Magma oxygen fugacity of mafic-ultramafic intrusions in convergent margin settings: insights for the role of magma oxidation states on magmatic Ni-Cu sulfide mineralization

Yonghua Cao [1, 2], Christina Yan Wang [1, 2]*, Bo Wei [1, 2]

[1] CAS Key Laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

[2] Guangdong Provincial Key Laboratory of Mineral Physics and Materials, Guangzhou 510640, China

Corresponding author: Dr. C.Y. Wang (wang_yan@gig.ac.cn)

Supplementary Tables

Table S1. Major element compositions of selected olivine-spinel pairs from the mafic-ultramafic intrusions in the central Asian orogenic belt

Table S2. Calculation results of parental magma composition (wt.%), olivine fraction (%), and V/Sc of parental magmas for the most primitive olivine orthocumulates from the mafic-ultramafic intrusions in the central Asian orogenic belt

Table S3. Magma fO_2 of the mafic-ultramafic intrusions in the central Asian orogenic belt

Table S1. Major element compositions of selected olivine-spinel pairs from the mafic-ultramafic intrusions in the central Asian orogenic belt (determined by EPMA)

Sample No.	Rock types	Olivine (wt.%)			Spinel (wt.%)							$Kd_{Mg/Fe}^{Ol\text{-}Sp}$	$T^{Ol\text{-}Sp}$ (K)	*P* (GPa)	fO_2 (FMQ)
		MgO	FeO	Fo	Al_2O_3	Cr_2O_3	MgO	FeO	Fe_2O_3	Cr#	Mg#				
Jinbulake intrusion (this study)															
QB-13	Wehrlite	44.20	16.40	83	45.70	15.40	10.00	21.30	7.40	18	46	5.7	720	0.2	2.4
QB-43	Wehrlite	45.00	14.40	85	34.60	23.20	8.40	22.40	10.10	31	40	8.4	780	0.2	2.4
QB-55	Wehrlite	45.10	14.70	85	37.00	22.70	7.90	23.60	9.20	29	37	9.2	724	0.2	2.5
QB-65	Wehrlite	44.70	14.70	85	29.30	30.80	8.40	23.80	6.50	41	39	8.6	798	0.2	1.4
QB-97	Wehrlite	46.30	14.10	85	32.20	29.90	7.70	23.30	6.60	38	37	9.9	754	0.2	1.7
QB-104	Wehrlite	45.80	13.90	86	34.20	29.70	9.40	21.30	5.30	37	44	7.5	794	0.2	1.2
QB-108	Wehrlite	45.40	14.00	85	29.70	28.30	7.20	23.30	10.00	39	35	10.5	778	0.2	2.3
QB2-21	Wehrlite	44.90	15.20	84	41.30	18.60	10.10	20.90	8.70	23	46	6.1	771	0.2	2.3
QB2-40	Wehrlite	45.50	14.20	85	35.00	26.80	8.60	22.20	6.30	34	41	8.2	761	0.2	1.7
QB2-48	Wehrlite	44.60	15.90	83	30.90	27.50	7.30	23.80	8.50	37	35	9.2	765	0.2	2.0
QB2-78	Wehrlite	45.10	14.40	85	32.00	30.20	9.50	21.00	7.80	39	45	6.9	853	0.2	1.6
QB2-102	Wehrlite	44.30	15.10	84	30.70	30.00	8.20	22.80	8.20	40	39	8.2	812	0.2	1.7
QB2-115	Wehrlite	44.60	15.20	84	16.60	34.80	3.80	26.80	15.20	59	20	21.0	790	0.2	2.6
QB2-194	Wehrlite	44.90	15.30	84	34.90	23.90	8.30	22.50	9.30	31	40	8.0	771	0.2	2.2
Heishan intrusion (this study; Wang et al., 2011)															
901-26	Harzburgite	44.80	14.90	84	15.50	35.40	7.30	26.40	12.80	61	33	11.0	999	0.3	2.1
901-37	Harzburgite	44.20	15.00	84	19.60	36.20	8.70	22.60	12.10	55	41	7.7	1002	0.3	1.8
901-39	Harzburgite	44.60	15.30	84	22.50	35.80	8.70	22.30	9.30	52	41	7.6	941	0.3	1.5
901-63	Harzburgite	44.80	14.60	85	21.70	36.80	11.10	20.60	9.20	53	49	5.7	1102	0.3	1.3
901-71	Harzburgite	43.90	15.60	84	20.50	31.80	6.60	25.30	14.50	51	32	10.8	882	0.3	2.3
GHH-87	Lherzolite	44.60	15.50	84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GHH-94	Lherzolite	46.70	12.70	87	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GHH-113	Lherzolite	46.40	13.60	86	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GHH-106	Lherzolite	43.40	16.70	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Sample No.	Rock types	Olivine (wt.%)			Spinel (wt.%)							$Kd_{Mg/Fe}^{Ol\text{-}Sp}$	$T^{Ol\text{-}Sp}$ (K)	*P* (GPa)	fO_2 (FMQ)
		MgO	FeO	Fo	Al_2O_3	Cr_2O_3	MgO	FeO	Fe_2O_3	Cr#	Mg#				
Erbutu intrusion (this study)															
18EBT-1	olivine orthopyroxenite	44.50	14.50	85	18.90	40.90	5.90	23.50	7.00	59	31	12.2	840	0.25	1.2
18EBT-2	olivine orthopyroxenite	44.90	15.10	84	17.00	45.10	5.30	25.00	5.30	64	27	14.0	822	0.25	0.6
18EBT-3	olivine orthopyroxenite	44.90	15.10	84	15.40	47.30	5.00	25.20	4.60	67	26	14.9	816	0.25	0.3
18EBT-4	olivine orthopyroxenite	44.40	16.20	83	15.70	46.00	5.40	24.50	5.60	66	28	13.7	843	0.25	0.7
18EBT-5	olivine orthopyroxenite	46.40	13.40	86	19.60	42.20	6.80	22.90	4.40	59	34	11.8	841	0.25	0.5
18EBT-6	olivine orthopyroxenite	44.80	14.60	85	18.50	42.50	5.90	24.10	6.10	61	30	12.7	834	0.25	0.9
18EBT-8	olivine orthopyroxenite	46.10	14.70	85	13.90	49.00	4.50	25.70	4.40	70	24	17.9	804	0.25	0.4
18EBT-9	olivine orthopyroxenite	44.70	15.30	84	14.80	46.00	4.90	25.20	6.40	68	26	15.0	833	0.25	0.9
18EBT-10	olivine orthopyroxenite	46.20	13.70	86	21.70	41.70	7.20	22.60	4.00	56	36	10.5	842	0.25	0.3
18EBT-12	olivine orthopyroxenite	44.80	15.10	84	17.60	45.90	5.20	24.70	4.00	64	27	14.1	799	0.25	0.1
18EBT-16	olivine orthopyroxenite	45.30	15.10	84	18.00	42.00	5.30	24.70	6.70	61	27	14.1	815	0.25	1.1
18EBT-17	olivine orthopyroxenite	45.80	14.30	85	21.50	40.20	6.80	23.40	5.20	56	34	11.1	834	0.25	0.8
18EBT-20	olivine orthopyroxenite	31.40	8.80	86	19.60	41.40	6.20	23.80	6.10	59	32	12.6	830	0.25	1.0
18EBT-21	olivine orthopyroxenite	45.80	13.40	86	26.90	38.40	9.80	19.70	3.20	49	47	6.9	900	0.25	-0.1
Baixintan intrusion (this study; Feng et al., 2017, 2018)															
BXT-1	Lherzolite	44.00	15.40	84	17.90	31.10	8.00	22.60	19.70	54	39	8.1	1030	0.40	2.5
BXT-2	Lherzolite	45.00	14.60	85	16.70	32.10	7.60	22.70	19.80	56	37	9.2	1009	0.40	2.7
BXT-3	Lherzolite	43.90	16.90	82	16.70	29.90	7.20	23.60	22.60	55	35	8.5	1024	0.40	2.6
BXT-4	Lherzolite	43.00	16.30	83	20.00	33.20	8.60	21.60	15.00	53	42	6.6	1029	0.40	2.0
BXT-7	Lherzolite	42.20	15.40	83	16.60	31.30	7.00	23.90	21.10	56	34	9.3	998	0.40	2.6
BXT-8	Lherzolite	43.00	15.10	84	13.50	26.30	5.70	25.40	29.50	57	28	12.8	982	0.40	3.3
BXT-ZK-2	Lherzolite	44.70	15.70	84	10.90	29.80	1.20	31.10	16.80	65	6	7.7	709	0.40	3.0

Sample No.	Rock types	Olivine (wt.%)			Spinel (wt.%)							$Kd_{Mg/Fe}^{Ol-Sp}$	T^{Ol-Sp} (K)	P (GPa)	fO_2 (FMQ)
		MgO	FeO	Fo	Al_2O_3	Cr_2O_3	MgO	FeO	Fe_2O_3	Cr#	Mg#				
BXT-ZK-4	Lherzolite	44.00	16.00	83	11.80	22.30	5.20	12.10	46.00	56	53	4.4	1581	0.40	3.0
BXT-ZK-1	Lherzolite	43.80	16.60	83	22.60	33.20	8.00	16.60	17.50	50	56	3.7	1261	0.40	1.3
BXT-ZK-3	Lherzolite	43.80	16.20	83	18.30	34.50	7.30	18.50	18.60	56	48	5.3	1183	0.40	1.7
ZK001-1.1	Lherzolite	43.80	16.20	83	6.50	28.70	4.40	25.90	34.00	75	23	16.0	1025	0.40	3.5
ZK001-4.1	Lherzolite	45.40	14.10	85	19.50	31.90	8.60	21.70	17.50	52	41	8.1	1004	0.40	2.5
ZK001-4.3	Lherzolite	44.20	14.80	84	17.90	31.10	8.00	22.60	19.70	54	39	8.5	1021	0.40	2.6
ZK001-4.4	Lherzolite	44.60	14.60	85	16.70	32.10	7.60	22.60	19.90	56	37	9.1	1012	0.40	2.7
ZK001-6.1	Lherzolite	43.40	16.40	83	20.00	33.20	8.60	21.50	15.00	53	42	6.6	1031	0.40	2.0
ZK0703-2.1	Lherzolite	43.40	17.40	82	16.30	31.80	6.00	25.50	18.90	57	29	10.7	945	0.40	2.5
ZK0802-4.1	Lherzolite	44.80	14.50	85	19.80	32.00	8.60	21.80	16.60	52	41	7.8	1007	0.40	2.4
ZK0802-6.1	Lherzolite	44.10	14.90	84	18.30	31.30	8.10	22.40	19.10	53	39	8.2	1018	0.40	2.5
ZK0803-6.1	Lherzolite	45.50	13.80	86	18.60	32.60	8.30	22.10	17.60	54	40	8.8	994	0.40	2.5
ZK0803-7.1	Lherzolite	43.60	16.20	83	18.30	33.00	7.60	23.60	17.10	55	36	8.4	993	0.40	2.3
ZK6602-1.1	Lherzolite	42.90	16.60	82	16.70	29.90	7.20	23.60	22.50	55	35	8.5	1025	0.40	2.6
Huangshannan intrusion (this study)															
HSN1612	Lherzolite	46.70	12.30	87	19.80	42.70	5.40	25.50	5.90	59	27	17.9	770	0.30	1.3
HSN1614	Lherzolite	46.80	12.30	87	23.00	41.20	6.70	24.10	4.00	54	33	13.7	785	0.30	0.6
HSN1616	Lherzolite	43.20	17.20	82	10.40	41.40	2.80	29.10	12.50	59	25	25.8	783	0.30	2.2
HSN1618	Lherzolite	45.20	14.30	85	18.70	43.90	5.90	20.90	9.90	73	15	12.9	832	0.30	0.9
HSN1620	Lherzolite	45.40	14.00	85	18.00	39.30	4.90	27.40	8.70	59	33	18.0	812	0.30	2.2
HSN1626	Lherzolite	46.20	13.50	86	19.50	42.10	6.50	24.60	6.00	58	29	12.3	848	0.30	1.4
HSN1627	Lherzolite	46.30	12.80	87	20.30	42.20	5.70	24.50	6.10	61	30	16.5	791	0.30	1.3
HSN1628	Lherzolite	46.30	13.70	86	20.30	40.60	5.00	25.50	6.10	57	26	17.4	756	0.30	1.3
HSN1629	Lherzolite	43.80	16.70	83	11.90	40.10	3.40	26.80	16.00	69	18	23.2	828	0.30	2.5
HSN1632	Lherzolite	42.70	18.30	81	8.70	40.10	2.00	28.70	17.60	76	11	32.8	778	0.30	2.6
HSN1635	Lherzolite	42.80	17.60	81	15.50	40.00	3.60	31.80	7.00	39	40	18.5	787	0.30	2.0
HSN1643	Lherzolite	43.80	16.30	83	24.10	35.70	4.90	22.70	10.40	63	19	14.0	733	0.30	1.5
HSN1644	Lherzolite	45.00	14.90	84	32.50	30.70	8.30	21.60	5.80	50	25	8.1	776	0.30	1.1

Sample No.	Rock types	Olivine (wt.%)			Spinel (wt.%)							$Kd_{Mg/Fe}^{Ol\text{-}Sp}$	$T^{Ol\text{-}Sp}$ (K)	*P* (GPa)	fO_2 (FMQ)
		MgO	FeO	Fo	Al_2O_3	Cr_2O_3	MgO	FeO	Fe_2O_3	Cr#	Mg#				
Tulaergen intrusion (this study)															
TLEG-18	Lherzolite	N/A	N/A	N/A	17.80	34.20	7.20	24.60	12.00	56	34	N/A	N/A	0.40	N/A
TLEG-21	Lherzolite	N/A	N/A	N/A	9.40	28.40	4.00	29.20	23.00	67	20	N/A	N/A	0.40	N/A
TLEG-20	Lherzolite	44.60	14.60	84	14.40	30.50	5.90	25.10	20.50	59	30	12.9	956	0.40	2.9
TLEG-26	Lherzolite	44.90	15.10	85	15.30	31.70	6.50	24.60	19.00	58	32	11.2	968	0.40	2.7
TLEG-25	Lherzolite	42.70	17.60	81	12.80	30.50	6.20	26.30	19.50	62	29	10.3	1044	0.40	2.5
TLEG-24	Lherzolite	N/A	N/A	N/A	15.70	31.20	6.20	24.30	18.40	57	31	N/A	N/A	0.40	N/A
Luodong intrusion (Su et al., 2011)															
LD-2	Dunite	46.80	11.70	88	32.00	30.00	10.40	22.70	2.90	44	38	11.6	777	0.70	0.3
LD-3	Dunite	47.10	11.50	88	26.30	34.20	7.70	24.90	6.80	47	35	13.3	779	0.70	1.5
LD-9	Dunite	45.00	14.50	85	28.90	30.90	6.00	28.10	5.30	42	28	14.5	711	0.70	1.1
LDZ01-55	Dunite	48.00	10.60	89	30.00	33.20	10.60	20.50	4.50	43	48	8.8	836	0.70	0.9
LDZ01-332	Dunite	46.00	13.20	86	29.50	31.30	11.00	20.00	7.60	42	50	6.4	933	0.70	1.3
LDZ01-334	Dunite	46.80	11.90	88	30.40	30.20	10.00	21.50	7.60	40	45	8.5	839	0.70	1.6
LDZ01-345	Dunite	46.80	12.10	87	28.30	30.80	8.20	23.60	7.90	42	38	11.0	792	0.70	1.7
LDZ01-356	Dunite	46.60	12.20	87	35.50	26.90	11.30	20.20	4.80	34	50	6.8	829	0.70	0.9
LDZ01-380	Dunite	46.50	12.20	87	33.80	28.70	9.80	22.30	4.40	36	44	8.6	779	0.70	0.9

Notes: $Kd_{Mg/Fe}^{Ol\text{-}Sp}$ =molar $(Mg/Fe^{2+})_{Ol}/(Mg/Fe^{2+})_{Spl}$, which represents the Mg/Fe exchange coefficient between olivine and spinel.

The FeO and Fe_2O_3 of spinel were calculated by assuming perfect stoichiometry. The calculated FeO and Fe_2O_3 of spinel for available samples were further corrected using the secondary spinel standards.

$T^{Ol\text{-}Spl}$ refers to the Mg/Fe exchange closure temperature of olivine-spinel pairs, which is calculated using the equation of Ballhaus et al. (1991).

Pressure was calculated using the clinopyroxene geobarometer given by Nimis and Ulmer (1998).

fO_2 was calculated using the olivine-spinel oxygen barometer of Ballhaus et al. (1991).

N/A means not available.

Table S2. Calculation results of parental magma composition (wt.%), olivine fraction (%), and V/Sc of parental magmas for the most primitive olivine orthocumulates of the mafic-ultramafic intrusions in the central Asian orogenic belt

Intrusions	Heishan			Huangshannan			Poyi			Luodong			Hongqiling No.2		
Tectonic settings	Arc setting			Post-subduction, extensional setting											
The most primitive olivine orthocumulates	GHH-94			ZK1701-257			PB-40			LDZ01-380			HQ2-54		
	Olivine	Whole rock	Parental magma	Olivine	Whole rock	Parental magma	Olivine	Whole rock	Parental magma	Olivine	Whole rock	Parental magma	Olivine	Whole rock	Parental magma
SiO_2 (wt.%)	39.70	45.15	56.73	40.80	41.70	47.23	40.14	42.35	52.09	40.60	42.24	45.27	40.01	42.57	49.35
TiO_2 (wt.%)	0.00	0.40	1.24	0.00	0.15	1.07	0.00	0.16	0.86	0.11	0.24	0.47	0.00	0.38	1.38
Al_2O_3 (wt.%)	0.00	4.60	14.38	0.00	2.33	16.64	0.00	2.96	15.99	0.14	5.17	14.51	0.00	6.17	22.52
Fe_2O_3(wt.%)	0 .00	0.68	1.30	0.00	0.68	1.00	0.00	0.24	1.30	0.00	0.58	1.68	0.00	0.63	0.50
FeO (wt.%)	12.50	11.70	9.90	13.30	11.62	7.30	10.80	10.62	9.83	9.88	10.37	12.05	13.85	10.73	3.79
MnO (wt.%)	0.16	0.17	0.18	0.20	0.17	-0.01	0.12	0.14	0.23	0.20	0.15	0.06	0.20	0.16	0.06
MgO (wt.%)	46.00	35.00	11.63	45.10	39.90	7.96	48.48	42.07	13.83	48.40	37.83	18.20	45.59	34.18	3.95
CaO (wt.%)	0.07	1.25	3.77	0.02	1.37	9.66	0.04	1.02	5.34	0.14	3.11	8.61	0.03	3.65	13.25
Na_2O (wt.%)	0.00	0.70	2.20	0.00	0.07	0.48	0.00	0.35	1.89	0.00	0.49	1.41	0.00	0.49	1.77
K_2O (wt.%)	0.00	0.84	2.61	0.00	0.04	0.32	0.00	0.00	0.00	0.00	0.04	0.12	0.00	0.22	0.79
P_2O_5 (wt.%)	0.00	0.08	0.24	0.00	0.04	0.32	0.00	0.00	0.00	0.00	0.03	0.09	0.00	0.05	0.20
Liquid Fe/Mg	0.85[(1)]		0.85[(2)]	0.92[(1)]		0.92[(2)]	0.7[(1)]		0.71[(2)]	0.64[(1)]		0.66[(2)]	0.95[(1)]		0.96[(2)]
Ol fraction (%)		0.68			0.86			0.81			0.66			0.73	
V (ppm)	3.9[(3)]	32.3[(4)]		3.5[(3)]	35.0[(4)]		1.4[(3)]	32.5[(4)]		7.8[(3)]	75.0[(4)]		3.7[(3)]	78.0[(4)]	
Sc (ppm)	4.5[(3)]	6.5[(4)]		3.2[(3)]	7.0[(4)]		3.5[(3)]	6.4[(4)]		6.0[(3)]	13.9[(4)]		3.8[(3)]	11.8[(4)]	
Liquid V (ppm)		92.5[(5)]			229[(5)]			157[(5)]			205[(5)]			279[(5)]	

Intrusions	Heishan	Huangshannan	Poyi	Luodong	Hongqiling No.2
Tectonic settings	Arc setting	Post-subduction, extensional setting			
Liquid Sc (ppm)	10.6[(5)]	30.3[(5)]	18.0[(5)]	29.2[(5)]	33.4[(5)]
Liquid V/Sc	8.7	7.5	8.7	7	8.3
Mantle fO_2	~FMQ+1.0	~FMQ	~FMQ+1.0	~FMQ	~FMQ+0.5

Notes: The fraction of olivine and the composition of parental magma for the most primitive olivine orthocumulates were estimated based on the method provided by Xue et al. (2019) and the mass balance principle of Li and Ripley (2011).

(1) The liquid Fe/Mg calculated based on olivine Fe/Mg (*e.g.*, Roeder and Emsile, 1970);

(2) The estimated parental magma FeO/MgO; Note that the calculated liquid Fe/Mg (1) are quite similar to (2), indicating that the results are valid;

(3) The measured average V and Sc concentrations of the olivine in the mafic-ultramafic intrusions in the CAOB;

(4) Whole-rock V and Sc concentrations of the most primitive olivine orthocumulates in the mafic-ultramafic intrusions in the CAOB;

(5) The V and Sc concentrations of parental magmas that were calculated based on the mass balance (*c.f.*, Godel et al., 2011). The mantle fO_2 of the intrusions was estimated based on the V/Sc of primary magmas of the intrusions and the V/Sc systematics proposed by Lee et al. (2005) and Mallmann and O'Neill (2009).

Data sources: Whole-rock data and chemical compositions of olivine for GHH-94, ZK1701-257, PB-40, LDZ01-380, and HQ2-54 are from Xie et al. (2012), Mao et al. (2016), this study, Su (2014), and Wei (2013), respectively.

Table S3. Magma fO_2 of the mafic-ultramafic intrusions in the central Asian orogenic belt (calculated based on the modeled partitioning of V in olivine)

Sample No.	Rock types	Spot numbers	Sc (ppm)		V (ppm)		$(V/Sc)_{Ol}$		$(V/Sc)_{Liq}^{(1)}$	$D_V^{Ol(2)}$	$fO_2^{(3)}$		fO_2 (Ol-Spl)
			Avg	SD	Avg	SD	Avg	SD			Avg	$SD^{(4)}$	
Heishan intrusion													
GHH-87	Lherzolite	72	7.2	1.1	4.7	1.4	0.7	0.2	8.7	0.02	2.3	0.5	N/A
GHH-94	Lherzolite	18	4.8	0.7	3.7	0.7	0.8	0.1	8.7	0.02	2.0	0.4	N/A
GHH-113	Lherzolite	25	5.9	0.6	4.0	0.6	0.7	0.1	8.7	0.02	2.2	0.4	N/A
GHH-106	Lherzolite	11	6.9	0.9	5.6	1.1	0.8	0.2	8.7	0.02	2.0	0.4	N/A
Erbutu intrusion													
18EBT-1	Olivine orthopyroxenite	8	2.8	0.7	3.6	2.2	1.3	0.5	6.0	0.04	0.9	0.4	1.2
18EBT-2	Olivine orthopyroxenite	8	2.6	0.6	3.4	1.7	1.3	0.4	6.0	0.04	0.9	0.4	0.6
18EBT-4	Olivine orthopyroxenite	5	2.6	0.6	3.5	1.5	1.3	0.5	6.0	0.05	0.8	0.4	0.7
18EBT-6	Olivine orthopyroxenite	5	2.8	0.5	3.3	1.2	1.2	0.5	6.0	0.04	1.0	0.4	0.9
18EBT-9	Olivine orthopyroxenite	6	3.0	0.6	3.3	1.5	1.1	0.9	6.0	0.04	1.1	0.4	0.9
18EBT-10	Olivine orthopyroxenite	6	2.2	0.5	2.9	1.5	1.3	0.7	6.0	0.04	0.8	0.4	0.3
18EBT-12	Olivine orthopyroxenite	6	3.0	0.7	4.7	2.0	1.6	0.4	6.0	0.05	0.6	0.4	0.1
18EBT-13	Olivine orthopyroxenite	7	2.3	0.3	3.2	1.4	1.4	0.5	6.0	0.05	0.8	0.4	N/A
18EBT-16	Olivine orthopyroxenite	6	2.7	0.2	3.9	0.8	1.4	0.3	6.0	0.05	0.7	0.4	1.1
18EBT-17	Olivine orthopyroxenite	5	2.2	0.5	2.2	0.9	1.0	0.3	6.0	0.03	1.2	0.4	0.8
18EBT-21	Olivine orthopyroxenite	6	2.0	0.6	3.7	1.5	1.8	0.4	6.0	0.06	0.4	0.4	-0.1
Huangshannan intrusion													
HSN1611	Lherzolite	9	3.1	0.7	2.5	1.7	0.8	0.4	7.5	0.02	1.8	0.4	N/A
HSN1612	Lherzolite	17	2.6	0.7	2.6	1.0	1.0	0.4	7.5	0.03	1.5	0.4	1.3
HSN1614	Lherzolite	14	3.7	0.9	3.8	2.0	1.0	0.3	7.5	0.03	1.5	0.4	0.6
HSN1616	Lherzolite	10	2.6	0.5	1.9	1.3	0.8	0.3	7.5	0.02	1.9	0.4	2.2
HSN1618	Lherzolite	11	3.1	0.4	3.0	1.1	1.0	0.3	7.5	0.03	1.5	0.4	0.9
HSN1620	Lherzolite	4	2.6	0.4	2.9	0.9	1.1	0.2	7.5	0.03	1.3	0.4	2.2

Sample No.	Rock types	Spot numbers	Sc (ppm)		V (ppm)		$(V/Sc)_{Ol}$		$(V/Sc)_{Liq}$[1]	$D_V^{Ol(2)}$	fO_2[3]		fO_2 (Ol-Spl)
			Avg	SD	Avg	SD	Avg	SD			Avg	SD[4]	
HSN1622	Lherzolite	10	4.2	0.9	4.9	1.4	1.2	0.3	7.5	0.03	1.3	0.4	N/A
HSN1627	Lherzolite	5	2.5	0.5	3.2	0.7	1.3	0.4	7.5	0.03	1.2	0.4	1.3
Luodong intrusion													
LD08-32	Dunite	12	5.0	1.4	5.5	1.9	1.1	0.3	7.0	0.03	1.3	0.4	N/A
LD08-31	Dunite	9	5.3	0.8	6.7	1.7	1.3	0.3	7.0	0.04	1.1	0.4	N/A
LD08-29	Dunite	7	6.6	1.1	9.6	1.8	1.5	0.4	7.0	0.04	0.9	0.4	N/A
LD08-6	Dunite	9	6.1	1.0	9.5	1.1	1.6	0.1	7.0	0.04	0.8	0.4	N/A
LD08-19	Dunite	8	6.2	0.7	6.1	0.9	1.0	0.1	7.0	0.03	1.4	0.4	N/A
LD08-38	Dunite	10	6.0	0.6	8.5	0.6	1.4	0.2	7.0	0.04	0.9	0.4	N/A
LD08-35	Dunite	11	6.8	1.4	9.7	1.5	1.4	0.3	7.0	0.04	0.9	0.4	N/A
Hongqiling No.1 and No.2 intrusions													
HQ18	Lherzolite	9	3.1	0.5	2.4	0.5	0.8	0.2	8.3	0.02	2.0	0.4	2.3
HQ21	Lherzolite	9	3.8	0.6	3.9	1.0	1.0	0.3	8.3	0.03	1.6	0.4	N/A
HQ14	Lherzolite	11	3.3	0.5	2.5	1.0	0.8	0.2	8.3	0.02	2.0	0.4	2.1
HQ17	Lherzolite	12	3.1	0.4	2.4	0.7	0.8	0.2	8.3	0.02	2.0	0.4	2.3
HQ31	Lherzolite	5	3.7	0.3	3.8	1.1	1.1	0.2	8.3	0.03	1.6	0.4	1.9
HQ35	Lherzolite	15	3.4	0.8	3.4	1.0	1.0	0.2	8.3	0.02	1.6	0.4	1.8
HQ2-58	Lherzolite	12	3.4	1.0	3.4	0.7	1.0	0.2	8.3	0.02	1.6	0.4	1.7
HQ2-55	Lherzolite	11	4.7	0.7	4.4	0.7	0.9	0.2	8.3	0.02	1.7	0.4	1.8
HQ2-63	Lherzolite	11	3.6	0.8	4.0	0.8	1.1	0.2	8.3	0.03	1.5	0.4	1.9
HQ2-66	Lherzolite	11	4.2	0.9	3.9	0.7	0.9	0.1	8.3	0.02	1.7	0.4	1.9
HQ2-54	Lherzolite	8	3.8	0.7	3.7	0.6	1.0	0.1	8.3	0.02	1.7	0.4	1.8
HQ2-68	Lherzolite	11	2.7	0.6	2.2	0.6	0.8	0.1	8.3	0.02	1.9	0.4	2.1

Notes: (1) $(V/Sc)_{Liq}$ represents the estimated V/Sc of parental magmas of the mafic-ultramafic intrusions in the CAOB, which has been calculated in Table S2. The V/Sc of parental magma of the Erbutu intrusion was assumed to be 6, based on which, the magma fO_2 of this intrusion calculated based on the V partitioning in olivine is consistent with the value based on the olivine-spinel oxygen barometer, see Fig. 9a in the text.

(2) the modeled partition coefficients of V between olivine and melt based on equation 6 in the text.

(3) fO_2 calculated based on equation 7 in the text.

(4) $SD_{(\triangle QFM)}$=-0.1375×logD_V^{Ol}+0.2 (Shishkina et al., 2018), SD=1σ standard deviation. The magma fO_2 calculated based on the olivine-spinel oxygen barometer is also given for comparison.

N/A means not available.

References cited

Ballhaus C., Berry R.F., and Green D.H. (1991) High pressure experimental calibration of the olivine-orthopyroxene-spinel oxygen geobarometer: implications for the oxidation state of the upper mantle. Contributions to Mineralogy and Petrology 107, 27–40.

Godel B., Barnes S.J., and Maier W. D. (2011) Parental magma composition inferred from trace element in cumulus and intercumulus silicate minerals: an example from the lower and lower critical zones of the Bushveld Complex, South-Africa. Lithos 125, 537–552.

Jochum K.P., Stoll B., Herwig K., Willbold M., Hofmann A.W., Amini M., Aarburg S., Abouchami W., Hellebrand E., and Mocek B. (2006). MPI-DING reference glasses for in situ microanalysis: New reference values for element concentrations and isotope ratios. Geochemistry, Geophysics, Geosystems 7, Q02008.

Jochum K.P., Weis U., Stoll B., Kuzmin D., Yang Q., Raczek I., Jacob D.E., Stracke A., Birbaum K., Frick D.A., Gunther D., and Enzweiler J. (2011) Determination of Reference Values for NIST SRM 610–617 Glasses Following ISO Guidelines. Geostandards and Geoanalytical Research 35, 397-427.

Lee C.T.A., Leeman W.P., Canil D., and Li Z.X.A. (2005) Similar V/Sc systematics in MORB and arc basalts: Implications for the oxygen fugacities of their mantle source regions. Journal of Petrology 46, 2313–2336.

Li C., and Ripley E.M. (2011) The giant Jinchuan Ni-Cu-(PGE) deposit; tectonic setting, magma evolution, ore genesis, and exploration implications. Reviews in Economic Geology 17, 163–180.

Mao Y., Qin K., Tang D., Feng H. and Xue S. (2016) Crustal contamination and sulfide immiscibility history of the Permian Huangshannan magmatic Ni-Cu sulfide deposit, East Tianshan, NW China. Journal of Asian Earth Sciences 129, 22–37.

Nimis P., and Ulmer P. (1998) Clinopyroxene geobarometry of magmatic rocks Part 1: An expanded structural geobarometer for anhydrous and hydrous, basic and ultrabasic systems. Contributions to Mineralogy and Petrology 133, 122–135.

Roeder P.L., and Emslie R.F. (1970) Olivine-liquid equilibrium. Contributions to Mineralogy and Petrology 29, 275–289.

Shishkina T.A., Portnyagin M.V., Botcharnikov R.E., Almeev R.R., Simonyan A.V., Garbe-Schönberg D., Schuth S., Oeser M., and Holtz F. (2018) Experimental Calibration and Implications of Olivine-Melt Vanadium Oxybarometry for Hydrous Basaltic Arc Magmas. American Mineralogist 103, 369–383.

Su B. (2014) Mafic-ultramafic intrusions in Beishan and Eastern Tianshan at Southern CAOB: Petrogenesis, Mineralization and Tectonic Implication. Springer Ph.D Theses, Chinese Academy of Sciences.

Wei B. (2013) Platinum-group element and Re-Os isotopic compositions of the magmatic Ni-Cu sulfide deposits in the Hongqiling-Chajianling-Piaohechuan region, eastern part of the Central Asian Orogenic Belt. Ph. D. thesis, University of Chinese Academy of Sciences.

Xie W., Song X., Deng Y., Wang Y., and Ba D. (2012) Geochemistry and petrogenetic implications of a Late Devonian mafic- ultramafic intrusion at the southern margin of the Central Asian Orogenic Belt. Lithos 144–145, 209–230.

Xue S.C., Li C., Wang Q., Ripley E.M., and Yao Z. (2019) Geochronology, petrology and Sr-Nd-Hf-S isotope geochemistry of the newly-discovered Qixin magmatic Ni-Cu sulfide prospect, southern Central Asian Orogenic Belt, NW China. Ore Geology Reviews 111, 103002.