GEODYNAMICS & TECTONOPHYSICS

PUBLISHED BY THE INSTITUTE OF THE EARTH'S CRUST
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCES

2017 VOLUME 8 ISSUE 3 PAGES 411–415 ISSN 2078-502X

https://doi.org/10.5800/GT-2017-8-3-0250

Proceedings of the Second Russia–China International Meeting on the Central Asian Orogenic Belt (September 6–12, 2017, Irkutsk, Russia)

GEOCHEMISTRY AND ORIGIN OF THE EASTERN SAYAN OPHIOLITES, TUVA-MONGOLIAN MICROCONTINENT (SOUTHERN SIBERIA)

**V. A. Belyaev[1, 2], K.-L. Wang[1, 3], M. A. Gornova[2], S. I. Dril'[2],
A. A. Karimov[2], A. Ya. Medvedev[2], Yu. V. Noskova[2]**

[1] *Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan*
[2] *A.P. Vinogradov Institute of Geochemistry, Siberian Branch of RAS, Irkutsk, Russia*
[3] *Department of Geosciences, National Taiwan University, Taipei, Taiwan*

For citation: *Belyaev V.A., Wang K.-L., Gornova M.A., Dril' S.I., Karimov A.A., Medvedev A.Ya., Noskova Yu.V.*, 2017. Geochemistry and origin of the Eastern Sayan ophiolites, Tuva-Mongolian microcontinent (Southern Siberia). *Geodynamics & Tectonophysics* 8 (3), 411–415. doi:10.5800/GT-2017-8-3-0250.

The Eastern Sayan ophiolites (1020 Ma) of the Tuva-Mongolian microcontinent are believed to be the most ancient ophiolite of the Central Asian Orogenic Belt [*Khain et al., 2002*]. The ophiolites obducted as a single nappe onto the Gargan block composed of Early Precambrian gneisses and Meso-Neoproterozoic sediments. The Eastern Sayan ophiolites form two belts surrounding Gargan block, with Dunzhugur massif in northern belt, and Ilchir massif in southern belt, which are the subject of this work. Previous studies reported boninites and boninite-series andesites, peridotite-pyroxenite-gabbroic rocks and mantle harzburgites and argued for the supra-subduction zone setting and formation of the ophiolites in an incipient Duznhugur island arc [*Dobretsov et al., 1985; Khain et al., 2002; Kuzmichev, 2004; Sklyarov et al., 2016*]. In this study, elemental and Nd isotope geochemistry of lavas and dikes in the Dunzhugur and Ilchir massifs are investigated to constrain the origin of the Eastern Sayan ophiolites.

Geochemistry and geodynamic implications. The whole-rock geochemistry is summarized on Fig. 1. The studied lavas and dikes from the Dunzhugur massif are low-TiO_2 (<0.5 %) varying from boninites (MgO > 8 %) to boninite-series andesites (MgO < 8 %) and subordinate dacites. One sample from dike complex is tholeiite (0.6 % TiO_2). Metamorphosed lavas from the Ilchir massif are boninites to andesites resembling Dunzhugur rocks, as well as tholeiite and basaltic andesites with elevated TiO_2 (0.85–1.30 %). The Dunzhugur and Ilchir boninite-series rocks are variously LREE- and Th-enriched with Nb and Ti depletions typical of

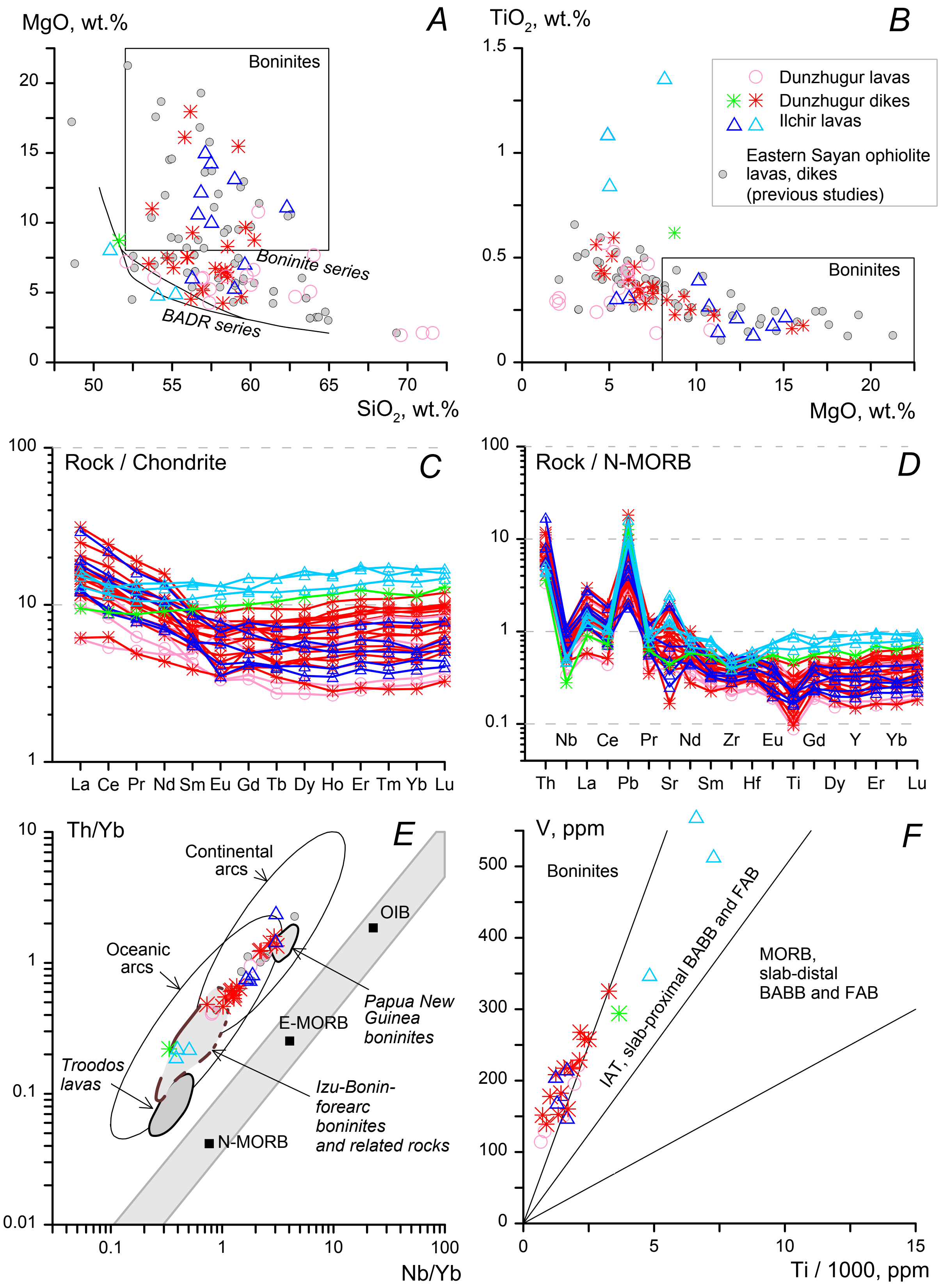

Fig. 1. Geochemical characteristics of volcanics and dikes from the Eastern Sayan ophiolites.

A, B – variations of SiO_2, MgO, TiO_2 contents. Field of boninite composition is after [*Le Bas, 2000*], border line between boninite and basalt-andesite-dacite-rhyolite (BADR) series is after [*Pearce, Robinson, 2010*]. *C, D* – chondrite normalized REE and N-MORB-normalized trace element patterns. Normalization values are from [*McDonough, Sun, 1995*]. *E* – Nb/Yb – Th/Yb diagram [*Pearce, 2008, 2014*]. Composition of Troodos lavas [*Pearce, 2014*], Izu-Bonin forearc boninites and related rocks [*Pearce et al., 1992*], and Papua New Guinea boninites [*König et al., 2010*] is shown for comparison. *F* – Ti – V diagram, [*Shervais, 1982*] with field subdivision of [*Pearce, 2014*]. Previously reported data for the Dunzhugur lavas and dikes [*Dobretsov et al., 1985; Khain et al., 2002; Kuzmichev, 2004; Sklyarov et al., 2016*] are shown in *A*, *B*, *E*.

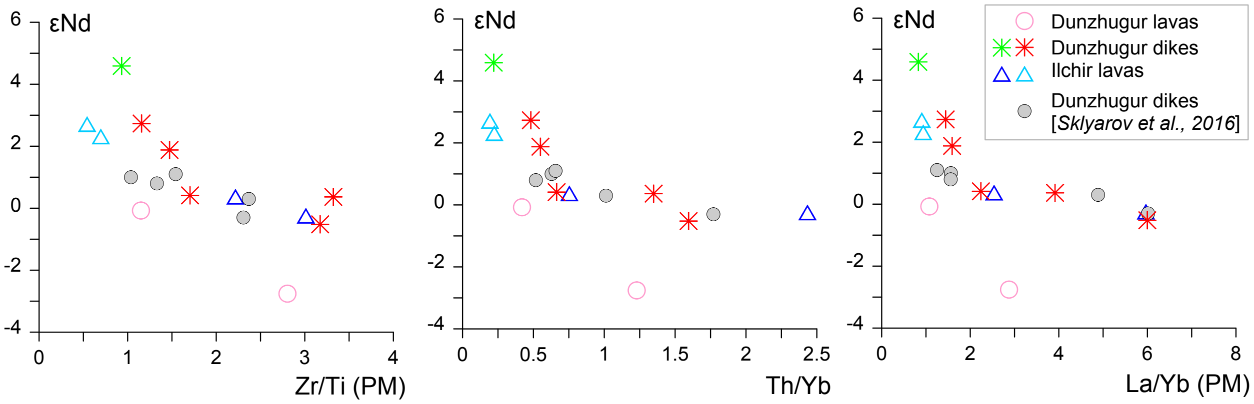

Fig. 2. Correlation of εNd (calculated at 1020 Ma) with selected trace element ratios. Zr/Ti and La/Yb ratios are normalized to primitive mantle [*McDonough, Sun, 1995*]. Compositions of the Dunzhugur dikes reported by [*Sklyarov et al., 2016*] are shown.

subduction-related magmas. Tholeiites from Dunzhugur and Ilchir have higher REE abundances without LREE enrichment, show negative Nb anomaly and lack of Ti depletion. The HREE contents of all studied samples are lower than in N-MORB, indicating derivation from the source more depleted than MORB mantle. Relative enrichment in LREE-Th can be explained as the mantle source metasomatised by fluids and/or melts from the subducting slab. On Nb/Yb vs. Th/Yb diagram [*Pearce, 2008, 2014*], tholeiites plot within oceanic arc, whereas boninites and andesites locate within oceanic to continental arc fields. On Ti–V plot [*Shervais, 1982*], tholeiites are classified as island arc tholeiites, and boninites to andesites plot within the boninite field. Nd isotope analysis revealed variations in εNd(1020) from –2.8 to +2.7 in Dunzhugur boninites and andesites, –0.2 to +0.4 in Ilchir boninites and andesites, and +2.3 to +4.5 in tholeiites from Ilchir and Dunzhugur massifs. The range of εNd(1020) from –1.0 to +1.5 was previously reported for the Dunzhugur andesite and boninite lavas, dikes, and gabbro [*Sklyarov et al., 2016*]. Overall, samples with lower εNd tend to be more enriched in terms of trace element ratios such as Zr/Ti, Th/Yb, La/Yb (Fig. 2).

The boninites represent second-stage melts derived from previously depleted mantle in subduction zone environment [*König et al., 2010; Shchipansky, 2016*]. They are classified into high-Ca type, generally originated from less depleted source under fluid flux, and low-Ca type, derived from more depleted source, generally fluxed by melts from subducting slab [*Crawford et al., 1989; König et al., 2010*]. The studied Eastern Sayan boninite-series rocks are similar in major-element composition to low-Ca and intermediate-Ca boninites and related rocks of Izu-Bonin-Mariana forearc [*Pearce et al., 1992*], but in terms of trace elements vary between Izu-Bonin and Papua New Guinea low-Ca boninites [*König et al., 2010*]. Low-Ca type of boninites is more typical of subduction initiation settings, while high-Ca boninites occur in environments varying from subduction initiation to back-arc and subduction zone influenced by a mantle plume [*Reagan et al., 2017; Shchipansky, 2016; Sklyarov et al., 2016*]. Boninite-series rocks in association with tholeiites are common for intra-oceanic subduction initiation settings recorded in modern forearcs [*Reagan et al., 2010, 2017*] and ophiolites [*König et al., 2010; Pearce, Robinson, 2010*]. Similarly, the Eastern Sayan ophiolites are likely to be originated in subduction initiation environment, but their enriched trace element and Nd isotope composition needs further consideration.

Phanerozoic boninite-series mostly have isotope characteristics of depleted mantle variously affected by an enriched component: εNd(T) +6.2 to +8.3 (Izu-Bonin-Mariana [*Pearce et al., 1992; Reagan et al., 2010*]), +3.9 to +5.1 (Papua New Guinea [*König et al., 2010*]), +5 to +6.8 (Troodos ophiolite [*König et al., 2008*]), +0.6 to +3.0 (Pindos ophiolite [*Pe-Piper et al., 2004*]). Boninites of these localities formed from depleted mantle variously affected by fluids and melts from subducting slab (subduction component), and additional OIB-type source is inferred for the Pindos ophiolite. Lack of typical intraplate alkaline basalts among the studied Eastern Sayan ophiolite rather rules out an OIB-source hypothesis. Slab melts and fluids can potentially represent an enriched component. Subducting basaltic crust is supposed to have MORB-like isotope variations and cannot explain alone such enriched isotope compositions observed in the Eastern Sayan ophiolites. Following [*Sklyarov et al., 2016*], subduction of sediments derived from a continental block, probably Gargan block with Neoarchean gneiss basement (εNd(1020) from –20.7 to –28.0), can cause enrichment in Nd isotopes. If this is the case, the melt derived from the sediment will be more effective in transporting trace elements than the fluid. Such process is not unusual for ophiolites. Felsic intrusions with negative εNd(T) interpreted as melts of subducted sediments were reported in Oman ophiolite [*Haase et al., 2015*] and some Tibetian ophiolites [*Zeng et al., 2016*]. The studied Eastern Sayan ophiolites might record similar case of sediment melt participation in ophiolite petrogenesis. Another explanation of enriched Nd isotope and trace element characteristics of the boninite-series is involvement of ancient lithosphere. The subcontinental lithospheric mantle is characterized by wide variations in Nd isotopes [e.g., *Carlson, Irving, 1994*]. Ancient lithospheric blocks are preserved in the modern ocean basins, e.g. in the Izu-Bonin-Mariana forearc [*Parkinson et al., 1998*]. If such ancient lithosphere existed beneath the Eastern Sayan (or Dunzhugur) forearc and if it was enriched in terms of Nd isotopes, its second-stage melting above the newly formed subduction zone might yield boninite-series magmas and explain the ophiolite geochemistry. This is supported by the Re-Os isotope study of the mantle peridotites from Ulan-Sardag and Hara-Nur massifs of the Eastern Sayan ophiolites, revealed low ^{187}Re/^{188}Os ratios and TMA model ages of 1.22 to 2.38 Ga, much older than ophiolite formation age, and reflecting ancient depletion event [*Wang et al., 2016*]. Further studies will help to clarify the ophiolite formation model.

Conclusion. Lavas and dikes from the Eastern Sayan ophiolites vary from boninites and boninite-series andesites to tholeiites. Similar chemistry of the Dunzhugur and Ilchir rocks support their occurrence as remnants of a single ophiolite nappe covered the Gargan block. Geochemical data point to the formation of the Eastern Sayan ophiolites in forearc setting during subduction initiation. Coupled trace-element and Nd isotope enrichment in boninite series relative to tholeiite basalts indicate progressive increase in enriched component in boninite-series petrogenesis, which might represent melts of subducted sediments or ancient lithospheric mantle.

REFERENCES

Carlson R.W., Irving A.J., 1994. Depletion and enrichment history of subcontinental lithospheric mantle: An Os, Sr, Nd and Pb isotopic study of ultramafic xenoliths from the northwestern Wyoming craton. *Earth and Planetary Science Letters* 126 (4), 457–172. https://doi.org/10.1016/0012-821X(94)90124-4.

Crawford A.J., Fallon T.J., Green D.H., 1989. Classification, petrogenesis and tectonic setting of boninites. In: A.J. Crawford (Ed.), Boninites and related rocks. Unwin Hyman, London, p. 2–44.

Dobretsov N.L., Konnikov E.G., Medvedev V.N., Sklyarov E.V., 1985. Ophiolites and olistostromes of the Eastern Sayan. In: N.L. Dobretsov (Ed.), Riphean – Early Paleozoic ophiolites of Northern Eurasia, p. 34–58 (in Russian).

Haase K.M., Freund S., Koepke J., Hauff F., Erdmann M., 2015. Melts of sediments in the mantle wedge of the Oman ophiolite. *Geology* 43 (4), 275–278. https://doi.org/10.1130/G36451.1.

Khain E.V., Bibikova E.V., Kröner A., Zhuravlev D.Z., Sklyarov E.V., Fedotova A.A., Kravchenko-Berezhnoy I.R., 2002. The most ancient ophiolite of the Central Asian fold belt: U-Pb and Pb-Pb zircon ages for the Dunzhugur complex, Eastern Sayan, Siberia, and geodynamic implications. *Earth and Planetary Science Letters* 199 (3–4), 311–325. https://doi.org/10.1016/S0012-821X(02)00587-3.

König S., Münker C., Schuth S., Garbe-Schönberg D., 2008. Mobility of tungsten in subduction zones. *Earth and Planetary Science Letters* 274 (1–2), 82–92. https://doi.org/10.1016/j.epsl.2008.07.002.

König S., Münker C., Schuth S., Luguet A., Hoffmann J.E., Kuduon J., 2010. Boninites as windows into trace element mobility in subduction zones. *Geochimica et Cosmochimica Acta* 74 (2), 684–704. https://doi.org/10.1016/j.gca.2009.10.011.

Kuzmichev A.B., 2004. Tectonic History of the Tuva-Mongolian Massif: Easrly Baikalian, Late Baikalian and Early Caledonian Stages. PROBEL-2000, Moscow, 192 p. (in Russian).

Le Bas M.J., 2000. IUGS reclassification of the high-Mg and picritic volcanic rocks. *Journal of Petrology* 41 (10), 1467–1470. https://doi.org/10.1093/petrology/41.10.1467.

McDonough W.F., Sun S.-S., 1995. The composition of the Earth. *Chemical Geology* 120 (3–4), 223–253. https://doi.org/10.1016/0009-2541(94)00140-4.

Parkinson I.J., Hawkesworth C., Cohen A.S., 1998. Ancient mantle in a modern arc: Osmium isotopes in Izu-Bonin-Mariana forearc peridotites. *Science* 281 (5385), 2011–2013. https://doi.org/10.1126/science.281.5385.2011.

Pearce J.A., 2008. Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust. *Lithos* 100 (1–4), 14–48. https://doi.org/10.1016/j.lithos.2007.06.016.

Pearce J.A., 2014. Immobile element fingerprinting of ophiolites. *Elements* 10 (2), 101–108. https://doi.org/10.2113/gselements.10.2.101.

Pearce J.A., Robinson P., 2010. The Troodos ophiolitic complex probably formed in a subduction initiation, slab edge setting. *Gondwana Research* 18 (1), 60–81. https://doi.org/10.1016/j.gr.2009.12.003.

Pearce J.A., Thirlwall M.F., Ingram G., Murton B.J., Arculus R.J., van der Laan S.R., 1992. Isotopic evidence for the origin of boninites and related rocks drilled in the Izu-Bonin (Ogasawara) forearc, Leg 125. *Proceedings of the Ocean Drilling Program, Scientific Results* 125, 237–261.

Pe-Piper G., Tsikouras B., Hatzipanagiotou K., 2004. Evolution of boninites and island-arc tholeiites in the Pindos Ophiolite, Greece. *Geological Magazine* 141 (4), 455–469. https://doi.org/10.1017/S0016756804009215.

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 (3), Q03X12. https://doi.org/10.1029/2009GC002871.

Reagan M.K., Pearce J.A., Petronotis K., Almeev R., Avery A.J., Carvallo C., Chapman T., Christenson G.L., Ferre E.C., Godard M., Heaton D.E., Kirchenbaur M., Kurz W., Kutterolf S., Li H., Li Y., Michibayashi K., Morgan S., Nelson W.R., Prytulak J., Python M., Robertsn A., Ryan J.G., Sager W.W., Sakuyama T., Shervais J.W., Shimizu K., Whattam S.A., 2017. Subduction initiation and ophiolite crust: new insights from IODP drilling. *International Geology Review* (in press). https://doi.org/10.1080/00206814.2016.1276482.

Shervais J.W., 1982. Ti-V plots and the petrogenesis of modern and ophiolitic lavas. *Earth and Planetary Science Letters* 59 (1), 101–118. https://doi.org/10.1016/0012-821X(82)90120-0.

Shchipansky A.A., 2016. Boninites through time and space: petrogenesis and geodynamic settings. *Geodynamics & Tectonophysics* 7 (2), 143–172, https://doi.org/10.5800/GT-2016-7-2-0202.

Sklyarov E.V., Kovach V.P., Kotov A.B., Kuzmichev A.B., Lavrenchuk A.V., Perelyaev V.I., Shchipansky A.A., 2016. Boninites and ophiolites: problems of their relations and petrogenesis of boninites. *Russian Geology and Geophysics* 57 (1), 127–140. https://doi.org/10.1016/j.rgg.2016.01.009.

Wang K.-L., Chu Z., Gornova M., Belyaev V., Lin K.-Y., O'Reilly S.Y., 2016. Depleted SSZ type mantle peridotites in Proterozoic Eastern Sayan Ophiolites in Siberia. *Goldschmidt Abstracts*, 3327*.* Available from: https://goldschmidt.info/2016//uploads/abstracts/originalPDFs/979.pdf.

Zeng Y.-C., Chen J.-C., Xu J.-F., Wang B.-D., Huang F., 2016. Sediment melting during subduction initiation: Geochronological and geochemical evidence from the Darutso high-Mg andesites within ophiolite melange, central Tibet. *Geochemistry, Geophysics, Geosystems* 17 (12), 4859–4877, https://doi.org/10.1002/2016GC006456.