

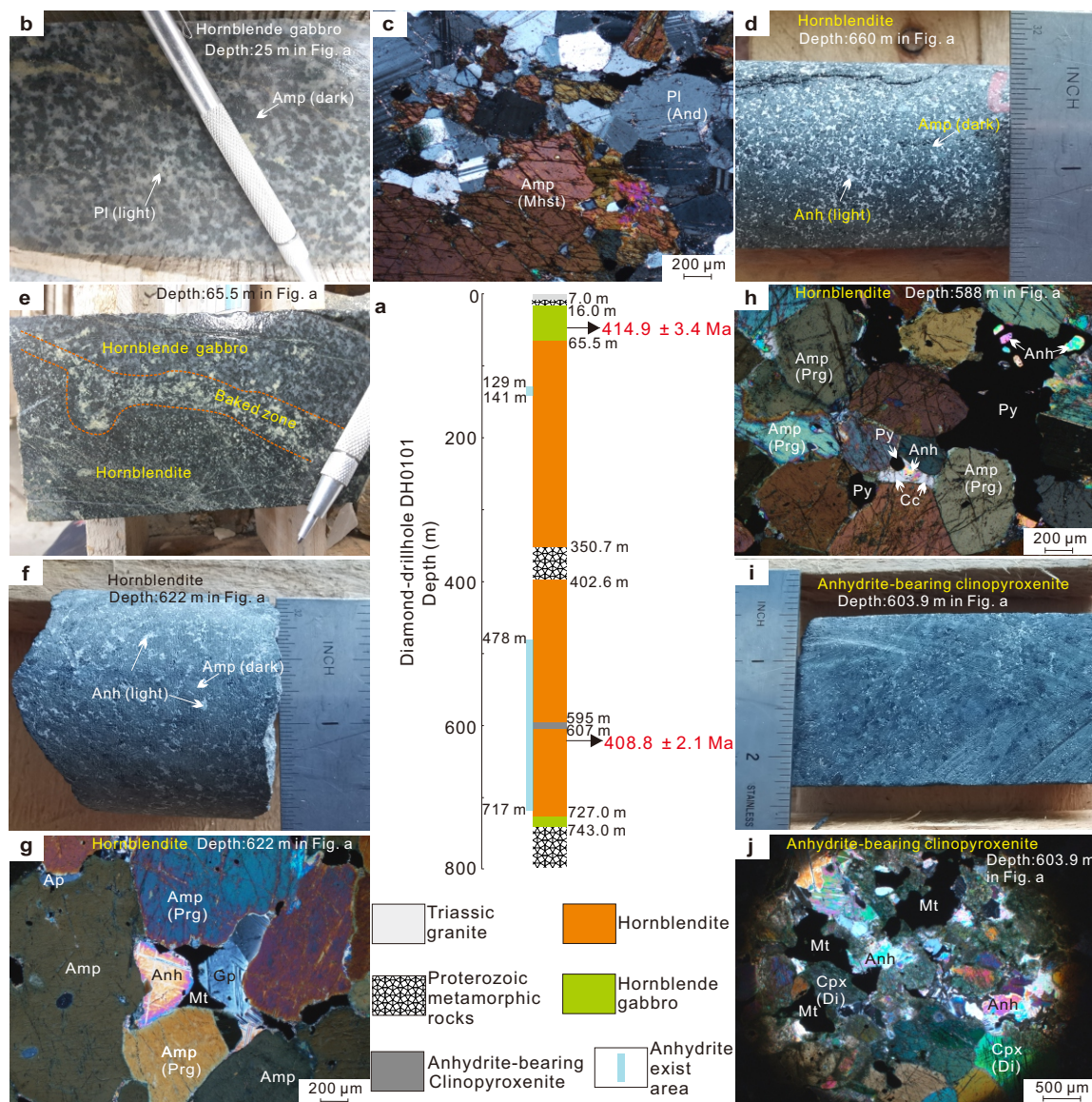


Figure 1. Core in diamond-drillhole DH0101 from the Langmuri PGE deposit.

Abbreviations: Amp = amphibole, Mhst = magnesio-hastingsite, Prg = pargasite, Cpx = clinopyroxene, Di = diopside, Pl = plagioclase, And = andesite, Anh = anhydrite, Gp = gypsum, Mt = magnetite, and Cc = calcite.

a, Rock distribution in DH0101. **b**, Hand specimen of hornblende gabbro.

c, Microscopic feature of hornblende gabbro. **d**, Hand specimen of gypsum-bearing hornblende (depth 660 m).

e, Hornblende gabbro hornfelsed by the intrusion of hornblende indicating that the hornblende gabbro is older than the hornblende.

f, Gypsum-bearing hornblende (depth 622 m). **g**, Anhydrite coexisting with gypsum and magnetite in hornblende.

h, Anhydrite associated with calcite or encased in pyrite. **i**, Hand specimen of gypsum-bearing clinopyroxene.

j, Photomicrograph of gypsum-bearing clinopyroxene, and its pyroxene type is diopside.

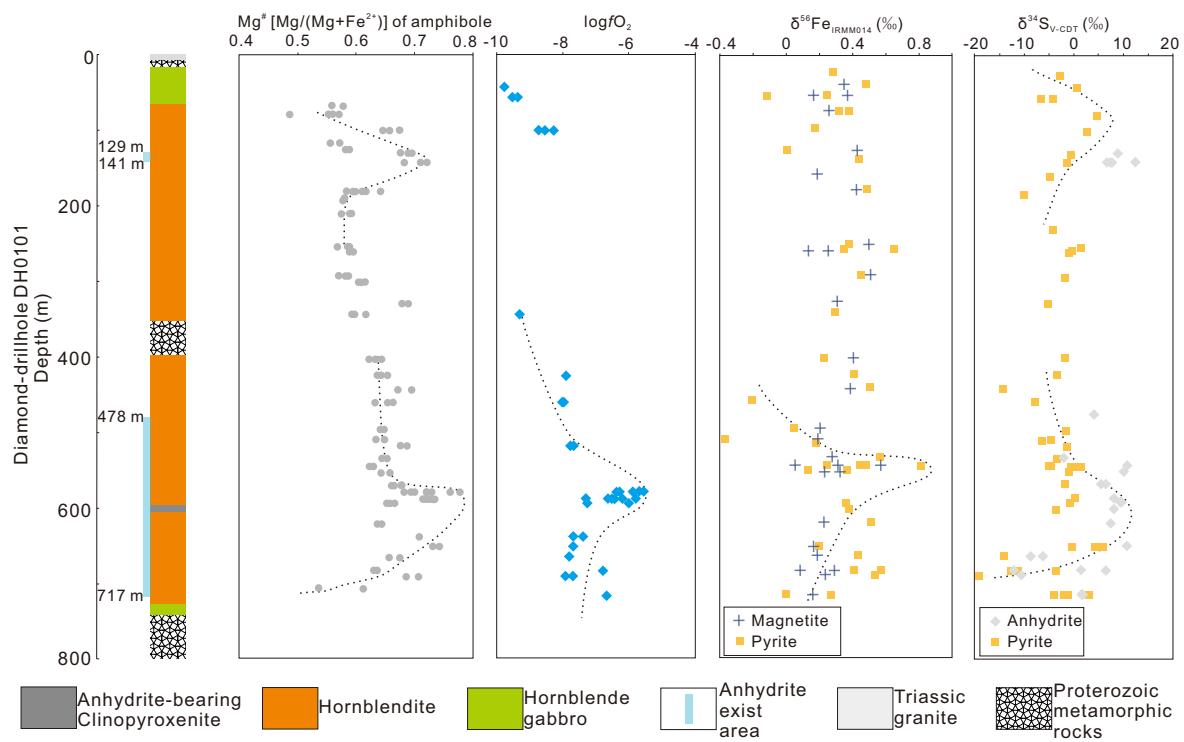


Figure 2. Spatial variation of the geochemistry in diamond-drillhole DH0101.

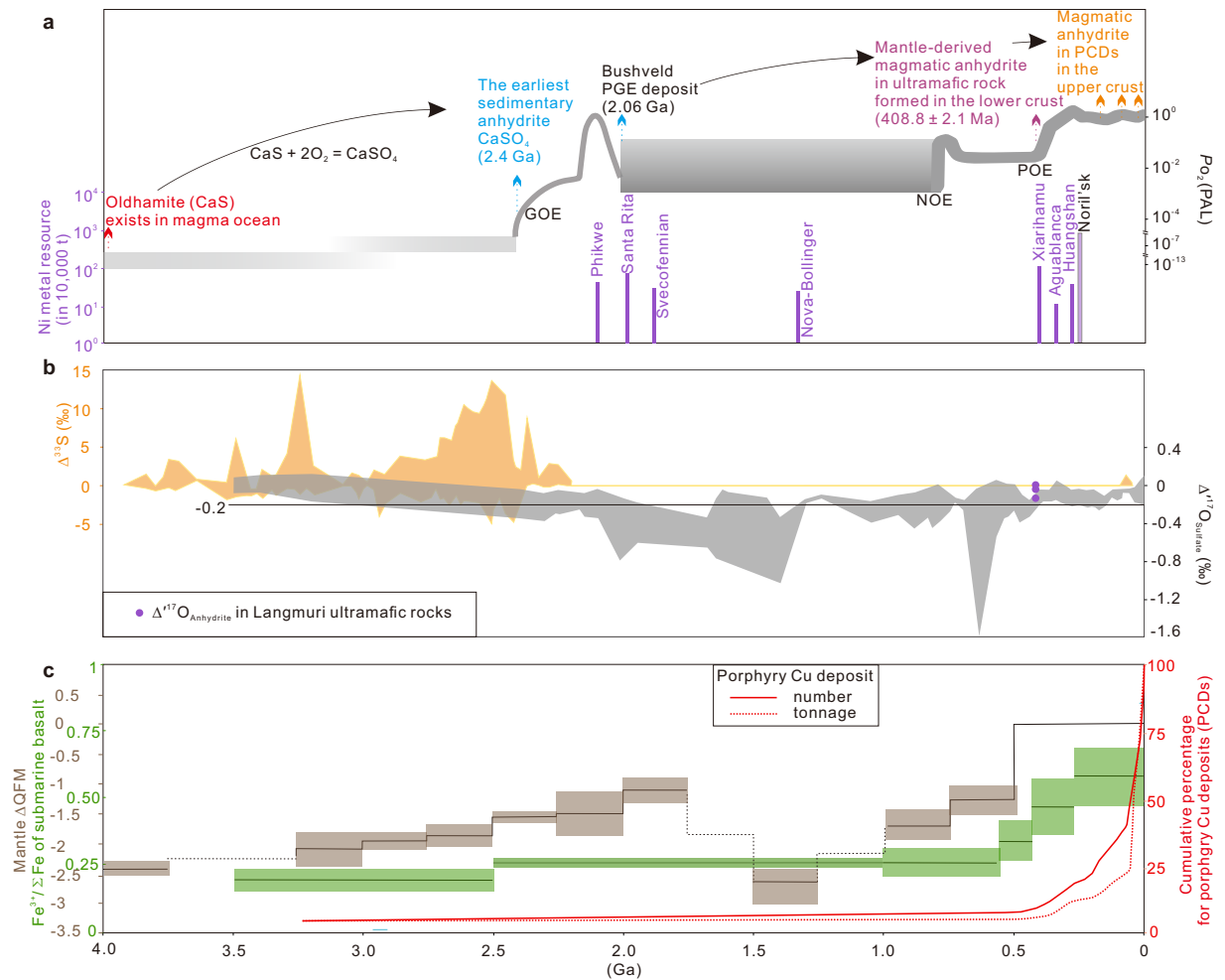


Figure 3. The relationship between the mantle and atmospheric oxidation and typical sulfide ore deposits.

a. Oldhamite (CaS) exists in magma ocean (ref. 33).

The world's earliest sedimentary anhydrite was found in the ca. 2.4 Ga upper Deutschland Formation (ref. 34).

Most magmatic anhydrites in PCDs are later than 168 Ma (ref. 18).

The dark purple pillars represent the top seven magmatic nickel deposits in orogen, while the light purple pillar represents the world's largest nickel deposit at Noril'sk, which is of mantle plume origin (the age, reserve, and geological setting references are listed in Supplementary Table 7).

GOE time is from refs. 3, 31, 35, NOE and POE time are from ref. 36 and ref. 4, respectively.

b. Integrated sedimentary Δ³³S and Δ¹⁷O sulfate records are from ref. 4 and references therein.

The black line represents the -0.2‰ Δ¹⁷O sulfate value, the lower limit observed in sulfate after POE (ref. 4).

c. Temporal correlation between global porphyry Cu deposits and mantle-ocean-atmospheric evolution through geological time.

The mantle oxygen fugacity is from ref. 6. The Fe³⁺/ΣFe ratios (in green) of the submarine basalts are from ref. 7.

The temporal distribution of global porphyry Cu deposits based on the database from ref. 9.

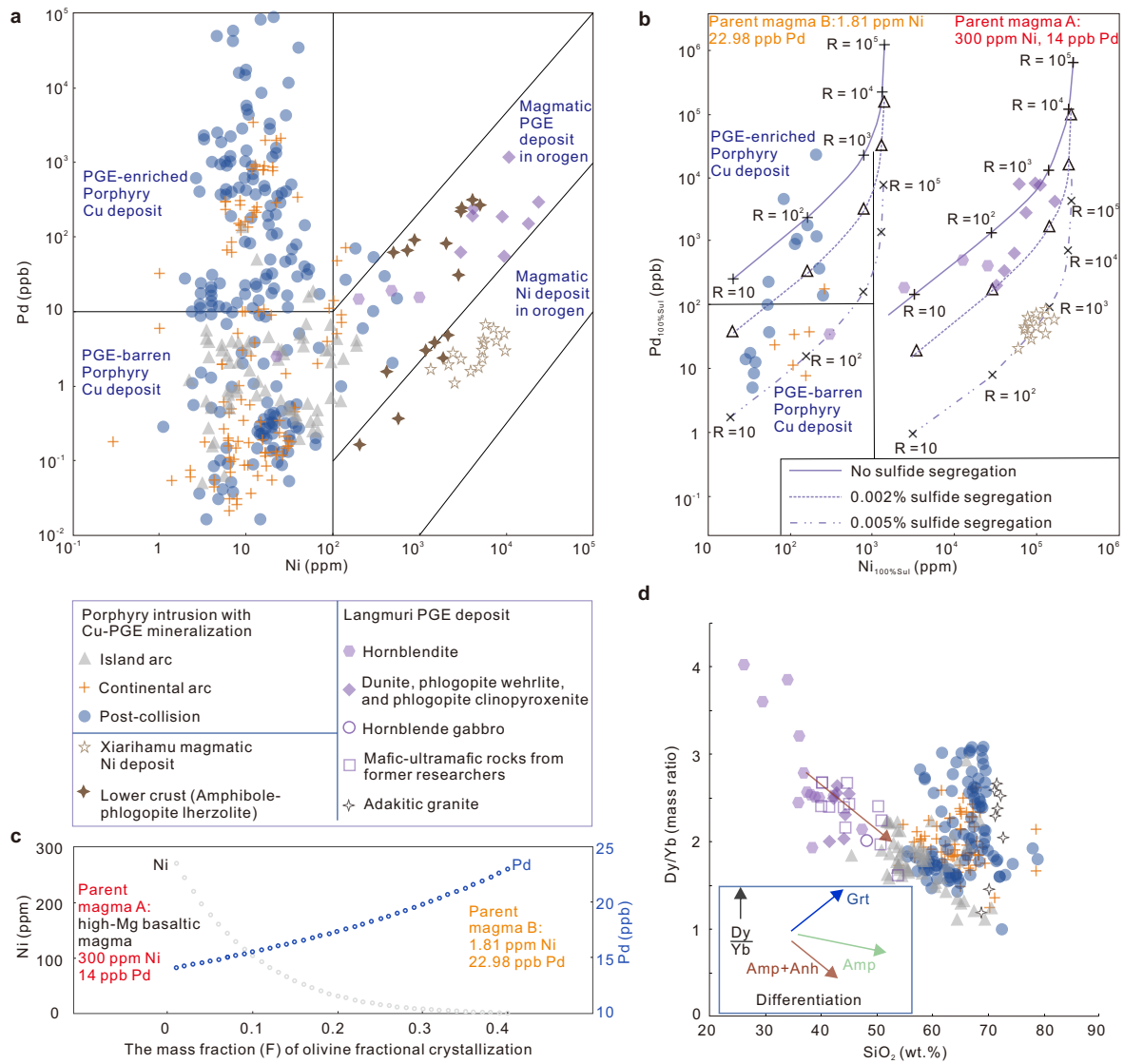


Figure 4. The intrinsic connection between magmatic PGE sulfide deposit and PGE-rich PCDs.

a, Whole-rock Ni-Pd elemental comparison between PCDs and the Langmuri magmatic PGE sulfide deposit, lower crust peridotite, and the largest magmatic Ni sulfide deposit in orogen (Xiarihamu magmatic Ni deposit).

b, Model calculations of the variation in Pd_{100%Sul} with Ni_{100%Sul} of sulfides from magmatic sulfide deposits and PCDs.

The Pd and Ni contents of the sulfides are corrected to 100% sulfide content (Methods, Supplementary Tables 9–10).

R is the ratio of the mass of silicate magma to the mass of sulfide that reached equilibrium together.

The right solid line represents the sulfide melts segregated from PGE-rich magma [Parent magma A (high-Mg basaltic magma)] with 14 ppb Pd and 300 ppm Ni under variable R values (labelled in the diagram). The left solid line displays the sulfide liquids separated from parent magma B with 22.98 ppb Pd and 1.81 ppm Ni (Methods, Supplementary Table 11).

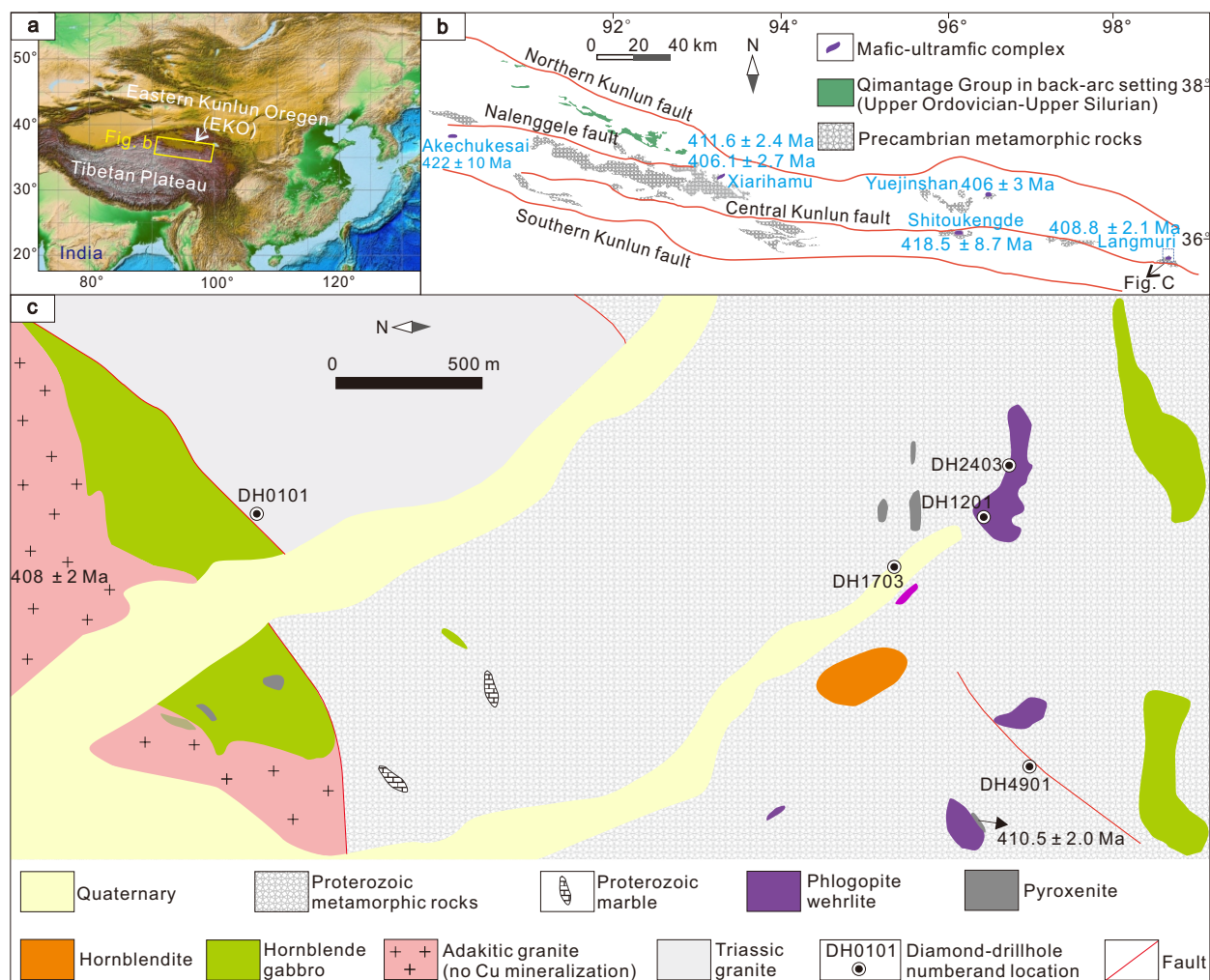
Parent magma B is the product of parent magma A after 40 wt% olivine crystallisation.

The dashed line and dashed-dotted line show the sulfide liquids produced by sulfide immiscibility in Pd-depleted magma due to 0.002% and 0.005% sulfide removal from Pd-rich magma, respectively.

c, The changing trend of Ni and Pd contents in the residual magma during the olivine fractionation crystallisation process of high-Mg basaltic magma (parent magma A) (Methods, Supplementary Table 12).

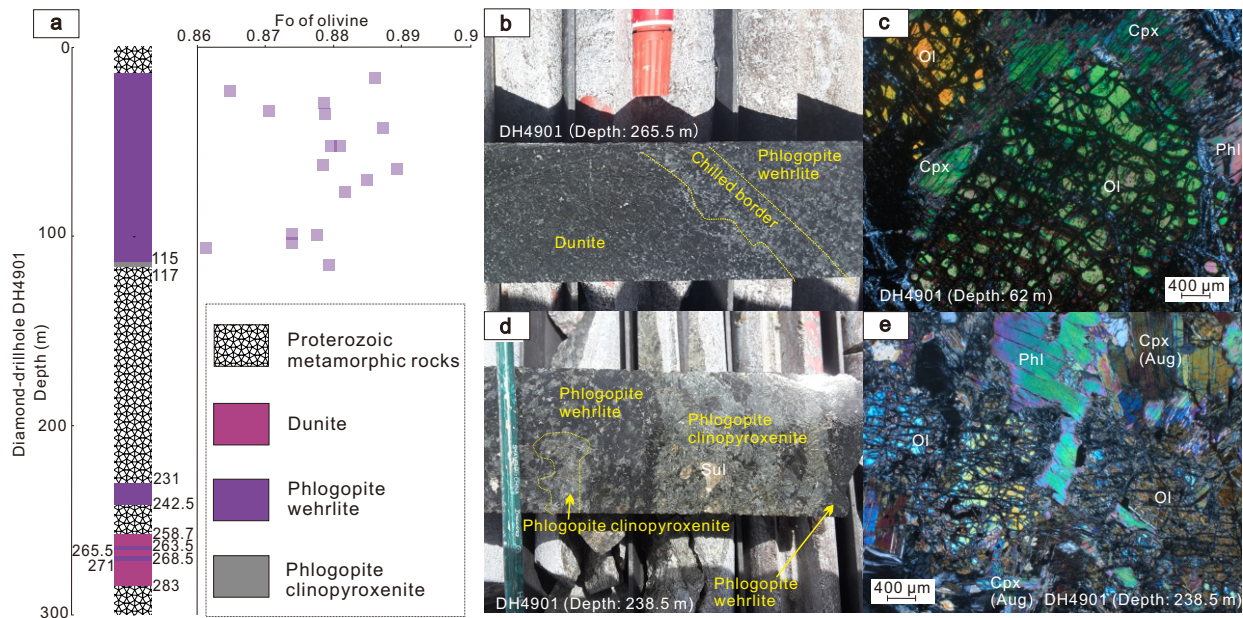
d, Dy/Yb vs. SiO₂. The crystallisation differentiation trend of garnet and amphibole is from ref. 45. Grt = garnet, Amp = amphibole, and Anh = anhydrite.

Data sources: Lower crust peridotite is from ref. 11; other original data and sources are listed in Supplementary Table 5, 8–10.



Extended Data Fig. 1. The simplified geological map of the Langmuri PGE deposit in the Tibetan Plateau.

The age data sources are listed in [Supplementary Table 14](#).



Extended Data Fig. 2. Geological and mineral composition features of diamond-drillhole DH4901 in the Langmuri PGE deposit.

Abbreviations: Ol = olivine, Cpx = clinopyroxene, Aug = augite, Phl = phlogopite, and Sul = sulfide.

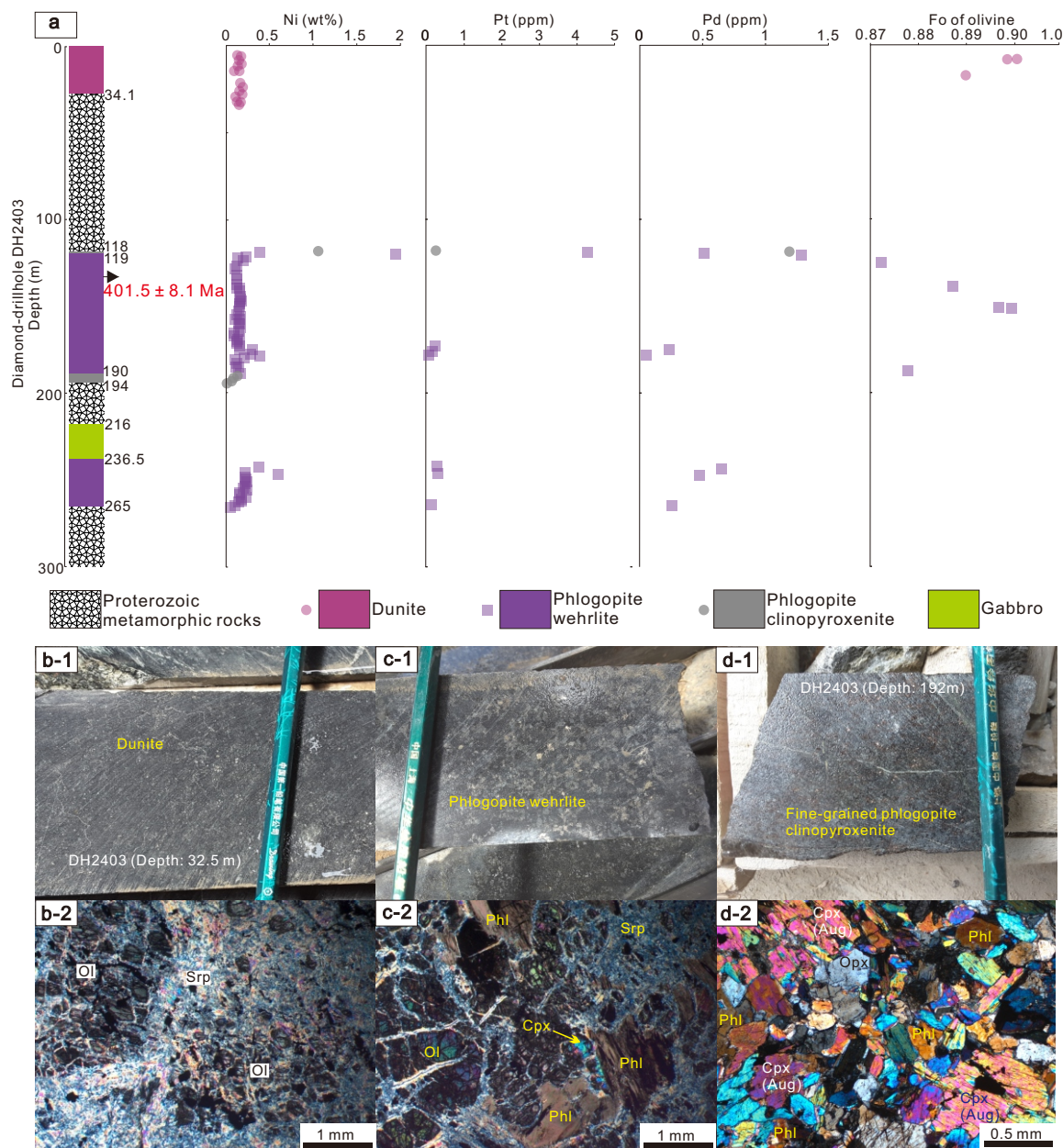
a, The Fo value of olivine from phlogopite wehrlite decreases from the central lithofacies to the margin lithofacies.

b, The contact boundary between dunite and phlogopite wehrlite shows the latter's chilled border, indicating that the phlogopite wehrlite is later than the dunite.

c, Microscopic characteristics of phlogopite wehrlite (Augite is confirmed by EMPA data in [Supplementary Table 2](#)).

d, The transformation from phlogopite wehrlite to phlogopite clinopyroxenite is not clearly defined, which is presumed to be the result of crystallisation differentiation; Sulfides are present in phlogopite clinopyroxenite, presumably later than the crystallisation of pyroxene, but roughly at the same time as the crystallisation of phlogopite.

e, Microscopic characteristics of the phlogopite wehrlite in Figure d (Augite is confirmed by EMPA data in [Supplementary Table 2](#)).



Extended Data Fig. 3. Lithofacies, ore-forming elements, and mineral composition characteristics of DH2403 in the Langmuri PGE deposit.

Abbreviations: Ol = olivine, Srp = serpentine, Phl = phlogopite, Cpx = clinopyroxene, Aug = augite, and Opx = orthopyroxene.

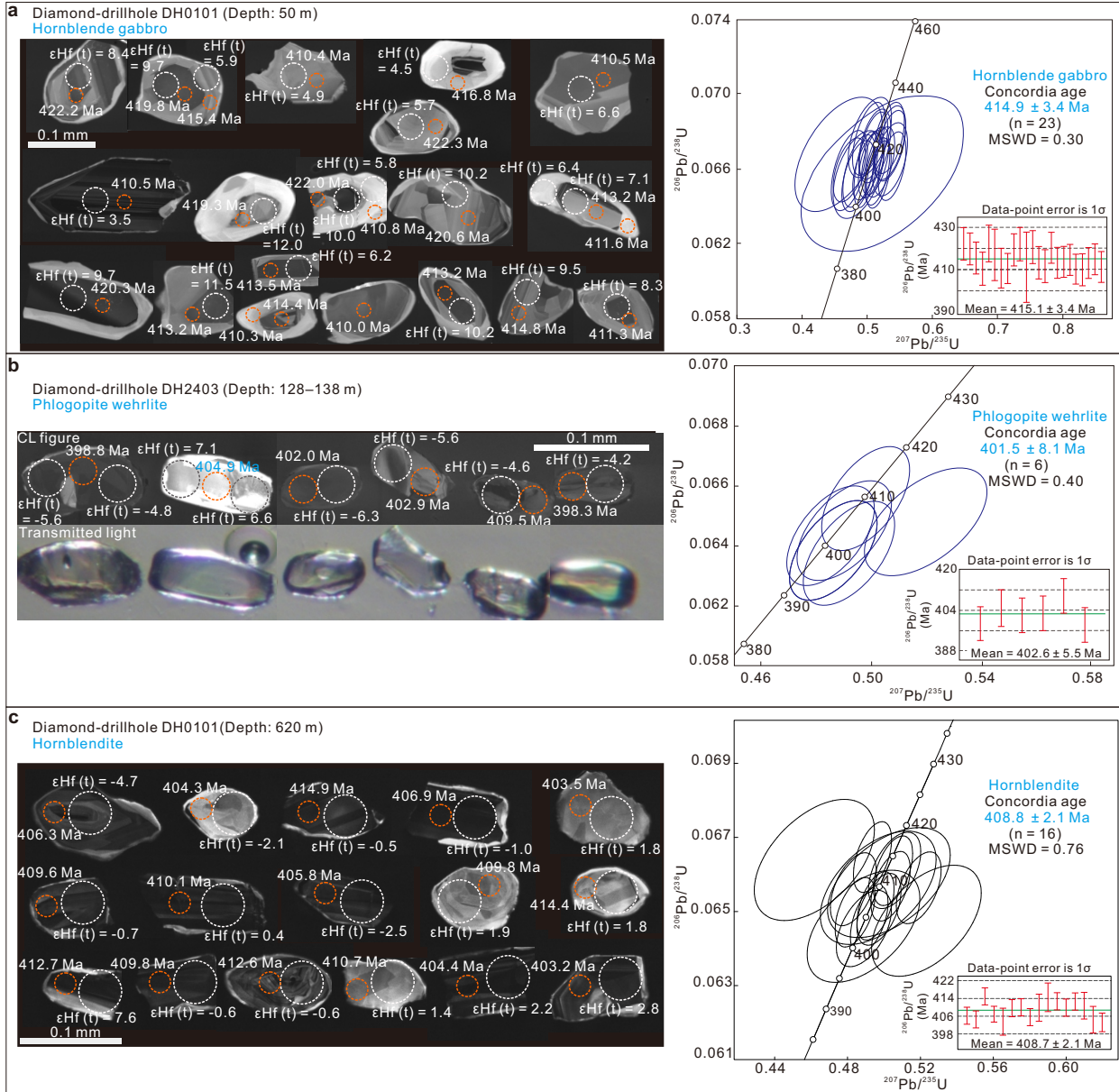
a, The whole-rock nickel content in the dunite is less than 0.2 wt%. Phlogopite clinopyroxenite with a thickness of 1–4 meters are visible at the margin of phlogopite wehrlite. The central part of the phlogopite wehrlite is almost devoid of sulfides, but disseminated sulfides exist at the top and bottom of the phlogopite wehrlite. Nickel, Pd, and Pt ore bodies are all located at the top and bottom of the phlogopite wehrlite. The Fo value of olivine in the phlogopite wehrlite is high in the central lithofacies and low at the marginal lithofacies.

b, Hand specimen (b-1) and microscopic features (b-2) of the serpentinised dunite.

c, Hand specimen (c-1) and microscopic features (c-2) of the serpentinised phlogopite wehrlite.

d, Hand specimen (d-1) and microscopic features (d-2) of the phlogopite clinopyroxenite.

Nickel, Pt, and Pd data sources are listed in [Supplementary Table 15](#).



Extended Data Fig. 4. Zircon U-Pb ages in Langmuri PGE deposit.

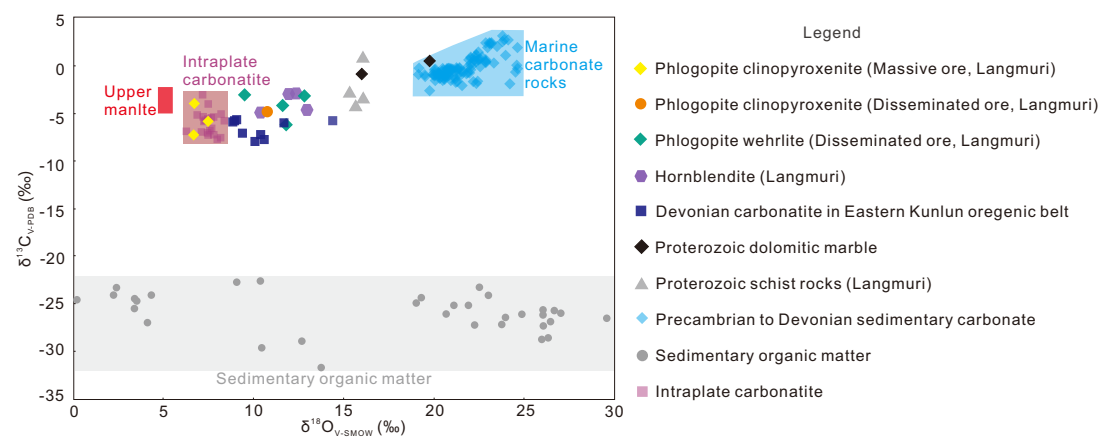
a, Zircon U-Pb ages in hornblende gabbro from DH0101 (Depth: 50 m),

including the zircon under cathodoluminescence in the left part and the concordia age of zircon in the right part.

b, Zircon U-Pb ages in phlogopite wehrlite from DH2403 (Depth: 128–138 m),

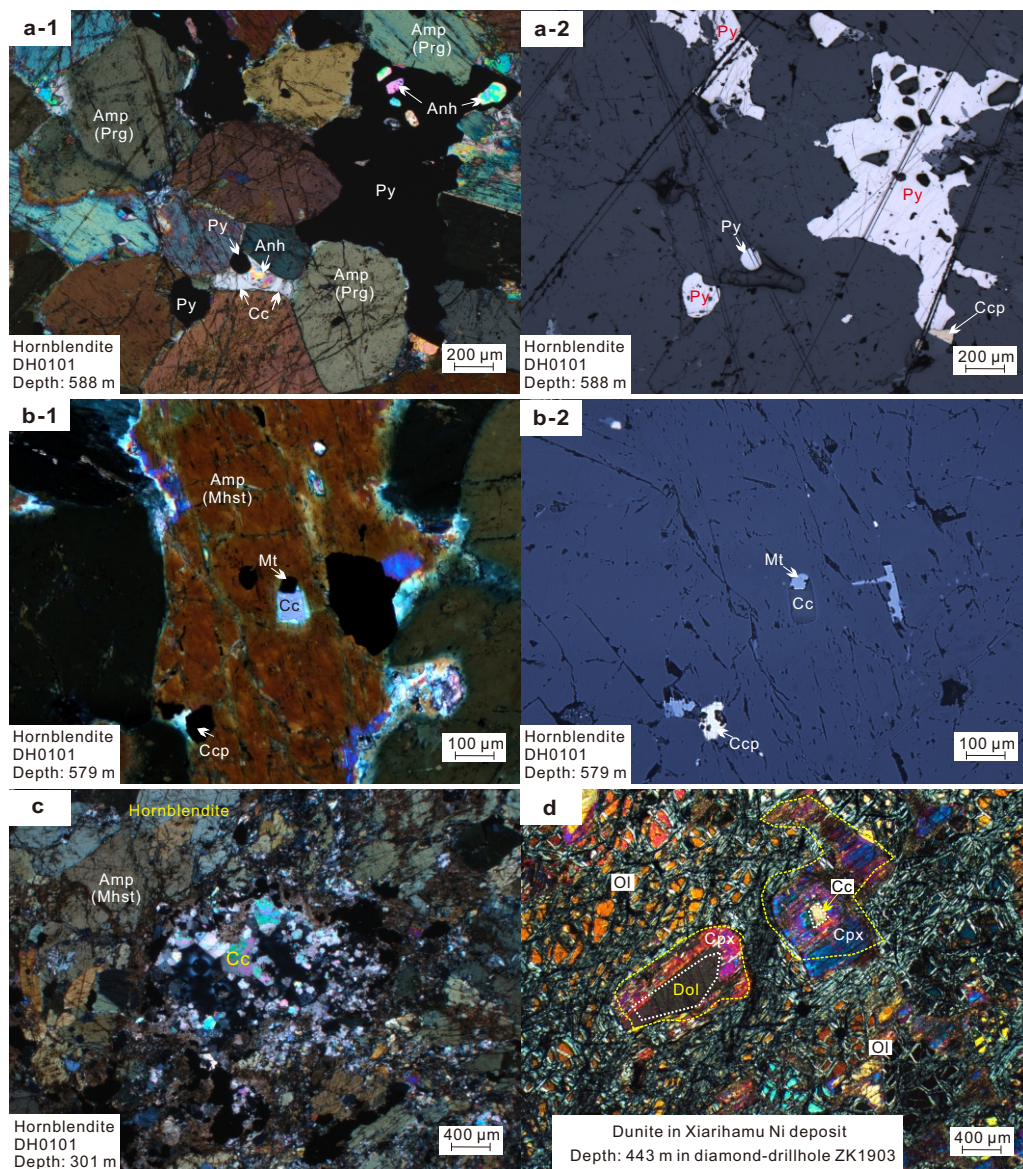
including the zircon under cathodoluminescence and zircon under transmitted light, and the concordia age of zircon in the right part.

c, Zircon U-Pb ages in hornblendite from DH0101 (Depth: 620 m).



Extended Data Fig. 5. C-O isotopic characteristics.

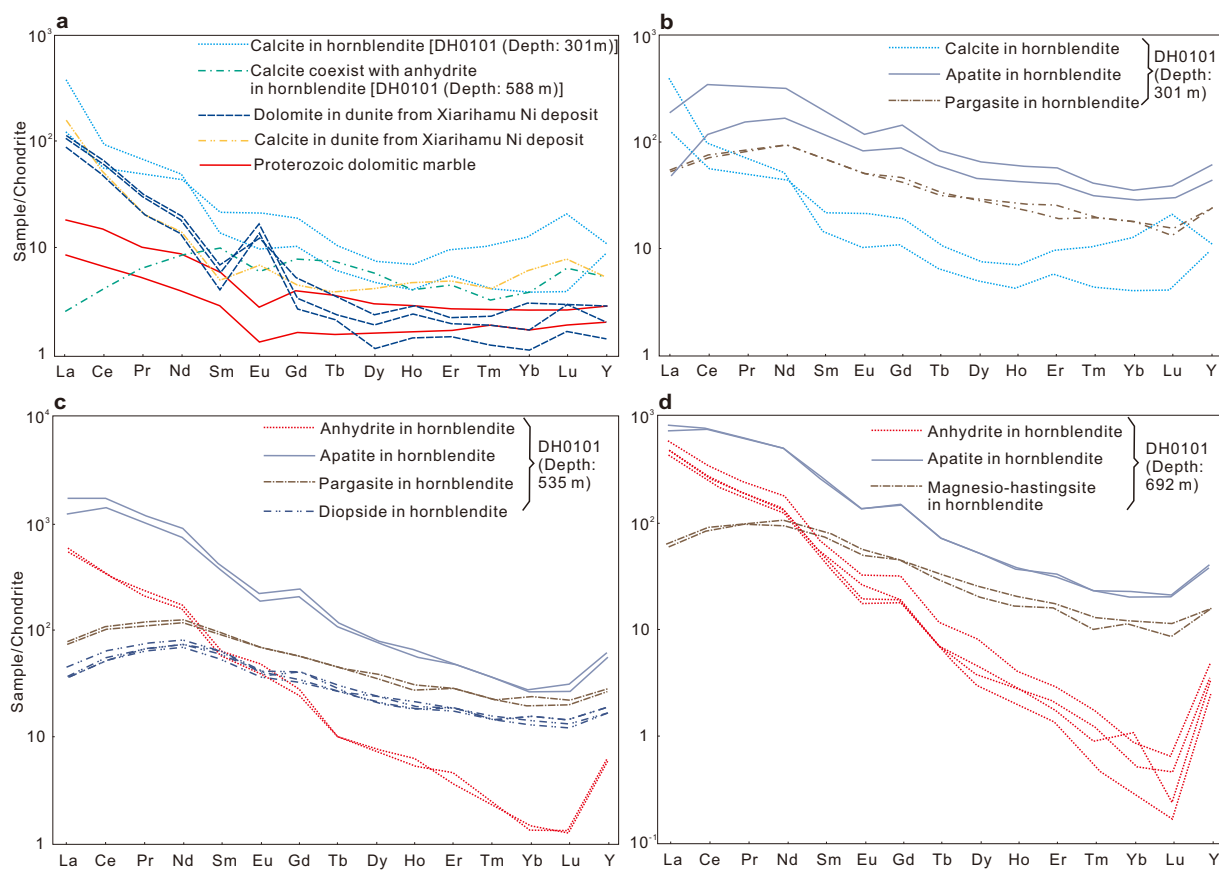
Carbon-O isotope data sources are listed in [Supplementary Table 16](#).



Extended Data Fig. 6. The calcite in hornblende from Langmuri PGE deposit (a-c) and the carbonate in dunite from Xiarihamu Ni deposit (d).

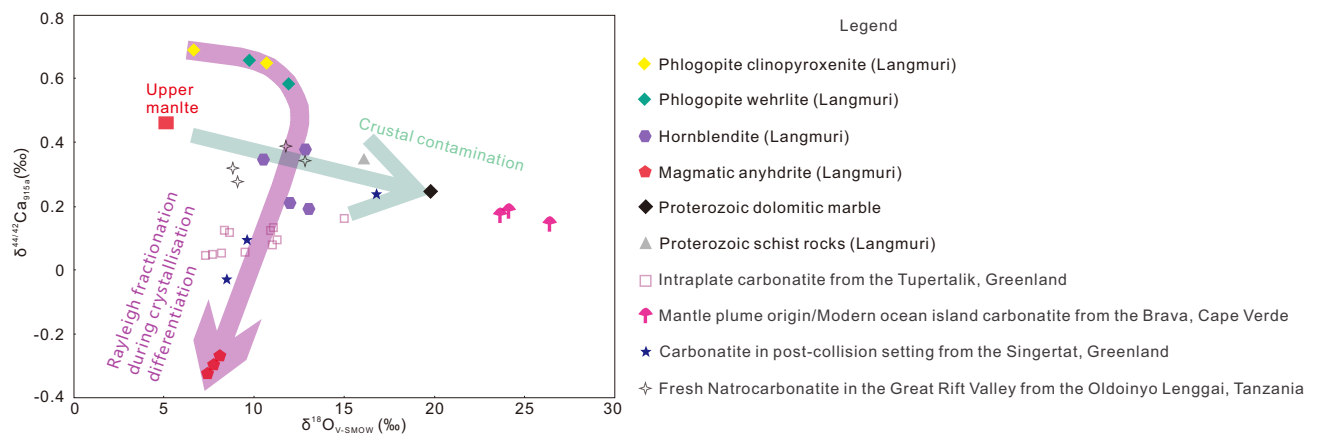
Abbreviations: Amp = amphibole, Prg = pargasite, Mhst = magnesio-hastingsite, Py = pyrite, Ccp = chalcopryrite, Anh = anhydrite, Cc = calcite, Dol = dolomite, Cpx = clinopyroxene, and Ol = olivine.

- a,** Calcite coexists with anhydrite and magnetite in hornblende; a-1 shows the characteristics under a transmission microscope, while a-2 shows the characteristics under a reflecting microscope.
- b,** Calcite and magnetite exist in hornblende as an inclusion.
- c,** Calcite exists in hornblende.
- d,** Calcite and dolomite are surrounded by clinopyroxene in dunite from Xiarihamu Ni deposit (modified from [ref. 21](#)).



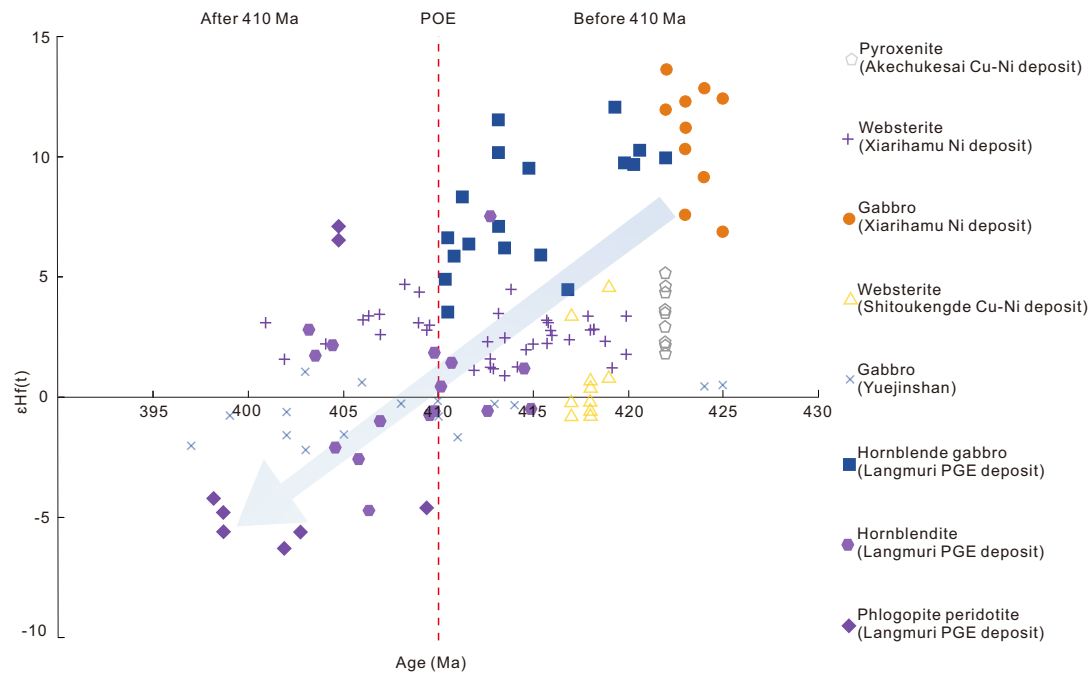
Extended Data Fig. 7. Chondrite-normalised rare earth elements diagrams of representative minerals and whole-rock marble in the study area.

Data source: The chondrite values are from [ref. 71](#).



Extended Data Fig. 8. Ca-O isotopic characteristics.

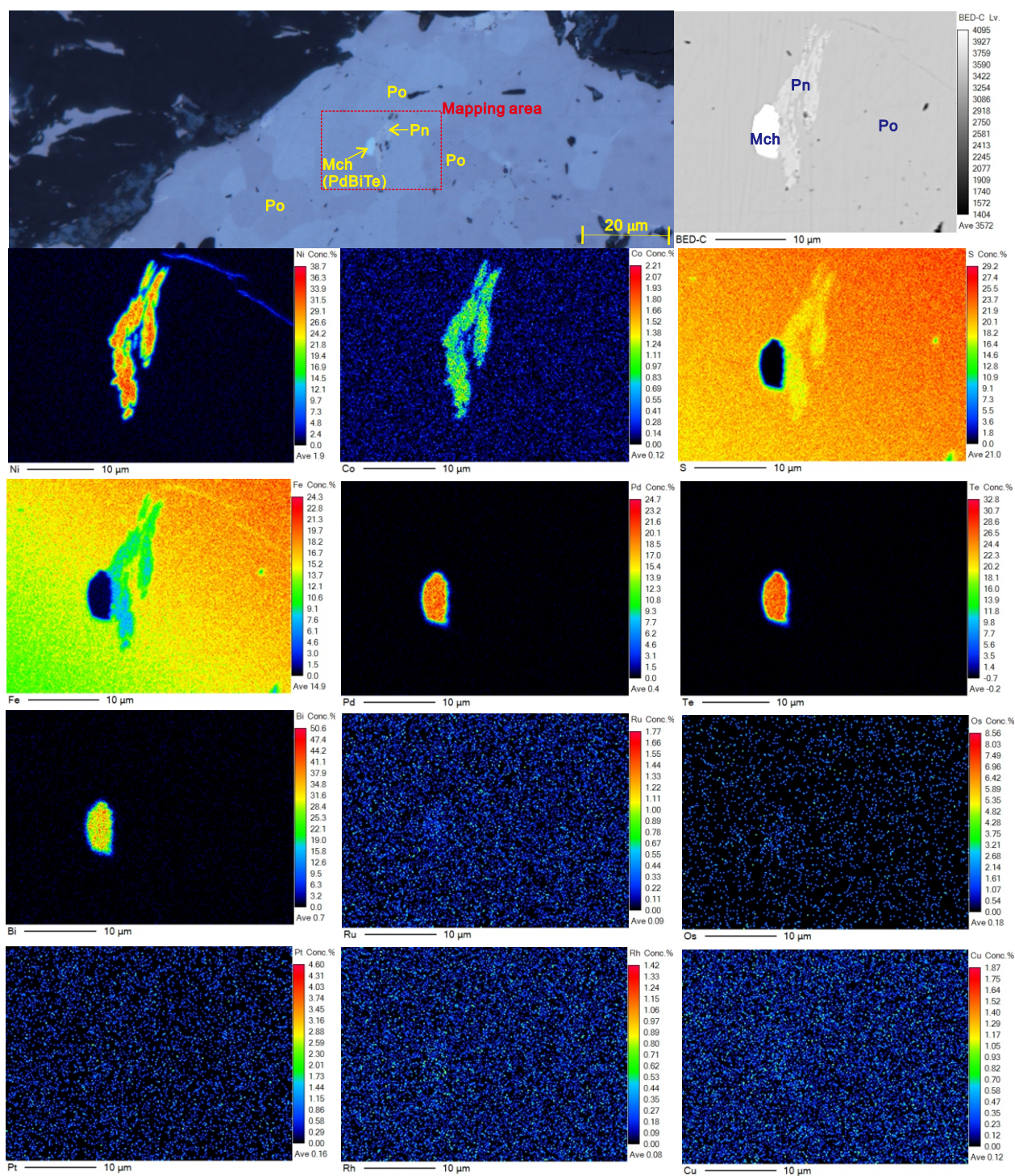
Calcium-O isotope data sources are listed in [Supplementary Table 16](#).



Extended Data Fig. 9. Zircon U-Pb ages versus $^{176}\text{Hf}/^{177}\text{Hf}(t)$ ratios (expressed as $\epsilon_{\text{Hf}}(t)$ values).

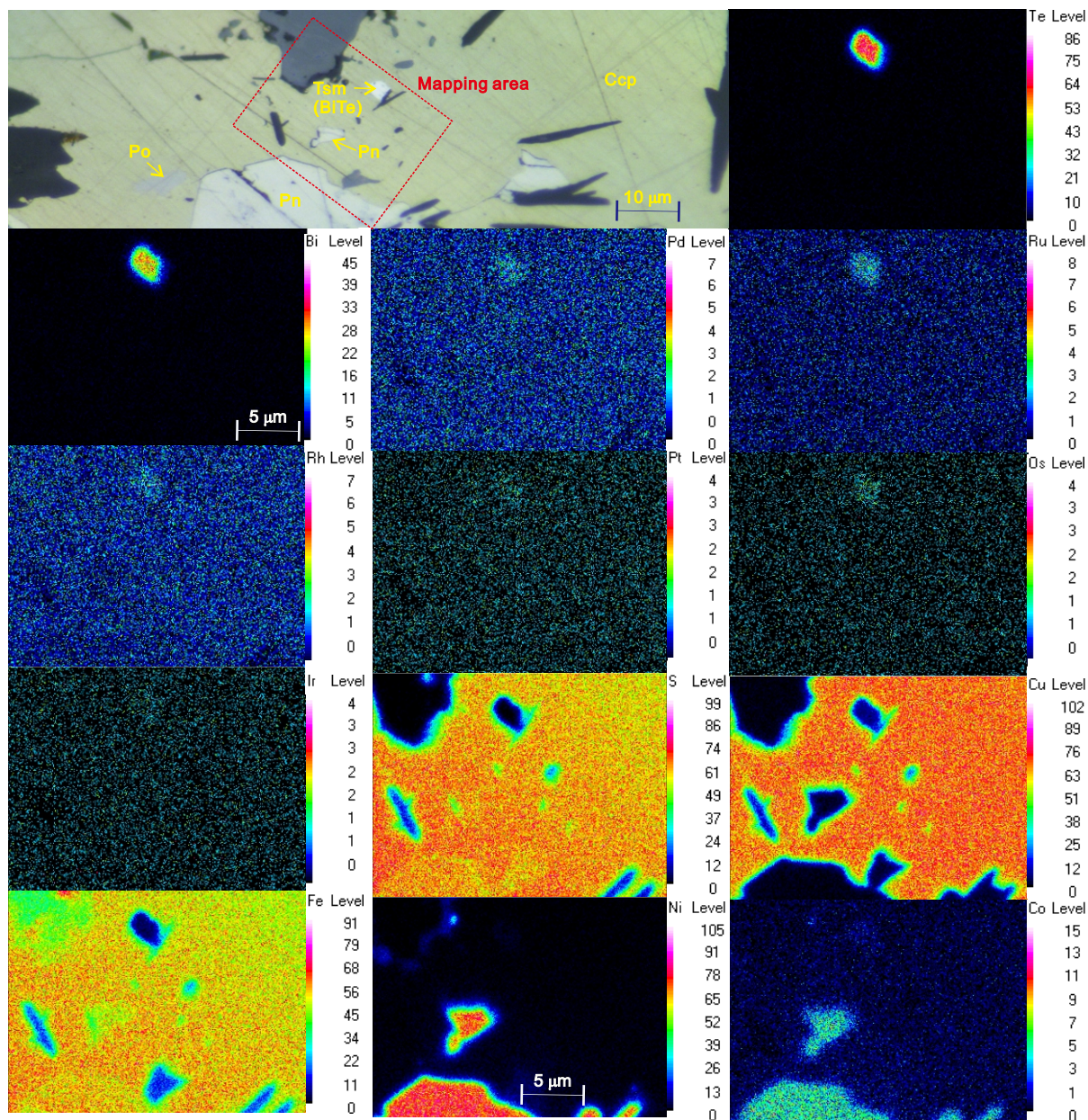
Most zircons before POE (410 Ma) have significantly positive $\epsilon_{\text{Hf}}(t)$, whereas zircons after 410 Ma have much lower $\epsilon_{\text{Hf}}(t)$.

Data sources are listed in [Supplementary Table 6](#).



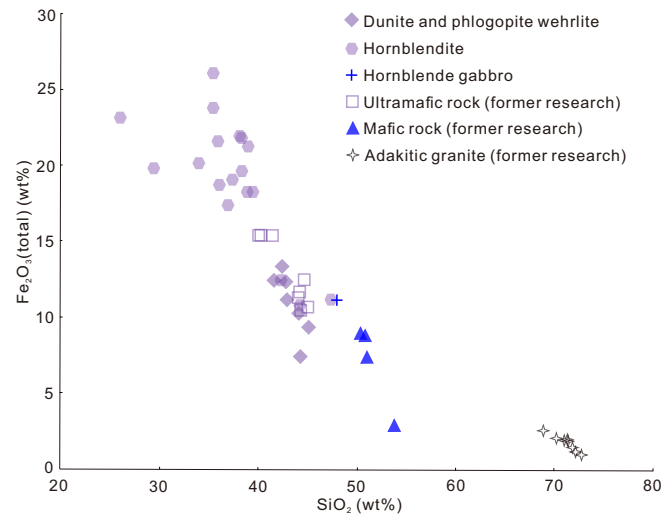
Extended Data Fig. 10. Michenerite (PdBiTe) and pentlandite in pyrrhotite from phlogopite clinopyroxenite.

Abbreviations: Mch = michenerite (PdBiTe), Pn = pentlandite, and Po = pyrrhotite.



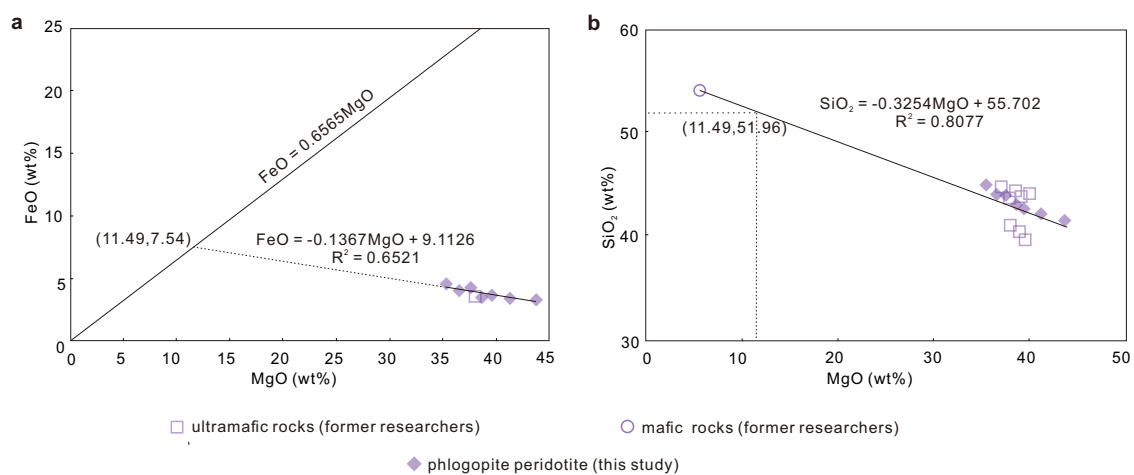
Extended Data Fig. 11. Tsumoite (BiTe) containing Pd-Ru-Rh occurs in chalcopyrite within phlogopite clinopyroxenite.

Abbreviations: Tsm = tsumoite (BiTe), Po = pyrrhotite, Pn = pentlandite, and Ccp = chalcopyrite.



Extended Data Fig. 12. Correlation between SiO_2 and $\text{Fe}_2\text{O}_3(\text{total})$ contents in the Langmuri complex.

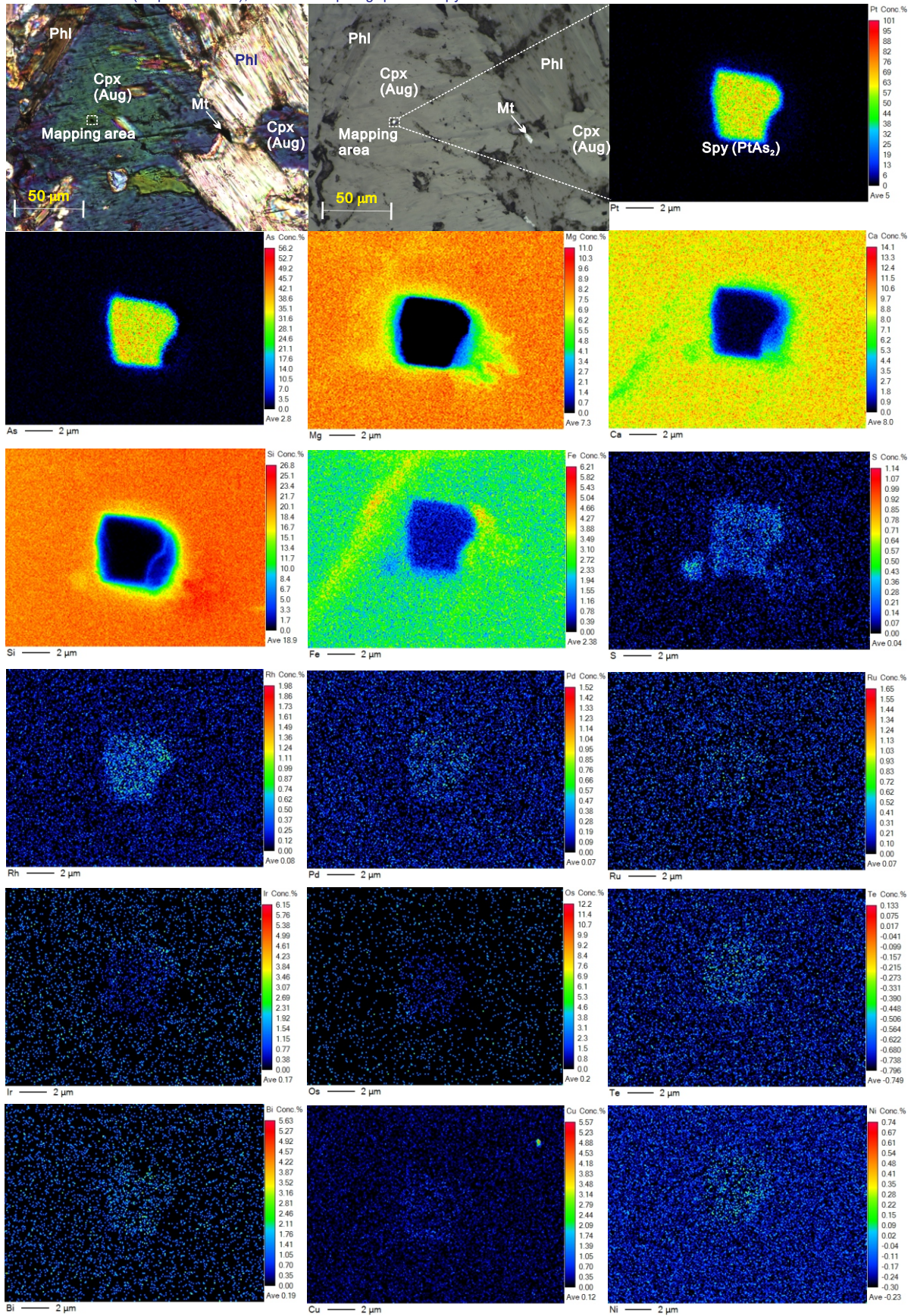
Data sources are listed in [Supplementary Table 5](#).



Extended Data Fig. 13. Estimation of the composition of the parent magma in the Langmuri PGE deposit.

Data sources are listed in [Supplementary Table 5](#).

Location: DH2403 (Depth: 118.8 m); Lithofacies: phlogopite clinopyroxenite.

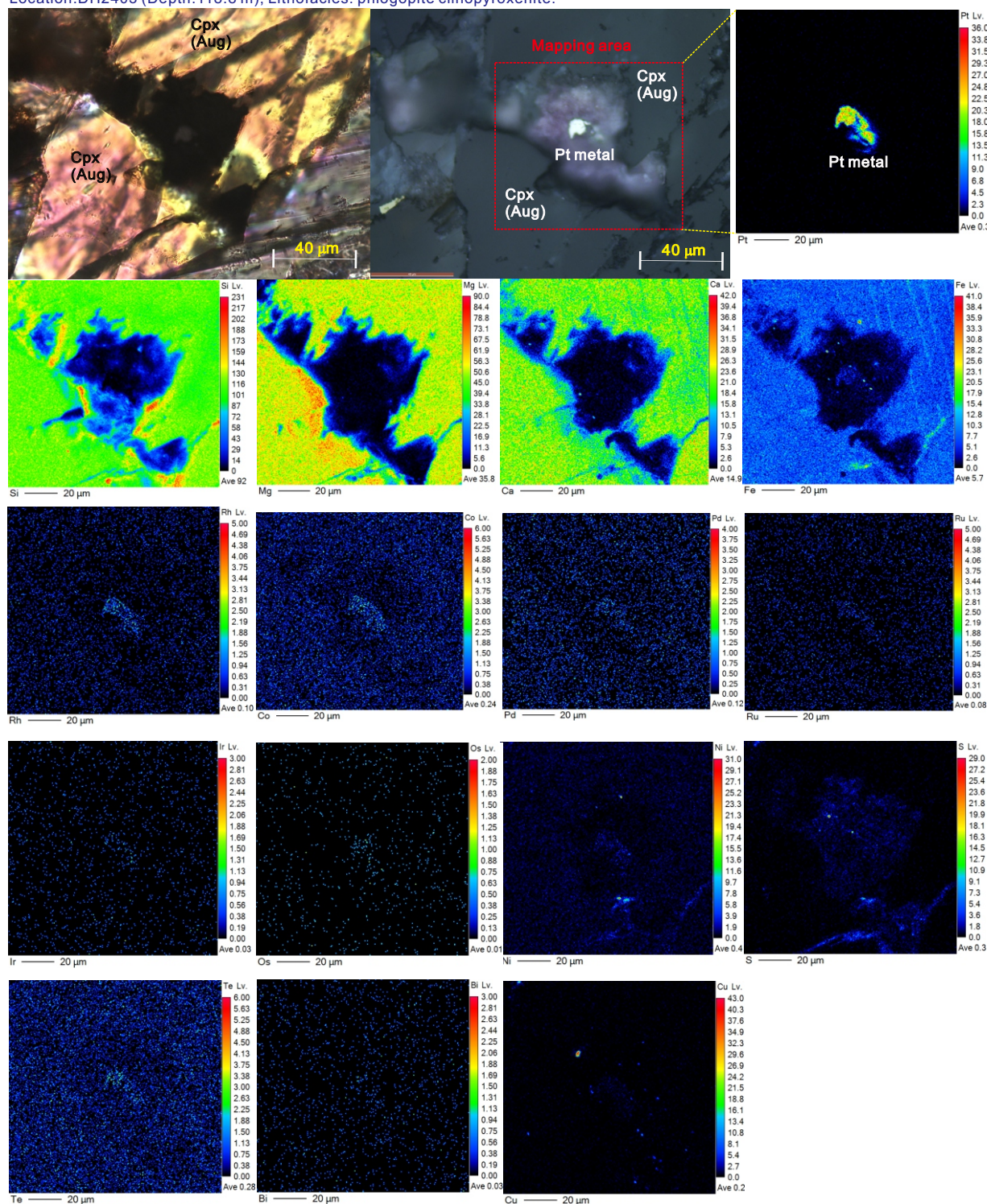


Extended Data Fig. 14. Sperrylite (PtAs_2) exists in augite as an inclusion in phlogopite clinopyroxenite.

The quantitative composition of the sperrylite is listed in [Supplementary Table 2](#).

Abbreviations: Cpx = clinopyroxene, Phl = phlogopite, Aug = augite, Spy = sperrylite, and Mt = magnetite.

Location:DH2403 (Depth:118.8 m); Lithofacies: phlogopite clinopyroxenite.



Extended Data Fig. 15. Pt metal (Pt = 95.35 wt%) with minor Fe (0.56 wt%) and Rh (0.29 wt%) exists in augite in phlogopite clinopyroxenite. The quantitative composition of the Pt metal is listed in [Supplementary Table 2](#).

Abbreviations: Cpx = clinopyroxene, and Aug = augite.