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WELCOME SPEECH OF VSEGEI DIRECTOR GENERAL
O.V. PETROV AT THE 4TH INTERNATIONAL SEMINAR
OF SHRIMP EQUIPMENT USERS (4TH SHRIMP WORKSHOP)

Saint Petersburg, 1 July 2008

Dear colleagues,

I am glad to welcome the leading specialists in the most innovative area of geological studies, local isotopic geochronology and geochemistry, at Russian Geological Research Institute. Such studies are carried out using unique secondary-ion high-resolution microsondes, such as SHRIMP and Cameca. This trend has arisen recently, and now it is the most popular, with the greatest number of publications and jointly implemented scientific and applied geological projects. Twenty-five years ago, the first significant publication by Compston and Clement appeared in “Nature” periodical; it started the epoch of new geochronology. Since then, several large laboratories have been organized, among them our Center of Isotopic Research (CIR), which was founded in 2000, is not at the bottom of the list. Holding of the traditional, 4th International Seminar of SHRIMP equipment Users (4th SHRIMP Workshop), in Saint Petersburg, which is the first one not only in Russia, but in Europe, became the recognition of its positive development.

Today, a large group of founders and developers of this trend, representatives of the “green continent”, Bill Compston, Trevor Ireland, Alan Kennedy, Ian Williams, Steve Clement, John Foster, Pete Kinny and their colleagues, as well as heads and employees of almost all world laboratories where SHRIMP equipment operates, in Canada, Korea, China, USA, Australia, Japan, Brasilia, and Russia are present here. Ed Roberts, who is now managing the major process of production, supply and launch of new instruments is also among us. Presence of a great number of young researchers as an evidence of scientific attractiveness of the method and good potential of its development is also remarkable.

Operation of SHRIMP equipment is a demonstrative example of implementing progressive nanotechnologies in the study of substance in geology, attaining a breakthrough in understanding geological structure and evolution of the Earth’s crust. For Russia with its huge territory and variety of genetic types of mineral deposits, obtaining of a large number of reliable and high-precision geochronological datings is of strategic importance for raw material base rehabilitation.

In recent years, a real technological revolution took place at VSEGEI. The Center of Isotopic Research, the largest isotopic laboratory in Russia was established. Its state certification was carried out, a highly skilled team of young specialists, which possesses a great scientific research potential, was organized. Dur-
ing a relatively short time, we succeeded in application and creation of dozens of new methods; this allowed proceeding to resolving tasks, which faced VSEGEI, at a new level and obtaining a qualitatively different, previously inaccessible information on the geological structure and mineral resources distribution. Modern approaches to ore deposits study, especially large and unique, and development of their formation models are impossible at present without application of new methods of ore matter study, specification of geological structure and exact datings of geological processes. Methods of local study, which give the most important geochronological and isotopic geochemical information without natural samples destruction (U-Pb age determination, Hf, O isotopic systematics, REE distribution, Zr-Ti thermometry), occupy a special position.

In recent years, VSEGEI has carried out large-scale geochronological and isotopic geochemical works along a number of major trends of federal importance. First of all, this is geochronological support of new generation of state geological maps compilation at scales 1:1,000,000 and 1:200,000. Each year, hundreds of high-accuracy ages of key geological objects are determined using uranium-lead, samarium-neodymium, rubidium-strontium and rhenium-ostmium methods; this exceeds the amount of data obtained by isotopic laboratories of the USSR and Russia for the preceding years by an order. Such data allow both rethinking, specifying and correlating serial map legends, and distinguishing new complexes and subsurface areas with metallogenic prospects.

Secondly, this is isotopic geochemical study of a number of major deposits of high-liquid raw material for understanding the processes of their formation and evolution, as well as for elaboration of their forecast criteria; this could be called isotopic metallogeny. For the first time, isotopic certification of primary platinoid deposits in laminated sulfide-bearing massifs of the Norilsk area, gold-silver and gold-sulfide deposits of Siberia and Northeast of the country was accomplished. The obtained data showed the key role of deep components, which actively interacted with the crustal matter during formation of the largest deposits.

A high quality of the work of the CIR and a uniqueness of its potential now attracts a great number of foreign researchers; this has already caused an abrupt expansion of international collaboration of VSEGEI, active and, above all, equal participation of the Russian side in international projects. Dozens of articles were published in national and foreign editions based on results of the CIR; not a single major international conference is held without a number of papers prepared by the CIR staff. According to the opinion of many foreign specialists, the Center of Isotopic Research is, without doubt, among the top ten of the best world laboratories of such profile.

It is necessary to maintain constant high technological conditions of the Center equipment; this includes regular software update, timely replacing of used components, and installation of the latest developments of the companies manufacturing the instruments widening the analytical potential.

Recently, the Minister of Natural Resources and Ecology of Russia Yu. Trutnev and the Head of Rosnedra A. Ledovskikh visited the CIR at VSEGEI. They
expressed a high opinion of high technologies and nanotechnologies application in the practice of regional and geological prospecting works; endorsed the idea of broadening the analytical potential of the CIR by means of modernization and advance updating of the instrumental base along the trends, which are prospective and in-demand in Russia for the upcoming years. Local isotopic geochronological and geochemical methods (laser ablation, secondary-ion isotopic sounding) are among the latter. A broader range of equipment utilization possibilities, from cosmogonic problems study to environmental pollution questions should not be forgotten.

A global trend of analytical centers development in the advanced countries is noteworthy. Instead of increasing the number of high-technology laboratories, enlargement and modernization of the existing ones takes place. This results in cost optimization and its considerable reduction by means of utilization of the already available infrastructure, trained staff, elaborated methods and a fair name. Scope of the Russian geology and the number of customers of high-quality analytical products are so large that, as it was shown in practice, they require a constant expansion of the CIR potential.

Along with the necessity of discussing the recent methodological developments, carrying-out interlaboratory results verification, and work experience interchange, educational component is the major task of this Seminar. Every effective application of analytical results into geological practice starts with recognizing the importance of such information and a correct problem formulation. Geological community should well understand the physical essence of isotopic analytical data, their potential and restrictions. The Plenary Session, to which representatives of the leading geological institutions of Saint Petersburg, Moscow and Kola Scientific Center as well as a number of mining companies are invited, is dedicated to these questions.

Finally, I would like to wish the participants of the conference a fruitful work and pleasant stay in Saint Petersburg during the famous “white nights”, as well as new scientific achievements.

Thank you for your attention!
U-PB AND HF-ISOTOPE SYSTEMATICS OF ZIRCONS FROM
THE SERGEEVSKY MAFIC COMPLEX,
THE PRIMORYE REGION, SE RUSSIA


VSEGEI, St. Petersburg
Adamskaya@mail.ru, Kirill_Lokhov@vsegei.ru
¹PPSE, Vladivostok

The Sergeevsky complex of mafic rocks is believed to be an oldest in the Sikhote-Alyn’ tectonic unit, which is situated in the Primorye region, SE Russia (Fig.1). The rocks of the complex are migmatized amphibolites and garnet amphibolites, sometimes with relics of primary magmatic minerals (pyroxene and plagioclase). The rocks of the complex are traditionally subdivided in two units: migmatite of Avdokimovsky unit and gabbro – amphibolite of the Sergeevsky unit. Available geochronological data are contradictory: K-Ar data exhibit Phanerozoic age (200–400 M. y.), Rb-Sr whole rock isochrones gave estimation of ca 2400 M. y. age for Avdokimovsky unit, and ca 1800 My for Sergeevsky one [1]. The recent SHRIMP U-Pb dating of zircon revealed age estimation near 400 M.y. [2].

In an attempt to solve existing geochronological problems zircons from a number of new samples from Sergeevsky and Avdokimovsky units have been studied. All measurements were done in CIR VSEGEI and included: (1) – U-Pb dating of zircons by SHRIMP-II, (2) – determination of the REE distribution patterns in the same grains by LA-ICPMS and (3) – investigation of Hf isotopic systematics in the zircons by means of LA-MC-ICPMS. Laser ablation instrumentation included ablation system DUV-193 and high resolution ICPMS ThermoFinnigan

Fig. 1
Element-2 for REE and multicollector ICPMS ThermoFinnigan Neptune for Hf isotopes measurement.

The data set obtained from U-Pb dating by SHRIMP-II reveal that there are several zircon generations. Among them there are groups with concordant the ages of 50 ± 2, 270 ± 10, and 405 ± 10 Ma. Another cluster has an ancient Proterozoic age, and the data set formally allow to draw the discordia with intercepts at 1812 ± 30 and 400 ± 8.3 Ma. (Fig.2).

CL images of the zircons have shown that they have different inner structure. The younger crystals have no pronounced oscillatory growth zoning, however in the group, forming the discordia only subconcordant grains have a kind of fine oscillatory zoning, characteristic for magmatic crystals.

REE patterns for the group of discordant 1800 Ma old zircons are displayed on the Fig. 3A, group of 405 Ma old on the Fig. 3B, and group of 270 and 50 Ma old on the plot Fig. 3C. Some crystals of the oldest group have REE distribution

Fig. 2

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patterns characteristic for “hydrothermal” or “pegmatite” zircons [3], and probably have been formed by migmatization event.

The study of Hf isotope systematics in zircons of different age groups revealed their obvious different genesis. The εHf(T) values are shown in the Fig. 2 as a numbers near corresponding analytical points. For young concordant zircons εHf(T) are +8 ± 2 (50 My), +3 ± 2 (270 My) and -4 ± 1 (405 My). This indicates input of a material of various geneses in the rocks during different metamorphic Phanerozoic events. The zircons, which were used for construction of the discordia, have different εHf(T) values, calculated to the time of 1812 M.y. This demonstrates, that they are not belonging to the single genetic and, probably, age group. The discordant zircons only with negative εHf(T) values probably were formed by Proterozoic metamorphic event and migmatization. The time of this metamorphic event is 1803 ± 32 Ma (discordia calculated without the point with positive εHf(T) value). The grain with εHf(T) = +5 have internal structure with “magmatic” fine oscillatory CL zoning and REE pattern supposing “magmatic” nature (Fig. 2, 3).

This combined study have shown a long and multistage evolution of the rocks with metamorphic events occurred at 50, 270, 400 and 1800 Ma. The data obtained did not allowed to estimate the time of magmatic formation for the rocks of the complex, but clearly indicate that this event was Early Proterozoic (>1800 Ma), and the mafic magma was originated from the depleted
mantle reservoir. The last result seems to be of particular importance, because confirms whole rock Rb-Sr data and hypothesis of Precambrian basement of Sikhote-Alyn’. One of the most designing result is that whole rock Rb-Sr isotope system was not disturbed despite numerous metamorphic events resulted in migmatization and foliation of the gabbroic rocks, formation of high temperature metamorphic mineral assemblages and in crystallization of at least four generations of zircons with different $\epsilon$Hf(T) values.

References

SHRIMP RG STUDY OF LOWER TO MIDDLE CRUSTAL XENOLITHS FROM BERING SEA REGION AND NORTHERN COAST OF OKHOTSK SEA

Akinin, V. V.1, Miller, E. L.2, Strickland, A.2, Wooden, J. L.3

1 North East Interdisciplinary Science Research Institute Russian Academy of Sciences Portovaya 16, Magadan 685000, Russian Federation. e-mail: akinin@neisri.ru
2 Department of Geological and Environmental Sciences, Stanford University, Bld. 320, Stanford, CA, 94305, USA
3 U. S. Geological Survey Menlo Park, CA, 94305, USA

Mafic to intermediate xenoliths from Late Neogene alkali basalts of the Bering Sea region and the Northern coast of the Okhotsk Sea were studied by combining petrologic, geochemical whole rock data with high-spatial resolution U-Pb geochronology of zircons (SHRIMP-RG). The gneissic, mostly mafic xenoliths (constituting less than two percent of the total xenolith population) are from lavas in the Enmelen, St. Lawrence, Nunivak, Seward Peninsula and Viliga volcanic field. These most likely originated by magmatic fractionation processes and continued residence at granulite-facies conditions. In general, zircons from deep-crustal xenoliths have commonly resided at high temperatures for prolonged time intervals, therefore may not have behaved as entirely closed systems. An important goal of this research was to find preserved and not wholly reset domains of zircons and to analyze as many as possible zircons.

Single-grain zircon analyses (n = 154) from the mafic xenoliths are interpreted as both magmatic and metamorphic ones, and are entirely Cretaceous to Paleocene in age (~ 138–60 Ma). Their age distributions correspond to the main pulses of magmatism in two belts of supracrustal volcanic and plutonic rocks in the northeastern Russia and Alaska (Okhotsk-Chukotka volcanic belt and southward slightly younger Anadyr-Bristol volcanic belt). Oscillatory-zoned igneous zircons with overgrowths, and metamorphic zircons that lack any older inheritance from the xenoliths provide strong evidence for juvenile additions of material to the crust during the Late Cretaceous to Paleocene.

The vast majority of all the xenoliths ages falls within 60–107 Ma span. However, one Imuruk xenolith has a zircon with the age of 134.1 ± 4.4 Ma, and one Viliga zircon yielded an age of 147 ± 1 Ma. Zircons from individual xenoliths show
the same variability. This inconsistency might be explained by differential growth and/or equilibration of zircon during superimposed high-grade metamorphic events, even at the scale of the samples themselves. Zircon cores are often older than rims, but this is not a systematic relationship.

Zircons from Enmelen xenoliths can be divided into three populations that correspond to their zoning as seen in the CL images (Fig.). The first population exhibits oscillatory-zoned cores and very thin or no obvious rims. They yield an age peak on an age probability density plot at or near 90 Ma but represent two age ranges: 88–90 Ma and 92–96 Ma. The second population exhibits both cores and slightly younger rims, yielding a peak on the probability density plot at or near 83.5 Ma represented by two major age ranges: 82–86 Ma and 88–90 Ma. The third population exhibits no CL-zoning, is U-poor and homogeneous in appearance. These zircons yield two peaks on the probability density plot with ages at or near 70 Ma and 78 Ma, corresponding to three groupings of single grain age ranges on the histograms: 66–72 Ma, 76–80 Ma, and 82–86 Ma. All three types of zircon are found in individual xenoliths. Most of the zircons belong to the second group and exhibit oscillatory- or sector-zoned cores overgrown by younger, homogeneous, U-poor rims. Based on the CL images, we interpret the zircons as mostly magmatic in origin, which is supported by the relatively high Th/U ratio of
the cores with variable amounts of metamorphic recrystallization or overgrowth. Decreasing Th/U ratios towards the U-poor rims was observed only in a few rare cases where different domains of the same crystals were dated. More often, relatively low Th/U ratios, typical of metamorphic zircons, characterize the overgrowths as illustrated by the third type of zircon population. Most of the first and second populations of zircons contain mineral-melt inclusions whereas the third population is clear and inclusion-free. Trace element measurements on zircons are in progress and may provide additional evidence on the nature of xenoliths and fine-scale Pb loss in zircons.

We interpret the ages of the three populations of zircons from the Enmelen xenoliths to record both the time of magmatic events as well as accompanying high-grade metamorphism in the deep crust. The age of these events appear to coincide well with the major pulses of calc-alkaline and basaltic magmatism represented by plutons and volcanic rocks (Okhotsk-Chukotka volcanic belt and Kuskokwim). The variation in $^{206}\text{Pb}/^{238}\text{U}$ ages of zircons from xenoliths may reflect fine-scale Pb loss and the fact that mid- to Late Cretaceous magmatic ages may have been partially reset during latest Cretaceous—early Paleocene high-grade metamorphism induced by a second major pulse of mantle-derived magmas into the crust at a slightly younger time and in a slightly more southerly position.

High-grade rocks in the gneiss domes (Chukotka and Alaska) preserve their earlier (protolith) histories as evidenced by U-Pb zircon ages (i.e. Cretaceous metamorphic rims on older cores). Xenoliths from the deep crust do not provide compelling evidence for the complete reconstitution/re-equilibration of continental crust from the bottom up during mantle-driven magmatism because their zircons record only Cretaceous magmatic and Cretaceous-Paleocene metamorphic ages.

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GEOCHRONOLOGY OF ENDOGENIC EVENTS IN PRIMORYE TERRITORY STRUCTURES BASED ON SHRIMP-DATING


VSEGEI, Saint Petersburg, Russia (antonina_alenicheva@vsegei.ru)

Under the project “Geochronological and isotopic geochemical support of geological mapping at 1:1,000,000 scale”, new isotopic data were obtained. Metamorphic and magmatic complexes of the Khankai Massif and Sikhote Alin accretionary system were studied.

In gneisses and crystalline schist of the Matveevsky-Nakhimovsky terrain (Khankai Massif) alleged as Proterozoic, two other metamorphic events the Neoproterozoic and the Ordovician were revealed corresponding to two zircon generations: 828 ± 12 and 474 ± 12 (the Iman Series), 916 ± 32, and 497 ± 18 (Fig.) (the Ussuri Series). The Voznesensky Complex leucogranite of the Yaro-

Concordia diagram for U-Pb dating and cathodoluminescence image of zircon from crystalline schists (sample 16)
slavl Pluton, which intrudes and metamorphoses the Khankai Massif rocks, yielded a concordant U-Pb age of 480 ±7 Ma. This confirmed the Ordovician collision of the Precambrian blocks within the Khankai Massif. A unique Voznesenskoye fluorite deposit is associated with the Voznesensky Complex granites. LA-ICPMS study of hafnium isotopes on the leucogranite zircons (\(^{176}\text{Hf}/^{177}\text{Hf} = 0.2825, \text{eHf} \sim 0\)) demonstrated a mixture of lower crust and mantle melts.

Concordant ages of 1785 ± 47, 857± 24, 486 ± 31 and 256 ± 7 Ma were obtained from the Lower Proterozoic metapelite gneiss complex in the Western Khankai Massif (Grodekovo fragment). Along with the Neoproterozoic and Ordovician zircon, other generations corresponding to the Early Proterozoic age of the protolith and the Late Permian metamorphic stage were revealed. During the Late Permian the >8,000 km² in square Grodekovo Batholith granitoid earlier assigned to Silurian has been formed. U-Pb dating of biotitic granites from different parts of the pluton showed concordant ages of 260± 4, 247 ± 2, 266 ± 3, 258± 2 Ma. The petrochemical data and results of REE study, pointed to potential gold mineralization of the Late Permian granitoids.

Early Cretaceous granitoids of the Sikhote Alin plutonic belt, and associated skarn tungsten deposits were studied. Concordant ages of 105 ± 0.5 Ma for the high-alumina Khungari Complex granodiorite and 103 ± 0.8 and 105 ± 2 Ma for biotite-hornblende granites of the Tatibe Complex were obtained. The 104 ± 6 Ma age of tungsten mineralization in the Legkoye tungsten-bearing skarns was determined by Re/Os on molybdenite. \(^{87}\text{Sr}/^{86}\text{Sr} = 0.7055\) in granitoids point to participation of mantle substance in ore-generating melt formation. The established range of age values 2450 ± 9, 1123 ± 12, 403 ± 7, 242 ± 2 Ma of zircon xenocrysts in the Early Cretaceous granitoids points to an ancient, at least, Early Proterozoic continental crust at the levels of granitic magma chambers.
U-Pb SHRIMP AGES FROM THE NEOPROTEROZOIC SOUTHERN PARAGUAY BELT: CONSTRAINING THE DEPOSITIONAL AGE AND SEDIMENT PROVENANCE OF GLACIOGENIC DEPOSITS

Babinski, M.; Fanning, C. M.; Trindade, R. I. F.; Boggiani, P. C.

1 Instituto de Geociencias, Universidade de Sao Paulo, Rua do Lago, 562, CEP 05508-080 Sao Paulo, SP, Brazil. E-mails: babinski@usp.br; boggiani@usp.br
2 The Australian National University, Canberra, Australia. E-mail: Mark.Fanning@anu.edu.au
3 Instituto de Astronomia, Geofisica e Ciencias Atmosfericas, Universidade de Sao Paulo, Rua do Matgr, 1226, CEP 05508-090 Sao Paulo, SP, Brazil. E-mail: rtrindad@iag.usp.br

The Paraguay belt comprises a thick sedimentary succession of glacially influenced sediments covered by carbonates deposited on the southern border of the Amazonian craton (North Paraguay belt) and at the eastern border of the Rio Apa block (South Paraguay belt). The sedimentary successions in the North and South branches of the Paraguay belt (more than 1000 km apart) have been correlated and considered coeval, in spite of striking differences in their sedimentary evolution and the lack of geochronological data. In fact, the only age constraint on these successions is a tentative correlation of the carbonate cover on the basis of their carbon isotope signature suggesting a late Neoproterozoic (Marinoan: 635 Ma) age for the succession.

Here we present the first U-Pb SHRIMP geochronological data on the Paraguay belt. These results were obtained at the Australian National University, using SHRIMP I and SHRIMP RG. We analyzed detrital zircon grains separated from the matrix of six samples of glacially influenced diamictites from the southern part of the Paraguay belt. Four of these samples were collected at the Bodoquena area, and the other two were collected at the Puga Hill, corresponding to the central and north sectors of the southern Paraguay belt, respectively, and about 50 km apart.

U-Pb ages (130 grains) from the Puga Hill show a large variation (Fig. 1), ranging from 759 Ma to 2128 Ma, and only one Archaean grain (2.7 Ga). Sources older than 1700 Ma predominate.

U-Pb ages (227 grains) from samples of the Bodoquena area (Fig. 2) range from 706 Ma to 1990 Ma, with main clusters at 729 Ma, 1223 Ma, 1411 Ma, and
1758 Ma, and only one grain of Archean age (3.0 Ga). A maximum depositional age for the glacial sediments can thus be derived from the age of the youngest zircon at 706 Ma.

Considering the triad of glacial events of Neoproterozoic age (Sturtian: 720 Ma, Marinoan: 635 Ma, and Gaskiers: 580 Ma), the Puga diamictites could thus be either Marinoan or Gaskiers. This assumption is reinforced by the presence of Cloudina fossils (c. 543 Ma) in the area.

The detrital zircon data were also used to infer the provenance of sediments. The large spectra of ages observed from diamictites from the Puga Hill area (Fig. 1) indicate that many sources have contributed to the initial sedimentation of the precursor basin of the Paraguay belt. The major clusters in both collections fit the age of different orogenic belts in the nearby Amazonian craton or the Rio Apa block (Tassinari and Macambira, 1999; Loewy et al., 2004; Thover et al., 2004). The main source of sediments (1758 Ma) in the diamictites from the Bodoquena area (Fig. 2) could be from the Paragua Block where ages of 1765 Ma have been found. This microcontinent was accreted to the southern margin of the Amazonian craton during the Sunsas orogeny, at ca. 1.1 Ga (Boger et al., 2005). The younger cluster at c. 730 Ma found in both sectors must be explained by other sources, probably from other cratonic units of the supercontinent Rodinia beyond the Amazonian craton.

Fig. 1. Cumulative probability diagram of SHRIMP U-Pb analyses of zircon grains from the Puga Hill diamictite. *All values are ²⁰⁷Pb/²⁰⁶Pb ages, except for grains younger than 800 Ma, which are ²³⁸U/²⁰⁶Pb ages
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References

MINERAL PREPARATION TECHNIQUE FOR PURPOSES OF LOCAL SIMS ANALYSIS (SHRIMP-II EXPERIENCE)

Berezhnaya, Natalya, Balashova, Yulia, Gavryutchenkova, Olga

Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI), St. Petersburg, Russia yulia_balashova@rambler.ru

To work out the technique of zircon preparation for U-Pb dating, Australian and Swedish (the NORDSIM) approaches were partly adopted. Taking into account the peculiarities of our task and the specific requirements, the following procedure has been developed.

These steps are:
1. The material for study is usually received as a mineral concentrate, which contains 60–100% of e.g. zircon. If the zircon concentration is less than 10%, additional enrichment is carried out using the isodynamic magnetic separator FRANZ L-1 (USA).
2. The next step is size fractioning using standard size sieve set. About the same size fraction of a certain mineral is to be mounded in a single puck.
3. Each sample is put in a separate line on the double-sided sticky tape SICAD S. d. a. Eurocel (Italy), using a needle and two binocular microscopes. 30-40 best grains are usually selected — this usually embrace all possible varieties from a magmatic non-altered sample. All the recognizable morphological types are to be hand-picked from a metamorphic sample with common total 40–60 grains. About 50–200 grains from a sedimentary sample have to be selected after quartering a concentrate. There are usually 4–8 samples in a puck.
4. When the puck is forming, each sample is documented. Minerals are described in detail. The number of each sample is shown on a sketch of a puck.
5. After samples have been placed, the standards 91500 and Temora are put on a sticky tape. The quantity of the standards is dependant on how many samples are in the puck.
6. The next stage is filling up a puck mould with an epoxy. The epoxy BUEHLER EPO-KWICK (fast cure epoxy kit) is mixed up with a hardening agent in a ratio of 5:1. Then this mixture is warmed up and thoroughly mixed up. Then the lightly lubricated mould is fixed on the sticky tape and is filled up with the mixture. Its thickness is about 0.6–0.8 cm. After warming up for 5–10 minutes the filled puck mould is inspected for air bubbles using a binocular microscope. Bub-
bles, if any, can be removed with a needle. It takes 5–7 days to harden the epoxy under temperature conditions of 27–30 °C.

7. Then the puck is separated from the sticky tape, and is taken out of the mould. Next the puck is processed with the polishing machine Struers, RotoPol-25, equipped with RotoForce-4 head. First, the backside of the puck is polished with the coarse disk MD Piano (220). Then the front-face area is polished on the MD Dac (TM) Struers disk with the diamond emulsion Metadi Supreme/Buehler 3 F µt and the lubricant Meta Di Fluid/Buehler. The polishing characteristic for each step is as follows: rotation speed — 600 RPM, the pressure— 25–30N, duration — 20–30 seconds. Then grains are half-sectioned. If there are big grains in the puck (more than 250 jm) it is necessary to polish out c 1/3 of grains thickness using a coarse diamond powder (5–7 jm).

8. Then the puck is mapped at magnification of 25–50 applying Leica DC300 camera. Afterwards, detailed images of minerals are made in the reflected and transmitted light at magnification of 100–200.

9. After proper washing with deionized water and a detergent in an ultrasonic bath the puck is coating with c 200E 99.999 % gold. Now it is ready for the cathode luminescence.

10. After in situ U-Pb dating (SHRIMP or LA–ICP-MS) the results are interpreted taking into account morphology, color and internal structure in the optics and CL, along with geochemical characteristics (U, Th, Th/U content).

11. This technique is universal for sample preparation for local isotopic research with SHRIMP or LA-ICP.
THE CRYOGENIAN RIFT-RELATED GRANITOGENESIS
OF THE DOM FELICIANO BELT, SOUTHERN BRAZIL

Basei, Miguel A. S1.; Nutman, Allen 2; Grasso, Carla B. 1; Vlach, Silvio 1;
Siga Jr, Oswaldo 1 & Osako, Liliane3

1 Instituto de Geociencias-USP- Rua do Lago 562, CEP-05508080, Sao Paulo, Brasil,
baseimas@usp.br.
2 Beijing Shrimp Centre, 26, Baiwanzhuang Road, Beijing,100037, China
3 Departamento de Geologia, Universidade Federal do Ceara, Bloco 912,
CEP60455-760, Brazil.

-For the first time the results of a geological study carried out on pre-tectonic,
mylonitic granitoids well-exposed in the Morro do Parapente, south of Gaspar,
are presented. These rocks occur in the Brusque Group metasediments and were
once considered Paleoproterozoic basement gneisses of the Brusque Group. Nd
model ages (TDM) obtained for these rocks fall in the 1.99–2.14 Ga interval,
which is a common pattern for Brusque Group rocks; µNd(t) values between -
9.17 and -9.47 indicate the crust had an important participation in the granite
genesis. These hololeucocratic, totally recrystallized and mylonitized granites are
geochemically classified as A-type granites. They are moderately peraluminous,
enriched in incompatible elements, and related to the syn-rifting granite genesis
that preceded sediment deposition in the Brusque paleobasin. U/Pb dating yield-
ed an U-Pb IDTIMS age of 834.7 ± 8.7 Ma for these leucogranites, obtained from
well-developed prismatic faces biterminated zircon crystals. The SHRIMP result,
843 ±12Ma, confirmed the value obtained by the conventional method. This age
places the magmatism in the lower Cryogenian, at the Tonian boundary, therefore
being the first occurrence of A-type igneous rocks in this period in southern Bra-
zil. Its characterization as pre-tectonic allows to infer that this was the period of
the rifting phase of the basin that generated the Brusque Group metasediments,
and consequently the oldest age known for the beginning of the Dom Feliciano
Belt geological history in Santa Catarina.

Pre-tectonic magmatism concentrated in a narrow and elongated NE-SW-
trending belt. The bodies that compose the Brusque Group pre-tectonic granite
magmatism are markedly deformed, being a common characteristic of mylonitic
rocks (figure 1). For this reason they have been stratigraphically placed together
with the Paleoproterozoic basement units. The main rock type is constituted by
mylonitic syeno-leucogranites. These are hololeucocratic (IC = 2 %), porphyro-
clastic, dark red rocks, composed of 2.5–3 mm sized mesoperthitic alkaline feld-
spar and stretched recrystallized quartz. Accessories are opaque minerals and zir-
con; secondarily only iron hydroxides occur. In the southern part of the body,
ultramylonitic, rosy, hololeucocratic (IC = 2 %) portions occur with 0.7mm-sized
alkaline feldspar porphyroclasts composing 30 % of the rock, immersed in a fine-
grained matrix formed by quartz, alkaline feldspar and accessory minerals. Subor-
dinately leucogneisses and rosy quartz feldspatic augen gneisses occur, showing
alteration of quartz-feldspatic and mafic bands.

Usually centimeter-sized potassic feldspar crystals mark the well-defined “au-
gen” texture, where dominant granoblastic felsic bands alternate with lepidoblastic bands mainly formed by biotite. Andesine is a minor constituent of the felsic bands and is much finer than microcline (ca. 0.5 mm in size). Anorthite contents vary from 30 to 32. In general the crystals, in particular their nuclei, are sericit-
ized. They are subidiomorphic to totally xenomorphic and deformed. Recrystal-
lized quartz is irregular in shape and the contacts between grains are polygonized.

Larger crystals (2 mm in size) are broken and crushed to very fine grains (0.05 mm).
They present very strong undulose extinction, evidencing deformation. Modal compositions allow the classification of these mylonitic granitoids as alkali-gran-
ites. The mylonitic leucogranites yielded an A/CNK value a little higher than 1
and normative corindon, thus characterizing the slightly peraluminous nature for
these rocks. Sr and Ba contents are low in the mylonitic leucogranites, whereas
the La, Ce and Nd contents are higher than those for the other granites intrusive
in the Brusque Group. Rb contents also vary a little, being slightly higher for the
mylonitic leucogranites (130 ppm), which in turn show high Fe/Mg ratio, high
Zr, Nb and Ta and low CaO, Sc, Cr, Co, Ba and Sr contents.

**U/Pb geochronology**—Zircons of the less magnetic fraction from the mylonit-
ic leucogranites used in the IDTIMS radiometric determination are fine-grained,
equidimensional crystals with well-developed pyramidal faces, transparent and
have frequent inclusions and fractures. The age of 834.7 ± 8.7 Ma calculated from
the average of $^{206}\text{Pb}/^{238}\text{U}$ ages was interpreted as the age of the rock crystallization.
Due to the uncertainties resulting from the high degree of discordance yielded by
the majority of fractions analyzed by IDTIMS, the geochronologic study was complemented with U-Pb analyses by SHRIMP. The age of 843 ± 12 Ma is a little older than the conventional age and confirms the magma generation in the lower Cryogenian, at the Tonian boundary. The zircon crystals are euhedral and the cathodoluminescence images (figure 2) confirmed lack of inherited nuclei and presence of simple internal structures resulting from igneous zoning associated with crystal growth. The analyses are plotted in the Tera-Wasserburg diagram (ratios are not corrected for common Pb). The result obtained represents the weighted average of the $^{206}\text{Pb} / ^{238}\text{U}$ ages and respective errors.

Discussion and conclusions- The initial $^{87}\text{Sr} / ^{86}\text{Sr}$ ratios together with $\mu$Nd(t) values, ranging between -9.17 and -9.47, points to an important crustal contribution in the Parapente granite genesis. Nd model ages (TDM) for these mylonitic leucogranites fall in the 1.99–2.14 Ga interval, which is a common pattern for the Brusque Group rocks. These hololeucocratic (IC = 2%) A-type mylonitic granites are enriched in incompatible elements, and related to the syn-rifting granite genesis that preceded the deposition of sediments in the Brusque paleobasin. IDTIMS U/Pb dating of these type-A mylonitic leucogranites yield an age of 834.7 ± 8.7 Ma, confirmed by the SHRIMP result of 843+/–12 Ma. The obtained age places this magmatism in the lower Cryogenian, at the Tonian boundary, thus being the first occurrence of type-A igneous rocks in this period in southern Brazil. Its characterization as pre-tectonic allow to infer that this is the age of the rift phase of the basin that generated the Brusque Group metasediments. It is the oldest age known for the beginning of the geologic history of the Dom Feliciano Belt in Santa Catarina.

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ZIRCON EVIDENCE FOR THE FIRST GRANULITE METAMORPHIC EVENT AT THE ENDERBY LAND: U-PB, REE AND TI-IN DATA

Belyatsky, Boris¹, Rodionov, N.², Antonov, A.², Paderin, I.² and Sergeev, S.²

¹ VNIIOkeangeologia; ² CIR VSEGEI (St.Petersburg, Russia, bbelyatsky@mail.ru)

Early rocks of the Earth are the unique source of information not only on the substance of the primary crust and crust forming processes at the early stages of Earth existence as a planet but on the conditions at the Earth in early Archaean. One of such areas is the Enderby Land with the oldest age estimations e”4000 Ma for crystalline rocks of the Earth [Sobotovich et al., 1974]. Further investigation of different geologic objects at the Enderby Land proved the unique old age of this segment of the crust [DePaolo et al., 1982; Black et al., 1986; Choi et al., 2006] as well as the unique P-T conditions accompanying evolution of these rocks (e” 1000 °C) [Sheraton et al., 1987; Sandiford, Wilson, 1984; Harley, Motoyoshi, 2000]. It has been marked [Sheraton et al., 1987; Asami et al., 2002; Harley, Black, 1997] that the most surprising fact in the study of the earliest rocks of the Enderby Land is the presence of a large time gap (more than one billion years) without any geochronologic traces of geologic activity. At the same time, the diversity of crystalline rocks of highly metamorphosed complexes evidence to complicated and long evolution of these complexes.

We have studied a collection of samples, which represent charnockite and enderbite gneisses, high-Al gneisses and mafic granulites from the central part of the Enderby Land (Napier Mountains). Zircon selected for detail study is represented by sub-idiomorphic, prismatic grains of (dark)-brown color with elongation ~2–2.5. Very often they demonstrate heterogeneous polyphase crystal structure with dark irregular central parts of grains and brown fine zoning outer parts. There are also grains with clear shell represented by zoned, transparent, brighter phase with lower birefringence. The results of U-Th-Pb SHRIMP study of these zircons unambiguously evidence to the early stage of metamorphism (granulitic facies) and accompanying intrusion of granodiorite composition at 3630–3620 Ma (Fig. 1) and the age of primary enderbite’s protolith origin 3980 Ma.
Crystallization temperature of zircon in charnockite gneisses correspond to 1000–1200 °C (Ti-in-zircon) [Watson et al., 2006], which coincides well with the earlier obtained estimations for granulitic metamorphism in this region [Harley, Motoyoshi, 2000], at the same time, zircon formation during the granodiorite intrusion (protoliths of massive enderbitic gneisses) took place at 860–950 °C (Fig. 2). It is known, that zircons crystallized under conditions of high temperature metamorphism show some specific features, such as: general increased content of rare and trace elements, weak fractionation of REE and flat distribution of LREE, weak positive Ce anomaly and strong negative Eu anomaly, which is caused by parallel crystallization of feldspar, orthopyroxene and garnet. In our case metamorphic zircons are characterized by the following composition: \( \text{Sm/La}_n = 2.4–4.7, \text{Lu/Gd}_n = 10–40, \text{Ce/} \text{Ce}^* = 1.5–3.4, \text{Eu/Eu}^* = 0.004–0.003 \) (Fig. 2).

This allows to distinguish these zircons from those of magmatic origin: \( \text{Sm/La}_n = 2.2–61, \text{Lu/Gd}_n = 16–118, \text{Ce/} \text{Ce}^* = 3.8–59, \text{Eu/Eu}^* = 0.03–0.08 \). Zircons formed at the second stage of regional metamorphism widely developed in all known rocks of Napier complex at the Enderby Land (2500 Ma, [Kelly, Harley, 2005]) are represented in the studied samples by newly formed whole grains and accretion hems over the earlier crystals. Their geochemical features allow to conclude that they were formed from the melt at regressive stage of this high grade metamorphism in the presence of garnet: \( 800–850 \, ^\circ \text{C}, \text{Sm/La}_n = 3–7, \text{Lu/Gd}_n = 5–65, \text{Ce/} \text{Ce}^* = 4.4–17.6, \text{Eu/Eu}^* = 0.01–0.02 \).
Fig. 2: a – Normalized trace element diagram for magmatic (solid field) and metamorphic (gray field) zircons; b – relative probability of crystallization temperature (Ti-in) for studied zircons of Napier Complex (n = 75)

References


ARCHAEOAN AGES OF METAMORPHIC EVENT IN GRANULITE AND GNEISSES OF THE SHARYZHYLGAY TERRANE: REE AND U-PB SIMS ZIRCON DATA

Berezhnaya, N. G.¹, Turkina, O. M.², Skublov, S. G.³, Lepekhina, E. N.¹, Paderin, I. P.¹, Saltykova, T. E.¹ and Sergeev, S. A.¹

¹ Centre of Isotopic Research, VSEGEI, St.-Petersburg, Russia, Natalia_Berezhnaya@vsegei.ru
² Institute of Geology and Mineralogy, SB RAN, Novosibirsk, Russia
³ Institute of Precambrian Geology and Geochronology RAN, St.-Petersburg, Russia

The four crustal blocks (Bulunsky, Onotsky, Kitoysky and Irkutny) compose the Sharyzhylgay terrane in south of the Siberian craton, Russia. The biotite gneisses (TTG) and Pl-granite gneisses (GG) are dominated in the Bulunsky block basement complex. Gneisses are locally migmatized. The TTG and GG model Nd-ages are T(DM) 3.3–3.5 Ga, eNd–0.3/+3.1. Their U-Pb ages are 3.25–3.3 Ga for zircon cores, and 3191 ± 17 Ma for rims (Turkina, 2008).

The southerly Irkutny block consists of granite and charnockite domes, while host-rocks are biotite-amphibole-hypersthene orthogneiss (BAHG) and amphibole-pyroxene schist, overlain by garnet-biotite paragneiss, amphibolite and high-titanium crystal schist (TCS). Archaean and Proterozoic granulite facies metamorphic events within the Irkutny block were dated by U-Pb ID-TIMS (Salnikova et al., 2007) to 2649 ± 6 Ma (metabasite), 2.56 Ga (anatexic granite) and 1.87 Ga (anatexic granite and charnockite).

High spatial resolution U-Pb SHRIMP zircon dating allowed recognition of individual ages, corresponding to specific part of zircon (cores, intermediate rims and marginal overgrowth). For BAHG these are 3347 ± 7, 3158 ± 15, 3026 ± 17 and 1850 ± 12 Ma, whereas that for TCS are 2663 ± 18, 2570 ± 13 and 1857 ± 40 Ma.

Zircons of metamorphic, magmatic and metissomatic origin show different geochemical characteristics (Rubatto, 2002; Hoskin, 2005). Thus, for meaningful interpretation of the obtained geochronological results, REE pattern in the dated zircon have been studied.

The major part of TTG and GG zircons has magmatic REE patterns, in spite of the metamorphic alteration/overgrowth under amphibolite facies conditions. The zircon cores ages date gneisses and granite gneisses protolith formation (3.34–
3.25 Ga). The rims with metamorphic REE patterns date the age of migmatization (in the Bulunsky block).

These new data allowed to recognize for the first time Mesoarchaean (3026 ± 17 Ma) granulite facies metamorphic event within the Irkutny block. The REE distribution of the analyzed zircons suggests different P-T conditions for Meso-Neoarchaean and Proterozoic granulite metamorphic events.

This case clearly demonstrates efficiency of combined local U-Pb and REE SIMS studies on the same zircons: It allowed to propose a reliable model of complicated metamorphic evolution.
References

Sensitive High Resolution Ion MicroProbe (SHRIMP) U-Pb dating of zircon from pelitic granulites, granites, nepheline syenites and dolerite, rhyolite dykes of the Proterozoic mobile belts and adjoining cratons of the Indian Peninsula has been carried out. Indian Peninsula is considered to be in juxtaposition with other landmasses of the East Gondwana assembly since the Rodinia orogeny at ca 1.0 Ga. However, the present study shows that the peninsula itself was not yet assembled into a single landmass till Pan-African time (ca 517 Ma); major convergence of landmasses has taken place in the late- Neoproterozoic period.

The Indian Peninsula is dominated by Precambrian rocks, which are distributed amongst several Cratons, Mobile Belts and Platform sequences. The Cratons are called as Marwar, Mewar, Bundelkhand, Bhandara, Singhbhum and Dharwar; mobile belts are Arvalli, Satpura, Singhbhum, Eastern Ghats, Southern Granulite Mobile Belts and Platform sequences are Vindhyans, Chhatisghard, Khariar, Cuddapah and Kaladgi sequences. The Cratons consists of TTG (Banded Gneissic Complex, Peninsular Gneisses and Singhbhum Granite gneisses) and greenstones (Dharwar Greenstone Belt) belonging to an age range of ca 3.8 Ga-2.5 Ga. The cratonisation was completed with the emplacement of the Berach granites in the NW part, the Closepet granite in the south and Late tectonic potassic granites in the east at 2.6 Ga. The mobile belts are mostly enriched with metasediments of Proterozoic age and contain reworked cratonic fragments (e.g. Banded Gneissic Complex inliers in the Aravalli Mobile Belt), while the platform sequences are composed of shale-sandstone sequence with less carbonates deposited at 1.6 Ga to 0.7 Ga.
All these crustal fragments of the Indian peninsula were juxtaposed along terrane margin shear zones showing prolonged history of reactivation. The strain along these shear zones varies spatially as well as temporally. Some of the shear zones show emplacement of nepheline syenite and granite plutons as in the case with Terrane Boundary Shear Zones of the Eastern Ghats Mobile Belt.

An important feature of the Peninsula is that, the Proterozoic mobile belts are viewed as mutually being connected to form a sinusoidal belt. The platform sequences occur along the margin of this belt showing a sinusoidal distribution pattern. It is thought that while the mobile belts formed from the closure of the oceans through subduction, the platform sequences were formed in the pericontinental marginal basins adjoining to those oceans and remained as undeformed and unmetamorphosed till date. However, the margins of these platform basins were deformed and thrust due to mobile belt orogeny.

The metasedimentary sequences in the mobile belt-platform sequences show a Proterozoic depositional history. The zircons recovered from the pelitic granulites and the associated synsedimentary volcanics of the Delhi Supergroup of the Aravalli Mobile belt show a depositional age of ca 1.2 Ga to 0.9 Ga. The Aravalli Supergroup, Satpura Mobile Belt, Eastern Ghats show Mesoproterozoic sedimentation history while Singhbhum Mobile belt show Paleoproterozoic sedimentation history. However, the Platform sequences began deposition post 1.6 Ga. Hence it is implied that the formation of such basins could be Paleoproterozoic age or younger.

The dykes in the Cratons bear testimony of such age. The Bastar Craton to the west of Eastern Ghats has been dissected by dyke swarms in several trends. The present SHRIMP study shows that the NNW trending dolerite, rhyolite and trachyte dykes close to the NW syntaxes of the Eastern Ghats yield U-Pb age of zircon of ca 1.4 Ga. To the SW margin the age has been found to be 1.8 Ga. Hence it is interpreted that the stage ending around 1.4 Ga was a period of extension and thermal weakening of the crust when the basins opened up.

The detailed structural and metamorphic study of the mobile belts indicates that the mobile belts are constituted of several terranes, which show distinct metamorphic and deformational history. The present study suggests that the granulite metamorphism in Delhi Supergroup of Aravalli Mobile Belt is ca 840 Ga while that in the Eastern Ghats is ca 617 Ga. These are the latest dynamothermal metamorphic event in the belts. Further from the age of the late stage granites in the Aravalli (ca 0.7 Ga) and nepheline syenites (0.5 Ga) the thrusting along the terrane margin shear zones and final juxtaposition of the mobile belt with the Cratons occurred at around 0.7 to 0.5 Ga.

This shows, for the first time, that the final configuration of the Indian Peninsula came about in the late Neoproterozoic and not, as so far thought, during the Mesoproterozoic. Thus the East Gondwana Assembly which was considered to be a single undivided mass was in fact consisted of multiple cratonic fragments dispersed till Neoproterozoic when they were assembled and formed Gondwana-land.
Although the original SHRIMP (I) was developed with the intention that it be applicable to a wide range of geological and geochemical investigations, in practice it and most of its successors have been primarily used for U/Pb geochronology. This has been largely due to the demand for U/Pb analyses, but also because of difficulties encountered in developing other applications, particularly the analysis of stable isotopes. Recent work at RSES has demonstrated that it is possible to obtain the high quality data required for useful stable isotope studies with the SHRIMP II equipped with a 5 detector multiple collector, but it has also highlighted a number of problems. Some of these have been solved while others have indicated the need for further instrumental development. The current project is the design and construction of an ion microprobe intended specifically for stable isotope analysis, the SHRIMP SI.

Progress reports on this development have been given at previous SHRIMP workshops: SHRIMP SI is based on the original Matsuda CQH layout of SHRIMP I and II, using the Electrostatic Analyser and Magnet as currently built by Australian Scientific Instruments. The multiple collector has been redesigned to improve stability and data quality. The source has been redesigned to allow the attainment of better vacuum in the target region and to reduce or eliminate sources of variable mass discrimination. The design is now virtually complete and will be reviewed in some detail and an update on the progress of construction of the new instrument will be given.
TIME-SCALE POINTS USING SHRIMP, MIXTURE MODELLING
AND THE SL13 STANDARD

Compston, W.¹, Williams, I. S.¹ and Jenkins, R. J. F.²

¹ The Australian National University, Canberra A.C.T.
² South Australian Museum, Adelaide, South Australia

Palaeozoic volcanics test the limits of measuring $^{206}\text{Pb}/^{238}\text{U}$ ages using SHRIMP. This is because most igneous rocks have multiple zircon sources, and SHRIMP usually cannot measure $^{207}\text{Pb}/^{206}\text{Pb}$ ratios well enough to apply the Concordia diagram, which otherwise would help to identify ages as volcanic, inherited or lowered by Pb-loss. Instead, many $^{206}\text{Pb}/^{238}\text{U}$ ages per sample can be made to identify inherited or lowered zircon ages, and reliance can be placed on averaging the remainder, presumably the volcanic $^{206}\text{Pb}/^{238}\text{U}$ ages, to reach an acceptable precision for that event. SHRIMP dating needs a known and uniform standard zircon, and it has been clear since 1995 that the original SL13 single crystal is not uniform in apparent age. L. P. Black has led a Geoscience Australia team who have documented a new standard, Temora, which is nearly flawless. We need to know whether earlier SHRIMP Palaeozoic ages are adequate or whether they should all be remeasured, or whether we should abandon this field altogether to the wet chemists (who have no doubts about the answer). In addition, there is continuing dispute amongst us how to screen the body of spot-ages per sample. It would be done best if features such as zircon overgrowth, crystal habit and grain morphology reliably discriminated between different zircon origins. Otherwise, we need to search for significant numerical structure within the collective $^{206}\text{Pb}/^{238}\text{U}$ ages using statistical methods such as mixture modelling. Most of us accept mixture modelling for the study of detrital zircons in sedimentary rocks, but many regard it as too ambiguous (the Mirror of Galadriel) for use in dating specific volcanic rocks that are relatable to the biostratigraphy of adjacent sediments.

As an example of the above issues, we present the problem of determining the age of the Sellicks Hill Tuff in the Early Cambrian of southeast Australia. A previous attempt to obtain a precise SHRIMP age for this rock had been made using the SL13 standard, giving $522 \pm 2$ Ma after deletion of inherited and Pb-loss ages. Recently R. J. F. Jenkins supplied a different sample of the tuff to the Geological Survey of South Australia for SHRIMP dating, and was later informed that the great majority of zircons gave an unexpectedly young age. A further sample from the identical site was collected to confirm this.
The Temora ages agree with each other to within measurement uncertainties. For the SH2 zircons, overgrowths and cores are absent and most crystals show simple sector zoning, leaving statistical analysis of the age values themselves as the only means of subdivision. Excluding the one young outlier in Fig. 1, the rest of the SH2 ages agree to within uncertainty at 512.3 ± 0.9 Ma. Including the external uncertainty, this becomes 512.3 ± 2.5 Ma at 95% confidence. Fig. 2 shows the SH ages as a histogram and as the kerned probability density. Mixture modelling isolates the one low analysis and confirms a single age group for the rest. We interpret 512 Ma to be the age of tuff volcanism, in strong contrast with the 522 Ma from the previous sample.

In a review of zircon ages in the original Sellicks Hill sample in 2002, various age groups including a small 508 Ma group were not well resolved from each other, probably because the assigned SL13 age had been changed slightly per session in an attempt to correct for sampling fluctuations in age within SL13. The small young
group was dismissed as produced by Pb loss. Here we recalculate the older results using exactly 572 Ma for the age of SL13, and apply mixture modelling per session using the internal errors. The calibration errors per session were then added to the uncertainty of each group age, and the estimates for each group from the four sessions then combined as weighted means. Two age groups are now well defined at 510 ± 2 Ma and 524 ± 2 Ma. The estimated proportion of the young group is greater, probably owing to the smaller errors used for mixture modelling. For the early Sellicks Hills analyses, we now consider that the 510 Ma group denotes the age of the tuff magmatism, not ca. 522 Ma as given previously. Mixture modelling of the combined spot ages for the recalculated early data (Fig. 3) illustrates the age structure. It resolves a large younger group at 508 ± 2 Ma within error of the 510 Ma result from the sessional means.

![Sellicks Hill using SL13](image)

The geological implications of the younger age for this Early Cambrian tuff will be discussed elsewhere. It is evident that the first Sellicks Hills sample contained a large fraction of inherited zircons that were either absent in the two later samples or not selected during analysis.

SL13 was measured in the same session as the new SH zircons, and it too shows relatively dispersed ages compared with Temora. As documented previously, it has two or more age groups within the single crystal, older and younger than the measured isotope dilution age. The mean SL13 age from the present session is 571 ± 3 Ma (1σ), close to the isotope dilution value but perhaps fortuitously so. The best procedure to optimise SL13-referenced ages remains a problem.
SHRIMP U-TH-PB DATING OF XENOTIME

Cross, Andrew¹, ² and Williams, Ian¹

¹ Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200
² OEMD, Geoscience Australia, GPO Box 378, Canberra, ACT 2601

Diagenetic and hydrothermal xenotime typically occur in rocks as tiny crystals (≤20 µm), either individually or as outgrowths on a zircon substrate. Currently only large radius ion microprobes such as the SHRIMP or Cameca 1270/1280 have the high sensitivity and spatial resolution necessary to analyse these crystals for U-Th-Pb isotopes. However, such analyses are prone to large matrix effects (ME) related to the wide natural range of U (0 to ~6 wt %) and REE (ΣREE: ~12 to 22 wt %) abundances in xenotime. Consequently, the ²⁰⁶Pb/²³⁸U calibration procedure for xenotime differs significantly from that employed for SIMS dating of zircon.

Contrasts in U, and to a lesser extent ΣREE, contents between the primary calibration standard and unknown xenotime can result in SHRIMP ²⁰⁶Pb/²³⁸U—²⁰⁸Pb/²³²Th ME of up to ~20 %. The matrix correction technique recently developed requires the concurrent analysis of three xenotime standards with a range of U and eREE concentrations on a session-by-session basis. The ²⁰⁶Pb/²³⁸U—²⁰⁸P/²³²Th ME is monitored by the analysis of two secondary standards, a high-ΣREE xenotime (BS1) and a high-U xenotime (Z6413). Additionally, the chemical composition of each spot is determined by EPMA prior to SHRIMP analysis. Each spot is corrected for ME by defining a series of simultaneous linear equations that relate the fractional ²⁰⁶Pb/²³⁸U—²⁰⁸P/²³²Th ME of the secondary standards to their U and eREE concentration contrasts with the primary calibration standard (MG1). On average, every 1 wt % contrast in U between the primary calibration standard and the unknown results in a ~12 % difference in the ²⁰⁶Pb/²³⁸U and ²⁰⁸P/²³²Th ratios, while a 1 wt % contrast in REE results in a difference in the ²⁰⁶Pb/²³⁸U and ²⁰⁸P/²³²Th ratios of ~1 wt %.

SHRIMP RG was used for these experiments because the analyses on that instrument are not prone to the molecular interferences or ‘scattered ions’ that affect the ²⁰⁴Pb peak when xenotime is analysed on SHRIMP II. An O⁻ primary beam was focused through a 30 mm Kohler aperture, producing spot diameters of ~5—7 mm. Matrix uncorrected ²⁰⁶Pb/²³⁸U ratios were determined from the raw ²⁰⁶Pb⁺/²³⁸U⁶O²⁺ ratios as suggested for zircon analyses by Stern and Amelin (2003).
The technique developed is broadly similar to the SHRIMP xenotime U-Th-Pb correction procedure proposed by Fletcher et al. (2004). Whereas Fletcher and others related SHRIMP xenotime $^{206}\text{Pb}/^{238}\text{U} - ^{208}\text{Pb}/^{232}\text{Th}$ ME to contrasts in U, Th, and $\Sigma$REE, however, our study indicates that the effect of Th on the $^{206}\text{Pb}/^{238}\text{U} - ^{208}\text{Pb}/^{232}\text{Th}$ ME is very minor to insignificant. It appears likely that for xenotime, it is the matrix sensitivity of the emission of the Pb$^+$ secondary ions, not U or Th species, that is the principal cause of the $^{206}\text{Pb}/^{238}\text{U} - ^{208}\text{Pb}/^{232}\text{Th}$ ME. Using the new matrix correction procedures reported here, it is now possible to measure $^{206}\text{Pb}/^{238}\text{U}$ and $^{208}\text{Pb}/^{232}\text{Th}$ ages of Phanerozoic xenotime with an accuracy and precision of about 2%.

References


WHEN GOOD ZIRCONS GO BAD – REDISTRIBUTION OF RADIOGENIC Pb IN GRANULITE GRADE ZIRCON, SNOWBIRD TECTONIC ZONE, CANADA

Davis, W.J., Rayner, N., Pestaj, T.
J.C. Roddick Ion Microprobe Laboratory
Geological Survey of Canada, 601 Booth St., Ottawa, ON Canada
Bill.Davis@nrcan.gc.ca

Understanding the cause of discordance and partial resetting of the U-Pb system in zircon is key in establishing robust geological interpretations of complicated data sets typical of high-grade or poly-metamorphic terranes.

An Archaean (ca. 2.7 Ga) mafic rock from the Snowbird Tectonic Zone, Canada experienced high-temperature granulite metamorphism at 1.9 Ga that resulted in partial resetting of the U-Pb system in zircon. Individual zircon analyses spread along a discordia chord from the original crystallization age to the age of metamorphic resetting (Figure 1). A significant subset (~60%) of the zircon analyses exhibit unusual secondary ion yield characteristics for Pb isotopes in which the secondary beam-normalized Pb counts vary non-systematically over the course of the analyses (Figure 2). Data evaluation using time series regression methods, such as the PRAWN data reduction, result in large error magnification in the cal-

![Figure 1. Concordia diagram illustrating spread of data from ~2.7 Ga crystallization age to 1.9 Ga metamorphic age. Data reduced using the SQUID data reduction package](image-url)
culated isotopic ratios with analytical errors in the $^{207}\text{Pb}/^{206}\text{Pb}$ age of 10–50 %. Secondary ions other than Pb (Zr$_2$O, U, UO, ThO, UO$_2$) do not exhibit the same scatter and behave similarly to analyses of the standard with errors dominated by counting statistics. This behaviour is weakly, or not correlated to the degree of apparent Pb-loss.

Alternative data reduction techniques such as the double interpolation method employed in the SQUID software are less affected by the variation in secondary yield of Pb and errors in the $^{207}\text{Pb}/^{206}\text{Pb}$ age are on the order of 0.2 to 1 %. Scan to scan count rates of the different Pb isotopes are highly correlated with the variation in isotopic ratios between scans is less than the variation in individual count rates. Interestingly, the PRAWN and SQUID data reduction schemes result in broadly similar ages despite the very large error propagation in the former.

This behaviour has been documented in a number of granulite samples from different geological settings. The cause remains uncertain. Variation in secondary Pb ionisation may be related to variations in the microstructural state of the zircon, or to inhomogeneous redistribution of radiogenic Pb during metamorphism. The zircons have moderately high U contents (150–500 ppm) but do not have high common Pb contents typical of altered, metamict zircon. To test if the microstructural state of the zircon contributes to this phenomenon, randomly selected zircons were selected from the sample and annealed at 1000 C for 48 hours prior to SHRIMP mount preparation. Annealed and non-annealed zircon were analysed within the same analytical session. Annealing did not mitigate the analytical problem suggesting that the present-day microstructural state of the zircon is un-
likely to be the principal cause of secondary Pb ion yield variability. As an aside, annealing of the 6266 and Temora standards did not result in significant improvement in the calibration relative to non-annealed standards.

An alternative possibility is that the radiogenic Pb produced between 2.7 and 1.9 Ga was inhomogeneously redistributed within the crystal during metamorphism. In this case the changes in secondary ion yield reflect real variations in unsupported radiogenic Pb concentrations at the sub-micron scale. A correlation cannot be established between the percentage of Pb lost at the time of metamorphism and variable Pb ionisation. Coincident REE ion probe analyses do not indicate significant differences in trace element content between zircons that demonstrate this effect and those that do not. Future research including additional microstructural studies is planned to expand our understanding of this effect, and its significance to resetting of U-Pb systematics in zircon.
Banded iron formation (BIF), a type of sedimentary rock restricted to the early Precambrian, is distinctive in its high iron content (generally c.30 % Fe) and the presence of alternating bands of silica (chert) and iron oxides at a range of scales. There is nothing like it being laid down on the modern Earth, and its origin has been controversial, although there is a near-consensus that it has been formed as a chemical precipitate from ferrous iron held in solution in a reducing ocean below an oxygen-free atmosphere. As isotope geochronology gradually enabled the Precambrian history of the Earth to be refined, and estimates of the ages of more BIFs were made, it began to appear that although some BIF was present in older Precambrian sequences the largest BIFs may all have been laid down within a very short time interval that occurred over 2000 Ma ago. Preston Cloud developed a hypothesis to account for this time-distribution, related to the early biochemical evolution. He suggested that early deposition of BIF was triggered by photosynthesizing microorganisms, which could not survive in an oxidising environment, and therefore needed to dispose of the oxygen they produced. They did so by using the dissolved ferrous iron of their ocean environment as a chemical sink; and the rate of BIF deposition was limited by the amount of iron available. When these organisms evolved a natural immunity to oxygen, Cloud argued, there was a global population explosion which completely flushed iron from the early oceans, and formed massive and contemporaneous BIF deposits over the whole Earth.

The development of SHRIMP in Canberra made it feasible to test the Cloud hypothesis by making precise U–Pb isotopic analyses of volcanic zircons from volcanic rocks associated with major BIFs. When a SHRIMP was acquired in Perth, in 1993, we began such a test, focused on a number of thick and extensive BIFs on the Gondwana continents: South America, India, Africa and Australia. Results have been published for the Hamersley Group BIFs of Western Australia (Trendall et al., 1998b, 2004), the Carajas Formation of the Amazon Craton in Northern Brazil (Trendall et al., 1998a), and the Mulaingiri Formation (Dharvar Supergroup) of the Karnataka Craton in India (Trendall et al. 1997). Our unpublished results from the Transvaal Supergroup BIFs of South Africa are consistent with the later and more extensive work of Pickard (2003).
In summary, these results show that while the giant BIFs of South Africa and Western Australia, which are by far the largest on Earth, were deposited synchronously between about 2560 Ma and 2450 Ma, deposition of the major BIFs of Brazil and India was completed slightly less than 200 million years beforehand. Thus the Cloud hypothesis in its simplest form cannot be sustained on the basis of these SHRIMP results. A modification of the hypothesis may be possible, in which a gradual increase in BIF size through the early Precambrian is related to an equally gradual evolution of the ability of early photosynthesizing microorganisms to live in an oxidising environment. But much more work would be needed, both by geochronologists and evolutionary biochemists, to validate this possibility.

References

SHRIMP SI is based on the same Matsuda design which has been used for the construction of SHRIMP II. As a consequence of this several components are identical to those in SHRIMP II. The current designs for the ESA and Magnet as used by Australian Scientific instruments have been used. The source chamber, sample handling and collector have been completely redesigned. Most of the components for the instrument have been built in our own workshops at RSES, and by Buckley Systems in Auckland, New Zealand. The parts for the vacuum system have been chosen so that an oil free high vacuum can be achieved in all sections of the instrument.
TH/U RATIO IN MAGMATIC AND METAMORPHIC ZIRCONS
(BASED ON U-PB DATA, SHRIMP-II)

Gavryutchenkova, Olga, Berezhnaya, N., and Balashova, Yu.
Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI),
St Petersburg, RussiaOlga_Gavryutchenkova@vsegei.ru

The contents of U and Th in a zircon depend to a large extent on concentration of the elements in a parent rock, presence of other co-crystallizing mineral concentrators, chemistry and P-T of environment. Despite of absence of general theory of U and Th incorporation into a zircon, still Th/U ratio in a zircon is considered as a genetic indicator in many publications.

The Th/U ratio of about 0.1 to 0.7 considered as a sign of zircon’s magmatic origin while Th/U <0.1 suggests metamorphic nature [4]. However a high Th/U ratio up to > 1.0 could be formed under the conditions of the granulite facies metamorphism [1, 3]. It is down to 0.01 in the eclogite zircon [2] and well above 1.5 in some basic rocks.

Our experience, based on study of more than 100 samples allowed us to draw out some general suggestions on Th-U-genesis dependence (Fig.).

The ellipses on the plot display areas of location of the majority of compositions. Actual data spread is and overlapping is much wider
There is no straight correlation between the U content, the Th/U ratio in magmatic zircons and the parental rock composition. A bulk analysis of basic rocks showed U content ranging 100–600 ppm with Th/U ratio – 0.1–1.6. For medium rocks – U = 0–600 ppm, Th/U = 0.4–1.7. For acid rocks – U = 30–400 ppm, Th/U = 0.1–1.2. There are also evidences of higher U and Th/U contents for all types of magmatic rocks.

For the amphibolite facies zircons the U content is generally 200–500 ppm, and the Th/U ratio is 0.04–0.16. But some outer rims have U = 800–1300, and Th/U = 0.19–1.63.

There are two zircon groups that are typical for granulite facies rocks: 1) newly-formed zircons with low U content (20–40 ppm), Th/U = 0.01–0.04; and 2) U = 200–350 ppm, Th/U = 0.02–0.3. Metamorphic zircons with U = 30–300, Th/U = 1.1–2.4 are unique. Such ratio is common for high-temperature granulite without monazite.

The plot clearly shows that U content and Th/U ratio of zircons of different nature widely overlap, which debars unequivocal recognition of zircon’s origin. Therefore, additional geochemical study (REE, μHf, inclusions) is strongly suggested for the zircon genesis interpretation. Elaboration of sound approach to the latter would be an important tool for studies of detrital and inherited zircons.

References

ZIRCONS FROM HIGH CARBON PALAEOPROTEROZOIC SEDIMENTS (SHUNGITES) OF THE ONEGA STRUCTURE (CENTRAL KARELIA, N.W. RUSSIA)

Goltsin, N. A.¹, Saltykova, A. K.¹, Polekhovsky², Yu. S., Presnyakov, S. L.¹, Prasolov, E. M.¹, Prilepsky, E. B.¹, Lokhov, K. I.¹

¹VSEGEI, St.Petersburg
²St Petersburg University Nikolay_Goltsin@vsegei.ru Kirill_Lokhov@vsegei.ru

The zircons from high carbon sedimentary Early Proterozoic rocks from the Onega structure (Fig. 1) have been studied. These rocks contain up to 90 % of amorphous carbon and are known as shungite. Shungites interlayer with volcanic rocks and form Palaeoproterozoic Ludikovian sequence.

We expected to find two generations of zircons: Archaean detrital ones and crystals formed at the time of Ludikovian volcanism. Optical and cathodolumi-
nescence investigation of the extracted zircons have shown that there are a num-
ber of zircon generations. Some crystals clearly were formed under high fluid con-
ditions, have abundant liquid-gas inclusions and contain inclusions of low tem-
perature minerals (titanite). However usually an individual zircons are homoge-
neous with no different generations.

U-Pb isotope systematics in the zircons has been investigated by means of the
SHRIMP-II ion probe. The majority of the studied crystals gave concordant U-
Pb ages (Fig. 2).

There are two clusters with the ages of 1746 ± 15 M.y. and
1573 ± 43 M.y., while some zircons showed concordant ages ranging
200–1200 M.y. Evidently detrital zircons are discordant, giving esti-
mation of the crystallization at
2748 ± 15 My and alteration at
218 ± 190 My (Fig. 3). Only some
discordant crystals correspond to the
time of Ludikovian volcanism at
around 2000 M.y.

The most abundant zircons with
the age of c.1570 My have specific
features: they are large prismatic
crystals rich in liquid-gas and solid inclusions. Zircons of all generations have surf-
icial traces of partial dissolution.

Fig. 3
We’ve studied REE distribution patterns by means of the SHRIMP-II with the aim to find traces of metasomatic or hydrothermal process: such a zircons are characterized by pattern with elevated LREE and suppressed Ce and Eu anomalies [2, 3]. Excluding younger (200 – 1200 M.y.) all the other zircons may be divided into two groups by REE pattern. The first type of REE distribution pattern is similar to those of magmatic and metamorphic zircons (Fig. 4a), the second has distribution pattern of “hydrothermal” type (Fig.4b). Since each zircon age-group has crystals with the both types of REE distribution pattern, we suggest that crystallization of these minerals occurred in conditions of heterogeneous CO₂–CH₄–H₂O fluid phase.

Obtained data suggest, that in the rocks of volcanogenic – sedimentary Ludikovian sequence a high scale and long living heterogeneous hydrothermal system functioned. In the span of more than 1200 My the rocks of this sequence have suffered multistage metasomatic alteration which is reflected in variability of car-

Fig. 4
bon isotopic composition of reduced shungite matter in large scale: $\delta^{13}C = -45–8 \%$.

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**References**

ISOTOPIC SHIFTS CAUSED BY NUCLEAR REACTIONS
IN NATURAL FISSION REACTORS

Hidaka, Hiroshi

Department of Earth and Planetary systems, Hiroshima University
Higashi-Hiroshima 739-8526, Japan
TEL:+81.82.424.7464, FAX:+81.82.424.0735, e-mail:hidaka@hiroshima-u.ac.jp

The Oklo uranium deposit in the Republic of Gabon, central Africa, had partly
functioned as natural fission reactors. Large-scale fission chain reactions sponta-
neously occurred at 16 separate areas in the Oklo deposit, so-called “reactor zones”
two billion years ago, and sustained for 24000 to 200000 years. Two more reactor
zones have been identified at the Okelobondo and Bangombi uranium deposits
close to Oklo.

Many elements of the Oklo reactor zones and the related samples show the
variations in the isotopic composition caused by a combination of nuclear fission,
neutron capture and radioactive decay. Isotopic studies provide useful informa-
tion to estimate reactor conditions and to understand behavior of radionuclides in
gеологічній средній [1]. Мost of previous isotopic analyses for the Oklo studies were
based on bulk analysis of the rock samples with chemical separation for individual
elements using thermal ionization mass spectrometry (TIMS) and inductively
coupled plasma mass spectrometry (ICP-MS) [2]. On the other hand, in my re-
cent work, in-situ isotopic analyses of individual tiny minerals in and around re-

Fig. 1. Back scattered electron
(BSE) image of a françoisite
grain found in sandstone sur-
rounding the Bangombi natu-
ral reactor. The scale bar cor-
responds to 50 μm
actor zones have been performed using a SHRIMP [3–6]. I report here current topics of geochemical behavior of fissiogenic isotopes migrated from the natural reactors.

Several kinds of U and REE bearing secondary minerals such as coffinite (USiO$_4$), florencite ((REE)Al$_3$(PO$_4$)$_2$(OH)$_6$) and franfoisite ((REE)(UO$_2$)$_3$O(OH)(PO$_4$)$_6$H$_2$O) (see Figure 1), found from the peripheral rocks of reactor zones, include variable amounts of $^{235}$U-depleted uranium ($^{235}$U/$^{238}$U<0.007252) and fissiogenic REE. Furthermore, isotopic data of $^{140}$Ce/$^{142}$Ce, $^{143}$Nd/$^{146}$Nd and $^{149}$Sm/$^{147}$Sm clearly reveal that these minerals resulted from mixing between fissiogenic component from the reactor zones and non-fissiogenic component from native minerals by recent geologic alteration [3].

Evidence for selective adsorption of radioactive isotopes into specific minerals was also observed from the Oklo isotopic studies. Isotopic enrichment of $^{235}$U ($^{235}$U/$^{238}$U=0.00944 to 0.0171) of apatite in the boundary layers between the reactor and the wall rock shows migration of $^{239}$Pu produced by neutron capture of $^{238}$U in the reactor [4,5]. REE data also support the Pu migration in apatite. High amount of fissiogenic Nd was also observed in the apatite grain. Since one of REE, Nd has been often used as an analogue of Pu in geochemical fields, it is reasonable that fissiogenic Nd and nucleogenic $^{239}$Pu were both incorporated into the apatite grain.

Pb isotopic study of the Oklo samples provides evidence of Ra transportation and its selective uptake into clay minerals. Radium has no stable isotopes. $^{226}$Ra having the longest half-life ($T_{1/2} = 1600$ year) among radium isotopes exists as a precursor of decay product from $^{238}$U in nature, and finally decays to $^{206}$Pb. Illite grains found in calcite veins included in sandstone adjacent to the Oklo uranium deposit (see Fig. 2) show extremely low $^{207}$Pb/$^{206}$Pb ratios (=0.015 to 0.05), suggesting the adsorption of $^{226}$Ra presently decayed to $^{206}$Pb [6]. Chemical data also support that the low $^{207}$Pb/$^{206}$Pb ratios were caused by selective adsorption of $^{226}$Ra. Ba has been often used as a chemical analogue of Ra. Illite grains having low $^{207}$Pb/$^{206}$Pb isotopic ratios also show a strong enrichment of Ba (1230 to 6010 ppm). Considering that Ba has been used as a chemical tracer of $^{226}$Ra because of the

Fig. 2. Secondary electron image of the sample used for Pb isotopic study. Small illite grains are found in calcite veins of quartz matrix. The scale bar is 200 µm
chemical similarities between Ba and Ra, the extremely low $^{207}\text{Pb}/^{206}\text{Pb}$ ratios strongly suggest the selective adsorption of $^{226}\text{Ra}$ as a precursor of $^{206}\text{Pb}$ in the illite grains.

SHRIMP isotopic analyses of several kinds of U-bearing minerals related to the Oklo natural reactor samples provide insights on the mechanism of mobilization and retardation of isotopes in repository materials for radioactive waste disposal.

References

MULTIPLE U-PB AGES FOR SINGLE JACK HILLS HADEAN ZIRCON GRAINS

Holden, Peter, Thorne, Jane, and Ireland, Trevor

Research School of Earth Sciences, Australian National University, Canberra A.C.T. (Peter.Holden@ANU.EDU.AU)

The detrital zircon age spectrum for the Jack Hills (western Australia) contains about 7% of grains older than 3.8 Ga. From these samples much information as to the status of the earliest crust has been gleaned. However, the presence of multiple age domains within these older crystals creates difficulties when interpreting these data in terms of crustal growth models. We present a slightly different approach in mapping each grain for age both in terms of U-Pb and Pb-Pb ages, by placing multiple spots systematically on the same grain.

The recently automated SHRIMP-1 is the instrument of choice in such an endeavour, as data exhibit surprisingly little sensitivity to the progressive removal of the conductive gold coat as acquisition proceeds. SHRIMP RG does not share this tolerance. The causes of instrumental mass fractionation exacerbated by progressive loss of conductivity were investigated using the POXI XML data extraction program (Lanc, this conference).

A variety of age spectra from single grains are presented, which are as varied individually as the Jack Hills detrital spectrum as a whole. Of particular interest was testing the significance of the Late Heavy Bombardment (LHB) signature as suggested by complementary depth profiling measurements in the pre-4.1Ga grains (Trail et al. 2007). This manifests itself as a persistent 3.9Ga age close to the margin of old crystals caused presumably by a thermal metamorphic overprint induced by regional burial under an ejecta blanket(s?). We find that if the signature is present, it appears to be no more significant than several others that appear in the post 4.1Ga component of older (>4.3Ga) grains.

Reference

EVIDENCE OF A CAMBRIAN TECTONOMAGMATIC EVENT IN EASTERN BORBOREMA PROVINCE: U/PB SHRIMP GEOCHRONOLOGY

Hollanda, M.H.B.M.¹; Archanjo, C. J.¹; Armstrong, R.²

¹ Instituto de Geociências, Universidade de São Paulo, Rua do Lago, 562, CEP 05508-080 São Paulo, SP, Brazil. E-mails: hollanda@usp.br; archan@usp.br
² The Australian National University, Canberra, Australia. E-mail: richard.armstrong@anu.edu.au

The Prata Magmatic Complex (PMC) comprises a combined plutonic and sub-volcanic igneous set, including granitic to gabbroic rocks and mafic-acid dyke swarms cropping out in northeasternmost Borborema Province (NE Brazil). Previous geochronological surveys in that province have defined a voluminous Neoproterozoic bimodal magmatism; but younger magmatic activity is rare, being found only at the border of Paleozoic sag basins. We present geochronological (and structural) data for all igneous facies from PMC. They were dated by SHRIMP II at the Australian National University, Canberra; ages are quoted at the 95% confidence level. U/Pb zircon ages defined an important data set of Cambrian ages.

The Prata pluton is the main unity of this complex, including a biotite-bearing porphyritic to medium-grained equigranular granites with common dioritic enclaves occurring mostly at southern part of the complex. This pluton is cut across by low-grade mylonites near to the Prata city (Fig. 1), through an ENE-WSW shear zone. This structure subdivides two segments — named Santa Catarina (south) and Sumï (north) lobes. Dacite to diabase dyke swarms are found associated to both segments.

Zircon grains from both granitic and dioritic facies from the Sumï lobe were dated yielding similar concordant ages of 533.2 ± 3.9 Ma (05PRT16 granite) and 534 ± 3.9 Ma (04PRT01 diorite). Dating of a dacite sample (05MTd3.1) from the Sumï dyke swarm shows a quite similar U/Pb age of 537.6 ± 3.8 Ma. Older ages were obtained from zircons separated from rocks of the Santa Catarina lobe. A mean age of 541.8 ± 9.3 Ma was calculated for the granite facies of this lobe that is a bit younger than a Concordia age of 548.1 ± 4.3 Ma defined for the zircons from a dolerite dyke (04SMd1) from the same south sector. This older age is interpreted preliminarily as a precursor of this important bimodal magmatic event. Norite to gabbro-norite stocks and NE-trending fine-grained granite dykes outcropping in the northern part of the Prata Complex and are spatially associated to the Coxix-
ola shear zone. Zircons from one of those bodies yielded a Concordia age of 541.9 ± 4.7 Ma. All these ages match paleomagnetic data obtained on both dyke swarms (R.I.F. Trindade, pers. comm.).

The U/Pb ages (and Ar/Ar ages from the Coxixola mylonites not presented here) place the Borborema Province in a geodynamic scenario of tectonomagmatic processes occurring during Neoproterozoic-Cambrian transition. The data show that magmatism and low-grade solid-state deformation are both spatial and time-related. Bimodal magmatism occurred between 550-535 Ma, preceding and/or being contemporaneous to low-grade shear zone development that affected the eastern part of the province during c. 10 Ma. Presence of dyke swarms indicates that solid-state deformation includes an important extensional component, which might also be responsible for the onset of the Paleozoic sedimentary basins.

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Zircon is one of accessory minerals, which are suited for in-situ U-Pb geochronology, because zircon contains high U but discriminates against the daughter element Pb during crystallization. Moreover, this mineral has been proposed as an immobilization phase for actinides because of the ability to incorporate large amounts of U and Pu. In the applications of zircon, the durability and chemical/mineralogical property is important, and is affected by radiation damage caused by the a-decay of constituent actinides. Recently, micro-Raman spectroscopy has been mainly applied to the study of radiation effects in zircon. The Raman spectra show that systematic shifts in frequency, width and intensity of the specific peak occur with increasing a-dose (metamictization state) and variation of trace element contents such as rare earth element (REE). In this study, we discuss a correlation between cathodoluminescence (CL) images, Raman spectroscopic data and SHRIMP U-Pb and REE results.

Zircons were collected from jadeitite in the Osayama serpentinite melange of the central Chugoku Mountains, Japan. Raman spectroscopy was completed on a Renishaw inVia Raman Reflex microscope with a dedicated Leica DMLM microscope using 50x objective lens at Hiroshima University. Spectra were excited with the 633 nm emission line of a He-Ne laser. The scattered Raman light was analyzed with a charge-coupled device (CCD) array detector after being dispersed by a grating at 1800 grooves per mm. In-situ U-Pb isotopic analyses and REE measurements of the same spots of the Raman analyses were performed by SHRIMP.

Current results of the Osayama zircon indicate different correlations between CL images and Raman spectroscopic data. As shown in Fig. 1, peak frequencies and FWHMs (full width at half-maximum) of the n3(SiO4) stretching band around 1008 cm⁻¹ of the zircon from the Osayama zircon correlate with a contrast of the CL image. This correlation is attributed to U content, because the FWHM of the
n_3(SiO_4) stretching band is the most sensitive to transition of crystallinity, namely metamict state. U-Pb data of the Osayama zircon show a concordant age of 510 ± 12 Ma. The results from SHRIMP analyses and Raman spectroscopic observation suggest that the zircon has not suffered from the intense radiation damage. On the other hand, some zircon grains do not show the correlation between the FWHM of the n_3(SiO_4) band and the contrast of the CL image. As shown in Fig. 2, these grains have the correlation between an intensity of the n_3(SiO_4) band and the contrast of the CL image. REE patterns of these zircons are different according to the contrast of the CL image. Therefore, the correlation between an intensity of the n_3(SiO_4) band and the contrast of the CL image is attributed to REE contents.
DETERMINING HIGH PRECISION IN SITU O ISOTOPE RATIOS WITH A SHRIMP II


Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia
Ryan.Ickert@anu.edu.au

The development of new techniques and instrumentation on the ANU SHRIMP II ion microprobe have made it possible to measure the oxygen isotope ratios of insulating and conducting phases (e.g. silicates, carbonates, phosphates and oxides) on a 25 µm scale with less than 1 ‰ precision and accuracy. Instrumental modifications include the addition of a multiple collector, an oblique-incidence high-energy electron gun and Helmholtz coils around the source chamber to counter mass dispersion by the Earth’s magnetic field. A re-design of sample mounts and mount holders has eliminated variable isotope fractionation across the mount surface during analysis. Techniques have been developed to minimize the effect of electron-induced secondary ionisation of oxygen, which has the potential to affect analytical results at the 1 ‰ level.

During a 6-minute analysis involving 140 seconds of data collection, d18O can be measured on one 25 µm spot with an internal-precision of <0.1 ‰ (1SE). Spot-to-spot reproducibility is commonly 0.3–0.4 ‰ (1SD). The absolute accuracy achieved in measurements relative to a set of analyses of matrix-matched reference material is typically ± 0.6 ‰ (95 % confidence limits) or better.

Example datasets will be presented, and potential future improvements to the technique will be discussed.
Secondary ion mass spectrometry provides a versatile platform for microanalysis. While in the geosciences we are most familiar with sector-magnet based SHRIMP and Cameca instruments, quadrupole and TOF mass spectrometers are widely used in materials and surface research. In addition, resonance ionisation of selected elements or total ionisation can be performed. Accelerator mass spectrometry has also been coupled with SIMS. For many elements, the ion yields from sputtering are high, allowing precise analyses on selected spots with minimal sample consumption. In many cases, SIMS still defines the practical limit for in situ analysis.

SHRIMP instruments are optimised for volumetric analyses of geological materials. The volume of material consumed is generally of the order of a few nanograms, which ironically is one of the shortcomings of the technique. The low sample consumption rate means that analyses of isotopic abundances at very low levels can be very long (even up to several hours for REE by energy filtering for example).

Laser Ablation ICPMS offers rapid consumption of material and hence signal to background levels can be much higher than for SIMS. For U-Pb, LA-ICPMS has been developed to a stage where U-Pb spot analyses can be made very rapidly (few minutes per analysis), on spots around 10 µm across and 6 µm deep. Thus, for many geological materials, LA-ICPMS can be more effective, or at least more expedient. However, geological materials can be very complex even on the scales of SIMS analysis and so increasing the sample size cannot be regarded as a desirable characteristic.

The use of alternate polarities for ion microprobes allows optimisation of both electronegative and electropositive elements. The ability to make subpermil analyses on a routine basis for major elements is an important attribute. Ion yields for some elements are already in the tens of percent level and so there is limited or no prospect of gains in sensitivity. The issues confronting these types of analyses are related to stable analytical configuration. For some elements with moderate ionisation levels, such as Pb, there may be some prospect of increasing ionisation
through the use of a laser ionisation system. However, the prospect of an order of magnitude increase in sensitivity would likely be at the expense of stability in the calibration. Pulsed systems where the laser is used to ionise for short periods of time have an inherent dead time so that there is no gain in efficiency in a given time, although smaller amounts of material might be consumed if the ion beam could be gated.

SIMS remains a highly valuable technique for ionising elements. Developments in the future will lie in specific methodologies for specific scientific requirements.
SIDE BY SIDE WITH SIMS. LA-ICPMS VS SHRIMP TECHNIQUES: INTERACTION AND INTEGRATION

Kapitonov, I. N., Lokhov, K. I., Sergeev, S. A.

Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI), St Petersburg, Russia (Igor_Kapitonov@vsegei.ru)

Despite the ion probe mass-spectrometer SHRIMP-II is very precise and sensitive instrument, some types of analyses can be better solved with combination with laser ablation — ICP MS technique. In the Centre of Isotopic Research at VSEGEI (CIR VSEGEI) this complex is equipped with laser ablation system DUV-193 (New Wave Research, USA) with ArF excimer laser COMPex-102, coupled with ICPMS Element-2 or multi-collector (MC) ICPMS Neptune (Thermo Fisher Scientific).

The first group of task, which can be solved by LA-ICPMS, is common for SIMS U-Pb and Pb-Pb in-situ dating. LA have some advantage in two cases: dating of U-rich minerals and high-productive dating of detrital zircons.

For high-uranium minerals we use the LA-ICP-MS only, because SHRIMP usage in the ion counting mode has no sense: there can be easily obtained signals high enough for measurement in static mode by multicollector Faraday cup system at the laser spot size about 5-10 mkm. This also helps us to avoid an excessive SHRIMP machine retuning and reduce the memory effects.

Routinely we analyze two types of such objects for obtaining reasonable geochronological information by LA-ICPMS:

- High uranium zircons (>5000 ppm).
- High uranium inclusions in other minerals, like garnet, quartz.

The two Faraday cups configurations can be used, as the below:

\[ ^{202}\text{Hg}-^{203}\text{Tl}-^{204}(\text{Hg}+\text{Pb})-^{205}\text{Tl}-^{206}\text{Pb}-^{207}\text{Pb}-^{208}\text{Pb} \] for Pb-Pb ages

or U-Pb cups configuration: \[ ^{202}\text{Hg}-^{204}(\text{Hg}+\text{Pb})-^{206}\text{Pb}-^{207}\text{Pb}-^{232}\text{Th}-^{235}\text{U}-^{238}\text{U} \].

Example of analytical results is shown on the Fig.

Another objects in our study are detrital zircons, important for provenance research, where statistics is crucial. Short acquisition time of the analysis by LA-ICPMS, typically 11 integrations per 1 second provides high productivity of the method (but with some loss of spatial resolution).

The second group of tasks, which can be solved by LA-ICPMS are usually followed after and complements a SHRIMP U-Pb dating of zircon. Namely this is study of Hf isotopic systematic in zircons, as well as rare earth and trace ele-
ments compositions, commonly in the same locations, as for SHRIMP U-Pb analysis. Essential amount of REE measurements by LA-ICPMS are possible due to high productivity of the method (typically about 30–50 second per analysis) although with a little drop of spatial resolution comparing with SHRIMP. One more of reason for LA technique usage in REE measurement is a grand SHRIMP workload.

In the CIR VSEGEI by LA-ICPMS a numerous determinations of rare earth and trace elements were carried out in such mineral as garnet, apatite, monazite and others.

Recently we carried out a pilot study of high productivity monitoring of carbon isotopes in natural samples by means of LA and MC-ICPMS technique. This success has been achieved by usage of continuous flow sample input. Overall linear speed of the analysis was near 10 mm/min at spatial resolution 200 micrometers.

Analytical details will be shown in the workshop presentation.

Acknowledgements: The study has been partly supported by the Rosnedra Federal Agency of Russia.
EXPANDING SHRIMP APPLICATIONS AT CURTIN: RECENT ADVANCES AND OLD PROBLEMS

Kennedy, Allen

Department of Imaging and Applied Physics, Curtin University of Technology, Kent. St., Bentley, 6102, Western Australia, A.Kennedy@curtin.edu.au

This talk examines (1) the factors that have allowed the SHRIMP facility of the John De Laeter (JdeL) Centre for Mass Spectrometry, at Curtin University, to expand its applications, and, (2) the systemic problems that contribute to our failures, inhibit expansion, and limit funding success. The attainment of “great science” requires technical advantage, intellectual property advantage, creativity, collaboration, adaptability, innovation, pragmatism, and grunt, plus a relaxed assessment of the term “great science”. What these descriptors mean within the JdeL SHRIMP facility will be examined by looking at recent advances and recurring problems covered by the following list:

Funding
- Government vs Research vs Commercial vs Data factory
- International partnerships that tap new funding sources
- Personnel
- SHRIMP users/researchers, and their time... limitations
- NCRIS funded technical support for users
- Complexity issues for the users of the multiple collector
- The Cameca IMS 1280 is just around the corner
- The NanoSIMS is on the other side of the river

New Applications
- Multiple collector program??
- Common Pb in low Pb, Archaean systems
- U-Pb in low U minerals
- S and O isotopes

Single Collector
- Double dating
- Interfacing with EBSD
- Trace elements

Remote data collection
- External web-based access to the JdeL SHRIMPs at Curtin
- Big brother and local control using Tight VNC.
New minerals and reference materials
   U-Pb {Allanite [MK, CAL, COL], Cassiterite, Gadolinite, Brookite}
   Common Pb {K-Feldspar, Sulphides}
   Stable isotopes and trace elements [O, S, Ti, REE]
Replacement and comparison U-Pb reference materials
   Zircon [M257, OG2, Keiji Misawa, Simonetti stone]
   Titanite [OLT vs Khan]
New sample mounting and coating methods
   Glass, steel, bullets, mega-mounts [glass, steel, epoxy]
   Double-coating.
Instrumental Issues
   Multiple collector vacuum (Mini Turbo)
   Electrometer stability
   First stage op amps in the counting system
   Electron Multiplier aging [ETP and SJUTS]
The SHRIMP (Sensitive High mass Resolution Ion Micro-Probe) technique, which has revolutionized geochronology by allowing routine in situ U-Pb age determinations in accessory minerals, is based upon comparison of standards and unknowns, and the accuracy of the final results depends heavily upon the quality of the reference material used as a standard. An ideal standard would have (1) isotopic homogeneity at a smaller scale than the analytical volume, (2) insignificant common Pb, (3) sufficiently high daughter and parent isotope abundances to ensure good counting statistics without there being significant damage to the crystal lattice, (4) a bulk composition which results in an absence of matrix effects, and (5) a well-characterised composition. The search for a suitable SIMS reference material is therefore demanding and any potential candidate must be carefully scrutinised. In this abstract we present analytical work characterizing zircon M257 (Nasdala et al., 2008), in view of its potential use as a SIMS U-Pb reference material. Our analyses focused on the determination of reliable “recommended mean values” for U-Pb age, isotopic ratios, and U concentration, and the investigation of internal homogeneity/heterogeneity of the specimen, in order to obtain reliable information on whether randomly selected chips are representative of the analytical means.

M257, a 25.7 carat, light brown, inclusion-free, colour-saturated, flawless, faceted gem from Sri Lanka, initially weighed 5.14 g. Electron microprobe and LA-ICP-MS chemical compositions have been determined for M257. This zircon is remarkably homogeneous, with (1) no observable internal texture in CL images, (2) a uniformly moderate degree of radiation damage, (3) concordant U-Pb systematics, and (4) relatively homogeneous U ~840 ppm, Th ~230 ppm, and...
## Table 1. Cross calibrated ages of zircon standards

<table>
<thead>
<tr>
<th>Zircon</th>
<th>No. analyses</th>
<th>M257</th>
<th>Pleťovice</th>
<th>CZ3</th>
<th>Temora</th>
<th>91500</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>25</td>
<td>26</td>
<td>28</td>
<td>28</td>
<td>16</td>
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<tr>
<td>Published age (Ma)</td>
<td>Calculated age (Ma)*</td>
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<td></td>
<td></td>
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<tr>
<td><strong>M257</strong></td>
<td></td>
<td>561.3</td>
<td></td>
<td>560.9 ± 3.1</td>
<td>567.6 ± 3.1</td>
<td>562.7 ± 3.0</td>
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<tr>
<td></td>
<td>MSWD†</td>
<td></td>
<td></td>
<td>4.5</td>
<td>3.6</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Pleťovice</strong></td>
<td></td>
<td>336.5</td>
<td>337.7 ± 1.5</td>
<td></td>
<td>339.8 ± 1.0</td>
<td>337.8 ± 1.8</td>
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<tr>
<td></td>
<td>MSWD†</td>
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<td>3.7</td>
<td></td>
<td>1.4</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>CZ3</strong></td>
<td></td>
<td>564</td>
<td>558.5 ± 3.2</td>
<td>557.8 ± 3.0</td>
<td></td>
<td>559.2 ± 3.5</td>
</tr>
<tr>
<td></td>
<td>MSWD†</td>
<td></td>
<td>3.7</td>
<td>4.6</td>
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<td>4.1</td>
</tr>
<tr>
<td><strong>Temora</strong></td>
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<td>417</td>
<td>415 ± 2.4</td>
<td>414.5 ± 2.4</td>
<td>419.0 ± 2.4</td>
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</tr>
<tr>
<td></td>
<td>MSWD†</td>
<td></td>
<td>3.5</td>
<td>4.6</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td><strong>91500</strong></td>
<td></td>
<td>1064</td>
<td>1064.2 ± 8.6</td>
<td>1061.7 ± 7.5</td>
<td>1074.8 ± 7.6</td>
<td>1064.5 ± 7.5</td>
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<tr>
<td></td>
<td>MSWD†</td>
<td></td>
<td>1.8</td>
<td>2.9</td>
<td>2.4</td>
<td>2.7</td>
</tr>
</tbody>
</table>

* Ages are weighted mean values, uncertainties are 95 % conf. limits.

Uncertainties include the uncertainty of the standard analyses.

† Mean Squared Weighted Deviate values > 1.0 indicate the scatter of the data is greater than that predicted from analytical uncertainty alone.
Th/U ~0.274. M257, which has been analysed by TIMS in four separate labs, has respective mean $^{206}\text{Pb}^{/}/^{238}\text{U}$ and $^{207}\text{Pb}^{/}/^{235}\text{U}$ isotopic ratios of 0.09101 ± 0.00003 and 0.7392 ± 0.0003, where the given uncertainties are 2Г errors. The mean $^{206}\text{Pb}^{/}/^{238}\text{U}$ age is 561.3 ± 0.3 Ma (2Г), and M257 is concordant if the uncertainties of the U-Pb decay constants are considered. LA-ICP-MS U-Pb data are also concordant with a mean Concordia age of 561.9 ± 1.7 Ma (2Г n = 80). M257 has a (U+Th)/He age of 419 ± 9 Ma (2Г) that is typical of untreated Sri Lankan zircons. A unit cell volume of 264.69 ± 0.10 Е³, a Raman spectral, $B\text{\textsubscript{lg}}$ vibrational mode at 1001.3 ± 0.5 cm$^{-1}$ with an FWHM of 11.7 ± 1.0 cm$^{-1}$, and a density of 4.63 g/cm$^{3}$ correlate well with the calculated dose of 1.66 $\times$ 10$^{18}$ alpha-events per gram. These facts allow us to exclude heat treatment or any other unusual thermal history that could have produced radiogenic Pb loss. SHRIMP data has been collected at Curtin and Beijing. Round-robin SHRIMP analysis (Table 1) comparing M257 to CZ3, 91500, Temora 2, and Plešovice (Sláma et al., 2008), shows that M257 is homogeneous at the scale of the ion probe spot and that it will be a superb international zircon reference material.

During analysis we made a surprising observation. The calculated ages for M257 and the other three reference standards appear slightly too old using CZ3 as a calibration standard and a $^{206}\text{Pb}^{/}/^{238}\text{U}$ age of 564 Ma (Pidgeon et al., 1994). Similar observations were made in two earlier series of M257 SHRIMP analyses, done on a different sample mount in two different SHRIMP laboratories. These analyses yielded mean $^{206}\text{Pb}^{/}/^{238}\text{U}$ ages for M257, of 566.5 ± 3.5 Ma (2Г error, 10 analyses; Curtin University) and 566.4 ± 3.7 Ma (11 analyses; Beijing SHRIMP center, China). In contrast, all SHRIMP ages determined for M257, Plešovice, Temora-2, and 91500 are correct within analytical errors when calibrated against a reference other than CZ3 (Table 1). These observations suggest that the $^{206}\text{Pb}^{/}/^{238}\text{U}$ age of CZ3 might be somewhat younger than 564 Ma. These doubts are reinforced by the initial TIMS results for CZ3 obtained at the Max Planck Institut für Chemie, Mainz, and Curtin University, Perth (R.T. Pidgeon, personal communication). Eleven TIMS analyses of CZ3 yielded $^{207}\text{Pb}^{/}/^{206}\text{Pb}$ ages in the range 562.2–567.5 Ma, averaging at 564 Ma (the published and recommended value). In contrast, the corresponding $^{206}\text{Pb}^{/}/^{238}\text{U}$ ages determined in these eleven analyses exhibited a slightly larger scatter in the range 553.0–564.0 Ma, with a mean of 561.5 Ma. This difference suggests that the U-Pb isotopic system of CZ3 might not be completely undisturbed.

References


GEOCHEMICAL BEHAVIOR OF RU, PD, TE IN MICRO-METALLIC AGGREGATES IN THE OKLO NATURAL REACTOR

Kikuchi, Makiko and Hidaka, Hiroshi

Department of Earth and Planetary Systems Science, Hiroshima University
Higashi-Hiroshima 739-8526, Japan (maki-ckw05@hiroshima-u.ac.jp)

The Oklo-Okelobond-Bangombï uranium deposits, the Republic of Gabon, known as natural fission reactors are useful natural analogues for radioactive waste disposal in geological media, because large-scale fission reactions occurred spontaneously 2.0 Ga ago. Our major concern is to understand the geochemical behavior of fission products generated in the reactors. Since Tc, Ru, Rh and Pd are highly produced by fission, their long-term behaviors are important for the radioactive waste disposal.

It has been known from the microscopic observation of artificial spent fuel that fissiogenic Ru, Rh and Pd formed aggregates [1]. Similar aggregates were also found in the Oklo reactors [2,3]. We found about forty metallic aggregates sized 10 to 40 μm in the Oklo reactor zone 13. EPMA analyses showed that the aggregates consist mainly of Ru, Rh, Pd, Te, Pb, U, Bi, As, Sb and S.

Figure 1 shows a BSE image of typical metallic aggregate measured in this study and figure 2 shows a correlation diagram between (Ru + Rh + Te + As + S) and (Pb + S) components of the aggregates. Interestingly, almost all of the data
points are plotted on a single line, suggesting that fissiogenic Ru, Rh, Te and Pd formed aggregates after mixing with microcrystal of galena.

Isotopic abundances of $^{96}$Ru, $^{98}$Ru, $^{99}$Ru, $^{100}$Ru, $^{101}$Ru, $^{102}$Ru and $^{104}$Ru in individual aggregates were determined by SHRIMP to estimate fission condition of the reactor, Tc. Our preliminary data show that the Ru in the aggregates are purely of fissiogenic origin, considering no detectable $^{96}$Ru and $^{98}$Ru isotopes. Furthermore, a significant variation of $^{99}$Ru isotopic abundance in individual aggregates suggests an occurrence of chemical fractionation between Ru and Tc during the formation of aggregates, because fissiogenic $^{99}$Ru once experienced long-lived radioactive precursor $^{99}$Tc ($t_{1/2} = 2.1 \times 10^5$ a).

Reference

The distribution and zoning patterns of monazite were investigated in the Barrovian-type metapelites of the Imjingang belt, Korea, to unravel: (1) the variation in metamorphic age as a function of elemental distributions; and (2) the growth mechanism. Monazite crystals occur exclusively in a kyanite-zone schist, together with accessory apatite, rutile, xenotime and zircon. Most monazite crystals are \(~10\ \mu m\) in diameter, but a few grains are larger (up to \(40\ \mu m\)), allowing us to obtain multiple isotopic spot analyses with an ion microprobe. Elemental distributions in monazite are heterogeneous, and are characterized by: (1) a rimward decrease in Y contents; and (2) Th zoning with high-Th spikes. Some monazite grains show an antithetic correlation between Y and Th, but most do not.

The U–Th–Pb ages of monazite were measured directly in thin section, using the SHRIMP-II. Common Pb contents were relatively high, so the ages were calculated from the lower concordia intercepts of the well-defined common Pb mixing lines. These ages from three kyanite-zone schists are 252 ± 5 Ma, 239 ± 7 Ma and 234 ± 9 Ma, respectively.

The Permian age is nearly identical to the age of peak metamorphism in the study area, defined by the zircon overgrowth in a paragneiss (253 ± 2 Ma; Cho et al. 2007). In contrast, the Triassic ages are likely to represent the exhumation stage. The range in the estimated ages may result from: (1) bulk-chemical control on the monazite stability; and (2) the passage of fluids during the exhumation. The \(^{208}\text{Pb}/^{232}\text{Th}\) ages differ between different monazite grains, but are identical within uncertainties in a single monazite crystal, regardless of their chemical zoning patterns. Thus, the Y zoning in monazite may result from: (1) an equilibrium growth in the course of decreasing temperatures; or (2) the transport control of Y incorporation into the growing crystal. The Th irregularity in monazite is probably inherited from a precursor allanite, which
is a major source of REE, Th and U for the monazite crystallization. These compositional and geochronological data suggest the disequilibrium growth of monazite in a single orogenic event.

Reference

ZIRCONOLOGY IN THE 21ST CENTURY

Kinny, Peter D.

The Institute for Geoscience Research, Curtin University, Perth, Australia
P. Kinny@curtin.edu.au

Zircon is a remarkable mineral, containing in measurable quantities no fewer than five radiogenic isotope decay schemes: $^{238}\text{U} - ^{206}\text{Pb}$, $^{235}\text{U} - ^{207}\text{Pb}$, $^{232}\text{Th} - ^{208}\text{Pb}$, $^{176}\text{Lu} - ^{176}\text{Hf}$ and $^{147}\text{Sm} - ^{143}\text{Nd}$. In the last few years, technology has caught up with scientific curiosity, enabling us to study every conceivable aspect of zircon chemistry and structure. Its crystalline/metamict state can be monitored by Raman spectroscopy. Its deformation state can be assessed by electron backscatter diffraction (EBSD). Its growth history can be revealed by cathodoluminescence (CL) imaging. Trace element, especially REE, and oxygen isotope ($\delta^{18}\text{O}$) compositions are indicators of host magmatic compositions or of co-precipitating metamorphic phases, while Ti content of zircon can be used as a geothermometer.

Robust, durable and reliable are words often used to describe zircon as a source of geochemical and geochronological data. Zircon’s widespread occurrence as an accessory mineral, its physical stability combined with slow rates of internal atomic diffusion leads to preservation of primary geochemical and isotopic signatures over a broad range of geological environments and to high closure temperatures for radiogenic Pb accumulation. The wealth of provenance information that can be obtained from zircon amplifies its value as a geochemical tracer because very often it is the “last mineral standing” after source rocks have been recycled by erosional, depositional, metamorphic and/or magmatic processes. This is exemplified by current interest in the >4.0 Ga Jack Hills meta-sedimentary zircons as unique time capsules from the Hadean Earth.

Modern studies of zircon typically involve a combination of isotopic, geochemical and imaging methods obtained using microbeam mass spectrometric (SIMS, LA-ICPMS, etc) and associated analytical/imaging techniques capable of within-grain analyses that can match in scale the often complex crystallization histories preserved within single zircon grains. In this talk I will present examples of recent applications that highlight the wealth and diversity of information that is uniquely obtainable from zircon.
Zircon grains from various granitoids of the Karkonosze Pluton (Western Sudetes, Poland) were dated by SHRIMP II. The pluton consists of an overlapping series of granitic intrusions, emplaced during the Paleozoic as a result of the collision between Gondwana and Laurasia. Previous authors constrained the age of the plutonism between 330 and 304Ma (for a review of geology and geochronology, see Ṣęk & Klomńska, 2007; Slaby & Martin, 2008). Previous attempts to date the pluton by SHRIMP analysis of zircon have produced scattered results. High U contents, common Pb contamination, corrosion and chemical alteration of magmatic zircon have had various effects on U and Th isotopic systems. Here, we present new chronological and chemical data that distinguish magmatic and metasomatic (hydrothermal) zircon production.

Zircon grains from six samples of different generations of granitoids were dated ($^{206}$Pb-corrected concordia ages, 95% confidence errors), in order of intrusion from field relationships: coarse-grained porphyritic granite MQKRK-M (308.7 ± 4.7Ma); medium-grained porphyritic granite MQKRK-H (313.0 ± 6.0Ma); early hybrid granodiorite MQKRK-F (314.5 ± 4.8Ma); composite dyke MQKRK-KA (308.7 ± 7.6Ma); and fine-grained equigranular granites ER1 (303.7 ± 6.6Ma) and ER2 (302.2 ± 6.4Ma).

Although zircon in all samples displays irregular internal zoning, many grains in the older samples (M, H and F) preserve magmatic characteristics (Fig. 1), with prismatic euhedral forms, oscillatory zoning, and U contents mostly below 3000ppm. Ages from samples H and F are consistent with intrusive relationships and the SHRIMP zircon dating of a c. 313Ma dyke by Awdankiewicz et al. (2007). Sample M is younger than expected, with some indications of metasomatic modification in analyzed grains. In strong contrast, all zircon grains from the younger samples (KA, ER1 and ER2) are externally euhedral, but exhibit internal textures
that indicate extreme modification of pre-existing magmatic zircon. Grains from KA and ER2 have convolute zoning and large, irregular inclusions of K-feldspar (Fig. 2) that suggest near-complete replacement of pre-existing magmatic zircon.

Textures in zircon from sample ER1, a scheelite + cassiterite-bearing granite, are more diverse, with euhedral grains that preserve (i) areas of unmodified high-U zircon, embayed by (ii) narrow alteration fronts of lower BSE zircon (Fig. 3); (iii) granular and porous intergrowths of zircon, thorite, K-feldspar, ?xenotime and unknown HREE-rich minerals, which typically replace the cores of zircon grains (Figs 3 & 4); and (iv) convolute zones with large “negative-space” inclusions similar to those seen in KA and ER2, which often surround type (iii) granular cores (Fig. 4). Type (ii) embayment textures are identical to those attributed to diffusion-reaction processes involving hydrothermal fluids, whereas type (iii) granular textures match those produced by coupled dissolution-reprecipitation (Geisler et al., 2007). The occasional presence of scheelite in type (iii) gran-
ular zircon indicates that metasomatism occurred with mineralization, through the interaction of the cooling granite with late-stage magmatic fluids and aqueous fluids derived from country rocks (SBaby & KozBowski, 2005). The transition from magmatic to metasomatic zircon had little effect on MREE to HREE and Y contents; in contrast, the disappearance of strong Ce anomalies and enrichment in LREEs, Ca and Ba suggest the action of reduced, LREE-bearing fluids. 204Pb-corrected 206Pb/238U ages on ER1 zircon are older and increasingly reverse discordant with increasing U and Th contents. Although U concentrations of <3600 ppm occur only on metasomatized (type (iii)) zircon, ages are surprisingly consistent and concordant, and we suggest that the c. 304 Ma ages from ER1 and ER2 indicate the timing of metasomatism and Sn-W mineralization, rather than magmatism. Although the magmatic age is less clear, it is unlikely to be more than 10 Ma earlier. Despite high U & Th contents, this period of time is insufficient for significant radiation damage to have accumulated; such damage is not a prerequisite to zircon modification by diffusion-reaction processes, as was suggested by Geisler et al. (2007).

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References


SHRIMP SOFTWARE UPDATE

Lanc, Peter

The Australian National University Research School of Earth Sciences Canberra
ACT 0200 Australia
peter.lanc@anu.edu.au http://shrimp.anu.edu.au

This talk will cover the SHRIMP related software development since the last SHRIMP Workshop in Perth.

The Automation has now been fully developed and is routinely operational on SHRIMP I, II, and RG. A new set-up screen has been implemented to facilitate operation. The reference point run mode is being used almost exclusively. The auto tune up for the automation has been made more flexible to accommodate different users with different requirements. A nine-point calibration for the map drive has been implemented.

Remote operation of the SHRIMP has a new faster live video, optimized bulk mass scan and QT1Y scan data delivery to the remote client. A simple, data-acquisition-only, version of the SHRIMP software for remote clients has been developed.

Multiple Collector Software has a new data acquisition format, new graphs showing permille values as well as measured ratios. MC Setup includes functionality previously located in the Mechanical Testing screen.

A number of new utilities make setup, tuning, and diagnostics easier. These include NIST610 Performance Check, Main Magnet Degauss, Peak Flatness, Primary and Secondary Continuous Scan.

The Meters Panel replaces the analogue meters and chart recorder. IVMS long term vacuum history graph is included as well.

The old TV has been replaced with LCD computer screen. This is a live image display with adjustable cross hair and image server built-in for the SHRIMP Automation. The horizontal flip TV function is no longer supported.

The SHRIMP Data Extractor (POXI) is a new data reduction software primarily developed for Multiple Collector data reduction. The software is designed to use the SHRIMP XML data files exclusively. Permille displays, mouse-click data point rejection, EISIE (Electron Induced Secondary Ion Emission) effect data correction are some of the POXI features.
Presently zircon is probably the most used and, say, popular mineral for U-Pb geochronology. Indeed, its robust enough to survive overprints and weathering, has low- to no initial Pb and occurs in wide varieties of rocks. Yet, dating practice demonstrate that the most used one isn’t an ideal. Partly zircon’s imperfection is induced by its sustainability, which causes presence of an older zircon as an inheritance in magmatic or metamorphic rocks. In worst cases inheritance hardly can be distinguished using optics, CL-imaging as well as chemical characteristics.

1. The pegmatitic gabbro case. The easy case of unobvious inheritance with a light hint of inhomogeneity in optic/CL/BSE images (Fig. 1). In the case presented, the outermost parts are enriched in inclusions (BSE/Reflected light) and somewhat CL-brighter, although these domains are scarce and inconspicuous. The dominating zircon type yielded slightly spread cluster with pooled 254 ± 1.1 Ma age (N = 7), which is inadmissible date, considering that the studied rock intruded Mid Triassic tuffaceous psammite. Extra 4 analyses of the outermost domains mentioned above gave pooled age of 235 ± 1.2 Ma. The domains analyzed are discrepant in age as well as U content and Th/U values, implying different growth environment. An extra attention helped to disclose this case.

2. Unaltered felsic volcanites, Germany (by courtesy of Prof. Dr Christoph Breitkreuz, Bergakademie, Freiberg). 27 to 30 U-Pb analyses have been done on
each rock sample. While a couple of zircons from entire population may be suspected as inherited by their appearance, the vast majority is pretty homogeneous in both morphology and CL-structure. Yet the results reveal bimodal age distribution extending over a 15 M.y. span (Fig. 2). Examination of analyses location within a zircon versus age gave no youthening outward, implying the case isn’t just a core-rim relation (which also comes from unaltered occurrence of the rocks). However, 15 M.y. is quite a long interval for a single volcanic pulse. The most possible interpretation would be a relatively long-lasting magmatic system, in which later portions of magma might capture zircons from similar earlier rocks. In such an instance inherited zircons hardly can be distinguished by morphology or chemistry. A possible way to reveal this could be in producing a large number of analyses with extra standards in order to minimize individual errors.

3. Non-metamorphosed diorite from Transbaikalia (by courtesy of Dr Ernst Hegner, the University of Mьnchen). A series of samples from polyphase intrusion have been dated. The majority of the zircons exhibit euhedral morphologies and simple fine concentric inner CL structure. The earlier main phases yielded indistinguishable within 2Г error limit age of 284 ± 3 (V-9, N = 10, MSWD = 0.67) and 283.7 ± 3.2 (V-21, N = 10, MSWD = 1.11), while the structurally latest diorite V-15, which crosscuts other rock types gave a pooled concordant age of 287 ± 3 (N = 10, MSWD = 0.04). Since all the three have been dated within a single analytical session an instrumental drift hardly may explain such a results, contradicting to field structural observations. The calculated dates include neither obvious outliers nor results from zircons with anhedral morphologies or cores.

Fig. 2. Age distribution for the volcanic suete
Examination of the V-15 sample data set using Probability Density option of the ISOPLOT revealed somewhat non-single mode age distribution. Screening off four older results the pooled age of 279.4 ± 3.7 (N = 6, MSWD = 0.06) has been obtained.

The three examples above surely not meant to dethrone zircon but given as a caveat: In a long-living magmatic system, when an old inherited zircon is recognizable by morphology and CL structure, a cryptic zircon contaminant may present. Being captured by younger portions of magma from earlier phases such a zircons hardly can be distinguished by shape, inner structure or chemistry.

A few measures are to be undertaken to avoid misdating: (I) Sampling of all the possible phases of a complex intrusion accompanied with thorough structural work; (II) Analysis of statistically reliable number of zircons per sample (two-three dozens) alongside with (III) Increasing number of standards per session in order to minimize error.

**Acknowledgements**: This work was partly done within frame of project supported by Rosnedra Agency and partly funded by German research foundations, which provided studies of Prof Breitkreuz and Dr Hegner.
Development of local U-Pb-Th isotope dating and its successful applying to oceanic crust zircon in last decade permitted to extend our knowledge about the formation of modern and Paleozoic oceans (John et al., 2004; Schwartz et al., 2005; Bea et al., 2001). We have studied zircon grains separated from the least of all altered oceanic gabbros of the modern Ashadze sulfide ore field which were dragged at 13°N MAR (Beltenev et al., 2005). All studied zircons may be divided into two crystal types: I Short to long prismatic weakly colored grains (10–100 µm) with dominating well preserved simple prismatic facets. CL images show typical magmatic planar or sectorial zoning; II Yellow-brownish (sometimes non-transparent) grains with ill-defined facets and edges. Grains are different in size but less than 150 µm. Zoning in CL is concentric, primary magmatic but overlapped by bright irregular stripes in the outer zones. Proportion of these zircon types varies significantly.

U-Pb isotope age of two zircon groups confirms its genetic difference: group I ages are not older 1 Ma (the best value 861 ± 29 Ky), group II is characterized by pre-Mesozoic ages. Majority of dated grains have the ages of 2700 ± 20 and 1750 ± 12 Ma. Geochemical features of two revealed zircon groups are also very different. Group I has U content of 450 ÷ 850, rarely up to 1800 ppm and Th/U 0.7 ÷ 2.95, whereas group II U<350 ppm and Th/U is 0.4 ÷ 0.9. Zircon II demonstrates enriched REE patterns with weakly pronounced Ce peak: [Ce/Ce]* 1 ÷ 12 (group I 30 ÷ 90) and weak negative Eu anomaly: [Eu/Eu]* 0.1 ÷ 0.07 (group I <<0.1); LREE distribution has flat character, while zircon I shows sharply fractionated LREE distribution ([Sm/La]n 1 ÷ 150 and 100 ÷ 750, correspondingly), but the degree of HREE fractionation for zircon of both groups is similar: [Lu/Gd]n 2 ÷ 30. Young zircon is characterized by higher U/Yb>>1.0 as well, but on diagrams Y vs U/Yb and Hf vs U/Yb (Grimes et al., 2007) all studied zircons are out of the oceanic crust field due to their high U. Temperature of zircon crystallization by Ti-in thermometer (Watson, Harrison, 2005) corresponds to 700°C for zircon I and 800–850 °C for zircon II. Measured 176Hf/177Hf isotope ratio increases from old to young zircons: from 0.281115 to 0.283397, which corresponds to
variation from +0.2 till +22.1 in μ value. Such Hf isotope composition implying origin of studied zircon from differently depleted source. Whereas for the young and 2700 Ma-old zircon this source may be directly compared with the depleted mantle, but for the 1750 Ma-old zircon this source was more enriched (μ= +0.2 ÷ +3.4).

The presented data suggest the participation of Precambrian substance in formation of basic-ultrabasic rocks founded within the MAR. However, the presence of two genetically different groups, especially young magmatic grains, which origin is straightly connected to the basalt flows formation, may indicate long-lasted evolution of the MAR gabbroids. Thus, the scenario that the studied gabbro-peridotites are older than Mesozoic opening of the Atlantic Ocean should not be excluded.
SHRIMP REMOTE CONTROL TECHNIQUE

Liu Dun-yi\textsuperscript{1}, Xiong Xing-chuang\textsuperscript{2}, Fan Run-long\textsuperscript{1}, Zhang Yu-hai\textsuperscript{1}, Huo Zheng-dan\textsuperscript{3}, Feng Jin-song\textsuperscript{3}, Wang Chen\textsuperscript{1}

\textsuperscript{1} Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China
\textsuperscript{2} National Research Center of Certified Reference Materials, Beijing 100013, China;
\textsuperscript{3} School of Electronic Science & Engineering, Jilin University, Changchun Jilin 130026, China

SHRIMP is a typical large scientific instrument based on computer control. Face to computer base scientific instruments, to realize remote control should have two functions as following: 1. it may operate SI via controlling computer at real time; 2. it may transfer the sample images to control terminal as quick as possible. The techniques based on remote measuring and controlling and image rapid transmission are effective solutions to the two issues mentioned above.

1. Software Measuring & Controlling

Software Measuring & Controlling technique is the key technique to implement SI remote operation based on software measuring & controlling. It makes the remote operation neither needs to interpret the source code of the operating software of SI, nor restricted by patent protection. Moreover, it is secure and reliable, needs less net transmission data, so that it is an effective technique to implement SI remote control based on computer operation.

User visible information in SI software operation is divided into static information and dynamic information. Static information refers to the invariable user visible information appears during the operation of the SI software, and dynamic information is the dynamic changeable user visible information caused by different factors during operation of SI software.

Denotation of static information of the software can be realized via programming of software interface. The user interface is designed as same as the SI software interface at server terminal, which makes remote operation like a simulation of local operation.

Remote Measuring & Controlling technique is adopted to obtain the dynamic information in software. The dynamic information of SI operation is transmitted to the remote users. Meanwhile, the orders of the users are transmitted to SI remotely, as operating SI software locally. Remote Measuring & Controlling technique may be subdivided into remote measuring technique and remote control technique.
1.1. Remote measuring technique

The obtained dynamic data needed during SI software operation can be subdivided into four types according to their characteristics: visible text data, visible image data, incomplete visible data and complete invisible data. To obtain these data should adopt techniques such as getting words from screen, capturing images partly, sharing clipboard and transmitting files.

1.2. Remote control technique

By using mouse and keyboard, the user operates SI software locally, so that remote control technique may be used for remote operating SI software, i.e. simulating keyboard and mouse operation on SI computer.

The key for simulating the actions of keyboard and mouse at server is judging the input aimed box. For example of keyboard simulation, when user’s terminal is inputting message to a box, a data package is sent to server’s terminal, which contains the inputted message, as well as a message digit for the ID numbers of the box. To numbering all boxes of SI software at server, each number should correspond to the message digit of this box’s ID number, it could confirm keyboard inputting aimed box, set aim box into active box by transferring windows user interface function “set foreground window”, then finish simulating keyboard action by transferring keybd- event.

2. Image rapid transmission

Firstly, it needs to solve data volume in net image transmission; transmitting time of each image should not be too long otherwise the experiment cannot be performed. Secondly, in coordinating experiments with multiple participators, net speed may have big difference between the key scientist and other coordinators in different locations, so that the synchronization of image transmission also needs to be solved. The current matured technology JPEG image compressing calculation method which has a high compression ratio is adopted here and a pyramidal transmission model is also set up and put forward. The model compresses original image first, then forms standard images with each quality level based on considering scale and vision effect of images, then divides the users into different levels according to their respective net speed, and each speed level corresponds to the different quality images. High speed users could get high quality image with big volume of data, whereas low speed users get lower quality image. It makes image obtained time near equal for different level users and solves asynchronous problem of image caused by difference or instability of net speed.

The successful application of Remote Software Measuring & Controlling technique and image rapid transmission technique in SHRIMP remote operation provides scientists seemly working at laboratory in person in anywhere of the world, conducting experiments via net control SHRIMP has proven these techniques might implement effective measuring and controlling SI software based on Windows and make operators could operate SI software remotely, then remote operate SI. It has set up the methodology for remote control and sharing of other large scientific instruments.
GEOCHEMISTRY AND UNUSUAL HAFNIUM ISOTOPIC SYSTEMATICS OF THE ZIRCONS FROM EARLY PRECAMBRIAN CARBONACEOUS ROCKS OF THE OKHOTSK TERRANE (N.E. RUSSIA)

Centre of Isotopic Research VSEGEI, St. Petersburg, Russia.
Kirill_Lokhov@vsegei.ru

The Okhotsk Precambrian terrane is situated in the NE of Russia (Fig.1) and contains the oldest metamorphic complexes with the age near 3.7 Ga. [1]. Among the rocks of the terrane there are some high carbonaceous rocks, known as calciphyre consisting of diopside, olivine, phlogopite, garnet along with diopside-bearing marbles. They were traditionally interpreted as an ancient metamorphosed carbonaceous sediments [2]. We investigated geochemistry and isotopic systematics of carbon and oxygen in these rocks and it was found that the values $\delta^{13}C$ and $\delta^{18}O$ in calcite are strongly correlated and varying from typical mantle ones $-6 \, \%_o$ and $+5 \, \%_o$ correspondingly, till $+6 \, \%_o$ and $+12 \, \%_o$. This effect could be caused by isotopic fractionation in the system carbonate $- CO_2$ -fluid phase, implying the rocks are not sedimentary, but of endogenous in origin. The rocks differ from carbonatite by depleted REE, Sr and Ba and this can additionally confirm their formation not from carbonatite melt but in presence of abundant fluid phase [3].

Microscopic observations have shown that the rocks contain zircons, and U-Pb SHRIMP-II dating of them has been carried out. Optical and cathodoluminescence study of the zircons revealed that they have heterogeneous structure with “blocky” or “coarse stripped” zoning. In
some cases light cores with fine rhythmic stripped zoning typical for metamorphic or igneous rocks were found in such crystals (Fig. 2). The studied zircons are sub-concordant, except of some analyses of grains (5.1, 10.1, 9.1, 8.1 and 4.1), and provide estimation of the calciphyre formation age at 1898 ± 29 Ma, which is contrasting younger then the host Palaeoarchaean metamorphic rocks.

If these zircons were formed in high – CO₂ fluid environment, they must have specific geochemical parameters. At first, all of them demonstrate relatively low Th/U < 0.4. The second - they could be enriched in LREE and have “hydrothermal” – like REE distribution patterns. REE also were analyzed by the SHRIMP-II and the results are shown on Fig.3. For the comparison our zircon data from rocks of different type and age in the Okhotsk terrane are plotted [4], as well as the data for zircons from graphite metasomatits of the Lapland granulite complex (Kola peninsula, NW Russia) [5]. Calciphyre zircons demonstrate REE distribution patterns clearly different from that of zircons from metamorphic rocks, and are characterized by enrichment in LREE relative to HREE with suppressed Ce and Eu anomalies (Fig.3).

Important peculiarity of calciphyre zircons is relative depletion in all REE as well as clear and contrast variability in REE distribution patterns between different grains. The crystals enriched in REE and with flat (“hydrothermal”-type) distribution patterns are discordant (points 10.1 and 5.1), whereas depleted especially by LREE are concordant ones (points 6.1 and 10.2).

Using different minerals from calciphyre we obtained mineral isochrones: Sm-Nd 1939 ± 18 Ma., e_{Nd}(T) = −16.6, and Rb-Sr 1678 ± 8 Ma, e_{Sr}(T) = +100. These data exhibit that the calciphyre forming process endured for near 150 M.y., and
revealed a clear contradiction: from Sr-Nd isotopic data their source was clear crustal, but unfractionated $\delta^{13}$C and $\delta^{18}$O of early precipitated carbonates are of typical mantle derived carbonatite values.

To solve this contradiction in an attempt to find mantle isotopic signal we studied Hf isotopic compositions in the same zircon sites, studied by SHRIMP-II with LA-MCICPMS complex (ThermoFinnigan Neptune coupled with Excimer 193 nm UV DUV-193 LA system)

The idea was based on known coherent behavior so Sm-Nd and Lu-Hf in mantle derived rocks, in general $e_{\text{Hf}}(T) = 1.4e_{\text{Nd}}(T)$, the “terrestrial line” in $e_{\text{Hf}}$ - $e_{\text{Nd}}$ plot [6]. In our case confirmation of mantle component presence can be $\{e_{\text{Hf}}(T)\}_{\text{zircon}} > 1.4\{e_{\text{Nd}}(T)\}_{\text{rock}}$. The data obtained were unexpected: except of the grains with crustal component with $e_{\text{Hf}}(T) = -21.7$, in some crystals it was found $e_{\text{Hf}}(T) = +80–+87$! The data are plotted on the Fig.4 (black circles and white triangles). Such a radiogenic isotopic composition of hafnium was found in zircons for the first time.

These high $e_{\text{Hf}}(T)$ values can correspond to the deep source with $^{176}\text{Lu}/^{177}\text{Hf}$ near 0.1, if it was isolated from uniform chondrite reservoir CHUR earlier than 4.4 B.y.. Later isolation time from the mantle reservoir require higher value of the ratio. For example, addition of REE-rich crustal material in the depleted mantle DM due to subduction in early Archaean time can produce hypothetic mantle source with $^{176}\text{Lu}/^{177}\text{Hf}$ near 0.2 (Fig. 4).

Minimal estimated value of $^{176}\text{Lu}/^{177}\text{Hf}$ ratio in deep source of the calciphyre is more than three times higher than in CHUR or even DM. Close values of the ratio is known only for the source of some Hadean zircons from Jack Hills, it is suggested that this Hadean reservoir was formed at early stage of the Earth’s differentiation and later it disappeared due to protocrust recycling and convection in
the DM [7]. Anomalies of initial hafnium ratio, due to which the data points are laying above the $e_{\text{Hf}} - e_{\text{Nd}}$ correlation plot line, a case $e_{\text{Hf}}(T) > 1.4e_{\text{Nd}}(T)$, which is a consequence of high values $^{176}\text{Lu}/^{177}\text{Hf} > (^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}}$ (for example in some of Hawaiian peridotite xenoliths [8]), can be interpreted as a result of subduction into DM of crustal material with high REE concentration, for example pelagic sediments – red clays.

The hypothesis of subduction of pelagic sediments into DM is suggesting existence at Hadean time a number of conditions: (1) subduction-type tectonic regime, (2) existence of the ocean with modern-time sedimentation and (3) differentiated continental crust with the regime of its weathering close to present.

All of the mentioned conclusions are questionable for Early Precambrian, so we suggest that strong fractionation of Hf and Lu could occur at the late stage of the Earth’s accretion due to impact – induced heat affect to proto-matter of the planet. The primary Earth’s matter was, as it supposed, analogous to the CI chondrite, which are composed of hydrous minerals, carbonates and reduced carbon species, which are main carriers of REE, whereas Hf is concentrated dominantly in high-temperature condensates. Relatively low-temperature impact process can cause thermal decomposition of the REE carriers, and consequently the fluids with high Lu/Hf can be generated producing “Enriched Hadean Impact Differentiates” (EHID) and complimentary residues with high-temperature condensates with low Lu/Hf “Depleted Hadean Impact Differentiate” (DHID) (Fig. 4) [9]. These heterogeneities in Hf, which could be originated at late stages of the Earth’s accretion in Early Hadean, probably were fixed in Hadean zircons from

![Fig. 4](image-url)
Jack Hills (JH) [7], and probably the same origin have deep source of the studied calciphyre. According to given interpretation the matter of calciphyre can contain a component of EHID matter which was preserved in the subcontinental lithospheric mantle (SCLM) under Early Precambrian Okhotsk terrane.

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References

TI-IN THERMOMETER FOR ZIRCONS FROM VARIOUS ROCK TYPES

Paderin, Ilya ¹, Levsky, L.² and Matukov, D. ¹

¹ Centre of Isotopic Research, VSEGEI, St. Petersburg, Russia (paderin@vsegei.ru)
² Institute of Precambrian Geology and Geochronology RAS, St. Petersburg, Russia

Ability of the new “titanium thermometer” to estimate zircon crystallization temperatures recently was shown by E. B. Watson and T. M. Harrison [Watson and Harrison, 2005]. We, alongside with other researchers argued theoretical and practical application of this thermometer for determination of crystallization temperature of zircon in rutile-saturated rocks. In general, the procedure of temperature determination aims measurement of Ti concentration in zircon.

The target of the present work was to adopt the procedure of local Ti content determination in zircons by the SHRIMP-II ion microprobe at the Centre of Isotopic Research (CIR) VSEGEI for further estimation of temperatures of their crystallization. For this, a representative number of zircons from the magmatic and metamorphic rocks of different geological and geodynamical situations was studied, namely:

– charnockite high temperature gneisses from Enderby Land, Eastern Antarctica [Harley and Motoyoshi, 2000];
– massive enderbites from Enderby Land, Eastern Antarctica [Sheraton et al., 1987];
– gabbro – troctolites from Mid–Atlantic Ridge (13°N).

Several homogeneous 91500 standard zircon grains were measured as reference material. All analytical work was carried out in CIR VSEGEI by means SHRIMP-II. The intensity of primary beam was from 4.9 to 5.2 nA. Mass stations 46SiO, 49Ti and 91Zr were measured during 4 cycles with integration time of 7, 20 and 2 seconds respectively. The energy filtering technique was used to avoid isobaric overlapping. Glass standard NIST 610 has also been analyzed for Ti content determination.

Intensity of secondary emission from NIST glass and standard zircon 91500 was comparable, but some systematic difference was found which is attributed to the matrix effect. Nevertheless this effect is weekly affected the result of temperature calculation and could be ignored. For comparison, results obtained with reference to both NIST 610 glass and 91500 zircon as a standard are listed in Table 1. These data clearly show that the difference is not essential and all further calcula-
Ttotal 13 grains from three “unknown” samples were analyzed. Earlier the metamorphic rocks from the Enderby Land (E. Antarctica) produced a lot of contradictory data. We attempted to solve some of problems using Ti-in zircon thermometer as a powerful tool. Local SIMS U-Th-Pb dating for two samples: D-22a – charnockite high-temperature gneisses and D-36 – massive enderbites revealed no differences in the time of zircon formation, but they have discrepant petrography and genesis. The obtained results evidence different zircon crystallization temperatures (Table 2, Fig. 1). In geological sense this means different thermal regime for two closely located geological objects, which attained to different metamorphic stage or in progressive and regressive phase of single metamorphism.

One more zircon sample studied during this analytical session was represented by large prismatic grains with sectorial and planar CL zoning from gabbro – troctolite (MAR, 1514-1). U-Th-Pb SHRIMP age for these zircons is $0.842 \pm 0.033$ Ma [Belyatsky et al., 2008]. Our estimation of Ti-in temperature is about $700 ^\circ$C for this zircon (Table 3, Fig. 2), which may prove crystallization of these grains under influence of upwelling basaltic melts onto host gabbroid [Belyatsky et al., 2008].

The obtained results showed great advantage of the Ti-in zircon thermometer for understanding temperature temporal evolution for different rocks and possi-

<table>
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Table 1

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Table 2

Fig. 1
bility of effective realization of this method on ion microprobe SHRIMP-II instrument at CIR VSEGEI.

References


Watson E. B., Harrison T. M. (2005), Zircon Thermometer Reveals Minimum Malt-
ing Conditions // SCIENCE, Vol. 308.
ISOTOPIC (He, Ar, S) AND AGE (U/PB – SHRIMP) CHARACTERISTICS OF ORES AND ROCKS OF UNIQUE Cu-Ni-PGE DEPOSITS IN NORILSK AREA, N EAST SIBERIA, RUSSIA

Centre of Isotopic Research, VSEGEI, Saint-Petersburg, Russia
Edward_Prasolov@vsegei.ru

The correlation between He and Ar isotope composition and Cu-Ni-PGE – ore richness in mafic intrusion of the Taimyr-Norilsk area has been revealed. We studied noble gases in gas-liquid microinclusions of sulphide ores and rocks, and found that variations of the composition correlates with a noble gases contribution from the three different global reservoirs – upper mantle, earth crust, and atmosphere – in (relict) mineral forming fluids.

Helium isotope ratio (3He/4He) allows to sort the mantle and crustal (radiogenic) constituents. The 40Ar/36Ar ratio permits to determine the atmospheric argon proportion and subsequently the degree of subsurface waters contribution in mineral formation.

In this report the new data on He and Ar isotopes in fluid inclusions from 15 layered mafic intrusions of the Taimyr-Norilsk area are presented. All studied objects were divided into three groups: economic ore-bearing with rich massive ores, ore-bearing with impregnated ores (medium) and barren.

Gases were separated from inclusions at high vacuum conditions by crushing of 2-grams whole-rock samples. The cleaning and isotopic analysis of noble gases was carried out on the mass-spectrometer Micromass 5400. The estimation of mantle helium input was done on basis of the 3He/4He ratio in the Earth’s mantle and crust, 1.2 × 10^{-5} and 2 × 10^{-8} correspondingly.

The difference of He isotopic composition between ore-bearing intrusions (rich and medium) and barren ones is (0.05–0.5) × 10^{-6} and (0.5–2.6) × 10^{-6}, respectively. These results corresponds to the share of mantle helium (0.4–4) % and (4–22) %.

Samples with various ore yield (rich vs. medium) were found to have different argon isotope composition. The share of the atmospheric argon in the medium-rich ore is much lower, about 75 %, whereas that in the ore-rich intrusions is everywhere more than 85 %. In barren objects the portion of the atmospheric argon
is also low. According to these results, each of the three groups of the studied intrusions has its definite position in the $^3\text{He}/^4\text{He}$ vs. $^{40}\text{Ar}/^{36}\text{Ar}$ diagram.

Thus, it seems that the data on the He and Ar isotopic composition allow to discriminate intrusions of the Taimyr-Norilsk area by ore productivity. The above-mentioned isotopic differences of the most of the ore-bearing objects are obviously associated with the peculiarities of the fluids mode formation. The most intensive ore accumulation occurred under the minor direct input of mantle fluids and at the active circulation of infiltration and meteoric waters from the host rocks.

Hence, it is very important to know, are the processes formed intrusions with different grade of ore production spread in time or not. Besides it, necessity of age information is redoubled by the fact that there are two exceptions out of regularity, mentioned above. Nizhny Talnakh and Nizhny Norilsk intrusions, considered as barren, are plotted at “middle” zone and near “rich” one in the He-Ar diagram. But these intrusions underlie the main (and rich) ones - Talnakh, Kharaelakh, Norilsk-1 (“nizhny” means “lower” in Russian). It is not unlikely that these two groups of intrusions (main and lower) are the derivatives of single and common magma-fluid source. So, the data, which confirms crystallization synchronism of these objects, are very valuable.

$\text{U/Pb zircon age determination (SHRIMP-II) from all the five intrusions demonstrates that the age of upper and lower objects is indistinguishable (table 1).}$ This result allows to assume that two groups of intrusions are really derivates of a single magmatogene system. The time gap of 20–25 Ma between crystallization

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<td>5</td>
<td>247 ± 6</td>
<td>230</td>
<td>1900</td>
<td></td>
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<tr>
<td>main</td>
<td>Talnakh</td>
<td>2.7</td>
<td>94</td>
<td>11</td>
<td>256 ± 1</td>
<td>221–231</td>
<td>zircons not found</td>
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<tr>
<td>main</td>
<td>Kharaelakh</td>
<td>1.3</td>
<td>88</td>
<td>12.5</td>
<td>265 ± 11</td>
<td>230–235</td>
<td>290, 300, 347 ± 16</td>
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<tr>
<td>lower</td>
<td>N.-Talnakh</td>
<td>0.6</td>
<td>84</td>
<td>7</td>
<td>254 ± 4</td>
<td>220–230</td>
<td>270, 300</td>
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<tr>
<td>granodiorite formation Bolgotoch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$T = 229 ± 0.4$ [Kamo et al., 2003]</td>
<td></td>
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</table>

$m$ - mantle helium share (%), $m = 100[(^{3}\text{He}/^{4}\text{He})_{\text{sample}} - (^{3}\text{He}/^{4}\text{He})_{\text{crust}}]/(^{3}\text{He}/^{4}\text{He})_{\text{mantle}}$

assumed value: $(^{3}\text{He}/^{4}\text{He})_{\text{mantle}} = 1.2 \times 10^{-5}$

$a$ - atmospheric argon share (%), $a = 100(^{40}\text{Ar}/^{36}\text{Ar})_{\text{atmosphere}}/(^{40}\text{Ar}/^{36}\text{Ar})_{\text{sample}}$

$r$ - radiogenic argon share (%), $r = 100 - a$

$T_1$ - age of magmatic crystallization

$T_2$ - age of metasomatic event(s), zircon rims and whole grains

$T_3$ - age of inherited zircon component
(250 Ma) and peak of metasomatic (230 Ma) events could be characterized by intensive fluid circulation.

As there is higher volume of the deep crustal component in lower ones (table 1), they represent the first stage of magmatic crystallization. In particular, intrusion of the hot melt caused circulation of fluids from wall sedimentary rocks. This process became especially intensive at the second stage of crystallization (after a brief hiatus or without it) and then it probably initiated ore forming event.

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REE PATTERNS IN ZIRCONS – AN IMPORTANT INSTRUMENT FOR REVEALING HISTORY OF ARCHEAN POLYMETAMORPHIC ROCKS

Presnyakov, S., Berezhnaya, N., Sergeev, S.

Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI), Sredny Prospect, 74, 197106, St Petersburg, Russia
Sergey_Presnyakov@vsegei.ru

U-Pb local SHRIMP dating of zircons, accompanied with study of REE in the same zircon domains, is an important instrument for revealing history of Archean polymetamorphic rocks.

The presented REE study has been performed on two geological objects:
I. The Tonalite-Trondjemite Gneiss of 2nd and 4th units of the Kola Superdeep Borehole (KSB);
II. The oldest (ca 3.36 Ga) gneisses and granite-gneisses of the Okhotsk Terrane NE Russia.

I. Recent study (Chupin et al., 2006) of presumably pristine zircons from tonalite-tronjemite gneiss of 8th unit (TTG-8) of the KSB showed abundant glass and CO₂ inclusions in central parts of crystals and high-K mineral silicate components in zircon’s rims. This observation allowed to suggest volcanic protolith for TTG-8 with prolonged history of the crystallization (U-Pb age for zircon central parts is 2854 ± 9 Ma and 2812 ± 8 Ma for edges). The youngest zircon from TTG-8 indicate the main metamorphic event at 2675 ± 13 Ma ago.

Our current study of zircons from upper layered TTG-2 and TTG-4 of the KSB, which are generally similar in composition to TTG-8 zircons, demonstrate that their central parts and rims are quite different in terms of U-Pb age and REE patterns. This contradicts the idea of >30-My magmatic evolution of the TTG protoliths. The central parts (cores) of TTG-2 zircons as old as 2820 ± 12 Ma, TTG-4 – 2804 ± 15 Ma while altered cores (TTG-4) – 2776 ± 12 Ma. Very thin rims of the same zircon grains gave 2780 ± 54 (TTG-2) and 2697 ± 41 (TTG-4) Ma.

REE patterns let us to interpret TTG-2 and TTG-4 zircon core material as of clearly magmatic crustal origin whereas both groups of rims demonstrate their HPT-metamorphic nature. On the REE pattern graph (Fig. 1), all the core and rim data form two separate bunches, where rims are right below.

TTG-2 Cores (Magmatic): 2820 ± 12 Ma; (Sm/La)n = 202–455; (Lu/Sm)n = 12–133; (Ce/Ce*) = 17–94; (Yb/Gd)n = 3.6–28.5; (Yb/Sm)n = 9.5–109; (Lu/Gd)n = 4–35;
TTG-2 Rims (HPT-metamorphic): 2780 ± 54 Ma; (Sm/La)n = 24–99; (Lu/Sm)n = 246–400; (Ce/Ce*) = 24–106; (Yb/Gd)n = 46–70; (Yb/Sm)n = 200–280; (Lu/Gd)n = 60–98;

TTG-4 Cores (Magmatic): 2804 ± 15 Ma; altered cores: 2776 ± 25 Ma; (Sm/La)n = 78–298; (Lu/Sm)n = 70–178; (Ce/Ce*) = 30–90; (Yb/Gd)n = 16–28; (Yb/Sm)n = 48–128; (Lu/Gd)n = 24–38;

TTG-4 Rims (HPT-metamorphic): 2697 ± 41 Ma; (Sm/La)n = 48–131; (Lu/Sm)n = 185–201; (Ce/Ce*) = 76–134; (Yb/Gd)n = 20–38; (Yb/Sm)n = 132–143; (Lu/Gd)n = 31–49;

Thus, we may conclude that the 2820–2800 Ma old magmatic rocks were protoliths of TTG-2, TTG-4 and at least partially TTG-8 of the KSB. These protoliths were survived, most probably, two HPT-metamorphic events (ca 2780 and ca 2660–2700 Ma ago), that more intensively affected the lower levels of the KSB TTG sequence.

II. To establish correlation between gneisses and granite-gneisses from the Okhotsk Terrane REE distribution in zircons had been studied.

1. Gneissose granite zircons displays two types of REE distribution: 1) for magmatic cores (3.3Ga) (Lu/n/Sm/n = 27–117, Eu/Eu* = 0.1) and 2) for metamorphic rims (2.7 Ga) (Lu/n/Sm/n = 165–428, Eu/Eu* = 0.2–0.5) (Fig. 2).

2. Cores in zircons from gneisses (3.28 Ga) show REE pattern (Lu/n/Sm/n = 45–166, Eu/Eu* = 0.1–0.2) similar to that for cores of the gneissose granite zircons (Fig. 3).

Fig. 1

Cores of zircons from the gneisses and gneissose granites show similar REE patterns that indicate their origin from common protoliths. REE distribution in the cores is similar to that of diorite magmatic zircons. (Hoskin, 2000) Lu/n/Sm/n and Eu/Eu* ratios of the rims corresponds to the zircons of garnet-free leucosome (Rubatto, 2002).
Acknowledgements: The study has been partly supported by the Rosnedra Federal Agency.

References

Chupin V.P. et al., (2006), *Doklady AN*, **406** N4, 533–537
Zircon is the favorable and the most widely used mineral for the U–Pb dating of different kind of rocks and geological events. But in some silica-undersaturated rock types, such as ultramafic and alkaline rocks, baddeleyite (ZrO₂) is more common zirconium mineral and in many cases more preferable than zircon for U-Pb isotope dating [Krogh et al., 1987]. The first ion microprobe dating of baddeleyite from lunar basalts [Anderson and Hinthorne, 1972] was successful: baddeleyite has yielded ²⁰⁷Pb/²⁰⁶Pb age of 4.1 Ga. However, U-Th-Pb studies of baddeleyite by the SHRIMP (procedure described by Wingate et al. 1998) hampered by discovery of orientation effect in baddeleyite, which resulted of measured ²⁰⁶Pb/²³⁸U ratios well beyond analytical precision [Wingate and Compston, 2000].

Our first experience baddeleyite dating of the Proterozoic Paleozoic carbonatite complexes by the SHRIMP II (Centre of Isotopic Research of VSEGEI, St.-Petersburg) ed good fit within age with zircon age for the same massifs. the continuous analytical session 87 analyses were done from randomly oriented relative to the mount surface baddeleyite crystals. During this session 30 measurements of Phalaborwa baddeleyite standard with ²⁰⁶Pb/²³⁸U ratio of 0.37652, corresponding to an age of 2060 Ma, were performed. In the standard U concentration ranges from 40 to 820 ppm (av. 222 ppm), with Th/U varying from 0.006 to 0.026. Because no suitably homogeneous concentration-standard of baddeleyite was available, only approximate concentrations were reported for ²³⁸U and ²³²Th, determined against SL13 standard zircon (238 ppm of U) as a reference. The proportion of common to total ²⁰⁶Pb was less than 0.7 % in the studied baddeleyites, so uncertainty due to common Pb correction is insignificant. Although the ²⁰⁸Pb-correction method is supposed a more reliable for low-Th/U minerals, such as baddeleyite, we used a measured ²⁰⁴Pb for common lead correction. All 30 analyses of standard give well-fitted calibration line with a slope of 2.13. Relative to the assigned mean age of 2060 Ma, the obtained ²⁰⁶Pb/²³⁸U ages for Phalaborwa standard baddeleyite display range from 1622 to 2411 Ma with an error in standard
calibration — 3.07% (2s). After rejection of 4 analyses from calculation this estimation becomes only 1.87% corresponding to the age dispersion from 1901 to 2225 Ma. We studied three samples of “unknown” baddeleyite from carbonatite massifs — PBR-3 (Phalaborwa complex, S. Africa), TO-154-210 (Tishkozero Proterozoic complex, N. Karelia) and K-1b (Kovdor Paleozoic complex, N. Karelia).

Baddeleyite PBR-3 from foscorite (Phalaborwa southbody) is represented by long-prismatic idiomorphic grains that differ in morphology from Phalaborwa standard baddeleyite. U concentrations for these grains range from 43 to 364 (av. 117) ppm, all Th/U ratios are less than 0.05, $^{206}\text{Pb}/^{238}\text{U}$ ages vary wider than $^{207}\text{Pb}/^{206}\text{Pb}$ (Fig. 1a), as expected. But if a few outlying results are excluded, the acceptable result can be obtained: the concordant age is 2052 ± 10 Ma (Fig. 1a), whereas a pooled mean $^{207}\text{Pb}/^{206}\text{Pb}$ age is 2054.3 ± 7.3 Ma (errors here and below are quoted 2s).

Lower uranium baddeleyite sample TO-154-210 (from 11 to 275, av. 91 ppm) was analyzed earlier by single grain TIMS and gave the age of 1996 ± 0.8 Ma. Our 20 U-Pb SHRIMP analytical presented on the Fig. 2b demonstrate an excellent agreement between $^{207}\text{Pb}/^{206}\text{Pb}$ ratios measured by and TIMS. The concordant age estimation corresponds to 1999 ± 12 Ma (Fig. 1b), the concordant age calculated via $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ ratios is 1998 ± 12 Ma, whereas a mean of all $^{207}\text{Pb}/^{206}\text{Pb}$ ages gives 1994.5 ± 9.7 Ma.

We also attempt to date baddeleyite sample from the
Kovdor Paleozoic complex. Its pages are 380±4 Ma for baddeleyite [Bayanova, 2006]; 378.54 ± 0.23 Ma for baddeleyite and 377.52 ± 0.94 Ma for zircon [Amelin and Zaitsev, 2002]. Although a precision of $^{207}\text{Pb} / ^{206}\text{Pb}$ age estimations for samples decreases significantly, the rocks dated precisely by baddeleyite is rich in uranium and statistical enough of analyses performed. In our case, only 15 analyses with average uranium content of 41 ppm is needed to estimate the age of baddeleyite with appropriate uncertainty (Fig. 2). Moreover, concordant age of 370 ± 11 Ma (MSWD = 2.5, probability of concordance is 0.12) can be obtained after correction to common lead and with a few analyses are rejected.

**Fig. 2.** U–Pb plot (measured ratios, uncorrected for common lead) and CL images of typical grains dated by SHRIMP (spot size is about 25 mm) for sample K-1b

This result is promising for future successful application of this technique for precise dating other Phanerozoic alkaline ultrabasic complexes.

**References**


MULTI-COLLECTOR SHRIMP IIE OF BRAZIL – FIRST RESULTS

Sato, Kei, Basei, Miguel A. S., Cordani, Umberto G., Tassinari, Colombo C. G., Siga Jr, Oswaldo

Instituto de Geociencias da Universidade de Sao Paulo, Rua do Lago 562, Cidade Universitaria, Sao Paulo, Brazil.CEP 05508-080 – e-mail:keisato@usp.br

GENERAL FEATURES: The SHRIMP IIe (fig. 1) is the developed version of SHRIMP II. The new version is enhanced by: a) advanced electronics coupled by fibre-optic control system; b) magnet control system for exceedingly stable operation at high and low fields; c) software, for ease of user operation, automa-

Fig. 1. BRAZIL MULTI-COLLECTOR SHRIMP IIE. General view
tion (using LabVIEW program and IBM-PC computer) and remote operation; d) analysis of light isotopes, with a sophisticated multicollector.

FIRST RESULTS FROM BRAZIL MULTI-COLLECTOR SHRIMP IIe

The first results with the SHRIMP IIe of Brazil were obtained on two international standards (FC1 and SL13) and one natural sample 2B BV 40A (KS11) from Santa Catarina – Luis Alves craton, Brazil. The U and Pb isotopic measurements were carried out during the acceptance test and performed at the Australian Scientific Instrument factory – Canberra.

FC1 and SL3 standard data values are plotted on a concordia diagram (fig. 2). The points are positioned on or very near to the Concordia curve with a median age of around 1100 ± 8 Ma (fig. 3). The ages determined for the zircons of the Duluth FC1 standard, analyzed on different days, were highly reproducible.

The zircons (sample 2B-BV-40, quartzite) from the Luis Alves craton present two different typologies (transmitted light - TL), one group are clear and transparent crystals whereas the other group are dark / brown zircons. The cathodelu-

![Concordia diagram: FC1 standard histogram](image)

Fig. 2. Concordia diagram: FC1 standard histogram

![FC1 Duluth standard age (1099Ma) — Analysis using by Brazil SHRIMP IIe is 1100Ma (average age)](image)

Fig. 3. FC1 Duluth standard age (1099Ma) — Analysis using by Brazil SHRIMP IIe is 1100Ma (average age)
minescence (CL) images for the transparent zircons don’t show evidence of overgrowths, whereas a nucleus and overgrowth rim are ubiquitous in the dark / brown zircons. Transparent zircons from sample 2B BV 40, previously dated by TIMS (MAT262) at CPGeo–IG-USP, present TeraWasserburg diagram concordant ages at 2182 ± 9 Ma, whereas all of the dark opaque zircons were discordant, suggesting a clear occurrence of two or more tectonic events registered (core and rim). The U-Pb isotopic data obtained by the Brazil SHRIMP IIe on transparent zircons (TL) and with no overgrowths (CL), yield concordant ages when plotted on a concordia diagram (fig 4), with a median age of 2197 ± 6.5 Ma, therefore, in terms of the inter-laboratory comparison the data is within experimental error. In situ SHRIMP IIe analyses of opaque, zoned zircons, clearly suggest two tectonic events recorded by an Archaean core and Palaeoproterozoic rim. Archaean core ages (~3.1Ga) are the first event in zircon formation. Palaeoproterozoic ages (zircon overgrowth rim and transparent zircons) are associated with the main granulite event that occurred in the Luis Alves Craton.

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URANIUM RADIOACTIVITY STUDIES FOR ISOTOPIC GEOLOGY

Shukolyukov, Yuri A.

Centre of Isotopic Research, VSEGEI, Institute of Precambrian Geology and Geochronology RAS, Geological Department of St. Petersburg State University, St Petersburg, Russia

On the July 18, 1898, P. and M. Curie for the first time used in their lecture the term “radioactivity” at the Paris Academy of Sciences session. The purpose of this paper is to show, how the knowledge on radioactive properties of the “main” radioactive element, uranium, accumulated subsequently in isotopic geology and to tell about its utilization in geosciences.

The \textit{a-radioactivity} discovered in 1899 by E. Rutherford, inherent to isotopes of uranium, thorium and members of their radioactive families, gave the opportunity of using the “isotopic clock” for the first time for geological time measurement. A handsome idea on the possibility of practical utilization of U-Th-He isotopic geochronology method stated in 1905 by E. Rutherford and B. Boltwood was a subject of study for many scientists during many decades. Finally, it became clear that helium could not be retained in lattice of most of minerals. Owing to the works of E.K. Gerling, the reasons of this fact became clear. He elaborated a physical-chemical model of helium migration according to the exponential law, which is formally analogous to the law of monomolecular chemical reaction of the first order. The quantitative characteristics of crystalline structures to retain more or less radiogenic He have been found. These are atomic packing density and subjugated He-migration parameters - activation energy and frequency factor. These are the characteristics, which cause helium volatilization from lattice for most of minerals. It may be possible to separate crystal areas with almost complete helium preservation, but only in particular cases using a special minerals processing procedure with active solvents. Thus, the researchers for a long time lost an interest in using this uranium and thorium systematics in isotope geology. Only in the last decade, a reincarnation of U-Th-He method occurred, now as the thermochronology. Knowledge on helium migration characteristics and determination of real concentration of helium residing in mineral allows to learn a lot about the past temperature history of a mineral and its host rock. This is a new field of isotopic geology, rapidly progressing at present due to the works by P. Reyners and many other researchers.

An alternative possibility of using \textit{a-radioactivity} in isotopic geology and geochronology is the application of U-Th-Pb isotope systematics. The two main complex scientific problems are solved for this technique.
The first of them is instrumental. Attempts in applying various physical methods were taken using different a-radioactivity features for dating uranium-bearing minerals. At the very first stages of isotopic geochronology development, the chemical dating method was used: it was presumed, that minerals contained only radiogenic lead, and the age was estimated as a function of lead and uranium concentration ratio (taking thorium into account). Indeed, such an approach appeared to be quite restricted due to the inherited lead in the most of minerals. Amazingly, that this approach has reappeared today, but in a somewhat upgraded form of CHIME. Failed attempts of using a-lead method based on sample a-radioactivity measurements and lead concentration in it were made, as well as optical spectral and x-ray-spectral techniques.

Only with the advent of the lead isotopic analysis using mass-spectrometers elaborated by A. Dempster, K. Bainbridge, A. Nier et al., a modern U-Th-Pb method emerged, first as the technique used surface Pb ionization or thermoionic emission from the emitter’s surface (P. Akishin), and in recent years, secondary ion ionization.

The second problem of using U and Th a-radioactivity consists is in interpretation of the obtained data. The one difficulty, primarily, consists in the necessity of measuring initial lead captured during crystallization within the dated minerals. The range of options is broad: from a priori assumptions on the isotopic composition of the captured lead to various graphic interpretation methods. The problem also consists in a possible open-systematics behavior of U-Th-Pb isotopes during geological history of minerals. Various methods of resolving this problem are proposed and used. For instance attempts of laboratory modeling and experimental Pb and U-loss by minerals were made (I. Starik). They allowed to make only general qualitative, but not quantitative conclusions. Graphic interpretation methods (G. Wetherill), techniques of physical (air-abrasion) and chemical (acid etching under high P-T conditions) removal of damaged-structure areas of mineral turned out to be much more efficient. However, the possibility of local dating using secondary ion mass-spectrometers proved to be a crucial breakthrough.

Spontaneous fission was another manifestation of uranium radioactivity, which is actively studied and widely used in isotopic geology. Several years after G. Flerov and K. Petzhak discovered the spontaneous fission, V. Khlopin and E. Gering proposed usage of this nuclear process in isotopic geochronology. Xe and Kr turned out to be prospective radiogenic components, because their natural (background) occurrence is many orders lower than clarke concentrations of any other element. Systematic study of uranium-bearing minerals (Yu. Shukolyukov) allowed determination of spontaneous fission rate and isotopic composition, as well as Xe and Kr absolute yields during \(^{238}\text{U}\) spontaneous fission. But, at the same time, it was determined that, though Xe is preserved better in crystalline structures than radiogenic Pb, nevertheless, many minerals loose a noticeable Xe and Kr proportion during the geological history. For several years, Xe–U isotopic system was used for studying radiogenic Xe in natural gases and investigating the kinetics of radiogenic Xe and Kr migration. As a result of these works, a new method of uranium radioactivity utilization, the neutron-induced Xe\(_s\)-Xe\(_n\) method (Yu.
Shukolyukov), was elaborated. Its advantages are in (1) no necessity of whatever concentration measurement, (2) dating using a mineral-monitor does not require determination of spontaneous fission rate constant and, (3) above all, in the possibility of dating minerals with an open-system behavior in relation to Xe. Application of the method to uranium and gold deposits, as well as to zircons of different age showed its high prospects for geochronology.

Spontaneous fission process both leads to generation of radiogenic isotopes and is accompanied by radiation structure damage caused by decay fragments striking it with kinetic a energy tens million times higher than atomic bonds in lattice. After etching primary tracks can be seen in an optical microscope. Observation and calculation of a specific number of tracks in a sample allows to achieve two main tasks: revealing the forms of U atoms occurrence in mineral structure and their age determination. In recent years, the fission track method became extensively applied for studying the thermal history of rocks. This is possible since tracks thermal annealing leads to damage relaxation. The link between the distribution of annealed tracks, temperature and heating pace, gives a possibility to decode very details of thermal and tectonic history of rocks.

Theoretical evaluations permitted P. Kuroda to find the possibility of use for not only spontaneous $^{238}\text{U}$ isotope natural fission, but also for the fission chain reaction of the other $^{235}\text{U}$ isotope. In the USA and the USSR, a vigorous search of the objects where this could happen was conducted at large and ancient uranium deposits located in various geological environments on different continents. The American researchers tried to discover uranium isotopic shifts; while the Soviet ones looked for anomalies in xenon isotopic composition. Conclusions based on these works were as the following: there are no indicators of Precambrian “natural nuclear reactors”, and in the Phanerozoic rocks, such a phenomenon could not exist at all. The irony of fate is in the fact that soon after this, French technical specialists casually discovered enormous isotopic shifts first in uranium, and later in many other chemical elements in the ore from Oklo Deposit, Republic of Gabon (Equatorial Africa). Xe in the ore from Oklo is a typical product of $^{235}$U fission, analogous to xenon in industrial nuclear reactors. This unambiguously pointed to a fission chain reaction, which had been taking place 2 billion years ago during approximately 500 thousand years. However, xenon study of Oklo samples brought us to the conclusion that there is also xenon with an anomalous isotopic composition in the ore. It differs from xenon in every object on the Earth studied so far. The stepwise acid etching allowed to isolate octahedral mica, with maximum concentration of Xe with anomalous isotope composition (Dang Wu Min). Its specific feature consists in a markedly fine structure of isotopes 132, as well as 131 and 134. Such xenon could be a product of a heavy transuranic element. However, comparison with xenon from similar minerals, collected from epicenter of a nuclear test explosions showed even more anomalous xenon with a isotopic enrichment up to 10000 % (A. Meshik). Enrichment degree is correlated with total lifetime of Xe parent isotopes in decay chains of fission fragments. A conclusion was made that the anomalies were caused by migration of these $\beta$-parent isotopes in specific mineral phases followed by a decay to the corresponding Xe isotopes. Such
xenon was named CFF Xe (Chemically Fractionated Fission Xe). An analogue of such Xe, an intensely migrating iodine isotope is discovered (J. Fabrika-Martin) in natural water. Further study showed that CFF Xe was present in many geological objects and explains the terrestrial Xe anomaly in the Solar System.

In the course of uranium minerals study, we succeeded in discovering features of another type of uranium radioactivity. In some minerals, large anomalies of neon and argon isotopic composition anomalies caused by (, n) and (a, p) nuclear reactions under the effect of uranium a-decay are well known. However, we also succeeded in recording additional excesses of $^{38}$Ar, $^{21}$Ne, $^{22}$Ne, and $^{40}$Ar, which were explained as a result of a strongly asymmetric fission of uranium and (or) members of its radioactive family. Later, English physicists, who recorded the similar phenomenon, confirming this phenomenon independently from us.

Studies of natural radioactive uranium decay have been for many years accompanied by search of decay processes of uranium nuclear analogues, heavier, transuranic elements. At present, decay products of a similar transuranic element, like $^{244}$Pu, are found in meteorites. This enabled us to determine the age of the most ancient magmatic rocks in the Solar System, which were brought to the Earth from Vesta Asteroid. We used Xe-Nd-Pu isotopic geochronology method for this purpose.

Uranium radioactivity played a significant role in isotopic geology development, both in isotopic geochronology and isotope geochemistry.
Approximately half of the amount of elements heavier than the iron-group in solar-system material originates from the slow neutron-capture process (s-process). The main component of the s-process is considered to be produced in Asymptotic Giant Branch (AGB) stars, i.e. evolved intermediate or low mass stars. The chemical abundances, especially isotopic ratios around branching points of s-process provide unique information on the neutron density and temperature of the s-process site [e.g. 1–5].

Here, we report the Eu isotopic compositions in presolar SiC grains from the Murchison meteorite using SHRIMP. Since the $^{151}\text{Sm}$ and $^{153}\text{Sm}$ branches of s-process reactions (Fig. 1) are sensitive to both temperature and neutron density, $^{153}\text{Eu}/^{151}\text{Eu}$ ratios in presolar grains could be a good probe to understand the physical parameters of nucleosynthesis in parent stars prior to formation of the Solar system. The mainstream grains SiC35 and SiC67, whose C and Si isotopic ratios suggest the low-mass AGB stars’ origin (See Terada et al. in SHRIMP WS 2004)
show $1.29 \pm 0.24$ and $1.33 \pm 0.24$ of $^{153}\text{Eu}/^{151}\text{Eu}$ ratios, constraining the possible s-process temperature and neutron density conditions to the gray area in Fig. 2. The plausible regions of $^{13}\text{C}(\alpha,n)^{16}\text{O}$ and/or $^{22}\text{Ne}(\alpha,n)^{25}\text{Mg}$ processes inferred from current stellar evolution models of thermally pulsing AGB stars [6-9], are also shown as dashed enclosures. It should be noted that our data closely match the current $^{13}\text{C}$-pocket model ($<10$ keV at about $10^7$ cm$^{-3}$), but the neutron source of $^{22}\text{Ne}(\alpha,n)^{25}\text{Mg}$ is still possibly about $10^{10}$ cm$^{-3}$. For tighter constraints on the s-process conditions, comprehensive isotopic analyses with other heavy elements sensitive to s-process branchings in the same grains, would be required [10].

References

METHOD OF GENETIC INTERPRETATION OF IN-SITU U-PB
ZIRCON GEOCHRONOLOGY OF METAMORPHIC ROCKS
USING DATA ON MELT AND FLUID INCLUSIONS IN ZIRCONS

Tolmacheva, E. V.¹, Saltykova, T. E¹, Sergeev, S. A.¹,
Veikoslavinsky, S. D.²

¹ Centre of Isotopic Research, VSEGEI, St.-Petersburg, Russia,
Elena_tolmacheva@vsegei.ru
² Institute of Precambrian Geology and Geochronology RAS, St.-Petersburg, Russia

As a result of in-situ U-Pb geochronology of polygenic zoned zircons from
metamorphic rocks we usually obtain several concordant age values, and each of
them may correspond to the age of a rock-forming process. Data on zircon mor-
phology, geochemistry, and cathodoluminescence are traditionally used for the
interpretation of obtained geochronological results. Mentioned characteristics
being quite sufficient for the interpretation of geochronological data for zircons
formed in a result of a single petrogenetic (mostly magmatic) process do not suf-
fice to reliable geochronological interpretation for complicated zircons from meta-
orphic rocks. In particular morphology of metamorphic zircons is often inherit-
ed from the protholith zircons, zircons of different origin may overlap in contents
of U and Th, cathodoluminescence data are not always show reliable zircon zon-
ing and do not allow a determination of continuous or corrosional type of bound-
daries between zircon zones.

In order to achieve of the most reliable interpretation of geochronologigal data
additional method based on study of melt and fluid inclusions in zircons is pro-
posed. This method suggests two steps.

1. First step includes optical study (at magnification of 500–1000) of compo-
sition and aggregation of primary inclusions from all the zircon grains and their
separate zones in a sample. This study intends to obtain direct information of zir-
con origin. Reliability of petrogenetic reconstruction increases with applying of
such additional characteristics as type and grade of integrity of primary inclusions
in each zone, relationship of neighbor zircon zones, grade of deformation of dif-
ferent zircon zones, presence of fine zoning within zircon zones, composition and
aggregation of secondary inclusions in each zircon zone.

2. The second step concerns the study of dated zircons, and represents a cor-
relation of obtained age values with results and their petrogenetic reconstruction
for the purpose of determination of origin of studied zircon areas, rejection of age
values, obtained from areas composed of two or more zircon zones and containing
foreign material (fluid and solid inclusions, fractures filled by fluid, and zones of
zircon recrystallization around some melt inclusions as well), which usually dis-
tort geochronological data. Estimate of rejection comes to 5–80 % depending on
size of separated zircons, complication of their structure, and the total amount of
inclusions as well. With the aim to minimize rejection preliminary location of op-
timal areas for microprobe analysis should be performed during the first step.

Acknowledgements: The study is based on results, obtained within the project
supported by the Rosnedra Federal Agency.
MEASURING SHRIMP Pb/U AGES OF PALAEOZOIC ZIRCONS: CAN WE DO BETTER?

Williams, Ian ¹ and Matukov, Dmitry ²

¹Research School of Earth Sciences, Australian National University, Canberra, Australia
Ian.Williams@anu.edu.au
²Centre of Isotopic Research, VSEGEI, St Petersburg, Russia
Dmitry_Matukov@vsegei.ru

It is now more than 25 years since we first started measuring Pb/U ratios with SHRIMP, but our calibration procedure is still essentially the same as the one used in the early days. We argue over the details, such as whether the slope of the calibration line is constant for a given mineral, and whether the calibration is more accurate using UO or UO₂, but my impression is that most of us expect that a good analytical session will give us a zircon Pb/U age measurement accurate to about 1 %. I wonder how often that expectation is actually met.

The Bega Batholith in south-eastern Australia consists of about 130 plutons, ranging in composition from minor gabbro, through dominant tonalites and granodiorites, to monzogranite. It covers an area of about 8900 km². The plutons show systematic regional changes in chemical and isotopic composition, and I have been working to try and determine whether those changes are related to differences in the ages of the granites. This has turned out to be more difficult than I expected, because many of the plutons were intruded over a relatively short period of time (~420–405 Ma). To define the age distribution pattern, the Pb/U ages need to be measured with an accuracy of 1 % or better.

At the SHRIMP workshop in 2003 I reported my first attempts to sort out the ages of the Bega granites. Using AS3 as the standard and focusing on just the granites from the western side of the batholith, I found that zircon from any two granites that I analysed on the same mount during the same analytical session gave mean ages equal within error (~1 %), but that zircon from the same granite suite on different mounts analysed at different times gave mean ages differing by as much as 3 %. Not only was this a worry analytically, but it made it impossible to determine if the granites in a single chemical suite were essentially coeval or not.

Following our adoption of Temora as the preferred standard for Pb/U measurements, I repeated some of the measurements. The ages were more internally consistent, but on average younger than those measured against AS3. There was also some evidence of bias in the measurements related to where the zircons were
positioned on the grain mount. As part of the tests, several of the granites were
dated on the *SHRIMP II* in St. Petersburg by our colleagues at VSEGEI, with U,
UO and UO$_2$ all included in the measurements.

The next stage of the experiment was to mount the zircons in megamounts.
This, combined with a recognition that Pb/U calibrations can sometimes drift
with time, and that there is normally a strong correlation between UO/U and UO$_2$/
U, has produced a much more internally consistent set of results. I am now much
more optimistic that, given a stable analytical session, an accuracy of about 1 % in
measuring the mean zircon Pb/U age of a Palaeozoic granite can be achieved.
SHRIMP U-TH-PB ANALYSIS OF MONAZITE IN THE DUCTILE SHEAR ZONE, HWACHEON GRANULITE COMPLEX, KOREA: A TRIASSIC RECRYSTALLIZATION

Yi, Keewook1, Cho, Moonsup2, Williams, Ian S.3, and Cheong, Chang-Sik 1

1 Geochronology Team, Korea Basic Science Institute, +82-42-865-3637, kyi@kbsi.re.kr
2 School of Earth and Environmental Sciences, Seoul National University
3 Research School of Earth Sciences, The Australian National University

The metamorphic ages of monazite separated from granulitic gneisses and adjacent mylonitic schists in the Hwacheon granulite complex (HGC) were determined using a sensitive high-resolution ion microprobe (SHRIMP-II). Monazite grains in the granulitic gneisses coexist with Grt + Sil + Bt + Pl + Kfs + Qtz + Zrn, and those in the retrogressive zone gneisses are partially resorbed and mantled by symplectites of hydrous minerals including apatite and allanite. On the other hand, monazite in mylonitic schists of the exhumation-related shear zone coexists with Bt + Ms + Pl + Qtz + ThSiO4 + Xtm.

Sixty-eight spots on monazite grains were analyzed using not only grain mounts but also thin sections, which were imaged by backscattered electron imaging as well as X-ray element mapping prior to the SHRIMP analyses. The 44069 monazite standard (425 Ma, [1]) was used for the data regression. The U-Pb age of monazite in the granulitic gneiss is determined at 1860 ± 11 Ma. This age is indistinguishable from that of metamorphic overgrowths on zircon, which were dated from a garnetiferous granulite (1872 +11/-9 Ma, [2]) and a mylonitic schist (1858 ± 17 Ma). The U-Pb age of monazite from the mylonitic schist, however, indicates a Triassic episode of recrystallization at 223.8 ± 2.6 Ma (n=11; MSWD=2.8). In addition, the Th-Pb age of that monazite yields a consistent result of 222.6 ± 2.6 Ma (n=12; MSWD=2.8).

Heavy rare earth elements (HREE), e.g., Y, Gd and Dy, are significantly higher in the Triassic monazite than in the Paleoproterozoic monazite, suggesting that the dissolution of HREE-rich minerals such as garnet and xenotime accompanied the recrystallization of monazite. Taken together, monazite grains of the HGC were grown at ca. 1.86 Ga and 223 Ma, and these growth episodes are consistent with composite P-T-t histories reported by Lee and Cho [3]. We also conclude
that monazite is useful for determining the absolute time of a shearing event, and that zircon remains relatively inert during mylonitic recrystallization.

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<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Email</th>
</tr>
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<tbody>
<tr>
<td><strong>Adamskaya, Elena V.</strong></td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9209</td>
<td><a href="mailto:Adamskaya@mail.ru">Adamskaya@mail.ru</a></td>
</tr>
<tr>
<td><strong>Akinin, V.V.</strong></td>
<td>North East Interdisciplinary Science Research Institute Russian Academy of Sciences Portovaya 16, Magadan 685000, Russian Federation</td>
<td><a href="mailto:akinin@neisri.ru">akinin@neisri.ru</a></td>
</tr>
<tr>
<td><strong>Alenicheva, Antonina A.</strong></td>
<td>VSEGEI, Saint Petersburg, Russia</td>
<td><a href="mailto:Antonina_alenicheva@vsegei.ru">Antonina_alenicheva@vsegei.ru</a></td>
</tr>
<tr>
<td><strong>Antonov A.</strong></td>
<td>Centre of Isotopic Research, VSEGEI, St.-Petersburg, Russia</td>
<td><a href="mailto:Anton_Antonov@vsegei.ru">Anton_Antonov@vsegei.ru</a></td>
</tr>
<tr>
<td><strong>Aoki, W.</strong></td>
<td>National Astronomical Observatory JAPAN</td>
<td></td>
</tr>
<tr>
<td><strong>Archanjo, C.J.</strong></td>
<td>Instituto de Geociencias, Universidade de Sao Paulo, Rua do Lago, 562, CEP 05508-080 Sao Paulo, SP, Brazil</td>
<td><a href="mailto:archan@usp.br">archan@usp.br</a></td>
</tr>
<tr>
<td><strong>Armstrong, R.</strong></td>
<td>The Australian National University, Canberra, Australia.</td>
<td><a href="mailto:richard.armstrong@anu.edu.au">richard.armstrong@anu.edu.au</a></td>
</tr>
<tr>
<td><strong>Babinski, M.</strong></td>
<td>Instituto de Geociencias, Universidade de Sao Paulo, Rua do Lago, 562, CEP 05508-080 Sao Paulo, SP, Brazil</td>
<td><a href="mailto:babinski@usp.br">babinski@usp.br</a></td>
</tr>
<tr>
<td><strong>Balashova, Yulia</strong></td>
<td>Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI), St Petersburg, Russia</td>
<td><a href="mailto:yulia_balashova@rambler.ru">yulia_balashova@rambler.ru</a></td>
</tr>
<tr>
<td><strong>Basei, Miguel A. S.</strong></td>
<td>Instituto de Geociencias da Universidade de Sao Paulo, Rua do Lago 562, Cidade Universitaria, Sao Paulo, Brazil.CEP 05508-080</td>
<td><a href="mailto:baseimas@usp.br">baseimas@usp.br</a>.</td>
</tr>
<tr>
<td><strong>Belyatsky, Boris</strong></td>
<td>VNIIOkeangeologia, St.-Petersburg, Russia</td>
<td><a href="mailto:bbelyatsky@mail.ru">bbelyatsky@mail.ru</a></td>
</tr>
<tr>
<td><strong>Berezhnaya, Natalya</strong></td>
<td>Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI), St Petersburg, Russia</td>
<td><a href="mailto:Natalia_Berezhnaya@vsegei.ru">Natalia_Berezhnaya@vsegei.ru</a></td>
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<tr>
<td>Bert De Waele</td>
<td>Tectonics Special Research Centre, The University of Western Australia M 004 School of Earth and Geographical Sciences, 35 Stirling Highway, Crawley, Western Australia 6009</td>
<td><a href="mailto:bdewaele@tsrc.uwa.edu.au">bdewaele@tsrc.uwa.edu.au</a></td>
</tr>
<tr>
<td>Boggiani, P.C.</td>
<td>Instituto de Geociencias, Universidade de Sao Paulo, Rua do Lago, 562, CEP 05508-080 Sao Paulo, SP, Brazil</td>
<td><a href="mailto:boggiani@usp.br">boggiani@usp.br</a></td>
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<tr>
<td>Budzyn, B.</td>
<td>Jagiellonian University, Institute of Geological Sciences, Krakow, Poland</td>
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<tr>
<td>Cheong, Chang-Sik</td>
<td>Geochronology Team, Korea Basic Science Institute, +82-42-865-3637</td>
<td><a href="mailto:kyi@kbsi.re.kr">kyi@kbsi.re.kr</a></td>
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<tr>
<td>Cho, Moonsup</td>
<td>School of Earth and Environmental Sciences, Seoul National University</td>
<td></td>
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<tr>
<td>Clement, Steve W.</td>
<td>consultant to RSES 1796 Rte 116, Crapaud, P.E.I., Canada C0A 1J0 Phone:1 902 658 2095</td>
<td><a href="mailto:stevec@isn.net">stevec@isn.net</a>&quot; <a href="mailto:stevec@isn.net">stevec@isn.net</a></td>
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<td>Compston, W.</td>
<td>The Australian National University, Canberra A.C.T.</td>
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<td>Cordani, Umberto G.</td>
<td>Instituto de Geociencias da Universidade de Sao Paulo, Rua do Lago 562, Cidade Universitaria, Sao Paulo, Brazil.CEP 05508-080</td>
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<tr>
<td>Davis, W.J.</td>
<td>J.C. Roddick Ion Microprobe Laboratory, Geological Survey of Canada, 601 Booth St., Ottawa, ON Canada</td>
<td><a href="mailto:Bill.Davis@nrcan.gc.ca">Bill.Davis@nrcan.gc.ca</a></td>
</tr>
<tr>
<td>De Laeter JR</td>
<td>Curtin University of Technology, Perth, Western Australia, phone 61 8 9266 3518, Fax: 61 8 9266 2377</td>
<td><a href="mailto:j.delaeter@curtin.edu.au">j.delaeter@curtin.edu.au</a></td>
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<tr>
<td>Dunkley, D. J.</td>
<td>National Institute of Polar Research, Tokyo, Japan</td>
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<tr>
<td>Fan Run-long</td>
<td>Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China</td>
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<tr>
<td>Fanning, C.M.</td>
<td>The Australian National University, Canberra, Australia</td>
<td><a href="mailto:Mark.Fanning@anu.edu.au">Mark.Fanning@anu.edu.au</a></td>
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<tr>
<td>Feng Jin-song</td>
<td>School of Electronic Science &amp; Engineering, Jilin University, Changchun Jilin 130026, China</td>
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<td>Foster John J.</td>
<td>Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia</td>
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</tr>
<tr>
<td>Gavryutchenkova, Olga</td>
<td>Centre of Isotopic Research, Russian Research Geological Institute (VSEGEI), St Petersburg, Russia</td>
<td><a href="mailto:Olga_Gavryutchenkova@vsegei.ru">Olga_Gavryutchenkova@vsegei.ru</a></td>
</tr>
<tr>
<td>Goltsin, N.A.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St-Petersburg 199106, Russia, +7(812) 328 9209</td>
<td><a href="mailto:Nikolay_Goltsin@vsegei.ru">Nikolay_Goltsin@vsegei.ru</a></td>
</tr>
<tr>
<td>Grasso, Carla B.</td>
<td>Instituto de Geociencias-USP, Rua do Lago 562, CEP-05508080, Sao Paulo, Brasil</td>
<td></td>
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<tr>
<td>Gruzdov, K.A.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St-Petersburg 199106, Russia, +7(812) 328 9209</td>
<td><a href="mailto:Konstantin_Gruzdov@vsegei.ru">Konstantin_Gruzdov@vsegei.ru</a></td>
</tr>
<tr>
<td>Hidaka, Hiroshi</td>
<td>Department of Earth and Planetary systems, Hiroshima University, Higashi-Hiroshima 739-8526, Japan</td>
<td><a href="mailto:hidaka@hiroshima-u.ac.jp">hidaka@hiroshima-u.ac.jp</a></td>
</tr>
<tr>
<td>Hiess, J.</td>
<td>Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia</td>
<td></td>
</tr>
<tr>
<td>Hofmeister, Wolfgang</td>
<td>Institut für Geowissenschaften, Johannes Gutenberg-Universität Mainz, Becherweg 21, D-55099 Mainz, Germany</td>
<td></td>
</tr>
<tr>
<td>Holden, Peter</td>
<td>Research School of Earth Sciences, Australian National University, Canberra A.C.T.</td>
<td><a href="mailto:Peter.Holden@ANU.EDU.AU">Peter.Holden@ANU.EDU.AU</a></td>
</tr>
<tr>
<td>Hollanda, M.H.B.M.</td>
<td>Instituto de Geociencias, Universidade de Sao Paulo, Rua do Lago, 562, CEP 05508-080 Sao Paulo, SP, Brazil</td>
<td><a href="mailto:hollanda@usp.br">hollanda@usp.br</a></td>
</tr>
<tr>
<td>Horie, Kenji</td>
<td>Institute of Geology and Geoinformation, Geological Survey of Japan, Central 7, Higashi 1-1-1, Tsukuba 305-8567, Japan</td>
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<tr>
<td>Huo Zheng-dan</td>
<td>School of Electronic Science &amp; Engineering, Jilin University, Changchun Jilin 130026, China</td>
<td></td>
</tr>
<tr>
<td>Ickert, R. B.</td>
<td>Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia</td>
<td><a href="mailto:Ryan.Ickert@anu.edu.au">Ryan.Ickert@anu.edu.au</a></td>
</tr>
<tr>
<td>Ireland, Trevor R.</td>
<td>Research School of Earth Sciences, The Australian National University, Canberra, Australia</td>
<td><a href="mailto:trevor.ireland@anu.edu.au">trevor.ireland@anu.edu.au</a></td>
</tr>
<tr>
<td>Iwamoto, N.</td>
<td>Japan Atomic Energy Agency, JAPAN</td>
<td></td>
</tr>
<tr>
<td>Jenkins, R.J.F.</td>
<td>South Australian Museum, Adelaide, South Australia</td>
<td></td>
</tr>
<tr>
<td>Kapitonov, I. N.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:Igor_Kapitonov@vsegei.ru">Igor_Kapitonov@vsegei.ru</a></td>
</tr>
<tr>
<td>Kennedy, Allen K.</td>
<td>Department of Imaging and Applied Physics, Curtin University of Technology, Kent. St., Bentley, 6102, Western Australia,</td>
<td><a href="mailto:A.Kennedy@curtin.edu.au">A.Kennedy@curtin.edu.au</a></td>
</tr>
<tr>
<td>Khalenev, V.O.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:Vladimir_Khalenev@vsegei.ru">Vladimir_Khalenev@vsegei.ru</a></td>
</tr>
<tr>
<td>Kikuchi, Makiko</td>
<td>Department of Earth and Planetary Systems Science, Hiroshima University, Higashi-Hiroshima 739-8526, Japan</td>
<td><a href="mailto:maki-ckw05@hiroshima-u.ac.jp">maki-ckw05@hiroshima-u.ac.jp</a></td>
</tr>
<tr>
<td>Kim, Yoonsup</td>
<td>Geochronology Team, Korea Basic Science Institute, Daejeon 305-333, Korea</td>
<td></td>
</tr>
<tr>
<td>Kinny, Peter D.</td>
<td>The Institute for Geoscience Research, Curtin University, Perth, Australia</td>
<td><a href="mailto:P.Kinny@curtin.edu.au">P.Kinny@curtin.edu.au</a></td>
</tr>
<tr>
<td>Kovalenko, S. V.</td>
<td>PPSE, Vladivostok</td>
<td></td>
</tr>
<tr>
<td>Kusiak, M. A.</td>
<td>Polish Academy of Sciences, Institute of Geological Sciences, Krakow, Poland</td>
<td><a href="mailto:ndkusiak@cyf-kr.edu.pl">ndkusiak@cyf-kr.edu.pl</a></td>
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<td>Name</td>
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<tr>
<td>Kuzmin, V.K.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia</td>
<td></td>
</tr>
<tr>
<td>Larionov, A.N.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9209</td>
<td></td>
</tr>
<tr>
<td>Lepekhina, E.N.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9209</td>
<td></td>
</tr>
<tr>
<td>Levsky, Lev.</td>
<td>Institute of Precambrian Geology and Geochronology RAS, St. Petersburg, Russia</td>
<td></td>
</tr>
<tr>
<td>Liu Dun-yi</td>
<td>Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China</td>
<td></td>
</tr>
<tr>
<td>Lokhov, Kirill I.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td></td>
</tr>
<tr>
<td>Martin, H.</td>
<td>Laboratoire Magmas et Volcans; OPGC, CNRS, Universite Blaise Pascal, Clermont-Ferrand, France</td>
<td></td>
</tr>
<tr>
<td>Matukov, Dmitry</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td></td>
</tr>
<tr>
<td>Miller, E.L.</td>
<td>Department of Geological and Environmental Sciences, Stanford University, Bld. 320, Stanford, CA, 94305, USA</td>
<td></td>
</tr>
<tr>
<td>Nasdala, Lutz</td>
<td>Institut für Mineralogie und Kristallographie, Universitat Wien, Althanstr. 14, A-1090 Wien, Austria</td>
<td></td>
</tr>
<tr>
<td>Nelson DR</td>
<td>Curtin University of Technology, Perth, Western Australia</td>
<td></td>
</tr>
<tr>
<td>Norberg, Nicholas</td>
<td>Institut für Mineralogie und Kristallographie, Universitat Wien, Althanstr. 14, A-1090 Wien, Austria</td>
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<tr>
<td>Nutman, Allen</td>
<td>Beijing Shrimp Centre, 26, Baiwanzhuang Road, Beijing, 100037, China</td>
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<td>Osako, Liliane</td>
<td>Departamento de Geologia, Universidade Federal do Ceara, Bloco 912, CEP60455-760, Brazil</td>
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<tr>
<td>Paderin, Ilya</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:paderin@vsegei.ru">paderin@vsegei.ru</a></td>
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<tr>
<td>Pestaj, T.</td>
<td>J.C. Roddick Ion Microprobe Laboratory, Geological Survey of Canada, 601 Booth St., Ottawa, ON Canada</td>
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<tr>
<td>Lanc Peter</td>
<td>The Australian National University Research School of Earth Sciences Canberra ACT 0200 Australia, <a href="http://shrimp.anu.edu.au">http://shrimp.anu.edu.au</a></td>
<td><a href="mailto:peter.lanc@anu.edu.au">peter.lanc@anu.edu.au</a></td>
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<tr>
<td>Polekhovsky, Yu.S.</td>
<td>St Petersburg University</td>
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<tr>
<td>Prasolov, Edward M.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:Edward_Prasolov@vsegei.ru">Edward_Prasolov@vsegei.ru</a></td>
</tr>
<tr>
<td>Presnyakov Sergey L.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:Sergey_Presnyakov@vsegei.ru">Sergey_Presnyakov@vsegei.ru</a></td>
</tr>
<tr>
<td>Prilepsky, Edward B.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:Edward_Prilepsky@vsegei.ru">Edward_Prilepsky@vsegei.ru</a></td>
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<tr>
<td>Rayner, N.</td>
<td>J.C. Roddick Ion Microprobe Laboratory, Geological Survey of Canada, 601 Booth St., Ottawa, ON Canada</td>
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<tr>
<td>Rodionov Nikolay</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
<td><a href="mailto:Nickolay_Rodionov@vsegei.ru">Nickolay_Rodionov@vsegei.ru</a></td>
</tr>
<tr>
<td>Saltykova, Anna K.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9155</td>
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<tr>
<td>Saltykova, Tatiana E.</td>
<td>VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia</td>
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<td>Sato, Kei</td>
<td>Instituto de Geociencias da Universidade de Sao Paulo, Rua do Lago 562, Cidade Universitaria, Sao Paulo, Brazil.CEP 05508-080</td>
<td><a href="mailto:keisato@usp.br">keisato@usp.br</a></td>
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<tr>
<td>Schram, N.</td>
<td>Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia</td>
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<tr>
<td>Sergeev, Sergey A.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9172</td>
<td><a href="mailto:Sergey_Sergeev@vsegei.ru">Sergey_Sergeev@vsegei.ru</a></td>
</tr>
<tr>
<td>Shukolyukov, Yuri A.</td>
<td>Centre of Isotopic Research, VSEGEI, Institute of Precambrian Geology and Geochronology RAS, Geological Department of St. Petersburg State University, St Petersburg, Russia</td>
<td><a href="mailto:xekrame@10093.spb.edu">xekrame@10093.spb.edu</a></td>
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<tr>
<td>Siga Jr, Oswaldo</td>
<td>Instituto de Geociencias da Universidade de Sao Paulo, Rua do Lago 562, Cidade Universitaria, Sao Paulo, Brazil.CEP 05508-080</td>
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<td>Skublov, S.G.</td>
<td>Institute of Precambrian Geology and Geochronology RAN, St. Petersburg, Russia</td>
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<td>Slaby, E.</td>
<td>University of Warsaw, Institute of Geochemistry, Mineralogy and Petrology, Poland</td>
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<tr>
<td>Strickland, A.</td>
<td>Department of Geological and Environmental Sciences, Stanford University, Bld. 320, Stanford, CA, 94305, USA</td>
<td></td>
</tr>
<tr>
<td>Biswal, Tapas Kumar</td>
<td>Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, 400076</td>
<td><a href="mailto:tkbiswal@iitb.ac.in">tkbiswal@iitb.ac.in</a></td>
</tr>
<tr>
<td>Tassinari, Colombo C. G.</td>
<td>Instituto de Geociencias da Universidade de Sao Paulo, Rua do Lago 562, Cidade Universitaria, Sao Paulo, Brazil.CEP 05508-080</td>
<td></td>
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<tr>
<td>Terada, Kentaro</td>
<td>Department of Earth and Planetary Systems Science, Hiroshima University, Higashi-Hiroshima 739-8526, Japan</td>
<td><a href="mailto:terada@sci.hiroshima-u.ac.jp">terada@sci.hiroshima-u.ac.jp</a></td>
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<td>Thorne, Jane</td>
<td>Research School of Earth Sciences, Australian National University, Canberra A.C.T.</td>
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<tr>
<td>Tolmacheva, Elena V.</td>
<td>Centre of Isotopic Research, VSEGEI, Sredny Prospect 74, St.-Petersburg 199106, Russia, +7(812) 328 9250</td>
<td><a href="mailto:Elena_tolmacheva@vsegei.ru">Elena_tolmacheva@vsegei.ru</a></td>
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<tr>
<td>Trendall, A. F.</td>
<td>Curtin University of Technology, Perth, Western Australia</td>
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<tr>
<td>Trindade, R.I.F</td>
<td>Instituto de Astronomia, Geofisica e Ciencias Atmosfericas, Universidade de Sao Paulo, Rua do Matao, 1226, CEP 05508-090 Sao Paulo, SP, Brazil</td>
<td><a href="mailto:Rtrindad@iag.usp.br">Rtrindad@iag.usp.br</a></td>
</tr>
<tr>
<td>Tsutsumi, Yukiyasu</td>
<td>Department of Geology and Paleontology, National Museum of Nature and Science, Shinjuku-ku, Tokyo 169-0073, Japan</td>
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<td>Turkina, O.M.</td>
<td>Institute of Geology and Mineralogy, SB RAN, Novosibirsk, Russia</td>
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<td>Velikoslavinsky, S. D.</td>
<td>Institute of Precambrian Geology and Geochronology RAS, St.-Petersburg, Russia</td>
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<td>Vlach, Silvio</td>
<td>Instituto de Geociencias-USP-Rua do Lago 562, CEP-05508080, Sao Paulo, Brasil</td>
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<tr>
<td>Wang Chen</td>
<td>Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China</td>
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<tr>
<td>Williams, Ian S.</td>
<td>Research School of Earth Sciences, The Australian National University</td>
<td><a href="mailto:Ian.Williams@anu.edu.au">Ian.Williams@anu.edu.au</a></td>
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<tr>
<td>Wooden, J. L.</td>
<td>U.S. Geological Survey Menlo Park, CA, 94305, USA</td>
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<tr>
<td>Xiong Xingchuang</td>
<td>National Research Center of Certified Reference Materials, Beijing 100013, China</td>
<td></td>
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<tr>
<td>Yi, Keewook</td>
<td>Geochronology Team, Korea Basic Science Institute, Daejeon 305-333, Korea +82-42-865-3637</td>
<td><a href="mailto:Kyi@kbsi.re.kr">Kyi@kbsi.re.kr</a></td>
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<td>Yoshida, T.</td>
<td>National Astronomical Observatory, JAPAN</td>
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<tr>
<td>Zhang Yu-hai</td>
<td>Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China</td>
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