

Titanium, Ti, A New Mineral Species from Luobusha, Tibet, China

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Abstract: We describe the new mineral species titanium, ideally Ti, found in the podiform chromitites of the Luobusha ophiolite in Tibet, People's Republic of China. The irregular crystals range from 0.1 to 0.6 mm in diameter and form an intergrowth with coesite and kyanite. Titanium is silver grey in colour, the luster is metallic, it is opaque, the streak is grayish black, and it is non-fluorescent. The mineral is malleable, has a rough to hackly fracture and has no apparent cleavage. The estimated Mohs hardness is 4, and the calculated density is 4.503 g/cm³. The composition is Ti 99.23–100.00 wt%. The mineral is hexagonal, space group *P6₃/mmc*. Unit-cell parameters are *a* 2.950 (2) Å, *c* 4.686 (1) Å, *V* 35.32 (5) Å³, *Z* = 2. The five strongest powder diffraction lines [*d* in Å (hkl) (*I*/*I*₀)] are: 2.569 (010) (32), 2.254(011) (100), 1.730 (012) (16), 1.478 (110) (21), and 0.9464 (121) (8). The species and name were approved by the CNMNC (IMA 2010–044).

Key words: Titanium, new mineral species, Ti, chromitite, Luobusha ophiolite, Tibet

1 Introduction

An in-depth mineralogical study of the Luobusha area was proposed after the discovery of diamonds in the Luobusha ophiolite rocks found at Dongqiao, Tibet in 1981 (Fang *et al.*, 1981). Apart from the natural occurrence of diamond, moissanite, etc. the presence of UHP minerals was confirmed, together with the discovery of native metallic elements Si, Fe, Zn, Pb, Al, Cr, Ni, Os, Ir, Ru, Rh, Pd, Au, Ag, W, Cu, S and Ti (IMA2010-044), various intermetallic compounds, as well as, platinum-group-element minerals (Bai *et al.*, 1993, 2000, 2003; Shi *et al.*, 2004, 2005; Li *et al.*, 2005, 2007).

Among the intermetallic compounds, the ferric silicides and ferric carbides were thoroughly investigated. In Fe-Si and Ti-Fe-Si system, the new minerals luobusaite (Fe_{0.83}Si₂) (IMA2005-052a) (Bai *et al.*, 2006), yarlongite ((Cr,Fe,Ni)₂₉C₄) (IMA2007-035) (Shi *et al.* 2009) and zangboite (TiFeSi₂) (IMA2007-036) (Li *et al.*, 2009), naquite (FeSi) (IMA2010-010) (Shi *et al.*, 2012) and linzhiite (IMA2010-011) were discovered. In the W-C, Cr-C and Ti-C system, qusongite (WC) (IMA2007-034) (Fang *et al.*, 2009), tongbaite (Cr₃C₂) and khamrabaevite (TiC) were identified.

The mineral having the composition Ti reported here was separated from the heavy-mineral constituents derived from a 1500 kg sample of chromitite collected from ore body 31, group II, of the Luobusha (Norbusa) mining district, in Qusong (Qusum) county, Shannan (Lhokha) Prefecture, Tibet (about 200 km east-southeast of Lhasa). The new mineral is named titanium after its chemical composition. The type material has been deposited at the Institute of Geology, Chinese Academy of Geological Sciences, Beijing People's Republic of China, catalogue number 74-3. The mineral species and name were approved by the Commission on New Minerals, Nomenclature and Classification (IMA 2010–044).

2 Location and Geology

The new species titanium was discovered in a podiform chromitite hosted in a harzburgite formation of the Luobusha ophiolite, situated in the Indus – Yarlong Zangbo suture zone. The ophiolite extends along Yarlong Zangbo (Brahmaputra) River for about 42 km from east to west and has a width of 1–4 km, with an exposed area of about 70 km². It consists mainly of harzburgite, with lesser amounts of dunite, cumulate mafic rocks, pillow lavas, and an ophiolitic mélange (Fig. 1; Bai *et al.*, 2000). Numerous podiform chromitite bodies are hosted in the

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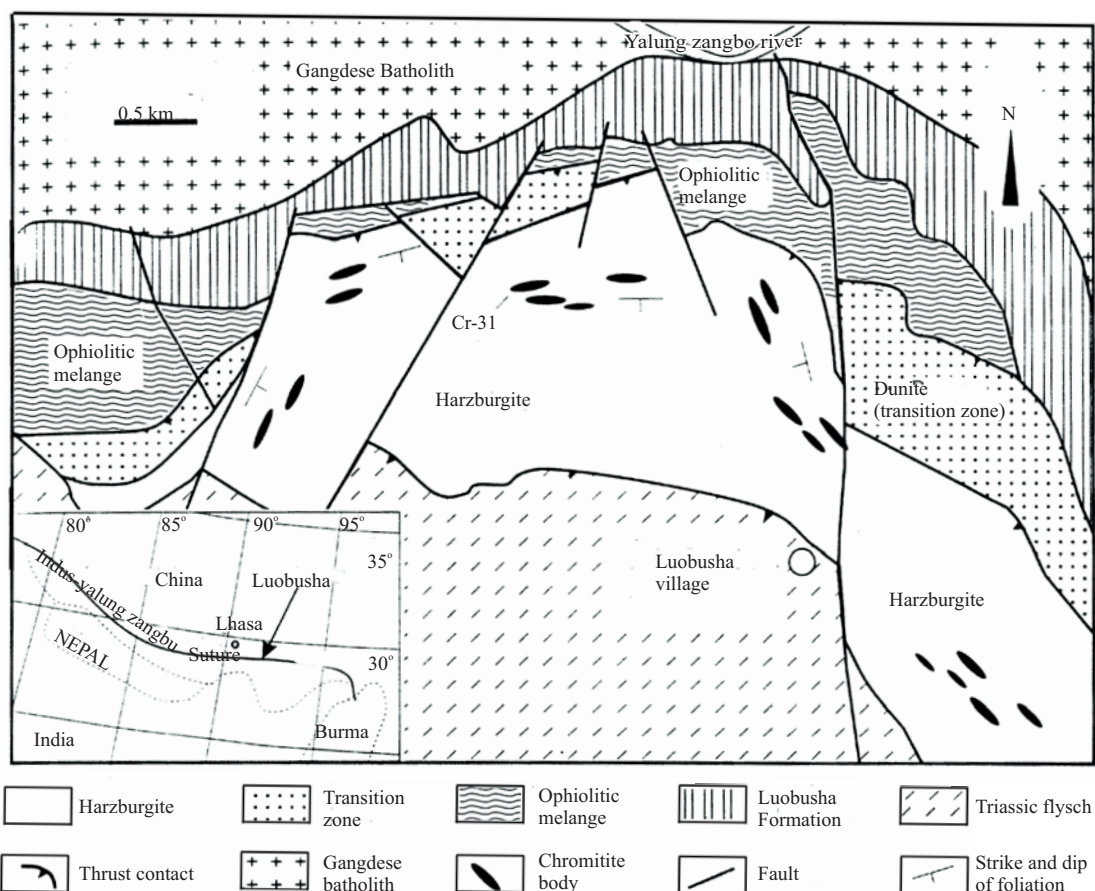


Fig. 1. Geological map of the Luobusha ophiolite showing the distribution of chromitite ore bodies (after Zhou et al., 1996).

mantle-derived harzburgite rocks, with an aggregate of about 5 million tonnes of ore.

The age of the ophiolite is uncertain. Zhou et al. (2002) obtained a Jurassic age (Sm–Nd isochron of 177 Ma), whereas Robinson et al. (2004) concluded that it has a Cretaceous age (126 Ma) on the basis of a SHRIMP analysis of zircon

3 Mineral Separation Procedures

The minerals were hand-picked from this heavy-mineral separate and the possibility of anthropogenic contamination was ruled out. The samples were taken directly from the outcrop and carefully cleaned before processing, and the same collection of minerals was recovered twice using completely different mineral separation laboratories (Fang and Bai, 1981). All equipment was dismantled and carefully cleaned before crushing and processing (Bai *et al.*, 2000). A 200-kg sample of granite from the Gangdese batholith was processed first to test for contamination during the separation process. The samples were hand-washed, air-dried, and crushed carefully to avoid any possible

anthropogenic contamination. Only quartz, feldspar, garnet, mica, apatite, and zircon were recovered from the granite. Any dark or metallic mineral would have been readily recognized but none was found. Using the same procedures and equipment with which the granite sample was processed, we found about 70–80 distinct metallic mineral species and alloys in these samples. These include: native metals and intermetallic compounds, grains of Os–Ir alloy with inclusions of diamond and metallic carbides and iron silicides. None of these minerals occur in the granite sample, although many of them have been recovered from chromitites of other ophiolites processed in completely different laboratories (Robinson and Yang, 2008). Mineral separation was carried out using gravity, magnetic, and electrical techniques in the Zhengzhou Institute of Multipurpose Utilization of Mineral Resources, Chinese Academy of Geological Sciences. The grains of titanium were hand-picked from separates of various grain-sizes. Selected grains were mounted in epoxy, polished, and analyzed with an electron microprobe. Therefore, we are confident that the Luobusha sample is free of contamination. The Ti specimens studied are clearly of natural origin.

4 Appearance and Physical Properties

Titanium occurs as grains or tabular crystals generally between 0.1 and 0.6 mm across (Fig. 2). Titanium is silver grey in colour, The luster is metallic, it is opaque, the streak is grayish black and it is non-fluorescent. The mineral is malleable; it has rough to hackly fracture and has no apparent cleavage. The estimated Mohs hardness is 4, and the calculated density is 4.503 g/cm³ (Titanium element density is 4.54 g/cm³). The composition is Ti 99.23–100.00 wt%. Reflectivity measurements were made in air, using a MPV-3 instrument and WC as a standard. The reflectance values for titanium are listed in Table 1.

5 Chemical Data

Quantitative chemical analyses were made using an electron microprobe (EPMA-1600 Shimadzu), run at an accelerating voltage of 15 kV, a beam current of 15 nA and a beam diameter of 1 or 5 μm. Multiple element standards from SW9100 NIST were used for calibration (Fe, Si, Ti, and Al). The results of analyses are given in

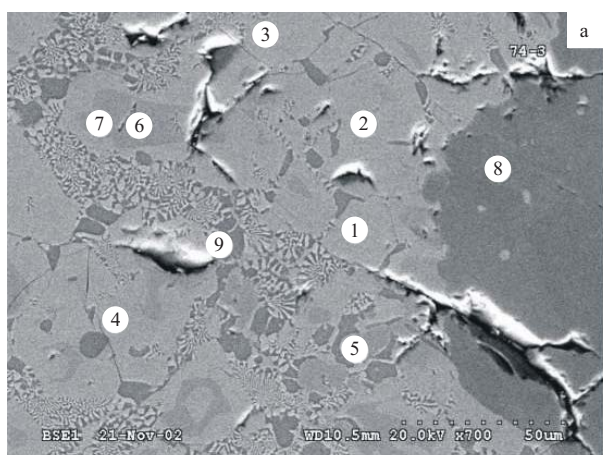


Fig. 2. BSE image (a) of an intergrowth of titanium (8-9) with Ti-Si-Fe-Ni (1-4) and Ti-Si-Fe (5-6), the chemical composition can see Table 2.

Table 3 The chemical composition of measurement points in Fig. 3 and Fig. 4 by EPMA

wt%	Si	O	Al	Ti	Fe	Ni	Total	remarks
74-3b-1	45.70	54.30					100.00	coesite
74-3b-2	46.02	53.98					100.00	coesite
74-3b-3	18.53	51.60	28.53	1.50			100.16	kyanite
74-3b-4	18.50	49.49	29.00	1.70			98.69	kyanite
74-3b-5	18.97	51.00	28.53				98.50	kyanite
74-3b-6	46.03	53.97					100.00	coesite
74-3b-7	19.15	49.02	29.00				97.17	kyanite
74-3b-8	46.34	53.66					100.00	coesite
74-3e-9	2.54			63.79	33.07	0.60	100.00	Ti-Fe-Si-Ni
74-3e-10	2.37			63.44	33.48	0.71	98.47	Ti-Fe-Si-Ni
74-3e-11	2.58			63.75	32.99	0.68	101.43	Ti-Fe-Si-Ni
74-3b-15				100.00			100.00	titanium
74-3b-16	0.69			99.31			100.00	titanium
74-3e-17	0.29		0.03	99.42	0.05	0.24	99.79	titanium
74-3e-18				100.00			100.00	titanium

Table 2 and Table 3.

The typical composition is usually close to the same as the ideal formula, Ti, which has the amounts of Ti 99.08 to 100.00 wt% (Table 2–3). However, small amount of Si (0.28–0.69 wt%), Fe (0.05–0.40 wt%), Ni (0.15–0.24 wt%) and trace amounts of Al (0.03 wt%) have been detected (Table 2–3 and Fig. 2–Fig. 4). The empirical formula of titanium is based on the analytically determined average values recalculated to the total of 1 atom per formula unit. The empirical formula (based on 1 atom *pfu*) is Ti_{0.988}Si_{0.012}. The simplified formula is Ti, which has the ideal composition Ti 100.00 wt%.

6 Crystallography

Single-crystal X-ray studies could not be carried out because the crystal grains were too small. X-ray powder diffraction data were collected using a Bruker SMART APEX-CCD and the Li et al. (2005) method. The powder

Table 1 Reflectance values for titanium

R (%)	λ/nm	R (%)	λ/nm
33.8	400	48.5	560
36.4	420	48.6	580
38.1	440	48.1	589 (COM)
40.6	460	48.1	600
40.3	470 (COM)	52.1	620
30.3	480	50.7	640
41.4	500	50.4	650 (COM)
41.8	520	50.0	660
45.1	540	51.2	680
45.2	546 (COM)	51.1	700

Table 2 The chemical composition of titanium(8-9) with Ti-Si-Fe-Ni(1-4) and Ti-Si-Fe(5-6)

wt%	Ti	Si	Fe	Ni	Total	remarks
74-3a-1	61.81	2.06	36.27	0.51	100.65	Ti-Fe-Si-Ni
74-3a-2	61.02	2.73	35.74	0.77	100.26	Ti-Fe-Si-Ni
74-3a-3	61.21	0.43	35.65	0.71	98.00	Ti-Fe-Si-Ni
74-3a-4	60.55	2.83	35.74	0.88	100.00	Ti-Fe-Si-Ni
74-3a-5	71.49	2.71	27.29		101.49	Ti-Fe-Si-Ni
74-3a-6	70.00	2.62	27.28		99.90	Ti-Fe-Si
74-3a-7	70.62	2.84	26.54		100.00	Ti-Fe-Si
74-3a-8	99.08	0.37	0.40	0.24	100.09	titanium
74-3a-9	99.17	0.28	0.40	0.15	100.00	titanium

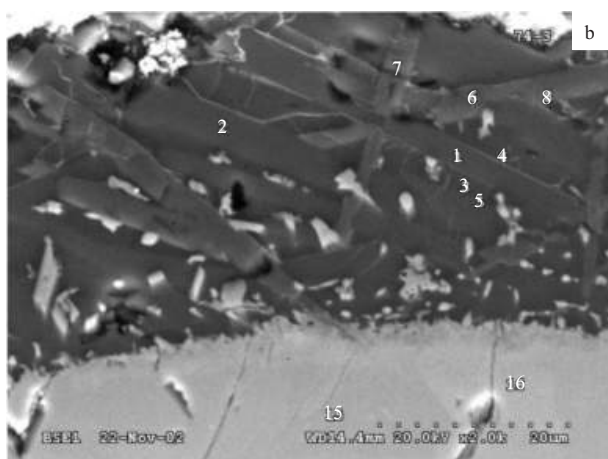


Fig. 3. BSE image (b) of an intergrowth of titanium with coesite and kyanite. Numbered points refer to microprobe analyses identifying coesite (1,2,6,8) kyanite (3,4,5,7) and titanium (15,16) in Table 3.

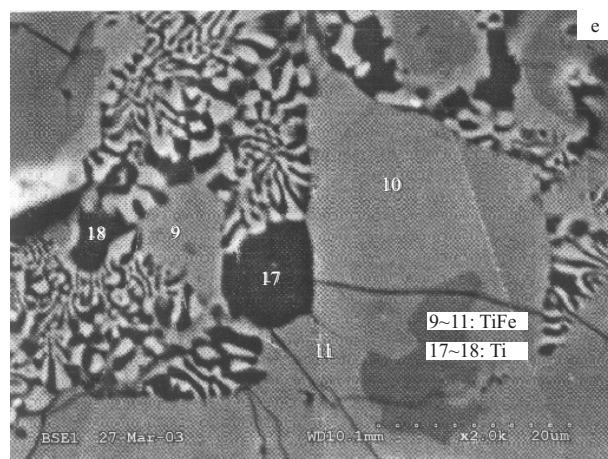


Fig. 4. BSE image (e) of an intergrowth of titanium with Ti-Fe-Si-Ni alloy. Numbered points refer to microprobe analyses identifying titanium (17,18) with Ti-Fe-Si-Ni alloy (9-11) in Table 3

pattern was obtained using GADDS software (Häming, 2000) and data are listed in Table 4 (in Å for $\text{MoK}\alpha$). The X-ray powder pattern can see Fig. 5. From unit cell refinement, titanium is hexagonal, space group $P6_3/mmc$. Its unit-cell parameters are: a 2.950(2) Å, c = 4.686(1) Å, V = 35.32(5) Å³, Z = 2.

7 Discussion

There have been many reports of native element minerals, intermetallic alloy minerals and inclusions in chromite (Melville, 1892; Bird and Weathers, 1975; Essene and Fisher, 1986; Rudashevsky et al., 1987; Melcher et al., 1997). The intergrowth of metallic minerals with UHP minerals was revealed in the Tibetan samples. An occurrence of diamond as inclusions in Os-Ir alloy and

Table 4 X-ray powder diffraction data for titanium (sample No. 58-1)

I_{rel}	d_{meas}	$d_{\text{calc.}}$	hkl	I_{rel}^*	d_{meas}^*	I_{rel}^{**}	d_{meas}^{**}
32	2.569	2.555	010	30	2.557	26	2.5556
				26	2.342	26	2.3410
100	2.254	2.243	011	100	2.244	100	2.2432
16	1.730	1.727	012	19	1.726	12	1.7262
21	1.478	1.475	110	17	1.475	12	1.4755
				16	1.332	11	1.3319
				2	1.276	2	1.2778
				16	1.247	11	1.2483
				13	1.233	7	1.2327
				20	1.224		
				2	1.171	1	1.1705
3	1.124	1.122	022	2	1.122	2	1.1216
				3	1.063		
5	0.9895	0.9888	023	6	0.9895		
8	0.9464	0.9458	121	11	0.9458		
4	0.9172	0.9173	114	10	0.9175		
1	0.8914	0.8928	122	4	0.8927		
2	0.8795	0.8798	015	4	0.8796		
				2	0.8634		
2	0.8506	0.8517	030	4	0.8514		
4	0.8214	0.8214	123	12	0.8211		
2	0.8001	0.8004	032	9	0.8005		

*ICDD05-682, **ICDD 89-2959

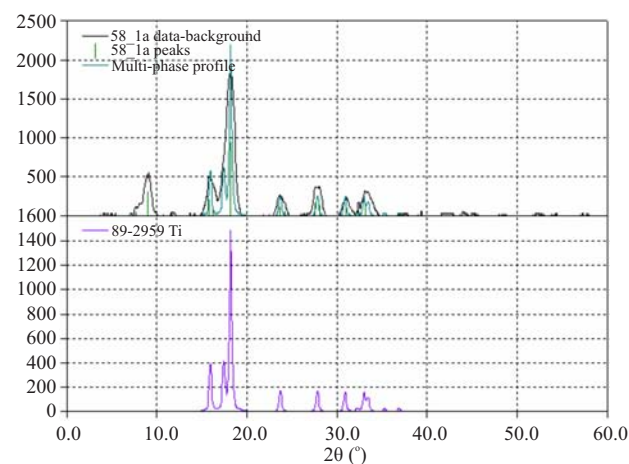


Fig. 5. The X-ray powder diffraction pattern of titanium in sample 58-1.

coesite as part of a silicate assemblage rimming a grain of Fe-Ti alloy was also reported by Yang et al. (2007) and Dobrzhinetskaya et al. (2008). Yamamoto et al. (2009) found sub-microscopic grains of coesite in the chromite of the Luobusha ophiolite. This occurrence confirmed the presence of UHP minerals in the Luobusha chromitite, requiring a minimum pressure of 2.8–4 GPa. Because the individual coesite “crystals” have an external shape similar to that of stishovite and are polycrystalline, a pseudomorphic replacement, implying a pressure above 9 GPa, was suggested. The explanation proposed for the origin of these minerals is that the UHP minerals were incorporated into the chromitites in the deep upper mantle.

Although titanium and other intermetallic compounds were collected from a podiform chromitite hosted in an ophiolitic harzburgite, they are unlikely to be primary

minerals in the sense of having crystallized from the melt that formed the Luobusha chromitites, given the chemical incompatibilities require a strongly reducing environment. Thus they are considered to be xenocrysts derived from deep mantle sources, transported up by a plume and incorporated in the ophiolite during seafloor spreading. Blocks of the mantle containing the exotic minerals were presumably picked up by later boninitic melts from which the chromitites precipitated, transported to a shallow depth and were partially digested in the melt, with insoluble residues incorporated into the chromitite (Robinson et al., 2004).

Titanium (Ti) as a mineral species has been reported elsewhere (Trumilina et al., 1988, Jambor et al., 1991). At the time of the discovery of titanium, we found many distinct metallic mineral species and alloys but also many native metallic elements (for example: Si, Fe, Zn, Pb, Al, Cr, Ni, Os, Ir, Ru, Rh, Pd, Au, Ag, W, Cu and S). In Figure 3 the intergrowth between titanium and coesite, kyanite is clearly visible. Therefore, the natural occurrence of titanium was confirmed.

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