**Supplementary material A**

**Chalcophile elements in post-subduction magmas and implications for long-term metal recycling in oceanic and continental subduction**

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**1. Tectonic background of Mesozoic to Cenozoic magmas in the North China Craton (NCC)**

Followed by Paleo-Tethyan oceanic subduction (Fig. 1), the Early Triassic mafic magmas formed in the Liaodong Peninsula (250 - 240 Ma, stage 1). They display low MgO and high total FeO (FeOt) contents (Fig. 2b), generally with ocean-island-basalt (OIB)-like trace element patterns (e.g., Ba/Nb: 10-20; Fig. S1) and slightly enriched Nd isotopes (e.g., εNd(i): -1 to -4; Fig. 1). Combined with their zircon Hf-O isotopes, these geochemical features were interpreted to reflect a metasomatized mantle source with involvement of hydrous melts from the altered oceanic crust and terrigenous sediments (Fang et al., 2019).

The Yangtze continental crust was subducted northward beneath the NCC in the Triassic, resulting in the Qinling-Tongbai-Hongan-Dabie and Sulu collisional orogenic belt (Fig. 1; e.g., Ernst et al., 2007; Zheng et al., 2013). Following this, the SCLM beneath the NCC was further metasomatized by silicic melts or supercritical fluids from the subducted Yangtze continental crust and overlying sediments (e.g., Dai et al., 2011; Jin et al., 2023). The post-collisional mafic rocks (219-200 Ma, stage 2) in the eastern NCC display high MgO and low FeOt contents (Fig. 2b), arc-like trace element patterns with very high Ba/Nb ratios (e.g., 100-500; Fig. S1), variably enriched Nd isotopes (e.g., εNd(i): -15 to -7) and O isotopes (Fig. 1; e.g., Fang et al., 2020a; Yang et al., 2007; Zhao et al., 2012). The increase of Nd isotopes in the mafic magmas from the southeastern to the northeastern NCC has been interpreted to reflect the waning effects of subducted Yangtze continental crust from the south to the north (e.g., Wang et al., 2020a; Yang et al., 2012a).

In the Jurassic, the subduction of the Paleo-Pacific oceanic plate further hydrated the mantle beneath the NCC through slab-derived fluids and hydrous melts, and the Jurassic (158-155 Ma, stage 3) to Early Cretaceous magmas (130-120 Ma, stage 4) formed episodically during the continuous subduction and retreat of subducted Paleo-Pacific plate (e.g., Fang et al., 2020b; Jiang et al., 2010; Wang et al., 2020a). These magmas also display similar geochemical features to Late Triassic magmas (219-200 Ma, stage 2) including high MgO and low FeOt contents (Fig. 2b), arc-like trace element patterns and enriched radiogenic isotopes (e.g., εNd(t): -2 to -20) and O isotopes (Fig. 1; e.g., Hong et al., 2020; Wang et al., 2020a; Zheng et al., 2018). This is significantly different from the characteristics of the Early Triassic magmas (250 - 240 Ma, stage 1). Consequently, the mantle sources of stage 4 magmas were interpreted to have strong imprints of both Yangtze continental subduction and Paleo-Pacific plate subduction (e.g., Wang et al., 2020a; Zheng et al., 2018).

After cratonic destruction at ~120 Ma, the ancient SCLM has been replaced by newly accreted juvenile SCLM, which has mainly been affected by aqueous fluids from the subducted Paleo-Pacific plate (e.g., Dai et al., 2016; Liu et al., 2019; Wu et al., 2019; Zheng et al., 2018). The Late Cretaceous to Cenozoic mafic magmas (<120 Ma, stage 5) generally display OIB-like trace element patterns (Fig. S1) and slightly enriched to depleted radiogenic isotopic compositions (e.g., εNd(t): -1 to 7) (Fig. 1; e.g., Cai et al., 2013; Dai et al., 2016; Zheng et al., 2018), similar to those of stage 1 magmas.

In this study, the Early Triassic (250-240 Ma, stage 1), Late Triassic (219-200 Ma, stage 2), and Late Jurassic rocks (158-155 Ma, stage 3) were taken from the Dalian and Huaziyu districts in the Northeastern part of NCC (Fig. 1). They are dikes with several metres to a hundred metres in width and up to several kilometres in length, intruding into the Precambrian basement rocks. Dike centres were sampled; they are petrographically fresh in the field with no visible veins or hydrothermal mineral assemblages. This indicates that they did not experience secondary overprinting by hydrothermal fluids (Fang et al., 2020a; Fang et al., 2019; Fang et al., 2020b). These samples contained sulfides including chalcopyrite, pyrrhotite, and pyrite (Fig. S2). Most of these sulfides were in irregular shape and located interstitially (Figs. S2a, b, c), and small amounts of sulfide inclusions formed within clinopyroxene or amphibole phenocrysts (Figs. S2e, f, g). Several silicate minerals can also be observed as inclusions in the sulfides, indicating that sulfide saturation mainly occurred at a late stage during magma cooling (Fig. S2c). The petrology, assemblage, and distribution of sulfides are similar to those observed in the Early Cretaceous and Late Cretaceous magmas and indicate a magmatic origin (e.g., Wang et al., 2022; Wang et al., 2024).

**2. Analytical methods**

**2.1 Whole-rock chalcophile element contents and Os isotopes**

The whole-rock PGE, Au, and Re contents were measured by high-sensitivity sector-field inductively coupled plasma mass spectrometry (Thermo Scientific® Element XR) and Thermo Triton Plus N-TIMS at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan (GPMR-CUG). A well-established, high-precision isotope dilution method was conducted on these samples (e.g., Cheng et al., 2019; Zou et al., 2020). Since most of these chalcophile elements are hosted by sulfides, a mixture of about 2 grams of sample powder and quantitative amounts of mixed spike solutions (190Os, 191Ir-99Ru-194Pt-105Pd-85Re) were digested by reverse aqua regia (5 ml of 14 mol/L HNO3 and 2.5 ml of 9 mol/L HCl) in a pre-cleaned Carius tube at 230 - 240 ℃ for 3 - 4 days. Osmium was first extracted from the aqua regia and transferred into a CCl4 solvent. This was followed by back-extraction into HBr solution and subsequent purification via microdistillation. The purified Os fraction was then loaded onto a platinum filament using HBr, with a Ba(OH)2 activator added. The Os was measured as on a Thermo Triton Plus N-TIMS using the SEM in a peak-jumping mode. Osmium isotope compositions were corrected for mass-dependent isotope fractionation and oxygen isotope interferences. About 0.1 ng Os loads of the Johnson-Matthey UMD and DROsS standards were measured along with the samples.

Analyses of 187Os/188Os yielded mean values of 0.11384 ± 0.00027 (n = 3) for UMD and 0.16085 ± 0.00038 (n = 3) for DROsS, which are both in the range of reference values (Luguet et al., 2008). The total procedural blank of Os was 1 - 2 pg with 187Os/188Os of about 0.16, which was negligible for all analyzed samples in this study (< 1%). The residual PGEs, Au, and Re were further purified and concentrated by cation exchange resin (AG50W-X8). The Ir, Pt, and Re contents were determined by isotope dilution methods, and Au by internal standardization of Au intensity to Pt. The remaining solutions were further purified on 2 ml Eichrom AG1-X8 (100 - 200 mesh) anion resin to remove the matrix and interferences to determine Ru and Pd contents (Cheng et al., 2019; Zou et al., 2020). The total procedural blanks were 3 ± 3 pg for Au (1s), 5 ± 3 pg for Pt, 0.4 ± 0.6 pg for Ir, 2 ± 1 pg for Re, 19 ± 11 pg for Ru, and 13 ± 9 pg for Pd. Sample replicates and geological reference standards BHV0-2, OKUM, and TDB-1 were measured along with samples (Table S1).

**2.2 Whole-rock S contents**

The S contents of samples were measured with a high-frequency carbon-sulfur analyzer. Approximately 0.1 g of the sample was weighed and combusted in an oxygen atmosphere by an induction furnace. The S contents were determined three times by the infra-red detector and yielded analytical uncertainties of ± 5% of reported values with a background of ~10 μg/g (Table S1).

**2.3 Major element analyses of sulfides**

The major element content of sulfides was obtained with a JEOL JXA-8230 electron microprobe analyzer (EPMA) at GPMR-CUG. Before acquiring the element contents, an optical microscope and BSE images were taken of each sulfide grain to assess alteration and assist in selecting sampling points (Fig. S2). Sulfides were analyzed using a 15 kV acceleration voltage and a 20 nA focused beam typically at 1 μm (spot analysis mode). The standards were pyrites, chalcopyrite and pentlandite. The EPMA data confirm that sulfides in these samples are pyrrhotite, chalcopyrite, and pyrite in composition (Table S3 and Fig. S4), which is consistent with the features observed under the microscope (Fig. S2).

**2.4 In-situ S isotopes of sulfides**

Large sulfide grains (> 30 μm) were chosen for in-situ sulfur isotope analysis via a 257 nm Yb femtosecond (fs) laser ablation system (NWR-FemtoUC, USA) coupled to a Neptune Plus multiple-collector inductively coupled plasma mass spectrometer (MC-ICP-MS, Thermo Fisher Scientific, Germany) at the GPMR-CUG. The sulfides were analyzed with a laser spot size of 32 μm, a pulse frequency of 4 Hz, and a laser fluence of ~2.5 J/cm2. The standard-sample bracketing method (SSB) was used to correct instrumental drift and mass bias, and the matrix effect of S isotope analysis during the sulfide ablation process can be avoided by using the femtosecond laser ablation system (Fu et al., 2017). We used ISO-Compass software for data reduction in LA-MC-ICP-MS analysis (Zhang et al., 2020). The S isotopes are expressed as δ34SV-CDT (‰), where V-CDT refers to the Vienna Canon Diablo Troilite (Ding et al., 2001). The pyrite standard PPP-1 (δ34SV-CDT = 5.3 ± 0.2 ‰) was taken as an external standard to correct the instrumental mass fractionation (IMF) of S isotope for sulfide minerals (Gilbert et al., 2014), and the pyrrhotite reference YP136 (1.50 ± 0.30) was analyzed repeatedly as an unknown using the same conditions for studied samples to monitor data quality (Li et al., 2019). The determined values for reference PPP-1 and YP136 were 5.27 ± 0.22 ‰ and 1.51 ± 0.21 ‰, respectively, which match the ranges of reference values (Table S4). The long-term external uncertainty for δ34SV-CDT is about 0.2 - 0.3 ‰. These results guarantee the reliability of the data obtained in this study.

**3. Modelling of sulfur (S) isotope fractionation during magmatic degassing and sulfide segregation**

Magmatic degassing and sulfide crystallization affect the δ34S of S dissolved in silicate melt. The extent of S degassing and sulfide segregation is primarily controlled by pressure, temperature, bulk composition, and oxygen fugacity (*f*O2), while the redox conditions which control the ratio of reduced (H2S) to oxidized S (SO2) govern the magnitude and sign of δ34S fractionation (Beaudry et al., 2018; Marini et al., 2011). For example, at reduced conditions, S exhibits low valence (S2-) in both sulfur-bearing phases and silicate melts, and the isotopic fractionation between them is very small (< 0.5 ‰) at 1150 ℃. However, under oxidized conditions with *f*O2 at ΔFMQ + 1.5 (FMQ: fayalite-magnetite-quartz buffer), where significant amounts of oxidized S species (SO42-) are present, segregated sulfides would have δ34S of 2 - 3 ‰ lower than the silicate melts (Marini et al., 2011).

Modelling of magmatic degassing at *f*O2 of ΔFMQ +0.5, +1, +1.3, and +1.5 have been conducted to explore a range of redox values that may encompass the full range for these samples. The range of *f*O2 is a reasonable assumption because metasomatized SCLM beneath the NCC in the Early Cretaceous was relatively oxidized with calculated *f*O2 from ΔFMQ +1 to +1.5 (Hong et al., 2020), which may represent the maximum ranges for the Triassic to Jurassic rocks. The models of Beaudry et al. (2018) and Marini et al. (2011) have been used to predict S isotope fractionation during magmatic degassing at hydrous and relatively oxidized magmatic systems (open-system process). A temperature of 1150 ℃ and a starting pressure of 300 MPa are assumed for the calculation in this study, which is appropriate for magmatic degassing under relatively hydrous and oxidized conditions (Beaudry et al., 2018). The sulfate fraction in total ionic S was calculated using the model of Jugo et al. (2010), while the SO2 fraction of total S in the gas phase was calculated by models of Burgisser et al. (2015) and Marini et al. (1998). The gas-melt equilibrium S isotope fractionation factor αgas-melts is thus calculated as 1.0029, 1.0012, 0.9996, and 0.9989 for *f*O2 ranging from ΔFMQ +0.5 to +1.5, respectively, using an empirical model of Marini et al. (2011) and fractionation factors of Fiege et al. (2015).

S isotope fractionation during sulfide (FeS) segregation has been conducted using the model from Marini et al. (2011). The parameters such as temperatures (1150 ℃), *f*O2, and S speciation in melts are consistent with the values discussed above. The calculated fractionation factor of S isotopes between the sulfide phase and silicate melt (αFeS-melts) is calculated as 1.0002, 0.9989, 0.9977, and 0.9972 for *f*O2 ranging from ΔFMQ + 0.5 to + 1.5, respectively. We also assume that all calculations have a total S isotope value (δ34S∑S) of 0 ‰ that may represent the δ34S values of mantle-derived magmas and conduct modelling in open systems to see the maximum values of S isotope fractionation in this process.

The divergent paths in the modelling of S degassing are primarily determined by *f*O2, transitioning from a system dominated by S2- (H2S) where αgas-melt > 1, to one dominated by S6+ (SO42-) where αgas-melt < 1 (Jugo et al., 2010). At *f*O2 of ΔFMQ +0.5 to +1, the S isotopes of the residual melt gradually decrease and can change by 5 ‰ after degassing of 80 % S. By comparison, at *f*O2 of ΔFMQ +1.3 to +1.5, the S isotopes of melts increase by 2 ‰ after degassing of 80 % S.

For sulfide segregation modelling, at low *f*O2 of ΔFMQ equal to +0.5, segregated sulfide (FeS) shows a slightly higher δ34S value than silicate melt and vice verse at *f*O2 of ≥ ΔFMQ +1. In particular, at *f*O2 of ΔFMQ + 0.5 to +1, there is only < 1 ‰ fractionation between segregated sulfides and silicate melt. In addition, the results also show that the silicate melts need to lose 60% of its total S before δ34S in melt changes by more than 1 ‰ at ΔFMQ + 1.

**4. Modelling of Cu and Au contents in post-subduction/collisional magmas during magmatic evolution**

Magmatic evolution could influence the chalcophile element contents of magmas (Jenner et al., 2010; Park et al., 2015), hence it is important to constrain the metal contents of primitive magmas. Since stage 4 magmas show the largest variations of Cu and Au contents that cover the ranges of other episodes of magmas, here we attempt to constrain the metal contents of their parental magmas. This may provide a possible range for parental magmas of all post-subduction/collisional magmas, though they may have different evolution pathways.

The magma evolution series (MgO: 15 to 3 wt.%) calculated using the software Rhyolite-MELTS (Gualda et al., 2012) were taken from (Wang et al., 2022), with similar major element contents and evolution trend to the natural stage 4 magmas. Using the continuous fractional crystallization model of Chen et al. (2020), here we modelled the Cu and Au contents of post-subduction/collisional magmas during magmatic evolution. The fractionated phases were divided into two groups: sulfides and non-sulfide minerals. Initial S contents of 1000, 1500, and 2000 μg/g, Cu contents of 20, 40, and 60 μg/g, and Au contents of 0.5, 1, 2, 3 ng/g were assumed for the modelled melts. The partition coefficient for Cu and Au between sulfide liquid (SL) and silicate melts (SM) of ~1000 and ~2000 were assumed, respectively (Chen et al., 2020; Li et al., 2019). The *DCu* of 0.05 and *DAu* of 0 are set for all non-sulfide minerals (Chen et al., 2020). Since Cu and Au are strongly chalcophile and incompatible in non-sulfide minerals, they are retained in the residual melt when no sulfide is segregated. Once sulfide reaches saturation and segregation, these metals partition strongly into fractionated sulfide phases, leading to the dramatic decrease of metal contents in residual melts. Most studied post-subduction/collisional magmas experienced insignificant sulfide saturation and segregation during magmatic evolution, which should follow the sulfide undersaturation evolution trend shown in Fig. 2. In contrast, the low Cu and Au contents of several evolved magmas may have resulted from the late-stage sulfide saturation. Thus, the Cu and Au contents of parental melts of these post-subduction/collisional magmas likely range from 20-60 μg/g and 0.5-3 ng/g, respectively.

**5. Source of reference data for figures**

**Fig. 1:** Data source: age and Nd isotopes of Mesozoic mafic magmas in the NCC (Fang et al., 2020a; Fang et al., 2019; Fang et al., 2020b; Jiang et al., 2010; Wang et al., 2020a; Xu et al., 2016; Zhao et al., 2012 and references therein), oxygen isotopes of olivine, clinopyroxene and magmatic zircons from Mesozoic mafic magmas in the NCC (Chen et al., 2017; Fan et al., 2017; Fang et al., 2020a; Fang et al., 2019; Guo et al., 2013; Hong et al., 2020; Liu et al., 2015; Wang et al., 2015; Wang et al., 2020a; Yang et al., 2012b, c; Zhang et al., 2012; Zhao et al., 2012 and references therein).

**Fig. 2:** Data source: MORB (Hao et al., 2021; Jenner and O'Neill, 2012; Lissner et al., 2014; Rehkämper et al., 1999), arc magmas (Jenner et al., 2010; Park et al., 2013; Park et al., 2015), part of stage 2 magmas (Xu et al., 2016; Zhao et al., 2012) and stage 3 magmas (Jiang et al., 2010), stage 4 and 5 magmas (Wang et al., 2020a; Wang et al., 2022; Wang et al., 2020b and references therein), global mantle peridotites (Saunders et al., 2018) and ranges for primitive mantle (McDonough and Sun, 1995).

**Fig. 3:** Data source: stage 4 magmas (Wang et al., 2022), Sr-Nd isotopes of Mesozoic magmas (Fang et al., 2020a; Fang et al., 2019; Fang et al., 2020b; Jiang et al., 2010; Wang et al., 2020a; Xu et al., 2016; Zhao et al., 2012 and references therein), the representative range of MORB (Wang and Becker, 2015 and references therein).

**Fig. 4:** Data source: the δ34S values of MORB and depleted mantle (Labidi and Cartigny, 2016; Labidi et al., 2012; Labidi et al., 2014). The δ34S values of stage 4 and 5 magmas (Wang et al., 2024).

**Fig. 5:** Data source: Sr-Nd isotopes of Mesozoic mafic magmas in the NCC (Fang et al., 2020a; Fang et al., 2019; Fang et al., 2020b; Jiang et al., 2010; Wang et al., 2020a; Xu et al., 2016; Zhao et al., 2012 and references therein), ranges of Sr-Nd isotopes for MORB and OIB (Wang et al., 2020a), S isotopes of stage 4 and 5 magmas (Wang et al., 2024), the median δ34S and Ba/Nb values of MORBs plotted as a diamond symbol (Jenner and O'Neill, 2012; Labidi et al., 2012), the Os isotopes of stage 4 magmas (Deng et al., 2023), stage 5 magmas (Cai et al., 2021), ranges of Os isotopes for MORB and primitive upper mantle (PUM) (Escrig et al., 2005; Gannoun et al., 2007).

**Fig. 6:** Data source: stage 4 and 5 magmas (Cai et al., 2021; Deng et al., 2023; Wang et al., 2022; Wang et al., 2020b), interstitial and enclosed sulfides in peridotites (Alard et al., 2000; Alard et al., 2011; Rielli et al., 2018), metasomatized peridotites (Alard et al., 2011; Kepezhinskas et al., 2002; McInnes et al., 1999; Wang et al., 2020b), ranges for MORB (Dale et al., 2008; Lissner et al., 2014; Rehkämper et al., 1999), primitive mantle (McDonough and Sun, 1995).

**Fig. 7:** Data source: stage 4 and 5 magmas (Wang et al., 2022; Wang et al., 2020b), ranges for MORB (Hao et al., 2021; Hertogen et al., 1980; Jenner and O'Neill, 2012; Mungall and Brenan, 2014).

**Fig. 8:** Data source: age distribution of Mesozoic mafic magmas (Dai et al., 2016; Wang et al., 2020a; Yang et al., 2021; Zheng et al., 2018; Zhu et al., 2012 and references therein), stage 4 and 5 magmas (Wang et al., 2022; Wang et al., 2020b), MORB and arc magma (Jenner et al., 2015; Jenner and O'Neill, 2012; Park et al., 2013; Park et al., 2015).

**6. Figure captions for Fig S1-7**

**Fig. S1: Primitive mantle-normalized trace element patterns for Mesozoic mafic magmas in the eastern NCC.** Stage 1 and 5 magmas display OIB-like trace element patterns with slightly elevated Ba/Nb ratios (10 - 20). In contrast, stage 2, 3, and 4 magmas display arc-like trace element patterns with much higher Ba/Nb ratios (100 - 500). Data sources: trace element contents and radiogenic Sr-Nd isotopes of Mesozoic mafic magmas in the NCC (Fang et al., 2020a; Fang et al., 2019; Fang et al., 2020b; Jiang et al., 2010; Wang et al., 2020a; Xu et al., 2016; Zhao et al., 2012 and references therein).

**Fig. S2: Photomicrographs of sulfides in the Early Triassic to Late Jurassic mafic rocks in the eastern NCC.** (a, b, c) The sulfides in these rocks are chalcopyrite, pyrrhotite, and pyrite, and most of them formed interstitially to phenocrysts such as clinopyroxene and amphibole. Several silicate minerals can be observed as inclusion in large grains of pyrite. This indicates that most sulfides crystallized at the late stage of magmatic evolution. (d, e, f) Very few sulfide inclusions can be observed in amphibole and clinopyroxene phenocrysts. Amp - amphibole, Cpx - clinopyroxene, Bt - biotite, Cpy - chalcopyrite, Po - pyrrhotite, Py – pyrite, Mgt – magnetite.

**Fig. S3: PGE, Au, Cu, and S contents of Mesozoic magmas in the eastern NCC.** The PGE in Mesozoic magmas correlates positively with each other. Their Au shows broadly positive correlation with Cu and S, and those samples with high Au but low S contents may reflect the Au enrichment in the mantle source (Wang et al., 2022). Data source is the same as Fig. 2.

**Fig. S4: The major composition of sulfides.** Sulfides in mafic rocks from the eastern NCC are chalcopyrites, pyrrhotites, and pyrites. Combined with their distribution and shapes, this indicates the magmatic origins of these sulfides. The sulfide phase diagram at 1100℃ is modified from Kullerud et al. (1969), and typical magmatic sulfides are presented for comparison (Brandl et al., 2022; Mandon et al., 2021).

**Fig. S5: Effects of magmatic and surface processes on δ34S variation of Mesozoic magmas in the NCC.** (a) Modelling of S isotope fractionation during magmatic degassing. The total S isotope value (δ34S∑S) of primary melts is assumed to be at 0 ‰ and oxygen fugacity (*f*O2) of ΔFMQ +0.5, +1, +1.3 and +1.5 are set for calculation in open-system processes, with a temperature of 1150 ℃ and pressure of 300 MPa, following the empirical equations provided by Marini et al. (2011) and Beaudry et al. (2018). The gas-melt equilibrium S isotope fractionation factor αgas-melts is calculated as 1.0029, 1.0012, 0.9996, and 0.9989 for *f*O2 ranging from ΔFMQ +0.5 to +1.5, respectively, using the empirical model of Marini et al. (2011) and fractionation factors from Fiege et al. (2015). The divergence in paths is primarily determined by *f*O2, transitioning from a system dominated by S2- (H2S) where αgas-melt > 1, to one dominated by S6+ (SO42-) where αgas-melt < 1 (Jugo et al., 2010). (b) Whole-rock S contents and sulfide δ34S in Mesozoic magmas. The δ34S values of these magmas are calculated from the mean δ34S values of sulfide (filled circles and rectangles). Despite the large range of S contents in Mesozoic magmas, the sulfide δ34S in each episode of magmas shows narrow ranges, regardless of sulfide type and sulfide distribution. Data source: degassed alkaline magmas (Beaudry et al., 2018), stage 4 and 5 magmas (Wang et al., 2024). (c) Modelling of S isotope fractionation between silicate melts and segregated sulfides. The equations are from Marini et al. (2011) and the same parameters of temperatures, *f*O2, and S speciation in melts as detailed above are used. The computed fractionation factors αFeS-melts range from 0.9972 to 1.0002. Under slightly oxidized conditions (*f*O2 of ΔFMQ + 0.5), the S isotope fractionation between segregated sulfides and silicate melts is limited (0.2 ‰). However, under highly oxidized conditions (*f*O2 > ΔFMQ + 1), the segregated sulfides have lower δ34S values than silicate melts, with S isotope fractionation increasing with *f*O2, from 1.1 ‰ (ΔFMQ + 1) to 2.8 ‰ (ΔFMQ + 1.5). As a result, the δ34S of remaining melts increases with sulfide segregation. (d) Binary mixing model of crustal contamination during melt ascent. The lines show end-member mixing between primitive mantle melts (with δ34S = -1 ‰ and S contents of 1000 and 4500 μg/g) and granitoids (with average δ34S = 7.4 ‰ and S contents of 30 μg/g), Precambrian basement rocks (with average δ34S = 13 ‰ and S contents of 402 μg/g) (Deng et al., 2020; Wang et al., 2021; Xu et al., 2022; Zhao et al., 2022). The high S isotopes of these samples cannot be acquired by mixing between assumed initial mantle-derived magmas and regional granitoids, and it requires very high degrees of crustal contamination by basement rocks (20% - 90%) to account for their high δ34S values. These ratios are unlikely and cannot explain the high S, MgO, Cr, and Ni contents of most samples.

**Fig. S6: 187Os/188Os, δ34S, and Ba/Nb ratios of stage 1-3 magmas.** Samples with low Os, δ34S, and Ba/Nb values display high 187Os/188Os values, indicating their radiogenic Os were irrelated to subduction addition. These extremely high 187Os/188Os values may not be indicative of mantle source but reflect the crustal contamination or Re-Os disequilibrium.

**Fig. S7: Primitive mantle normalized PGE, Au, Cu, S, and Re contents for global mantle peridotites, pyroxenites, and sulfides.** (a) The fertile lherzolites generally show chalcophile metal patterns akin to the primitive mantle. After high degrees of mantle melting, mantle residues are highly depleted in Pt, Pd, Au, Cu, S, and Re (e.g., harzburgites). However, even after strong metasomatism related to subduction, the mantle peridotites in the NCC and Lihir island still display relatively low contents of chalcophile metals (mostly lower than fertile peridotites). (b) The mantle metasomatism by pyroxenite melts or oxidized fluids may replenish chalcophile metals into the depleted mantle, and global metasomatized peridotites thus exhibit transitional chalcophile metal patterns between depleted harzburgites and fertile lherzolites. Some orogenic peridotites with native Au nanoparticles could have high Au contents (> 10 ng/g), suggesting heterogeneous precipitation from volatile-rich melts, yet most samples do not show such enrichments (e.g., Lorand et al., 2021; Saunders et al., 2018). Comparably, mantle pyroxenites, which generally crystalize from mafic melts and commonly act as metasomatic agents in the upper mantle, show variably higher Pt, Pd, Au, Cu, and S, Re contents (e.g., Holwell et al., 2019; McInnes et al., 1999; Wang and Becker, 2015). Although mantle metasomatism by pyroxenite melts or volatile-rich melts may replenish sulfides and metals into the SCLM, these mediums only take up 5 - 10 % of shallow SCLM (Downes, 2007) and show contents of chalcophile metals that are similar to or slightly higher than the primitive mantle. (c) The enclosed sulfides in peridotites generally reflect the mantle residue upon partial melting, displaying high IPGE but lower PPGE, Au, Cu, and Re contents. In contrast, the interstitial sulfides with metasomatic origins display low IPGE (Os, Ir, Ru) but higher PPGE (Pt, Pd), Au, Cu, and Re contents, which are similar to those of pyroxenites-hosted sulfides. Notably, the absolute contents of chalcophile metals in metasomatic sulfides and pyroxenite-hosted sulfides are still lower than, or indistinguishable from enclosed sulfides (e.g., Alard et al., 2011; Saunders et al., 2016; Tassara et al., 2018). This explains why the metasomatic sulfides or metasomatized peridotites have high Os/Ir, Ru/Ir, and Pd/Ir ratios but their whole-rock chalcophile metal contents are still similar to or lower than the asthenospheric mantle. Consequently, mantle metasomatism related to subduction is difficult to result in large-scale enrichment of strongly chalcophile metals in the SCLM. Data sources: Fertile lherzolites, depleted harzburgites, and mantle pyroxenites (Fischer-Gödde et al., 2011; Wang and Becker, 2015), metasomatized peridotites (Alard et al., 2011; Holwell et al., 2019; Lorand et al., 2021; Maier et al., 2012; McInnes et al., 1999; Saunders et al., 2018; Wang et al., 2020b), enclosed sulfides and pyroxenites-hosted sulfides (Alard et al., 2011; Saunders et al., 2016), interstitial sulfides in metasomatized peridotites (Alard et al., 2011; Aulbach et al., 2021; Rielli et al., 2018; Tassara et al., 2018). Primitive mantle normalization values are from McDonough and Sun (1995) and Becker et al. (2006).

**References:**

1. Alard, O., Griffin, W.L., Lorand, J.P., Jackson, S.E., O'Reilly, S.Y., 2000. Non-chondritic distribution of the highly siderophile elements in mantle sulphides. Nature 407, 891-894.
2. Alard, O., Lorand, J.-P., Reisberg, L., Bodinier, J.-L., Dautria, J.-M., O'Reilly, S.Y., 2011. Volatile-rich Metasomatism in Montferrier Xenoliths (Southern France): Implications for the Abundances of Chalcophile and Highly Siderophile Elements in the Subcontinental Mantle. J. Petrol. 52, 2009-2045.
3. Aulbach, S., Giuliani, A., Fiorentini, M.L., Baumgartner, R.J., Savard, D., Kamenetsky, V.S., Caruso, S., Danyushevky, L.V., Powell, W., Griffin, W.L., 2021. Siderophile and chalcophile elements in spinels, sulphides and native Ni in strongly metasomatised xenoliths from the Bultfontein kimberlite (South Africa). Lithos 380-381, 105880.
4. Beaudry, P., Longpré, M.-A., Economos, R., Wing, B.A., Bui, T.H., Stix, J., 2018. Degassing-induced fractionation of multiple sulphur isotopes unveils post-Archaean recycled oceanic crust signal in hotspot lava. Nat. Commun. 9, 5093.
5. Becker, H., Horan, M.F., Walker, R.J., Gao, S., Lorand, J.P., Rudnick, R.L., 2006. Highly siderophile element composition of the Earth's primitive upper mantle: Constraints from new data on peridotite massifs and xenoliths. Geochim. Cosmochim. Acta 70, 4528-4550.
6. Brandl, P.A., Portnyagin, M., Zeppenfeld, H., Tepley, F.J., III, de Ronde, C.E.J., Timm, C., Hauff, F., Garbe-Schönberg, D., Bousquet, R., 2022. The Origin of Magmas and Metals at the Submarine Brothers Volcano, Kermadec Arc, New Zealand. Econ. Geol. 10.5382/econgeo.4973.
7. Burgisser, A., Alletti, M., Scaillet, B., 2015. Simulating the behavior of volatiles belonging to the C–O–H–S system in silicate melts under magmatic conditions with the software D-Compress. Computers & Geosciences 79, 1-14.
8. Cai, R., Liu, J., Pearson, D.G., Li, D., Xu, Y., Liu, S.-A., Chu, Z., Chen, L.-H., Li, S., 2021. Oxidation of the deep big mantle wedge by recycled carbonates: Constraints from highly siderophile elements and osmium isotopes. Geochim. Cosmochim. Acta 295, 207-223.
9. Cai, Y.-C., Fan, H.-R., Santosh, M., Liu, X., Hu, F.-F., Yang, K.-F., Lan, T.-G., Yang, Y.-H., Liu, Y., 2013. Evolution of the lithospheric mantle beneath the southeastern North China Craton: Constraints from mafic dikes in the Jiaobei terrain. Gondwana. Res. 24, 601-621.
10. Chen, H., Xia, Q.-K., Ingrin, J., Deloule, E., Bi, Y., 2017. Heterogeneous source components of intraplate basalts from NE China induced by the ongoing Pacific slab subduction. Earth. Planet. Sci. Lett. 459, 208-220.
11. Cheng, H., Wang, Z., Chen, K., Zong, K., Zou, Z., He, T., Hu, Z., Fischer-Gödde, M., Liu, Y., 2019. High-precision Determination of Gold Mass Fractions in Geological Reference Materials by Internal Standardisation. Geostand. Geoanal. Res. 43, 663-680.
12. Dai, L.-Q., Zhao, Z.-F., Zheng, Y.-F., Li, Q., Yang, Y., Dai, M., 2011. Zircon Hf–O isotope evidence for crust–mantle interaction during continental deep subduction. Earth. Planet. Sci. Lett. 308, 229-244.
13. Dai, L.-Q., Zheng, Y.-F., Zhao, Z.-F., 2016. Termination time of peak decratonization in North China: Geochemical evidence from mafic igneous rocks. Lithos 240-243, 327-336.
14. Dale, C.W., Luguet, A., Macpherson, C.G., Pearson, D.G., Hickey-Vargas, R., 2008. Extreme platinum-group element fractionation and variable Os isotope compositions in Philippine Sea Plate basalts: Tracing mantle source heterogeneity. Chem. Geol. 248, 213-238.
15. Deng, J., Wang, Q., Zhang, L., Xue, S., Liu, X., Yang, L., Yang, L., Qiu, K., Liang, Y., 2023. Metallogenetic model of Jiaodong-type gold deposits, eastern China. Sci. China Earth Sci. 66, 2287-2310.
16. Deng, J., Yang, L.-Q., Groves, D.I., Zhang, L., Qiu, K.-F., Wang, Q.-F., 2020. An integrated mineral system model for the gold deposits of the giant Jiaodong province, eastern China. Earth. Sci. Rev. 208, 103274.
17. Ding, T., Valkiers, S., Kipphardt, H., De Bièvre, P., Taylor, P.D.P., Gonfiantini, R., Krouse, R., 2001. Calibrated sulfur isotope abundance ratios of three IAEA sulfur isotope reference materials and V-CDT with a reassessment of the atomic weight of sulfur. Geochim. Cosmochim. Acta 65, 2433-2437.
18. Downes, H., 2007. Origin and significance of spinel and garnet pyroxenites in the shallow lithospheric mantle: Ultramafic massifs in orogenic belts in Western Europe and NW Africa. Lithos 99, 1-24.
19. Ernst, W.G., Tsujimori, T., Zhang, R., Liou, J.G., 2007. Permo-Triassic Collision, Subduction-Zone Metamorphism, and Tectonic Exhumation Along the East Asian Continental Margin. Annu. Rev. Earth Planet. Sci. 35, 73-110.
20. Escrig, S., Schiano, P., Schilling, J.-G., Allègre, C., 2005. Rhenium–osmium isotope systematics in MORB from the Southern Mid-Atlantic Ridge (40°–50° S). Earth. Planet. Sci. Lett. 235, 528-548.
21. Fan, W., Jiang, N., Xu, X., Hu, J., Zong, K., 2017. Petrogenesis of the middle Jurassic appinite and coeval granitoids in the Eastern Hebei area of North China Craton. Lithos 278-281, 331-346.
22. Fang, W., Dai, L.-Q., Zheng, Y.-F., Zhao, Z.-F., Chen, Q., Zhou, Y., 2020a. Syn-exhumation magmatism in an active continental margin above a continental subduction zone: Evidence from Late Triassic mafic igneous rocks in the southeastern North China Block. GSA Bulletin 133, 1267–1282.
23. Fang, W., Dai, L.-Q., Zheng, Y.-F., Zhao, Z.-F., Ma, L.-T., 2019. Tectonic transition from oceanic subduction to continental collision: New geochemical evidence from Early-Middle Triassic mafic igneous rocks in southern Liaodong Peninsula, east-central China. GSA Bulletin 132, 1469-1488.
24. Fang, W., Dai, L.-Q., Zheng, Y.-F., Zhao, Z.-F., Ma, L.-T., Zhao, K., 2020b. Identification of Jurassic mafic arc magmatism in the eastern North China Craton: Geochemical evidence for westward subduction of the Paleo-Pacific slab. GSA Bulletin 133, 1404-1420.
25. Fiege, A., Holtz, F., Behrens, H., Mandeville, C.W., Shimizu, N., Crede, L.S., Göttlicher, J., 2015. Experimental investigation of the S and S-isotope distribution between H2O–S±Cl fluids and basaltic melts during decompression. Chem. Geol. 393-394, 36-54.
26. Fischer-Gödde, M., Becker, H., Wombacher, F., 2011. Rhodium, gold and other highly siderophile elements in orogenic peridotites and peridotite xenoliths. Chem. Geol. 280, 365-383.
27. Fu, J., Hu, Z., Li, J., Yang, L., Zhang, W., Liu, Y., Li, Q., Zong, K., Hu, S., 2017. Accurate determination of sulfur isotopes (δ33S and δ34S) in sulfides and elemental sulfur by femtosecond laser ablation MC-ICP-MS with non-matrix matched calibration. Journal of Analytical Atomic Spectrometry 32, 2341-2351.
28. Gannoun, A., Burton, K.W., Parkinson, I.J., Alard, O., Schiano, P., Thomas, L.E., 2007. The scale and origin of the osmium isotope variations in mid-ocean ridge basalts. Earth. Planet. Sci. Lett. 259, 541-556.
29. Gilbert, S.E., Danyushevsky, L.V., Rodemann, T., Shimizu, N., Gurenko, A., Meffre, S., Thomas, H., Large, R.R., Death, D., 2014. Optimisation of laser parameters for the analysis of sulphur isotopes in sulphide minerals by laser ablation ICP-MS. Journal of Analytical Atomic Spectrometry 29, 1042-1051.
30. Guo, J., Guo, F., Yan Wang, C., Li, C., 2013. Crustal recycling processes in generating the early Cretaceous Fangcheng basalts, North China Craton: New constraints from mineral chemistry, oxygen isotopes of olivine and whole-rock geochemistry. Lithos 170-171, 1-16.
31. Hao, H., Campbell, I.H., Arculus, R.J., Perfit, M.R., 2021. Using precious metal probes to quantify mid-ocean ridge magmatic processes. Earth. Planet. Sci. Lett. 553, 116603.
32. Hertogen, J., Janssens, M.J., Palme, H., 1980. Trace elements in ocean ridge basalt glasses: implications for fractionations during mantle evolution and petrogenesis. Geochim. Cosmochim. Acta 44, 2125-2143.
33. Holwell, D.A., Fiorentini, M., McDonald, I., Lu, Y., Giuliani, A., Smith, D.J., Keith, M., Locmelis, M., 2019. A metasomatized lithospheric mantle control on the metallogenic signature of post-subduction magmatism. Nat. Commun. 10, 3511.
34. Hong, L., Xu, Y., Zhang, L., Liu, Z., Xia, X., Kuang, Y., 2020. Oxidized Late Mesozoic subcontinental lithospheric mantle beneath the eastern North China Craton: A clue to understanding cratonic destruction. Gondwana. Res. 81, 230-239.
35. Jenner, F.E., Hauri, E.H., Bullock, E.S., König, S., Arculus, R.J., Mavrogenes, J.A., Mikkelson, N., Goddard, C., 2015. The competing effects of sulfide saturation versus degassing on the behavior of the chalcophile elements during the differentiation of hydrous melts. Geochem. Geophys. Geosyst. 16, 1490-1507.
36. Jenner, F.E., O'Neill, H.S.C., 2012. Analysis of 60 elements in 616 ocean floor basaltic glasses. Geochem. Geophys. Geosyst. 13.
37. Jenner, F.E., O’Neill, H.S.T.C., Arculus, R.J., Mavrogenes, J.A., 2010. The Magnetite Crisis in the Evolution of Arc-related Magmas and the Initial Concentration of Au, Ag and Cu. J. Petrol. 51, 2445-2464.
38. Jiang, Y.-H., Jiang, S.-Y., Ling, H.-F., Ni, P., 2010. Petrogenesis and tectonic implications of Late Jurassic shoshonitic lamprophyre dikes from the Liaodong Peninsula, NE China. Mineralogy and Petrology 100, 127-151.
39. Jin, D., Xiao, Y., Tan, D.-B., Wang, Y.-Y., Wang, X., Li, W., Su, W., Li, X., 2023. Supercritical fluid in deep subduction zones as revealed by multiphase fluid inclusions in an ultrahigh-pressure metamorphic vein. Proc Natl Acad Sci U S A 120, e2219083120.
40. Jugo, P.J., Wilke, M., Botcharnikov, R.E., 2010. Sulfur K-edge XANES analysis of natural and synthetic basaltic glasses: Implications for S speciation and S content as function of oxygen fugacity. Geochim. Cosmochim. Acta 74, 5926-5938.
41. Kepezhinskas, P., Defant, M.J., Widom, E., 2002. Abundance and distribution of PGE and Au in the island-arc mantle: implications for sub-arc metasomatism. Lithos 60, 113-128.
42. Kullerud, G., Yund, R.A., Moh, G.H., Wilson, H.D.B., 1969. Phase Relations in the Cu-Fe-S, Cu-Ni-S, and Fe-Ni-S Systems\*, Magmatic Ore Deposits. Society of Economic Geologists, p. 0.
43. Labidi, J., Cartigny, P., 2016. Negligible sulfur isotope fractionation during partial melting: Evidence from Garrett transform fault basalts, implications for the late-veneer and the hadean matte. Earth. Planet. Sci. Lett. 451, 196-207.
44. Labidi, J., Cartigny, P., Birck, J.L., Assayag, N., Bourrand, J.J., 2012. Determination of multiple sulfur isotopes in glasses: A reappraisal of the MORB δ34S. Chem. Geol. 334, 189-198.
45. Labidi, J., Cartigny, P., Hamelin, C., Moreira, M., Dosso, L., 2014. Sulfur isotope budget (32S, 33S, 34S and 36S) in Pacific–Antarctic ridge basalts: A record of mantle source heterogeneity and hydrothermal sulfide assimilation. Geochim. Cosmochim. Acta 133, 47-67.
46. Li, R., Xia, X., Yang, S., Chen, H., Yang, Q., 2019. Off-Mount Calibration and One New Potential Pyrrhotite Reference Material for Sulfur Isotope Measurement by Secondary Ion Mass Spectrometry. Geostand. Geoanal. Res. 43, 177-187.
47. Lissner, M., König, S., Luguet, A., le Roux, P.J., Schuth, S., Heuser, A., le Roex, A.P., 2014. Selenium and tellurium systematics in MORBs from the southern Mid-Atlantic Ridge (47–50°S). Geochim. Cosmochim. Acta 144, 379-402.
48. Liu, J., Cai, R., Pearson, D.G., Scott, J.M., 2019. Thinning and destruction of the lithospheric mantle root beneath the North China Craton: A review. Earth. Sci. Rev. 196, 102873.
49. Liu, J., Xia, Q.-K., Deloule, E., Chen, H., Feng, M., 2015. Recycled oceanic crust and marine sediment in the source of alkali basalts in Shandong, eastern China: Evidence from magma water content and oxygen isotopes. Journal of Geophysical Research: Solid Earth 120, 8281-8303.
50. Lorand, J.-P., Pont, S., Guttierez-Narbona, R., Gervilla, F., 2021. Chalcophile-siderophile element systematics and regional-scale magmatic percolation in the Ronda peridotite massif (Spain). Lithos 380-381, 105901.
51. Luguet, A., Nowell, G.M., Pearson, D.G., 2008. 184Os/188Os and 186Os/188Os measurements by Negative Thermal Ionisation Mass Spectrometry (N-TIMS): Effects of interfering element and mass fractionation corrections on data accuracy and precision. Chem. Geol. 248, 342-362.
52. Maier, W.D., Peltonen, P., McDonald, I., Barnes, S.J., Barnes, S.J., Hatton, C., Viljoen, F., 2012. The concentration of platinum-group elements and gold in southern African and Karelian kimberlite-hosted mantle xenoliths: Implications for the noble metal content of the Earth's mantle. Chem. Geol. 302, 119-135.
53. Mandon, C.L., Christenson, B.W., Seward, T.M., Schipper, C.I., 2021. Magma mixing, degassing and late sulfide saturation: Insights into the 1976–2000 eruptive sequence at White Island, New Zealand. Journal of Volcanology and Geothermal Research 417, 107299.
54. Marini, L., Chiappini, V., Cioni, R., Cortecci, G., Dinelli, E., Principe, C., Ferrara, G., 1998. Effect of degassing on sulfur contents and δ34S values in Somma-Vesuvius magmas. Bulletin of Volcanology 60, 187-194.
55. Marini, L., Moretti, R., Accornero, M., 2011. Sulfur Isotopes in Magmatic-Hydrothermal Systems, Melts, and Magmas. Rev. Mineral. Geochem. 73, 423-492.
56. McDonough, W.F., Sun, S.s., 1995. The composition of the Earth. Chem. Geol. 120, 223-253.
57. McInnes, B.I.A., McBride, J.S., Evans, N.J., Lambert, D.D., Andrew, A.S., 1999. Osmium isotope constraints on ore metal recycling in subduction zones. Science 286, 512-516.
58. Mungall, J.E., Brenan, J.M., 2014. Partitioning of platinum-group elements and Au between sulfide liquid and basalt and the origins of mantle-crust fractionation of the chalcophile elements. Geochim. Cosmochim. Acta 125, 265-289.
59. Park, J.-W., Campbell, I.H., Arculus, R.J., 2013. Platinum-alloy and sulfur saturation in an arc-related basalt to rhyolite suite: Evidence from the Pual Ridge lavas, the Eastern Manus Basin. Geochim. Cosmochim. Acta 101, 76-95.
60. Park, J.W., Campbell, I.H., Kim, J., Moon, J.W., 2015. The Role of Late Sulfide Saturation in the Formation of a Cu- and Au-rich Magma: Insights from the Platinum Group Element Geochemistry of Niuatahi-Motutahi Lavas, Tonga Rear Arc. J. Petrol. 56, 59-81.
61. Rehkämper, M., Halliday, A.N., Fitton, J.G., Lee, D.C., Wieneke, M., Arndt, N.T., 1999. Ir, Ru, Pt, and Pd in basalts and komatiites: new constraints for the geochemical behavior of the platinum-group elements in the mantle. Geochim. Cosmochim. Acta 63, 3915-3934.
62. Rielli, A., Tomkins, A.G., Nebel, O., Raveggi, M., Jeon, H., Martin, L., Ávila, J.N., 2018. Sulfur isotope and PGE systematics of metasomatised mantle wedge. Earth. Planet. Sci. Lett. 497, 181-192.
63. Saunders, J.E., Pearson, N.J., O’Reilly, S.Y., Griffin, W.L., 2016. Gold in the mantle: The role of pyroxenites. Lithos 244, 205-217.
64. Saunders, J.E., Pearson, N.J., O’Reilly, S.Y., Griffin, W.L., 2018. Gold in the mantle: A global assessment of abundance and redistribution processes. Lithos 322, 376-391.
65. Tassara, S., Gonzalez-Jimenez, J.M., Reich, M., Saunders, E., Luguet, A., Morata, D., Gregoire, M., van Acken, D., Schilling, M.E., Barra, F., Nowell, G., Corgne, A., 2018. Highly siderophile elements mobility in the subcontinental lithospheric mantle beneath southern Patagonia. Lithos 314, 579-596.
66. Wang, X.-C., Wilde, S.A., Li, Q.-L., Yang, Y.-N., 2015. Continental flood basalts derived from the hydrous mantle transition zone. Nat. Commun. 6, 7700.
67. Wang, X., Wang, Z., Cheng, H., Foley, S., Xiong, L., Hu, Z., 2020a. Early cretaceous lamprophyre dyke swarms in Jiaodong Peninsula, eastern North China Craton, and implications for mantle metasomatism related to subduction. Lithos 368-369, 105593.
68. Wang, X., Wang, Z., Cheng, H., Zong, K., Wang, C.Y., Ma, L., Cai, Y.-C., Foley, S., Hu, Z., 2022. Gold endowment of the metasomatized lithospheric mantle for giant gold deposits: Insights from lamprophyre dykes. Geochim. Cosmochim. Acta 316, 21-40.
69. Wang, X., Wang, Z., Zhang, W., Ma, L., Chen, W., Cai, Y.-C., Foley, S., Wang, C.Y., Li, J., Deng, J., Feng, Y., Zong, K., Hu, Z., Liu, Y., 2024. Sulfur isotopes of lamprophyres and implications for the control of metasomatized lithospheric mantle on the giant Jiaodong gold deposits, eastern China. GSA Bulletin doi.org/10.1130/B37274.1.
70. Wang, Z., Becker, H., 2015. Fractionation of highly siderophile and chalcogen elements during magma transport in the mantle: Constraints from pyroxenites of the Balmuccia peridotite massif. Geochim. Cosmochim. Acta 159, 244-263.
71. Wang, Z., Cheng, H., Zong, K., Geng, X., Liu, Y., Yang, J., Wu, F., Becker, H., Foley, S., Wang, C.Y., 2020b. Metasomatized lithospheric mantle for Mesozoic giant gold deposits in the North China craton. Geology 48, 169-173.
72. Wang, Z., Xu, Z., Cheng, H., Zou, Y., Guo, J., Liu, Y., Yang, J., Zong, K., Xiong, L., Hu, Z., 2021. Precambrian metamorphic crustal basement cannot provide much gold to form giant gold deposits in the Jiaodong Peninsula, China. Precambrian Res. 354, 106045.
73. Wu, F.-Y., Yang, J.-H., Xu, Y.-G., Wilde, S.A., Walker, R.J., 2019. Destruction of the North China Craton in the Mesozoic. Annu. Rev. Earth Planet. Sci. 47, 173-195.
74. Xu, H., Zhang, J., Wang, Y., Liu, W., 2016. Late Triassic alkaline complex in the Sulu UHP terrane: Implications for post-collisional magmatism and subsequent fractional crystallization. Gondwana. Res. 35, 390-410.
75. Xu, Z., Wang, Z., Guo, J.-L., Liu, Y., Guo, J., Cheng, H., Chen, K., Wang, X., Zong, K., Zhu, Z., Hu, Z., Li, H., 2022. Chalcophile elements of the Early Cretaceous Guojialing granodiorites and mafic enclaves, eastern China, and implications for the formation of giant Jiaodong gold deposits. Journal of Asian Earth Sciences 238, 105374.
76. Yang, D.-B., Xu, W.-L., Pei, F.-P., Yang, C.-H., Wang, Q.-H., 2012a. Spatial extent of the influence of the deeply subducted South China Block on the southeastern North China Block: Constraints from Sr–Nd–Pb isotopes in Mesozoic mafic igneous rocks. Lithos 136-139, 246-260.
77. Yang, J.-H., Sun, J.-F., Chen, F., Wilde, S.A., Wu, F.-Y., 2007. Sources and petrogenesis of late triassic dolerite dikes in the liaodong peninsula: Implications for post-collisional lithosphere thinning of the eastern North China Craton. J. Petrol. 48, 1973-1997.
78. Yang, J.-H., Xu, L., Sun, J.-F., Zeng, Q., Zhao, Y.-N., Wang, H., Zhu, Y.-S., 2021. Geodynamics of decratonization and related magmatism and mineralization in the North China Craton. Sci. China Earth Sci. 64, 1409-1427.
79. Yang, Q.-L., Zhao, Z.-F., Zheng, Y.-F., 2012b. Modification of subcontinental lithospheric mantle above continental subduction zone: Constraints from geochemistry of Mesozoic gabbroic rocks in southeastern North China. Lithos 146-147, 164-182.
80. Yang, Q.-L., Zhao, Z.-F., Zheng, Y.-F., 2012c. Slab–mantle interaction in continental subduction channel: Geochemical evidence from Mesozoic gabbroic intrusives in southeastern North China. Lithos 155, 442-460.
81. Zhang, J., Zhao, Z.-F., Zheng, Y.-F., Liu, X., Xie, L., 2012. Zircon Hf–O isotope and whole-rock geochemical constraints on origin of postcollisional mafic to felsic dykes in the Sulu orogen. Lithos 136-139, 225-245.
82. Zhang, W., Hu, Z., Liu, Y., 2020. Iso-Compass: new freeware software for isotopic data reduction of LA-MC-ICP-MS. Journal of Analytical Atomic Spectrometry 35, 1087-1096.
83. Zhao, S.-R., Li, Z.-K., Li, J.-W., Zhao, X.-F., Jiang, S.-Y., Lin, H.-T., Jie, Y.-Q., Tao, H., Du, S.-G., 2022. Trace element and S-Pb isotopic compositions of pyrite from the Precambrian metamorphic rocks and their derivative pegmatites in the Xiaoqinling district, southern North China Craton: Implications for possible gold source of the Early Cretaceous gold deposits. Precambrian Res. 377, 106739.
84. Zhao, Z.-F., Zheng, Y.-F., Zhang, J., Dai, L.-Q., Li, Q., Liu, X., 2012. Syn-exhumation magmatism during continental collision: Evidence from alkaline intrusives of Triassic age in the Sulu orogen. Chem. Geol. 328, 70-88.
85. Zheng, Y.-F., Xiao, W.-J., Zhao, G., 2013. Introduction to tectonics of China. Gondwana. Res. 23, 1189-1206.
86. Zheng, Y., Xu, Z., Zhao, Z., Dai, L., 2018. Mesozoic mafic magmatism in North China: Implications for thinning and destruction of cratonic lithosphere. Sci. China Earth Sci. 61, 353-385.
87. Zhu, R.-X., Yang, J.-H., Wu, F.-Y., 2012. Timing of destruction of the North China Craton. Lithos 149, 51-60.
88. Zou, Z., Wang, Z., Cheng, H., He, T., Liu, Y., Chen, K., Hu, Z., Liu, Y., 2020. Comparative Determination of Mass Fractions of Elements with Variable Chalcophile Affinities in Geological Reference Materials with and without HF‐desilicification. Geostand. Geoanal. Res. 44, 501-521.