Contents

In memoriam, Alfred Kröner (1939-2019)

Professor Alfred Kröner, Emeritus Professor at the University of Mainz, Advisory Council Member for IGCP 662 project, Honorary Professor and Senior Research Fellow in the Beijing SHRIMP Center, Chairman of the International Precambrian Research Center of China, and Advisory Council Member International Association for Gondwana Research, passed away on 22nd May, 2019. We record his sudden demise with deep regret.

Alfred was born on 8th September, 1939 in Kassel, Germany. He graduated with a B.Sc.-equivalent degree from the High School of mining in Clausthal-Zellerfeld, Germany, in 1962 and continued his research work at the University of Vienna, Austria, and the Technical University in Munich, Germany, where he obtained his M.Sc. degree in 1965. He then moved to the Precambrian Research Unit (PRC) of the University of Cape Town where he conducted research on rock relationships in Namaqualand and got his Ph.D. degree in 1968. After one year's working as a base-metal-exploration geologist in Namibia, he returned to Cape Town as a Senior Research Fellow of the PRC and was involved in research projects in the Damara and Gariep Belts and the Namaqualand Metamorphic Complex. After recognizing the importance of geochronology to understanding crustal evolution, he began isotopic studies in the Bernard-Price Institute of Geophysical Research at Witwatersrand University, Johannesburg and continued these studies while visiting Leeds University, UK and the Universities of Montpellier and Strasbourg, France. In 1977, he moved back to Germany and accepted the Chair of Geology at the University of Mainz. In 1981/82, he spent a Sabbatical at Stanford University, USA, where he was involved in palaeomagnetic studies in the Dmara Belt of Namibia and the early Archean Barberton terrane, South Africa. In 1985/86, a further sabbatical led him to Australian National University where he learned to operate SHRIMP I and became hooked to zircon geochronology. In 2007, he became the Honorary Professor and a regular annual visitor to the Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences.

In 1996, Prof. Kröner started his research in the Central Asian Orogenic Belt (CAOB) and further extended his studies to the CAOB in Mongolia, Kyrgyzstan and China. His footsteps covered most importance areas of the CAOB, and he has many friends from Mongolia, China, Russia and other countries. He has made a great contribution to research on the CAOB. He also did lots for helping an application for the IGCP 662 project.

During his career life, Prof. Kröner had a stunning capacity for work with tireless and sometimes alarming enthusiasm. He was author and co-author of more than 300 publications including research paper as well as textbooks. He also became involved in many international activities. He was Secretary of the IUGS Commission on Tectonics (1978-1989), Chairman of Working Group 3 (Proterozoic Geology) of the International Lithosphere Program (1983-1993), Leader of IGCP-Project 280 (The oldest rocks on Earth) (1988-1993), Co-Chairman of the ERAS-Project of the renewed International Lithosphere Program (2006-2010), and member of several IGCP-Projects. He served as President of the German Geological Society (GeologischeVereinigung) (1986-1991), Vice-President of the European Union of Geosciences (1997-1999), and Chairman of the IPRCC (2016-2019) and was also Advisory Council Member of the International Association of Gondwana Research. He was Co-Editor of the journals Precambrian Research (1984-2007) and Terra Nova (1996-2012), and Associate Editor of Gondwana Research. Prof. Kröner's scientific achievements and social activities won him the Jubilee Medal of the Geological Society of South Africa (1974), Honorary Fellowships of the Geological Societies of America and South Africa, the Ananda Coomaraswamy Memorial Medal of the Geological Society of Sri Lanka (1999), the Emanuel Boricky Medal of Charles University, Prague, Czech Republic (2000), the Distinguished Service Medal of the Province of Rhineland-Palatinate in Germany (2006) and Honorary Professorships at Northwest Univeristy, Xi'an (1986) and in the Chinese Academy of Geological Sciences (2008), and the Chinese Government Friendship Award (2010).

Alfred had a personality marked by smart wits, and hardworking combined with generosity. He devoted his life to science and made great contributions to advancing Earth Science worldwide. His demise is a great loss to the academic and scientific community. He will be missed as an outstanding scientist and a good colleague by the Earth Science community.

IGCP 662 Organizing Committee;

Beijing SHRIMP Center, Institute of Geology;

Chinese Academy of Geological; Sciences, Beijing, China;

Institute of Paleontology and Geology, Mongolian Academy of Sciences;

Mongolian University of Science & Technology

In memoriam, Academician Onongo Tomurtogoo, (1939-2019)

It is a great sadness to report that Onongo Tomurtogoo, a Honorary Scientist of Mongolia, Academician, Leading Scientist, Doctor of Sciences, Professor passed away 30 May 2019. He will be remembered vividly by many of his former research colleagues across the world. His scientific reputation was recognized throughout his career.

O.Tomurtogoo was born in 1939 in the Khuvsgulsoum of Dornogoviaimag (province). His career developed rapidly. After graduation from the Moscow Institute of Geology and Exploration in 1963 he started to work as a teacher of Regional Geology and Geology of Mongolia at the newly established Department of Geology at the Mongolian State University.

He was the Academic Secretary of the Geological Institute of the Mongolian Academy of Sciences, and later Director of this Institute, and since 2015 the Director's Adviser. He was a member of the National Council on Science and Technology, member of Little Assembly on Geology and Geography, and member of the Council for defending PhD degrees, and head and a member of the Council for defending ScD degrees under the Mongolian Academy of Sciences, Member of Scientific Council of the Institute of Geology and Mineral Resources, Institute of Paleontology and Geology, a member of the Council for Mineral Resources under the Mineral Resources and Petroleum Authority of Mongolia (MRPAM), and he was a member of executive council of the Mongolian Geological Society

He was the author of over 200 publications, including 37 monographs, and 17 geological maps and co-author of 18 reports, 10 books, 2 national atlas and member of editorial board of 57 proceedings of the Mongolian-Russian joint geological expedition.

From 1970-1992, O.Tomurtogoo was co-author and editor of a series of maps: Tectonic Map of Mongolia, Map of Mesozoic and Cenozoic tectonics, Map of Geological Formations at the scale of 1:500 000, Geological map of North Mongolia and Khangai at the scale of 1:500 000 and Geological and Tectonic maps for National Atlas of Mongolia. He led the first Geological Map of Mongolia at the scale of 1:1 000 000 published in 1999. The first Tectonic map of Mongolia at the scale of 1:100000 compiled and published in 2002 by O.Tomurtogoo was a major achievement in Mongolian Geology in the 20th century and also a great contribution to the Mongolian Integrated Database.

He also contributed to the Geological database of Asia and map compilation within international projects, including the Tectonic map of North Asia published in 1979 in Russia, the Tectonic map of China and contiguous countries published in China in 1997, Geodynamic map of Northeast Asia published in 2002 by USGS, Atlas of geological maps of Central Asia published by Geological Surveys of five Asian countries, and the Geological map of Asia published in 2013 by International Union of Geological Sciences.

O.Tomurtogoo always applied his research results to geological practice and played an important role in activating collaboration between governmental organizations e.g. Mongolian Academy of Sciences, Ministry, and MRPAM. Since 1997 he was a member of Mineral Resources Council, member of Mongolia's Stratigraphy Commission, since 2004 the Chief editor of the Editorial Board for the UGZ-200 project (National Geological set maps at the scale of 1:200 000), and participated in Geologic and Tectonic maps compilation within the joint project "Complete Geological map of Mongolia and China border areas" and edited the first Geological map of Mongolia at the scale of 1:500 000 that was approved by Mineral Resources Council of the Ministry of Mining and Heavy Industry.

Appreciating the contribution of Tomurtogoo, the Mongolian Government awarded him the Order of North Star (Altan Gadas, 1996), Medals of Mongolian People's Revolution and Great Mongol Empire. In 1991 he was elected to the Mongolian Academy of Sciences, in 1999 he was nominated as Honorary Professor of the Mongolian University of Science & Technology, and Leading Scientist. In 2000 he was awarded First Prize for best work of the Ministry of Education (2000), Gold Medal of the Mongolian Academy of Sciences for best work (2007), Honor Geologist of the Professional Geological Societies of Mongolia (2012), Khubilai Khan medal of the Mongolian Academy of Sciences (2012) and Honorary Scientist of Mongolia by the Order of the President of Mongolia (2014).

O.Tomurtogoo a leading geologist of high international standing devoted his life to international and Mongolian geological science; his high ability, honesty, humility, and friendliness will remain in our heart, and the hundreds of his geological publications, will not be lost in Mongolian science. We are confident that the academic community will continue to celebrate his achievements and his work will be preserved and renewed.

IGCP 662 Organizing Committee
Institute of Paleontology and Geology, Mongolian Academy of Sciences
Mongolian University of Science & Technology

Accretionary and collisional processes forming Mongolian tract of the Central Asian Orogenic Belt

Karel Schulmann

Centre of Lithospheric Research, Czech Geological Survey, Prague, Czech Republic

Institute de Physique de Globe, UMR 7516, EOST, Université de Strasbourg, France

Accretionary processes operated continuously along Pacific boundary since the Late Proterozoic and are responsible for the origin of the archetypal Palaeozoic peripheral system, Terra Australis Orogen (Cawood, 2005). This linear accretionary orogen was progressively constructed through alternation of retreating and advancing subduction events. At the same period, several "*interior*" oceans opened within Gondwana and separated continental ribbons that moved northwards to collide with Laurussia landmass. Progressive amalgamation of microcontinents accompanied by oceanic and continental subductions shaped the "*interior*" Caledonian/Appalachian and Variscan orogens. Finally, Pangea supercontinent was formed surrounded by circum-Pacific subduction zones.Coevally with TAO, another accretionary orogen developed, ten million square kilometres in area, known as the Central Asian Orogenic Belt (CAOB) located at the north-eastern part of the Pangea. The CAOB is traditionally considered to be a type example of the accretionary orogen, marked by dominance of oceanic units, i.e. island arc, back arcs, accretionary wedges of various ages. This orogen is expected to develop by peripheral accretion from the paleo-Pacific. However, its location between the northerly Siberian Craton and the southerly Gondwana derived continental blocks implies that it is in a position of a typical "*interior*" orogen.

Altogether, the Paleozoic CAOB shares features of both types of orogens, typified by the "*interior*" collisional Caledonian and Variscan orogens and purely "*peripheral*" accretionary. This dichotomy opens two major issues: 1) The two giant accretionary systems, CAOB and TAO, evolved simultaneously in the interior and peripheral configurations, respectively. This would invalidate hypothesis that major accretion occurs only along "*peripheral*" orogens while continental collision develops only in the "*interior*" configuration. 2) The CAOB was originally a prolongation of peripheral/accretionary circum-Pacific orogen which became later incorporated into the interior/collisional Eurasian orogen during late stages of the Pangea formation.

In order to solve which alternative is the right one we discuss geodynamic evolution of the eastern part of the CAOB, which is located close to ancient Pacific border in the east, but it is limited by the Siberian craton in the north and North Chinese craton in the south. We provide first a review of architecture of the belt followed by newly constrained tectonostratigraphy of principal units based on existing and new geochronological, mainly U-Pb zircon data. This analysis allows identification and geodynamic setting of continental, pericontinental and intraoceanic lithotectonic assemblages accross Mongolia, China and Russia and their mutual affinities. To this end we provide a review of Hf isotopic data from principal units to characterize the interior or exterior nature of the orogenic system. Finally, the principal tectono-metamorphic events and magmatic evolution of the belt are revised to constrain the cycles of advancing and retreating subduction events of Paleo-Asian ocean before being intergrated into Pangea supercontinent.

It can be shown that the growth of eastern Pangea involves three contrasting orogenic cycles: 1) Baikalian cycle (570-540 Ma) consists of accretion of peri-Rodinian continental, Mirovoi and Panthalassan oceanic fragments to the Siberian margin followed by extensional HT reworking, the growth of magmatic arc, giant accretionary wedge and intraoceanic basin. 2) Altai cycle is typified by crustal thickening followed by syn-extensional melting of the accretionary wedge (420-380 Ma) and the opening of Mongol-Okhotsk ocean. Cycle terminates by the growth of migmatites domes (370-340 Ma), thrusting of intraoceanic ophiolites and relamination of molten material beneath oceanic crust. 3) Paleotethysian cycle (300-220 Ma) is represented by oroclinal buckling of the hybrid oceanic lithosphere. The Baikalian cycle is related to advances and retreats of Panthalassa ocean. Altai cycle results from dynamically advancing and retreating subduction of young and hot Rheic type ocean beneath Pacific one. This hot, weak and hybrid lithospheric segment was shortened and incorporated into Pangea supercontinent during opening of Paleotethys ocean.This complex template of Eastern Pangea is correlated with the interior European system and discussed with the whole dynamics of the formation of Pangea supercontinent.

A Comparison of Nd isotopes of Granitoids from the Central Asian Orogenic Belt and Qinling-Dabie Orogen and Implications for Understanding ofCrustal Growth from Accretion to Collision

Tao Wang[1,2], Xiaoxia Wang[3], Ying Tong[1], He Huang[1], Shan Li[1],Jianjun Zhang[1], Lei Guo, LeiZhang[1], Penguin Son[1], Qie Qin[1]

[1]*Key Laboratory of Deep-Earth Dynamics, Ministry of Natural Resources, Institute of Geology, ChineseAcademy of Geological Sciences, Beijing 100037, China* Taowang@cags.ac.cn

[2]*Beijing SHRIMP Center, Beijing, 100037, China*

[3]*MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources,Chinese Academy of Geological Sciences, Beijing 100037, China.* xiaoxiawang@hotmail.com

Key words: Granitoids, accretionary orogeny, juvenile crust, Central Asian Orogenic Belt.

Orogens can be generally divided into two types: accretionary and collisional orogens. What are fundamentaldifferences in deep-crustal compositions and architecture from accretion to collision and how to identify them have not been well understood. This is one of the major aims of IGCP 662 project (www.igcp662.org.cn).

The Central Asian Orogenic Belt (CAOB) is a typical and the world's largest Phanerozoic accretionary orogenic belt and the most important site of Phanerozoic continental growth (Jahn 2000). Comparably, the Qinling-Dabie orogen is a typical for collisional or composite orogen. The two orogens are the best ones for such comparisonbecause both of them were formed during Paleozoic and have the same cratons (North China-Alshan craton). This study attempts to compare them and discusses these problems by juvenile compositions defined by Nd-Hf isotopic mapping of granitoids in the southwestern segment of the Central Asian Orogenic Belt (CAOB), a typical and the world's largest Phanerozoic accretionary orogenic belt, and in the Qinling-Dabie Orogen, a typical subductional-collisional orogen.

The CAOB, bounded by the Siberian Craton to the north and the Tarim-North China Craton, is the most important site of Phanerozoic continental growth on the Earth (e.g., Şengör et al., 1993; Jahn et al., 2000; Kovalenko et al., 2004), even if the growth was probably overestimated (Kröner et al., 2013). The Nd isotopes and sources of granitein Central Asian Orogenic Belt can be classified into four types (Wang et al., 2017): (1) juvenilecrust source, characterized by young Nd-mode age (0.8-0.2Ga), positive εNd(t) value (0 to +8), and positive εHf(t) value,mainly distributed in the Altai (Wang T et al., 2009), the easternand western Junggar region, the southern Great Khinganand adjacent area (Yang et al., 2017); (2) slightly-mixedsource, characterized by slightly old Nd-mode age (1.0-0.Ga), εNd(t) value around 0, and slightly old Hf-mode age (1.0-0.6 Ga); (3) mixed source, where obvious features of mixedsource area and isotopes are shown, characterized by olderNd-mode age (1.6-1.0 Ga), lower εNd(t) value (-10 to 0), olderHf-mode age (2.0-1.2 Ga), and a εHf(t) value (-15 to +7)varies widely. The granite in the Altai region can be consideredas a typical example; (4) ancient source, characterized byvery old Nd-mode age (2.8-1.6 Ga), very low εNd(t) value (-23to -6), very old Hf-mode age (3.0-1.6 Ga), and a εHf(t) value (-20 to -5). These granites are mainly exposed to some Precambrianmicro-continental-segments or old terrains, which areformed by recycling crustal materials (Wang T et al., 2017).

The Qinling-Dabie Orogen is one of the main orogenic belts in Asia and mainly consists of four distinct blocks or terranes. These are, from north to south, the North China Craton (NCC), the North Qinling Belt (NQB), the South Qinling Belt (SQB) and the South China Craton (SCC). Voluminous Paleozoic and Mesozoic granitoids in the southern margin of the NCC have εNd(t) values from −21.9 to −10.9, from −14 to +5.4 in the NQB, from −10 to −1.8 in the SQB and from −6.5 to -3.2 in the northern margin of the SCC, respectively (Wang et al., 2015). Correspondingly, Nd model ages (TDM) vary from 2.82 to 1.47 Ga，2.38 to 0.73 Ga, 1.79 to 1.13 Ga and 1.52 to 1.25 Ga, respectively (Wang et al., 2015). These results indicate the southern margin of the NCC with old basement rocks, the SQB and the northern margin of the SCC with slightly older basement rocks and the NQB with more complex basement rocks. Mesozoic granitoids in the Dabie Orogen show εNd(t) values ranging from −22 to −8, corresponding TDM from 1.8 to 2.0 Ga (Hong et al., 2003). It suggests old basement rocks, being similar to those of the NCC, for the Dabie Orogen.

All these signatures indicate that the granitoids in the CAOB have significant differences in Nd isotopic compositions from collisional orogens such as Qinling-Dabie Orogen in the central China (Hong et al. 2003; Wang et al., 2015), suggesting different deep crustal compositions for them. Compared with the general orogens, the CAOB has much juvenile compositions and more crustal growth (juvenile materials) during Phanerozoic time, distinct from a typical collisional orogen. This study reveals that isotopic compositions of magmatic rocks can trace deep compositions of orogens and provide significant information for understanding compositions and evolution stages (from juvenile accretionary, subductional to collisional) of orogens.

Acknowledgements

This research was supported financially by the NSFC projects (U1403291, 41802074, 41830216) and projects of the China Geological Survey (Nos. 1212011120477, 1212010611803, 1212010811033, 12120113096500, and 12120113094000 and DD20160123). This paper contributes to IGCP 662 and DDE (Deep-time Digit Earth).

References

Hong D.W., Wang T., Tong Y., Wang X.X., 2003.Mesozoic granitoids from North China Block and Qinling-Dabie-Sulu Orogenic Belt and their deep dynamic process. Earth Science Frontiers 10(3),231-25.

Jahn, B.M., Wu, F.Y., Chen, B., 2000. Granitoids of the Central Asian Orogenic Belt andContinental Growth in the Phanerozoic. Transactions of the Royal Society ofEdinburgh. Earth Sciences 91, 181–193.

Kovalenko, V.I., Yarmolyuk, V.V., Kovach, V.P., Kotov, A.B., Kozakov, I.K., Sal'nikova, E.B.,Larin, A.M., 2004. Isotope provinces, mechanisms of generation and sources of thecontinental crust in the Central Asian Mobile Belt: geological and isotopic evidence.Journal of Asian Earth Sciences 23 (5), 605–627.

Kröner, A., Kovach, V., Belousova, E., Hegner, E., Armstrong, R., Dolgopolova, A., Seltmann, R.,Alexeiev, D.V., Hoffmann, J.E., Wong, J., Sun, M., Cai, K., Wang, T., Tong, Y., Wilde, S.A., Degtyarev, K.E., Rytsk, E. 2013. Reassessment of continental growth during the accretionary history of the CentralAsian Orogenic Belt. Gondwana Research, http://dx.doi.org/10.1016/j.gr.2012.12.023

Sengör, A.M.C., Natal'in, B.A., Burtman, V.S.,1993. Evolution of the Altaid tectonic collageand Palaeozoic crustal growth in Eurasia. Nature 364, 299–307.

Wang T, Jahn B.M., Kovach V.P., Tong Y., Hong D.W., Han B.F., 2009. Nd–Sr isotopic mapping of the Chinese Altai and implications for continental growth in the Central Asian Orogenic Belt. Lithos 110(1), 359-372.

Wang X.X., Wang T., Ke C.H., Yang Y., Li J.B., Li H.Y., Qi Q.J., Lv X.Q., 2015. Nd-Hf isotopic mapping of Late Mesozoic granitoids in the East Qinling orogen, central China: Constraint on the basements of terranes and distribution of Mo mineralization. Journal of Asian Earth Sciences 103,169-183.

Yang Q.D., Wang T., Guo L., Tong Y., Zhang L., Zhang J.J., HouZ.Q., 2017. Nd isotopic variation of Paleozoic–Mesozoic granitoids from the DaHinggan.

The phenomenon of prolonged magmatism within the Olkhon terrane (northern segment of the Central Asian Orogenic Belt)

D.P. Gladkochub[1], T.V. Donskaya[1], E.V. Sklyarov[1], V.S. Fedorovsky[2], A.M. Mazukabzov[1]

[1]*Institute of the Earth's crust SB RAS, Irkutsk, Russian Federation,* gladkochub@mail.ru

[2]*Geological Institute RAS, Moscow, Russian Federation,*valentinfedorovskii@mail.ru

The Baikal collisional metamorphic belt is a part of the Early Paleozoic accretionary-collisional system of the Central Asian Orogenic belt composed of Derba, Kitoikin, Sludyanka, Olkhon and Barguzinmetamorphic terranes that located along southern boundary of the Siberian craton [Donskaya et al., 2000]. Main events of collisional metamorphism and magmatism in all these terranes spanned a period from 500 to 470 Ma [Salnikovaet al., 1998, Donskaya et al., 2000, Nozhkin et al., 2005, Gladkochub et al., 2008, 2019 etc.]. However, in the Olkhon terrane, magmatism was prolonged for another 20 million years (from 470 to 450 Ma). This is a distinctive feature of the Olkhonterrane compared to other terranes of the Baikal collisional belt.

The Olkhon terrane is a collage of numerous chaotically mixed tectonic units composed of rock complexes of different ages originated in different tectonic settings [Donskaya et al., 2017]. Main events of metamorphism and syn-metamorphic magmatism in Olkhon terrane took place from 500 to 470 Ma. The Olkhon collisional collage results from two main deformation events: thrusting followed by strike-slip faulting. Strike-slip faulting dramatically reworked the earlier thrust system and produced the currently exposed tectonic framework of shear zones. The strike-slip tectonics also determined the start of the synorogenic collapse of the collisional structure. The wide development of the strike-slip tectonics of the Olkhon terranedistinguishes this terrane from other terranes of the Baikal collisional belt.The formation of numerous granite veins in the Olkhon region was related to strike-slip deformations. The U-Pb zircon ages of granite veins corresponding to the latest strike-slip event vary from 470 to 460 Ma.

Moreover, in the Olkhon terrane there are some intrusions and few rock assemblages possibly related to a post-collision extension or/and plume-tectonics. They are, namely, gabbro-granite mingling dykes; the Tazheransyenite, Ne-syenite, svyatonosite, and sub-alkaline gabbro; rare-metal granite; injection carbonates and carbonate-silicates; medium-, high-, and ultrahigh metasomatic rocks.The Tazheransyenites and Ne-syenites, high-temperature metasomatic rocks and gabbro-granite mingling dykes yield U-Pb ages from 470 to 450 Ma [Sklyarov et al., 2009,Fedorovsky et al., 2010,Starikova et al., 2014, unpublished data].

Thus, there is an overlap of ages associated with the strike-slip event and plume event in the Olkhon terrane, which is a unique feature of this terrane. Prolonged magmatism in the Olkhon terrane is likely to reflect the influence of the mantle plume on the collision tectonics at the stage of collapse of the Early Paleozoic collision orogen.

This research was supported in part by grants from the Russian Foundation for Basic Research # 19-05-00266.

References

Donskaya, T.V., Sklyarov, E.V., Gladkochub, D.P., Mazukabzov, A.M., Sal'nikova, E.B.,Kovach, V.P., Yakovleva, S.Z., Berezhnaya, N.G., 2000. The Baikal collisional metamorphicbelt.Doklady Earth Sciences, 374, 1075–1079.

Donskaya, T.V., Gladkochub, D.P., Fedorovsky, V.S., Sklyarov, E.V., Cho, M., Sergeev, S.A.,Demonterova, E.I., Mazukabzov, A.M., Lepekhina, E.N., Cheong, W., Kim, J., 2017.Pre-collisional (>0.5 Ga) complexes of the Olkhon terrane (southern Siberia) as anecho of events in the Central Asian Orogenic Belt.Gondwana Research, 42, 243–263.

Fedorovsky, V.S., Sklyarov, E.V., Izokh, A.E., Kotov, A.B., Lavrenchuk, A.V., Mazukabzov,A.M., 2010. Strike-slip tectonics and subalkaline mafic magmatism in the Early Paleozoiccollisional system of the western Baikal region. Russian Geology and Geophysics, 51,534–547.

Gladkochub, D.P., Donskaya, T.V., Wingate, M.T.D., Poller, U., Kröner, A., Fedorovsky, V.S.,Mazukabzov, A.M., Todt, W., Pisarevsky, S.A., 2008.Petrology, geochronology, andtectonic implications of c. 500 Ma metamorphic and igneous rocks along the northernmargin of the Central-Asian Orogen (Olkhon terrane, Lake Baikal, Siberia). Journal of the Geological Society of London, 165, 235–246.

Gladkochub, D.P., Donskaya, T.V., Stanevich, A.M., Pisarevsky, S.A., Zhang, S., Motova, Z.L.,Mazukabzov, A.M., Li, H., 2019. U-Pb detrital zircon geochronology and provenance of Neoproterozoicsedimentary rocks in southern Siberia: New insights into breakup ofRodinia and opening of Paleo-Asian Ocean. Gondwana Research, 65, 1–16

Nozhkin, A.D., Bayanova, T.B., Turkina, O.M., Travin, A.V., Dmitrieva, N.V., 2005. Early Paleozoicgranitoidmagmatismand metamorphism on the Derba microcontinent, easternSayan region: new isotope–geochronological data. Doklady Earth Sciences, 404,1084–1089.

Salnikova, E.B., Sergeev, S.A., Kotov, A.B., Yakovleva, S.Z., Steiger, R.H., Reznitskiy, L.Z.,Vasil'ev, E.P., 1998. U-Pb zircon dating of granulitemetamorphism in the Sludyanskiycomplex, eastern Siberia.GondwanaResearch, 1, 195–205.

Sklyarov, E.V., Fedorovsky, V.S., Kotov, A.B., Lavrenchuk, A.V., Mazukabzov, A.M., Levitsky,V.I., Sal'nikova, E.B., Starikova, A.E., Yakovleva, S.Z., Anisimova, I.V., Fedoseenko, A.M.,2009. Carbonatites in collisional settings and pseudo-carbonatites of the Early PaleozoicOl'khon collisional system.Russian Geology and Geophysics, 50, 1091–1106.

Starikova, A.E., Sklyarov, E.V., Kotov, A.B., Sal'nikova, E.B., Fedorovskii, V.S., Lavrenchuk,A.V., Mazukabzov, A.M., 2014. Vein calciphyre and contact Mg skarn from theTazheran massif (Western Baikal area, Russia): age and genesis. Doklady Earth Sciences, 457, 1003–1007.

Does continental crust grow significantly by collision and/or subduction?

Suzanne Y. O'Reilly[1] and W. L. Griffin[1]

[1]*ARC Centre of Excellence for Core to Crust Fluid Systems of Excellence for Core to Crust Fluid Systems (CCFS) and GEMOC, Macquarie University, NSW 2109, Sydney, Australia,*

sue.oreilly@mq.edu.au; bill.griffin@mq.edu.au

Introduction

Over the last decade, our view of the Earth has changed dramatically with the rapid development of planetary- and lithosphere-scale seismic tomography at increasingly higher resolution, and other global datasets such as gravity, magnetic and magnetotellurics (MT). We now have access to geochemical (including isotopic) data for a large proportion of the elements in the periodic table, at very low levels in bulk rocks and in tiny volumes of tiny volumes. These advances, along with imaging of microstructures, enormous databanks for tectonic syntheses, and robust geodynamic modelling, have generated new concepts in understanding lithosphere evolution, structure and processes. The latest high-resolution MT data reveal dramatic vertical lithospheric structures invisible to seismic signals. Our Global Lithospheric Architecture Mapping (GLAM) project has worked over 15 years to integrate geophysical, geochronological, tectonic, microstructural, petrological and geochemical data in a GIS digital environment and has illuminated the 4D structure and composition of the lithospheric mantle through time beneath continents and some ocean basins (Begg et al, 2009). Using this unique database referenced to the continually refined global tomography model of S. Grand (Pers. comm.) we can deconvolve the impact of collision and subduction processes on crustal formation and stability.

Crust formation

Crust is formed and shaped by mantle processes. New crustal additions can happen by:

- vertical addition (magma addition from mantle melts at any crustal level from the crust-mantle boundary to the surface)
- horizontal accretion in collision/subduction zones

Vertical addition to continental crust has taken place continually and, at least since the Archean, substantial underplating and overplating at the crust-mantle boundary (CMB) has accompanied all basaltic province volcanism. This can result in new mafic lower crust around 5 km thick in ~10 my with common vertical intrusion addition rates of 900m/my from one event. A spectacular example is the Bushveld intrusion that added around 600,000 cubic km (with a vertical height of 10 km) within the crust in one large-scale magmatic episode.

The effects of extrusive additions are clearly visible where igneous provinces are still exposed. The underplating and overplating additions are clearly seen in seismic reflection profiles and result in the transitional crust-mantle boundary (CMB) typical of all young tectonic regions that have experienced basaltic volcanism. All xenoliths from lower crustal depths show it is composed of mafic rocks (generally mafic granulites and pyroxenites) that may show quasi-igneous microstructures to those with high degrees of deformation. Such lower crust appears to be rheologically coupled with the uppermost mantle and is very rarely exposed.

The relative buoyancy and rheology of lithospheric mantle domains control the longevity of crustal terranes: significant volumes of accreted crust only have longevityif underlain by “life rafts” of Archeancratonic material. So it is imperative to understand the formation and properties of lithospheric mantle formed at different times, its longevity and transformations through Earth’s evolution, and the implications for different outcomes for the lifespan of crustal domains in different collision/subduction scenarios.

The GLAM mapping shows thatcontinents can only “grow”substantially by accretion of cratonic blocks with Archean buoyant mantle heritage; theseaccreted blocks thenriftagain, disperse and re-assemble in different configurations, as geotectonicprocesses successively repeat rifting ofcratonic blocks, formation of new ocean and then docking in a different configuration – a shifting 4D Earthscape.

Convergent geochronology datasets of Hf isotopic model ages for zircons and Re-Os model ages for mantle sulfides and platinum group minerals, reinforced by other geochemical and tectonic criteria, indicate that over 75% of the SCLM and its overlying crust (now mostly lower crust) formed at about 3.5 Ga, probably in a series of global overturn events that marked a change in Earth’s fundamental geodynamic behaviour. The persistence of ancient lithospheric mantle, even in ocean basins (O’Reilly et al., 2009), attests to its buoyancy (depleted composition) and may also explain basaltic magmas with geochemical signatures of ancient lithospheric components (EM1 and EM2; O’Reilly et al, 2009; Boyet et al. 2019)

Formation, evolution and life-raft role of the Sub-Continental Lithospheric Mantle (SCLM)

Earth Scientists have two ways of examining and mapping the structure and composition of the subcontinental lithospheric mantle (SCLM): remotely sensed geophysical surveys, and studies of direct mantle samples from volcanic rocks or exposed terranes. Interpretation of both types of data requires an understanding of some basic strengths and limitations of each approach.

Continents survive through time only if they have a thick, stiff, buoyant underlay (the "life raft") of depleted SCLM; without this support, the weak continental crust will ultimately be "stirred" back into the convecting mantle. It is important to recognize that a buoyant lithospheric mantle requires not only a high Mg# (the result of melt extraction) but a low content of FeO (<8 wt%; Griffin et al., 2018). Such FeO-depleted mantle is not produced by the melting processes that function on Earth today, as observed forbasalts produced at spreading ridges or beneath Large Igneous Provinces. Regardless of the degree of depletion, the FeO content of the residues of these "modern" processes stays constant at around 8%, and they are gravitationally unstable relative to the convecting mantle. Experimental studies suggest that such *Fe-depleted mantle residues were produced by a specifically Archean process,* involving high-temperature, high-degree melting at depths of >150 km. These residues range from dunite (dominantly olivine) to harzburgite (olivine + orthopyroxene); the extracted magmas may have been broadly komatiitic in composition (Griffin et al., 2018).

A worldwide compilation of Re-Os data on mantle peridotites (both whole-rock and single-sulfide analyses) has failed to find any Os TRD model ages older than 3.5 Ga, and shows one major peak from ca 3.1 Ga to 2.5 Ga. This suggests that no significant volumes of SCLM were generated before ca 3 Ga, and that the processes responsible for its formation did not function after ca 2.5 Ga. This one simple observation suggests that the scarcity of EoArchean to PaleoArchean crustal rocks simply reflects the lack of an SCLM "life-raft". The available zircon data (U-Pb, Hf- and O-isotopes) suggest that from 4.5 Ga to ca 3.4 Ga, Earth's crust was essentially stagnant and dominantly mafic in composition. This quiescent state was broken by pulses of juvenile magmatic activity at ca 4.2 Ga, 3.8 Ga and 3.3–3.4 Ga, and this scarce information from the oldest crustal rocks contain clues to the genesis of the SCLM.

Continental growth in collision/subduction tectonic regimes?

GLAM mapping of global regions, especially the western US, Tibet, East Central Asia Orogenic Belt (ECAOB) reveals that continents grow bycollision of continental domains overlying Archean blocks: continents cannot grow or be formed by collision of juvenile arcs.

Juvenile lithosphere lacking an Archean component is preferentially destroyed and becomes part of the tectonic recycling process. The ECAOB is atextbook example of the package of the sub-arc mantle domain is initially thermally buoyant, but on cooling becomes dense and the package delaminates. Newly upwelling asthenosphere causes heating and magmatism:the new fertile SCLM cools, becomes unstable (due to increased density) and delaminates with cyclicity on variable timescales.

Conclusion

Integration of all the disparate datasets presented, indicates that horizontally accreted new crust does not substantially survive unless it is underlain by Archean lithosphere. Most new crust generated in juvenile subduction settings is ephemeral and is delaminated on a relatively short timescale – leaving only thin ribbon-like remnants in the geological record: this process does not grow enduring volumes of new continental crust.

References

Begg, G.C., Griffin, W.L., Natapov, L.M., O'Reilly, S.Y., Grand, S.P., O'Neill, C.J., Hronsky, J.M.A., PoudjomDjomani, Y., Swain, C.J., Deen, T. and Bowden, P. 2009. The lithospheric architecture of Africa: Seismic tomography, mantle petrology and tectonic evolution. Geosphere 5, 23-50.

Boyet, M., Doucelance, R., Israel, C., Bonnand, P., Auclair, D., Suchorski. K. and Bosq, C., 2019. New Constraints on the Origin of the EM-1 component revealed by the measurement of the La-Ce isotopesystematics in Gough Island lavas.

Griffin, W.L., O'Reilly, S.Y., Afonso, J.C. and Begg, G. 2010. The composition and evolution of lithospheric mantle: A re-evaluation and its tectonic implications. Jour. Petrology 50, 1185-1204.

Griffin W.L. Belousova E.A., O'Neill C., O'Reilly, S.Y., Malkovets, M., et al., 2014, The world turns over: Hadean-Archean crust-mantle evolution, Lithos189:, 2-15.

Griffin, W.L. and O'Reilly, S.Y. 2018. The earliest subcontinental mantle. In M. Van Kranendonk, V.C. Bennett and J.E. Hoffmann (eds.) Earth's Oldest Rocks. 2nd edition. Elsevier, Amsterdam pp. 881-102.

O'Reilly, S.Y., Zhang, M., Griffin, W.L., Begg, G. and Hronsky, J. 2009. Ultradeep continental roots and their oceanic remnants: a solution to the geochemical "mantle reservoir" problem? Lithos 112, Supp. 2, 1043-1054.

The Orkhon-Selenge volcanic-plutonic belt of the Mongol-Okhotsk Orogen:
Petrology and new geochronological data

O. Gerel, B. Munkhtsengel, A. Chimedtseren, B. Batkhishig, B. Altanzul, B.Soyolmaa

Mongolian University of Science & Technology, Ulaanbaatar, Mongolia.

gerel@must.edu.mn

The Mongol-Okhotsk orogen is a tectonic collage of Devonian-late Jurassic age accreted in the late Paleozoic to early Mesozoic and consists of the Permian to Jurassic Orkhon-Selenge and late Carboniferous-early Permian Khangai continental arcs. The arcs are composed of continental margin overlap assemblages, turbidite terranes and subduction zone terranes. The Mongol-Okhotsk orogen formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terrane beneath the southern margin of the North Asian craton and previously accepted terranes (Nokleberg ed., 2010). The Orkhon-Selenge volcanic-plutonic belt extends for 2,000 km in northern Mongolia and the Transbaikal region. The belt consists of calc-alkaline volcanic and plutonic rocks in the lower part of the section grading upward into bimodal alkaline rocks, and Kovalenko and Yarmolyuk (1990) interpreted this belt was formed in rift zones.Despite long years study many controversial questions still remain.The Orkhon-Selenge belt is composed of Proterozoic basement, Permian Khanui Group volcanics, early Triassic plutonic suite of the Selenge Complex, the Erdenet porphyry association with Cu-Mo deposit, and late Triassic-early Jurassic volcanic rocks of Mogod Formation and Orkhon Complex dikes and intrusions. We present new geochronological data and geochemistry of volcanic and plutonic rocks. Large granitoid plutons mapped as Neoproterozoic basement rocks of gabbro-diorite-granodiorite-granite suite are mid- to high-Kcalc-alkaline series of I-type, metaluminous, depleted in Nb, Rb, Pand are typical volcanic arc rocks with U-Pb age of 263.8±1.7Ma and 260.3±3.4Ma. The U-Pbisochron age data from basement in central uplifted Erdenetblock of the Orkhon-Selenge belt, previously interpreted as Neoproterozoic also was dated as Permian (277.5±5.1 and 283.5±4.6Ma, Munkhtsengel et al., 2009). Simultaneously, some granitoidspreviously belong to Neoproterozoic show Ordovician age (452±6 and 442±5Ma). These ages are in agreement with Ordovician granitoids intruded in the Khentii. Permian volcanic rocks of the Khanui

Group are divided into lover rhyolite, dacite, tuffs and sedimentary rocks that have typical volcanic arc geochemical signatures, and upper sequence of mafic trachybasalt-trachyandesite-trachydacite-rhyolite series is related to subalkaline, but still with typical volcanic arc geochemistry. Plutonic rocks in the Orkhon-Selenge belt are classified to the Selenge Complex forming gabbro-granodiorite-granite series are wide spread occupying an area of 2800 km^2. Geochemically, the Selenge Intrusive Complex exhibits typical subduction-related geochemical signatures that are enriched in U, Th, Ba, Rb, Zr, depleted Nb and Ti, and may be classified as moderate to high K-calc-alkaline, I-type, with Na_2O > K_2O (Gerel and Munkhtsengel, 2005). Ages of Selenge complex are defined from 245 to 210 Ma. Porphyry association comprising quartz diorite-granodiorite-granite and leucograniteis common in the belt, but mineralization is associated with granodiorite porphyry of 242 Ma, mineralization age of molybdenite of 240 Ma (Watanabe and Stein, 2000), and K-alunite of 223.5±1.9 Ma (Kavalieris et al., 2017). Porphyritic rocks with mineralization show adakitic signature with high Sr/Y and La/Yb, Nb depletion and lack of Eu anomaly (Gerel et al., 2017) Very characteristic is depletion in mid-HREE. The volcanic rocks related to Mogod Formation poorly dated of 228-195 Ma are high -Al, subalkaline K-Na series, but some basalts and trachytes are alkaline. They are enriched in LREE, Nb, Zr, Hf and Li, Be, B and F without or have positive Eu anomaly. Comagmatic with these rocks granites that form dikes and shallow plutons geochemically are very similar to the Selengegranitoids. Based on geochemistry and geochronology we conclude that the Orkhon-Selenge volcanic-plutonic belt was formed in active continental margin of the Mongol-Okhotsk Ocean with volcanic arc rocks in Permian dated of 270-280 Ma (Munkhtsengel, 2007). Intrusive rocks classified previously as Neoproterozoic show 268-253 Ma and could be comagmatic with Permian basalt-trachybasalt rocks. These granitoids are very similar with early Triassic Selenge Complex rocks of gabbro-granodiorite-granite-quartz syenite series. Maybe some of them are related to the Selenge Complex, other are Ordovician and require detailed study. The Cu-Mo mineralization is associated with granodiorite porphyry stocks cut the Selenge Complex granitoids. Porphyries are similar to host granodiotites by geochemical features. Similar geochemistry of late Permian - early Mesozoic magmatic rocks show similar source and additional precise dating is needed to understand the magmatic history of the Orkhon-Selenge belt.

References

Gerel, O. and Munkhtsengel B., 2005.ErdenetiinOvoo porphyry copper molybdenum deposit in northern Mongolia, in Seltmann, R., Gerel, O., and Kirwin, D., eds., Geodynamics and metallogeny of Mongolia with special emphasis on copper and gold deposits: London, UK, p. 85-105.

Gerel, O., Batkhishig B, Munkhtsengeland B. Chimedtseren A. 2013. Porphyry type deposits associated with adakitic magma: case study of porphyry Cu-Au and Cu-Mo deposits in Mongolia. The 8th International Forum on Strategic Technology. Ulaanbaatar, Vol. 1, p. 537-542.

Kavalieris I., Khashgerel B., Morgan L.E., Undrakhtamir A., Borohul A. 2017. Characteristics and 40Ar/39Ar Geochronology of the Erdenet Cu-Mo Deposit, Mongolia. Economic Geology, Vol. 112, p. 1033–1053.

Kovalenko, V.I. and Yarmolyuk, V.V., 1990, Evolution of magmatism in Mongolian structures, in Evolution of Geological Processes and Metallogenesis of Mongolia: Moscow, U.S.S.R. Academy of Sciences, p. 23-54 (in Russian).

Munkhtsengel B., Tsuchiya N., Dan D and Gerel O. 2009. Intrusive rocks in the Erdenet area and SHRIMP U-PB zircon age of host rocks and relation to Mineralization age of the ErdenetiinOvoo deposit Mongolian Geoscientist 34, p. 120-125 (In Mongolian).

Nokleberg, W.J., ed., 2010, Metallogenesis and tectonics of northeast Asia: U.S. Geological Survey Professional Paper 1765, 624 p.

Watanabe, Y., and Stein, H. J., 2000. Re-Os ages for the Erdenet and TsagaanSuvarga porphyry Cu-Mo deposits, Mongolia, and tectonic implications: Economic Geology, v. 95, p. 1537–1542

South Siberian post-collision magmatic belt: geochemical features of felsic and mafic rocks

T.V. Donskaya[1], D.P. Gladkochub[1], A.M. Mazukabzov[1], S.A. Pisarevsky[2]

[1]*Institute of the Earth's crust SB RAS, Irkutsk, Russian Federation,* tatiana_donskaya@mail.ru

[2]*The Institute for Geoscience Research (TIGeR), Department of Applied Geology, Curtin University, WA 6845, Australia,* sergei.pisarevskiy@curtin.edu.au

The Siberian Craton was assembled in Paleoproterozoic by collisions of Archean and Paleoproterozoic superterranes. The South Siberian post-collision magmatic belt has beenformed during the final stage of thatassembly and possibly related to its incorporation into the Paleoproterozoic supercontinent. This belt is mainly composed of the ca. 1.88 – 1.84 Ga granitoids and felsic volcanics with minor mafic intrusions.Despite the similarage and geodynamic settings, there are geochemical differences betweengranitoids and felsic volcanics in variousparts of the belt.

Post-collisional felsic rocks of the South Siberian belt in the Baikal uplift include biotite-amphibole granites, rapakivi-like granites, charnockites, and felsic volcanics. All granitoids and felsic volcanic of the Baikal uplift show similargeochemical characteristics. For example, (i) all of them demonstrate high alkalinity;(ii) almost all granitoids and volcanic are ferroan; (iii) allshow geochemical signaturesof the *A*-type granites. These granitoids and volcanics show variable negative $\varepsilon_{Nd}(t)$ values. Some granitoids were produced from the lower crustal sources, butmost granitoids and felsic volcanic were generated from mixed sources derived both from crust and from mantle in variousproportions.According to the Pearce's classification, majority granitoids and felsic volcanics correspond to thewithin-plate granites. Thus, the post-collisional granitoids and volcanic of the South Siberian belt in the Baikal uplift are geochemicallysimilar to the granites formed in the intracontinental setting (i.e. anorogenic granites).We suppose that within-plate geochemical characteristics of the 1.88–1.84 Ga post-collision granitoids and volcanics in the Baikal uplift suggest the approximately 100 million years earlier collisional events in this area, which took place at 1.98–1.97 Ga.

However, post-collisional felsic rocks of the South Siberianmagmatic belt in the Birusa and Sharyzhalgaiuplifts include biotite-amphibole granites, biotite granites, two-mica granites, tonalities, diorites, and felsic volcanics. These granitoids and felsic volcanic are geochemically close to TTG-type, calc-alkaline *I*-type, *S*-type and *A*-type granites.Their alkalinity varies.Theyare both magnesian and ferroan. These granitoids and volcanic show variable negative $\varepsilon_{Nd}(t)$ values and rarely slightly positive $\varepsilon_{Nd}(t)$ values. The geochemical and isotopic features of granitoids and volcanic in the Birusa and Sharyzhalgaiuplifts reflect both mixed (crust–mantle) sources and solely crustal sources. We believe that the diversity of compositions of post-collisional granitoids and volcanic in the Birusa and Sharyzhalgaiuplifts is also associated with previous collisional events in this area that took place at 1.90–1.87 Ga, i.e. shortlybefore the emplacement of granitoids and volcanics.In this part of the Siberian craton, the post-collisional granitoids and volcanic can be locally considered as collisional rocks, according to their diverse geochemical characteristics.

Mafic intrusions of the South Siberian post-collision magmatic beltare subordinate to felsic intrusions. All dolerites, gabbro and mafic volcanics are sub-alkaline and alkaline. All of them demonstrate negative Nb-Ta anomaliesin multi-element diagrams. Most of them are characterized by close to zero or negative $\varepsilon_{Nd}(t)$ values. We believe that most ofmafic rocks of the South Siberian were generated from enriched lithospheric mantle source with a subduction-derived component. The geochemical data of mafic intrusions of the South Siberian belt reflect a composition of Paleoproterozoic subcontinental lithospheric mantle under the Siberian craton. This mafic magmatismmight be related to subduction processes preceded the Siberian craton's assembly.

We conclude thatthe geochemical features of felsic and mafic rocks the South Siberian post-collision magmatic belt are related to subduction and collisional eventspreceded formation of the belt.

This research was supported in part by grants from the Russian Foundation for Basic Research # 18-05-00764.

Early Carboniferous metamorphism of the Neoproterozoic South Tien Shan-Karakum basement: New geochronological results from Baisun and Kyzylkum, Uzbekistan

D. Konopelko[1], [2] Yu. Biske[1], K. Kullerud[3], R. Seltmann[4], I. Safonova[2]

[1]St. Petersburg State University, 7/9 University Embankment, St. Petersburg, 199034, Russia

[2]Novosibirsk State University, 1 Pirogova St., Novosibirsk, 630090, Russia[3]Norwegian Mining Museum, P.O. Box 18, 3602 Kongsberg, Norway[4]Natural History Museum, CERCAMS, London SW7 5BD, UK

Paleozoic evolution of the western Tien Shan, which is built up on the basement of the Karakum continent, is poorly constrained compared to the better investigated Tien Shan terranes along the margin of the TarimCraton. We present magmatic, metamorphic and detrital zircon ages for the regionally metamorphosed Baisun block and the metasediments comprising the Karakum basement in the westernmost parts of the South Tien Shan terrane. Age spectra of detrital zircon from metasediments of the Baisun metamorphic block and the western South Tien Shan show remarkable similarities over the vast area extending for ca. 500 km and are characterized by major Neoproterozoic peak at 1200 – 600 Ma and smaller peaks at 2300 - 1700 and 2700 - 2400 Ma. The 570 - 540 Ma ages of the youngest grains define late Neoproterozoic (Ediacaran) – early Cambrian maximum depositional ages of the metasediments. Comparison of the obtained age spectra with those published for the adjacent Tien Shan terranes indicate that the detrital zircon grains in the studied Ediacaran sediments were derived from the southern Precambrian continents of Karakum and Tarim while transport from the Northern Tien Shan was limited. The age of the Barrovian metamorphism in the Baisun block is constrained by ages of anatectic granites in the range 352 - 340 Ma, corresponding to early Carboniferous. These ages well match the 340 - 330 Ma ages, established for the adjacent Lolabulak and Garm metamorphic blocks. Based on the regional distribution of suture zones we suggest that during the Carboniferous the relatively small tectonic blocks of the South Gissar comprised an archipelago, located between the larger continents of Karakum and Tarim and possibly connected with the Paleotethys Ocean. The archipelago scenario can explain hot and rapid metamorphic and tectonic processes, documented in the South Gissar, similar to the ongoing collision along the Australia – SE Asia junction. The study was supported by the Ministry of Education and Science of the Russian Federation (project No 14.Y26.31.0018).

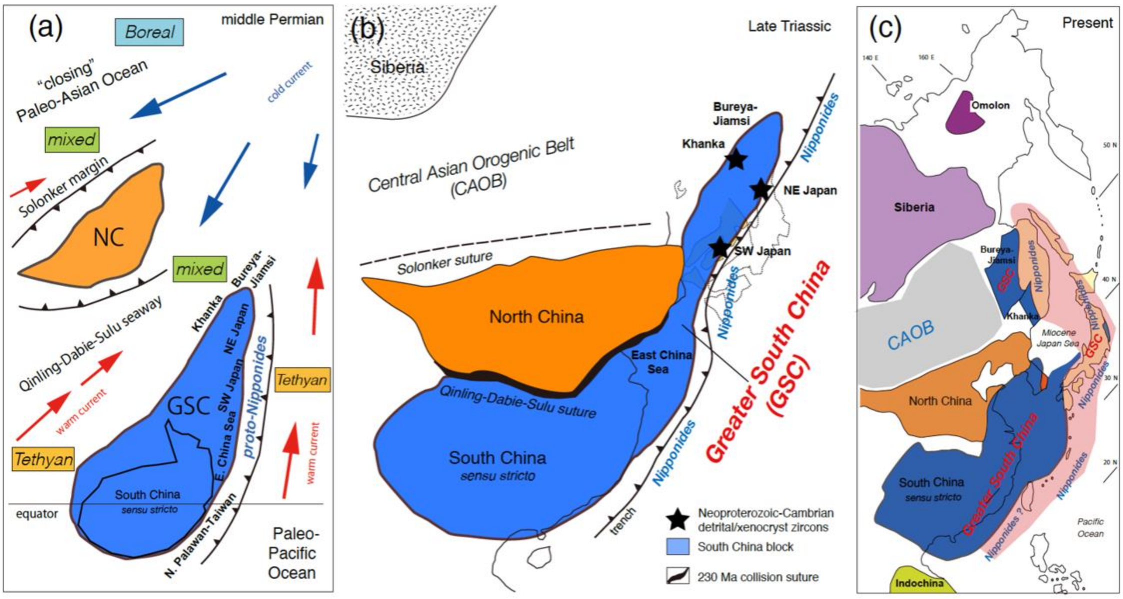
A visage of early Paleozoic Japan: Geotectonic and paleobiogeographical significance of Greater South China with respect to CAOB

Yukio Isozaki

Dept. Earth science & Astronomy, The University of Tokyo, Tokyo 153-8902, Japan

isozaki@ea.c.u-tokyo.ac.jp

The current state of knowledge on the early Paleozoic evolution of Japan is reviewed. Although early Paleozoic Japan marked the foundation of long-lasting subduction-related orogenic growth throughout the Phanerozoic, details of this have not been fully revealed. Nevertheless, U-Pb dating of zircons both in Paleozoic granitoids and sandstones is revealing several new aspects of early Paleozoic Japan. The timing of the major tectonic change, from a passive continental margin setting (Stage I) to an active one (Stage II), was constrained to the Cambrian by identifying the oldest arc granitoid, high-P/T blueschist, and terrigenous clastics of arc-related basins. Ages of recycled zircons in granitoids and sandstones provided critical information on the homeland of Japan, i.e., the continental margin along which proto-Japan began to grow. The early Paleozoic continental margin that hosted the development of an arc-trench system in proto-Japan had cratonic basement composed mostly of Proterozoic crust with a minor Archean component.The predominant occurrence of Neoproterozoic zircons in Paleozoic rocks, as xenocrysts in arc granitoids and also as detrital grains in terrigenous clastics, indicates that the relevant continental block was a part of South China, probably forming a northeastern segment of Greater South China (GSC) together with the Khanka/Jiamsi/Bureya mega-block in Far East Asia. GSC was probably twice as large as the present conterminous South China on mainland Asia. Paleozoic Japan formed a segment of a mature arc-trench system along the Pacific side of GSC, where the N-S-trending Pacific-rim orogenic belt (*Nipponides*) developed with an almost perpendicular relationship with the E-W-trending Central Asian orogenic belt. The faunal characteristics of the Permian marine fauna in Japan, both with the Tethyan and Boreal elements, can be better explained than before in good accordance with the relative position of GSC with respect to the North China block during the late Paleozoic.



References

Isozaki, Y., Aoki, K., Sakata, S., & Hirata, T., 2014. The eastern extension of Paleozoic South China in NE Japan evidenced by detrital zircon. GFF 136, 123-126.

Isozaki, Y., Ehiro, M., Nakahata, H., Aoki, K., Sakata, S., & Hirata, T., 2015. Cambrian arc plutonism in Northeast Japan and its significance in East Asia: new U-Pb zircon ages of the oldest granitoids in the Kitakami and Ou Mountains. Journal of Asian Earth Sciences 108, 136-149.

Isozaki, Y. Nakahata, H., Zakharov, Y.D., Popov, A.M., Sakata, S., & Hirata, T., 2017.Greater South China extended to the Khanka block: detrital zircon chronology of the middle-upper Paleozoic sandstones of the Sergeevkablet, Far East Russia. Journal of Asian Earth Sciences 145, 565-575.

Isozaki, Y., 2019. A visage of Paleozoic Japan: geotectonic and paleobiogeographical significance of Greater South China. Island Arc, 28, e12296.

Basement of the Tuva-Mongolia terranes: Provenance implication and tectonic evolution

Uyanga Bold[1] and Yukio Isozaki[2]

[1]*Department of Research and Cooperation, Mongolian University of Science and Technology, 8th khoroo, Bagatoiruu 34, Sukhbaatar district, Ulaanbaatar-14191, Mongolia*

[2]*Department of Earth Sciences and Astronomy, The University* of Tokyo, 3-8-1 *Komaba, Meguro, Tokyo 153-8902, Japan*

Abstract

A number of ancient continental crustal fragments has been described in Mongolia, Kyrgyzstan, and most of Kazakhstan (Badarch et al., 2002; Byamba, 2009; Degtyarev et al., 2017; Tomurtogoo, 2005). However, contextual interpretation and integration of the available geologic data are still need to be completed. The Gargan block makes up the basement of the Tuva-Mongolia terranes (TMT; e.g. Kuzmichev, 2015), which occupies a large region in southern Russia and northernmost Mongolia sharing a tectonic boundary with the Siberian Craton to the northeast (Fig. 1A). Geologic descriptions of the Gargan block has been restricted to southern Russia only and based primarily on lithostratigraphic comparisons, their possible southern extensions were inferred in Mongolia. Here we present field observations and new zircon U-Pbgeochronologic data from previously undated basement gneisses and the overlying Neoproterozoic meta-sedimentary rocks of southern part exposed in Mongolia (Fig. 1A and 1B). By constraining/refining the age of its basement, extent, and provenance in regional tectonic framework, we integrated the geologic data into a global geotectonic framework of the CAOB with a proposed Proterozoic to early Paleozoic tectonic evolution model of the Gargan block (Fig. 1C). Obtained data confirm the existence of Neoarchean-Neoproterozoic basement in the TMT and for the first time reveal multiple stages of Neoproterozoic metamorphic events at ~ 1 Ga and between ~ 814 and ~ 782 Ma. Older event may relate to an assembly of several of the ancient continental crustal fragments in Mongolia. The basement age comparison and detrital zircon provenance do not favor any known cratons in and around the CAOB suggesting that the Gargan block may have travelled alone in most of the Proterozoic.

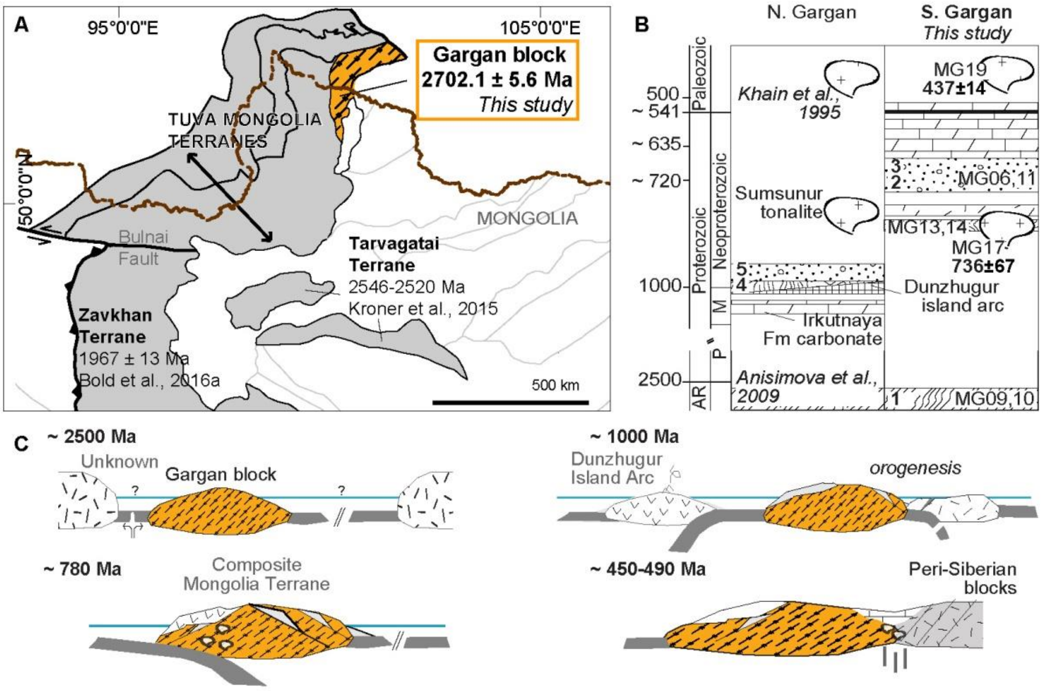


Figure 1. Tectonic evolution model of the Gargan block(Bold et al., accepted). A) Archean-Proterozoic continental crustal fragments described in north-central Mongolia (after Badarch et al., 2002). Regional outline of the Tuva-Mongolia terranes: Basement ages are shown with respective references. B) Time-space diagram of the Gargan block. C) Tectonic evolution model of the Gargan block at ~ 2500, ~ 1000, ~ 780, and ~ 450 Ma.

References

Badarch, G., Cunningham, W. D., and Windley, B., 2002, A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia, Journal of Asian Earth Sciences, Volume 21, p. 87-110.

Bold, U., Isozaki, Y., Aoki, S., Sakata, S., Ishikawa, A., Sawaki, Y., and Sawada, H., accepted, Precambrian basement, provenance implication, and tectonic evolution of the Gargan block of the Tuva-Mongolia Zone, Central Asian Orogenic Belt: Gondwana Research.

Byamba, J., 2009, Late Paleozoic to Early Mesozoic structures (in Mongolian), in Byamba, J., ed., Geology and Minerals of Mongolia: Lithosphere plate tectonics, Volume 6: Ulaanbaatar, Soyombo Printing, p. 353-358.

Degtyarev, K., Yakubchuk, A., Tretyakov, A., Kotov, A., and Kovach, V., 2017, Precambrian geology of the Kazakh uplands and Tien Shan: an overview: Gondwana Research, v. 47, p. 44-75.

Kuzmichev, A., 2015, Neoproterozoic accretion of the Tuva-Mongolian massif, one of the Precambrian terranes in the Central Asian Orogenic Belt: The Central Asian Orogenic Belt, p. 66-92.

Tomurtogoo, O., 2005, Tectonics and structural evolution of Mongolia, in Seltmann, R., et al., ed., Geodynamics and Metallogeny of Mongolia with a Special Emphasis on Copper and Gold Deposits: International Association on the Genesis of Ore Deposits (IAGOD) Guidebook Series, Volume 11, p. 5-12.

U-Pb detrital zircon ages of Cambrian–Ordovician sandstones from the Taebaeksan Basin, Korea: Provenance variability in platform sequencesand paleogeographic implications

Moonsup Cho, Wonseok Cheong and Yoonsup Kim

Department of Earth and Environmental Sciences, Chungbuk National University, Cheongju 28644, Korea(E-mail: moonsup@snu.ac.kr)

The earlyPaleozoicpaleogeography of various terranes in the East Gondwana, includingthe North China Craton (NCC), remains contentious partly because of the lack of studies integrating geochronological, biogeographic, and tectonic datasets. Here we presentin-situU-Pbages of detrital zircons available from the Cambrian–Ordovician sandstones of the Taebaekand Yeongwolgroupsin the Taebaeksan Basin (TB), Korea. Both groups consist of platform shelf sequences and contain trilobite assemblages diagnostic of the NCC. Detrital zircons of sandstones from the TaebaekGroup reveal threedistincttypes ofage distribution, characterizedrespectively by: (1)double peaks at ~1.87 Ga and 2.5 Ga diagnostic ofthe NCC; (2)minor to moderate population of Mesoproterozoic zirconsin additionto the double peaks; and(3)predominance of Mesoproterozoic and Neoproterozoic zirconswithout the double peaks. Type 3 is also prevalent infine-grained sandstones of the YeongwolGroup, suggesting that both TBgroups shared the same provenance.The marked contrast betweentypes 1 and 3 reflects a significant shift in provenance from inboard proximal to outboard distal sources. In addition, all the TBformations except for the lowermost unit contain the Cambrian–Ordovician zircon populationswhose U-Pb ages systematicallydecrease upsection from ~510 Ma to ~480Ma. Such anupsection decreasetogether with syndepositionalages of the youngest population arebest accounted for by sedimentary influx from contemporaneous igneous rocks. In conjunction with arc-related whole-rock geochemistry and juvenile Nd isotopic signature, we interpret that early Paleozoic detrital zircons represent first-cycle detritus supplied for >30m.y. from a peri-NCC magmatic arc.Such amagmatic complex mayinclude the proto-Japan arc developing around the proto-Pacific ocean, possiblyin conjunction with the Terra Australis orogen.

Rift-related mafic protolithsof Cambrian eclogites inthe Ross orogen, Antarctica: The Ediacaranmissing link for continental rifting and detrital zircon source along the East Gondwana margin

Taehwan Kim[1], Yoonsup Kim[2], Moonsup Cho[2], Jong Ik Lee[3]

[1]*Seoul National University, Republic of Korea, slitmotw@snu.ac.kr*

[2]*Chungbuk National University, Republic of Korea*

[3]*Korea Polar Research Institute, Republic of Korea*

Paleogeographic linkage between Australia and Antarctica has played a key role for reconstruction of East Gondwana during the Neoproterozoic, but the presence of Ediacaran rifting event along the East Antarctic margin remains uncertain. The dearth of late Neoproterozoic geological records in the Ross orogen of the Transantarctic Mountains brought another issues regarding the source rocks of *c.* 700–500 Ma Pacific-Gondwana zircon population, which isubiquitousand widespread in voluminous Neoproterozoic to Triassic sandstone-mudstone sequences along the paleo-Pacific margin of Gondwana. The late Neoproterozoic rift systemshave been regarded as one of the potential provenances. In this study, we report the finding of such a rift-related mafic magmatism preserved in Cambrian eclogites of the Ross orogen in northern Victoria Land, Transantarctic Mountains (Kim et al., 2019). The inherited zircon core ages (591 ± 8 Ma and 603 ± 4 Ma, $t\sigma$) and E-MORB to within-plate basalt affinity of the eclogites as well as adjacent metasedimentary rocks of dominantly siliciclastic composition suggest that their gabbroic protoliths should be a spatial-temporal equivalent to *c.* 600–580 Ma rift to passive margin magmatic rocks in eastern Australia. Our result is in contrast to the Cryogenian(*c.* 670–650 Ma) rifting followed by Ediacaran (*c.* 590–570 Ma)arc initiation of the Ross orogeny (Goodge et al., 2012; Hagen-Peter et al., 2016). Therefore, we suggest twodiscrete tectonic inversionevents along the Australian and Antarctic margins: i.e., Cryogenian(*c.* 670–650 Ma) and Ediacaran (*c.* 600–580 Ma) continental riftingto accretionary orogenyat Ediacaran (*c.* 590–570 Ma) and early Cambrian (*c.* 540–530 Ma) times, respectively. These late Neoproterozoic rift-related rocks might provide the Pacific-Gondwana zircon in the Paleozoic Gondwana 'mud-pile'.

References

Goodge, J.W., Fanning, C.M., Norman, M.D., & Bennett, V.C., 2012. Temporal, isotopic and spatial relations of early Paleozoic Gondwana-margin arc magmatism, central Transantarctic Mountains, Antarctica. Journal of Petrology, 53, 2027–2065.

Hagen-Peter, G., Cottle, J.M., Smit, M., & Cooper, A.F., 2016. Coupled garnet Lu–Hf and monazite U–Pb geochronology constrain early convergent margin dynamics in the Ross orogen, Antarctica. Journal of Metamorphic Geology, 34, 293–319.

Kim, T., Kim, Y., Cho, M.&Lee, J.I., 2019.*P–T* evolution and episodic zircon growth in barroisiteeclogites of the Lanterman Range, northern Victoria Land, Antarctica. Journal of Metamorphic Geology, 37, 509-537.

The middle Triassic high-*P* metamorphism and late Triassic medium-*P* overprint of metapelites in the Nam Co accretionary complex, Song Ma suture zone, NW Vietnam

Bui Vinh Hau[1,2], Yoonsup Kim[1], Yeon-Joong Jeong[3]
[1]*Chungbuk National University, Republic of Korea*, yoonsup@cbnu.ac.kr; [2]*Hanoi University of Mining and Geology, Vietnam;* [3]*Korea Basic Science Institute, Republic of Korea*

The *P*–*T* evolution and monazite geochronology of metapelitic schists from the Nam Co complex, central Song Ma suture zone, Vietnam, were investigated in order to reveal two-stage metamorphic and deformation evolution during the Indosinian orogeny. Representative mineral assemblage of the metapelites consists of chlorite + white mica (~3.1 Si apfu)+ albeit + quartz ± garnet ± biotite (M_2), and an aggregate of white mica and chlorite defines the major foliations (S_n). Earlier metamorphic event (M_1) was partly recorded by relict mineral inclusions such as rare garnet + white mica (~3.2–3.4 Si apfu) + chlorite + graphitic material inside albeit porphyroblasts, and the inclusions commonly define straight to sigmoidal internal fabrics (S_i) discontinuous to S_n. Porphyroblastic garnet contains a paucity of inclusions except for rare quartz and titanium-oxide needles in the core, and shows compositional zonation typified by a bell-shaped spessartine profile.In contrast, the almandine and grossular contents of rare garnet inclusion are higher than those of porphyroblastic garnet. Monazite occurs not only in the matrix, but also within albeit as an inclusion. The latter monazite is aligned subparallel to S_i (M_1) whereas the former to S_n (M_2). The compositions of monazite in the matrix are depleted in Th and Si, but are enriched in P, La, Ce relative to those of monazite inclusions. The *P*–*T* conditions of M_1 based upon isochemical phase diagram and geothermobarometry are estimated as 440–470℃ and ~15–17kbar whereas those of M_2 as 440–490℃ and 8–12 kbar. The U–Th–Pb isotopic compositions of monazite were measured using both SHRIMP and LA-MC-ICP-MS.Spot analyses using the former machine yielded well-defined common Pb mixing lines; the lower intercept $^{206}Pb/^{238}U$ ages of monazite inclusion and matrix monazite were244±11 Ma (2σ) and 234±10 Ma (2σ), respectively. In order to reduce analytic spot size, the U–Th–Pb isotopic compositions of monazite were reanalyzed using LA-MC-ICP-MS. The weighted mean $^{208}Pb/^{232}Th$ ages of monazite inclusion and matrix monazite were 242±5 Ma (*t*σ) and 221±4Ma (*t*σ). The Middle Triassic M_1might be accompanied by the subductionof supracrustal materials along the southwestern margin of the South China craton, and the Late

Triassic M_2 by the final stage of collision between the Indochina and South China cratons.

Tectonic Evolution of the Central Asia Orogenic Belt (CAOB): Constraints from the PTt paths of metamorphism in the central Inner Mongolia

Chunjing Wei[1], Jinrui Zhang[1], Hang Chu[2]

[1] *School of Earth and Space Sciences, Peking University, Beijing, 100871, China*

[2]*Tianjin Institute of Geology and Mineral Resources, Tianjin 300170, China*

The tectonic evolution of Xing'an-Inner Mongolia Orogenic Belt (XIMOB) in the southeastern segment of the Central Asian Orogenic Belt has been highly argued: whether the Paleo-Asian Ocean (PAO) was closed in Devonian or Early Mesozoic and whether the tectonic regimes during Carboniferous and Permian were operated by continuous subduction-arc systems or extension after the orogenic process. Comprehensive studies of metamorphism for four metamorphic units including the Ondor Sum Group, Baoyintu Group, Xilingol Complex, and early Triassic metamorphic sequences in the central Inner Mongolia provide good constraints on the argument points of the XIMOB. Zircon U-Pb dating analyses suggest that quartz schists of the Ondor Sum Group in northern and southern orogenic belts (NOB and SOB) yield broad zircon age range from early Paleozoic to late Archean with similar lower limited deposition age of 430-434 Ma, but they are different in detrital age population with absence of ~ 650 Ma peak in the SOB. Biotite gneiss of the Xilingol Complex has similar age population and lower limited deposition age of 436Ma with the Ondor Sum Group in the NOB, while amphibolites in the complex yield metamorphic zircon age of 321 ± 3 Ma and hornblende $^{40}Ar/^{39}Ar$ age of 309 ± 2 Ma. The early Triassic metamorphic sequences including metabasite in Wulangou ophiolite suite and Shuangjing mica-schist both yield broad zircon age range from late Paleozoic to late Archean. Their protoliths are constrained to be formed later than 258 Ma and 261 Ma respectively and the metamorphism occurred soon afterwards in the Early Triassic constrained by actinolite ^{40}Ar-^{39}Ar age of 241±19 Ma in metabasite and muscovite ^{40}Ar-^{39}Ar age of 242±26 Ma in mica-schist. Four phases of metamorphism are identified in the central Inner Mongolia since the Paleozoic, including (i) the Silurian (426–430 Ma) high *P/T* metamorphism in the Ondor Sum Group, indicating bidirectional subduction processes; (ii) the Devonian (~400Ma) medium *P/T* metamorphism in the Baoyintu Group, suggesting a crustal thickening orogeny; (iii) the Carboniferous (309–337 Ma) high temperature–low pressure metamorphism of in the Xilingol Complex, indicating an extension process of a previous orogen and (iv) the Early Triassic (~240Ma) extensive medium-low *P/T* metamorphism along the Solonker suture zone which is attributed to closure of limited sea basins. Thus, an alternative tectonic scenario for the central Inner Mongolia involves: (i) the early Paleozoic trench–arc system (500–425Ma); (ii) the Devonian collisional orogeny due to closure of the Paleo-Asian-Ocean (400–360Ma); (iii) the Carboniferous and Permian extension after the collision (350–250 Ma), and (iv) the Early Triassic within-plate orogeny due to closure of limited sea basins (~240 Ma).

The Beishan orogen of the southern Central Asian Orogenic Belt: microcontinental crustal evolution and tectonic implications

Zhen-Yu He[1], Reiner Klemd[2]

[1]*Institute of Geology, Chinese Academy of Geological Sciences, 26 Baiwanzhuang Road, Beijing 100037, China,* hzy@cags.ac.cn

[2]*GeoZentrumNordbayern, Friedrich-Alexander Universität Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany*

The Beishanorogen occupies the central segment of the southernmost part of the CAOB and is suggested to haveformed during the Paleozoic through multiple accretions of different arc terranes (Fig. 1; Xiao et al., 2010; Tian et al., 2014). Scattered medium- to high-grade metamorphic rocks were assumed to represent Precambrian basement of these arc terranes, and thus the host terranes were interpreted as ancient microcontinents or continental margins of the Beishan orogen. However, the origin and tectonic correlations of the microcontinental terranes are still controversially discussed. In the present study, *in situ* zircon U–Pb age and Hf isotopic data of 64 Paleozoic and early Mesozoic (from 499–217 Ma) as well as 14 Mesoproterozoic and Neoproterozoic (from 1555–871 Ma) granitic samples from four major arc terranes of the Beishan orogeny, including the Shibanshan, Shuangyingshan, Mazongshan, and Hanshan terranes, were compiled in order to assess the nature of their crustal basement as well as the subsequent Paleozoic tectonic evolution (Fig. 1).

Zircon $\varepsilon_{Hf}(t)$ values and calculated Hf model ages are similar for all arc terranes with Hf model age peaks at approximately 1.0–0.8 Ga and 2.0–1.8 Ga. We propose that these terranes formed on a single uniform continental terrane instead constituting individual terranes with different crustal basements. We further suggest the name ‘Liuyuan continental terrane’ for this uniform terrane, comprising the Shibanshan, Shuangyingshan, Mazongshan and Hanshanterranes, which were separated by fore-arc, inter-arc or back-arc basins as a result of slab rollback in the late Paleozoic (Xiao et al., 2018). The ancient crust of the ‘Liuyuan continental terrane’ was probably formed as early as the Paleoproterozoic (ca. 2.5 Ga) and subsequently underwent new Mesoproterozoic (ca. 1.4 Ga) crustal growth as evidenced by the mainly depleted Hf isotopic compositions as well as the broadly mantle-like zircon $\delta^{18}O$ values (5.29 to 6.43‰) of the Mesoproterozoic granitic gneiss sample (Fig. 2).

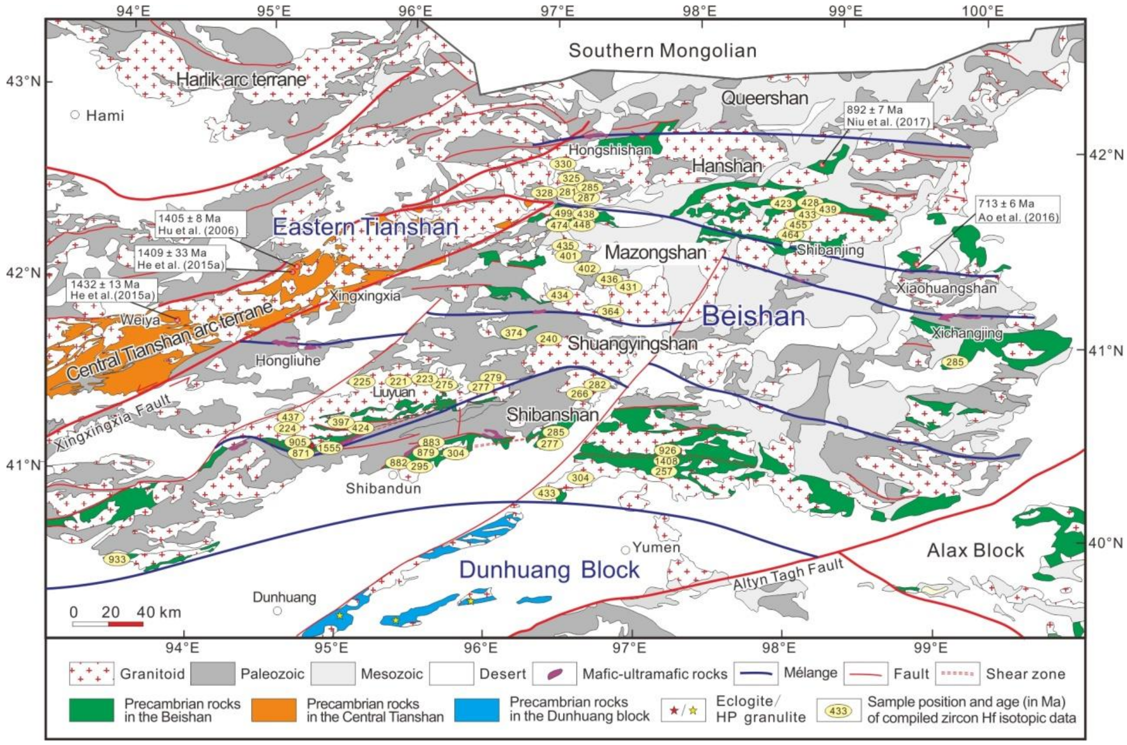


Fig. 1. Simplified geological map of the Beishanorogen and the adjacent Chinese Eastern Tianshanorogen and Dunhuang block (modified after Xiao et al., 2010; Tian et al., 2014), showing major arc terranes of the Beishanorogen and the mélanges separating the terranes. The complied samples with Hf isotopic data are indicated by ovals with crystallization ages (in Ma). See He et al., 2018a for the Data sources.

Current data show that the Mesoproterozoic (ca. 1.4 Ga) crustal growth are typical characteristics of the microcontinents in the southern CAOB and therefore suggest that an extensive belt of Mesoproterozoic (ca. 1.4 Ga) juvenile continental crust had formed in a continental terrane, fragments of which now occur over a distance of more than thousand kilometers in the southern CAOB ranging from the Kyrgyz North Tianshan through the Yili, Central Tianshan, Beishan and northern Alxa blocks (or microcontinents) in NW China to the Xilinhot block in NE China (Kröner et al., 2013; He et al., 2015, 2018b; Shi et al., 2016; Konopelko and Klemd, 2016; Han et al., 2017; Degtyarev et al., 2017; Yakubchuk, 2017;Yuan et al., 2019). Among the cratons bordering the CAOB, Baltica displays most similarities with this continental terrane, while a Mesoproterozoic correlation with the Tarim Craton is rather questionable.

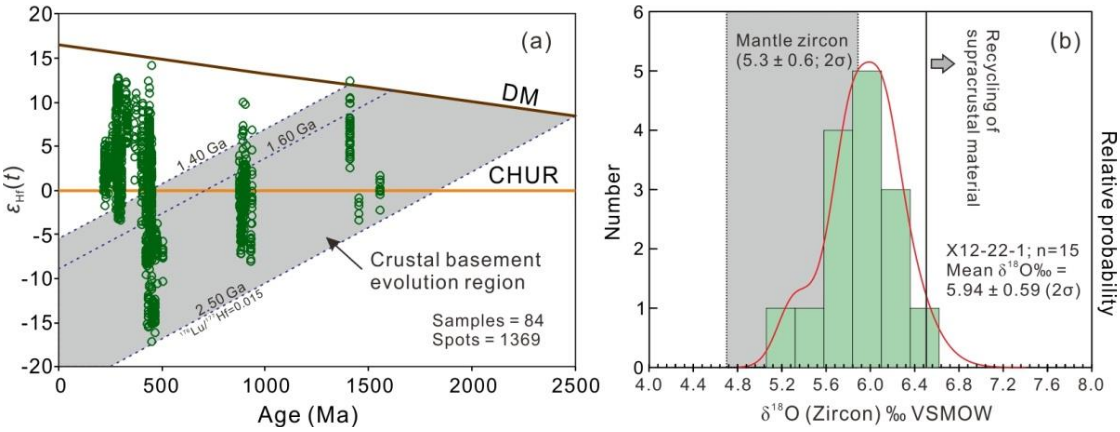


Fig. 2. (a) Zircon Hf isotopic evolution diagrams summarizing the granitic rocks of the Beishanorogen. Note that the juvenile crustal growth in the Mesoproterozoic (ca. 1.4 Ga) as evidenced by the mainly depleted Hf isotopic compositions. (b) Histogram showing zircon $\delta^{18}O_{VSMOW}$ values for the 1408 ± 4 Ma Jiujing granitic orthogneiss. The sample has broadly mantle-like zircon $\delta^{18}O$ values (< 6.5‰). See He et al. (2018a) for the Data sources.

References

Degtyarev, K., Yakubchuk, A., Tretyakov, A., Kotov, A., Kovach, V., 2017. Precambrian geology of the Kazakh uplands and Tien Shan: an overview. Gondwana Research, 47, 44–75.

Han, J., Zhou, J.-B., Li, L., Song, M.-C., 2017. Mesoproterozoic (~1.4Ga) A-type gneissic granites in the Xilinhot terrane, NE China: First evidence for the break-up of Columbia in the eastern CAOB. Precambrian Research, 296, 20–38.

He, Z.-Y., Klemd, R., Zhang, Z.-M., Zong, K.-Q., Sun, L.-X., Tian, Z.-L., Huang, B.-T., 2015. Mesoproterozoic continental arc magmatism and crustal growth in the eastern Central Tianshan Arc Terrane of the southern Central Asian Orogenic Belt: Geochronological and geochemical evidence. Lithos, 236, 74–89.

He, Z.-Y., Klemd, R., Yan, L.-L., Zhang, Z.-M., 2018a.The origin and crustal evolution of microcontinents in the Beishanorogen of the southern Central Asian Orogenic Belt. Earth-Science Reviews, 185, 1–14.

He, Z.-Y., Klemd, R., Yan, L.-L, Lu, T.-Y., Zhang, Z.-M., 2018b.Mesoproterozoic juvenile crust in microcontinents of the Central Asian Orogenic Belt: evidence from oxygen and hafnium isotopes in zircon. Scientific Reports, 8, 5054.

Konopelko, D., Klemd, R., 2016. Deciphering protoliths of the (U) HP rocks in the Makbal metamorphic complex, Kyrgyzstan: geochemistry and SHRIMP zircon geochronology. Eur. J. Mineral., 28, 1233–1253.

Kröner, A., Alexeiev, D., Rojas-Agramonte, Y., Hegner, E., Wong, J., Xia, X., Belousova, E., Mikolaichuk, A., Seltmann, R., Liu, D., 2013.Mesoproterozoic (Grenville-age) terranes in the Kyrgyz North Tianshan: zircon ages and Nd–Hf isotopic constraints on the origin and evolution of basement blocks in the southern Central Asian Orogen. Gondwana Research, 23, 272–295.

Shi, X.J., Zhang, L., Wang, T., Zhang, J.J., Liu, M.H., Zhou, H.S., Yan, Y.T., 2016.Zircon geochronology and Hf isotopic compositions for the Mesoproterozoic gneisses in Zongnaishan area, northern Alxa and its tectonic affinity. ActaPetrologicaSinica, 32, 3518–3536 (in Chinese with English abstract).

Tian, Z., Xiao, W., Windley, B.F., Lin, L.n., Han, C., Zhang, J.e.,Wan, B., Ao, S., Song, D., Feng, J., 2014. Structure, age, and tectonic development of the Huoshishan–Niujuanziophiolitic mélange, Beishan, southernmost Altaids. Gondwana Research, 25, 820–841.

Xiao, W.J., Mao, Q.G., Windley, B.F., Han, C.M., Qu, J.F., Zhang, J.E., Ao, S.J., Guo, Q.Q., Cleven, N.R., Lin, S.F., Shan, Y.H., Li, J.L., 2010. Paleozoic multiple accretionary and collisional processes of the Beishanorogenic collage. Am. J. Sci., 310, 1553–1594.

Xiao, W., Windley, B.F., Han, C., Liu, W., Wan, B., Zhang, J.e., Ao, S., Zhang, Z. and Song, D., 2018. Late Paleozoic to early Triassic multiple roll-back and oroclinal bending of the Mongolia collage in Central Asia. Earth-Science Reviews,186, 94–128.

Yakubchuk, A., 2017. Evolution of the Central Asian Orogenic Supercollage since Late Neoproterozoic revised again. Gondwana Research, 47, 372–398.

Yuan, Y., Zong, K., Cawood, P.A., Cheng, H., Yu, Y., Guo, J., Liu, Y., Hu, Z., Zhang, W., Li, M., 2019. Implication of Mesoproterozoic (~1.4 Ga) magmatism within microcontinents along the southern Central Asian Orogenic Belt. Precambrian Research, 327, 314–326.

Hf isotopic mapping of Paleozoic Granitoids in the Yili Block, NW China: implications for continental growth in the Central Asian Orogenic Belt

He Huang, Tao Wang, Qin Qie, Ying Tong, Peng Song

Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

Clarification of the large-scale spatio-temporal distribution of various (juvenile, reworked, ancient) crusts and understanding of geologic processes controlling the formation of crust is one of the major subjects of geologic studies, and is also extremely important in mineral exploration and prospecting. The Yili Block is a triangular microcontinent bordered by sutures and fault zones in the western Chinese Tianshan, SW CAOB. Voluminous igneous rocks, mostly granitoids, were exposed and constitute two major belts stretching in southern and northern margins of the Yili Block. We synthetically compile up-to-date geochronogical, zircon Hf isotopic and whole-rock geochemical data for granitoids from the Yili Block and adjacent tectonic domains. Paleozoic granitoids were mainly emplaced at three stages, i.e., ~470 to ~390 Ma, ~370 to ~320 Ma and ~320 to 250 Ma. The first-stage granitoids are characterized by relatively ancient Hf isotopic compositions [$\varepsilon Hf(t)$=-5.2 to +8.3, crustal Hf model ages ($T_{DM}{}^{c}$) range from 0.91 to 1.77 Ga, mostly >1.1 Ga]. On the contrary, the second- and third-stage granitoids show more juvenile Hf isotopic signatures ($\varepsilon Hf(t)$=-4.5 to +15.7, $T_{DM}{}^{c}$=0.35 to 1.60 Ga, mostly <1.15 Ga). Spatially, granitoids with more ancient Hf isotopic features are dominantly exposed in comparatively marginal parts of the Yili Block, whereas the inner parts are dominated by granitoids with juvenile Hf isotopic features. The temporal and spatial variation in zircon Hf isotope is indicative of heterogeneity in lithospheric architecture. The genesis of granitoids with juvenile isotopic signatureswas likely related to anatexis of basic to intermediate, juvenile igneous/metaigneousrocks. The crustal evolution of the Yili Block and adjacent regions was characterized by long-lasting, gradually increasing involvement of juvenile crustal components, implying that the CAOB accretionary orogenesis played an important role in formation and preferential preservation of juvenile crust.

Key words: Hf-in-zircon isotope; Granitoid; Yili Block

Tectonic affinity of the northern Longshoushan-Beidashan: constraints from the Zircon geochronology and Hf isotopic compositions of the Haisen Chulu gneiss

Wang Maomao[1, 2], Zhang Lei[1*], Huo Yujia[1, 2], Shi Xingjun[3], Liu Cui[2], Wang Tao[1]

[1]*Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China*

[2]*School of Earth Sciences and Resources,China University of Geosciences (Beijing), Beijing 100083, China*

[3]*Faculty of City and Environmental Science, Xinyang Normal University, Xinyang 464000*

Determination of the north boundary of the Alxa Block will enhance our understanding on not only the tectonic division but also tectonic evolution of the northern Alxa. In the past years, the north boundary of the mid-east northern Alxa has been proposed to be represented by the Chagan Chuluophiolite (Shi et al., 2014a, 2014b, 2016; Zhang et al., 2015; Ye et al., 2016). It is still unclear how to extend this scheme to the western Alxa. Minor Precambrian rocks exposed in the northern Beidashan area of Alxa,which were traditionally considered asa part of the Longshoushan Group.The age and isotopic characteristics of these Precambrian rocksare important for the understanding of the local basement characteristics and the tectonic architectureof north Alxa area.Field observation and petrological features indicate that the Haisen Chulu gneiss is orthogneiss.LA-ICPMSzircon U-Pb dating performed on the inner part of the zircons obtainedan upper intercept age of 1408±29 Ma (MSWD=13) on the concordia diagram, which indicates that the protolith for the gneissintruded at ~ 1.4 Ga.The zircons from Haisen Chulu gneiss show positiveε_{Hf}(t) values between +0.13 and +6.68 and the two-stage Hf model agesare in the range of 2.07 to 1.62 Ga, indicating that the protoliths were mainly derived from the juvenile crust.Thisstudy,incombination with previous works (Song et al., 2017),indicate that the Precambrianrocks outcropped in northern Longshoushan-Beidashan area,to the north of the Tebai ophiolite (Zheng et al., 2018), was formed in Mesoproterozoic or later, but not as Archean or Paleoproterozoic as previously proposed. Both age and sources of the Precambrianrocks from the northern Longshoushan-Beidashan areaare different from the Precambrianrocks from thesourthernLongshoushan-Beidashan area (e.g., Gong et al., 2011, 2012, 2016; Zhang and Gong, 2018).Therefore, the northern Longshoushan-Beidashan could not be part of the Alxa block during early Precambrian time, andthe north boundary of the Alxa Block could be represented by the Tebai ophiolite.

References

Gong JH, Zhang JX, Wang ZQ, Yu SY, Li HK, Li YS. 2016. Origin of the Alxa Block, western China: New evidence from zircon U-Pb geochronology and Hf isotopes of the Longshoushan Complex. Gondwana Research, 36: 359-375

Gong JH, Zhang JX, Yu SY, Li HK, Hou KJ. 2012. Ca 2.5Ga TTG rocks in the western Alxa Block and their implications. Chinese Science Bulletin, 57: 4064-4076 (in Chinese with English abstract)

Gong JH, Zhang JX, Yu SY. 2011. The origin of Longshoushan Group and associated rocks in the southern part of the Alxa block: Constraint from LA-ICP-MS U-Pb zircon dating. Acta Petrologica et Mineralogica, 30: 795-818 (in Chinese with English abstract)

Shi XJ, Wang T, Zhang L, Castro A, Xiao XC, Tong Y, Zhang JJ, Guo L, Yang QD. 2014a. Timing, petrogenesis and tectonic setting of the Late Paleozoic gabbro-granodiorite-granite intrusions in the Shalazhashan of northern Alxa: Constraints on the southernmost boundary of the Central Asian Orogenic Belt. Lithos, 158-177

Shi XJ, Zhang L, Wang T, Xiao XC, Tong Y, Zhang JJ, Geng JZ and Ye K. 2014b. Geochronology and geochemistry of the intermediate- acid intrusive rocks from Zongnaishan area in northern Alxa, Inner Mongolia, and their tectonic implications. Acta Petrologica et Mineralogica, 33: 989-1007 (in Chinese with English abstract)

Shi XJ, Zhang L, Wang T, Zhang JJ, Liu MH, Zhou HS, Yan YT. 2016. Zircon geochronology and Hf isotopic compositions for the Mesoproterozoic gneisses in Zongnaishan areas, northern Alxa and its tectonic affinity. Acta Petrologica Sinica, 32: 3518-3536(in Chinese with English abstract)

Song DF, Xiao WJ, Collins A, Glorie S, Han CM, Li YC. 2017. New chronological contains on the tectonic affinity of the Alxa Block, NW China. Precambrian Research, 299: 230-243

Ye K, Zhang L, Wang T, Shi XJ, Zhang JJ, Liu Chao. 2016. Characteristics of geochronology, geochemistry and zircon Hf isotope of Permian intermediate-acid magmatic rocks in Yabulai area, Ala and its tectonic significance. Acta Petrologica et Mineralogica,(in Chinese with English abstract)

Zhang JJ, Wang T, Zhang L, Tong Y, Zhang ZC, Shi XJ, Guo L, Huang H, Yang YD, Zhao JX, Ye K, Hou JY. 2015. Tracking deep crust by zircon xenocrysts within igneous rocks from the northern Alxa, China: Contraints on the southern boundary of the Central Asian Orogenic Belt. Journal of Asian Earth Sciences, 108: 150-169

Zhang JX, Gong JH. 2018. Revisiting the nature and affinity of the Alxa Block. Acta Petrologica Sinica, 34: 940-962 (in Chinese with English abstract)

Zheng RG, Li JY, Xiao WJ, Wang LJ. 2018. A new ophiolitic mélange containing boninitic blocks in Alxa region: Implications for Permian subduction events in southern CAOB. Geoscience Frontiers, 9: 1355-1367

The origin of the Ordovician Gubaoquaneclogite in the Beishan Orogenic Collage in NW China

Jordy de Vries[1], Shoufa Lin[1], Cees van Staal[1], Chris Yakymchuk[1]

[1]*University of Waterloo, Waterloo, Canada,* jdevries@uwaterloo.ca

The Ordovician Gubaoquaneclogite is situated in the southern part of the Palaeozoic Beishan Orogenic Collage of the Central Asian Orogenic Belt in NW China. It currently is the only eclogite documented in the Beishan Orogenic Collage (Xiao et al, 2018).The eclogite has been proposed to be of oceanic or continental affinity based on trace element analysis. However, field relationships were not previously documented, whilstthis information is crucial for determining the parentage and tectonic significance of the eclogite.

The study area is underlain by a highly deformed belt of metamorphic tectonites, comprising orthogneiss, mafic schist, quartzite and marble. These are locally cut by granitoid intrusions, subvolcanic rhyolites and several mafic-felsic dyke suites. Towards the north, the belt is bound by a granitoid batholith, whilst in the south a major fault separates it from the Permian Liuyuan ophiolite. The Gubaoquaneclogite is situatedat the contact between orthogneisses (south)and meta-sediments (north), but overall lies in an area dominated by granitoid orthogneisses. Its southern contact was sheared, whilst its northern contact is obscured by diabase dykes and unconsolidated sediments.

Foliations trend E-W to NW-SE, dipping >60° in the north of the mapping area, gradually changing to ~30° in the south. N-S-trending isoclinal F1 folds are refolded by N-S-trending, easterly overturned; upright open to tight chevron and kink F2 folds. Lastly, south-directed brittle–ductile thrusts with down-dip lineations are common towards the south.Their formation may be coeval withE-W-trending, open to tight asymmetrical F3 folds, which overprinted earlier lineations.

Within the metasedimentary rocks and felsic orthogneisses, metamorphic assemblages contain garnet, staurolite and rutile as well as sillimanite and andalusite (Fig. 1B-C). Metabasitesare usually characterised by hornblende-bearing assemblages, but somecontain garnet, ortho- and clinopyroxene (Fig. 1D). Only the Gubaoquaneclogite preserves garnet and omphacite pseudomorphs (Fig. 1A). Subsequent greenschist metamorphismaffected many assemblages as well as many of the undeformed mafic intrusions.Thus, the area may have experienced both high pressure and low pressure paragenesis. Growth relationships suggest high-pressure metamorphism predated the low-pressure stage (Fig. 1B-C)

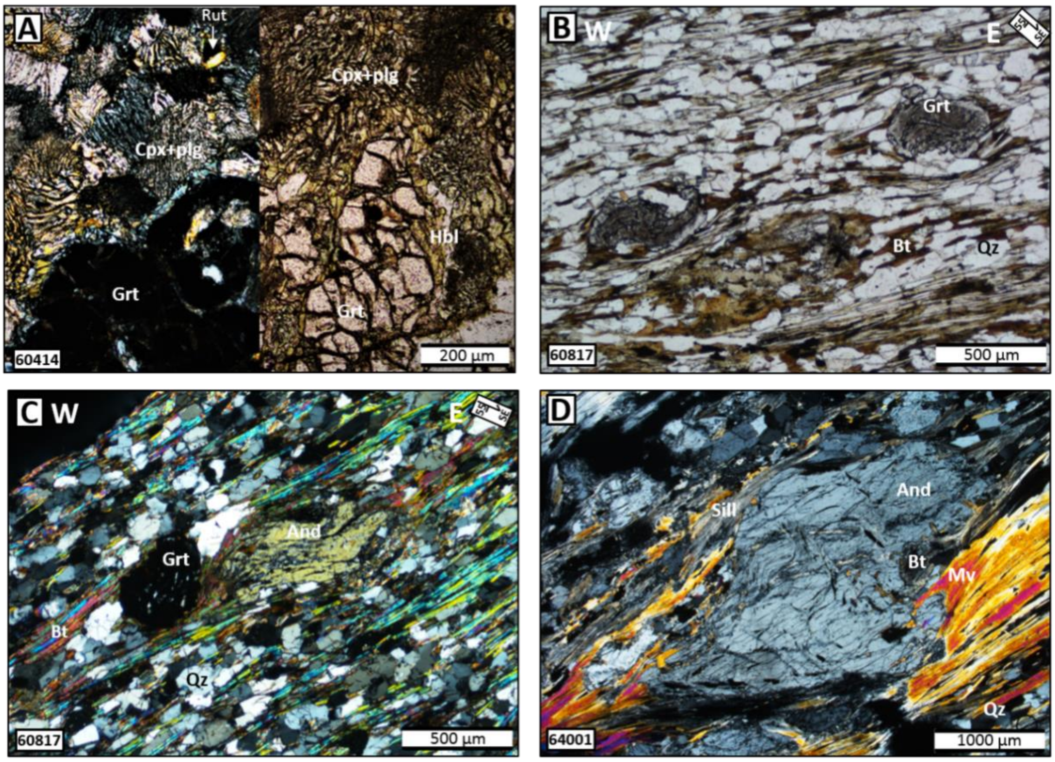


Fig. 1:Thin section photographs: A: eclogite; B-C: garnet-andalusitebiotite schist; D: andalusite-sillimanite two-mica schist

In summary, the Gubaoquaneclogite's structural relationship is rather unusual, both for continental and oceanic eclogites(Guillot et al, 2009).Whilst a continental origin seems most conceivable, the observed lithological associations may have undergone significant tectonic modification. This leaves the door open for a potential oceanic parentage.Furthermore, the current observations indicate a complicated structural-metamorphic history that has not been reportedin previous work. Further studies should constrain the tectonic implications of these findings.

References

Guillot, S., Hattori, K., Agard, P., Schwartz, S., & Vidal, O. (2009). Exhumation processes in oceanic and continental subduction contexts: a review. In *Subduction zone geodynamics* (pp. 175-205). Springer, Berlin, Heidelberg.

Xiao, W., Windley, B. F., Han, C., Liu, W., Wan, B., Zhang, J. E., ... & Song, D. (2018). Late Paleozoic to early Triassic multiple roll-back and oroclinal bending of the Mongolia collage in Central Asia. *Earth-Science Reviews*, *186*, 94-128.

Late Carboniferous-Early Permian Mafic-ultramafic Complexes in Beishan, Southwestern Central Asian Orogenic Belt and Their Significance

Kang Lei[1,2], Ji Wenhua[2], Wang Tao[*3], Li Wenming[2], Sun Jiming[2]

[1] Department of Geology, Northwest University, Xi'an 710069, China

[2] Key Laboratory for the Study of Focused Magmatism and Giant Ore Deposits, MLR, Centre of Orogenic Belt Geology, CGS, Center of Geological Survey, CGS, Xi'an, 710054, China

[3]Key Laboratory of Deep-Earth Dynamics, Ministry of Natural Resources, Institute of Geology, Chinese Academy of Geological Sciences, Beijing, 100037, China

**Corresponding author's E-mail: taowang@cags.ac.cn.*

Abstract

NumeralPermian mafic-ultramafic complexes occur in theBeishana inthe northeastern margin of the Tarim craton, southwestern Central Asian Orogenic Belt (Qin et al., 2011; Xue et al., 2018). The Baishan mafic-ultramafic complex which was discovered in recent years, is one of the largest layered complexes with an exposed area of about 132 km^2(Fig.1). We present a preliminary result of an integration study, including of field mapping, LA-ICP-MS zircon U-Pb dating and Lu-Hf isotope,whole-rock major and trace element and Sm-Nd isotope analyses.

LA-ICP-MS zircon U-Pb dating yield 306 to 297 Ma, which belong to Late Carboniferous-Early Permian. It is the oldest mafic-ultramafic complexrecognized from theBeishan. The samples have lower SiO_2 (36.31% to 51.62%) and K_2O+Na_2O(0.22% to 4.72%), higher MgO (5.76% to 34.34%)and display an enrichment of light rare earth elements(LREEs)($(La/Yb)_N$=1.07 to 4.09), enriching Eu elements to varying degrees, and pronounced negative Nb, Ta, enrichment ofRb, Ba, Th, U, K(LILE) (Fig.2). The mafic-ultramafic rocks havepositive $\varepsilon Nd_{(t)}$ values (+1.7 to +5.7) and positive$\varepsilon Hf_{(t)}$(mainly +4 to +18) (Fig.3), which show the isotopic signatures of depleted mantle. Systematic change trends in both major and trace elements of gabbro, olivine-gabbro, troctolite, norite, lherzolite and augite-peridotite, support their genetic linkage, and the crystallization differentiation of olivine, pyroxene and plagioclase during magma evolution.Considering their Nb/La=0.42 to 1.00(≤1), $(Th/Nb)_N$=0.07 to 12.78 (mostly, ≥1) and positive anomalies for Th, K and Sr, we suggest that magma experienced crustal contamination.

These geochemical signatures suggest that allthe mafic-ultramafic rocks were predominately derived from depleted mantle, witha litter addition of in the enrichment of

lithospheric mantle components and of crustalcontamination in an extensional setting.All these, combined with theregional tectono-thermal events, we conclude that the Baishan mafic-ultramafic complex formed in an initial continental rift tectonic setting, indicating that the northeastern margin of the Tarim craton started rift in 306 to 297Ma. It is an interesting question whether this rifting reflects the start or early time of Tarim Large IgneousProvince (LIP)(peek at 273 to 290Ma)(Zhou et al., 2009; Zhang et al., 2010; Yu et al., 2011) and magma formation mechanism.

Key words: magmatic sulfide deposits, classification, small intrusions, metallogenesis

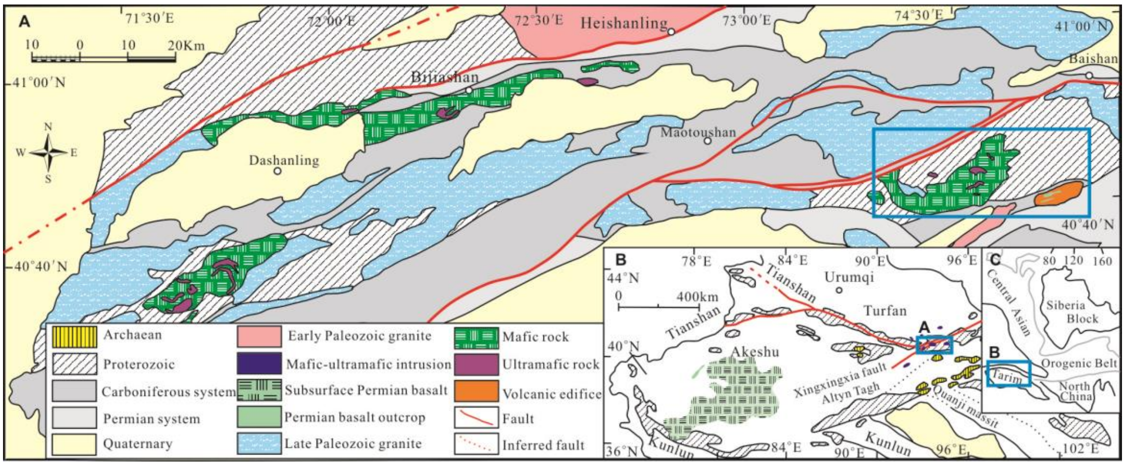


Fig.1. Regional map of the Baishan mafic-ultramafic complex in the northeastern margin of the Tarim craton (Modified after Zhang et al., 2017 and Lu et al., 2008)

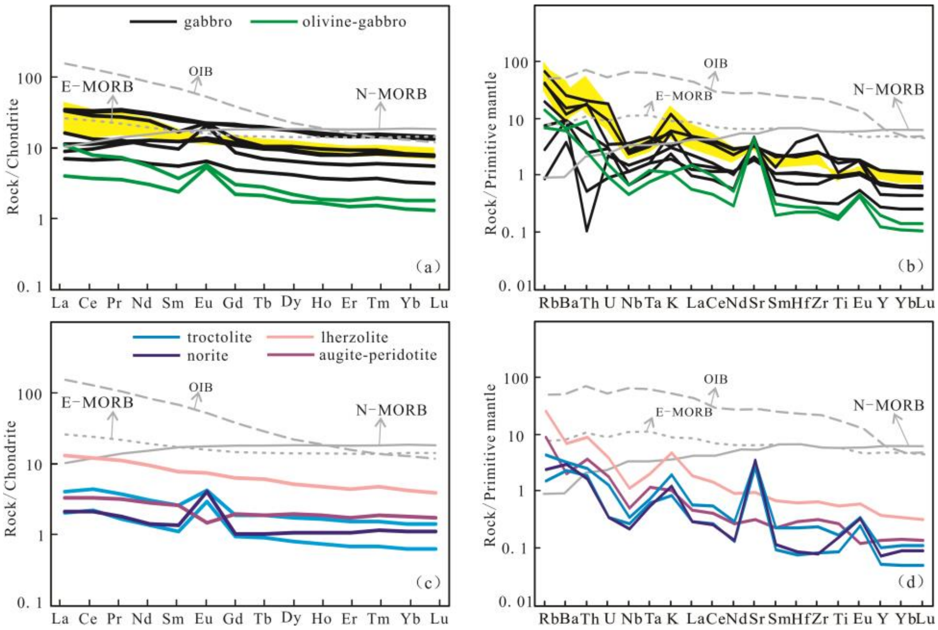


Fig.2. REE patterns normalized to chondrite values (Sun and McDonough, 1989)(a, c) and trace element plots normalized to the composition of primitive mantle (Sun and McDonough, 1989)(b, d)

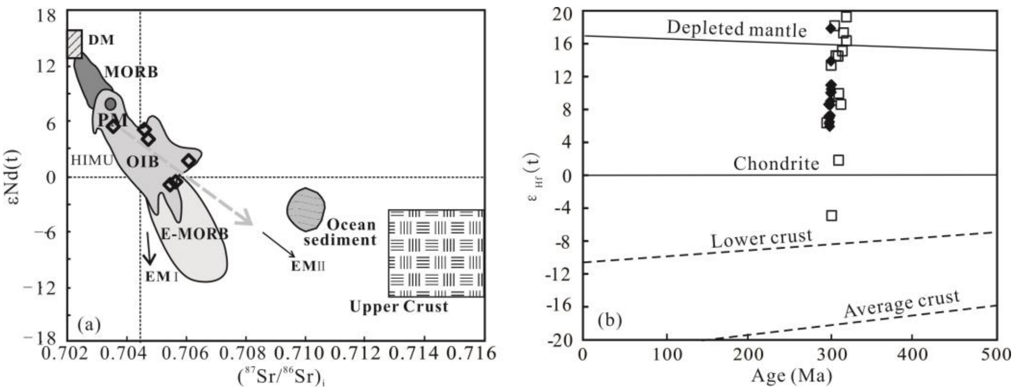


Fig.3. εNd(t) versus (^{87}Sr/^{86}Sr)$_i$ diagram(a) and εHf(t) versus age diagram(b) for gabbro

Acknowledgments

This research was supported financially by the NSFC projects (U1403291, 41802074, 41830216, 41202044) and projects of the China Geological Survey (Nos. 1212010811033, 12120113096500, 12120113094000, DD20160123, DD20160009 and DD20179607). This paper contributes to IGCP 662.

References

Lu, S.N., Zhao, G.C., Wang, H.C., Hao, G.J., 2008. Precambrian metamorphic basementandsedimentary cover of the North China Craton. Precambrian Res. 160(2008): 77-93.

Qin K.Z., Su B.X., Sakyi P.A. 2011. SIMS Zircon U-Pbgeochronology and Sr-Nd isotopes of Ni-Cu bearing mafic-ultramafic intrusions in Eastern Tianshan and Beishan incorrelation with flood basalts in Tarim Basin (NW China).American Journal of Science, 311: 237-260.

Sun, S.S., McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts:implication for mantle composition and processes. In: Saunder, A.D., Norry, M.J.(Eds.), Magmatism in the Ocean Basins: Geological Society. London, SpecialPublications 42(1989):313-345.

Xue S.C., QinK.Z., LiC.S., YaoZ.S., RipleyE.M., Wang X.S. 2018. Geochronological, mineralogical and geochemical studies of sulfide mineralization in the Podong mafic-ultramafic intrusion in northern Xinjiang, western China. Ore Geology Reviews, 101: 688-699.

Yu X., Yang S.F., Chen H.L., Chen Z.Q., Li Z.L., Batt G.E., Li Y.Q. 2011. Permian flood basalts from the Tarim Basin, Northwest China: SHRIMP zircon U-Pb dating and geochemical characteristics. Gondwana Research, 20: 485-497.

Zhang C.L., Xu Y.G., Li Z.X., Wang H.Yan., Ye H.M. 2010. Diverse Permian magmatism in the Tarim Block, NW China: Genetically linked to the Permian Tarim mantle plume?Lithos, 119: 537-552.

Zhang, M.J., Tang Q.Y., CaoC.H., Li, W.Y., Wang, H., Li, Z.P.,Yu, M., Feng, P.Y., 2017. The origin of Permian Pobei ultramafic complex in the northeastern Tarimcraton, western China: Evidences from chemical and C-He-Ne-Ar isotopiccompositions of volatiles. Chemical Geology, 469(2017): 85-96

Zhou M.F., Zhao J.H., Jiang C.Y., Gao J.F., Wang W., Yang S.H. 2009. OIB-like, heterogeneous mantle sources of Permian basaltic magmatism in the western Tarim Basin, NW China: Implications for a possible Permian large igneous province. Lithos, 113: 583-594.

Contrasting deep crustal compositions between the Altai and EastJunggar orogens, SW Central Asian Orogenic Belt: Evidence from zirconHf isotopes

Peng Song[1], Tao Wang[1], Ying Tong[1], and Jianjun Zhang[1]

[1]*Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China(songpengyx@foxmail.com)*

There are long–standing uncertainties over the deep crustal composition and basement nature of the Chinese Altai and Junggar orogens of the southwestern Central Asian Orogenic Belt (CAOB). Zircon Lu–Hf isotopic tracer techniques applied to granitoids are helpful in distinguishing old from young deep crustal compositions. This study aims to characterize the basement nature (ancient & juvenile) of the Chinese Altai and East Junggar orogens using Hf isotopic mapping of granitoids (510–200 Ma). Zircon Hf isotopic data (18 new and 98 published samples) indicate that the study area can be divided into six Hf isotopic provinces on the basis of T_{DM}^{C} ages: Province I, >1.4 Ga; II, 1.4–1.2 Ga; III, 1.2–1.0 Ga; IV, 1.0–0.8 Ga; V, 0.8–0.6 Ga; and VI, 0.6–0.4 Ga. Provinces I, II, and III occur mainly in the central (units 2 and 3) and southern (unit 4) Altai orogen, and have slightly positive zircon $\varepsilon_{Hf}(t)$ values of +0.5 to +9.1 with slightly old T_{DM}^{C} ages of 1.53–0.81 Ga. Provinces IV and V are mainly distributed in the northern (unit 1) and southernmost (unit 5) Altai orogen, with zircon $\varepsilon_{Hf}(t)$ values of +7.5 to +11.1 and young T_{DM}^{C} ages of 0.84–0.60 Ga.In contrast, Province VI (East Junggar orogen) has zircon $\varepsilon_{Hf}(t)$ values of +11.6 to +14.9, with much younger T_{DM}^{C} ages of 0.59–0.35 Ga, except for the small Taheir area with a negative $\varepsilon_{Hf}(t)$ value of –2.5 and an older T_{DM}^{C} age of 2.5 Ga. There is a sharp contrast between the deep crustal compositions of the Altai and Junggar orogens, which are ancient in central Altai and relatively juvenile in East Junggar. This confirms that significant Neoproterozoic–Phanerozoic continental crustal growth occurred in the southern Altai and Junggar orogens,with juvenile crust occupying ~78% of the study area, and that the CAOB is a site of significant Phanerozoic continental growth. The distribution of juvenile and ancient crust in the Altai and East Junggar orogens provides new evidence for the tectonic division of the two orogens by the Erqis fault zone, and explains the heterogeneity of crustal growth in the southwestern CAOB.

Genesis and tectonic setting of adakitic intrusive rocks in the Upper Heilongjiang Basin, NE China

Guang Wu[1], Gongzheng Chen[1], Yinglei Li[1, 2], Fei Yang[1, 2], Tiegang Li[1]

[1]*MNR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China*

[2]*Key Laboratory of Orogen and Crust Evolution, Peking University, Beijing 100871, China*

The Upper Heilongjiang Basin, located in the northern end of the Great Xing'an Range, develops along the China–Russia border and strikes about 250 km from east towest, with a width of about 60 km, covering an area of 15000 km^2 in China (Fig. 1).The basin is bound by the Mongol–Okhotsk suture zone to the north, the Mohe–Tahe fault to the south, and the Derbugan fault to the southeast.A series of intermediate-felsic porphyries, mainly including the Longgouhe, Malinxi, Walagan, and Ershiyizhan intrusions from west to east, occur in the basin, which were closely related to porphyry Cu–Au mineralization.In this paper we report zircon U–Pb ages, geochemistry, and Hf isotope of the Longgouhe and Malinxiintrusions,and discuss the petrogenesis and tectonic setting of the intermediate-felsic porphyries.

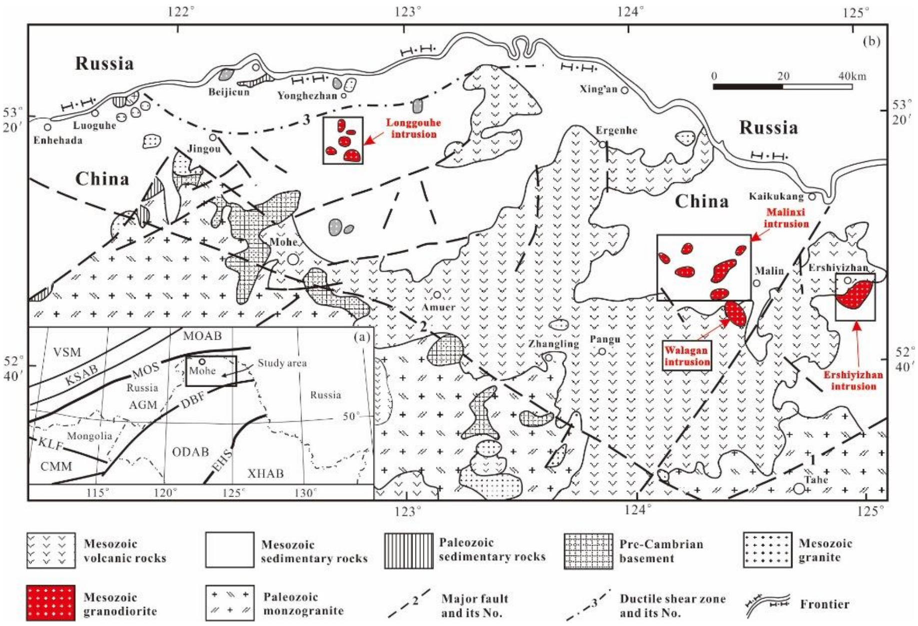


Fig. 1. Geological sketch map of the Upper Heilongjiang Basin

1.Zircon U–Pb dating

Fourteen zircons from quartz monzonite porphyry (sample HPB1-1)and 12 zircons from tonalite porphyry (sample HPB1-5) of the Longgouhe intrusion yield weighted mean $^{206}Pb/^{238}U$ ages of121±1 Ma (Fig. 2a) and 124±1 Ma (Fig. 2b), respectively. Eighteen zircons and 13 zircons from two tonalite porphyry samples (HPB5-4 and HPB5-14) of the

Malinxiintrusionyield weighted mean $^{206}Pb/^{238}U$ ages of120 Ma and 131 Ma, respectively (Fig. 2c and d).

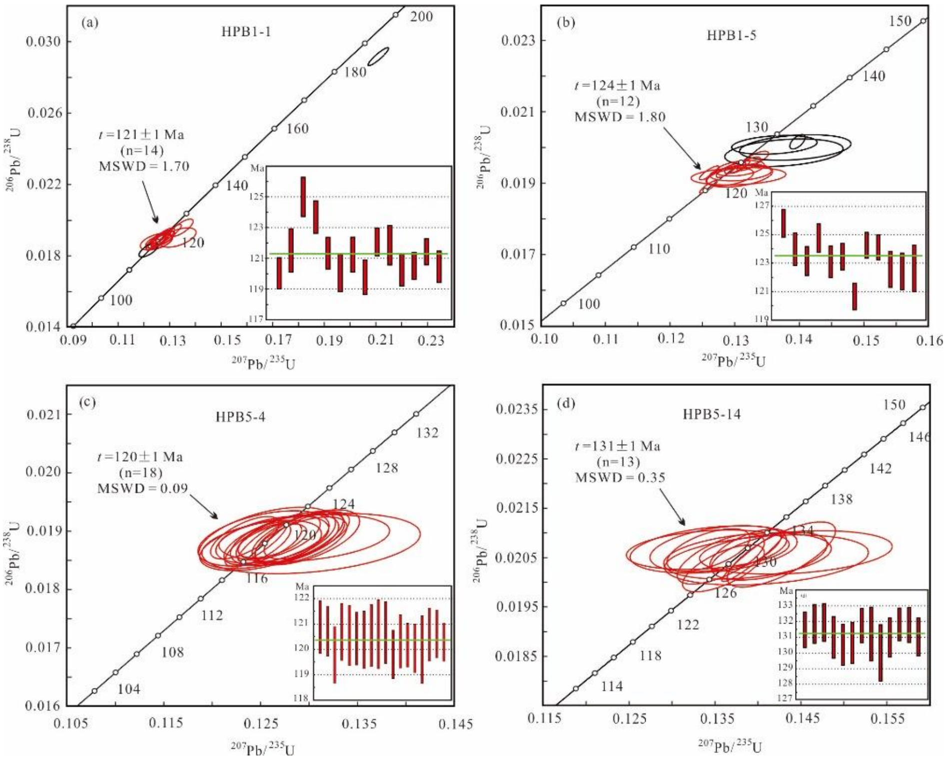


Fig. 2. Zircon U–Pbconcordia diagrams for the Longgouhe (a and b) and Malinxi intrusions (c and d)

2.Geochemistry

Fifteensamples from the Longgouhe intrusioncontain SiO_2= 62.44–66.11%, Al_2O_3= 15.77–16.97%, and MgO=1.42–3.07%, with Na_2O/K_2O, A/CNK, and $Mg^{\#}$values of 0.89–1.36, 0.87–1.13, and 50–59.In the R1 versus R2 diagram,these samples plot mainly in the quartz monzoniteand tonalitefields (Fig. 3a), and in the SiO_2 versus K_2O diagram, almost all the samples fall within the high-K calc-alkalinefield (Fig. 3b). Twenty-foursamples from the Malinxi intrusioncontainSiO_2= 62.49–68.01%, Al_2O_3= 14.57–16.93%, and MgO= 1.46–2.87%, with Na_2O/K_2O, A/CNK, and $Mg^{\#}$values of 1.02–1.69, 0.86–0.98, and 50–59.In the R1 versus R2 diagram, these samples plot mainly in the tonalitefield (Fig. 3a), and in the SiO_2 versus K_2O diagram, all samples fall within the high-K calc-alkalinefield (Fig. 3b).

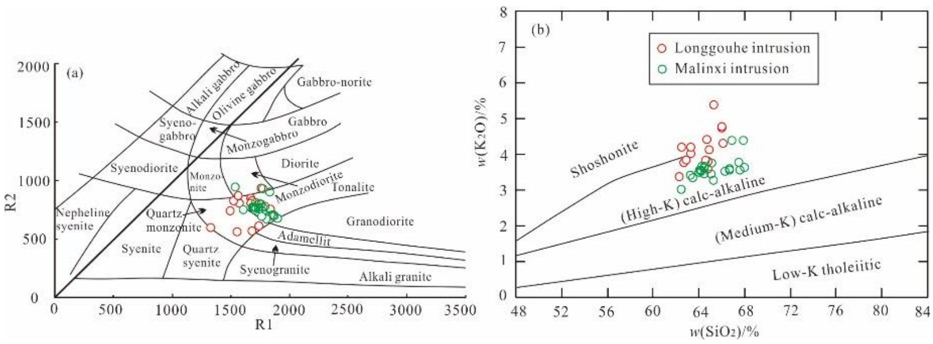


Fig. 3.Diagrams of R1 verses R2 (a) and SiO_2 versus K_2O (b) forthe Longgouhe and Malinxiitrusions

The Longgouhe and Malinxi intrusionshave similar characteristics of rare earth elements (REEs) and trace elements, with high Sr content (721–1351 ppm) and low Yb(0.52–1.12 ppm) and Y (6.25–13.3 ppm) contents.These rocks reveal slight negative Eu anomalies (Eu/Eu^{*} = 0.84–0.97)and relatively significant fractionation between light REE and heavy REE (Fig. 4a and c).They are enriched in largeion lithophile elements (LILEs) and depleted in high field strengthelements (HFSEs; e.g., Nb, Ta, P, and Ti) as well as Th(Fig. 4b and d).

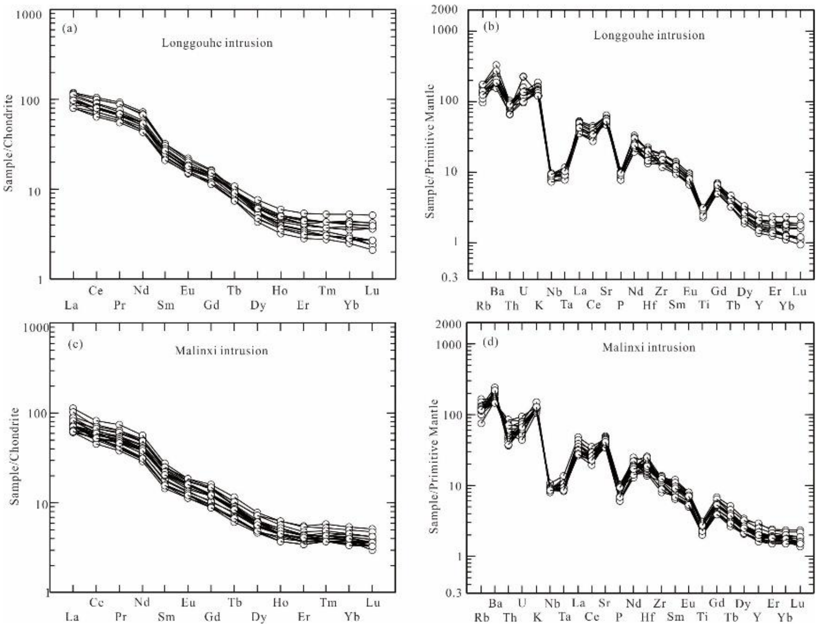


Fig. 4.Chondrite-normalized REE patterns (a and c), and primitive mantle-normalized trace element spidergrams (b and d) for the Longgouhe and Malinxi intrusions

3.In situ zircon Hf isotopic composition

The $\varepsilon_{Hf}(t)$and Hf two-stagemodel ages of the Longgouhe intrusion range from –1.6 to 0.9 and 1123 to 1281 Ma, respectively, except for one captured zircon (Fig. 5).The $\varepsilon_{Hf}(t)$ and Hf two-stagemodel ages of the Malinxi intrusion range from –3.1 to 0.9 and 1130 to 1373 Ma, respectively, except for three captured zircons (Fig. 5).

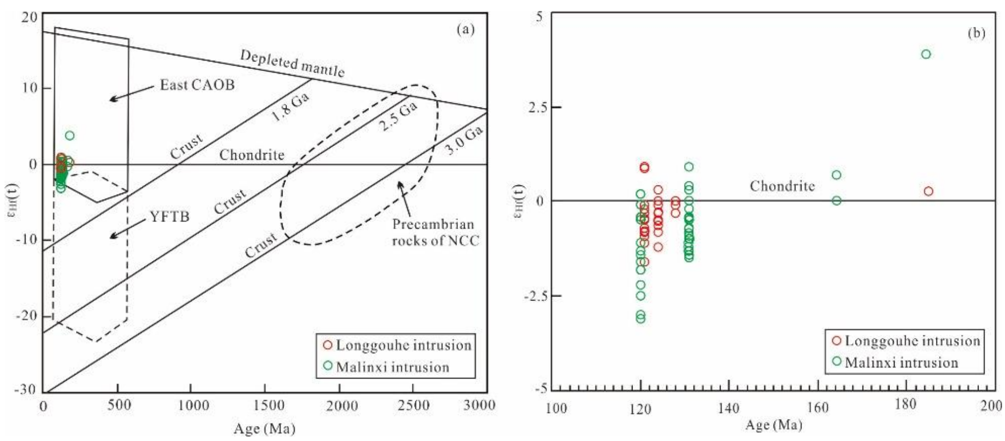


Fig. 5. Correlation diagrams between Hf isotopic compositions and ages of zircons

4.Petrogenesis and tectonic setting

Both the Longgouhe intrusion and the Malinxi intrusion have high Al_2O_3 and Srcontents and low Yb and Y contents and are characterized byslight negative Eu anomalies, which are similar to the geochemical signatures of adakites in the world. In Fig. 6, all of the samples plot in the adakite field.Given that the Paleo-Asian Ocean and Mongol–Okhotsk Ocean were closed in the Late Paleozoic and Permian-Middle Jurassic, respectively, the formation of the intrusive rocks is not related to partial melting of a subducting oceanic slab. High $Mg^{\#}$ values can exclude the rocks being formed by partial melting of a thickened lower crust. Therefore, we infer that the adakitic rocks in the Supper Heilongjian Basin were most likely formed bypartial melting of a delaminated lower crust and that the Mongol–Okhotskorogenic belt developed into a post-orogenic extension stage.

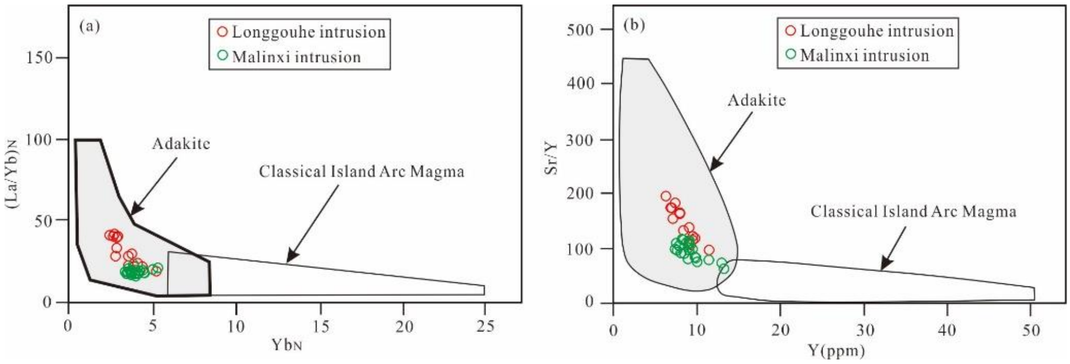


Fig. 6.Diagrams of $(La/Yb)_N$–Yb_N (a) and Sr/Y–Y (b) for the Longgouhe and Malinxiintrusions

Sm-Nd Isotope Systematics of the Cenozoic Sand Deposits of the Eastern Flank of the Baikal Rift Zone: A New Information on the Age of the Continental Crust in the Western Part of the Aldan Shield

A.B. Kotov[1], T.M. Skovitina[2], V.P. Kovach[1], S.D. Velikoslavinskii[1],
I.N. Buchnev[1], E.V. Tolmacheva[1], V.A. Gorovoy[2]

[1]*Institute of Precambrian Geology and Geochronology of RAS, St. Petersburg, Russia*, abkotov-spb@mail.ru, v.p.kovach@gmail.com, sd1949@yandex.ru, helena-tolmacheva@yandex.ru

[2]*Institute of the Earth's Crust of SB RAS, Irkutsk, Russia,* skovit71@gmail.com, vagorovoi@mail.ru

Within the western part of the Aldan Shield there are large Chara and Tokko depressions of the eastern flank of the Baikal rift zone, made up of Cenozoic sand sediments (Fig. 1). The sands of the Chara rift depression are characterized by Paleoproterozoic Nd values of model age ($t_{Nd\ (DM)}$ = 2.4 Ga) and negative values $\varepsilon_{Nd}(0)$ = -27.2 ... -27.5. Consequently, the source of these sands are rocks with an average Paleoproterozoic Nd model age. The sands of the Tokko depression have Mesoarchean Nd model ages ($t_{Nd\ (DM)}$ = 3.0 Ga) and lower values of $\varepsilon_{Nd}(0)$ = -31.4 ... -42.4, which indicates the predominance of Meso-Archean or younger rocks with their average Mesoarchean Nd model age.

The Nd model ages of the sands of the Chara rift depression are significantly different from the Nd model ages of the Mesoarchean tonalite-trondjemite orthogneisses, as well as from the Paleoproterozoic and Mesoarchean intrusive granitoids of the western part of the Aldan Shield. According to the Nd isotope characteristics, the sands of the Chara rift depression are most similar to the Paleoproterozoic meta-sedimentary rocks of the Udokan Group. This allows us to consider the latter as their main source (Fig. 2).

The results of Sm-Nd isotope-geochemical studies of the sands of the Tokko rift depression (Fig. 2) confirm the idea that the western part of the Aldan Shield is an area of intense manifestation of crust-forming processes not only of the Paleoarchean, but also of the Mesoarchean age. The formation of the Paleoproterozoic terrigenous rocks of the Udokan Group, which were the main source of sands of the Chara rift depression, is associated with the destruction of the Archean igneous rocks of the western part of the Aldan Shield, and derived from the juvenile continental crust igneous rocks of the Paleoproterozoic orogens, located probably in its southern and western framing. Therefore, the Paleoproterozoic estimates of Nd model age, characteristic of the sands of the Chara rift depression, do not constitute a basis for identifying the Paleoproterozoic stage of the formation of the continental crust of the western part of the Aldan Shield. However, it is possible that the rocks directly involved in the formation of the Paleoproterozoic juvenile continental crust of the western part of the Aldan Shield, whose presence has not yet been established, were one of the sources of the sands of the Chara rift depression.

The study was supported by the Russian Science Foundation, project no. 19–17–00205.

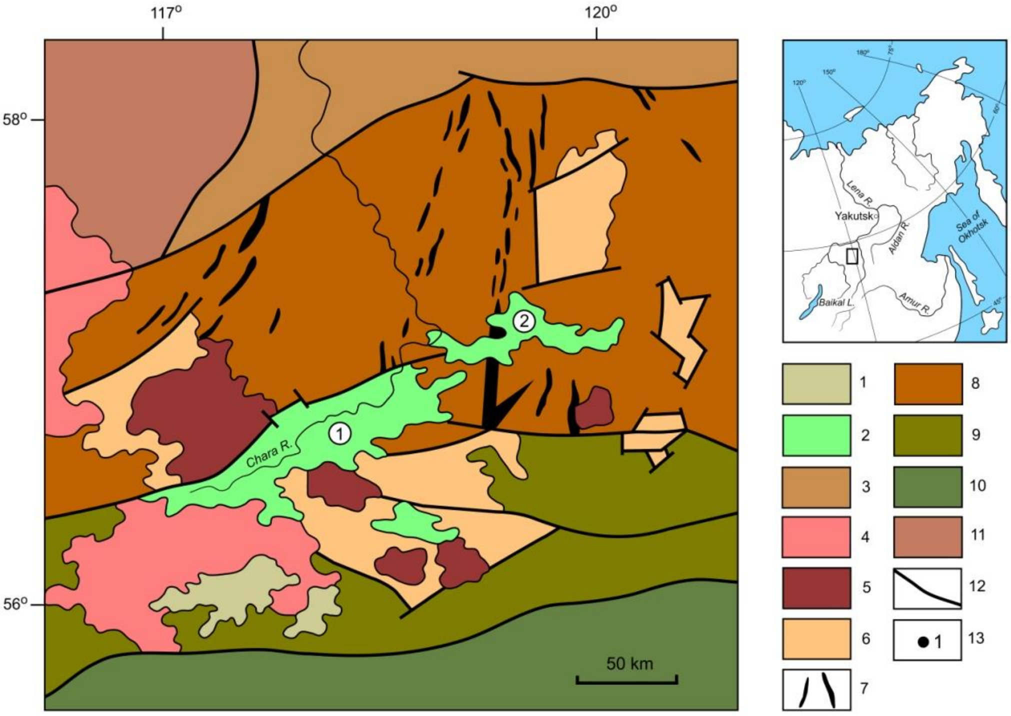


Figure 1. Schematic geological structure of the western part of the Aldan Shield.

1 – flood-basalts (N_2-Q); 2 – Cenozoic sand deposits; 3 – Mesozoic, Paleozoic and Upper Proterozoic platformal rocks; 4 – Phanerozoic granitoids; 5 – Paleoproterozoic granites of the Kodar Complex; 6 – metasedimentary rocks of the Udokan Group; 7 – weakly metamorphosed sedimentary and volcanic rocks from the greenstone belts of the Subgan Complex; 8 – Meso- and Paleoarchean tonalite-trondhjemite orthogneisses and Mesoarchean intrusive granitoids of the Aldan Shield; 9 – junction zone between the Aldan Shield and Central Asian mobile belt (Stanovoi suture); 10 – Selenga-Stanovoi superterrane of the Central Asian mobile belt; 11 – Baikal orogenic zone; 12 – faults. Numbers in circles are rift depressions: 1 – Chara, and 2 – Tokko.

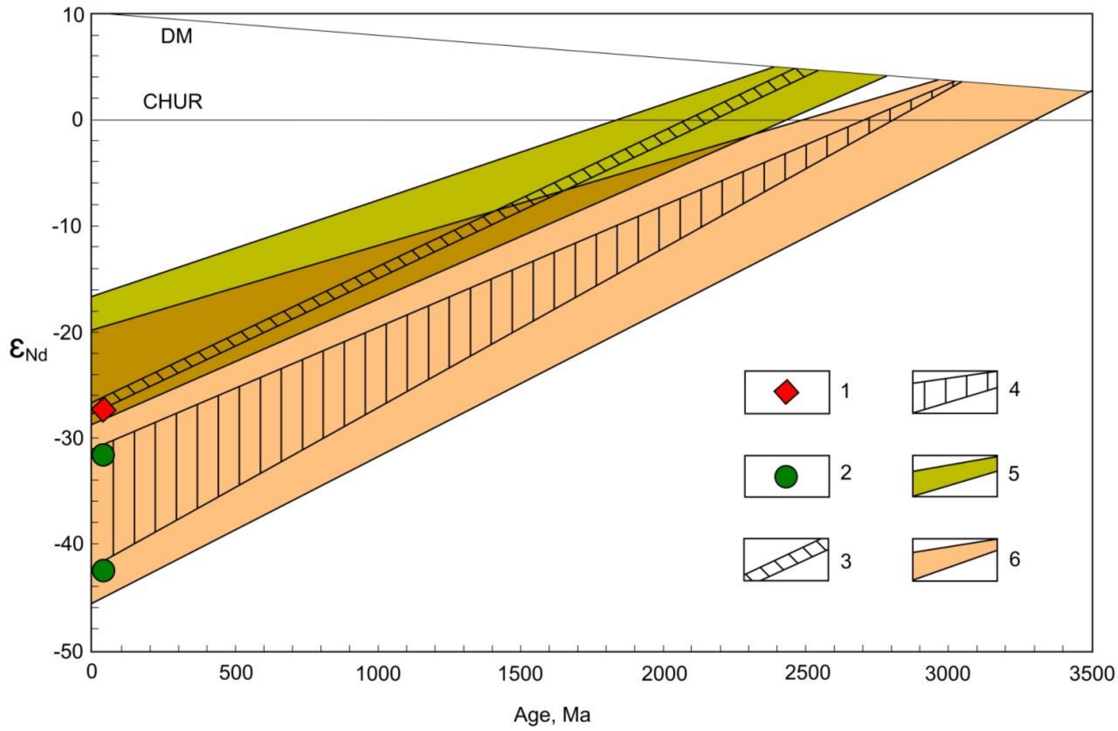


Figure 2. ε_{Nd} versus age diagram for the sands from the Chara and Tokko rift depressions.

1–2 – Nd isotopic data points for the sands: 1 – Chara rift depression, 2 – Tokko rift depression; 3–6 – Nd isotopic evolution fields: 3 – sands of the Chara rift depression; 4 – sands of the Tokko rift depression; 5 – Paleoproterozoic terrigenous sediments of the Udokan Group from the Kodar-Udokan trough; 6 – Meso- and Paleoarchean tonalite-trondhjemite orthogneisses and Mesoarchean intrusive granitoids of the Aldan Shield.

Nd Isotopic Characteristics of Granitoids from the Newfoundland Appalachians

Wang Chaoyang[1], WangTao[1, 2*], Cees van Staal[3], Lin Shoufa[4] andZhang Jianjun[1]

[1]*Key Laboratory of Deep-Earth Dynamics, Ministry of Natural Resources, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China*

[2]*Beijing SHRIMP Center, Beijing, 100037, China*

[3]*Geological Survey of Canada, 1500-605 Robson Street, Vancouver, BC V6B 5J3, Canada*

[4]*Department of Earth and Environmental Sciences, University of Waterloo, Waterloo, Ontario, Canada*

* *Corresponding author's E-mail:* real_wt@163.com

Introduction

The Appalachian orogen in North America is currently considered to be a Paleozoic accretion-type orogenic belt, or a collage, formed by collision of many ancient blocks between Laurentian and Gondwanan margins (Williams et al., 1979, 1988; Van Staal et al., 2007). A study of isotopic compositions of granitoids can provide information on deep crustal compositions and continental growth of this orogenic belt. This paper compiles available Nd isotopic data of granitoids from the Newfoundland Appalachians. The aim is to understand general characteristics of granitoids from the Newfoundland Appalachians, particularly their spatial-temporal variation in order to understand deep compositions of the orogen, and lay foundations for a comparative study of the deep crustal compositions and architecture of the orogen with a large accretionary Central Asian Orogenic Belt.

Methods

The Newfoundland Appalachians preserve one of the most complete and best-exposed cross-sections through the Appalachian mountain belt, making it an ideal area for studying the Appalachians (Fig.1). It is traditionally subdivided into the Humber Zone, the Dunnage Zone, the Gander Zone and the Avalonia Zone. The Dunnage Zone can be further subdivided into the Notre Dame Subzone and Exploits Subzone.

With ongoing support by IGCP 662andthe National Natural Science Foundation, we plan to carry out field surveys and petrological, geochronological, geochemical, and isotopic studies of Granitic rocks along the Appalachians Orogenic. Before that, in order to initially explore their isotope characteristics, Nd and Sr isotopic data of 92 granitic samples were compiled from the Dunnage Zone and Avalonia Zone in order to assess their material composition and to provide constraints on the deep crustal compositions and continental growth of the accretionary orogenic belt.

Results

The results show that the granitoids in the Dunnage Zone have widely varying $\varepsilon_{Nd}(t)$ values, from -9.2 to +8.1 (with peaks at -7.8 to +2.9 Ga; Fig. 2) and the Nd model ages peak at approximately 0.8-1.0 Ga, 1.2-1.4 Ga and 1.6-1.8 Ga (Fig. 3). These data suggest that the granitoids were mainly derived from ancient crustal compositions and mixed with small amount of partial melting of juvenile crust. These results also display characteristics of Neoproterozoic to Mesoproterozoic juvenile crustal growth. It is noteworthy that some granitoids with $\varepsilon_{Nd}(t) > 6$ are distributed along the Red Indian line suture, suggesting that juvenile crust was related to subduction and suturing.

In the Avalon Zone, the Precambrian plutonic suites mostly have $\varepsilon_{Nd}(t)$ values from +0.8 to +6.3, and Paleozoic plutonic suites mostly also have positive $\varepsilon_{Nd}(t)$ values between +0.5 and +3.6. Thus, the Precambrian and Paleozoic crust of the Avalon Zone is largely "juvenile". This isotopic signature is rarely found across the rest of the transect.

Based on the Nd isotopic signatures, it is concluded that the majority of the studied granitoid plutons in the Avalon and Dunnage zones were sourced from continental lithosphere. Most model ages of these granitoids are older than 1.0 Ga, significantly older than these of the Central Asian Orogenic Belt (Wang et al., 2009, 2017).

Conclusions

All these signatures indicate that the granitoids in the Newfoundland Appalachians have Nd isotopic compositions that are significantly different from those in the CAOB (many high positive $\varepsilon_{Nd}(t)$ = +3 to +9 with young T_{DM} = 0.5-1.0 Ga in the latter). These suggest the two orogens have different deep crustal compositions, more juvenile for the CAOB and less juvenile for the Newfoundland Appalachian orogen, although both belong to accretionary orogens.

Appendix

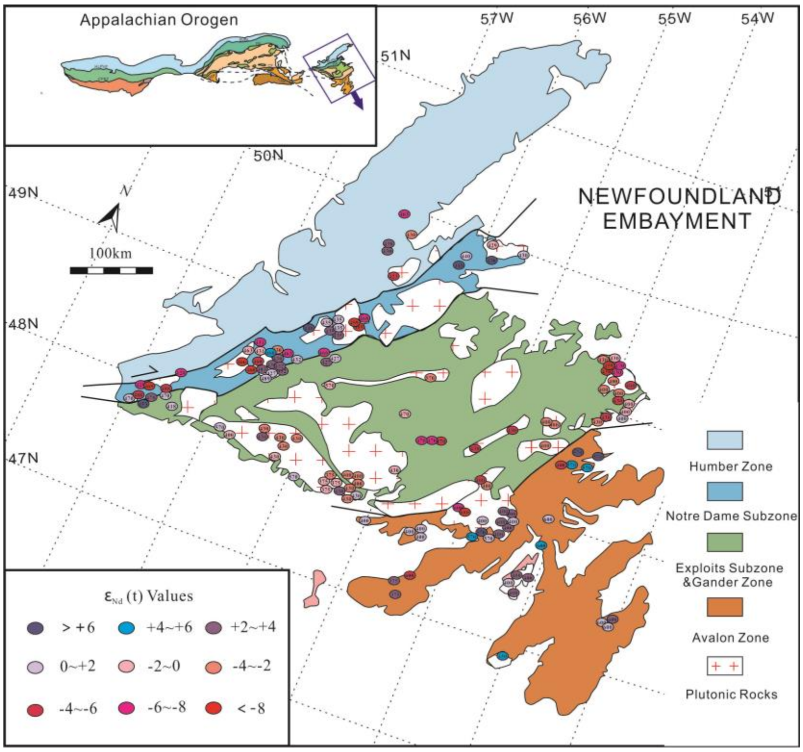


Fig. 1. Tectonic settingand regional geological mapof the Newfoundland Appalachians. (Date from Cutts et al., (2012); Fryer et al.,(1992); Kerr et al., (1995); Van Staal et al., (2007); Whalen et al., (1997a,1997b,2006); Zagorevski et al., (2007))

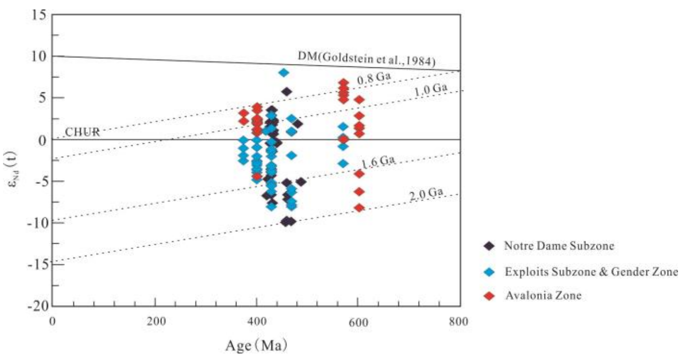


Fig. 2. Age (Ma) vs. εNd(t) values diagram for granitoids in the Newfoundland Appalachians.

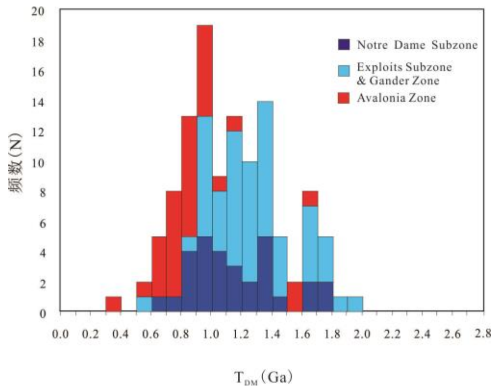


Fig. 3. T_{DM} values diagram for granitoids in the Newfoundland Appalachians.

Acknowledgements

This research was supported financially by the NSFC projects (U1403291, 4180207441830216) and projects of the China Geological Survey (Nos. 1212011120477, 1212010611803, 1212010811033, 12120113096500, and 12120113094000 and DD20160123). This paper contributes to IGCP 662 and DDE (Deep-time Digit Earth).

References

Cutts, J.A., Zagorevski, A., McNicoll, V., and Carr, S.D., 2012. Tectono-stratigraphic setting of the Moreton's Harbour Group and its implications for the evolution of the Laurentian margin: Notre Dame Bay, Newfoundland. *Canadian Journal of Earth Sciences*, 49(1):111–127.

Fryer, B.J., Kerr, A., Jenner, G.A., and Longstaffe, F.J., 1992. Probing the crust with plutons: Regional isotopic geochemistry of granitoid intrusions across insular Newfoundland. *Current Research,* 92(1): 119–139.

Kerr, A., Jenner, G.A., and Fryer, B.J. 1995. Sm–Nd isotopic geochemistry of Precambrian to Paleozoic granitoid suites and the deep-crustal structure of the southeast margin of the Newfoundland Appalachians. *Canadian Journal of Earth Sciences,* 32(2):224–245.

Van Staal, C.R., Whalen, J.B., Mcnicoll, V.J., Pehrsson, S., Lissenberg, C.J., Zagorevski, A., van Breemen, O., and Jenner, G.A.,2007. The Notre Dame arc and the Taconic orogeny in Newfoundland. *Memoir of the Geological Society of America*, 200(26): 511–552.

Wang, T., Jahn, B.M., Kovach, V.P., Tong, Y., Hong, D.W., Han, B.F., 2009. Nd-Sr isotopic mapping of the Chinese Altai and implications for continental growth in the Central Asian Orogenic Belt. *Lithos*, 110(1–4): 359–372.

Wang, T., Tong, Y., Zhang, L., Li, S., Huang, H., Zhang, J.J., Guo, L., Yang, Q.D., Hong, D.W., Donskaya, T., Gladkochub, D., and Tserendash, N., 2017. Phanerozoic granitoids in the central and eastern parts of Central Asia and their tectonic significance. *Journal of Asian Earth Sciences*, 145: 368–392.

Whalen, J.B., Jenner, G.A., Longstaffe, F.J., and Fryer, B.J., 1997a. Implications of granitoid geochemical and isotopic (Nd, O, Pb) data from the Cambrian- Ordovician Notre Dame Arc for the evolution of the Central Mobile belt, Newfoundland Appalachians. *Memoir of the Geological Society of America*, 191: 367–396.

Whalen, J.B., Mcnicoll, V.J., van Staal, C.R., Lissenberg, C.J., Longstaffe, F.J., Jenner, G.A., and Van Breeman, O., 2006. Spatial, temporal and geochemical characteristics of silurian collision-zone magmatism, newfoundland appalachians: an example of a rapidly evolving magmatic system related to slab break-off. *Lithos,* 89(3): 377–404.

Whalen, J.B., van Staal, C.R., Longstaffe, F.J., Gariepy, C., and Fryer, B.J., 1997b. Insights into tectonostratigraphic zone identification in southwestern Newfoundland based on isotopic (Nd, O, Pb) and geochemical data. *Atlantic Geology*, 33(3): 231–241.

Williams, H., 1979. Appalachian Orogen in Canada..*Canadian Journal of Earth Sciences*, 16, 792–807.

Williams, H., Colman-Sadd, S.P. and Swinden, H. S.1988. Tectonicstratigraphic subdivisions of centralNewfoundland, In: Current Research, Part B.*Geological Survey of Canada,* Paper, 88–1B, 91–98.

Zagorevski, A., Van Staal, C. R., Mcnicoll, V. J., Rogers, N., and Valverdevaquero, P. , 2007. Tectonic architecture of an arc-arc collision zone, Newfoundland Appalachians. *The Geological Society of America*, 436: 1–26.

Development of approaches to integration of isotope data and geological map resources for DDE International Project

O.Petrov, V.Snezhko, V.Khalenev, F.Larionov

*A.P.Karpinsky Russian Geological Research Institute (VSEGEI)*opetrov@vsegei.ru, viktor_snezhko@vsegei.ru, vladimir_khalenev@vsegei.ru, alexander_larionov@vsegei.ru

Since 2003, the Center for Isotopic Research (CIR VSEGEI) provides the State Geological Mapping of the territory of Russia with analytical data. Together with results from the other laboratories (as well as published data) this information is integrated into the Isotope Database (IDB-VSEGEI) created at VSEGEI.

Information from this Database is open, free and available through Geochronologic Atlas of Major Geologic Complexes of Russia, (http://geochron-atlas.vsegei.ru). The data can be presented in a form of shapefiles or as web services. All the analytical results are supplied with general information (Sample ID, Coordinates, Geological Unit name, Analytical Method, Rock name, Mineral, Age, Laboratory, References, Descriptions of the geological unit (magmatic complex) and additional information on Rock & Mineral Isotope Data, CL etc images for in situ analyses (Tables, Plots etc.)

Since 2018, we develop the information system that integrates data from our geological maps and isotope database. This system uses web services. In 2019, we have started preparation of a new map series the “Maps of Magmatic Formations of Russia”. It also will be implemented as an interactive web map on the VSEGEI website and will become one of the main open resources, summarizing information on magmatic complexes in Russia. The isotopic database of Russia will be one of the main elements of this interactive web map. Thus, access to relevant isotope geochemical data is becoming one of the key elements, required for international cooperation. In order to use such information effectively, it is necessary to create a consolidated publicly available global resource on isotope data and petrology, for example, similar to the international project OneGeology.

In February 2019, the first meeting of the DDE International project was held in Beijing, China. The project will be carried out under the auspices of UNESCO and the International Union of Geological Sciences (IUGS). The goal of the project is to provide digital geological information in the form of consistent data in a convenient form for science, public and industry. One of the key activities of the DDE initiative is “Isotopic Geochemistry and Petrology,” supervised by the assembled working group. Its task is to form a consolidated resource, combining data on petrology and geochemistry from a variety of databases, created by various geological surveys, scientific and educational institutions. To accomplish this task, the working group proposed a conceptual model and a prototype of the database structure.

Based on these proposals, VSEGEI began to develop approaches for information integration from the Isotope database of Russia into a unified structure proposed in the international DDE project.

To do this, we expanded our Isotope database with additional tables and dictionaries provided for the DDE project, and we began to prepare and publish relevant web services. In the course of the work, we clarified a number of parameters of the proposed unified structure and began to develop a Multilingual Thesaurus, which is designed to ensure the terminological correspondence of the used dictionaries. The Multilingual Thesaurus is necessary for each participating country to conduct its database in its native language, and at the same time ensure the possibility of publishing its data in any language of the project participants. At the first stage, we plan to include the following dictionaries into the Multilingual Thesaurus: Names of Rocks, Minerals, and Isotope Analytical Methods. We are currently working on the “Names of Rocks” dictionary, based on the SimpleLithology dictionary from the IUGS standard GeoSciML. This dictionary has been significantly expanded to include more than 500 terms, some of which are linked up with the Asian Multilingual Geology Thesaurus (AMTG) published in 2006. It has been developed with the support of UNESCO (CCOP Coordination Committee for Geological Programs in Southeast Asia). Currently, the AMTG includes 9 Asian languages: Khmer, Chinese, Indonesian, Japanese, Korean, Laotian, Malaysian, Thai, Vietnamese, as well as English and French (Mongolian is absent). We propose to perform the linking of the remaining terms in the framework of the project IGCP 662. This will provide a solution of the correlation problem of the most of Asian languages. Comparisons with the terms of European languages can be made on the basis of the earlier published Multilingual Thesaurus on Earth Sciences (1995), which was created under the auspices of the International Union of Geological Sciences (IUGS) and the Commission on Geoinformatics (COGEODOC): the Thesaurus contains terminology in 6 European languages: English, Russian, French, German, Spanish, and Italian. To integrate multilingual dictionaries into the database structure, they are prepared as a web service. A technology of their online connection to external information systems has also been developed by our group.

The need to use standardized terminology from geological thesauri is dictated by the inability of widely accessible Internet resources (for example, Google Translator) for accurate automatic interpretation of special terminology, since they focus primarily on common vocabulary and have a limited lexicon (for example, there are no equivalents for many mineral and textural rock varieties). Those Internet resources can not also solve problems of a semantic ambiguity of terms in different languages. In addition, not every translation of a term into another language conveys a geological meanincorrectly: the choice of an unambiguous term that is widely used in geological practice to denote a particular concept can only be made by a national specialist who is a native speaker (the development of multilingual thesauri is what international Working Groups are assembled for).

By the end of 2019, we plan to complete the development of information integration technology of the Isotope database into the structures, devised by the working group on geochemistry and petrology of the DDE project, as well as, with a help of our colleagues in the IGCP 662 project, to finalize the multilingual thesaurus "Name of Rocks" for 6 Asian languages and to introduce the Mongolian language into the thesaurus.

Large-scale latest-Triassic to Early Jurassic I-type felsic rocks in the northern Great Xing'an Range, NE China: evidence for southward subduction of the Mongol–Okhotsk Ocean

Yinglei Li [1, 2], Guang Wu [1, *]

[1]*MNR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China*

[2] *Key Laboratory of Orogen and Crust Evolution, Peking University, Beijing 100871, China*

The closure of the Paleo-Asian Ocean during the late Paleozoic to early Mesozoic resulted the amalgamation of Siberian, Tarim, and North China cratons, forming the world famous Central Asian Orogenic Belt (CAOB) through a gigantic accretionary orogeny(Fig. 1a). NE China, locatedin the eastern section of the CAOB, consists of a collage of microcontinental massifs, including the Khanka, Jiamusi, Songnen–Zhangguangcai Range, Xing'an, and Erguna massifs. Large-scaleLate Triassic to Early Jurassic igneous rocksin the Great Xing'an Range (GXR) area are mainly distributed in the northern GXR (i.e., Erguna and Xing'an massifs). With regard to origin of the Late Triassic to Early Jurassic igneous rocks, three main tectonic models have been proposed, including:(1) intraplate extension aroused by the Paleo-Asian Ocean subduction (Fan et al., 2003; Ma et al., 2009; Ying et al., 2010; Zou et al., 2011);(2) the Paleo-Pacific Ocean subduction and associated slab rollback (Sun, 2013); and (3) the Mongol-Okhotsk oceanic plate subduction and subsequent post-collision extension (Zhao et al., 2004). In this study, we focused on geochronology and geochemistry of the early Mesozoic igneous rocks in the northern GXR area,and our aim was to determine the formation age, petrogenesis, and tectonic setting of the igneous rocks, and propose a tectonic evolution model for the northern GXR area during the early Mesozoic.

We carried out zircon U–Pb dating on two rhyolite samples, two quartz diorite samples, one granodiorite sample, and four monzogranite samples. The two rhyolite samples yielded weighted mean $^{206}Pb/^{238}U$ ages of 206±2 Ma (MSWD=1.1, N=7; Fig. 2a) and 195±2 Ma (MSWD=2.2, N=13; Fig. 2b);the two quartz diorite samples yielded weighted mean $^{206}Pb/^{238}U$ ages of 196±1 Ma (MSWD=1.8, N=23, Fig. 2c)

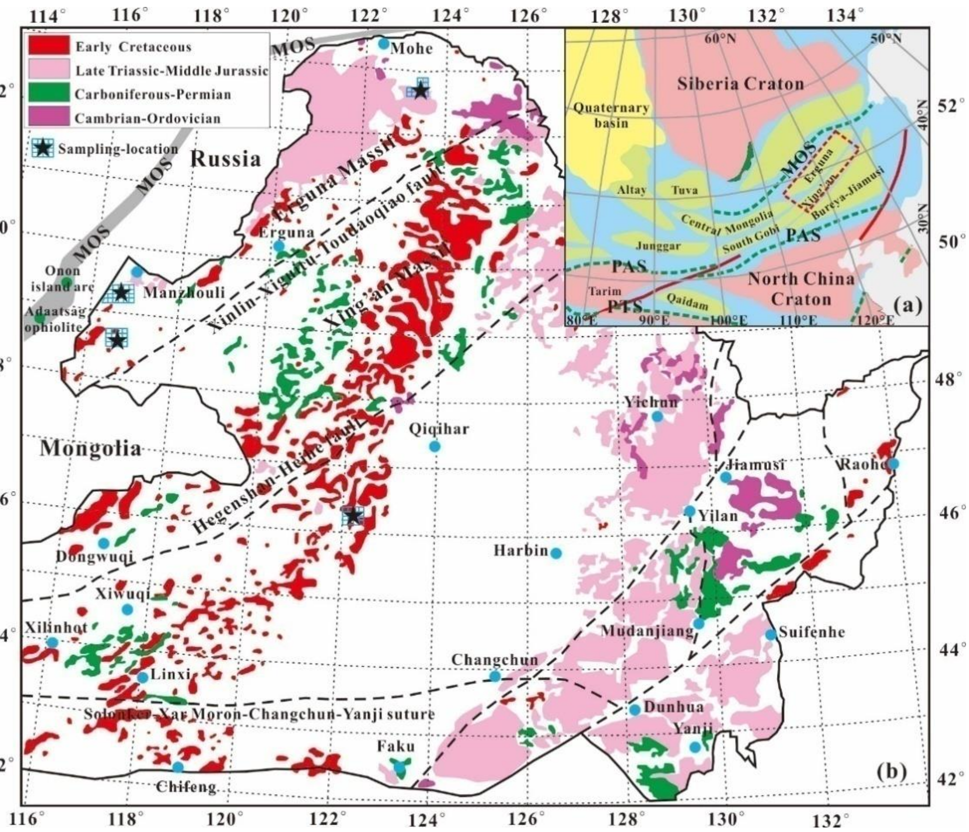


Fig. 1. (a) Tectonic setting of Northeast Asia (modified after Tang et al., 2016), and (b) simplified geological map of NE China (after Wu et al., 2003b; Zhou et al., 2015). MOS, Mongol–Okhotsk suture; PAS, Paleo-Asian suture; PTS, Paleo-Tethys suture.

and 187±1 Ma (MSWD=0.29, N = 24, Fig. 2d); the granodiorite sample gave a weighted mean $^{206}Pb/^{238}U$ age of 189±2 Ma (MSWD=2.7, N=26; Fig. 2e); and the four monzogranite samples yielded weighted mean $^{206}Pb/^{238}U$ ages of 208±8 Ma(MSWD=0.23, N=13; Fig. 2f), 195±3 Ma (MSWD=3.0, N=11; Fig. 2g), 178±2 Ma (MSWD=0.67, N=22; Fig. 2h), and 185±2 Ma (MSWD=1.7, N=14; Fig. 2i). These ages are interpreted as the crystallization age of these igneous rocks.

Six Late Triassic rhyolite samples reveal high SiO_2 (75.22%–77.61 wt. %) and low MgO contents with $Mg^{\#}$values of 9.24–18.7 and A/CNK values of <1.1;twenty-nine Late Triassic–Early Jurassic granodiorite,quartz diorite, and monzogranite samples have SiO_2contents of 60.85%–76.42 wt. % andtotal alkali (K_2O + Na_2O) contents of 6.29%–9.49 wt. %, with A/CNK values lower than 1.1; moreover, the P_2O_5content of the Late Triassic–Early Jurassic igneous rocks decreases with increasing SiO_2 content. The geochemical characteristics of major elements indicate that the igneous rocks have ahigh-K calc-alkaline I-type granite affinity.

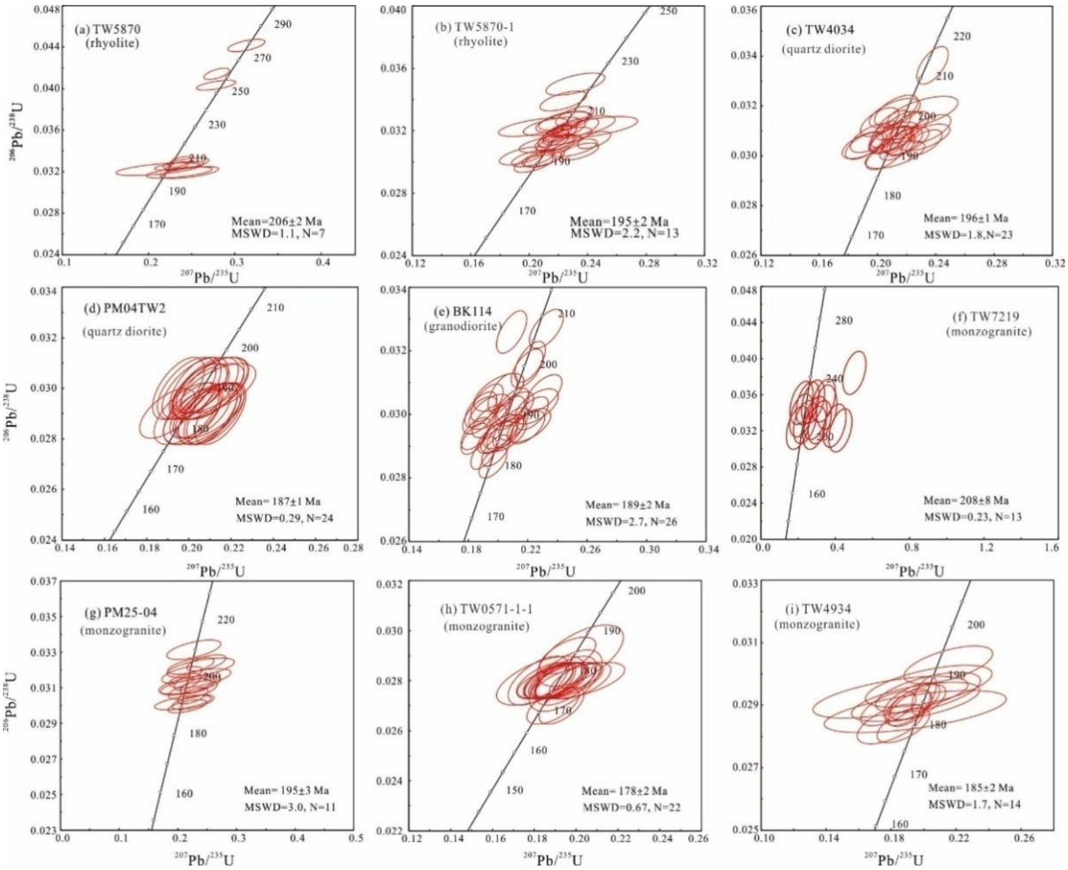


Fig. 2. LA-ICP-MS zircon U–Pb Concordia diagrams for representative samples

Sixty in-situ zircon Hf isotopic analyses for a rhyolite (TW5870-1),a granodiorite (BK114), and a quartz diorite (TW4034) sampleswere carried. These zircons have $\varepsilon_{Hf}(t)$ values of +4.3 to +12.2 (Fig. 3a), and their Hf single-stage (T_{DM1}) and two-stage (T_{DM2}) model ages vary from 0.4 to 0.7 Ga and 0.5 to 1.0 Ga (Fig. 3b), respectively. Hf isotopic composition suggests that the early Mesozoic igneous rocks were most likely formed by partial melting of a Neoproterozoic juvenile lower crust.

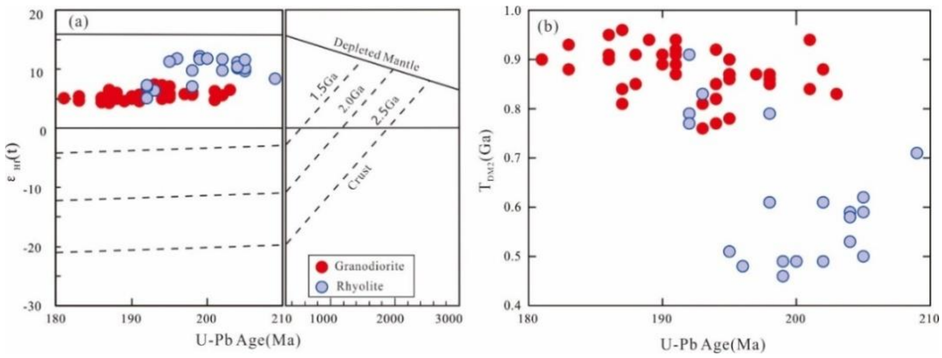


Fig. 3. Zircon ages (Ma) vs. $\varepsilon_{Hf}(t)$ values forthe latest-Triassic to Early Jurassic I-type felsic rocks in the northern GXR

On the discrimination diagrams of Rb versus Y + Nb and Nb versus Y proposed by Pearce et al. (1984), all the samples plot in the field of volcanic arc granite, sugesting that theAndean-type arc setting, is more plausible for their generation.

Given the Paleo-Asian Ocean was finally closed along the Solonker–Xar Moron–Changchun–Yanji Sutureduring the late Paleozoic to early Mesozoic, it is thus impossible to relate the latest-Triassic–Early Jurassic igneous rocks of active continental margin. ANW-dipping subduction of the Paleo-Pacific plate beneathEurasia is a possible genesis model for generation of the latest-Triassic–Early Jurassic igneous rocks; however these igneous rocks are mainly distributed within Erguna and Xing'an massifs of the northern GXR. Therefore, we exclude this genetic model. The only remaining model, which is responsible for the origin of these early Mesozoic igneous rocks, is the southward subduction of the Mongol–Okhotsk Ocean plate beneath the GXR. The Mongol–Okhotsk suture has been identified cropping out mainly in Russia and Mongolia based on the studies of Adaatsag ophiolite in central Mongolia (325 Ma) and Late Carboniferous oceanic island basalt with pelagic radiolarian chert in the Gorkhi Formation (Tomurtogoo et al., 2005; Ruppen et al., 2014). For its closing process, Li et al. (2015) and Tang et al. (2016) subdivided the Early Mesozoic magmatic activity in the Erguna Massif into four stages at ~246 Ma, ~225 Ma, ~205 Ma, and ~185 Ma and proposed an active continental margin setting for their generation; Liu et al. (2018) identified two isolated phases of magmatic activity at ca. 267–225 Ma and ca. 215–165 Ma, and argued for a two-stage tectonic model for the southward subduction of the Mongo–Okhotsk Ocean;Zeng et al. (2014) studied the Badaguan complex at the western margin of the Erguna massif and argued that it is related to the Mongol–Okhotsk Ocean subduction. Moreover, precious palaeomagnetic data suggest that the Mongol–Okhotsk Ocean finally closed during the Middle to Late Jurassic (Yang et al., 2015; Fritzell et al., 2016).

Considering the geochronological and geochemical data obtained in this study and previous research results for the GXR area together, we concluded that thelatest-Triassic to Early Jurassic igneous rocks formed in an active continental margin environment, which was related to the southward subduction of the Mongol–Okhotsk Ocean plate, and that the Mongol–Okhotsk Ocean tectonic system in NE China mainly affected the northern GXR area, i.e., the Erguna and Xing'an massifs.

Early Cretaceous forearc extension in the Neo-Tethyan subduction zone, southern Tibet: A record from mafic dike swarms

Lingsen Zeng, Qian Xu, Haitao Wang, Yinglong Di, Yu Shen, Yaying Wang, Zhaoping Hu, Yafei Wang

Key Laboratory of Deep-Earth Dynamics, Ministry of Natural Resources, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China. E-mail: lzeng1970@163.com

In modern subduction systems, forearc extension is common and associated with the retreat or roll-back of subducting oceanic slab (Fitch, 1972; Whitmore et al., 1997; Schellart and Lister, 2005; Morell et al., 2011; Reitz and Seeber, 2012; Reagan et al., 2010; Maffione et al., 2015; Xiong et al., 2016). Whether such extension is limited to the crustal level or involves the mantle lithosphere is one of the interesting questions poorly resolved. The Cretaceous Xigatze forearc basin developed along the southern margin of the Gangdese batholith is one of the best preserved forearc basins worldwide (Einsele et al., 1994; Wu et al., 2010). Within this basin, except for the mid-Miocene dioritic dikes (Chen et al., 2014; Zeng et al., 2017), there occur a series of nearly E-W trending dikes of diabasic to dioritic composition. Zircon U-Pb dating results show that these dikes might represent at least three phases of magmatism at 124.5±2.9 Ma, 110.7±0.8 Ma, and 100.2±1.1 Ma, respectively (Fig. 1). These mafic dikes are characterized by (1) enrichment in LREE, depletion in HREE, and nearly flat HREE distribution patterns; (2) strong depletion in Rb, Ba, Nb, and Ta, weak depletion in Ti, and no anomalies in Zr and Hf; (3) low Sr ($^{87}Sr/^{86}Sr(t)=0.704830\sim0.705083$) and high Nd($\varepsilon_{Nd}(t)=+3.6\sim+4.0$) isotope compositions; (4) high and positive zircon ε_{Hf} values (>+11.7 and up to +15.4); and (5) presence of possibly captured ~140-190 Ma zircon grains. Though the earliest phase is similar to those ages of gabbro dikes within the Xigatze ophiolite and to the initiation of forearc extension at ~130 Ma (Xiong et al., 2016), the later two phases are substantially younger by ~15 to 25 myrs. These observations suggest that the development of the Xigatze forearc basin was accompanied by intensive and protracted forearc extension which induced partial melting of relatively depleted forearc mantle lithosphere and the generation of basaltic magmas different from typical arc basalts. The early Cretaceous forearc extension and melting could be triggered by enhanced corner flow due to southward retreat of the subducting Neo-Tethyan oceanic slab (Fig. 2). Zircon grains with ages greater than ~140 Ma from the diabases might suggest the presence of early Jurassic crystalline rocks beneath the Xigaze forearc basin.

Acknowledgments

This work is supported by the Second Tibetan Plateau Scientific Expedition and Research (STEP, 2019QZKK0702), National Natural Science Foundation of China (Grant No. 41425010 & 41873023) and China Geological Survey (Grant No. DD20190057).

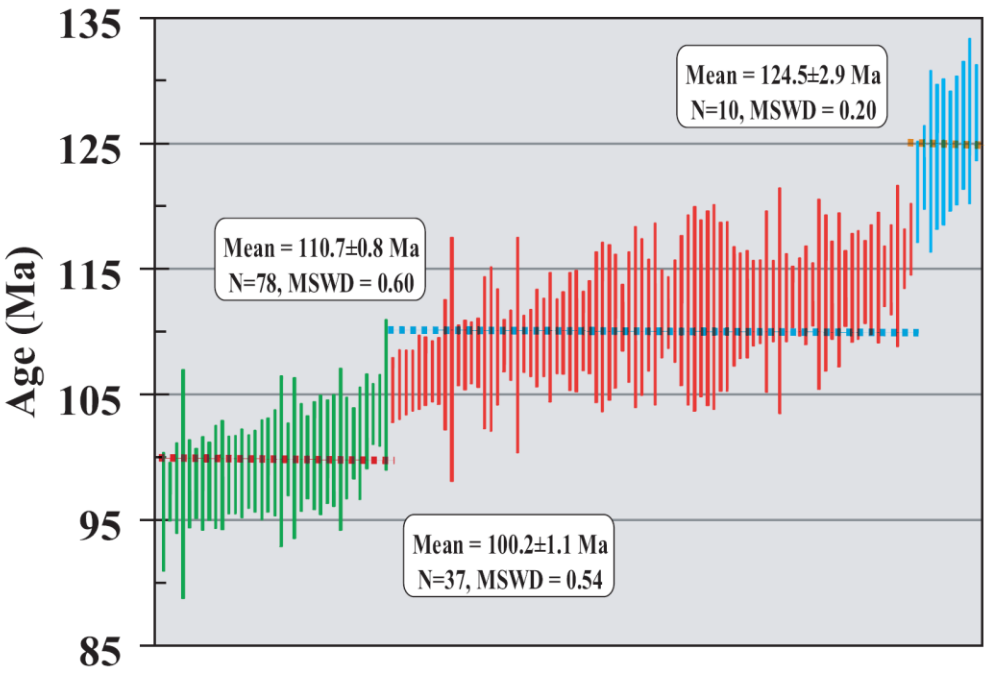


Figure 1. Age distribution diagram for U-Pb analytical results for zircon grains from the diabase within the Xigatze forearc basin, southern Tibet

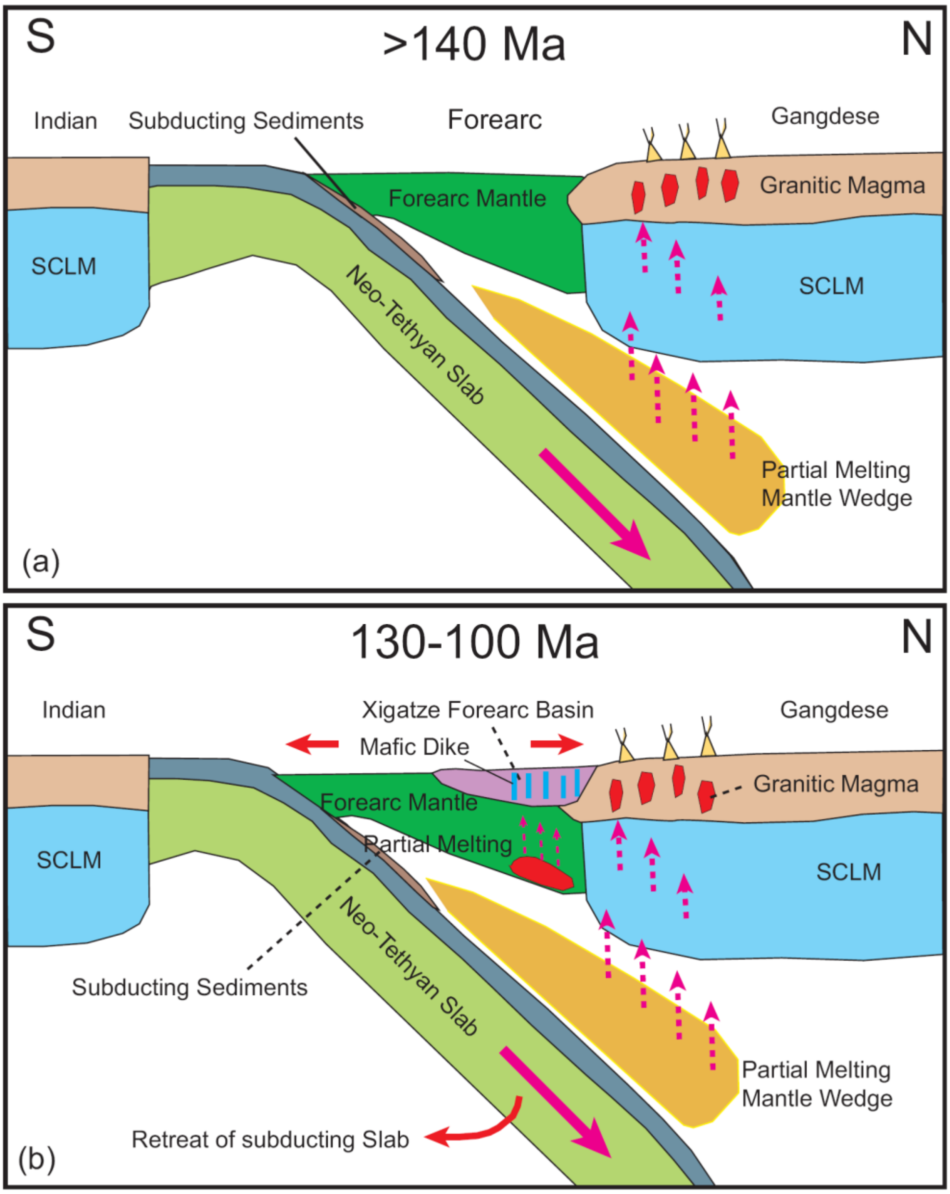


Figure 2. Schematic cartoons (not to scale) illustrating the tectonic evolution of forearc region of the Gangdese Arc from >140 Ma to 100 Ma.

References

Chen, X.J., Xu, Z.Q., Meng, Y.K. & He, Z.Y., 2014. Petrogenesis of Miocene adakitic diorite-porphyrite in middle Gangdes batholith, southern Tibet: Constraints from geochemistry, geochronology and Sr-Nd-Hf isotopes. Acta Petrologica Sinica, 30, 2253-2268

Einsele, G., Liu, B., Dűrr, S., Frisch, W., Liu, G., Luterbacher, H.P., Ratschbacher, L., Ricken, W., Wendt, J., Wetzel, A., Yu, G. & Zheng, H., 1994. The Xigaze forearc basin: Evolution and facies architecture (Cretaceous, Tibet). Sedimentary Geology, 90, 1–32

Fitch, T.J., 1972. Plate convergence, transcurrent faults, and internal deformation adjacent to Southeast Asia and the western Pacific. Journal of Geophysical Research, 77, 4432–4460

Maffione, M., van Hinsbergen, D.J.J., Koomneef, L.M.T., Guilmette, C., Hodges, K., Borneman, N., Huang, W.T., Ding, L. & Kapp, P., 2015. Forearc hyperextension dismembered in the south Tibetan ophiolites. Geology, 43, 475–478

Morell, K.D., Fisher, D.M., Gardner, T.W., Femina, P.L., Davidson, D. & Teletzke, A., 2011. Quaternary outer fore-arc deformation and uplift inboard of the Panama Triple Junction, Burica Peninsula. Journal of Geophysical Research: Solid Earth, 116, B5, doi: 10.1029/2010JB007979

Reagan, M.K., Ishizuka, O., Stern, R.J., Kelley, K.A., Ohara, Y., Blichert-Toft, J., Bloomer, S.H., Cash, J., Fryer, P., Hanan, B.B., Hickey-Vargas, R., Ishii, T., Kimura, J.I., Peate, D.W., Rowe, M.C. & Woods, M., 2010. Fore-arc basalts and subduction initiation in the Izu–Bonin–Mariana system. Geochemistry, Geophysics, Geosystems, 11, Q03X12, doi: 10.1029/2009GC002871

Reitz, M.A. & Seeber, L., 2012. Arc-parallel strain in a short rollback-subduction system: The structural evolution of the Crotone basin (northeastern Calabria, southern Italy). Tectonics, 31(4), 4017, doi: 10.1029/2011TC003031

Schellart. W.P. & Lister, G.S., 2005. The role of the East Asian active margin in widespread extensional and strike-slip deformation in East Asia. Journal of the Geological Society, London, 162, 959–972

Whitmore, G.P., Johnson, D.P., Crook, K.A.W., Galewsky, J. and Silver, E.A., 1997. Convergent margin extension associated with arc-continent collision: The Finsch Deep, Papua New Guinea. Tectonics, 16, 77–87

Wu, F.Y., Ji, W.Q., Liu, C.Z. & Chung, S.L., 2010. Detrital zircon U–Pb and Hf isotopic data from the Xigaze fore-arc basin: constraints on Transhimalayan magmatic evolution in southern Tibet. Chemical Geology, 271, 13–25

Xiong, Q., Griffin, W.L., Zheng, J-P., O'Reilly, S.Y., Pearson, N.J., Xu, B. & Belousova, E.A., 2016. Southward trench migration at ~130–120 Ma caused accretion of the Neo-Tethyan forearc lithosphere in Tibetan ophiolites. Earth and Planetary Science Letters, 438, 57–65

Zeng, L.S., Gao, L.E., Guo, C.L., Hou, K.J. & Wang, Q., 2017. Early Cretaceous forearc extension of the Gangdese continental arc，southern Tibet. Acta Petrologica Sinica，33, 2377-2394

The Liuyuan Complex in the Beishan Orogen, NW China: an ophiolite at the southern edge of the Central Asia Orogenic Belt? Insights from new mapping, petrology and geochemistry

Gabriel Sombini dos Santos[1*], Jean Bedard[2], Shoufa Lin[1], and Cees van Staal[1]

[1]*Department of Earth and Environmental Science, University of Waterloo, Waterloo, ON, N2L 3G1, Canada.*

[2]*Geologial Survey of Canada, Quebec Office, 490, Rue de la Couronne, Quebec, QC, G1K 9A9. *Corresponding author* <gabriel.santos@uwaterloo.ca>.

The Early Permian Liuyuan Complex, located at the southern edge of the Beishan Orogen, along the southern tip of the Central Asia Orogenic Belt, is mainly composed of pillow basalts, with subordinate gabbro, trondhjemite, and associated turbidites, carbonates and cherts. Although the area has been investigated by several workers in recent years (e.g. Mao et al. 2012, Wang et al. 2017), thereis still considerable debate if the Liuyuan Complex comprises a continental rift (Wang et al. 2017) or an oceanic setting (Mao et al. 2012). The internal structure and stratigraphy ofthe Complex are poorly known and controversial. The importance of the Liuyuan Complex for understanding the Beishan Orogen and hence, the terminal stages of the Paleo-Asian Ocean justifies a more detailed petrological and structural analysis. Investigation of the gabbro at the base of the Liuyuan Complex led to its subdivision into troctolite, olivine-gabbro, melanogabbro, leucogabbro, hornblende gabbro, tonalite, and diorite. These gabbros are intruded by trondhjemite and diabase, locally forming metre-scale mingling textures in composite dykes. The top section of the Liuyuan Complex is composed of spectacular exposures of sheeted dykes and pillow basalts, preserving lava tubes. The pillow basalts are intruded by several E-W trending gabbro dikes, approximately 1 m wide. The Complex is bounded both to the north and the south by steeply north-dipping faults, the kinematics and tectonic significance of which at present are not well understood. An approximately 1-kilometre wide E-W shear zone is also present near the southern edge of the Complex. Preliminary structural data suggests it is a triclinic transpressional shear zone.

In rare earth elements (REE) spiderplots, the gabbros can clearly be subdivided into cumulates and fractionates, with cumulate gabbros generally showing lower total REE, low La/Yb, and positive Eu anomalies. The fractionated gabbrosshow higher total REE contents, low La/Yb, and negative Eu anomalies. For the basalts, the La/Yb ratio is variable, but close to unity, and slightly negative Eu anomalies are present. The basalts display the same REE patterns as the fractionated gabbros. On the trace element spiderplot the cumulates display an overall irregular pattern, with negative Zr anomalies, and variable behavior of Th, Nb and Ta. However, the element behavior for the fractionated gabbros and the basalts is similar, with variable Th enrichment, negative Ta - Nb anomalies, and negative Ti anomalies. The late diabase dykes intruding the gabbros, and the gabbro dykes intruding the basalts are geochemically indistinguishable from the basalts, suggesting they are feeder dykes. Molar element ratio analysis (Stanley 2016) further suggests the mafic rocks that comprise the Complex are comagmatic. The existing major element variation can be fully accounted for by fractionation of olivine, plagioclase, and minor clinopyroxene.

The geochemical signatures and the relative high abundance of magmatic amphibole suggest the ophiolite formed in a supra-subduction environment. This interpretation is further supported by the tectonic discrimination diagrams of Agrawal et al. (2008). Given that it is imbricated with Permian sediments, the Liuyuan Complex is interpreted to be an ophiolite complex incorporated in anaccretionary wedge during closure of the last vestige of the Paleo-Asian Ocean. Future work will focus on the petrological and structural aspects of the Liuyuan Complex to refine the models for the late evolution of the Beishan Orogen.

References

Agrawal, S., Guevara, M., & Verma, S.P., 2008. Tectonic discrimination of basic and ultrabasic volcanic rocks through log-transformed ratios of immobile trace elements. International Geology Review, 50-12, 1057-1079.

Mao, Q., Xiao, W., Windley, B.F., Han, C., Qu, J., Ao, S., Zhang, J.&Guo, Q., 2012. The Liuyuan complex in the Beishan, NW China: a Carboniferous–Permian ophiolitic fore-arc sliver in the southern Altaids. Geological, 149, 483–506.

Stanley, C., 2017. Molar element ratio analysis of lithogeochemical data: a toolbox for use in mineral exploration and mining. Proceedings of Exploration 17: Sixth Decennial International Conference on Mineral Exploration, edited by V. Tschirhart and M.D. Thomas, 471–494.

Wang. Y., Zhaohua, L., Santosh, M. Shuzhi, W.& Na, W., 2017. The Liuyuan Volcanic Belt in NW China revisited: evidence for Permian rifting associated with the assembly of continental blocks in the Central Asia Orogenic Belt. Geological Magazine, 154, 265-285.

Tracking deep ancient crustal components by statistical analysis on information of xenocrystic/ inherited zircons within igneous rocks from the Altai-East Junggar regions

Jianjun Zhang[1, 2], Tao Wang[1], Ying Tong[1], Zhaochong Zhang[2], He Huang[1], Lei Zhang[1], Lei Guo[1], Peng Song[1], Zengqian Hou[1]

[1]*Key Laboratory of Deep-Earth Dynamics of Ministry of Natural Resources, Institute of Geology, Chinese Academy of Geological Sciences, Beijing, 100037, China.*

[2]*State Key laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Beijing, 100083, China*

The deep crustal continental components and architecture of the Central Asian Orogenic Belt has long been a matter of debate (Wang et al., 2009; Kröner et al., 2014, 2017; Xiao et al., 2015; Yang et al, 2017; Song et al, 2019). We present an integrated study of geochronological and Hf-in-zircon isotopic data for xenocrystic zircons from the Paleozoic granitoid rocks and associated felsic volcanic rocks of the Chinese Altai, East Junggar and nearby regions. The aim is to trace the age spatial distribution of deep old crustal components in these key parts of the western Central Asian Orogenic Belt.

Three major zircon xenocrysts provinces are defined by their pre-magmatic age distribution and available Hf-in-zircon isotopes in our complied dataset (Fig. 1). Province I, mainly situated in the eastern part of the central Chinese Altai, is characterized by the abundant inherited zircons with Meso-proterozoic and Paleo-proterozoic ages (1000-1600 and 1600-2500 Ma), and variable $\varepsilon_{Hf\ (t)}$ values ranging from -15 to +7 with ancient Hf crustal model ages (T_{DMC}) ranging from 1.5 to 2.9 Ga. A few scattered parts of province I are scattered situated in the East Junggar (individual areas, e.g., Taheir and Shuangchagou). Province II, situated mostly in the central Chinese Altai, is characterized by abundant xenocrystic zircons with NeoProterozoic ages (542-1000 Ma), $\varepsilon_{Hf(t)}$ values ranging from -6.8 to +8.1 and correspond Hf crustal model ages of ~1.0 to 1.3 Ga. Province III contains abundant Phanerozoic (<541 Ma) xenocrystic zircons that show highly positive $\varepsilon_{Hf(t)}$ values ranging from +5 to +16 and the youngest Hf crustal model ages (0.4-0.95 Ga). The main part of Province III occupies in most areas of the East Junggar and the southernmost and northern parts of the Chinese Altai.

Identification of the ancient (pre-Neoproterozoic) Hf crustal model ages in the eastern part of the central Chinese Altai (Province I) supports the suggestions that ancient concealed crustal components exist in the Chinese Altai. In contrast, Province III in the East Junggar predominantly displays young model ages, which indicates that it is mainly composed of juvenile components and likely a typical accretionary belt. Besides, a few small areas with ancient model ages are recognized in the East Junggar, providing evidence for the local existence of Precambrian crust or micro-blocks within the accretionary belt. The zircon xenocrysts provinces are consisted with the Nd isotopic province and provide further evidence for the ancient and juvenile compositions in deep.

Key words: Central Asian Orogenic Belt, zircon xenocrysts, deep continental architectures.

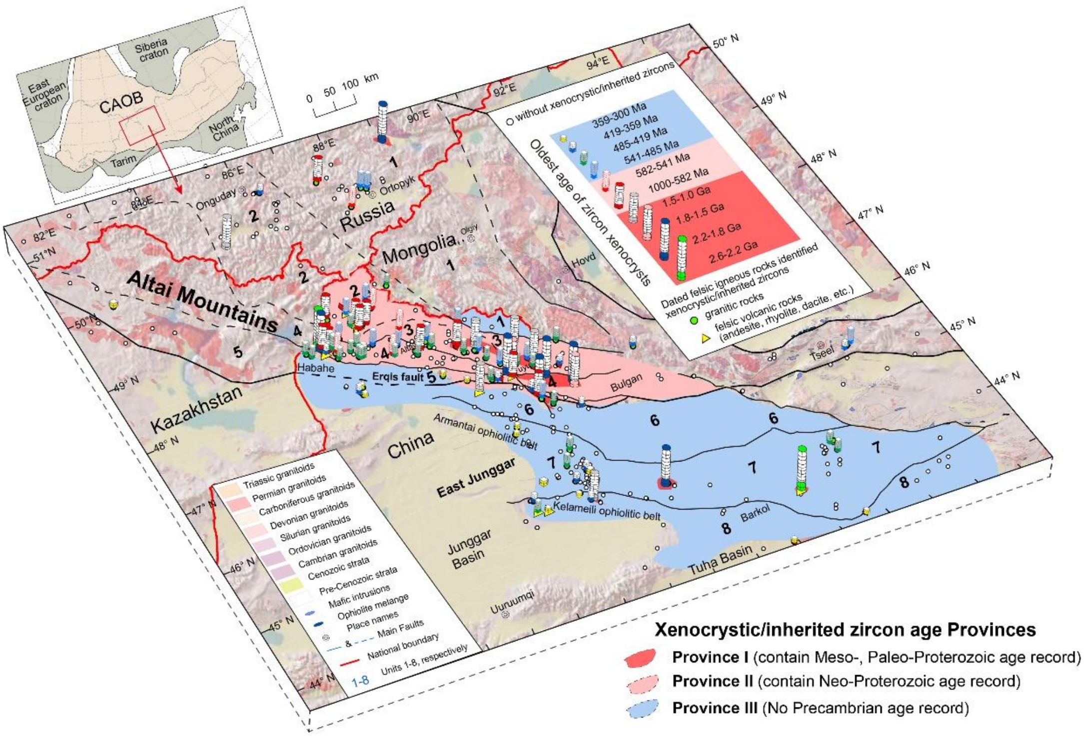


Figure 1: The inferred framework of old zircon xenocryst provinces, based on the variations in spatial characteristics of age and Hf isotopic compositions (t_{DMC}) of xenocrystic zircons within Paleozoic felsic igneous rocks. These provinces reveal the architecture and distribution of deep ancient continental components in the Altai-East Junggar terrane and adjacent regions (after Zhang et al., 2017).

References

Jahn, B.-M., 2004, The Central Asian Orogenic Belt and growth of the continental crust in the Phanerozoic. Geological Society, London, Special Publications 226, 73-100.

Kröner, A., Kovach, V., Belousova, E., Hegner, E., Armstrong, R., Dolgopolova, A., Seltmann, R., Alexeiev, D.V., Hoffmann, J.E., Wong, J., Sun, M., Cai, K., Wang, T., Tong, Y., Wilde, S.A., Degtyarev, K.E., Rytsk, E. 2014. Reassessment of continental growth during the accretionary history of the Central Asian Orogenic Belt. Gondwana Research 25, 103-125.

Kröner, A., Kovach, V., Alexeiev, D., Wang, K.L., Wong, J., Degtyarev, K. and Kozakov, I., 2017. No excessive crustal growth in the Central Asian Orogenic Belt: Further evidence from field relationships and isotopic data. Gondwana Research, 50, 135-166.

Song, P., Wang, T., Tong, Y., Zhang, J.J., Huang, H. and Qin, Q., 2019. Contrasting deep crustal compositions between the Altai and East Junggar orogens, SW Central Asian Orogenic Belt: Evidence from zircon Hf isotopic mapping. Lithos, 328, pp.297-311.

Wang, T., Jahn, B.-M., Kovach, V.P., Tong, Y., Hong, D.-W., Han, B.-F. 2009. Nd–Sr isotopic mapping of the Chinese Altai and implications for continental growth in the Central Asian Orogenic Belt. Lithos 110, 359-372.

Xiao, W.J., Windley, B., Sun, S., Li, J.L., Huang, B.C., Han, C.M., Yuan, C., Sun, M., Chen, H.L. 2015. A Tale of Amalgamation of Three Permo-Triassic Collage Systems in Central Asia: Oroclines, Sutures, and Terminal Accretion. Annual Review of Earth and Planetary Sciences 43, 477-507.

Yang, Q.D., Wang, T., Guo, L., Tong, Y., Zhang, L., Zhang, J.J., Hou, Z.Q. 2017. Nd isotopic variation of Paleozoic-Mesozoic granitoids from the Da Hinggan Mountains and adjacent areas, NE Asia: implications for the architecture and growth of continental crust. Lithos 272-273, 164-184.

Zhang, J.J., Wang, T., Tong, Y., Zhang, Z.C., Song, P., Zhang, L., Huang, H., Guo, L., Hou, Z.Q. 2017. Tracking deep ancient crustal components by xenocrystic/inherited zircons of Palaeozoic felsic igneous rocks from the Altai–East Junggar terrane and adjacent regions, western Central Asian Orogenic Belt and its tectonic significance. International Geology Review, 1-20.

Geochemistry and Geochronology of Dulaankhan pluton, Northern Mongolia

B.Gendenjamts[1], B.Munkhtsengel[2], D.Odgerel[1], D.Sanchir[1], B.Ganbat[3]

[1]*Institute of Paleontology and Geology of Mongolian Academy of Sciences, P.O.B 46/650, Danzan street 3/1, 4th khoroo, Chingeltei district, Ulaanbaatar, Mongolia;* gendenjamtsb@mas.ac.mn

[2]*School of Geology & Mining, Mongolian University of Science & Technology P.O.B 46/520210646, Ulaanbaatar, Mongolia*

[3]*Faculty of Geochemistry and Environment, University of Science and Technology of China, Hefei, China*

Mongolia occupies a key position in the large-scale tectonic structure, termed the Central Asian Orogenic belt COAB (Windley et al., 2007). This continental-scale unit was formed as a result of the amalgation of numerous tectonostratigraphic terranes of different geological histories (e.g., Badarch etal., 2002). According to studies, (e.g., Badarch et al., 2002, Khain et al., 2003, Buchan et al., 2002), the present geological structure of Mongolia has been formed by complicated accretion and subduction processes taking place from the Neoproterozoic up to the Mesozoic. The study area which is situated in the contacts of the Northern Mongolia-Western Transbaikalia rift zone with the neighboring Daurian-Khentei batholith. Their two belts are composed various magmatic process and an origin hypothesis:(i) a role of juvenile component in granitoid origin (Jahn et al. 2004, 2009), (ii) the major role to an activity of a mantle plume, triggering the intraplate magmatism, interaction between asthenospheric and lithospheric mantle, continental collision, and melting of crustal rocks (Yarmolyuk et al. 2013, 2014), (iii) Mesozoic granitoids originated during subduction processes and formed in active continental margin or back-arc environment (Donskaya et al. 2013, Li et al., 2013).

The Daurian Khentei batholith, which has been dated at 227–207 Ma (Yarmolyuk et al., 2002; Li et al., 2013). The Northern Mongolia–Western Transbaikalia rift zone is the largest Mesozoic riftogenic structure which were formed between 233 - 188 Ma and are filled with basaltic and basalt–comendite (bimodal) volcanic associations accompanied by numerous peralkaline granite massifs (Vorontsov et al., 2007).

The one of them is the Dulaankhan pluton (12 x 7 km), a roughly circular shape, which is dominantly consisted of peralkine granite, quartz syenite, biotite bearing leucogranites,as well as consists of monzodiorites, monzonites.The host rock is Late PermianSelenge Complex intrusion, which is defined calc-alkaline, gabbro-granodiorite-granite of the Selenge Intrusive Complex with subsequent intrusion of Porphyry Association are related to calc-alkaline, I-type, magnetite series, medium and high

K rock, and enriched in LIL, depleted in Nb, Ta, Ti and P that typical for continental arc environment (Munkhtsengel et al., 2007).

Peralkaline granites of the Dulaankhan pluton made up of the fine to coarse-grained and typically very similar in composition and texture that are mostly hypidiomorphic to equigranular, with megacrysts of K-feldspar (65-70%), quartz (20-25%), plagioclase (4-5%) and rare biotite,Albitic rims growth at the contact with K-feldspars, myrmekites are common.

Two samples DUL-03-17 (N 49°56'30.4", E 106° 09' 53,2") and DUL-06-17(N 49° 57' 45,6", E 106°10'57,7") were selected for U-Pb SHRIMP zircon and LA-ICPMS U-Pb zircon dating, Zircons are separated from the sample DUL-03-17 are lightbrownish colorless, and have subhedral, prismatic crystals, generally 50-200 μm in length, and zoning features. Totally, 50 zircon grains were collected and thirty spots from 21 zircons of peralkaline granite (DUL-03-17) were analyzed. The peralkaline granite yields a SHRIMP zircon U-Pb age of 198±0.74 Ma (MSWD = 0,049), indicating the granitic magmas crystallization formed in the Early Jurassic.The quartz syenite (DUL-06-17) yields LA-ICPMS zirconU-Pb age of 180.2±1 (MSWD = 0.067) which is associated with late stage fractional of magma.

The trace elements data that pluton granitoids are expressed enrichment in LILE and LREE, and depletion in Nb, Ta, Sr and Ti. Respectively, they also show a significant negative Eu anomalies in Primitive mantle-normalized (Sun and McDonough, 1989)spiderplots. Geochemical data display typical A-type granitic geochemical affinity. In represent of the new geochemicaland geochronological data in this study, the peralkaline granite and quartz syenite, which aregenerated from partial melting of crustal rocks ratherthan fractional crystallization of the basaltic melt.

Our study of geochemical characteristics and emplacement ages of the pluton suggests that the plutons were mainly emplaced in intra-continental back-arc basins during 198-180 Ma. As well, we suppose that opening of the back-arc basins along active continental margins. Probably, Mongol-Okhotsk subduction related back-arc basins extensional environment, which probably related to the Mongol-Okhotsk oceanic plate during the north towards to subduction under the Siberian plate.

Acknowledgments

Authors are very grateful to Prof. A.A.Tsygankov, Valentine Khubanov, Molon Buyantuev and Evgeniya Dugdanova at the Laboratory of Physical Methods of Analysis of the Geological Institute, Siberian Branch of Russian Academy of Sciences are thanked for their assistances during zircon LA-ICPMS U-Pb dating. Also, we would like to thankful to

Ms. Tserendash Narantsetseg and Anaad Chimedtseren their invaluable and constructive comments. This is a part of the MSc thesis by the first author.

References

Badarch, G., Cunningham, W.D., Windley, B.F., 2002. A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia, Journal of Asian Earth Sciences 21 (2002) 87-110

Buchan, C., Pfänder, J.,Kröner, A., Brewer, T.S., Tomurtogoo, O., Tomurhuu, D., Cunningham, D., Windley, B., 2002. Timing of accretion and collisional deformation in the Central Asian Orogenic Belt: implications of granite geochronology in the Bayankhongor Ophiolite Zone, Chemical Geology 192, 23-45

Donskaya T.V., Gladkochub D.P., Mazukabzov A.M., Ivanov A.V., 2013. Late Paleozoic– Mesozoic subduction-related magmatism at the southern margin of the Siberian Continent and the 150 million-year history of the Mongol- Okhotsk Ocean. J Asian Earth Sci 62: 79–97

Jahn, B.M., Capdevila, R., Liu, D., Vernov, A., Badarch, G., 2004. Sources ofPhanerozoic granitoids in the transect Bayanhongor–Ulan Baator, Mongolia: geochemical and Nd isotopic evidence, and implications of Phanerozoic crustalgrowth. Journal of Asian Earth Sciences 23, 629–653.

Jahn, B.M., Litvinovsky, B.A., Zanvilevich, A.N., Reichow, M., 2009. Peralkalinegranitoid magmatism in the Mongolian–Transbaikalian Belt: evolution, petrogenesis and tectonic significance. Lithos 113, 521–539.

Khain, E.V., Bibikova, E.V., Salnikova, E.B., Kröner, A., Gibsher, A.S., Didenko, A.N.,Degtyarev, K.E., Fedotova, A.A., 2003. The palaeo-asian ocean in the Neoproterozoic and early palaeozoic: new geochronologic data and palaeotectonic reconstructions.Precambrian. Res. 122, 329–358.

Li, S., Wang, T., Wilde, S.A., Tong, Y., (2013) Evolution, sourceand tectonic significance of Early Mesozoic granitoidmagmatism in the Central Asian Orogenic Belt (centralsegment). Earth-Sci Rev 126: 206–234

Munkhtsengel, B., Gerel, O., Tsuchiya, N., Ohara, M., 2007. Petrochemistry of Igneous Rocks in Area of the Erdenetiin Ovoo Porphyry Cu-Mo Mineralized District, Northern Mongolia, AIP Conference Proceedings 898:1, 63-65

Sun, S.S., McDonough, W. F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Saunders, A.D., Norry, M.J. (Eds.), Magmatism in the Ocean Basins. Geological Society London Special Publication 42, 313–345

Windley, B.F., Alexeiev, D., Xiao, W.J., Kroner, A., Badarch, G., 2007. Tectonic models foraccretion of the Central Asian Orogenic Belt. Bicentennial Review. Journal ofGeological Society 164, 31–47.

Yarmolyuk, V.V., Kovalenko, V.I., Sal’nikova E.B., Budnikov, S.V., Kovach, VP., Kotov, A.B., Ponomarchuk, V.A., 2002. Tectono-magmatic zoning, magma sources, and geodynamicsof the Early Mesozoic Mongolo-Transbaikalianmagmatic area. Geotectonics 36: 293–311

Yarmolyuk, V.V., Kuzmin, M.I., Kozlovsky, A.M., 2013. LatePaleozoic–Early Mesozoic within-plate magmatism innorth Asia: traps, rifts, giant batholiths, and the geodynamicsof their origin. Petrology 21: 101–126

Yarmolyuk, V.V., Kuzmin, M.I., Ernst,R.E., 2014. Intraplategeodynamics and magmatism in the evolution of the CentralAsian Orogenic Belt. J Asian Earth Sci 93: 158–179

Multiple metamorphic events recorded within eclogites of the Chandman district, SW Mongolia

O. Javkhlan*[1, 2], Akira Takasu[3], Md Fazle Kabir[3], D.Batulzii[1]

[1]*School of Geology and Mining Engineering, Mongolian University of Science and Technology, Ulaanbaatar 46/520, Mongolia*

[2]*Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China*

[3]*Department of Geoscience, Shimane University, Matsue 690-8504, Japan*

The eclogite-bearing Alag Khadny metamorphic complex in the Lake Zone, SW Mongolia occupies the central region of the Central Asian Orogenic Belt, the largest orogenic belt in the world. The complex consists mainly of orthogneisses intercalated with eclogites and micaschists in a mélange zone. Most of eclogites are strongly amphibolitized.

In this study, we examined petrography and mineral chemistry of eclogites and amphibolitized eclogites. The result of our research shows that Chandman eclogites experienced multiple events of metamorphism in throughout their subduction and subsequent collision history. We revealed that eclogites were subjected to blueschist facies metamorphism before the peak eclogite facies stage. The peak pressure-temperature conditions of eclogite facies stage are estimated as 520-570°C and 22-24 kbar. After the peak eclogite facies metamorphism, eclogites were decompressed into amphibolites facies metamorphism. These results suggest a clockwise P-T path may have reflected to development of eclogites.

We have also studied amphibolitized eclogite, and revealed that another distinct progressive medium pressure (MP) epidote-amphibolite facies metamorphic event took place in the eclogite, related with collision. The peak conditions for MP metamorphic event in the amphibolitized eclogite have been estimated as 550-610°C and 7-9 kbar. The multiple events of metamorphism in eclogites have been revealed by zonation textures of HP amphiboles zoned with glaucophane→barroisite→Mg-hornblende and MP amphiboles zoned with actinolite/winchite→barroisite→Mg-hornblende→tschermakite. These amphiboles with different zonation textures reflect their metamorphic history of subduction to collision events.

The internal architecture of the Early Paleozoic accretionary prism, Tseel unit, southern Mongolia – new geochronological, structural and petrological constraints

Turbold Sukhbaatar[1,2], Ondrej Lexa[1], Karel Schulmann[2,4], Carmen Aguilar [2], Štípská Pavla[2,4], Pavel Hanžl[3]

[1] *Institute of Petrology and Structural Geology, Charles University, 12843 Praha 2, Czech Republic*

[2] *Centre for Lithospheric Research, Czech Geological Survey, 11821 Praha 1, Czech Republic*

[3] *Czech Geological Survey, Geologická 6, 15200 Praha 5, Czech Republic*

[4] *EOST, Institut de Physique du Globe, UMR 7516, Université de Strasbourg, 1 rue Blessig, 67084 Strasbourg, France*

The Tseel unit in the Mongolian Altai zone is a part of the large Cambrian-Ordovician accretionary system extending approximately 2,000 km from Russia to Mongolia and representing one of the critical elements for reconstructing early Paleozoic geodynamics of the Central Asian Orogenic Belt (CAOB). The studied area is dominated by a strongly deformed succession of low- and high-grade metasedimentary rocks characterised by dominant terrigenous components mixed with volcanogenic material. The studied section could be divided to three distinct domains with the newly contrasting metamorphic, structural and geochronological record. The northernmost part of the studied area is dominated by volcano-sedimentary sequences affected by Barrovian-type metamorphism manifested by garnet to kyanite bearing assemblages in pelitic rocks. The dominant metamorphic fabric S1 is NE-SW trending and is affected by upright folding under greenschistfacies conditions. The dominant age of detrital zircons spans from ca. 539-445 Ma indicating Early Paleozoic age of sediments, while narrows metamorphic zircons reveal ages from ca. 430-393 Ma suggesting Late Silurian – Early Devonian age of high-grade metamorphism. The central part of the studied section reaches high-temperature conditions manifested by partial melting and large abundance of S-type granites in its southern and structurally deepest part. This part shows a progressive increase in the intensity of superposed deformation and development of sub-horizontal metamorphic foliation S2. This metamorphic foliation is affected by late upright folding accompanied with the development of ENE-WSW trending shear zones. The zircon ages show inheritance of both above-mentioned populations with the addition of newly-formed zircons in migmatites and granites of Early to Late Devonian age (ca. 388-359 Ma). The southernmost part of the studied section is lithologically distinct and structurally most complex. It is dominated by dark greywackes affected by very high-temperature (granulite facies) metamorphism. The refractory rocks exhibit similar zircon populations like the central part of the section with a slightly older range of Cambro-Ordovician population (ca. 539-460 Ma). In contrast, the more fertile migmatitic rocks are dominated by zircons that show Late Carboniferous – Permian ages (ca. 269-300 Ma). This distinct geochronological records spatially coincide with the distinct structural record, suggesting localised vertical extrusion of deeper crustal rocks during Permian convergence.

Comparison of architectures of the Meso-Cenozoic (Western Pacific) and Later Neoproterozoic-Paleozoic (CAOB) accretionary orogenics

Otgonbaatar D[1]., Buslov M.M[2]., Kulikova A.V[2]., Oyunchimeg T[1]., Dagva-Ochir L[1]., Sharav D[1]., Erdenechimeg D[1], Bulganzaya L[1]

[1]*Intitute of Paleontology and Geology, Mongolian Academy of Sciences*

[2]*V.S. SobolevIntitute of Geology and Mineralogy, Siberian branch, Russian Academy of Sciences.*

The major sites of juvenile continental crust areusually formed along the convergent plate margins, where subducted oceanic lithosphereunder the condition of the mantle wedgeforms accretionary orogens, as resulting as, continental mass is grownup. Each accretionary orogen is mainly characterized by the orogenic accretion interval and terrane lifespan. They present primary complexes (terranes) of juvenile continental crustand metallogenic criteria.

Mezo-Cenozoic Pacific-Circle accretionary orogenic is “type alternative example”for arc-accretion systems and this model can interpret an ancient accretionary orogens. Subduction zone in the convergent margin of the Pacific-Circle creates severally arc crusts and (Stern et al., 2003; Jaxybulatov et al., 2012) and migrated accretionary systems (Moore et al., 1991). For example, Izu-Bonin trench lives long probably 40Ma and formed three arc crusts (Stern et al., 2003). Otherwise, there is one accretionary complex, but three arc-crust. In this case, an accretionary complex can include different chronological HP-UHP rocks. Jurassic-Quaternary arc related volcano-sedimentary rocks are stratigraphically overlapped by each other, but accretionary complex is migratinginto seaward during the period of Jurassic to Quaternary (Moore et al., 1991). These main concepts have to similarly occur in both of Proterozoic and Paleozoic periods.

We would like to present Chagan-Uzun ophiolite melange, where different chronological metamorphic rock that divided into five subgroups (Table 1). This metamorphic belt extends southeastward to the Chandmany eclogite in the Lake Zone, Western Mongolia (Stipska et al., 2010). The Chandmany eclogite belongs to foursubtypes. This metamorphic belt can present the Later Neoproterozoic analogy of the Izu-Bonin accretionary-trench system.

Paleozoic arc, back-arc type example is Mongol-Okhotsk Foldbelt, which subdivides to symmetric several accretionary terranes named as Dzag-Kharaa, Onon, Asraltkhayrkhan, Ulaanbaatar, Tsererleg, Kharkhorin (Tomurtogoo, 2008). The Onon and Kharaa terranes are composed of Ordovician arc-related volcano-plutonicand sedimentary complexes which are located inboth side of the Mongol-Okhotsk Foldbelt, and Middle Silurian-Devonian oceanic plate stratigraphic succession is classified between them (Kurihara et al., 2009; Otgonbaatar et al., 2018). This regional geological and chronological data support Ordovician arc-crust subdividing, as resulting as, Middle Silurian-Devonian oceanic crust is newly opened as likely as Izu-Bonin (Otgonbaatar et al., 2018; Altanzul et al., 2018).

Table 1. Metamorphic cycles of the Chagan-Uzun and Chandmany

Metamorphic cycles (Ma)	I 640-620	II 605-580	III 575-560	IV 545-520	V 490-470
Eclogite	636±10♦ [2]; 635±10♦ [3]; 629±5♦ [3]; 629±9♦ [5]; 627±5♦ [2]; 619±13† [6]		562±11♦ [3]	535±24∗ [1]; Chandmany *543±4♦ [9];	
Granat-bearing amphibolite	631±12♦ [7]	604±6† [5]; 593±3♦ [4]; 586±6♦ [7]; 584±4♦ [8]; 583±8♦ [8]; 580±10♦ [7];	569±5♦ [7]; 565±7♦ [7]; 564♦ [5]; 563±4♦ [7] 573±5♦ [7]	544±10♦ [7]; 524±4♦ [8]; 521±4♦ [7]	487±22∗ [1]; 473±13∗ [1]
Amphibolite		594±10♦ [8] 580±6♦ [7];	571±4♦ [7]	523±23∗ [1]	
Metabasalt (Greenschist)			567±11∗ [1]	540±24∗ [1]	
Plagiogranite	610±3† [6]; 604±3♦ [8]; 598±6† [6]				

Geochronological dating methods and authors: ∗ - K-Ar; ♦ - Ar-Ar; †-U-Pb.[1] Buslov et al., 1996; [2] Buslov et al., 2001; [3] Buslov et al., 2002; [4] Volkova et al., 2007; [5] Ota et al., 2007; [6] Gusev et., 2012; [7] Kulikova et al., 2017; [8] Kulikova, 2018; *[9] Stipska et al., 2010.

Finally, we would like to note that arc-accretionary is a very complicated structure, and some arc-crusts can be none of the subduction-accretionary systems, but few arcs have subduction-accretionary systems in CAOB.

References:

Altanzul Ch., Oyungerel S., Jargal L., Insung Lee, Yenming Kim, Khasmaral T., 2018. New geochronological data of igneous rocks from the Boroo-Dzuunmod districts. Khaiguulchin, vol. 58, p. 210-232 (in Mongolian).

BuslovM.M., Watanabe T., 1996. Intrasubduction collision ant its role in the evolution of an accretionary wedge: Khurai zone of Gorny Altay. Russian Geology and Geophysics, vol., 37 (1), p. 75-84.

Buslov M.M., SafonovaI.Yu., Watanabe Y., Obut O.T., Fujiwara Y., Iwata K., Semakov N,N., Sugai Y., Smirnova L.V., KazanskyA.Yu., 2001. Evolution of the Paleo-Asian Ocean (Altai-Sayan Region, Central Asia) and collision of possible Gondwana-derived terranes with the southern marginal part of the Siberian continent. Geosciences, vol. 5 (3), p. 203-224.

Buslov M.M., Watanabe Y., SafonovaI.Yu., Iwata K., Travin A., Akiyama M., 2002. A Vendian-Cambrian Island Arc System of the Siberian Continent in Gorny Altai (Russia, Central Asia). Gondwana Research, vol. 5 (4), p. 781-800.

Gusev N.I., Berejnaya N.G., Skublov S.G., Larionov A.N., Paderin I.P., 2012. Baltirgansky eclogite-amphibolite complex in Gorny Altay: composition, age and geochemistry of zircon. Regional geology and metallogeny, vol. 49, p. 60-69 (in Russian).

Jaxybulatov K,Koulakov I., Dobretsov N.L., 2012. Solid Earth Segmentation of the Izu-Bonin and Mariana slabs based on the analysis of the Benioff seismicity distribution and regional tomography results. Solid Earth, vol. 4, p. 59–73.

Kulikova A.V., Buslov M.M., Travin A.V., 2017. Geochronology of the metamorphic rocks in the Kurai accretionary prism (South-Eastern Gorny Altai). Geodynamics & Tectonophysics, vol. 8 (4), p. 1049-1063 (with English abstract, Russian).

Kulikova A.V., 2018. Condition of formation basic-ultrabasic rocks and metabasic complex in Kurai accretionary zone (Gorny Altay), PhD thesis, Novosibirsk,173p(in Russian).

Kurihara T., Tsukada K., Otoh Sh., Kashiwagi K., Chuluun M., Byambadash D., Boijir B., Gonchigdorj S., Nuramkhan M., Niwa M., Tokiwa T., Hikichi G., Kozuka T., 2009. Upper Silurian and Devonian pelagic deep-water radiolarian chert from the Khangai–Khentei belt of Central Mongolia: Evidence for Middle Paleozoic subduction–accretion activity in the Central Asian Orogenic Belt. Journal of Asian Earth Sciences, vol. 34, p. 209–225.

Moore J.C., Diebold J., Fisher M.A., Sample J., Brocher T., Taiwani M., Ewing J., Huene R.V., Stone D., Rowe C., Stone D., Stevens Ch., Sawyer D., 1991. EDGE deep seismic reflection transect of the eastern Aleutianarc-trench layered lower crust reveals underplatingand continental growth. Geology, vol., 19, p. 420-424.

Ota Ts., Utsunomiya A., UchioYu., IsozakiYu,BuslovM.M., Ishikawa A., Maruyama Sh, Kitajima K., Kaneko Yo., Yamamoto H., Katayama I.,2007. Geology of the Gorny Altai subduction–accretion complex,southern Siberia: Tectonic evolution of an Ediacaran–Cambrianintra-oceanic arc-trench system. Journal of Asian Earth Sciences, vol. 30, p. 666–695.

Otgonbaatar D, Oyunchimeg T, Tomurtogoo O, Erdenechimeg D, Battushig A, Enkhdalai B, Sharav D, Bulganzaya L, Dagva-Ochir L, 2018. The Onon island arc terrane: geochemical evidence and new modelling. Journal of Geological Issues, vol. 494 (16), p.166-168

Tomurtogoo, 2008. Problems of Mongol-Okhotsk Paleooceanic in Khangay-Khentey Orogenic Systems. Trans-action 18, IGMR, p. 9-28 (with English abstract, Mongolian).

Stern R.J., Fouch M.J., Kliemperer S.L., 2003. Overview of the Izu-Bonin-Mariana Subduction factory. American Geophysical Union, Geophysical Monography 138, p.175- 222

Stipska P.,Schulmann K., Lehmann J., Corsini M., Lexa O., Tomurhuu D., 2010. Early Cambrian eclogites in SW Mongolia: evidence that the Palaeo-Asian Ocean suture extends further east than expected. Journal of Metamorphic Geology, vol. 28, p.915-933.

Volkova eN.I., Sklyarov E.V., 2007. High-pressure complexes of Central Asian Fold Belt:geologic setting, geochemistry, and geodynamic implications. Russian Geology and Geophysics, vol. 48, p. 83–90.

Crustal structure study in Mongolian Altai

Baasanbat Ts.,[1] Baatarchuluun Ts[2]

[1]*Institute of Astronomy and Geophysics of MAS, Ulaanbaatar, Mongolia,* baasanbat@iag.ac.mn

[2]*National University of Mongolia, Dept. Geology and Geophysics,* baatarchuluun@num.edu.mn

Abstract

Mongolian Altai is western part of Mongolia and it is considered seismically active region. There are several active faults such as Sagsai, Ar-Khutul and effect of movement on these active faults cause earthquakes along these faults and in this region. In order to study detailed seismotectonic and crustal structure in Mongolian Altay range, 12 broadband seismic stations were installed in Mongolian Altai range between September 2017 and December 2018, by Institute of Astronomy and Geophysics. Currently, hundredsof local and teleseismic events detected and recorded on temporary seismic network and study on detailed seismicity in this region and study result suggests that Mongolian Altay is still seismically active region. Distribution of seismicity shows relatively improved location of epicenters which concentrated along the active faults in this region. Moreover, result from teleseismic receiver function analysis for crustal structure suggests that thickness of crust reaches about 60 kms in this mountainous region.

Influence of Late Cenozoic Volcanism on the Morphology of River Valleys in the South-Baikal Volcanic Province

E.V. Lebedeva[1], T.M. Skovitina[2], D.V. Mikhalev[3], V.A. Pellinen[2], D.V. Mishurinsky[3]

[1]*Institute of Geography of RAS, Moscow, Russia,* ekaterina.lebedeva@gmail.com
[2]*Institute of the Earth's Crust of SB RAS, Irkutsk, Russia,* skovit71@gmail.com, vadim.a.pellinen@ya.ru
[3]*Lomonosov Moscow State University, Moscow, Russia,* mikhalev.dmitry@gmail.com, mishurinsk@mail.ru

Late Cenozoic volcanism is widespread in Central Asia, and its sources have been determined by different geodynamic settings. Volcanism is confined either to the boundaries of lithospheric plates or large regional fault systems; or volcanic fields are intraplate fields being located at a great distance from them (Yarmolyuk et al., 2001, 2003, 2004; Ivanov et al., 2015; etc.). Volcanic relief is represented mainly by lava plateaus and cinder cones, but the most spectacular form of its manifestation is lava rivers. Lava flows are common on the Vitim Plateau, in the Udokan and South Khangai volcanic regions, in the East Tuva volcanic area, and in the basins of the Dzhida, Oka, Yenisei and other rivers (e.g., Bazarov, Antoshchenko-Olenev, 1974; Antoshchenko-Olenev, 1975;Yarmolyuk et al., 2001, 2003, 2004; etc.). In the South-Baikal volcanic region, the Cenozoic basalts effusions of different ages are often associated with young fault zones. Many river valleys were formed along these faults, and often the basalt effusion centers are located directly in these erosion-tectonic forms. The valley's lava flows, as a rule, have a considerable length – tens of kilometers; they cause changes in the stream flow, morphology and longitudinal profile of the valleys, as well as restructuring of the river network (Lebedeva, 2012, 2016).

We analyzed the impact of effusive volcanism on the morphology and development of river valleys using the example of the Jom-Bolok lava field in the system of the intermountain valleys of the East Sayan Mts. The main conclusions of our research are the following.

1. Lava flows cause deviations of the river channels, but if they fill the valley entirely, a new channel of the river is more often formed along one of the sides of the valley. In some areas, water flow can go under the lava' surface: the watercourse uses internal voids – lava tubes, whose diameter reaches 5–15 m with a length from the first kilometers to several dozens of them (Lebedeva, 2016). Under a constant underground flow, the tunnels gradually collapse and chains of lakes and then a well-defined river-bed are formed there.

2. Lava flows block the valleys of the tributaries, and dammed lakes are formed in their mouths, sometimes originating in the main valley (Skovitina, 2002; Shchetnikov, 2002). Gradually, lava dams are destroyed, and the lakes descend.

3. Lava influences the development of valleys as a lithological factor, too. Strong effusive rocks become the local erosion base level, which determines development of the entire overlying basin.

4. Development of the fluvial processes for valleys with lava flows is dramatically different from the surrounding territory.For instance, a slow gradual incision into solid basalts with the formation of erosion floodplains and then terraces occurs. A more easily eroded material (coming from side tributaries) is often dominates in alluvium.

5. Most of the valleys of the considered region are located in the permafrost zone, but due to the high temperature of lavas (800–1000°C) effusions led to the melting of ground ice, resulting in a change in the features of permafrost processes in the valley beds.

In the report, we will give examples illustrating the above. The study was supported by the RFBR, project no. 18–05–00967.

References

Antoshchenko-Olenev I.V.,1975. Cenozoic of the Dzhida region of Transbaikalia. Novosibirsk: Nauka, 127.

Bazarov D.B., and Antoshchenko-Olenev I.V., 1974. The Selenga middle mountains and the Dzhida mountain region / Highlands of Baikal and Transbaikalia. Moscow: Nauka, 163–209.

Ivanov A.V., Arzhannikov S.G., Demonterova E.I., Arzhannikova A.V., and Orlova L.A., 2011. Jom-Bolok Holocene volcanic field in the East Sayan Mts., Siberia, Russia: structure, style of eruptions, magma compositions, and radiocarbon dating. Bull of Volcanol, 73, 1279–1294.

Ivanov A.V., Demonterova E.V., Huaiyu H., Perepelov A.B. Travin A.V. Lebedev V.A., 2015. Volcanism in the Baikal rift: 40 years of active-versus-passive model discussion. ESR, 148, 18–43.

Lebedeva E.V., 2012. Drainage network alterations: reasons and drivers. Geomorfologiya, 3, 21–32.

Lebedeva E.V., 2016. Impact of the lava flows on the structure of valleys and development of the river network. Geomorfologiya, 3, 78–91.

Skovitina T.M., 2002. The barrier lakes of the Sayan-Baikal Mountain Region. Geomorfologiya,3, 79–88.

Shchetnikov A.A., 2002. The lakes of the Okinsk Table-Land. Geomorfologiya, 3, 88–95.

Yarmolyuk V.V., Nikiforov A.V., Ivanov V.G. 2003 The structure, composition, sources and mechanism of Jom-Bolok valley lava flows (Holocene, South-Baikal volcanic area). Volcanol Seismol, 5, 41–59.

Yarmolyuk V.V., Kozlovskii A.M., Kudryashova E.A., Lebedev V.I., Sugorakova A.M., 2004. Major valley lava flows in Asia during Cenozoic time: structure, composition, and the environment of the "lava river" forming in the Lesser Enisey R.Valley. Volcanol Seismol, 4, 3–20.

Yarmolyuk V.V., Lebedev V.I., Sugorakova A.M., Bragin V.Yu., Litasov Yu.D., Prudnikov S.T., Arakelyants M.M., Lebedev V.A., Ivanov V.G.,and Kozlovskii A.M., 2001. The East Tuva region of recent volcanism in Central Asia: periods, products and types of volcanic activity. Volcanol Seismol, 3, 3–32.

Multiscale geophysical characterization of the Central Asian Orogenic Belt: Case study of southern Mongolia

Alexandra Guy[1]*, Karel Schulmanna[1,2], Nils Holzrichter[3], Jörg Ebbing[3], Marc Munschy[2]

[1]*Centre for Lithospheric Research, Czech Geological Survey, Prague, Czech Republic*

[2]*Institut de Physique du Globe, EOST CNRS UMR7516, Université de Strasbourg, France*

[3]*Institute of Geosciences Christian-Albrechts-Universität Kiel, Germany*

The Central Asian Orogenic Belt (CAOB) is a Paleozoic accretionary-collisional orogen located at the eastern Pangea in between the Siberian Craton to the north and the North China and Tarim Cratons to the south. Several contradictory geodynamic models were proposed to explain the tectonic assemblage: oroclinal bending and strike slip duplication of giant intraoceanic arc or progressive lateral accretion of linear continental and oceanic terranes towards the Siberian Craton. However, none is generally accepted. A multidisciplinary and multiscale approach integrating potential field analysis with geologicalinterpretation provides new insights into the understanding of the crustal structure beneath the CAOB and particularly beneath southern Mongolia.The geophysical characterization of the orogeny allow us to: (1) correlate the contrasting tectonic domains with the thickness of the crust thereby revealing the inheritance of Paleozoic and Mesozoic orogenic history, (2) unravel the existence and distribution of suspect terranes in accretionary systems,and (3) determine the significance and possible origin of the major anomalies which are related to tectonic processes such as lower crustal relamination, presence of deep seated fault zones or main tectonomagmatic zones. With the case study of southern Mongolia, we demonstrate the real benefit and the significant progress which can be achieved byusing gravity and magnetic anomalies in the construction of the CAOB.

Stress field and fault zones in the crust at the Ulaanbaatar city (Central Mongolia)

K.Zh. Seminsky[1], S. Demberel[2]

[1]*Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences,*

seminsky@crust.irk.ru

[2]*Institute of the Astronomy and Geophysics MAN,*

demberel@iag.ac.mn

The study area – the Ulaanbaatar geodynamic testing area (Fig. 1) – is situated within the western boundary of the Amur plate, which longitudinally crosses Central Mongolia. The stress fields and the architecture of the fault network in this region have not been studied in detail yet.

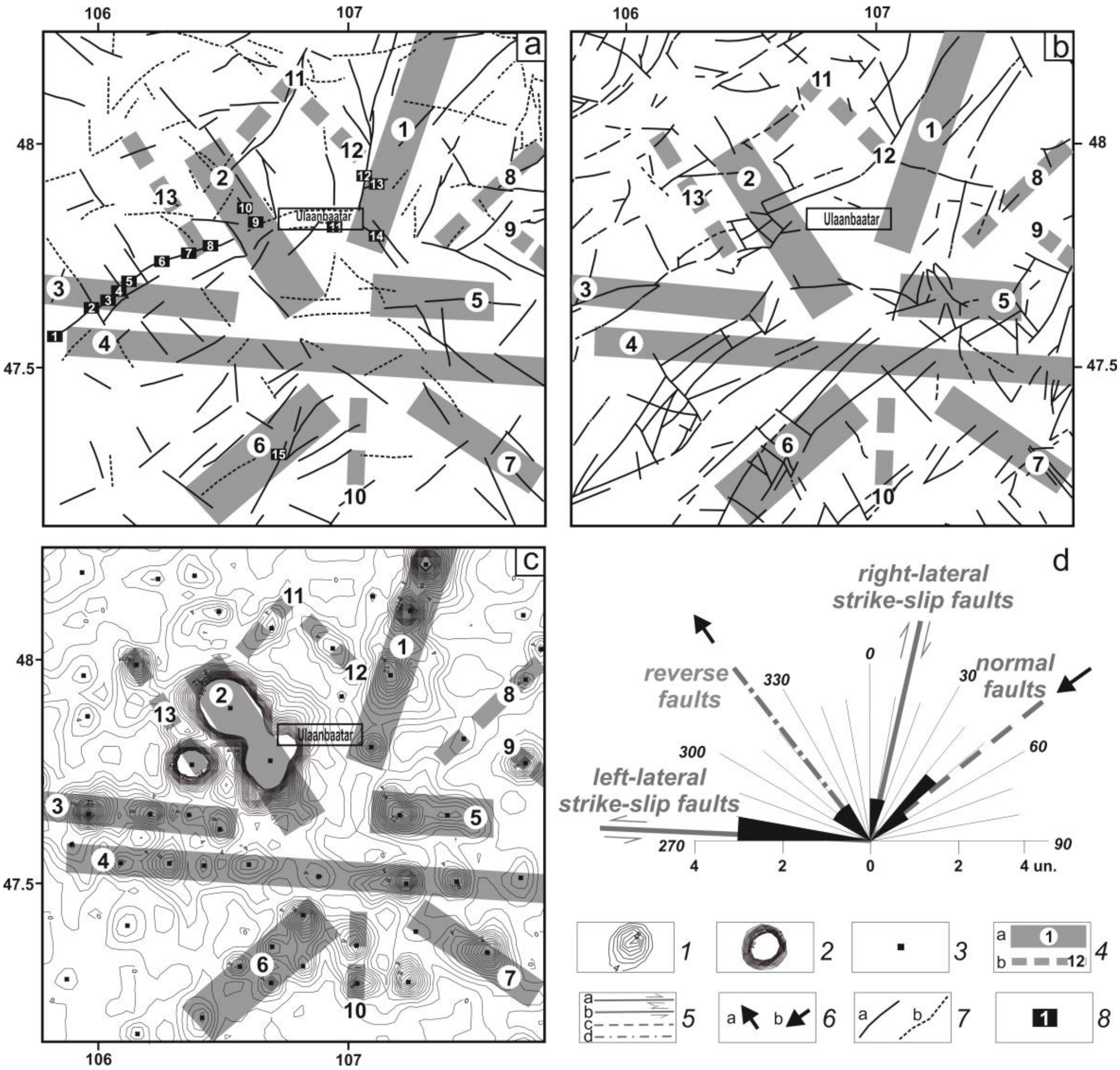


Fig. 1. The faults and fault zones of the Ulaanbaatar geodynamic testing area (Central Mongolia), identified from the data analysis.

a - scheme of Neogene faults and the areas of soil-radon measurements; b - fault network in the geological map

(scale 1:500,000); c - scheme of the earthquake epicenters density (2000-2014); d - rose diagram of fault zones shown in Fig. 1c, and the kinematics of active fault systems in the 1st order stress field.
1 – isolines of earthquake epicenter density (D); 2 – maximums with D>25; 3 – center of maximum; 4 – fault zones, reliably (a) and less reliably (b) identified in the field of earthquake epicenters; 5 – systems of right-lateral (a), left-lateral (b), normal (c) and reverse (d) fault zones; 6 – orientation of the subhorizontal axes of the main normal extension (a) and compression (b) stresses in the 1st order stress field; 7 – confirmed (a) and assumed (b) faults; 8 – sites for which the profile radon survey was carried out to assess the radon fault activity.

Our study aimed at establishing the positions of the fault zones and their activity style at the recent stage of the crust development.

The following data was analyzed:

- scheme of faults, identified in a 3D relief model (Fig. 1, a);
- scheme of the earthquake epicenters density within the geodynamic testing area in 2000-2014 years (Fig. 1, c);
- field of soil-radon activity near faults, which is clearly manifested in the relief (Fig. 1, a);
- fault network in the geological map (scale 1:500 000) (Fig. 1, b).

Bases on the study results, the interrelation of seismic and radon activity of fault zones was established. In the vicinity of Ulaanbaatar there is a network of 13 active fault zones, which form four systems (Fig. 1). The NW and SE zones develop along the Neogene faults, while the latitudinal and longitudinal zones usually intersect them (Fig. 1, a, d). The fault zones of the orthogonal network are clearly distinguished by the chains of maximums in the field of earthquake epicenters (Fig. 1, c). These are strike-slip faults that develop along the conjugate planes of maximum shear stresses.

The recent shear stress field was reconstructed for the study area. The compression axis is oriented in the SW-NE direction while the extension axis is SE-NW oriented (Fig. 1, d). This field is a remote result of the Indo-Asiatic collision in the regions located southwest of Ulaanbaatar. The western boundary of the Amur Plate should be developed in the right-lateral strike-slip regime in this stress field. Taking into account the fact that more than a third of the country’s population lives in the capital of Mongolia, the established faulting style is of fundamental importance for assessment of the seismic hazard of Ulaanbaatar.

Remnant Paleo-Asian Ocean subduction zones within the continental lithosphere: evidences from deep seismic reflection profiles

H. Hou[1], R. Gao[2], W. Fu[1], A. Kröner[2,4,] X. Zhang[3] , J. Zhou[3], J. Yang[1], R. Guo[1]

[1]*SinoProbe Center, Chinese Academy of Geological Sciences, Beijing 100037, China*

[2]*Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China*

[3]*Jilin University, Changchun 130061, China*

[4] *Institute of Geosciences, University of Mainz, 55099 Mainz, Germany*

The Paleo-Asian Ocean (PAO), evolutionfrom ocean opening at ca. 1020 Ma to final ocean closure in the Permian and collision of the North China, Siberia and Tarim cratonswith formation of an orogenic collage lasted some 800 Ma (Kröner et al., 2014), and its subduction-accretion history is an important element to study the evolution of the Central Asian OrogenicBelt (CAOB). Although much remarkable progress has been made to study the closure of the eastern Paleo-Asian Ocean, the deep structure of the crust and its evolution is less constrained, and two outstanding issues need to be resolved (Wilde, S.A., 2015).One is to define the eastern limit of the CAOB, the other controversial issue is the view that the CAOB contains numerous Precambrian microcontinental blocks of mainly Neoproterozoicage, and their tectonic relationship still remains to be studied.

The crustal and upper mantle structure and deformation was derived from a total of 660 kmof 5 reflection seismic profilesin NE China, recently acquired or reprocessed with support of China Geological Surveyand the Chinese SinoProbe Project. Many mantle reflections were identified, some reflective features represent ancient subduction, and some reflecting characteristics may characterize traces of mantle activity, revealing deep processesin the eastern CAOB in northeast China.The paleo-Asian Ocean is characterized by two-way subduction.

Professor Kröner, one of the co-authors of this paper, strongly recommended that we report the latest results of deep seismic reflection profiling in eastern CAOBat numerous international conferences. Professor Kroner is a tutor with global geological evolution vision, the founder of CAOBresearch, the pioneer of promoting the combination of deep geophysics and surface geology, and the greatest geologist ever since. We would love to commemorate him with this abstract.

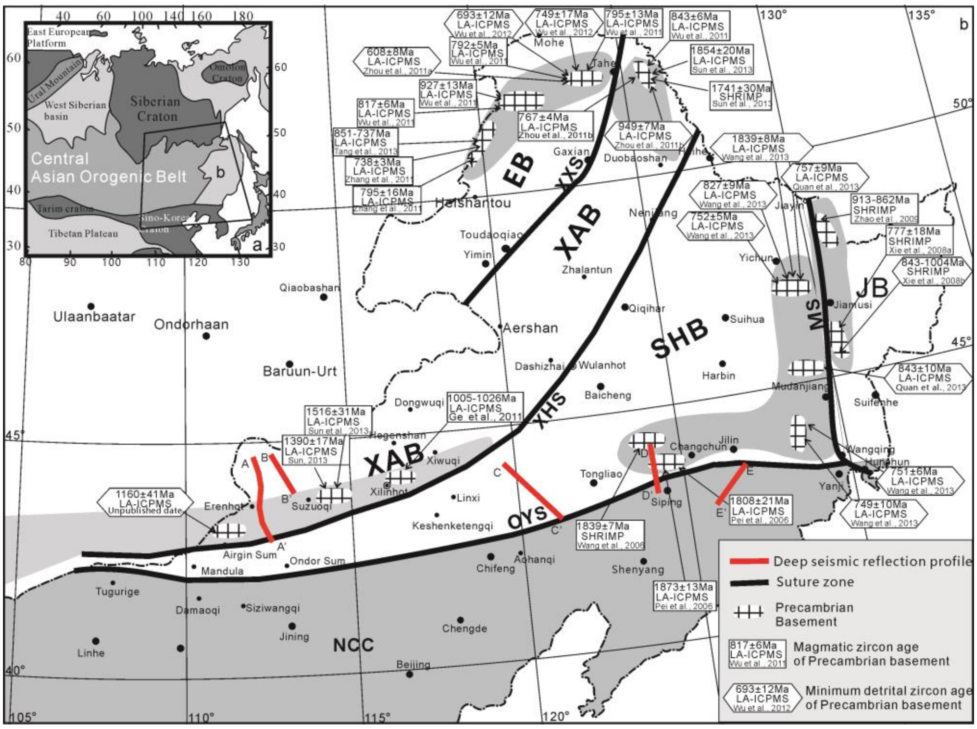


Figure 1. Pre-Devonian blocks in the Xing'an–Mongolia Orogenic Belt (XMOB) of northeast China. Inset (a) location of the Central Asian Orogenic Belt; inset (b) in (a) is location of Fig. 1 in northeastern China. The main map shows location of deep seismic reflection profiles deployed across various tectonic blocks in the XMOB. Modified from Xu et al. (2015). EB = Erguna Block; XAB = Xing'an-Airgin Sum Block; SHB = Songliao-Hunshandake Block; JB = Jamusi Block; XXS = Xinlin-Xiguitu suture; XHS = Xilinhot-Heihe suture; MS = Mudanjiang suture; OYS = Ondor Sum-Yongji suture.

This research is supported by China Geological Survey (No.20160207,20190010), China NSF (No.41474081), and SinoProbe-02.

References

Xu, B., Zhao, P., Wang, Y.Y., Liao, W., Luo, Z.W., Bao, Q.Z., Zhou, Y.H., 2015. The pre- Devonian tectonic framework of Xing'an–Mongolia Orogenic belt (XMOB) in north China. Journal of Asian Earth Sciences 97, 183–196.

Kröner, A., Kovach, V., Belousova, E., Hegner, E., Armstrong, R., Dolgopolova, A., Seltmann,R., Alexeiev, D.V., Hoffmann, J.E., Wong, J., Sun, M., Cai, K., Wang, T., Tong, Y., Wilde,S.A., Degtyarev, K.E., Rytsk, E., 2014. Reassessment of continental growth during the accretionary history of the Central Asian Orogenic Belt. Gondwana Research 25, 103–125.

Wilde S.A., 2015. Final amalgamation of the Central Asian Orogenic Belt in NE China: Paleo-Asian Ocean closure versus Paleo-Pacific plate subduction — A review of the evidence. Tectonophysics 662:345-62.

Geological & Geophysical Appraisal of MashkiChah Porphyry (Cu-Au-Mo) Prospect in ChagaiMagmatic Arc; With an Introduction to the Tethys Belt in W-NW Himalayas, Pakistan

Yasir Shaheen Khalil[1,2,3]*,Li Wenyuan[3],Syed Ali Abbass[1],M, A Zhonping[3], Hong Jun[3]

*[1]Geological Survey of Pakistan, Islamabad, Pakistan; [2]Chang'an University, Xi'an, China; [3]Xi'an Institute of Geology and Mineral Resources, CGS, Xian,China;*Corresponding Author's email;*
yasirshaheen2189@gmail.com

Abstract

The Himalayan Formation and Tethys Ocean closure were spectacular events in the history of earth. Thousands ofkilometers of sedimentary rocks, oceanic crust, island arcswere compressed, consumed, folded and elevated into just 500 km stretch of mountain belt which has been cut/sliced by the Indus River and tributaries. In Pakistani Himalayas, two volcano magmatic arcs, Kohistan-Ladakh Arc and Chagai Arc are the products of Himalayan Orogeny. Kohistan Arc, being one of the best developed and well exposed in the whole Tethyan Metallogenic Belt, has not been so far known to host any significant porphyry copper or any other significant metallic deposit. On the other hand,Chagai Arc is famous for its porphyry copper potential and hosts many world class porphyry copperprospects.

The practical work of our current investigation isin MashkiChah area in Chagai Magmatic Arc. Integrated geophysical surveys (Magnetics, Induced Polarization & Resistivity) in an area of 1859.50 Acres, pointed out sulfide mineralization of huge dimension, in the foothills of Plio-Pleistocene Dam Koh Volcano.Three exploratory wells were drilled to check the presence of sulfide mineralization. The geological work involved logging of the drilled cores, ore mineralogy, identification of alterations zones associated with porphyry system, petrography and geochemistry for gold, copper, molybdenum and silver.

Andesite porphyry and diorite porphyry are the main rock units encountered in the drilled cores, with considerable alteration. The ore minerals observed include, pyrite, chalcopyrite, magnetite, molybdenite, galena etc. in decreasing order of abundance. The alteration zones of a typical porphyry system are also present including propylitic and potash, while, some phyllic and argillic alteration has also been observed.

The percentage of copper in selective samples varies from 0.013 to 2.2 %. The geochemical concentration of gold varies from 0.2 to 3.08 ppm; silver concentration varies from 0.4 to 0.6 ppm while that of molybdenum varies from 6.5 to 290 ppm.

Seismic Bright spots in Qiangtang Terrane from deep reflection surveying

Zhanwu Lu[1,2], Rui Gao[1,2], Wenhui LI[1,2] and Hongqiang Li[3]

[1]*Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China*

[2]*Key Laboratory of Deep-Earth Dynamics of Ministry of Natural Resources, China, Beijing, China*

[3]*Chinese Academy of Geological Sciences, SinoProbe Center, Beijing,China*

Deep seismic reflection profiling is one of the finest methods to probe the crustal structure. By a lot ofdeep seismic reflection survey, the scientists found that there are many “bright spots” with unusually highamplitude reflection characteristics in the crust. There are different from the “bright spots” reflecting thehydrocarbon accumulation in oil exploration. The “deep reflection bright spots” are usually located in thecrustal scale structures, which often are related to subduction, crustal thickening and other geologicalevents based on publicly reported in the literature.

The Qiangtang terrane lies between the Jinsha suture（JS）to the north and the Bangong-Nujiang suture（BNSto the south. It is about 500–600 km wide in central Tibet, but narrows to 150 km both to the west and the east in the western Kunlun and eastern Tibet. Structurally, Qiangtang terrane can be regarded as a large scale anticlinorium and can be divided into two sub-terranes (the Southern Qiangtang sub-terrane and Northern Qiangtang sub-terrane) by a prominent blueschist-bearing metamorphic belt in its central part. The central part was occupied by an anticline of pre-Jurassic strata or metamorphic rocks and the northern and southern limbs by synclines of mainly Jurassic sedimentary rocks (Pullen et al., 2008; Zhai et al., 2011, 2013).

Seismic reflection data used in this article were acquired by SinoProbe in 2009. The SinoProbe profile starts west of Silin Co in the northern Lhasa terrane, crosses the BNS to west of Lunpola, skirts the eastern extension of the central Qiantang anticline and ends at Dogai Coring just to the south of JS .The bright spot is located in the northern border of the central uplift.

In the Qiangtang terrane, central Tibet, the bright spot on deep seismic reflection profile occurs at ~6.0 s TWT with high amplitude seismic reflectors in the upper crust. We calculate a typical shot gather and get an amplitude decay curve. The result show that the bright spot at higher amplitude compare to background levels.

Although effective estimation of absolute reflection coefficients is rarely possible, the high amplitudes of many of these crustal bright spots have led to their interpretation as deep fluids, most often magma. This kind of bright spots are normally characterized by strong reflectors with high amplitude, negative reflection polarity, strong converted shear wave. But the bright spot at the north boundary of the central uplift of the Qiangtang terrane behave a different observations. This Qiangtang bright spot combine with positive polarity, non weak S wave and lower Vp/Vs and Poisson'ratio. Moreover. We speculate that a rigid base result in the events above. Zircon cathodoluminescence(CL) image analyses, in conjunction with reginal geological characteristics, show that the main metamorphism of the gneiss rocks occurred from 1780Ma to 1666Ma(Tan et al.,2009). We suggest the most possible reason of the bright spot at the north edge of the Qiangtang central uplift terrane is the presence of Precambrian crystalline basement in this area.

References

Pullen, A., Kapp, P., Gehrels, G.E., Vervoort, J.D., Ding, L., 2008. Triassic continental subduction in central Tibet and Mediterranean-style closure of the Paleo-Tethys Ocean. Geology 36, 351-354.Pullen, A., Kapp, P., Gehrels, G.E., Ding, L., Zhang, Q.H., 2010. Metamorphic rocks in central Tibet: Lateral variations and implications for crustal structure. Geological Society of America Bulletin, doi:10.1130/B30154.1

.Zhai, Q.G., Jahn, B., Zhang, R.Y., Wang, J., Su, L., 2011a. Triassic Subduction of the Paleo-Tethys in northern Tibet, China: Evidence from the geochemical and isotopic characteristics of eclogites and blueschists of the Qiangtang Block.Journal of Asian Earth Sciences 42, 1356–1370.

Zhai, Q.G., Jahn, B., Su, L.,Wang, J., Mo, X.X., Lee, H., Wang, K., Tang, S.H., 2013. Triassic arc magmatism in the Qiangtang area, northern Tibet: Zircon U–Pb ages, geochemical and Sr–Nd–Hfisotopic haracteristics, and tectonic implications. Journal of Asian Earth Sciences 63, 162–178.

Tan, FW., Wang, J., Fu, XG., Chen M.,Du BW. 2009. U-Pb zircon SHRIMP age of metamorphic rocks from the basement of the Qiangtang basin, northern Tibet, and its geological significance. ActaPetrologicaSinica, 25(1),139-146

Formation and evolution of Precambrian continental crust in Phansipan Northewest Vietnam

Pham Trung Hieu, Pham Minh

VNU-HCM University of Science

pthieu@hcmus.edu.vn

Phan Si Pan zone, Northwest Vietnam is one of the oldest basement in southeast Asia. Our results, together with published data, indicated that the oldest age of these magmatic rocks is about 2.9 Ga (Mesoarchean), and then 2.3-1.8 Ga (Paleoproterozoic). These stages play an important role in the evolution of the Earth's crust with intense magmatic activities. However, previous studies suggested that these stages in Northwest Vietnam have not been well revealed. Finally, the stage is 840-760 Ma (Neoproterozoic). In this study, we analyzed both the U-Pb zircon age and the Hf isotopic component of the magmatic rocks to shed insights into the magmatic-tectonic activity of these stages. The results of U-Pb zircon ages are at 2.9 Ga, 2.3-1.8 Ga and then 760 Ma. Two-stage Hf model ages of 3.4 Ga, 3.1 Ga, and 1.8 Ga indicate that the magmatic rocks originated from the Archean and Paleoproterozoic rocks. The values of $\varepsilon_{Hf}(t)$ range from -2.8 to +0.7, from -25 to -10, and from -16.1 to +3.4, respectively. This is the evidence of crust-mantle mixing. Precambrian formations in Northwest Vietnam are close to those in South China block, suggesting that the basement of Northwest Vietnam is closely related to that of South China block. Hence, Northwest Vietnam and South China continent must have been the same continent.

***Key words*:**Northwest Vietnam, Phan Si Pan, evolution, zircon age, Hf isotopic.

Acknowledgements

This study was supported by the National Foundation for Sciences and Technology Development of Vietnam (NAFOSTED project No. 105.01-2016.23)

Compressional Sedimentary Basins Orogenic Belts - Plate Tectonics Fold and Thrust Belts:Hydrocarbon Exploration

Sunjay

Research Geophysicist,sunjaytellus@gmail.com

Abstract

Plate tectonics is of very great significance as it represents the spatial relationships of volcanic rock suites at plate margins, the distribution in space and time of the conditions of different metamorphic facies, the scheme of deformation in mountain belts, or orogens, and the association of different types of economic deposit(hydrocarbon-oil & gas, minerals, coal, etc.).Orogenic belts are characterized by extensivethrust faulting, movements along large strike-slipfault zones, and extensional deformation that occurdeep within continental interiors. Within oceanic areas there also are regions of crustalextension and accretion in the backarc basins that arelocated on the landward sides of many destructive platemargins.Trenches(destructive plate margins) mark boundaries where two plates are converging by the mechanism of the oceanic lithosphere of one of the plates being thrust under the other, eventually to become resorbed into the sub-lithospheric mantle. Since the Earth is not expanding significantly, the rate of lithospheric destruction at trenches must be virtually the same as the rate of creation at ocean ridges.Orogenic belts are long, commonly arcuate tracts ofhighly deformed rock that develop during the creationof mountain ranges on the continents. The process ofbuilding an orogen, or *orogenesis*, occurs at convergentplate margins and involves intra-plate shortening,crustal thickening, and topographic uplift.The processes that control orogenesis vary considerably depending on the tectonic setting and the type of lithosphere involved in the deformation. Noncollisionalorogens result from ocean–continent convergence where plate motions and other factors controlling subduction lead to compression within the overriding plate. Collisional orogens develop where a continent or island arc collides with a continental margin as a result of subduction. Collisional and noncollisiona lorogens can be explainedby differences in the strength and rheology of the continental lithosphere and by processes that influence theseproperties during orogenesis. Compressional Sedimentary Basins-Sedimentary basins that either form or evolve in response to regional compression are common in orogenic belts. Among the most recurrent types are foreland basins which form as a direct result of the crustal thickening and topographic uplift

that accompany orogenesis, and basins that initially form during a period of extension or transtension and laterevolve during a period of subsequent compression. This latter process, called basin inversion also occurs in association with strike-slip faulting and is the mechanism by which old passive margin sequences deform during continental collision. Any sedimentary basin in compression may develop a fold and thrust belt whose characteristics reflect the strength of the continental lithosphere and the effects of pre-existing stratigraphic and structural heterogeneities.In sedimentary basins, site effects also lead to the generation of surface waves at the basin edgesSeismic site effects are related to the amplification of seismic waves in surficial geological layersBasin's Sedimentary-Tectonic Wave Analysis Based on **Wavelet Transform.**

On the basis of the time-frequency scaling property of the wavelet transform, accumulation rates and stratigraphic completeness can be calculated for various observation time spans (ot) by using wavelet analysis. Wavelet analysis also allows automatic detection of high-frequency sedimentary cyclicity, and abrupt and gradual variations in sedimentation rate.

Tectonic geomorphology is a wonderfully integrativefield that presents stimulatingchallenges to anyonetrying to extract information from deforming landscapes. Landscapes in tectonically active areasresult from a complex integration of the effects of verticaland horizontal motions of crustal rocks and erosionor deposition by surface processes.An understanding of paleoseismology, geodesy, structural geology, geomorphology, geochronology, paleoclimatology, stratigraphy and rock mechanics, because each underpins some aspects of the interplay of tectonics and erosion. Folds are a fundamental component of many orogenic settings. Folding is ubiquitous above blind thrusts, as well as almost any thrust fault that ruptures the surface.Deepwater Fold-Thrust Belts-accretinary prism for hydrocarbon exploration.

Crustal Evolution, Global Tectonics,Hydrothermal Mineral Deposits and MineralExploration -Geotectonic and Metallogenic Analysis of Orogenic Belts,Crustal Hydrothermal Fluids and Mesothermal Mineral Deposits.

Hydrocarbon prospects of Schuppen Belt Assam Arakan Basin, The **Schuppen belt** of north-east India forms the outermost fringe of the mobile **belt** of the Assam–Arakan basin.

The complex geology(series of thrusts),steep dips,inaccessible topography has posed a challenge for exploration in terms of seismic data acquisition,processing and interpretation in Complex topography fold and thrust belts in foothills area.For this virgin frontier area prolific oil & gas potential, precise subsurface imaging of conflicting dips, thrust plane reflections and associated intricate structure(listric fault) applying finsler geometry(seismic ray theory in anisotropic inhomogeneous media is studied based on non-Euclidean geometry) is pertinent task before geoscientists.

Integration loop of seismic, Tomography, electromagnetic and gravity data in a thrust belt region- Another approach for improving seismic imaging and geological interpretation is tocombine seismic and non-seismic methodologies, such as long offset seismic, gravity andelectromagnetic techniques. After the acquisition of multi-disciplinary data the challenge isto integrate the whole information. Improving static correction-integrating gravity in seismic data processing(Grav-stat)-the processed gravity data are inverted in to surface constant residual seismic statics. Velocity and density variations caused by lateral changes in the geology of near surface foothills significantly reduce seismic data quality-poor seismic first breaks are common along basin margins. Seismic imaging in a **thrust belt** can be extremely poor due to a combination of multiple geological and geophysical reasons. Shallow heterogeneities can cause sharp lateralvelocity variations, with consequential problems of static corrections; moreover, scatteringand attenuation effects due to the presence of thrusts can cause an extremely low S/N ratio.Coherent noise like ground roll, vertical inversions of velocity field etc can further complicate the picture.One possibility to approach the imaging problems in a thrust belt is to use a more effective acquisition layout expanding the range of azimuth and offset. The objective is to improve the seismic illumination of the target and the overburden. Nowadays, modern multi-channel systems allow setting up acquisition layouts characterised by very long offsets. Moreover the utilisation of standalone stations (nodal systems) can assure multi-azimuth coverage also in complex landscapes and difficult terrains. Long offset data include not only near vertical reflections, commonly used in seismic exploration but also wide angle events, supercritical reflections anHydrocarbon prospects of Schuppen Belt Assam Arakan Basin d turning rays propagating down to the target depth.

Geological and Seismic Characteristics of Triangle Zones-Triangle zones are particularly prominent at the **foothills margin**. It appears in areas where conjugate thrusts are developed as a result of the compressive stress propagation onto the foreland. A triangle zone or passive roof duplex is composed of a sequence of dipping autochthonous rocks juxtaposed against opposite-dipping strata contained in imbricate thrust structure. These sequences are usually underlain by relatively underformedrocks.The upper detachment separates the autochthonous rocks on its hanging-wall from the allochthonous rocks in its footwall. The lower detachment is a surface common to the entire thrust and fold belt. It separates allochthonous from autochthonous rocks. The roof and floor of the thrust have opposite vergence and merge at depth to form a frontal tip line that marksthe extremity of the intercutaneous wedge. The wedge will continue thickening and advancing into the foreland basin until a critical point along the lower detachment.

Seismic Imaging Difficulties-In triangle zones, several factors reduce the effectiveness of seismic methods. The topography in the central part of the triangle zone is usually rugged and is associated with near-surface velocity inversions which degrade the quality of the seismic image. These characteristics lead to low signal-to-noise ratio, inadequate penetration of energy through overburden, poor geophone coupling with the surface and wave scattering.Because of the limited assumptions of time processing, the quality of the time sections is usually deteriorated and seismic interpretation oft en leads to erroneous structural interpretation. Seismic processing workflow must be selected according to the characteristicsof the velocity variations. Therefore, depth migration which takes into account lateral velocity variations is the adapted technique for depth seismic imaging in complex areas. But, in order to deliver a reliable depth image, this processing needs a depth velocity model for accurately focussing the diffracted energy and shift ing the events in their true position.Thus, better imaging the triangle zone features by an improvement of both seismic propagation understanding and depth migration processing.The analysis of the deformation of sandbox models using X-ray tomography suggests that the initiation of thrust and wrench faults is influenced by pre-existing salt domes which represent weak zones in the sedimentary section.

Depth Seismic Imaging Techniques-Seismic processing relates to the process of altering the seismic data to suppress noise, enhancing the desired signal (higher signal-to-noise ratio) and migrating seismic events to their appropriate location in space and depth. Processing steps generally include analysisof velocities, static corrections, moveout corrections, stacking and migration. Optimal seismic processing results in depth profiles readily interpretable, showing clear and unambiguous subsurface structures and reflection geometries. Depth migration can be viewed as a two-step processing procedure. The first step is to focus the diffracted energy, as for any migration processing. The second step is to convert the seismic data from the time domainto the depth domain. Both pre-stack and poststack depth migration techniques directly provide depth seismic images, but require the construction of a detailed velocity model describing the geometry of the geological layers and the intra-bed velocity variationsin the depth domain. Post-stack depth migration can be an adequate processing technique if the conventional stack sections can be reasonably considered to represent a zero-off set section and if coherent seismic reflectors are visible. Post-stack depth migrationapplication is an interpretative processing technique, requiring simple velocity scan analysis and several iterations between seismic interpreters and processors for structural consistency control. Post-stack depth migration allows only a few control points at well locationson velocity variations within the overburden layers. Pre-stack depth migration techniques (hereafter termed PSDM) provide the best seismic images in terms of geometry but present the disadvantage of being dependent on the reliability of the input velocity model.

Exploration seismology Bow-tie effect-Shadow Zones-areas with no reflections (dead areas). These are called shadow zones and are common in the vicinity of faults and other discontinuous areas in the subsurface. Shadow zones result when energy from a reflector is focused on receivers that produce other traces. As a result, reflectors are not shown in their true positions.Subsurface Discontinuities-Diffractions occur at discontinuities in the subsurface such as faults and velocity discontinuities (as at “bright spot” terminations).Bow-tie effect caused by the two deep-seated synclines.The appearance of a buried focus on a seismic section. It is two intersecting seismic events with apparent anticline below it.Buried focusFor zero offset and constant velocity, buried focus occurs if a reflector’s center of curvature lies beneath the recording plane. Note that diffractions mask out the true subsurface structure due to the bow-tie effect. Kirchhoff migration.Migration unties the bow-ties and turns the structure into a series of synclines.

Volumetric Curvature: Seismic Attributes curvature is a measure of how bent or deformed a surface is at a particular point. The more deformed the surface, the larger its curvature. Curvature measures various morphologic forms like domes, ridges, valleys, bowls, well,listric fault and thrust belt which has to do with shape indices.

UAV Unmanned Aerial Vehicles Drones with wireless sensors seismic survey is quite helpful in complex topography hill-valley areas ,marshy land, rainforest, glaciers, permafrost, Antarctica, arctic, etc. METIS, Multiphysics Exploration Technology Integrated System **Complex topography fold and thrust belts in foothills.**

Acknowledgement

I am grateful to the Project Leaders of IGCP 662 - Orogenic architecture and crustal growth from accretion to collision, http://igcp662.org.cn/[2018-2022].