Differential crustal rotation and its control on giant ore-clusters along the eastern margin of Tibet

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GRAVITY DATA ANALYSES

The Moho topography was determined by the following procedure. Firstly, the free-air gravity was acquired after field data preprocessing and indoor processing, and the Bouguer gravity data was obtained by removing the terrain effects of the topography using the Terrain Correction modules of the Oasis Montaj software (Tong et al., 2018). Subsequently, the Bouguer gravity was corrected for known short and long wavelength effects to get high frequency filtered Bouguer gravity anomaly data, which is used for Moho depth estimation (Bagherbandi et al., 2013; Xu et al., 2017), and then the Bouguer gravity signal coming from Moho deflections was extracted using spectral analysis (Sjöberg, 2009; Prasanna et al., 2013). Finally, the extracted gravity signals are applied to invert for the Moho topography using the Parker–Oldenburg gravity inversion method (Parker, 1973; Oldenburg, 1974; Gómez-Ortiz and Agarwal, 2005).

GEOCHEMICAL CHARACTERISTICS FOR THE PORPHYRIES AT YULONG AND BEIYA ORE CLUSTER

Potassic adakite-like porphyries in Yulong and Beiya are characterized by high

Sr (328-1272 ppm) but low Y (4.3-12.1 ppm) and Yb (0.37-0.88 ppm) contents, with elevated Sr/Y (38-243) and La/Yb (24-50) ratios. All of samples plot in the adakite field owing to their high Sr/Y and La/Yb ratios and low Y and Yb contents (Defant and Drummond, 1990). There is a close match in the Sr and Nd isotope compositions of the potassic adakite-like porphyries and the western Yunnan amphibolite xenoliths hosted by the potassic felsic intrusions, indicating that amphibolites may be the primary source of the adakite-like porphyries. To test this hypothesis, batch melting modeling was conducted to simulate the Sr/Y vs Y and La/Yb vs Yb variations, following the methods of Haschke et al. (2002, 2010). The starting composition for the modeling is an amphibolite xenolith sampled at Liuhe in western Yunnan (sample LH14b, Wang et al., 2003). The variations for the potassic adakite-like porphyries broadly follow the trends expected for partial melting with up to 5 wt.% garnet in the restite. Detailed geochemical bulk-rock and Sr–Nd isotope data suggest that all these porphyries were plausibly derived by partial melting of a thickened lower crust with minor input from mafic component (Lu et al., 2013; He et al., 2017).

JINDING MVT ORE CLUSTER

The Oligocene MVT Pb–Zn polymetallic deposits, with a variety of accompanying metals including Ag, Sr, Cu, among others, were widely developed in the Mesozoic basin (Fig. 1). The most important among these ore deposits is the Jinding Zn–Pb deposit located in the Lanping basin (Kyle and Li, 2002). This deposit is the largest Zn–Pb deposit in China with reserves of 12.84 Mt Zn and 2.64 Mt Pb (Xue et al., 2007). Based on field observations of the ore textures, breccias, and the sandstone host rocks, the ores formed in a dome that was created by the diapiric migration of evaporites in the Lanping Basin during Paleogene deformation and thrust loading. Most of the ore occurs in sandstones that are interpreted to be a former evaporite glacier containing a mélange of extruded diapiric material, including breccias, fluidized sand, and evaporites that mixed with sediment from a fluvial sandstone system. A pre-ore hydrocarbon and reduced sulfur reservoir formed in the evaporite glacier that became the chemical sink for Zn and Pb in a crustal-derived

metalliferous fluid (Leach et al., 2017). Although the most important host rocks are sandstones, not marine platform carbonates, the mineral assemblage and textures, mineralizing fluid, and mineralization processes at Jinding are consistent with those typical of MVT deposits (Xue et al., 2007; Song et al., 2019). The Jinding deposit and its ores and host rocks are best characterized as a sediment-hosted Zn–Pb deposit in a diapiric environment. It does not define a unique class of ore deposits; rather, the Jinding deposit should be classified as a diapir-related Zn–Pb deposit or as a MVT sub-type deposit hosted in a diapiric environment (Leach et al., 2017).

REFERENCES CITED

- Bagherbandi, M., Tenzer, R., Sjöberg, L.E., Novák, P., 2013, Improved global crustal thickness modeling based on the VMM isostatic model and non-isostatic gravity correction: *Journal of Geodynamics*, v. 66, p. 25–37, <https://doi.org/10.1016/j.jog.2013.01.002>.
- Chang, L., Flesch, L.M., Wang, C., and Ding, Z., 2015, Vertical coherence of deformation in lithosphere in the eastern Himalayan syntaxis using GPS, Quaternary fault slip rates, and shear wave splitting data: *Geophysical Research Letters*, v. 42(14), p. 5813–5819, <https://doi.org/10.1002/2015GL064568>.
- Chen, K.X., 2006, The forming mechanism of copper-silver polymetallic ore concentration area in the north of Lanping foreland basin in Yunnan province: A dissertation submitted to China University of Geosciences (Wuhan) for doctoral degree, p. 1–128 (in Chinese with English abstract).
- Chen, H.H., Dobson, J., Heller, F., and Jie, H., 1995, Paleomagnetic evidence for clockwise rotation of the Simao region since the Cretaceous: a consequence of India-Asia Collision: *Earth and Planetary Science Letters*, v. 134, p. 203–217, [https://doi.org/10.1016/0012-821X\(95\)00118-V](https://doi.org/10.1016/0012-821X(95)00118-V).
- Cogné, J.P., Halim, N., Chen, Y., and Courtillot, V., 1999, Resolving the problem of shallow magnetizations of Tertiary age in Asia: insights from paleomagnetic data from the Qiangtang, Kunlun, and Qaidam blocks (Tibet, China), and a new hypothesis: *Journal of Geophysical Research*, v. 104, p. 17715–17734, <https://doi.org/10.1029/1999jb900153>.
- Cogné, J. P., Besse, J., Chen, Y., and Hankard, F., 2013, A new Late Cretaceous to Present APWP for Asia and its implications for paleomagnetic shallow inclinations in Central Asia and Cenozoic Eurasian plate deformation: *Geophysical Journal International*, v. 192(3), p. 1000–1024, <https://doi.org/10.1093/gji/ggs104>.
- Defant, M.J., and Drummond, M.S., 1990. Derivation of some modern arc magmas by melting of young subducted lithosphere: *Nature*, v. 347, p. 662–665, <https://doi.org/10.1038/347662a0>.

- Deng, W.M., Huang, X., and Zhong, D.L., 1998, Petrological characteristics and genesis of Cenozoic alkali-rich porphyry in West Yunnan, China: *Scientia Geologica Sinica*, v. 33, p. 412-425, (in Chinese with English abstract).
- Du, A.D., He, H.L., and Yin, W.N., 1994, The study on the analytical methods of Re-Os age for molybdenites: *Acta Geologica Sinica*, v. 68, p. 339–346 (in Chinese with English abstract).
- Funahara, S., Nishiwaki, N., Murata, F., Otofujii, Y.I., and Wang, Y.Z., 1993, Clockwise rotation of the Red River fault inferred from paleomagnetic study of Cretaceous rocks in the Shan-Thai-Malay block of western Yunnan, China: *Earth and Planetary Science Letters*, v. 117(1-2), p. 29-42, [https://doi.org/10.1016/0012-821X\(93\)90115-P](https://doi.org/10.1016/0012-821X(93)90115-P).
- Gao, L., Deng, J., Wang, Q., Zhang, S., and Yang, Z., 2018, New Paleomagnetic results from the Beiya porphyry-skarn gold-polymetallic deposit at the Western Dali faulted-block: Implications for the Cenozoic tectonic rotation of the Chuan-Dian Fragment, Southeastern Tibetan Plateau: *Tectonophysics*, v. 747, p. 163-176, <https://doi.org/10.1016/j.tecto.2018.10.004>.
- Gao, L., Yang, Z., Tong, Y., Wang, H., and An, C., 2015, New paleomagnetic studies of Cretaceous and Miocene rocks from Jinggu, western Yunnan, China: Evidence for internal deformation of the Lanping–Simao block: *Journal of Geodynamics*, v. 89, p. 39-59, <https://doi.org/10.1016/j.jog.2015.06.004>.
- Gómez-Ortiz, D., Agarwal, B.N.P., 2005, 3DINVER.M: a MATLAB program to invert the gravity anomaly over a 3D horizontal density interface by Parker–Oldenburg’s algorithm: *Computers and Geosciences*, v. 31, p. 513–520, <https://doi.org/10.1016/j.cageo.2004.11.004>.
- Guo, L.G., Liu, Y.P., Xu, W., Zhang, X.C., Qin, K.Z., Li, T.S., and Shi, Y.R., 2006, Constraints to the mineralization age of the Yulong porphyry copper deposit from SHRIMP U-Pb zircon data in Tibet: *Acta Petrologica Sinica*, v. 21, p. 1009–1016 (in Chinese with English abstract).
- Guo, Z.F., Hertogen, J., Liu, J.Q., Pasteels, P., Boven, A., Punzalan, L., He, H.Y., Luo, X.J., and Zhang, W.H., 2005, Potassic magmatism in western Sichuan and

- Yunnan provinces, SE Tibet, China: Petrological and geochemical constraints on petrogenesis: *Journal of Petrology*, v. 46, p. 33–78, <https://doi.10.1093/petrology/egh061>.
- Halim, N., Cogné, J.P., Chen, Y., Atasiei, R., Besse, J., Courtillot, V., Gilder, S., Marcoux, J., and Xhao, R.L., 1998, New Cretaceous and Early Tertiary paleomagnetic results from Xining-Lanzhou basin, Kunlun and Qiangtang blocks, China: implications on the geodynamic evolution of Asia: *Journal of Geophysical Research*, v. 103, p. 21025–21045, <https://doi.org/10.1029/98JB01118>.
- Haschke, M., Siebel, W., Gunther, A., and Scheuber, E., 2002. Repeated crustal thickening and recycling during the Andean orogeny in north Chile (21–26S): *Journal of Geophysical Research*, v. 107, p. 1–18, <https://doi.10.1029/2001JB000328>.
- Haschke, M., Ahmadian, J., Murata, M., and McDonald, I., 2010. Copper mineralization prevented by arc-root delamination during Alpine-Himalayan collision in central Iran: *Economic Geology*, v. 105, p. 855–865, <https://doi.10.2113/gsecongeo.105.4.855>.
- He, W.Y., Mo, X.X., Yang, L.Q., Xing, Y.L., Dong, G.C., Yang, Z., Gao, X., Bao, X.S., 2016. Origin of the Eocene porphyries and mafic microgranular enclaves from the Beiya porphyry Au polymetallic deposit, western Yunnan, China: Implications for magma mixing/mingling and mineralization: *Gondwana Research*, v. 40, p. 230–248, <https://doi.org/10.1016/j.gr.2016.09.004>.
- Hou, Z.Q., Ma, H.W., Zaw, K., Zhang, Y.Q., Wang, M.J., Wang, Z., Pan, G.T., and Tang, R.L., 2003, The Himalayan Yulong porphyry copper belt: product of large-scale strike-slip faulting in Eastern Tibet: *Economic Geology*, v. 98, p. 125–145, <https://doi.org/10.2113/98.1.125>.
- Hou, Z.Q., Zeng, P.S., Gao, Y.F., Du, A.D., and Fu, D.M., 2006, Himalayan Cu-Mo-Au mineralization in the eastern Indo-Asian collision zone: constraints from Re-O dating of molybdenite: *Mineralium Deposita*, v. 41, p. 33–45, <https://doi.org/10.1007/s00126-005-0038-2>.

- Huang, K.N., Opdyke, N.D., Li, J.G., and Peng, X.J., 1992, Paleomagnetism of Cretaceous rocks from eastern Qiangtang block of Tibet: *Journal of Geophysical Research*, v. 97, p. 1789–1799, <https://doi.org/10.1029/91jb02747>.
- Huang, K.N., Opdyke, N.D., 1993. Paleomagnetic results from Cretaceous and Jurassic rocks of South and Southwest Yunnan: evidence for large clockwise rotations in the Indochina and Shan-Thai-Malay Terranes: *Earth and Planetary Science Letters*, v. 117, p. 507–524, [http://dx.doi.org/10.1016/0012-821X\(93\)90100-N](http://dx.doi.org/10.1016/0012-821X(93)90100-N).
- Huang, X.L., Niu, Y., Xu, Y.G., Chen, L.L., and Yang, Q.J., 2010. Mineralogical and geochemical constraints on the petrogenesis of post-collisional potassic and ultrapotassic rocks from western Yunnan, SW China: *Journal of Petrology*, v. 51, p. 1617-1654, <https://doi.10.1093/petrology/egq032>.
- Jiang, Y.H., Jiang, S.Y., Ling, H.F., Dai, B.Z., 2006. Low-degree melting of a metasomatized lithospheric mantle for the origin of Cenozoic Yulong monzogranite–porphyry, east Tibet: geochemical and Sr–Nd–Pb–Hf isotopic constraints: *Earth and Planetary Science Letters*, v. p. 241 (3-4), 617–633, <https://doi.org/10.1016/j.epsl.2005.11.023>.
- Kondo, K., Mu, C., Yamamoto, T., Zaman, H., Miura, D., Yokoyama, M., Ahn, H.S., and Otofujii, Y., 2012, Oroclinal origin of the Simao Arc in the Shan-Thai Block inferred from the Cretaceous palaeomagnetic data: *Geophysical Journal International*, v. 190(1), p. 201–216, <https://doi.org/10.1111/j.1365-246X.2012.05467.x>.
- Kyle, J.K., Li, N., 2002. Jinding: a giant tertiary sandstone-hosted Zn-Pb deposit, Yunnan, China. *Society of Economic Geologists Newsletter*, v. 50, p. 9-16.
- Leach, D.I., Song, C.Y., and Hou, Z.Q., 2017, The world-class Jinding Zn–Pb deposit: ore formation in an evaporite dome, Lanping Basin, Yunnan, China: *Mineralium Deposita*, v. 3, p. 281-296, <https://doi.org/10.1007/s00126-016-0668-6>.
- León Soto, G., Sandvol, E., Ni, J.F., Flesch, L., Hearn, T.M., Tilmann, F., Chen, J., and Brown, L.D., 2012, Significant and vertically coherent seismic anisotropy

- beneath eastern Tibet: *Journal of Geophysical Research*, v. 117, B05308, <https://doi.org/10.1029/2011JB008919>.
- Li, S., Yang, Z., Deng, C., He, H., Qin, H., Sun, L., Yuan, J., Douwe J. J., Hinsbergen, v., Wout, K., Mark J.D., Pan, Y., and Zhu, R., 2017, Clockwise rotations recorded in redbeds from the Jinggu Basin of northwestern Indochina: *GSA Bulletin*, v. 129(9-10), p. 1100-1122, <https://doi.org/10.1130/B31637.1>.
- Li, Y.L., Dong, J.L., Yang, R.H., and Yu, X.Z., 2002. Gold deposit geology and remote sensing in Sanjiang region of east Tibet: *Remote Sensing for Land and Resources*, v. 4, p. 22–26 (in Chinese with English abstract).
- Li, Z.X., Liu, L.H., and Ji, H., 2012b, The ore prospecting idea of buried deposit of Luoboshan Pb-Zn in Puer, Yunnan: *Geology of Yunnan*, v. 31, p. 39–42 (in Chinese with English abstract).
- Liang, H.Y., Campbell, I.H., Allen, C., Sun, W.D., Liu, C.Q., Yu, H.X., Xie, Y.W., and Zhang, Y.Q., 2006, Zircon Ce⁴⁺/Ce³⁺ ratios and ages for Yulong ore-bearing porphyries in eastern Tibet: *Mineralium Deposita*, v. 41, p. 152–159, <https://doi.org/10.1007/s00126-005-0047-1>.
- Liang, H.Y., Xie, Y.W., and Zhang, Y.Q., 2004a. Constrains to the mineralization of the copper deposits from forming and evolution of kalium-rich alkali rock at Machangqing copper deposit: *Progress in Nature Science*, v. 14, p. 116–119 (in Chinese with English abstract).
- Lin, J., and Watts, D.R., 1988, Palaeomagnetic results from the Tibetan Plateau: *Philosophical Transactions of the Royal Society of London A*, v. 327, p. 239–262, <https://doi.org/10.1098/rsta.1988.0128>.
- Liu, Z.Q., Li, X.Z., Ye, Q.T., Luo, J.N., Shen, G.F., Mo, X.X., Chen, F.Z., Chen, B.W., Yang, Y.Q., Lü, B.X., Chen, J.S., Pan, G.T., Jia, B.J., Hu, Y.Z., and Zheng, L.L., 1993, Division of tectonomagmatic belts and distribution of the ore deposits in Sanjiang region: *Geological Publishing House, Beijing*, p. 1–243 (in Chinese).
- Lu, Y.J., Kerrich, R., Cawood, P.A., McCuaig, T.C., Hart, C.J.R., Li, Z.X., Hou, Z.Q., and Bagas, L., 2012, Zircon SHRIMP U-Pb geochronology of potassic felsic intrusions in western Yunnan, SW China: Constraints on the relationship of

- magmatism to the Jinsha suture: *Gondwana Research*, v. 22, p. 737–747, <https://doi.org/10.1016/j.gr.2011.11.016>.
- Lu, Y.J., Kerrich, R., Kemp, A.I.S., Mccuaig, T.C., Hou, Z.Q., Hart, C.J., Li, Z.X., Cawood, P.A., Bagasi L., Yang, Z.M., Cliff J., Belousov E.A., Jourdan, F., and Evans, N.J., 2013, Intracontinental Eocene-Oligocene porphyry Cu mineral systems of Yunnan, Western Yangtze Craton, China: Compositional Characteristics, Sources, and Implications for Continental Collision Metallogeny: *Economic Geology*, v. 108, p. 1541–1576, <https://doi.org/10.2113/econgeo.108.7.1541>.
- Oldenburg, D.W., 1974, The inversion and interpretation of gravity anomalies: *Geophysics*, v. 39 (4), p. 526–536, <https://doi.org/10.1190/1.1440444>.
- Parker, R.L., 1973, The rapid calculation of potential anomalies: *Geophysical Journal of the Royal Astronomical Society*, v. 31, p. 447–455, <https://doi.org/10.1111/j.1365-246X.1973.tb06513.x>.
- Qin, P.L., 2009, Metallogenic conditions and prediction in Linjiang, Yunnan: A dissertation submitted to Kunming University of Science and Technology for doctoral degree, p. 1–78 (in Chinese).
- Richards, J.P., and Kerrich, R., 2007, Adakite-like rocks: Their diverse origins and questionable role in metallogenesis: *Economic Geology*, v. 102, p. 537–576, <https://doi:10.2113/gsecongeo.102.4.537>.
- Roperch, P., Dupont-Nivet, G., Guillot, S., Goussin, F., Huang, W., Replumaz, A., Yang, Z., Guo, Z., and Song, B., 2017, Paleomagnetic constraints on early collisional deformation along the eastern margin of the Qiantang block (Tibetan plateau) at 50 and 37 Ma: In *EGU General Assembly Conference Abstracts* , v. 19, p. 9476.
- Prasanna, H.M.I., Chen, W., İz, H.B., 2013, High resolution local Moho determination using gravity inversion: A case study in Sri Lanka: *Journal of Asian Earth Sciences*, v. 74, p. 62-70, <https://doi.org/10.1016/j.jseas.2013.06.005>
- Sato, K., Liu, Y., Zhu, Z., Yang, Z., and Otofujii, Y.I., 1999, Paleomagnetic study of middle Cretaceous rocks from Yunlong, western Yunnan, China: evidence of

- southward displacement of Indochina: *Earth and Planetary Science Letters*, v. 165(1), p. 1-15, [https://doi.org/10.1016/S0012-821X\(98\)00257-X](https://doi.org/10.1016/S0012-821X(98)00257-X).
- Sato, K., Liu, Y., Zhu, Z., Yang, Z., and Otofujii, Y.I., 2001, Tertiary paleomagnetic data from northwestern Yunnan, China: further evidence for large clockwise rotation of the Indochina block and its tectonic implications: *Earth and Planetary Science Letters*, v. 185(1-2), p. 185-198, [https://doi.org/10.1016/S0012-821X\(00\)00377-0](https://doi.org/10.1016/S0012-821X(00)00377-0).
- Sato, K., Liu, Y., Wang, Y., Yokoyama, M., Yoshioka, S. Y., Yang, Z., and Otofujii, Y.I., 2007, Paleomagnetic study of Cretaceous rocks from Pu'er, western Yunnan, China: evidence of internal deformation of the Indochina block: *Earth and Planetary Science Letters*, v. 258(1-2), p. 1-15, <https://doi.org/10.1016/j.epsl.2007.02.043>.
- Sjöberg, L.E., 2009, Solving Vening Meinesz–Moritz inverse problem in isostasy: *Geophysical Journal International*, v. 179 (3), p. 1527–1536, <https://doi.org/10.1111/j.1365-246X.2009.04397.x>.
- Song, Y.C., 2009, Characteristics and genetic model of sediment-hosted base metal deposits in Sanjiang area, southwest China. Beijing: Post doctoral Report, Chinese Academy of Geological Sciences, p. 1–120 (in Chinese with English abstract).
- Takemoto, K., Halim, N., Otofujii, Y., Tran, V.T., Le, V.D., and Hada, S., 2005, New paleomagnetic constraints on the extrusion of Indochina: Late Cretaceous results from the Song Da block, northern Vietnam: *Earth and Planetary Science Letters*, v. 229, p. 273–285, <https://doi.org/10.1016/j.epsl.2004.09.040>.
- Tanaka, K., Mu, C., Sato, K., Takemoto, K., Miura, D., Liu, Y., ... and Uno, K., 2008, Tectonic deformation around the eastern Himalayan syntaxis: constraints from the Cretaceous palaeomagnetic data of the Shan-Thai Block: *Geophysical Journal International*, v. 175(2), p. 713-728, <https://doi.org/10.1111/j.1365-246X.2008.03885.x>.

- Tang, R.L., and Luo, H.S., 1995, The geology of Yulong porphyry copper (molybdenum) ore belt, Xizang (Tibet): Geological Publishing House, Beijing, p. 1–320 (in Chinese with English abstract).
- Tong, Y.B., Yang, Z.Y., Wang, H., Zhang, X.D., An, C.Z., Xu, Y.C., and Zhao, Y., 2014, The Cretaceous paleomagnetic results from the central part of the Simao Terrane in the southwest part of China and its tectonic implications: *Chin. J. Geophys.*, v. 57(1), p. 179-198, <https://doi.org/10.6038/cj920140116> (in Chinese with English abstract).
- Tong, Y.B., Yang, Z., Wang, H., Gao, L., An, C.Z., Zhang, X.D., and Xu, Y.C., 2015, The Cenozoic rotational extrusion of the Chuan Dian Fragment: New paleomagnetic results from Paleogene red-beds on the southeastern edge of the Tibetan Plateau: *Tectonophysics*, v. 658, p. 46-60, <https://doi.org/10.1016/j.tecto.2015.07.007>.
- Wang, C.Y., Chang, L.J., Lu, Z.Y., Qin, J.Z., Su, W., Paul, S., & Lucy, F., 2007, Seismic anisotropy of upper mantle in eastern Tibetan Plateau and related crust-mantle coupling pattern: *Science China-earth Sciences*, v. 50(8), p. 1150-1160, <https://doi.org/10.1007/s11430-007-0053-5>.
- Wang, H., 2016, Paleomagnetic results and their tectonic significance from late Mesozoic to Cenozoic sedimentary strata of the Chuan-Dian Fragment, southeastern margin of the Tibetan Plateau: *Chinese Academy of Geological Sciences* (in Chinese with English abstract).
- Wang, J., Li, J.P., and Wang, J.H., 2003, Shoshonitic magmatism in Dali-Jianchuan area, western Yunnan: A geochemical study of arc magmatism in a post-collisional strike-slip extensional setting: *Acta Petrologica Sinica*, v. 19, p. 61–70 (in Chinese with English abs.).
- Xu, S.M., 2007, Metallogenic modeling of the Beiya gold deposit in western Yunnan and its relation to the Cenozoic alkali-rich porphyries: A dissertation submitted to China University of Geosciences (Beijing) for doctoral degree, p. 1–125 (in Chinese with English abstract).

- Xu, C., Liu, Z.W., Luo, Z.C., Wu, Y.H., Wang, H.H., 2017, Moho topography of the Tibetan Plateau using multi-scale gravity analysis and its tectonic implications: *Journal of Asian Earth Sciences*, v. 138, p. 378–386, <https://doi.org/10.1016/j.jseaes.2017.02.028>.
- Xue, C.J., Zeng, R., Liu, S.W., Chi, G.X., Qing, H.R., Chen, Y.C., Yang, J.M., Wang, D.H., 2007, Geologic, fluid inclusion and isotopic characteristics of the Jinding Zn-Pb deposit, western Yunnan, South China: a review: *Ore Geology Reviews*, v. 31 (1-4), p. 337-359, <https://doi.org/10.1016/j.oregeorev.2005.04.007>.
- Yang, L.Q., Deng, J., Zhao, K., and Liu, J.T., 2011, Tectono-thermochronology and gold mineralization events of orogenic gold deposits in Ailaoshan orogenic belt, Southwest China: Geochronological constraints: *Acta Petrologica Sinica*, v. 27, p. 2519–2532 (in Chinese with English abstract).
- Yalikun, Y., Xue, C.j., and Symons, D.T.A., 2017, Paleomagnetic age and tectonic constraints on the genesis of the giant Jinding Zn-Pb deposit, Yunnan, China: *Mineralium Deposita*, v. 2, p. 245-259, <https://doi.org/10.1007/s00126-017-0733-9>.
- Yang, Z.Y., Sun, Z.M., Ma, X.H., Yin, J. Y., and Otofujii, Y., 2001a, Paleomagnetic study of the Early Tertiary on both Sides of the Red River Fault and its geological implications: *Acta Geologica Sinica-Chinese Edition*, v. 75, p. 35-44, <https://doi.org/10.3321/j.issn:0001-5717.2001.01.004> (in Chinese with English abstract).
- Yang, Z.Y., Yin, J.Y., Sun, Z.M., Otofujii, Y., Sato, K., 2001b. Discrepant Cretaceous paleomagnetic poles between Eastern China and Indochina: a consequence of the extrusion of Indochina: *Tectonophysics*, v. 334, p. 101–113, [http://dx.doi.org/10.1016/S0040-1951\(01\)00061-0](http://dx.doi.org/10.1016/S0040-1951(01)00061-0).
- Yu, C.L., Liu, Q., and Zhong, S.X., 2012, Geological and geochemical characteristics of the Xifanping porphyry deposit, Yanyuan, Sichuan: *Acta Geologica Sichuan*, v. 32 (Suppl), p. 157–164 (in Chinese).
- Zhang, H.F., Tong, Y.B., Wang, H., and Yang, Z.Y., 2012, Early Cretaceous Paleomagnetic results from Simao of Indochina Block and its tectonic

implications: *Acta Geologica Sinica-Chinese Edition*, v. 86 (6), p. 923–939, <https://doi.org/10.3969/j.issn.0001-5717.2012.06.007> (in Chinese with English abstract).

Zhang, L.S., and Schärer, U., 1999, Age and origin of magmatism along the Cenozoic Red River shear belt, China: *Contributions to Mineralogy and Petrology*, v. 134, p. 67-85, <https://doi.10.1007/s004100050469>.

Zhang, Y., Huang, W., Huang, B., Van Hinsbergen, D.J., Yang, T., Dupont-Nivet, G., and Guo, Z., 2018, 53–43 Ma deformation of eastern Tibet revealed by three stages of tectonic rotation in the Gongjue basin: *Journal of Geophysical Research: Solid Earth*, v. 123(5), p. 3320-3338, <https://doi.org/10.1002/2018jb015443>.

Zindler, A., and Hart, S.R., 1986, Chemical geodynamics: *Annual Review of Earth and Planetary Sciences*, v. 14, p. 493–571, <https://doi.org/10.1016/j.actaastro.1996.10.015>.

Fig. S1 The Moho depth in km across eastern margin of Tibet and its adjacent region. As shown in Fig. DR1, the crustal thickness in northern segment ranges from 60 to 63 km. In the central to southern segment, the thickness is only from 47 to 50 km, thinner than that in the northern segment.

Fig. S2 Variation of (A) Sr/Y vs Y (B) La/Yb vs Yb , showing the results of batch-melting modeling. Variation of (C) $(^{87}Sr/^{86}Sr)_i$ vs. $\epsilon_{Nd}(t)$ for the felsic intrusions at Yulong and Beiya ore cluster. The four curves in the A and B represent melting leaving a restite of amphibole eclogite and 5% garnet amphibolite, respectively, based on a shoshonitic amphibolite xenolith from Liuhe, western Yunnan, as the starting composition (LH14b, Wang et al., 2003). The melt percentage is shown next to the melting curves. Dotted field is of Paleogene mafic volcanic rocks in western Yunnan (Huang et al., 2010). Fields of adakite and normal andesite-dacite-rhyolite are after Richards and Kerrich (2007). Batch-melting modeling calculations follow Haschke et al. (2002, 2010). Literature data plotted for comparison include western Yunnan potassic mafic rocks (Guo et al. 2005; Huang et al. (2010), leucogranite within AilaoShan-Red River shear zone in western Yunnan

(Zhang and Schärer, 1999), and amphibolites xenoliths hosted by Eocene potassic felsic intrusions in western Yunnan (Deng et al., 1998; Zhao et al., 2004). Mantle source reservoirs BSE, MORB, DMM, EM I, and EM II are from Zindler and Hart (1986). Indian MORB and Pacific MORB are after Guo et al. 2015.