model ages ( $T_{DM}$ ) of  $\sim 1.3$  Ga. Granitoids of the second stage (Tatibi Group; 110–98 Ma) are more variable in composition and show a wider range of K/Na and A/CNK, higher CaO and lower  $P_2O_5$  than granitoids of the first stage. They belong to S- and I-type granites. Six Sm–Nd isotopic analyses yielded  $\epsilon_{Nd}(t) = -0.7$  to  $-3.8$ , and  $T_{DM}$  ages of 0.82–1.55 Ga. When geochemical and Nd isotopic data of the upper crustal rocks of the Samarka terrane (=sandstones and siltstones of the turbidite matrix of a Jurassic accretionary prism and intercalated basalts) are compared, the Early Cretaceous granitoids were considered to have been produced by partial melting of the Samarka accretionary prism (Kruk et al., 2014a). By contrast, the generation of the second stage granitoids involved underplating of basaltic magmas and triggered anatexis of a mixed rock assemblage including metabasaltic and metasedimentary rocks of accretionary complex. This produced a great diversity of granitoids from S- to I-type (Kruk et al., 2014a).

### 6.3. Juvenile crustal growth and comparison with other parts of the Western Pacific orogens

Generation and intrusion of granitoid magmas represent upward transport of crustal materials from the lower part of the



**Fig. 12.** Proportions of the mantle component vs.  $\epsilon_{\text{Nd}}(t)$  plot for the granitoids from Sikhote-Alin. The data of Hokkaido (Japan) and five terranes of the Central Asian Orogenic Belt are shown for comparison. The mantle component of the Sikhote-Alin samples varies from 36% to 77%.

crust and/or from the upper mantle. Anatexis of metasedimentary rocks may lead to the formation of peraluminous leucogranite, but such pure crustal melts are often limited in volume and in tectonic setting. Many lines of evidence advocate that generation of voluminous granitoid melts must have involved participation of mantle-derived liquid. The evidence includes (1) close association of granitic and basaltic rocks in orogenic belts in continental hot-spots and in regions of crustal extension; (2) petrological and geochemical arguments in favor of mixing of a mantle-derived component and crustal melt, including numerous mafic microgranular enclaves characteristic of many quartz diorite and granodiorite plutons of the studied region, and (3) thermal consideration and experimental demonstration of basalt-induced crustal melting (Huppert and Sparks, 1988). Thus, the generation of granitoid magmas implies an input of mantle material to the continental crust. Basaltic underplating to the lower crust and voluminous emplacement of basaltic sills are commonly considered to be the most effective way to trigger partial melting as well as to provide the mantle component to the granitoid liquids. If the source rocks are pre-existing metabasic rocks, the partial melts could become pure juvenile granitoids. Oxygen isotopic compositions (Valui et al., 2008) come to a similar conclusion regarding a significant contribution of juvenile protolith in the generation of granitoid rocks.

Using the Nd isotopic constraint, the proportion of the mantle component in the generation of the granitoids from Sikhote-Alin can be estimated. Fig. 12 shows a crude estimate of the proportion of the mantle (juvenile) to recycled components. The estimate was done using a simple two-component mixing calculation, assuming the two end-members to be a mantle-derived basalt (=mantle component) and an old continental crust (=crustal component). The data of the Cenozoic granitoids from Hokkaido (Jahn et al., 2014) and Paleozoic-to-Mesozoic granitoids from Central Asia (Jahn, 2004) are also shown for comparison. The mixing proportions for all granitoid samples can be calculated using the following equation:

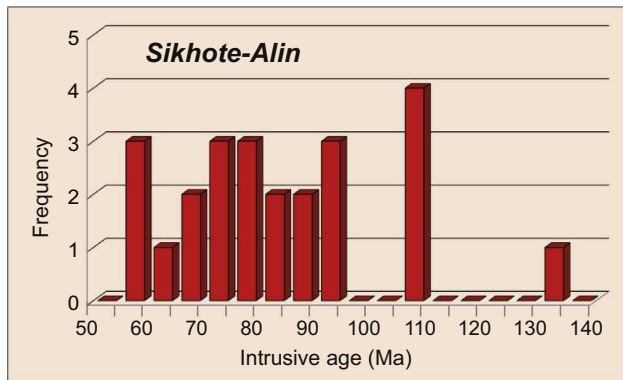
$$X^m = \text{Nd}_c \times (\epsilon^c - \epsilon^f) / [\epsilon^f \times (\text{Nd}_m - \text{Nd}_c) - (\epsilon^m \times \text{Nd}_m - \epsilon^c \times \text{Nd}_c)] \times 100$$

where  $X^m$  = mantle-derived juvenile component (represented by basalt);  $\epsilon^c$ ,  $\epsilon^f$ ,  $\epsilon^m$  = Nd isotopic compositions of the crust, rock measured, and mantle component, respectively.  $\text{Nd}_c$ ,  $\text{Nd}_m$  = Nd concentration in the crust and mantle components, respectively. The inset of Fig. 12 was taken from Jahn (2004), and the assumed parameters used are:  $\epsilon^m = +8$ ,  $\epsilon^c = -12$  (NE China and Inner Mongolia),  $-30$  (Central Mongolia and Transbaikalia),  $-15$  (Altai Mountains),  $-4$  (Junggar),  $-15$  (Kazakhstan),  $\text{Nd}_m = 15$  ppm, and  $\text{Nd}_c = 25$  ppm. For the granitoids of Hokkaido and Sikhote-Alin,  $\epsilon^m = +10$  and  $\epsilon^c = -10$  were used; but we chose  $\text{Nd}_c = 26.6$  ppm (average of 9 sedimentary rocks; Khanchuk et al., 2013; Kruk et al., 2014a) for the case of Sikhote-Alin.

Fig. 12 shows that the proportion of the mantle component in the granitoids of Sikhote-Alin varies from 77% to 36%. This represents a significant addition of juvenile crust to the Sikhote-Alin orogenic belt. However, the amount is lower than the granitoids from the Cenozoic accretionary terranes in Hokkaido (ca. 65–95%) and the Paleozoic accretionary terranes in the Central Asian Orogenic Belt. In any case, the overall range of slightly negative  $\epsilon_{\text{Nd}}(t)$  values (mostly from 0 to  $-4$ ) requires a contribution of older crustal rocks in the granitoid generation. The large range of zircon Hf isotope compositions also supports a role of recycled crust in the generation and differentiation of granitic magmas.

In the above estimate of the mantle/crust proportion, the major sources of error come from the poor knowledge of the end members. Based on the peraluminous S-type character and negative  $\epsilon_{\text{Nd}}(t)$  values ( $-4.0$  to  $-0.7$ ), Kruk et al. (2014a) proposed that the Khungari group granitoids of the Samarka Terrane were produced by partial melting of the accretionary complex. The accretionary complex is characterized by sandstone, siltstone, mixed clastic layers, large olistoliths and plates of flints. Occasionally, basalt, gabbro, limestone, and meta-ophiolitic schist also occur (Eliseeva et al., 1976). The terrigenous matrix rocks contain radiolarians of Jurassic age (Kemkin and Khanchuk, 1992), whereas the siliceous rocks from inclusions are dated mainly at the Triassic–Early Jurassic or, less commonly, Paleozoic ages (Kemkin and Golozubov, 1997; Mazarovich, 1985; Volokhin et al., 2003).





**Fig. 13.** Zircon age histogram for the Sikhote-Alin granitoids. A gap may be observed for the period from 130 to 110 Ma (magmatic quiescence period). The small gap of 110–95 Ma is probably an artifact because granitoids of 100–105 Ma have been recognized by conventional zircon dating of two granitoids from the Uspensk Intrusion (Khanchuk et al., 2008).

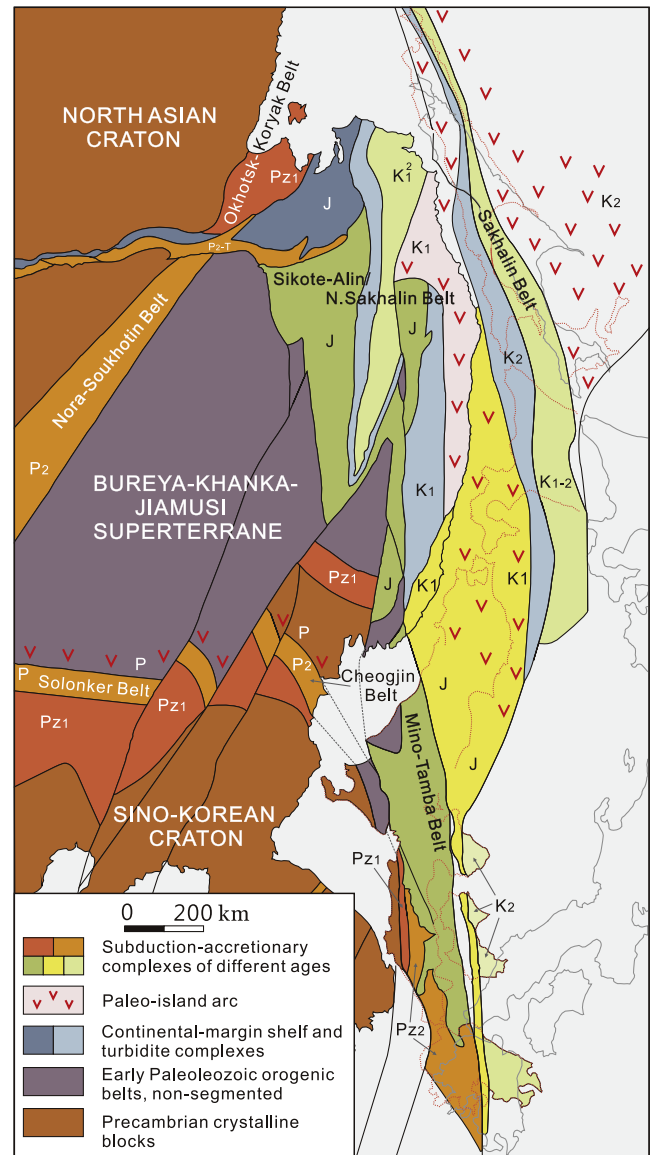
#### 6.4. Tectonic implications

##### 6.4.1. Paleo-Pacific and Eurasian plate interaction

The formation and evolution of the East Asian continental margin have involved complicated tectonomagmatic processes, including subduction, accretion and magmatism. Furthermore, the tectonic processes are characterized by the “transform” nature or strike-slip displacement of individual terranes or blocks of different tectonic history (e.g., Abrajevitch et al., 2012; Isozaki et al., 2010; Kemkin, 2008; Khanchuk, 2001, 2006; Kirilova, 2003; Kojima, 1989; Maruyama et al., 1997; Tazawa, 2004; Zonenshain et al., 1990a,b). A large part of the Russian Far East is built up of accretionary complexes that formed along the convergent margin during the Cretaceous. A complex distribution of coeval complexes as well as juxtaposition of different age units indicates a considerable margin-parallel translation of terranes, which was represented by the sinistral strike-slip fault systems in the region, of which the Central Sikhote-Alin Fault is the most celebrated (e.g. Khanchuk, 2001, 2006; Otsuki, 1992; Sengor and Natal'in, 1996; Tazawa, 2004). A paleomagnetic study led Abrajevitch et al. (2012) to hypothesize that the West Sakhalin Basin has moved from sub-equatorial latitude during the early Cretaceous to about 40°N by the late Cretaceous. Similarly, the Nadanhada Terrane of NE China (or Nadanhada-Bikin Terrane in Fig. 1) was probably accreted to the Asian continental margin from low-latitude during the late Mesozoic (Mizutani and Kojima, 1992).

The tectonic evolution and crustal formation are intimately linked to the interaction between the Paleo-Pacific (=Izanagi) and Eurasian plates. Fig. 13 shows an apparent magmatic quiescence period between 130 and 110 Ma (Early Cretaceous). A second apparent gap between 105 and 95 Ma, based only on our zircon age data, cannot be taken for another quiescence period because two granitoids from the Uspensk Intrusion from South Primorye have been dated at 103 and 104 Ma by the conventional zircon U–Pb method (Khanchuk et al., 2008). The Early Cretaceous quiescence period may imply the lack of subduction activity due probably to a strike-slip or transformal plate interaction, as depicted from the tectonic analysis of Golozoubov (2006). However, the present database of 24 zircon ages (Fig. 13) is likely insufficient to reach a definite conclusion.

Nevertheless, the quasi-continuous magmatism in the Late Cretaceous (Fig. 13) indicates that the Paleo-Pacific plate subduction was active, and the apparent regular younging of granitic intrusion ages, from 80 to 56 Ma (Fig. 2), in the Taukha Terrane may in fact suggest an oblique subduction of the oceanic plate beneath the Eurasian continental margin. The subduction-induced magmatism

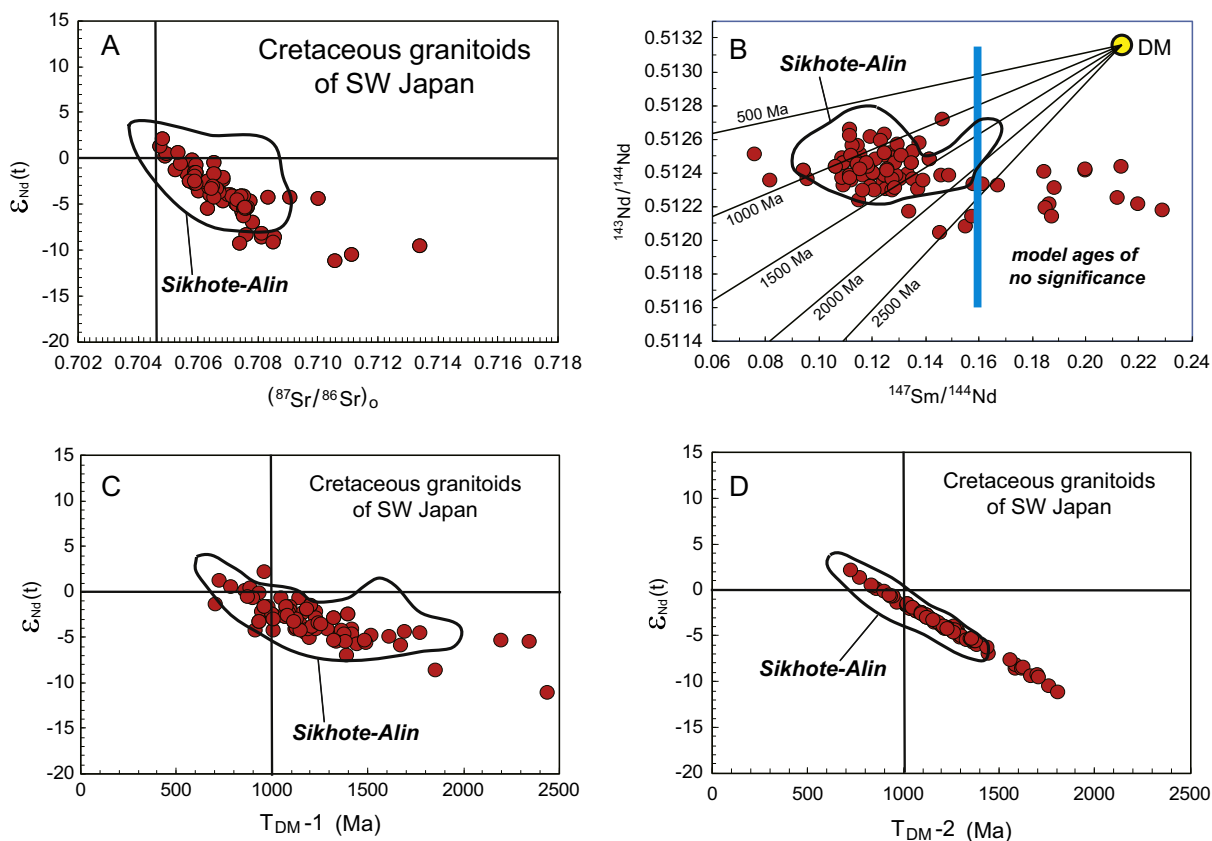


**Fig. 14.** A reconstructed terrane map of Khanchuk (2001) showing the correlation and geologic continuity between the Japanese Islands and Sikhote-Alin. Note that the “North Asian Craton” used by Khanchuk (2001) and shown in the upper left is equivalent to the more familiar “Siberian Craton”.

produced not only granitic intrusion, but also abundant silicic volcanism accompanied by subordinate basaltic eruptions. An important implication from the present geochronological work is that during Late Cretaceous the Paleo-Pacific plate motion probably changed from a parallel or sub-parallel (magmatic quiescence) to oblique (active arc magmatism) relative to the continental margin of Sikhote-Alin. Late Cretaceous rapid sea-floor spreading at about 100 Ma (Larson, 1991; Larson and Pitman, 1972) induced highly active subduction and led to voluminous magmatism in the entire circum-Pacific areas (Jahn, 1974).

##### 6.4.2. Geological correlation between Sikhote-Alin and SW Japan

Finally, we discuss the problem of the geological correlation between the Sikhote-Alin and the Japanese Islands. Based on the lithostratigraphy, biostratigraphy (radiolarian assemblages) and geological structures, the Samarka terrane was correlated with the Nadanhada terrane in China and the Mino-Tamba belt in Japan (Fig. 14; Kojima, 1989; Khanchuk, 2001). These terranes represent fragments of the same Jurassic accretionary complex. Khanchuk



**Fig. 15.** Sr and Nd isotopic compositions of Cretaceous granitoids from SW Japan, with superposition of the envelopes of the Sikhote-Alin data sets. A remarkable similarity between the two sets of data is observed. Data sources of SW Japan: Jahn (2010), Kagami et al. (1992), Arakawa and Shinmura (1995), Fujii et al. (2000), Izumi et al. (2000), Ishioka and Izumi (2003).

(2001) also considered that the Central Sikhote-Alin Fault and the Median and Tanakura Tectonic Lines (Japan) belong to the same Early Cretaceous Fault, and are comparable to the present San Andreas Fault in California. The Hida Belt could be correlated with the Sergeevka Terrane and the Khanka Block. The Taukha terrane may be a part of the Early Cretaceous subduction complex associated with the coeval arc volcanic rocks in NE Honshu and SW Hokkaido of Japan (Kiminami et al., 1992). Based on tectonic and faunal data, Matsukawa et al. (1997) proposed that the Jurassic to Early Cretaceous accretionary wedge and Early Cretaceous arc terranes (Taukha and others in NE Japan) were displaced from their original positions more than 1000 km northward and then accreted to the continental margin in the Albian time (113–100 Ma). Based on the age, lithology and structural position data of ophiolites and blueschists that occur in Sikhote-Alin and Japan, Ishiwatari and Tsujimori (2003) proposed a geologic continuation between Sikhote-Alin and Japan before the Miocene opening of the Japan Sea.

Evidence for the geologic correlations mentioned above may be strong for some cases but weak for the others. Geologic correlation could be made with two considerations: chronostratigraphic and lithostratigraphic. Based on the fossil assemblages and range of granitoid emplacement ages (Nakajima et al., 1990), the chronostratigraphic correlation between Sikhote-Alin and SW Japan could be well acceptable. However, we note that the similar Cretaceous age pattern is not unique to the two areas but is rampant in the Circum-Pacific regions. Therefore, the correlation has to be made with great care.

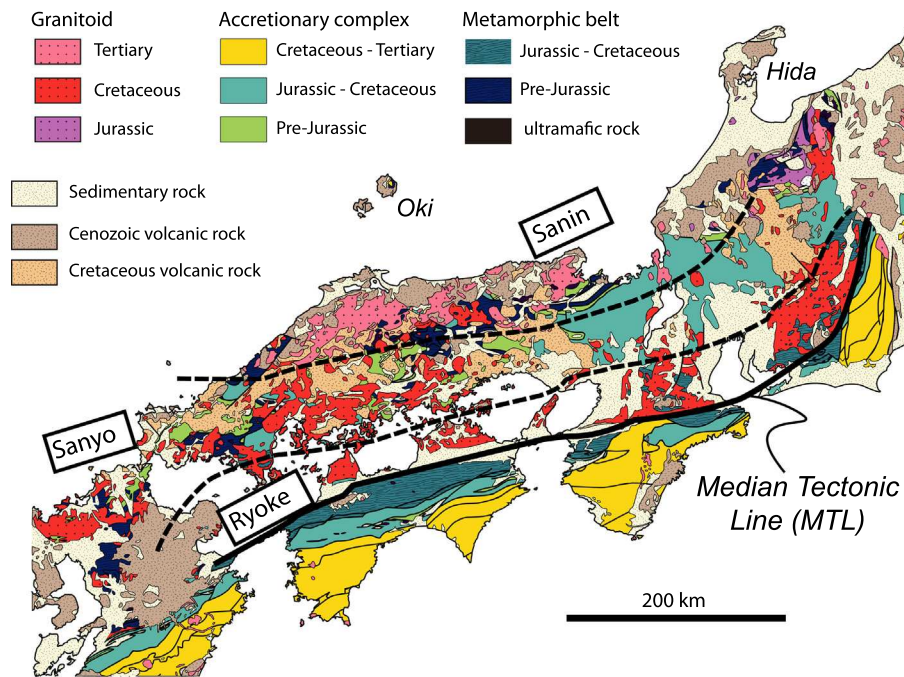
On the other hand, the whole-rock Sr–Nd isotopic data obtained for granitoid samples may be used to test the geologic correlation between Sikhote-Alin and SW Japan. The Sr–Nd isotopic data of

Sikhote-Alin (Fig. 9) fall within the range of SW Japan (Jahn, 2010; Jahn et al., 2014), though the range of Sikhote-Alin is much smaller and does not show very negative values as seen in SW Japan. However, if only the data of Cretaceous granitoids are examined, a remarkable similarity between Sikhote-Alin and SW Japan is observed (Fig. 15). Therefore, the available age and isotopic signatures of granitoids lend support to the geologic correlation.

It has been hypothesized that the initial development of the Japanese accretionary orogen began in the early Paleozoic, in the eastern margin of Cathaysia, SE China (Isozaki, 1996, 1997; Isozaki et al., 2010; Maruyama et al., 1997). The proto-Japan (microcontinent) was rifted off after the Cretaceous. The available Sr–Nd isotope data of granitoids (e.g., Jahn, 2010 and references therein) and detrital zircon ages (Fujisaki et al., 2014) support the affinity of SW Japan to Cathaysia. If Sikhote-Alin can indeed be correlated with SW Japan and both formed a physical continuity as depicted in Fig. 14 (Khanchuk, 2001), we may also expect the initial development of Sikhote-Alin along Cathaysia. In any case, many lines of evidence support the correlation between the SW Japan and Sikhote-Alin accretionary orogens, but some of them can be challenged, particularly between the Taukha Terrane and NE Japan as advocated by Kiminami et al. (1992) and followed by many workers. The challenge comes mainly from the contrasting Sr–Nd isotopic signatures of granitoids from these two tectonic units (Jahn et al., in preparation).

## 7. Conclusions

Based on the newly obtained geochemical, isotopic and geochronological data, we present the following conclusions:



**Fig. A1.** General geologic map of SW Japan. The Median Tectonic Line (MTL) separates the granitoid-dominated terrane to the north from the Mesozoic-Cenozoic accretionary wedge to the south. The granitoid terrane is divided into three granitic belts (Ryoke, Sanyo and Sanin) based on the type of mineral deposits and oxygen fugacity (Ishihara, 1971).

- Zircon dating revealed that granitoids of the Sikhote-Alin orogen were intruded from 130 to 56 Ma (Cretaceous to Paleogene). Granitoids in the coastal area were emplaced in the Taukha Terrane from 90 to 56 Ma, whereas those along the Central Sikhote-Alin Fault intruded the Samarka Terrane from 110 to 75 Ma. The “oldest” monzogranite (131 Ma) was emplaced to the west of the Central Sikhote-Alin Fault and within the Khanka Block. Thus, the most important tectonothermal events in the East Sikhote-Alin occurred in the Cretaceous.
- Geochemical analysis indicates that most granitoids are I-type. Whole-rock Sr–Nd isotopic data suggest that the magmas were generated by partial melting of mixed source rocks including the subduction-related accretionary complex as well as unexposed Paleozoic-Proterozoic basement rocks. Zircon Hf isotopic data further indicate that zircon grains crystallized from mixed-source melts and that crustal assimilation took place during magmatic differentiation. Overall, the Sr–Nd–Hf isotopic data indicate a significant proportion of the mantle component (36–77%) in the generation of the granitoid rocks. This suggests an addition of juvenile crust in Sikhote-Alin.
- The apparent regular change of granitic intrusion ages from 80 to 56 Ma in the Taukha Terrane was probably produced by oblique subduction of the Paleo-Pacific plate beneath the Eurasia continental margin.
- Subduction-induced magmatism produced not only widespread granitoids, but also abundant silicic volcanic rocks. During the Late Cretaceous the Paleo-Pacific plate motion probably changed from a parallel or sub-parallel (=magmatic quiescence period) to oblique (active arc magmatism period) relative to the continental margin of Sikhote-Alin. We admit that the idea of the change of plate motion is speculative as the age and geochemical data do not provide an unequivocal support.
- The geologic correlation between the Sikhote-Alin and SW Japan accretionary orogenic belts is supported by the present geochronologic and Sr–Nd isotopic study.

## Acknowledgments

We are deeply indebted to the following people and laboratories for their assistance in the acquisition of the data reported in this paper: Dunyi Liu (Beijing SHRIMP Center, for CL images), Sun-Lin Chung (NTU-Geosciences; chemical and zircon U–Pb and Hf isotope analyses), Chi-Yu Lee (NTU-Geosciences, major elements), and Wen-Yu Hsu (IES-AS; Sr–Nd isotope analyses). Ms. Jia-Ping Liao assisted in producing the U–Pb Concordia plots with color codes for Th/U ratios. A field excursion in southeastern Sikhote-Alin led by Galina Valui and Igor Alexandrov in September 2013 was very helpful. The Beijing SHRIMP Center (Dunyi Liu) and the University of Hong Kong (Min Sun) provided temporary shelters to BMJ in May 2014 and November 2014, respectively, for preparation of the manuscript. The early draft has been reviewed by Boris Litvinovsky and Igor Alexandrov. Their in-depth comments and suggestions are most appreciated. Constructive reviews by Profs. Gary Ernst, Alfred Kroner and Tatsuki Tsujimori have greatly improved the quality of this paper. BMJ acknowledges the support of NSC-Taiwan (MOST-Taiwan) through research projects of NSC-100-2923-M-002-010, NSC101-2116-M-002-003, NSC102-2116-M-002-031, MOST 104-2923-M-002-005.

## Appendix A. Brief geological description of SW Japan

The Japanese Islands have developed mainly through convergence between oceanic and continental plates along active margins (e.g., Isozaki, 1997; Isozaki et al., 2010). According to Isozaki et al. (2010), 9 belts of accretionary complex occur as thin subhorizontal fault-bounded units, i.e., nappe, and they show a clear downward and oceanward younging polarity. Numerous oceanic fragments derived from subducted oceanic plates, including deep-sea sediments and seamount basalts and reef limestone, were accreted to Japan. Furthermore, the Permo-Triassic tectonics is regarded as

most important because the basic framework of the Japanese orogenic belts was established and stabilized at that time (Isozaki, 1996). The occurrence of Permo-Triassic tectonic units is well developed in SW Japan and the Ryukyu Islands, but rarely recognized in NE Honshu and Hokkaido.

The Median Tectonic Line (MTL) is a prominent strike-slip fault running through most of SW Japan. It divides SW Japan into two zones: the “Inner Zone” on the back-arc side, and the “Outer Zone” on the fore-arc side (Fig. A1). In the Outer Zone, the post-Jurassic accretionary complexes are arranged to show oceanward younging from the Cretaceous to Miocene (Taira et al., 1988), and further to the present accretionary prism at the Nankai Trough. No collision-related Permo-Triassic units have been identified. The deep part of the accretionary complexes is exposed as a low-pressure to high-pressure regional metamorphic belt, which includes the eclogite-bearing Sanbagawa Belt. Conspicuous Miocene granitic rocks also occur on the Pacific side of SW Japan. These granitoids intruded into the Cretaceous and Tertiary accretionary complexes, and they were likely produced by remelting of the Shimanto accretionary complex (Shinjoe, 1997; Jahn, 2010).

In the Inner Zone (Fig. A1), Cretaceous to Paleogene granitoids are extensively distributed. Note that the majority of granitic intrusions were emplaced in the Cretaceous, and they intruded into the pre-Cretaceous accretionary complexes which include regional metamorphic rocks. Similar to Sikhote-Alin, the intrusive granitoids in SW Japan are associated with coeval rhyolites and ignimbrites even though much of the cover series has been eroded to expose the intrusive rocks. Besides, a few collisional belts, or non-accretionary units (Hida and Oki belts), occur in the northern part, and they are composed of polymetamorphic gneiss and schist complexes, with a Triassic regional metamorphism of intermediate pressure facies (Komatsu, 1990).

Ishihara (1971) made a detailed study of the granitoids and associated ore deposits. He divided the Inner Zone into three metallogenic provinces, from south to north, a Barren, a Tungsten, and a Molybdenum Province (see also Ishihara and Murakami, 2006). The three provinces correspond to the Ryoke, Sanyo and San-in Belts as delineated by Murakami (1974) on the basis of granite petrography and age data. The lithological types in the Inner Zone are more complicated than the granitoids and acid volcanic rocks alone. The Ryoke belt is a plutonic-metamorphic terrane that comprises pre-Cretaceous accretionary complexes with high-level granites and high-grade, but low P/T, metasediments with migmatites and gneissose granites. Granitic rocks are dominant over metamorphic rocks. The Ryoke and Sanyo granitoids were likely produced by Cretaceous subduction of the Kula-Pacific ridge (Nakajima, 1994). Isozaki et al. (2010) described that the Inner Zone is composed of a 15 km-thick lower crust of unknown composition, a 20 km-thick granitic upper crust and thin roof-pendants of the Paleozoic to Jurassic accretionary complex (AC) units on the surface. These AC units are characterized by subhorizontal stacking of multiply fault-bounded units, previously recognized “nappes”, with a gentle dip angle toward the Eurasian continent.

In addition to granitoids, ophiolite complexes also occur widely in SE Japan (Ishiwatari and Tsujimori, 2001; Ishiwatari and Tsujimori, 2003; Fig. A2). They were emplaced from early Paleozoic to Cenozoic. In SW Japan the early Paleozoic Oeyama ophiolite occupies the highest structural position, and tectonically overlies the late Paleozoic Renge blueschist, the Yakuno ophiolite, and the Permian Akiyoshi (and Ultra-Tamba) accretionary complexes. These tectonic units are separated by thrust faults.

The Yakuno ophiolite is a rather complete succession composed of harzburgite tectonite, dunite-wehrlite-clinopyroxenite cumulate, metagabbro, amphibolite and metabasalt with abundant black shale. Study of radiolarian fossils from the black shale (Kurimoto

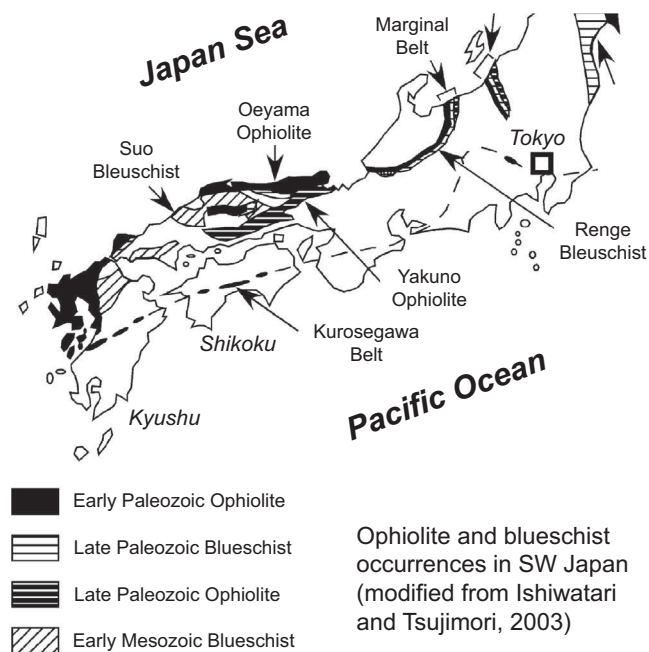


Fig. A2. Distribution of ophiolites and blueschists in SW Japan (modified from Ishiwatari and Tsujimori, 2003).

and Makimoto, 1990) and radiometric dating (K–Ar on metagabbro (Shibata et al., 1977) and zircon U–Pb on plagiogranite (Herzig et al., 1997) indicate that the ophiolite formed in Early Permian (ca. 285 Ma) and was metamorphosed later during 240–280 Ma.

The Renge blueschist occurs as thin tectonic slices or blocks in serpentinite mélanges underlying the Oeyama ophiolite (Tsujimori, 1998), and has a phengite K–Ar age of 320 Ma (Tsujimori and Itaya, 1999).

## References

- Abrajevitch, A., Zybrev, S., Didenko, A.N., Kodama, K., 2012. Paleomagnetism of the West Sakhalin Basin: evidence for northward displacement during the Cretaceous. *Geophys. J. Int.* 190, 1439–1454.
- Arakawa, Y., Shinmura, 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.
- Baskina, V.A., Favorskaya, M.A., 1969. Age of the igneous rocks of the Imansky block (East Sikhote-Alin) is fixed by the K–Ar method. *DAN the USSR* 184, 905–908 (in Russian).
- Bijwaard, H., Spakman, W., Engdahl, E.R., 1998. Closing the gap between regional and travel time tomography. *J. Geophys. Res.* Solid Earth 103, 30055–30078.
- Chiu, H.Y., Chung, S.L., Wu, F.Y., Liu, D., Liang, Y.H., Lin, I.J., Iizuka, Y., Xie, L.W., Wang, Y., Chu, M.F., 2009. Zircon U–Pb and Hf isotopic constraints from eastern Transhimalayan batholiths on the pre-collisional magmatic and tectonic evolution in southern Tibet. *Tectonophysics* 477, 3–19.
- Chu, M.F., Chung, S.L., Song, B., Liu, D.Y., O’Reilly, S.Y., Pearson, N.L., 2006. Zircon U–Pb and Hf isotope constraints on the Mesozoic tectonics and crustal evolution of southern Tibet. *Geology* 34, 745–748.
- DePaolo, D.J., Linn, A.M., Schubert, G., 1991. The continental crust age distribution: methods of determining mantle separation ages from Sm–Nd isotopic data and application to the Southeastern United States. *J. Geophys. Res.* 96, 2017–2088.
- Eliseeva, V.K., Lipman, R.Kh., Svyatogorova, N.N., 1976. New data on the stratigraphy of central Sikhote-Alin. *Geologiya i Geofizika (Soviet Geol. Geophys.)* 17, 30–43 (22–32).
- Ellis, D.J., Thompson, A.B., 1986. Subsolvus and partial melting reactions in the quartz-excess CaO+MgO+Al<sub>2</sub>O<sub>3</sub>+SiO<sub>2</sub>+H<sub>2</sub>O system under water-excess and water-deficient conditions to 10 kb: some implications for the origin of peraluminous melts from mafic rocks. *J. Petrol.* 27, 91–121.
- Frost, B.R., Barnes, C.G., Collins, W.J., Arculus, R.J., Ellis, D.J., Frost, C.D., 2001. A geochemical classification for granitic rocks. *J. Petrol.* 42, 2033–2048.
- Fujii, H., Tainosho, Y., Kagami, H., Kakiuchi, T., 2000. Sr–Nd isotopic systematics and geochemistry of the intermediate plutonic rocks from Ikoma mountains, Southwest Japan: Mesozoic magmatic activity in the Ryoke Belt. *Island Arc* 9, 37–45.
- Fujisaki, W., Isozaki, Y., Maki, K., Sakata, S., Hirata, T., Maruyama, S., 2014. Age spectra of detrital zircon of the Jurassic clastic rocks of the Mino-Tamba AC belt

- in SW Japan: constraints to the provenance of the mid-Mesozoic trench in East Asia. *J. Asian Earth Sci.* 88, 62–73.
- Geology of the USSR, 1971. Primorsky Region. Part 1. Geological Structure, vol. 32. Nedra, Moscow, 695 p (in Russian).
- Golozubov, V.V., 2006. Tectonics of the Jurassic and Lower Cretaceous Complexes of the North-Western Framing of Pacific Ocean. *Dal'nauka, Vladivostok*, 239 p. (in Russian).
- Golozubov, V.V., Khanchuk, A.I., 1996. Taukha and Zhuravlevka terranes of South Sikhote-Alin – fragments of the Early Cretaceous margin of Asia. *Russian J. Pac. Geol.* 12, 203–220.
- Gonevchuk, V.G., 2002. Tin-bearing System of the Far East: Magmatism and Ore Genesis. *Dal'nauka, Vladivostok*, 296p (in Russian).
- Gonevchuk, V.G., Gonevchuk, G.A., Korostelev, P.G., Semenyak, B.I., Selmann, R., 2010. Tin deposits of the Sikhote-Alin and adjacent areas (Russian Far East) and their magmatic association. *Aust. J. Earth Sci.* 57, 777–802.
- Gonevchuk, V.G., Gonevchuk, G.A., Lebedev, V.A., Orekhov, A.A., 2011. Association of monzonitic rocks of the Kavalerovo ore district (Primorye): geochronology and genesis. *Russian J. Pac. Geol.* 30, 20–31.
- Goolaerts, A., Mattielli, N., de Jong, J., Weis, D., Scoates, J.S., 2004. Hf and Lu isotopic reference values for the zircon standard 91500 by MC-ICP-MS. *Chem. Geol.* 206, 1–9.
- Grebennikov, A.V., Popov, V.K., 2014. Petrochemical aspects of the Late Cretaceous and Paleogene igmimbrite volcanism of East Sikhote-Alin. *Russian J. Pac. Geol.* 8, 38–55.
- Griffin, W.L., Wang, X., Jackson, S.E., Pearson, N.J., O'Reilly, S.Y., Xu, X., Zhou, X., 2002. Zircon chemistry and magma mixing, SE China: in-situ analysis of Hf isotopes, Tonglu and Pingtan igneous complexes. *Lithos* 61, 237–269.
- Griffin, W.L., Pearson, N.J., Belousova, E.A., Saeed, A., 2006. Comment: Hf-isotope heterogeneity in zircon 91500. *Chem. Geol.* 233, 358–363.
- Gvozdev, V.I., 2010. Ore-magmatic Systems of Skarn Scheelite–Sulfide Deposits in Eastern Russia. *Dal'nauka, Vladivostok* (in Russian).
- Herzig, C.T., Kimborough, D.L., Hayasaka, Y., 1997. Early Permian zircon uranium–lead ages for plagiogranites in the Yakuno ophiolite, Asago district, Southwest Japan. *Island Arc* 6, 396–403.
- Huppert, H.E., Sparks, R.S., 1988. The generation of granitic magmas by intrusion of basalt into continental crust. *J. Petrol.* 29, 599–624.
- Iizumi, S., Imaoka, T., Kagami, H., 2000. Sr–Nd isotope ratios of gabbro and dioritic rocks in a Cretaceous–Paleogene granite terrain, Southwest Japan. *Island Arc* 9, 113–127.
- Ishihara, S., 1971. Modal and chemical composition of the granitic rocks related to the major molybdenum and tungsten deposits in the inner zone of southwest Japan. *J. Geol. Soc. Jpn* 77, 441–452.
- Ishihara, S., Murakami, H., 2006. Fractionated ilmenite–series granites in Southwest Japan: source magma for REE–Sn–W mineralizations. *Resour. Geol.* 56, 245–256.
- Ishioka, J., Iizumi, S., 2003. Petrochemical and Sr–Nd isotope investigations of Cretaceous intrusive rocks and their enclaves in the Togouchi–Yoshida district, northwest Hiroshima prefecture, SW Japan. *Geochem. J.* 37, 449–470.
- Ishiwatari, A., Tsujimori, T., 2003. Paleozoic ophiolites and blueschists in Japan and Russian Primorye in the tectonic framework of East Asia: a synthesis. *Island Arc* 12, 190–206.
- Isozaki, Y., 1996. Anatomy and genesis of a subduction-related orogen: a new view of geotectonic subdivision and evolution of the Japanese islands. *Island Arc* 5, 289–320.
- Isozaki, Y., 1997. Constrasting two types of orogen in Permo-Triassic Japan: accretionary versus collisional. *Island Arc* 6, 2–24.
- Isozaki, Y., Aoki, K., Nakama, T., Yanai, S., 2010. New insight into a subduction-related orogeny: a reappraisal of the geotectonic framework and evolution of the Japanese Islands. *Gondwana Res.* 18, 82–105.
- Jahn, B.M., 1974. Mesozoic thermal events in southeast China. *Nature* 248, 480–483.
- Jahn, B.M., 2004. The Central Asian Orogenic Belt and growth of the continental crust in the Phanerozoic. In: Malpas, J., Fletcher, C.J.N., Ali, J.R., Aitchison, J.C. (Eds.), *Aspects of the Tectonic Evolution of China*, vol. 226. Geological Society of London Special Publications, pp. 73–100.
- Jahn, B.M., 2010. Accretionary orogen and evolution of the Japanese Islands – implications from a Sr–Nd isotopic study of the Phanerozoic granitoids from SW Japan. *Am. J. Sci.* 310, 1210–1249.
- Jahn, B.M., Wu, F.Y., Chen, B., 2000a. Massive granitoid generation in Central Asia: Nd isotope evidence and implication for continental growth in the Phanerozoic. *Episodes* 23, 82–92.
- Jahn, B.M., Wu, F.Y., Chen, B., 2000b. Granitoids of the Central Asian Orogenic Belt and continental growth in the Phanerozoic. *Trans. Royal Soc. Edinburgh: Earth Sci.* 91, 181–193.
- Jahn, B.M., Wu, F., Capdevila, R., Martineau, F., Zhao, Z., Wang, Y., 2001. Highly evolved juvenile granites with tetrad REE patterns: the Woduhe and Baerzhe granites from the Great Xing'an Mountains in NE China. *Lithos* 59, 171–198.
- Jahn, B.M., Capdevila, R., Liu, D.Y., Vernon, A., Badarch, G., 2004. Sources of Phanerozoic granitoids in the transect Bayanhongor–Ulaan Baatar, Mongolia: geochemical and Nd isotopic evidence, and implications for Phanerozoic crustal growth. *J. Asian Earth Sci.* 23, 629–653.
- Jahn, B.M., Litvinovsky, B.A., Zanzivilevich, A.N., Reichow, M., 2009. Peralkaline granitoid magmatism in the Mongolian-Transbaikalian Belt: evolution, petrogenesis and tectonic significance. *Lithos* 113, 521–539.
- Jahn, B.M., Usuki, M., Usuki, T., Chung, S.L., 2014. Generation of Cenozoic granitoids in Hokkaido (Japan): constraints from zircon geochronology, Sr–Nd–Hf isotopic and geochemical analyses, and implications for crustal growth. *Am. J. Sci.* 314, 704–750.
- Kagami, H., Iizumi, S., Tainosho, Y., Owada, M., 1992. Spatial variations of Sr and Nd isotope ratios of Cretaceous–Paleogene granitoid rocks, SW Japan Arc. *Contrib. Miner. Petrol.* 112, 165–177.
- Kemkin, I.V., 2008. Structure of terranes in a Jurassic accretionary prism in the Sikhote-Alin-Amur area: implications for the Jurassic geodynamic history of the Asian eastern margin. *Russ. Geol. Geophys.* 49, 759–770.
- Kemkin, I.V., Golozubov, V.V., 1997. The first find of the Early Jurassic radiolarians in the cherty allochthons of the Samarka accretionary prism (Southern Sikhote-Alin). *Russian J. Pac. Geol.* 13, 1111–1118.
- Kemkin, I.V., Khanchuk, A.I., 1992. New data on the age of the paraautochthone of the Samarka accretionary complex, southern Sikhote-Alin. *Dokl. Akad. Nauk* 324, 847–851.
- Kemkin, I.V., Khanchuk, A.I., 1994. Jurassic accretionary prism in the southern Sikhote Alin. *Geol. Pac. Ocean* 10, 831–846.
- Kemkin, I.V., Takedani, Y., 2008. Structure and age of lower structural unit of Taukha terrane of Late Jurassic–Early Cretaceous accretionary prism, southern Sikhote-Alin. *Island Arc* 17, 517–530.
- Khanchuk, A.I., 2001. Pre-Neogene tectonics of the Sea-of-Japan region: a view from the Russian side. *Earth Sci. (Chikyu Kagaku)* 55, 275–291.
- Khanchuk, A.I. (Ed.), 2006. *Geodynamics, Magmatism, and Metallogeny of Eastern Russia*, Book 1. Dal'nauka, Vladivostok, 572 pp. (in Russian).
- Khanchuk, A.I., Kemkin, I.V., 2003. The Mesozoic geodynamic evolution of the Japan Sea region. *Bull. DVO RAN* 6, 99–116.
- Khanchuk, A.I., Panchenko, I.V., Kemkin, I.V., 1988. Geodynamic Evolution of Sikhote-Alin and Sakhalin in the Paleozoic and Mesozoic. Far East Branch of the USSR Academy of Sciences, Vladivostok, 56 pp.
- Khanchuk, A.I., Ratkin, V.V., Ryazantseva, M.D., Golozubov, V.V., Gonokhova, N.G., 1996. Geology and Mineral Deposits of Primorsky Krai. *Dal'nauka, Vladivostok*, 61 pp.
- Khanchuk, A.I., Kruk, N.N., Valui, G.A., Nevolin, P.L., Moskalenko, E.Yu., Fugzan, M.M., Kirnozova, T.I., Travin, A.V., 2008. The Uspensk intrusion in South Primorye as a reference petrotype for granitoids of the transform continental margins. *Dokl. Earth Sci.* 421, 734–737.
- Khanchuk, A.I., Vovna, G.M., Kiselev, V.I., Mishkin, M.A., Lavrik, S.N., 2010. First results of zircon LA-ICP-MS U–Pb dating of the rocks from the granulite complex of Khanka Massif in the Primorye Region. *Dokl. Earth Sci.* 434, 1164–1167.
- Khanchuk, A.I., Kruk, N.N., Golozubov, V.V., Kovach, V.P., Serov, P.A., Kholodnov, V.V., Gvozdev, V.I., Kasatkin, S.A., 2013. The nature of the continental crust of Sikhote-Alin as evidenced from the Nd isotopy of rocks of Southern Primorie. *Dokl. Earth Sci.* 451, 809–813.
- Kiminami, K., Niida, K., Ando, H., Iwata, K., Miyashita, S., Tajika, J., Sakakibara, M., 1992. Cretaceous–Paleogene arc-trench systems in Hokkaido. In: Adachi, M., Suzuki, K. (Eds.), *29th IGC Field Trip Guide Book. I: Paleozoic and Mesozoic Terranes, Basement of the Japanese Island Arcs*, pp. 1–43.
- Kirilova, G.L., 2003. Cretaceous tectonics and geological environments in East Russia. *J. Asian Earth Sci.* 21, 967–977.
- Kojima, S., 1989. Mesozoic terrane accretion in Northeast China, Sikhote-Alin and Japan regions. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 69, 213–232.
- Kojima, S., Kemkin, I.V., Kametaka, M., Ando, A., 2000. A correlation of accretionary complexes of southern Sikhote-Alin of Russia and the Inner Zone of Southwest Japan. *Geosci. J.* 4, 175–185.
- Komatsu, M., 1990. Hida “Gaien” Belt and Joetsu Belt. In: Ichikawa, K., Mizutani, S., Hara, I., Hada, S., Yao, A. (Eds.), *Pre-Cretaceous Terranes of Japan*, Publication of IGCP Project 224: Pre-Jurassic Evolution of Eastern Asia. Osaka, Nippon Insatsu Shuppan, pp. 25–40.
- Kruk, N.N., Simanenkov, V.P., Gvozdev, V.I., Golozubov, V.V., Kovach, V.P., Serov, P.I., Kholodnov, V.V., Moskalenko, E.Yu., Kuibida, M.L., 2014a. Early Cretaceous granitoids of the Samarka terrane (Sikhote-Alin): geochemistry and sources of melts. *Russ. Geol. Geophys.* 55, 216–236.
- Kruk, N.N., Simanenkov, V.P., Golozubov, V.V., Kovach, V.P., Vladimirov, V.G., Kasatkin, S.A., 2014b. Geochemistry of rocks in the Anuy metamorphic dome, Sikhote-Alin: composition of the protoliths and the possible nature of metamorphism. *Geochem. Int.* 52, 229–246.
- Krimskii, R.Sh., Pavlov, V.A., Rub, M.G., Belyatskii, V.B., Levskii, L.K., 1998. Rb–Sr and Sm–Nd isotopic systematics of the granitoids and ores of the Vostok-2 scheelite deposit, Primorie. *Petrology* 6, 1–11.
- Kurchavov, A.M., 1979. *Lateral Variability of Volcanic Rocks: On the Example of Southern Primorye*. Nauka, Moscow, 145 p (in Russian).
- Kurimoto, C., Makimoto, H., 1990. *Geology of Fukuchiyama Area. 1:50,000 Scale Quadrangle Map*. Geological Survey of Japan, Tsukuba (in Japanese with English abstract).
- Larson, R.L., 1991. Latest pulse of Earth: evidence for a mid-Cretaceous superplume. *Geology* 19, 547–550.
- Larson, R.L., Pitman, W.C., 1972. World-wide correlation of Mesozoic magnetic anomalies, and its implications. *Geol. Soc. Am. Bull.* 83, 3645–3662.
- Lin, I.J., Chung, S.L., Chu, C.H., Lee, H.Y., Gallet, S., Wu, G., Ji, J., Zhang, Y., 2012. Geochemical and Sr–Nd isotopic characteristics of Cretaceous to Paleogene granitoids and volcanic rocks, SE Tibet: petrogenesis and tectonic implications. *J. Asian Earth Sci.* 53, 131–150.
- Lin, T.-H., Chung, S.-L., Kumar, A., Wu, F.-Y., Chiu, H.-Y., Lin, I.-J., 2013. Linking a prolonged Neo-Tethyan magmatic arc in South Asia: zircon U–Pb and Hf isotopic constraints from the Lohit batholith, NE India. *Terra Nova* 25, 453–458.
- Malinovsky, A.I., Golozubov, V.V., Simanenkov, V.P., 2006. The Kema island-arc terrane, Eastern Sikhote-Alin: formation settings and geodynamics. *Dokl. Earth Sci.* 410, 1026–1029.

- Malinovsky, A.I., Golozubov, V.V., Simanenko, V.P., Simanenko, L.F., 2008. Kema terrane: a fragment of a back-arc basin of the Early Cretaceous Moneron-Samarga island-arc system, East Sikhote-Alin range, Russian Far East. *Island Arc* 17, 285–304.
- Maruyama, S., 1997. Pacific-type orogeny revisited: Miyashiro-type orogeny proposed. *The Island Arc* 6, 91–120.
- Maruyama, S., Isozaki, Y., Kimura, G., Terabayashi, M., 1997. Paleogeographic maps of the Japanese islands: plate tectonic synthesis from 750Ma to the present. *Island Arc* 6, 121–142.
- Matsukawa, M., Takahashi, O., Hayashi, K., Ito, M., Konvaloy, V.P., 1997. Early Cretaceous paleogeography of Japan, based on tectonic and faunal data. *Mem. Geol. Soc. Jpn.* 48, 29–42.
- Melnikov, N.G., Golozubov, V.V., 1980. Olistostromal thickness and consedimentation tectonic covers in the Sikhote-Alin. *Geotectonics* 4, 95–106 (in Russian).
- Mazarovich, A.O., 1985. Tectonic Development of the Southern Primor'e in Paleozoic and Early Mesozoic. *Nauka, Moscow*, 103 p (in Russian).
- Mikhailov, V.A., 1989. Magmatism of the Volcanotectonic Structures of the Southern East Sikhote-Alin Volcanic Belt. *Dal'nauka, Vladivostok*, 171 p (in Russian).
- Miller, C.F., 1985. Are strongly peraluminous magmas derived from pelitic sedimentary sources? *J. Geol.* 93, 673–689.
- Mizutani, S., Kojima, S., 1992. Mesozoic radiolarian biostratigraphy of Japan and collage tectonics along the eastern continental margin of Asia. *Paleogeogr. Paleoclimatol. Paleoecol.* 96, 3–22.
- Moskalenko, E.Yu., Kruk, N.N., Valui, G.A., 2011. New data on the geology and geochemistry of granitoids of the Uspenky massif, southern Primorye. *Russian J. Pac. Geol.* 30, 80–92.
- Murakami, N., 1974. Some problems concerning late Mesozoic to early Tertiary igneous activity on the inner side of Southwest Japan. *Pac. Geol.* 8, 139–151.
- Nakajima, T., 1994. The Ryoke plutonometamorphic belt: crustal section of the Cretaceous Eurasian continental margin. *Lithos* 33, 51–66.
- Nakajima, T., Shirahase, T., Shibata, K., 1990. Along-arc lateral variation of Rb–Sr and K–Ar ages of Cretaceous granitic rocks in Southwest Japan. *Contrib. Miner. Petrol.* 104, 381–389.
- Natal'in, B.A., 1991. Mesozoic accretionary and collisional tectonics of the USSR South Far east. *Geol. Pac. Ocean* 5, 3–23.
- Natal'in, B.A., Faure, M., Monie, P., Borukaev, Ch.B., Prikhod'ko, V.S., Vrublevskii, A.A., 1994. The Anyui metamorphic dome, Sikhote-Alin, and its significance for the Mesozoic geodynamic evolution of Eastern Asia. *Tikhookeanskaya Geol.* 6, 3–25.
- Nevolina, S.I., 1960. New finds of Cretaceous and Tertiary floras in Primorye. *Inform. Sbornik Prmorsk. Geol. Upravlenit* 1, 41–44 (in Russian).
- Otsuki, K., 1992. Oblique subduction, collision of microcontinents and subduction of oceanic ridge: their implications on the Cretaceous tectonics of Japan. *Island Arc* 1, 51–63.
- Parfenov, L.M., 1984. Continental Margins and Island Arcs of the Mesozoides of Northeastern Asia. *Nauka, Novosibirsk*, 192 pp.
- Pearce, J.A., Harris, N.W., Tindle, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *J. Petrol.* 25, 956–983.
- Popov, V.K., Grebennikov, A.V., 2001. The new data about age of effusions in the Bogopolsky suite in Primorski Krai. *Pac. Geol.* 3, 47–54 (in Russian).
- Rodionov, S.M., Khanchuk, A.I., Obolenskiy, A.A., Ogasawara, M., Seminskiy, Z.V., Prokopiev, A.V., Timofeev, V.F., Nokleberg, W.J., 2010. Middle Jurassic through Quaternary metallogenesis and tectonics of northeast Asia. In: Nokleberg, W.J. (Ed.), *Metallogenesis and Tectonics of Northeast Asia*. U.S. Geological Survey Professional Paper 1765, 138 pp (Chapter 8).
- Rodnikov, A.G., Rodkin, M.V., Stroev, P.A., Ueda, S., Isedsaki, N., Siki, T., 1996. Deep structure and geophysical fields along the Philippine Sea Geotravers. *Fisika Zemli*, 12, 100–108.
- Rodnikov, A.G., Sergeeva, N.A., Zabarinskaya, L.P., Filatova, N.I., Piip, V.B., Rashidov, V.A., 2008. The deep structure of active continental margins of the Far East (Russia). *Russian J. Earth Sci.* 10 (ES4002), 2008. <http://dx.doi.org/10.2205/2007ES000224>, 23 pages.
- Rub, M.G., Pavlov, V.A., Gladkov, N.G., Jashukhin, O.I., 1982. Tungsten-Bearing and Tin-Bearing Granitoids of Some Regions in USSR. *Nauka, Moscow*, 263 p, (in Russian).
- Sakhno, V.G., 2001. Late Mesozoic–Cenozoic Continental Volcanism of East Asia. *Dal'nauka, Vladivostok*, 336 p. (in Russian).
- Sakhno, V.G., Kovalenko, S.V., Alenicheva, A.A., 2011. Monzonitic magmatism of the porphyry copper deposit Lazurnoe: U–Pb and K–Ar-dating and magma genesis from evidence isotopic and geochemical study (Primor'e, Russia). *Doklady AN* 438, 82–90 (in Russian).
- Sato, K., Kovalenko, S.V., Romanovsky, N.P., Nedachi, M., Berdnikov, N.V., Ishihara, T., 2004. Crustal control on the redox state of granitoid magmas: tectonic implications from the granitoid and metallogenic provinces in the circum-Japan Sea Region. *Trans. Royal Soc. Edinburgh, Earth Sci.* 95, 319–337.
- Sato, K., Rodionov, S.M., Vrublevsky, A.A., 2006. Lermontovskoe tungsten deposit: the oldest mineralization in the Sikhote-Alin orogen, Far East Russia. *Resour. Geol.* 56, 257–266.
- Sengor, A.M.C., Natal'in, B.A., Burtman, V.S., 1993. Evolution of Altaid tectonic collage and Paleozoic crustal growth in Eurasia. *Nature* 364, 299–307.
- Sengor, A.M.C., Natal'in, B.A., 1996. Turkic-type orogeny and its role in the making of the continental crust. *Annu. Rev. Earth Planet. Sci.* 24, 263–337.
- Shibata, K., Igi, S., Uchiyumi, S., 1977. K–Ar ages of hornblendes from gabbroic rocks in Southwest Japan. *Geochem. J.* 11, 57–64.
- Shinjoe, H., 1997. Origin of the granodiorite in the forearc region of SW Japan: melting of the Shimanto accretionary prism. *Chem. Geol.* 134, 237–255.
- Simanenko, V.P., Khanchuk, A.I., Golozubov, V.V., 2002. The first data on geochemistry of Albian–Cenomanian volcanism in the Southern Primorye, Russian Far East. *Geochem. Int.* 40, 86–90.
- Soloviev, S.G., 1995. Geologo-genetic features of the tungsten deposit Skrytoe in the Central Sikhote-Alin (Russia). *Geol. Ore Deposits* 37, 142–158 (in Russian).
- Soloviev, S.G., Krivoshechekov, N.N., 2011. Vostok-2 gold-base metal-tungsten skarn deposit, Central Sikhote-Alin, Russia. *Geol. Ore Deposits* 53, 478–500.
- Streckeisen, A., Le Maitre, R.W., 1979. A chemical approximation to the modal QAPP classification of the igneous rocks. *Neues Jahrbuch für Mineralogie, Abhandlungen* 136, 169–206.
- Sun, S.S., McDonough, W.E., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Karthika, A.D., Norry, M.J. (Eds.), *Magmatism in the Ocean Basins*, vol. 42. Geological Society of London Special Publications, pp. 313–345.
- Taira, A., Katto, J., Tashiro, M., Okamura, M., Komada, K., 1988. The Shimanto Belt in Shikoku, Japan—evolution of cretaceous to Miocene accretionary prism. *Mod. Geol.* 12, 5–46.
- Tazawa, J., 2004. The strike-slip model: a synthesis on the origin and tectonic evolution of the Japanese Islands. *J. Geol. Soc. Jpn.* 110, 503–517.
- Tsujimori, T., 1998. Geology of the Osayama serpentinite melange in the central Chugoku Mountains, southwestern Japan: 320 Ma blueschist-bearing serpentinite melange beneath the Oeyama ophiolite. *J. Geol. Soc. Jpn* 104, 213–231 (in Japanese with English abstract).
- Tsujimori, T., Itaya, T., 1999. Blueschist-facies metamorphism during the Paleozoic orogeny in southwestern Japan: phengite K–Ar ages of blueschist-facies tectonic blocks in a serpentinite mélangé beneath early Paleozoic Oeyama ophiolite. *Island Arc* 8, 190–205.
- Utkin, V.P., 1980. Fault Displacements and Their Research Procedure. *Nauka, Moscow*, 144 p.
- Valui, G.A., 2004. Petrologic features of granitoids of the East Sikhote-Alin volcanic Belt. *Tikhookean. Geol.* 23, 37–51.
- Valui, G.A., 2014. Petrology of Granitoids and Differentiation of Melts Under Shallow-depth Conditions (East-Sikhote-Alinsky Volcanic Belt). *Dal'nauka, Vladivostok*, 245 pp. (in Russian).
- Valui, G.A., Moskalenko, E.Yu., Strizhkovka, A.A., Sayadyan, G.R., 2008. Oxygen isotopes in the Cretaceous–Paleogene granites of Primorye and some problems of their genesis. *Russian J. Pac. Geol.* 2, 150–157.
- Valui, G.A., Moskalenko, E.Yu., 2010. First data on the isotopes of Sm–Nd and Sr for Cretaceous–Paleogene granitoids of Primor'e and some problems of their genesis. *Dokl. Earth Sci.* 435, 1516–1519.
- Volokhin, Yu. G., Mikhailik, E.V., Burii, G.I., 2003. Triassic Siliceous Association of the Southern Sikhote-Alin. *Dal'nauka, Vladivostok*, 252 pp. (in Russian).
- Whalen, J.B., Currie, K.L., Chappell, B.W., 1987. A-type granites: geochemical characteristics, discriminations and petrogenesis. *Contrib. Miner. Petrol.* 95, 407–419.
- Whitney, D.L., Evans, B.W., 2010. Abbreviations for names of rock-forming minerals. *Am. Mineral.* 95, 185–187.
- Wilde, S., 2015. Final amalgamation of the Central Asian Orogenic Belt in NE China: Paleo-Asian Ocean closure versus Paleo-Pacific plate subduction—a review of the evidence. *Tectonophysics*, in press. <http://dx.doi.org/10.1016/j.tecto.2015.05.006>.
- Wilde, S.A., Dorsett-Bain, H.L., Liu, J.L., 1997. The identification of a Late Pan-African granulite facies event in northeastern China: SHRIMP U–Pb zircon dating of the Mashan Group at Liu Mao, Heilongjiang Province, China. *Proceedings of the 30th IGC: Precambrian Geology and Metamorphic Petrology*, vol. 17. VSP International Science Publishers, Amsterdam, pp. 59–74.
- Wilde, S.A., Zhang, X.Z., Wu, F.Y., 2000. Extension of a newly-identified 500 Ma metamorphic terrain in Northeast China: further U–Pb SHRIMP dating of the Mashan Complex, Heilongjiang Province, China. *Tectonophysics* 328, 115–130.
- Wilde, S.A., Wu, F.Y., Zhang, X.Z., 2003. Late Pan-African magmatism in northeastern China: SHRIMP U–Pb zircon evidence from granitoids in the Jiamusi Massif. *Precamb. Res.* 122, 311–327.
- Wilde, S.A., Wu, F.Y., Zhao, G.C., 2010. The Khanka Block, NE China, and its significance to the evolution of the Central Asian Orogenic Belt and continental accretion. In: Kusky, T.M., Zhai, M.G., Xiao, W.J. (Eds.), *The Evolved Continents: Understanding Processes of Continental Growth*, vol. 338. Geological Society of London, Special Publication, pp. 117–137.
- Woodhead, J.D., Hergt, J.M., 2005. A preliminary appraisal of seven natural zircon reference materials for in situ Hf isotope determination. *Geostand. Geoanal. Res.* 29, 183–195.
- Woodhead, J., Hergt, J., Shelley, M., Eggins, S., Kemp, R., 2004. Zircon Hf-isotope analysis with an excimer laser, depth profiling, ablation of complex geometries, and concomitant age estimation. *Chem. Geol.* 209, 121–135.
- Wu, F.Y., Sun, D.Y., Jahn, B.M., Wilde, S., 2004. A Jurassic garnet-bearing granitic pluton from NE China showing tetrad REE patterns. *J. Asian Earth Sci.* 23, 731–744.
- Wu, F.Y., Yang, Y.H., Xie, L.W., Yang, J.H., Xu, P., 2006. Hf isotope compositions of the standard zircons and baddeleyites used in U–Pb geochronology. *Chem. Geol.* 234, 105–126.
- Wu, F.Y., Sun, D.Y., Ge, W.C., Zhang, Y.B., Grant, M.L., Wilde, S.A., Jahn, B.M., 2011. Geochronology of the Phanerozoic granitoids in northeastern China. *J. Asian Earth Sci.* 41, 1–30.

- Xie, L.W., Zhang, Y.B., Zhang, H.H., Sun, J.F., Wu, F.Y., 2008. *In situ* simultaneous determination of trace elements, U–Pb and Lu–Hf isotopes in zircon and baddeleyite. *Chin. Sci. Bull.* 53, 1565–1573.
- Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990a. Plate Tectonics of the USSR Territory, vol. 2. Nedra, Moscow, p. 334.
- Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990b. Geology of the USSR. A Plate Tectonic Synthesis, vol. 21. AGU Publications, 242 pp.
- Zhou, J.B., Wilde, S.A., Zhao, G.C., Zhang, X.Z., Zheng, C.Q., Wang, H., Zeng, W.S., 2010. Pan-African metamorphic and magmatic rocks of the Khanka Massif, NE China: further evidence regarding their affinity. *Geol. Mag.* 147, 737–749.
- Zhou, J.B., Wilde, S.A., Zhang, X.Z., Ren, S.M., Zheng, C.Q., 2011. Pan-African metamorphic rocks of the Erguna block in the Great Xing'an Range, NE China: evidence for the timing of magmatic and metamorphic events and their tectonic implications. *Tectonophysics* 499, 105–177.
- Zhou, J.B., Wilde, S.A., 2013. The crustal accretion history and tectonic evolution of the NE China segment of the Central Asian Orogenic Belt. *Gondwana Res.* 23, 1365–1377.