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Coesite in eclogite from the North Qaidam Mountains and its implications

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Coesite provides direct evidence for ultrahigh pressure metamorphism. Although coesite has been found as inclusions in zircon in paragneiss of the north Qaidam Mountains, it has never been identified in eclogite. In this contribution, based on petrographic observations and *in situ* Raman microprobe spectroscopy, coesite was identified as inclusions in garnet of eclogite from the Aercituoshan, Dulan UHP metamorphic unit, north Qaidam Mountains. Coesite is partly replaced by quartz, showing a palisade texture. This is the first report on coesite in eclogite from the north Qaidam Mountains, and is also supported by garnet-omphacite-phengite geothermobarometry (2.7–3.25 GPa, 670–730 °C). Coesite and its pseudomorphs have not been found in eclogites and associated rocks of other units of the north Qaidam Mountains. Further studies are required to confirm if all metamorphic units in the north Qaidam Mountains underwent the ultrahigh-pressure metamorphism.

North Qaidam Mountains, Dulan, eclogite, coesite, Ultrahigh pressure metamorphism

The ultrahigh-pressure (UHP) metamorphism refers to the metamorphism above the coesite-quartz transition. Therefore, although a number of mineralogical indicators have been considered as evidence for UHP metamorphism, coesite is still one of the most direct indicators for UHP metamorphism.

Over the past ten years, a new HP/UHP metamorphic terrane has been confirmed along the north Qaidam Mountains in western China^[1–13]. It has been correlated to the south Altyn Tagh HP/UHP metamorphic terrane, and constrains a 400 km offset for the Altyn Tagh fault. Therefore, South Altyn-North Qaidam was considered as a single HP-UHP metamorphic belt truncated by a large strike-slip fault, similar to the case of the Dabie-Sulu HP-UHP metamorphic zone which was truncated by the sinistral Tanlu strike-slip fault in eastern China, and split into the Dabie and Sulu regions^[14–21]. However, in contrast to Dabie-Sulu in eastern China, where UHP metamorphic evidence has been commonly recognized in different rock types, evidence of UHP metamorphism is relatively rare in the north Qaidam (NQD) and south

Altyn Tagh (SAT)^[11,22,23]. Up to now, coesite was only reported as inclusions in zircons of amphibolite-facies paragneiss in the Dulan area, eastern NQD. This high-pressure silica polymorph has never been positively identified in eclogite from the NQD and SAT. Although polycrystalline quartz inclusions in garnet and omphacite in the Jianggelesayi eclogite of SAT and Dulan eclogite of NQD were interpreted as pseudomorphs after coesite, the polycrystalline aggregates cannot be simply the result of a transformation from coesite because they contain small amounts of K-feldspar^[24,25].

Recently, detailed field work and petrographic observations have led to the first discovery of coesite inclusions in garnet of eclogite in the northern slope of Aercituoshan, southern Dulan HP/UHP metamorphic unit, north Qaidam Mountains.

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The North Qaidam HP-UHP metamorphic belt is located on the northeastern margin of the Tibetan Plateau in northwestern China, along the northern margin of the Qaidam Basin, and extends over a distance of 350 km from Yuka-Luofengpo in the west to Yematan-Shaliuhe (the location of this study) in the east. Based on rock associations, petrologic criteria and field relationships, four HP/UHP metamorphic units can be distinguished from west to east: the Yuka-Luofengpo eclogite-gneiss unit, the Luliangshan garnet peridotite-gneiss unit, the Xitieshan eclogite-gneiss unit, and the Dulan eclogite-gneiss unit^[21].

The Dulan eclogite-gneiss unit consists of granitic gneiss, paragneiss (schist), eclogite lenses enclosed within gneiss and minor ultramafic rock. On the basis of spatial relations, rock associations and metamorphic evolution of eclogites and associated rocks, two subbelts, namely, the South Dulan Belt (SDB) and the North Dulan Belt (NDB), are recognized^[3,11]. These two sub-belts are separated by the Yematan granitic pluton. Eclogite in the NDB, which has been relatively well studied, consists mainly of garnet, omphacite, rutile and phengite. Polycrystalline inclusions of quartz + K-feldspar (sanidine) in garnet, and exsolved quartz lamellae in omphacite, which are considered as indicators of UHP

metamorphism, have been observed^[23]. The estimated peak metamorphic conditions are $P > 2.8$ GPa, $T = 600$ – 750°C ^[11]. A few coesite inclusions have been found in zircons from paragneiss in the NDB^[4,11,13]. In contrast to NDB eclogites, eclogites in the SDB have been less extensively studied. Previous studies indicate that some eclogites in the SDB contain kyanite, and/or minor phengite^[11,15]. The estimated P - T conditions for eclogites also fall within the coesite stability field, and a few coesite pseudomorphs have been reported^[15]. However, thus far no coesite has been recognized.

Coesite-bearing eclogite was discovered in the Aercituoshan, eastern segment of the north Qaidam Mountains (Figure 1), belonging to the south belt of the Dulan HP/UHP metamorphic unit^[3,11]. Eclogites occur as lenses within white mica-bearing felsic gneiss. Based on petrographic observations on about 20 samples of eclogites, coesite was recognized in two fresh eclogite samples. The two eclogite samples consist mainly of garnet, omphacite, phengite and rutile with minor apatite and zircon. These samples contain 3%–5% phengite, significantly more than is found in other eclogites in the Dulan HP/UHP metamorphic unit. Coesite-bearing eclogites exhibit a clear foliation defined by oriented gar-

Figure 1 Simplified geological map of the Dulan UHP metamorphic unit and sample locations.

net, omphacite and phengite. The microprobe analyses show that elliptical garnet is unzoned in sample Q07-8-2.3 (Prp₁₆₋₁₈Alm₅₃₋₅₅Gro₂₈₋₃₀Sps_{1-1.2}) and sample Q07-8-2.2 (Prp₂₀₋₂₃Alm₄₇₋₅₀Gro₂₇₋₃₀Sps_{1-1.3}; mineral abbreviations are according to ref. [26] except phengite (Phe)). Omphacite contains 37–50 mol% jadeite, and jadeite content of omphacite in sample Q07-8-2.3 is obviously higher than that in sample Q07-8-2.2. Phengite contains 6.88–7.03 Si p.f.u. (based on 22 oxygen atoms; Table 1).

Figure 2 displays the well-preserved coesite inclusions in garnet and coesite pseudomorphs in omphacite. High relief coesite in the center of the inclusion is surrounded by low relief quartz, showing the typical palisade texture. Raman spectra of the various preserved coesite grains were obtained at the Key Laboratory for Continental Dynamics, Ministry of Land and Resources of China, Beijing, with a Renishaw-1000 laser Raman spectroscope using the 514 nm line of an Ar-ion laser. Figure 3 shows that the well-preserved coesite relicts display strong coesite Raman lines 521–522 and 271 cm⁻¹, and a relatively weak quartz Raman line 464–465

cm⁻¹. In contrast, small coesite relicts exhibit weak coesite Raman lines 521–522 and 271 cm⁻¹, and a relatively strong quartz Raman line 464–465 cm⁻¹ (Figure 3).

The garnet-clinopyroxene-phengite geobarometer^[27] combined with the garnet-clinopyroxene geothermometer^[28] was used to estimate the peak *P-T* conditions of two coesite-bearing eclogite samples. The results are 670–705° and 2.7–3.05 GPa for sample Q07-8-2.3, and 680–730 °C and 2.85–3.25 GPa for sample Q07-8-2.2 (Figure 4). The estimated *P-T* conditions for both samples are consistent with coesite stability.

For two coesite-bearing eclogite samples, except for coesite inclusions, abundant polycrystalline quartz inclusions were also observed in the same thin section (Figure 2). EDS analysis indicates that these polycrystalline inclusions are pure SiO₂. Quartz aggregates surrounding coesite relicts show a similar palisade texture to polycrystalline quartz inclusions. This implies that these polycrystalline inclusions consisting of pure quartz resulted from the transformation of coesite. In addition, it

Table 1 Representative mineral compositions (wt%) in coesite-bearing eclogites^{a)}

Sample	Q07-8-2.3									Q07-8-2.2								
Mineral	Grt	Omp	Phe	Grt	Omp	Phe	Grt	Omp	Phe	Grt	Omp	Phe	Grt	Omp	Phe	Grt	Omp	Phe
SiO ₂	37.64	55.46	53.89	37.97	54.79	52.66	37.49	55.28	51.92	38.45	55.46	52.65	38.79	54.78	52.46	38.04	55.1	51.86
TiO ₂	0.25	0.16	0.73	0.12	0.19	0.72	0.05	0.20	0.68	0.03	0.05	0.71	0.03	0.08	0.77	0.08	0.09	0.79
Al ₂ O ₃	21.62	10.87	25.24	21.50	10.50	25.05	21.44	11.05	26.23	21.57	9.23	24.91	21.64	9.75	25.48	21.47	9.41	25.45
Cr ₂ O ₃	0.00	0.00	0.00	0.03	0.00	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02
FeO	25.54	5.91	2.67	25.09	6.24	2.82	25.54	6.15	2.94	22.38	4.05	1.43	22.79	4.43	1.62	22.87	4.31	1.49
MnO	0.43	0.06	3.99	0.50	0.00	0.00	0.47	0.00	0.01	0.47	0.04	0.00	0.40	0.05	0.00	0.48	0.00	0.00
MgO	4.43	7.25	0.00	4.00	7.15	3.90	4.13	7.32	3.66	5.68	9.26	4.21	5.95	9.57	4.14	5.78	9.34	4.42
CaO	9.80	12.82	0.02	10.75	12.59	0.01	10.03	12.92	0.00	10.46	15.41	0.02	9.58	16.05	0.00	10.31	15.70	0.03
Na ₂ O	0.00	7.22	0.00	0.00	7.32	0.29	0.00	7.30	0.31	0.00	5.76	0.30	0.00	5.41	0.33	0.00	5.89	0.35
K ₂ O	0.00	0.00	10.28	0.00	0.00	10.6	0.00	0.00	10.31	0.00	0.00	10.44	0.00	0.00	10.62	0.00	0.00	10.75
Total	99.71	99.75	97.13	99.96	98.78	96.05	99.19	100.24	96.06	99.04	99.26	94.67	99.18	100.12	95.42	99.03	99.88	95.16
O	12	6	22	12	6	22	12	6	22	12	6	22	12	6	22	12	6	22
Si	2.958	1.982	7.033	2.977	1.977	6.983	2.970	1.965	6.880	2.999	1.994	7.026	3.014	1.956	6.963	2.977	1.967	6.915
Al	2.002	0.458	3.883	1.987	0.446	3.915	1.999	0.464	4.096	1.983	0.391	3.819	1.982	0.410	3.986	1.980	0.396	4.000
Ti	0.015	0.004	0.072	0.007	0.005	0.072	0.003	0.005	0.068	0.002	0.001	0.071	0.002	0.002	0.077	0.005	0.002	0.079
Cr	0.000	0.000	0.000	0.002	0.000	0.000	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002
Fe ³⁺	0.000	0.043	0.000	0.000	0.066	0.000	0.000	0.040	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.011	0.000
Fe ²⁺	1.678	0.134	0.291	1.645	0.123	0.313	1.690	0.143	0.326	1.460	0.111	0.160	1.481	0.132	0.180	1.497	0.118	0.166
Mn	0.029	0.002	0.000	0.033	0.000	0.000	0.031	0.000	0.001	0.031	0.001	0.000	0.026	0.002	0.000	0.000	0.000	0.000
Mg	0.519	0.386	0.776	0.467	0.385	0.771	0.487	0.388	0.723	0.660	0.496	0.837	0.689	0.509	0.819	0.674	0.497	0.878
Ca	0.825	0.491	0.003	0.903	0.485	0.001	0.850	0.492	0.000	0.874	0.595	0.003	0.798	0.614	0.000	0.864	0.600	0.000
Na	0.000	0.500	0.081	0.000	0.512	0.075	0.000	0.503	0.080	0.000	0.401	0.078	0.000	0.375	0.085	0.000	0.408	0.090
K	0.000	0.000	1.710	0.000	0.000	1.793	0.000	0.000	1.743	0.000	0.000	1.777	0.000	0.000	1.798	0.000	0.000	1.829
Total	8.026	4.000	13.849	8.002	4.000	13.922	8.030	4.000	13.916	8.008	4.000	13.871	7.993	4.000	13.908	8.029	4.000	13.964

a) Minerals were analyzed at the Institute of Geology and Geophysics, Chinese Academy of Sciences, using CAME-CAUSX-51 and JXA8100 electron probe with 15 kV accelerating voltage, 20 nA beam current and a 5 μm beam. The Fe³⁺ contents in omphacite were calculated by Fe³⁺ = Na/(Al + Cr).

Figure 2 Photomicrographs showing textural features of coesite and its pseudomorph in eclogite. a and b, Coesite (high relief, center) surround by quartz, enclosed in garnet in eclogite. b is detail of a (sample Q07-8-2.3). c and d, Polycrystalline quartz inclusion in omphacite, showing palisade texture (sample Q07-8-2.3). e and f, Coesite inclusion (high relief, center) surround by quartz (sample Q07-8-2.2).

is noteworthy that in addition to pure polycrystalline quartz inclusions, some polycrystalline quartz-K-feldspar aggregates also occur as inclusions within garnet and omphacite from the same eclogite samples. These inclusions show conspicuous radial cracks in the host minerals. Previously reported polycrystalline inclusions in eclogites in the south Altyn Tagh and Dulan area of the north Qadim Mountains belong mainly to this type, and also had been interpreted as coesite pseudomorphs^[22,23], but Massonne^[24] suggest that polycrystalline quartz inclusions with additional K-feldspar in eclogitic garnet and omphacite may instead represent the former K-cymrite. However, inclusions of polycrystalline quartz-K-feldspar aggregates occur in the

same sample in which coesite relicts were also recognized. This implies that polycrystalline quartz-K-feldspar inclusions may also be the result of a transformation from a UHP phase such as K-cymrite, although further detailed investigation is needed to verify the former mineral and transformation process.

In the NQD HP/UHP metamorphic belt, except for the Dulan HP/UHP metamorphic unit^[11,15,29], coesite, polycrystalline quartz after coesite, and polycrystalline quartz+K-feldspar aggregates have not been discovered in eclogite and associated rocks of the other units including the Yuka-Luofengpo eclogite-gneiss unit and Xitieshan eclogite-gneiss unit. *P-T* estimates for phengite-bearing eclogites in the western segment of the

Figure 3 Raman spectra from spot measurements of coesites. a and b for sample Q07-8-2.3; c and d for sample Q07-8-2.2.

Figure 4 Results of geothermobarometry from coesite-bearing eclogite. Grt-Cpx-Phe barometer: From ref. [28]; Grt-Cpx thermometer: from ref. [29].

NQD also suggest that they formed in the quartz stability field^[8,9]. Up to now, unambiguous UHP metamorphic evidence was only recognized in eclogite and paragneiss from the Dulan area and garnet peridotite from the Lu-liangshan area. Therefore, in contrast to the Dabie-Sulu UHP terrane in eastern China, where UHP metamorphic evidence has been recognized in many rock types and

voluminous continental materials were considered to subduct to UHP depths, abundant rocks in the NQD may record only HP metamorphism, whereas small amounts of rocks were subducted to UHP depths. Further studies are needed to confirm this interpretation.

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- 1 Yang J J, Deng J F. Garnet peridotites and eclogites in the Northern Qaidam Mountains, Tibetan plateau: A first record. In: First Workshop on UHP Metamorphism and Tectonics (eds Ernst W G, Liou J G), 1994. A-20, ILP Task Group III-6, Stanford University
- 2 Yang J S, Xu Z Q, Li H B, et al. The discovery of eclogite in the northern margin of Qaidam basin, China. *Chin Sci Bull*, 1998, 43(8): 1755—1760[DOI]
- 3 Yang J S, Song S G, Xu Z Q, et al. Discovery of coesite in the north Qaidam Early Paleozoic ultrahigh-pressure (UHP-HP) metamorphic belt, NW China (in Chinese with English abstract). *Acta Geol Sin*, 2001, 75(2): 175—179
- 4 Yang J S, Xu Z Q, Zhang J X, et al. Early Palaeozoic North Qaidam UHP metamorphic belt on the north-eastern Tibetan plateau and a paired subduction model. *Terra Nova*, 2002, 14: 397—404[DOI]
- 5 Yang J S, Liu F L, Wu C L, et al. Two ultrahigh-pressure metamorphic events recognized in the central orogenic belt of China: evidence from the U-Pb dating of coesite-bearing zircons. *Int Geol Rev*, 2005, 47: 327—343[DOI]
- 6 Zhang J X, Yang J S, Xu Z Q, et al. Peak and retrograde age of eclogites at the northern margin of Qaidam basin, northwestern China: evidences from U-Pb and Ar-Ar dates (in Chinese with English abstract). *Geochimica*, 2002, 29(3): 217—222
- 7 Zhang J X, Meng F C, Yang J S. Eclogitic metapelites in the western segment of the north Qaidam Mountains: Evidence on “*in situ*” relationship between eclogite and its country rock. *Sci China Ser D-Earth Sci*, 2004, 47(12): 1102—1112[DOI]
- 8 Zhang J X, Meng F C, Yang J S. PT evolution of eclogites in the North Qaidam Mountains (in Chinese with English abstract). *Acta Petrol Mineral*, 2005, 24(3): 245—254
- 9 Zhang J X, Yang J S, Mattinson C G, et al. Two contrasting eclogite cooling histories, North Qaidam HP/UHP terrane, western China: Petrological and isotopic constraints. *Lithos*, 2005, 84: 51—76[DOI]
- 10 Zhang J X, Yang J S, Meng F C, et al. U-Pb isotopic studies of eclogites and their host gneisses in the Xitieshan area of the North Qaidam Mountains, western China: New evidence for an early Palaeozoic HP-UHP metamorphic belt. *J Asian Earth Sci*, 2006, 28: 143—150[DOI]
- 11 Song S G, Yang J S, Xu Z Q, et al. Metamorphic evolution of the coesite-bearing ultrahigh-pressure terrane in the north Qaidam, northern Tibet, NW China. *J Metamorph Geol*, 2003, 21: 631—644[DOI]
- 12 Song S, Zhang L, Niu Y, et al. Geochronology of diamond-bearing zircons from garnet peridotite in the North Qaidam UHPM belt, Northern Tibetan Plateau: A record of complex histories from oceanic lithosphere subduction to continental collision. *Earth Planet Sci Lett*, 2005, 234: 99—118[DOI]
- 13 Song S, Zhang L, Niu Y, et al. Evolution from oceanic subduction to continental collision: A case study of the Northern Tibetan Plateau inferred from geochemical and geochronological data. *J Petrol*, 2006, 47: 435—455[DOI]
- 14 Song S, Zhang L, Niu Y. Ultra-deep origin of garnet peridotite from the North Qaidam ultrahigh-pressure belt, Northern Tibetan Plateau, NW China. *Am Mineral*, 2004, 89: 1330—1336
- 15 Zhang G, Song S, Zhang L, et al. The subducted oceanic crust within continental-type UHP metamorphic belt in the North Qaidam, NW China: Evidence from petrology, geochemistry and geochronology. *Lithos*, 2008, 104: 99—118[DOI]
- 16 Liu L, Che Z C, Luo J H, et al. Recognition and implication of eclogite in the western Altun Mountains, Xinjiang. *Chin Sci Bull*, 1997, 42(10): 931—934[DOI]
- 17 Liu L, Sun Y, Xiao P, et al. Discovery of ultrahigh pressure magnetite-bearing garnet ilmenite (3.8 GPa) in the Altyn Tagh, Northwest China. *Chin Sci Bull*, 2002, 47(9): 881—885[DOI]
- 18 Liu L, Chen D L, Zhang A D, et al. Ultrahigh pressure gneissic K-feldspar garnet clinopyroxene in the Altyn Tagh, W China Evidence from clinopyroxene exsolution in garnet. *Sci China Ser D-Earth Sci*, 2002, 48(11): 1000—1010[DOI]
- 19 Zhang J X, Zhang Z M, Xu Z Q, et al. Petrology and geochronology of eclogites from the western segment of the Altyn Tagh, northwestern China. *Lithos*, 2001, 56(2-3): 189—208
- 20 Zhang J X, Mattinson C G, Meng F C, et al. An Early Palaeozoic HP/HT granulite-garnet peridotite association in the south Altyn Tagh, NW China: P-T history and U-Pb geochronology. *J Metamorph Geol*, 2005, 23: 491—510[DOI]
- 21 Zhang, J X, Mattinson C G, Meng F C, et al. Polyphase tectonothermal history recorded in granulitized gneisses from the North Qaidam HP/UHP metamorphic terrane, Western China: Evidence from zircon U-Pb geochronology. *Geol Soc Am Bull*, 2008, 120(5-6): 732—749[DOI]
- 22 Zhang J X, Yang J S, Xu Z Q, et al. Evidence for UHP metamorphism of eclogite from the Altun Mountains. *Chin Sci Bull*, 2002, 47(7): 751—755[DOI]
- 23 Song S G, Yang J S. Sanidine + quartz inclusions in Dulan eclogites: evidence for UHP metamorphism on the north margin of the Qaidam basin, China (in Chinese with English abstract). *Acta Geol Sin*, 2001, 75(2): 180—185
- 24 Massonne H J. First find of coesite in the ultrahigh-pressure metamorphic area of the central Erzgebirge, Germany. *Eur J Mineral*, 2001, 13: 565—570[DOI]
- 25 Yang J J, Godard G, Smith D C. K-feldspar-bearing coesite pseudomorphs in an eclogite from Lanshantou (Eastern China). *Eur J Mineral*, 1998, 10: 969—985
- 26 Kretz R. Symbols for rock-forming minerals. *Am Mineral*, 1983, 68: 277—279
- 27 Ravna E J K, Terry M P. Geothermobarometry of UHP and HP eclogites and schists—An evaluation of equilibria among garnet-clinopyroxene-kyanite-phengite-coesite/quartz. *J Metamorph Geol*, 2004, 22: 579—592[DOI]
- 28 Ravna E K. The garnet-clinopyroxene Fe²⁺-Mg geothermometer: An updated calibration. *J Metamorph Geol* 2000, 18: 211—219[DOI]
- 29 Zhang G B, Zhang L F, Song S G, et al. UHP metamorphic evolution and SHRIMP geochronology of a meta-ophiolitic gabbro in the North Qaidam, NW China. *J Asian Earth Sci*, doi: 10.1016/j.jseas.2008.11.013[DOI]