Yarlongite: A New Metallic Carbide Mineral

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Abstract: Yarlongite occurs in ophiolitic chromitite at the Luobusha mine (29°5′N 92°5′E, about 200 km ESE of Lhasa), Qusum County, Shannan Prefecture, Tibet Autonomous Region, People's Republic of China. Associated minerals are: diamond, moissanite, wüstite, iridium ("osmiridium"), osmium ("iridosmine"), periclase, chromite, native iron, native nickel, native chromium, forsterite, Cr-rich diopside, intermetallic compounds Ni-Fe-Cr, Ni-Cr, Cr-C, etc. Yarlongite and its associated minerals were handpicked from a large heavy mineral sample of chromitite. The metallic carbides associated with yarlongite are cohenite, tongbaite, khamrabaevite and qusongite (IMA2007-034). Yarlongite occurs as irregular grains, with a size between 0.02 and 0.06 mm, steel-grey colour, H Mohs: 5½-6. Tenacity: brittle. Cleavage: {0 0 1} perfect. Fracture: conchoidal. Chemical formula: $(Cr_4Fe_4Ni)_{\Sigma9}C_4$, or $(Cr,Fe,Ni)_{\Sigma9}C_4$, Crystal system: Hexagonal, Space Group: $P6_3/mc$, $a = 18.839(2)$ Å, $c = 4.4960(9)$ Å, $V = 745.7(2)$ Å^3, $Z = 6$, Density (calc.) = 7.19 g/cm^3 (with simplified formula). Yarlongite has been approved as a new mineral by the CNMNC (IMA2007-035). Holotype material is deposited at the Geological Museum of China (No. M11650).

Key words: yarlongite, new mineral, metallic carbides, ophiolite, luobusha, Tibet

1 Introduction

The mineralogical study of the Luobusha area was proposed after the discovery of diamonds in ophiolite rocks located in Luobusha and at Dongqiao, Tibet in 1981 (Fang and Bai, 1981).

Apart from the natural occurrence of diamond, moissanite, wüstite, etc. the presence of UHP minerals was confirmed, together with the discovery of several native metallic elements (Si, Fe, Zn, Pb, Al, Cr, Ni, Os, Ir, Ru, Rh, Pd, Au, Ag, W, Cu, S and Ti), and intermetallic compound minerals (Fe-Si, Fe-Ti-Si, Ni-Fe-Cr, Ni-C, Fe-C, Cr-C, Ti-C, W-C, Si-C, Fe-Co, Al-Fe-La, W-Co, Fe-Mn, Au-Ag, Ag-Sn Ti-W, Cu-Zn, Si-Ca, Ti-N, Fe-Si Si-Ca-Cu as well as platinum-group-element minerals (Ni-Fe-Ir, Rt-Fe, Pt-Fe-Pd, Fe-Ru) (Bai et al., 2000a, 2000b), 2003; Shi et al., 2005b, 2005c; 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 mineral luobusaite $(Fe_{0.83}Si_2)$ (IMA2005-052a) (Bai et al., 2006) and zangboite (TiFeSi$_2$) (IMA2007-036) were discovered. In

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the W-C, Cr-C and Ti-C system, qusongite (WC) (new mineral, IMA2007-034), tongbaite (Cr$_3$C$_2$) and khamrabaevite (TiC) were identified. Yarlongite is a species of the above-mentioned metallic carbides from this area.

As new minerals, luobusaite (IMA 2005-052a), qusongite (IMA2007-034) and zangboite (IMA2007-036) have been discovered (Bai et al., 2006). Yarlongite is also a new ferric carbide mineral from the podiform chromitites of the Luobusha ophiolite in Southern Tibet.

2 Geological Setting

The new mineral yarlongite occurs in the ophiolitic podiform chromitite at the Luobusha mine (29°5′N, 92°5′E, about 200 km ESE of Lhasa), Qusum County, Shannan Prefecture, Tibet Autonomous Region, People's Republic of China. The chromitites occur as tabular, lenticular and podiform bodies in depleted harzburgites. Most of the chromitite bodies are surrounded by envelopes of dunite. Structurally the ophiolite consists of several thrust slices, and the lowest rocks are harzburgite that contain dunite dykes with chromitite bodies (Bai et al., 2000a). The top

of the ophiolite is a cumulate dunite layer and ophiolitic melange. There are differing views as to the age of the ophiolite. While we believe this formation to be from the Jurassic period, one study shows that it was formed in the Cretaceous period (Robinson et al., 2004).

3 Sampling and Separation

The chromitite has been mined at the Luobusha mine for over a decade, and a number of pods are exposed in open pits. About 1500 kg of ore was removed from the orebody C31 of the Luobusha mine. The samples were hand-washed, air-dried and crushed to pass a 1-cm sieve, before being transported to the Institute for Multipurpose Mineral Separation in Zhengzhou, China for mineral separation. Mineral separation was carried out using a variety of magnetic, electric and heavy-liquid techniques (Hu, 1999; Bai et al., 2000a; Robinson et al., 2004). The mineral samples were handpicked from separates of various grain sizes. Selected grains were mounted in epoxy, polished and then analyzed by an EPMA-1600 microprobe.

4 Analytical Methods

Selected **yarlongite** grains were analyzed by an EPMA-1600 microprobe and an S-3500 N scanning electron microscope with an energy-dispersive spectrometer. The operating conditions for the microprobe were a voltage of 20 kV and beam current of 15 nA. The SW9100 NIST multiple element standards were used for calibration. Chemical analyses were made by means of the electron microprobe. X-ray diffraction experiments were carried out with an X-ray diffractometer equipped with CCD detector (SMART APEX, Bruker AXS Inc.) in the X-ray Diffraction Laboratory of China University of Geosciences (Beijing).

Fig. 1. SEM image of yarlongite. It is shown as the greyish area in the center of the figure. The chemical composition of measurement points 1 and 3 are listed in Table 3.

5 Physical Properties

Yarlongite occurs as irregular grains, with a size between 0.02 mm and 0.06 mm (Fig. 1). Colour: steel-grey. Streak: black. Lustre: metallic. Diaphaneity: opaque. Non-fluorescent. H Mohs: 5½–6. Tenacity: brittle. Cleavage: {0 0 1} perfect. Fracture: conchoidal. Density (meas.): could not be measured because of small grain size. Density (calc.): 7.19 g/cm^3 (using simplified formula).

6 Optical Properties

In incident polarized light: greyish white colour, no bireflectance, no pleochroism, medium anisotropy, and no internal reflections. The reflectance values (air) for **yarlongite** are listed in Table 1.

Table 1 Reflectance values (air) for yarlongite

R (%)	Wavelength (nm)	R (%)	Wavelength (nm)
42.90	400	47.60	560
39.24	420	46.99	580
40.03	440	48.59	589 (COM)
42.90	460	50.19	600
42.74	470 (COM)	52.75	620
42.58	480	49.72	640
43.13	500	51.10	650 (COM)
45.72	520	51.10	660
45.81	540	54.85	680
46.70	546	51.61	700

Table 2 Chemical composition of Yarlongite by EPMA

No.	45-4-1	45-4-4	45-5-1	45-5-3	45-6-1	45-6-2	45-6-3	1-18-1	Avg.
C (%)	13.75	11.84	6.56	8.06	7.45	8.03	6.47	11.60	9.22
Cr	82.05	84.82	49.66	48.82	11.27	10.68	11 13	32.60	41.38
Fe	2.06	1.76	24.14	24.74	76.52	76.36	77.03	42.20	40.60
Ni	2.14	1.58	17.63	18.38	4 76	4.92	5.33	13.60	8.54
Σ	100.00	100.00	97.99	100.00	100.00	99 99	99 96	100.00	99.74

Table 3 Calculated X-ray powder-diffraction pattern for yarlongite

I	d_{calc}	h	k	l	I	d_{calc}	h	k	l
100	6.920	1	1	0	98	2.023	4	2	1
10	5.993	2	0	0	32	1.998	6	0	0
35	4.530	2	1	0	16	1.942	5	1	1
10	4.210	1	0	1	47	1.825	6	0	1
10	3.995	3	0	0	54	1.798	4	0	2
55	3.596	2	0	1	1	1.749	3	2	2
19	3 191	2	1	1	8	1.730	4	4	0
14	2 996	4	0	0	11	1.559	6	2	1
23	2 986	3	0	1	9	1.315	6	4	1
7	2.750	3	2	0	5	1.256	8	2	1
17	2 615	4	1	0	17	1.199	6	0	3
36	2.493	4	0	1	19	1.173	6	4	2
23	2.265	4	2	0	9	1.158	10	0	1
16	2.260	4	1	1	12	1.153	6	6	0
9	2.209	1	0	2					
10	2.115	4	2	2					
50	2 105	2	1	4					

7 Chemical Data

Chemical analyses were carried out by means of an electron microprobe, and the results are listed in Table 2. The empirical formula (based on 4 C atoms per formula unit) is $(Cr_{4.14}Fe_{3.79}Ni_{0.76})_{\Sigma8.69}C_4$. The simplified formula is

$(Cr_4Fe_4Ni)_{\Sigma9}C_4$. Considering that the transition metal content has a wide range from Table 2, the chemical formula can be also written as $(Cr,Fe,Ni)_{\Sigma9}C_4$.

8 Crystallography

Single-crystal X-ray studies were carried out using a Smart Apex single-crystal X-ray diffractometer with a Bruker AXS CCD, and gave the following data:

Hexagonal   Space Group: $P6_3/mc$
$a = 18.839(2)$ Å $c = 4.4960(9)$ Å
$V = 745.7(2)$ Å³ $Z = 6$

The X-ray powder-diffraction data were calculated from the single-crystal structure (Table 3).

9 Crystal Structure

An X-ray single-crystal structure determination (Lab. sample No: 2001–195) was carried out using a Smart APEX CCD System. The distance between the crystal and the detector was 5.07 cm, using MoKα (λ = 0.71073 Å),
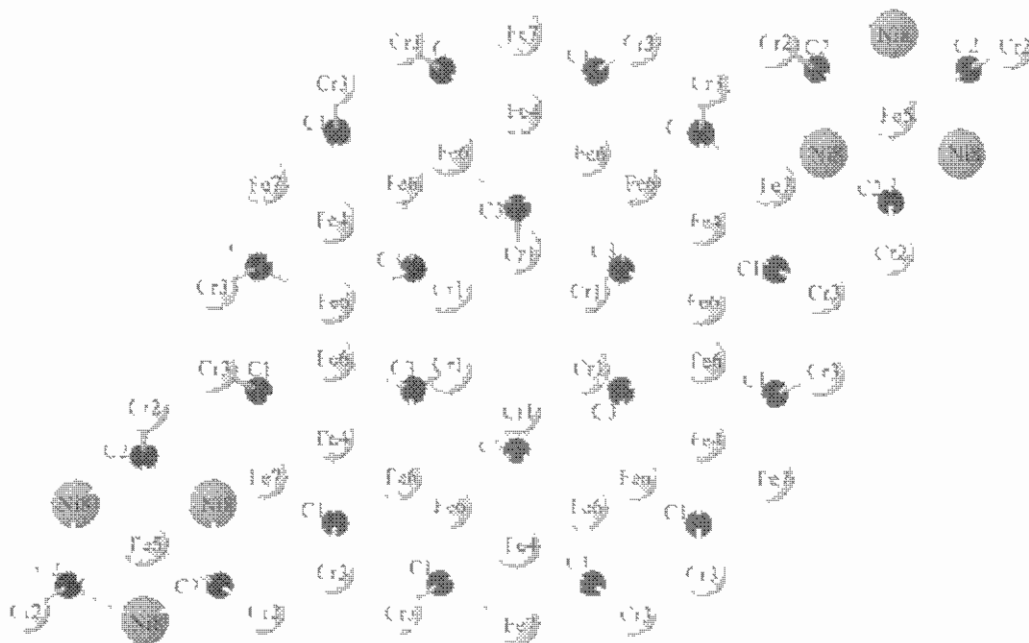

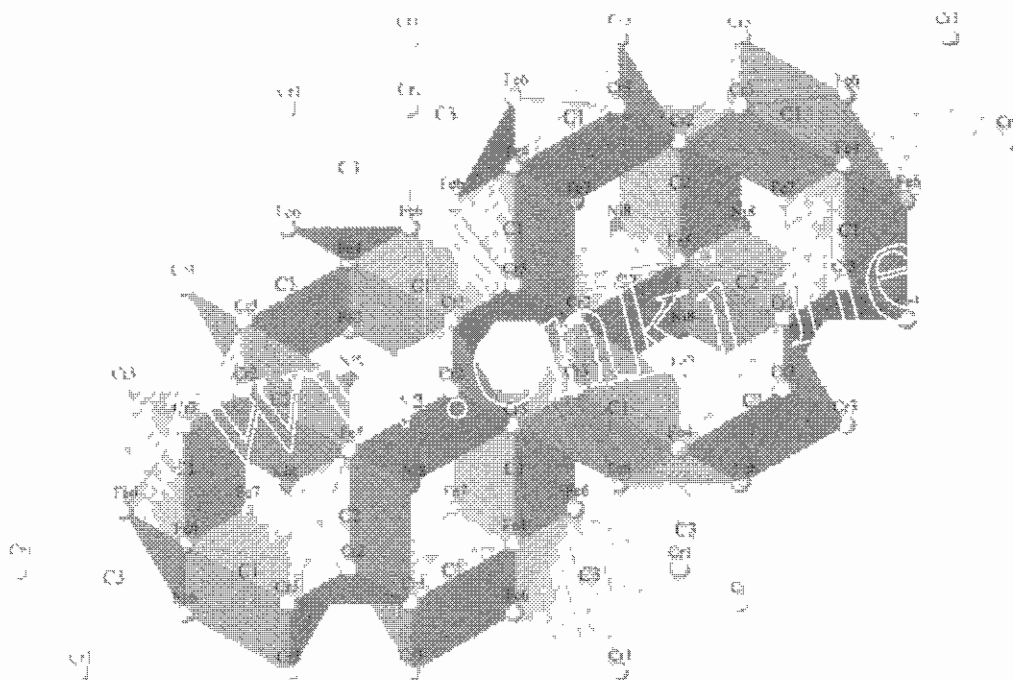Fig. 2. Arrangement of the atoms in yarlongite (small black sphere is carbon)

Fig. 3. Distribution of trigonal-prismatically coordinated polyhedra in yarlongite.

45 kV, 30 mA, and graphite monochromator. The crystal structure has been solved by Bluker Shelextl procedures, then refined using full matrix least squares. Anisotropic refinement using all 918 measured independent data and the reflections with $I > 2\sigma(I)$ resulted in an R_1 factor of 0.079 and WR_2 of 0.177, respectively. The results were published by Shi et al. (2005a).

The arrangement of the atoms in **yarlongite** is shown in Fig. 2. The determination indicated that deficiencies of the Fe, Cr and Ni in their crystallographic positions were detected. The crystallochemical formula calculated by the determination of the crystal structure is $(Fe_4Cr_4Ni)_{\Sigma9}C_4$. The crystal structure is characterized by trigonal-prismatically coordinated polyhedra formed by a combination of the metallic atoms Fe, Cr and Ni with C. In the mineral, the close-packed layers are arranged alternately along the c axis (Fig. 3). Particularly, the layers of Fe, Ni and layers of Cr, C are stacked alternately between flat layers and wrinkled layers respectively. Fe, Cr and Ni can be linked with each other to form bonds and the bond distances are in the range of 2.486–2.698 Å. The distances between Fe, Cr, Ni and C are in the range of 1.899–2.175 Å.

10 Name

The name is for the first two syllables of the name of the Yarlong Zangbo River, which is near the Luobusha ophiolite (also known as the Brahmaputra River). It has been approved as a new mineral by the CNMNC (IMA2007-035). Holotype material is deposited at the Geological Museum of China under specimen number M11650. Another specimen is deposited at the Institute of Geology, Chinese Academy of Geological Sciences (IG-CAGS), under specimen number 45.

11 Discussion

Among metallic carbide minerals, khamrabaevite ((Ti, V,Fe)C), niobocarbide ((Nb,Ta)C), tantalcarbide (TaC), tongbaite (Cr_3C_2), isovite (($Cr,Fe)_{23}C_6$), haxanite ((Fe,Ni) $_{23}C_6$) and cohenite ((Fe, Ni, Co)$_3$C) have been discovered. Some of these transition-metallic element carbides are listed in Table 4. There are two types of carbon coordination in the five minerals, i.e. trigonal-prismatically coordinated polyhedra (**yarlongite**, cohenite and tongbaite) and octahedral polyhedra (isovite and haxonite). In trigonal-prismatically coordinated polyhedra, the crystal structure is characterized by double trigonal prisms with shared edges. In **yarlongite** the main structural unit are polymers formed by linking three trigonal prisms via shared edges (Fig. 3). This new linking mode is rare in metallic carbides. The crystal structure of **yarlongite** and its mineral data, which are listed in Table

Table 4 Comparison of transition-element (Fe, Cr, Co and Ni) carbides

Mineral		**Yarlongite**	Cohenite	Isovite	Haxonite	Tongbaite
Formula		$(Cr,Fe,Ni)_9C_4$	$(Fe,Ni,Co)_3C$	$(Cr,Fe)_{23}C_6$	$(Fe,Ni)_{23}C_6$	Cr_3C_2
Crystal system		Hexagonal	Orthorhombic	Cubic	Cubic	Orthorhombic
Unit cell parameters	a	13.839 (2)Å	4.518Å	10.65Å	10.55Å	5.57Å
	b	13.839 (2)Å	5.069	10.65Å	10.55Å	11.47
	c	4.4960 (9)Å	6.736	10.65Å	10.55Å	2.816Å
	V	745.7(2)Å^3	154.27 Å^3	1207.95Å^3	1174.24 Å^3	179.91Å^3
	Z	6	4	1	4	4
	Space group	$P6_3/mc$	$Pbnm$	$Fm3m$	$Fm3m$	$Pnmb$
Chemical composition (electron probe) (%)	C	9.22	6.56	5.77	5.70	13.34
	Fe	40.60	55.92	26.82	89.50	
	Ni	8.54	28.86		4.91	
	Cr	41.38		67.41		86.66
	Co		9.66		0.18	
	Σ	99.74	100.00	100.00	100.29	100.00

4, indicate that **yarlongite** is a new species. Therefore, **yarlongite** is different from other formerly discovered metallic carbides both in chemical composition and crystal structure.

Yarlongite is not part of the eutectic compositions within the Luobusha chromitites. In fact, the Fe-C compounds (including yarlongite) are considered to be xenocrysts from the mantle, transported to shallow depths by a rising plume and then captured by the melts from which the Luobusha chromitites crystallized (Robinson et al., 2004).

Acknowledgements

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