Geochemical Perspectives Letters

Pyrite Re-Os dating confirms synchronous magmatism and hydrothermalism in Troodos ophiolite

B.-X. Su, B.-Y. Gao, S. Ning, V. Symeou

Supplementary Information

The Supplementary Information includes:

- Analytical Procedure of Re-Os Isochron Dating
- Tables S-1 and S-2
- Supplementary Information References

Analytical Procedure of Re-Os Isochron Dating

Rhenium-osmium isotopic analyses were conducted at Metallogenic Elements and Isotopes Lab in the Institute of Geology and Geophysics, Chinese Academy of Sciences. 1 g of sample was weighed and loaded in a Carius tube. The mixed ^{185}Re and ^{190}Os spike, 5 ml of 10 M HCl and 15 ml of 15 M HNO_3 were added while the bottom part of the tube was frozen at -80 °C to -50 °C in an ethanol-liquid nitrogen slush; and the top was sealed using an oxygen-propane torch. After 15 mins of ultrasonic oscillating the tube was then placed in a stainless-steel jacket and heated for 48 h at 220 °C. Upon cooling, the bottom part of the tube was kept frozen and the neck of the tube was broken. The Os was separated as OsO_4 from the inverse aqua regia solution by distillation in the steam bath, and trapped in 2 ml ice water for Os isotope ratio determination (Jin *et al.*, 2013). The residual Re-bearing solution was evaporated to dryness at 80 °C and purified by solvent extraction method using $NH_3{\cdot}H_2O$-butanone (Gao *et al.*, 2022). The Os and Re isotope ratios were determined using an inductively coupled plasma mass spectrometer (ICP-MS Element-XR). The reference material JCBY analyzed in this study yielded concentrations of 38.39 ± 0.26 ng/g for Re and 16.13 ± 0.20 ng/g for Os and ^{187}Os/^{188}Os ratio of 0.3389 ± 0.0056, in good agreement with the results in literature (38.61 ± 0.54 ng/g Re and 16.23 ± 0.17 ng/g Os, Qu *et al.*, 2010; 0.33602 ± 0.00022 ^{187}Os/^{188}Os, Qu *et al.*, 2009). The four blanks yielded average concentrations of 3.0 ± 0.7 pg/g for Re and 0.51 ± 0.13 pg/g for Os and ^{187}Os/^{188}Os ratio of 2.719 ± 0.022 (1 s.d.). In radiogenic sulfides the blank-induced errors on ^{187}Os/^{188}Os and ^{187}Re/^{188}Os are strongly correlated, so they have little effect on the isochron slope (i.e., the age) (e.g., Stein *et al.*, 2000; Li *et al.*, 2025). Our samples have low common Os and high ^{187}Re/^{188}Os ratios (generally >1000). The blank mainly affects the initial ^{187}Os/^{188}Os intercept, not the slope.

Supplementary Tables

Table S-1 Re and Os isotope data of pyrite from four sulfide deposits in the Troodos ophiolite.

Sample	Re (ng/g)	2σ	Common Os (ng/g)	2σ	^{187}Os (ng/g)	2σ	^{187}Re/^{188}Os	2σ	^{187}Os/^{188}Os	2σ
Agrokipia deposit										
24TR-28-1	7.803	0.057	0.01132	0.00022	0.00755	0.00011	3524	76	5.22	0.13
24TR-28-2	6.776	0.054	0.00570	0.00009	0.00647	0.00011	6444	124	9.34	0.23
24TR-28-3	7.173	0.058	0.00453	0.00016	0.00673	0.00014	8867	371	12.67	0.59
24TR-29-1	1.657	0.016	0.00234	0.00011	0.00207	0.00008	4670	293	7.99	0.61
24TR-30-1	5.408	0.036	0.00254	0.00004	0.00572	0.00004	13633	283	21.76	0.46
24TR-30-2	5.268	0.037	0.00265	0.00005	0.00539	0.00006	12583	332	19.37	0.55
24TR-30-3	5.386	0.035	0.00257	0.00005	0.00563	0.00008	13363	370	21.08	0.65
24TR-31-1	0.613	0.005	0.00370	0.00013	0.00097	0.00002	956	40	1.69	0.09
24TR-31-2	0.587	0.004	0.00387	0.00018	0.00097	0.00002	868	47	1.61	0.10
Memi deposit										
24TR-45-1	2.900	0.025	0.00153	0.00003	0.00331	0.00005	15428	578	25.57	1.04
24TR-45-2	2.862	0.022	0.00171	0.00002	0.00325	0.00005	12693	300	20.87	0.58
24TR-45-3	2.850	0.020	0.00173	0.00005	0.00323	0.00002	12419	578	20.40	0.95
24TR-47-1	2.332	0.018	0.01224	0.00034	0.00506	0.00015	979	30	3.21	0.14
24TR-47-2	2.494	0.018	0.01190	0.00020	0.00442	0.00005	1068	21	2.82	0.06
24TR-47-3	2.441	0.016	0.01222	0.00028	0.00425	0.00007	1015	25	2.63	0.08
24TR-47-4	2.382	0.017	0.01147	0.00018	0.00407	0.00006	1060	20	2.68	0.06
24TR-47-5	2.444	0.021	0.01152	0.00022	0.00480	0.00035	1095	24	3.24	0.26
Kokkinopezoula deposit										
24TR-58-1	2.586	0.019	0.00297	0.00004	0.00276	0.00003	5325	98	8.10	0.17
24TR-58-2	2.429	0.024	0.00263	0.00006	0.00257	0.00003	5833	185	8.72	0.29
24TR-58-3	2.494	0.019	0.00273	0.00004	0.00268	0.00002	5729	121	8.72	0.19
24TR-59-1	9.373	0.071	0.01052	0.00016	0.01000	0.00008	4572	82	7.53	0.14
24TR-59-2	9.382	0.069	0.01070	0.00018	0.01001	0.00015	4496	85	7.41	0.17
24TR-59-3	9.355	0.065	0.01020	0.00008	0.00990	0.00004	4719	52	7.72	0.07
24TR-60-1	5.918	0.041	0.00193	0.00005	0.00600	0.00006	21930	835	33.65	1.31
24TR-60-2	5.423	0.039	0.00180	0.00005	0.00539	0.00008	22326	1013	35.30	1.67
24TR-60-3	5.483	0.039	0.00178	0.00005	0.00552	0.00006	23045	972	36.94	1.58
24TR-61-1	1.793	0.013	0.00473	0.00017	0.00215	0.00005	2104	89	3.47	0.17
24TR-61-2	1.839	0.014	0.00448	0.00010	0.00220	0.00004	2298	61	3.79	0.12
24TR-61-3	1.782	0.014	0.00454	0.00015	0.00213	0.00003	2195	85	3.60	0.15

Note: Re, ^{187}Os, and common Os concentration data are blank-corrected; ^{187}Os values represent total ^{187}Os.

Table S-1 continued.

Sample	Re (ng/g)	2σ	Common Os (ng/g)	2σ	^{187}Os (ng/g)	2σ	^{187}Re/^{188}Os	2σ	^{187}Os/^{188}Os	2σ
Apliki deposit										
24TR-4-1	70.88	0.51	0.00708	0.00036	0.06858	0.00064	53008	3013	81.26	4.64
24TR-4-2	70.88	0.48	0.00822	0.00039	0.06895	0.00090	45099	2348	69.51	3.70
24TR-4-3	65.23	0.44	0.05128	0.00092	0.06592	0.00105	6220	120	9.96	0.24
24TR-5-1	112.88	1.48	0.01716	0.00046	0.10721	0.00172	33200	1030	50.05	1.62
24TR-5-2	113.96	1.62	0.01447	0.00026	0.10665	0.00107	40082	948	59.54	1.27
24TR-6-1	333.49	2.24	0.02851	0.00054	0.30735	0.00295	57763	1190	84.62	1.84
24TR-6-2	331.51	2.33	0.03098	0.00062	0.30633	0.00311	52744	1134	77.47	1.76
24TR-6-3	331.61	2.25	0.03098	0.00044	0.30476	0.00258	52760	845	77.07	1.29
24TR-7-1	481.58	3.59	0.86784	0.00984	0.48532	0.00499	2682	36	4.30	0.07
24TR-7-2	48.34	0.36	0.08641	0.00118	0.04864	0.00054	2721	43	4.33	0.08
24TR-7-3	40.84	0.31	0.01157	0.00029	0.04067	0.00034	18017	495	28.34	0.78
24TR-7-4	39.34	0.30	0.01839	0.00048	0.03756	0.00055	10763	302	16.24	0.50

Note: Re, ^{187}Os, and common Os concentration data are blank-corrected; ^{187}Os values represent total ^{187}Os.

Table S-2 Compilation of age data from the Troodos ophiolite.

Rock	Dating method	Mineral/Whole rock	Age (Ma)	Error (Ma)	Data source
Umberiferous strata overlying ophiolite	Radiolarian biostratigraphy		89-91		Blome and Irwin, 1985
Pelite interlayered with upper pillows	Radiolarian biostratigraphy		75-84		Desmet, 1977
Strata between upper and lower pillows	Foraminiferal biostratigraphy		91-98		Mantis, 1971
Celadonite-zeolite vein	Rb-Sr	Mineral pair	86.1	0.4	Staudigel et al., 1986
Celadonite	Rb-Sr	Whole rock	74.0	5.0	Laureijs et al., 2021
Celadonite	Rb-Sr	Whole rock	76.0	4.0	Laureijs et al., 2021
Depleted boninite	Ar-Ar	Whole rock	55.5	0.9	Osozawa et al., 2012
Pillow lava	U-Pb	Titanite	83.0	55.0	Su et al., 2025
Pillow lava	K-Ar	Whole rock	75.0	5.0	Delaloye and Desmet, 1979
Altered rock (Agrokipia deposit)	Rb-Sr	Whole rock	95	8	Kawahata and Scott, 1990
Sulfide ore (Agrokipia deposit)	Re-Os	Pyrite	93.0	5.9	This study
Sulfide ore (Apliki deposit)	Re-Os	Pyrite	88.2	1.5	This study
Sulfide ore (Kokkinopezoula deposit)	Re-Os	Pyrite	92.7	4.0	This study
Sulfide ore (Memi deposit)	Re-Os	Pyrite	93.1	4.2	This study
Arc tholeiite	Ar-Ar	Whole rock	90.6	1.2	Osozawa et al., 2012
Andesite of the arc tholeiite suite	K-Ar	Whole rock	84.7	2.3	Staudigel et al., 1986

Table S-2 continued.

Rock	Dating method	Mineral/Whole rock	Age (Ma)	Error (Ma)	Data source
Sheeted dike	K-Ar	Whole rock	83.0	3.0	Delaloye et al., 1980
Sheeted dike	K-Ar	Whole rock	79.2	3.8	Desmet et al., 1978
Diabase	U-Pb	Zircon	94.5	0.4	Su et al., 2025
Diabase	U-Pb	Titanite	93.2	2.0	Su et al., 2025
Diabase	U-Pb	Titanite	91.6	6.3	Su et al., 2025
Diabase	U-Pb	Titanite	89.2	5.8	Su et al., 2025
Diabase	U-Pb	Titanite	87.8	3.7	Su et al., 2025
Diabase	U-Pb	Titanite	86.8	3.4	Su et al., 2025
Diabase	U-Pb	Titanite	82.9	4.3	Su et al., 2025
Diabase	U-Pb	Titanite	81.1	3.4	Su et al., 2025
Diabase	U-Pb	Titanite	81.0	22.0	Su et al., 2025
Plagiogranite	U-Pb	Zircon	91	0.4	Chen et al., 2020
Plagiogranite	U-Pb	Zircon	91.8	0.4	Chen et al., 2020
Plagiogranite	U-Pb	Zircon	90.1	0.7	Chen et al., 2020
Plagiogranite	U-Pb	Zircon	91.2	1.0	Mukasa and Ludden, 1987
Plagiogranite	U-Pb	Zircon	91.6	1.4	Mukasa and Ludden, 1987
Plagiogranite	U-Pb	Zircon	90.8	1.6	Konstantinou et al., 2007
Plagiogranite	U-Pb	Zircon	91.1	1.3	Konstantinou et al., 2007
Plagiogranite	U-Th/He	Zircon	83.0	3.0	Morag et al., 2016
Plagiogranite	U-Th/He	Zircon	92.0	3.0	Morag et al., 2016
Plagiogranite	U-Pb	Titanite	90.8	1.8	Su et al., 2025
Plagiogranite	U-Pb	Zircon	90.5	1.1	Su et al., 2025
Gabbro	U-Th/He	Zircon	101.0	12.0	Morag et al., 2016
Gabbro	U-Th/He	Zircon	94.0	4.0	Morag et al., 2016
Gabbro	U-Pb	Titanite	93.4	4.6	Su et al., 2025
Gabbro	U-Pb	Zircon	91.6	0.3	Su et al., 2025
Gabbro	U-Pb	Zircon	91.2	0.7	Su et al., 2025
Amphibolite	Ar-Ar	Hornblende	88.9	0.8	Chan et al., 2007
Amphibolite	Ar-Ar	Hornblende	80.5	0.3	Chan et al., 2007
Amphibolite	Ar-Ar	Hornblende	76.5	0.4	Chan et al., 2007
Amphibolite	Ar-Ar	Hornblende	75.7	0.3	Chan et al., 2007

Supplementary Information References

Blome, C.D., Irwin, W.P. (1985) Equivalent radiolarian ages from ophiolitic terranes of Cyprus and Oman. *Geology* 13, 401–404. https://doi.org/10.1130/0091-7613(1985)13<401:ERAFOT>2.0.CO;2

Chan, G.H.-N., Malpas, J., Xenophontos, C., Lo, C.-H. (2007) Timing of subduction zone metamorphism during the formation and emplacement of Troodos and Baer-Bassit ophiolites: insights from ^{40}Ar-^{39}Ar geochronology. *Geological Magazine* 144, 797–810. https://doi.org/10.1017/S0016756807003792

Chen, Y., Niu, Y., Shen, F., Gao, Y., Wang, X. (2020) New U-Pb zircon age and petrogenesis of the plagiogranite, Troodos ophiolite, Cyprus. *Lithos* 362–363, 105472. https://doi.org/10.1016/j.lithos.2020.105472

Delaloye, M., Desmet, A. (1979) Nouvelles données radiométriques sur les pillow-lavas du Troodos (Chypre). "New radiometric data on the Troodos pillow lavas (Cyprus)." *Comptes Rendus de l'Académie des Sciences (D)* 288, 461–464.

Delaloye, M., Desmet, A., Desmons, J., Gagny, Cl., Rocci, G. (1980) Geochronological interpretation of the Troodos sheeted dike complex. *Ofioliti* 5, 27–34.

Desmet, A. (1977) *Contribution à l'étude de la croûte océanique mésozoïque de Méditerranée orientale: les pillow-lavas du Troodos (Chypre). "Contribution to the study of the Mesozoic oceanic crust of the Eastern Mediterranean: the Troodos pillow lavas (Cyprus)".* Doctoral dissertation, Université de Nancy.

Desmet, A., Lapierre, H., Rocci, G., Gagny, Cl., Parrot, J.-F., Delaloye, M. (1978) Constitution and significance of the Troodos sheeted complex. *Nature* 273, 527–530. https://doi.org/10.1038/273527a0

Gao, B., Li, W., Chu, Z., Zhang, L. (2022) An improved solvent extraction procedure for Re isotopic measurements. *Microchemical Journal* 180, 107568. https://doi.org/10.1016/j.microc.2022.107568

Jin, X., Li, W., Xiang, P., Sakyi, P.A., Zhu, M., Zhang, L. (2013) A contribution to common Carius tube distillation techniques. *Journal of Analytical Atomic Spectrometry* 28, 396–404. https://doi.org/10.1039/C2JA10374E

Kawahata, H., Scott, S.D. (1990) Strontium isotopes and water-rock interaction of the Agrokipia 'B' stockwork deposit in the Troodos ophiolite, Cyprus: a fossil subseafloor ore body. *Geochemical Journal* 24, 349–356. https://doi.org/10.2343/geochemj.24.349

Konstantinou, A., Wirth, K., Vervoort, J. (2007) U-Pb isotopic dating of Troodos plagiogranite, Cyprus by LA-ICP-MS. *Geological Society of America Annual Meeting*, Denver, 28–31 October 2007, Session 143, Paper 16.

Laureijs, C.T., Coogan, L.A., Spence, J. (2021) Regionally variable timing and duration of celadonite formation in the Troodos lavas (Cyprus) from Rb-Sr age distributions. *Chemical Geology* 560, 119995. https://doi.org/10.1016/j.chemgeo.2020.119995

Li, Y., Glorie, S., Selby, D. (2025) Re–Os geochronology for sulfides and organic-rich sediments. National Science Review 12, nwaf300. https://doi.org/10.1093/nsr/nwaf300

Mantis, M. (1971) Paleontological evidence defining the age of the Troodos pillow lava series. *Cypriakos Logos* 3, 202–208.

Morag, N., Haviv, I., Katzir, Y. (2016) From ocean depths to mountain tops: Uplift of the Troodos ophiolite (Cyprus) constrained by low-temperature thermochronology and geomorphic analysis. *Tectonics* 35, 622–637. https://doi.org/10.1002/2015TC004069

Mukasa, S.B., Ludden, J.N. (1987) Uranium-lead isotopic ages of plagiogranites from the Troodos ophiolite, Cyprus, and their tectonic significance. *Geology* 15, 825–828. https://doi.org/10.1130/0091-7613(1987)15<825:UIAOPF>2.0.CO;2

Osozawa, S., Shinjo, R., Lo, C.-H., Jahn, B.-m., Hoang, N., Sasaki, M., Ishikawa, K., Kano, H., Hoshi, H., Xenophontos, C., Wakabayashi, J. (2012) Geochemistry and geochronology of the Troodos ophiolite: An SSZ ophiolite generated by subduction initiation and an extended episode of ridge subduction?. *Lithosphere* 4, 497–510. https://doi.org/10.1130/L205.1

Qu, W.J., Du, A.D., Li, C., Sun, W.J. (2009) High-precise determination of osmium isotopic ratio in the Jinchuan copper-nickel sulfide ore samples. *Rock And Mineral Analysis* 28, 219–222 (in Chinese with English abstract).

Qu, W.J., Du, A.D., Yang, G., Li, C., Stein, H.J., Hannah, J.L. (2010) Re-Os reference material: JCBY and CORO. *Mineral Deposits* 29, 831–832 (in Chinese with English abstract).

Staudigel, H., Gillis, K., Duncan, R. (1986) K/Ar and Rb/Sr ages of celadonites from the Troodos ophiolite, Cyprus. *Geology* 14, 72–75. https://doi.org/10.1130/0091-7613(1986)14<72:AASAOC>2.0.CO;2

Stein, H.J., Morgan, J.W., Scherstén, A. (2000) Re-Os Dating of Low-Level Highly Radiogenic (LLHR) Sulfides: The Harnäs Gold Deposit, Southwest Sweden, Records Continental-Scale Tectonic Events. *Economic Geology* 95, 1657–1671. https://doi.org/10.2113/gsecongeo.95.8.1657

Su, B.-X., Wang, J., Pan, Q.-Q., Xiao, Y., Cui, M.-M. (2025) Impact-induced 'young' zircon in old rocks from Troodos ophiolite, Cyprus. *Journal of the Geological Society* 182, jgs2024-192. https://doi.org/10.1144/jgs2024-192