

Naquite, FeSi, a New Mineral Species from Luobusha, Tibet, Western China

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Abstract: A new mineral species, named naquite(FeSi), is found in the podiform chromitites of the Luobusha ophiolite in Qusong County, Tibet, China. The detailed composition is Fe 65.65, Si 32.57 and Al 1.78 wt%. The mineral is cubic, space group $P2_13$. The irregular crystals range from 15 to 50 μm in diameter and form an intergrowth with luobusaite. Naquite is steel grey in color, opaque, with a metallic lustre and gives a grayish-black streak. The mineral is brittle, has a conchoidal fracture and no apparent cleavage. The estimated Mohs hardness is 6.5, and the calculated density is 6.128 g/cm^3 . Unit-cell parameters are a 4.486 (4) \AA , V 90.28 (6) \AA^3 , $Z=4$. The five strongest powder diffraction lines [d in \AA (hkl) (I/I_0)] are: 3.1742 (110) (40), 2.5917(111) (43), 2.0076 (210) (100), 1.8307 (211) (65), and 1.1990 (321) (36). Originally called ‘fersilicite’, the species and new name have now been approved by the CNMNC (IMA 2010–010).

Key words: new mineral, fersilicite, chromite, 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 and Bai, 1981). Apart from the natural occurrence of diamond, moissanite, wüstite, khamrabaevite, qusongite (IMA2007-034), among others and the presence of UHP (Ultra High Pressure) 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 and Ti (IMA2010-044), the intermetallic compounds 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 and Si-Ca-Cu, as well as the platinum-group-element minerals Ni-Fe-Ir, Rt-Fe, Pt-Fe-Pd and Fe-Ru (Bai et al., 1993, 2000, 2003, 2005; Shi et al., 2005; Li et al., 2007).

Among the intermetallic compounds, the ferric silicides and ferric carbides were thoroughly investigated. In the Fe-Si and Ti-Fe-Si systems, the new minerals luobusaite ($\text{Fe}_{0.83}\text{Si}_2$) (IMA2005-052a) (Bai et al., 2006), yarlongite ($(\text{Cr,Fe,Ni})_{29}\text{C}_4$) (IMA2007-035) (Shi et al., 2009) and zangboite (TiFeSi_2) (IMA2007-036) (Li et al., 2009) were

discovered. In the W-C, Cr-C and Ti-C systems, qusongite (WC) (Fang et al., 2009), tongbaite (Cr_3C_2) and khamrabaevite (TiC) were identified. The new mineral introduced here, Naquite, is also one of the above-mentioned metallic silicides from the podiform chromitites of the Luobusha ophiolite.

The mineral having the composition FeSi 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, western China, about 200 km ESE of Lhasa. The new mineral is named after the Naqu (Nagchu) Prefecture, Tibet, which is near the locality. The holotype specimen of naquite is deposited in the collection of the Geological Museum of China, Beijing, People’s Republic of China, catalogue number M11798. The mineral species and name has been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (CNMNC IMA 2010–010).

2 Location and Geology

The new species naquite was discovered in a chromitite hosted in a harzburgite formation of the Luobusha

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ophiolite, situated in the Indus–Yarlung Zangbo suture zone. The ophiolite extends along Yarlung 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 mélangé (Fig. 1; Zhou et al., 1996). Numerous podiform chromitite bodies are hosted in the mantle-derived harzburgite rocks, with an aggregate of about 5 million tones 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 was of Cretaceous age (126 Ma) on the basis of a SHRIMP analysis of zircon. Comparing the age of other ophiolites of the Yarlung Tsangpo suture zone (Xia bin et al., 2011), the ophiolites in this belt formed at about 126Ma is reasonable.

3 Mineral Separation Procedures

Since the minerals were hand-picked from this heavy-mineral separate, the possibility of natural or anthropogenic contamination can be 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. 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 the samples from the Luobusha chromitite. These include: native metals and intermetallic compounds, grains of Os–Ir alloy with inclusions of diamond and metallic carbides. In addition,

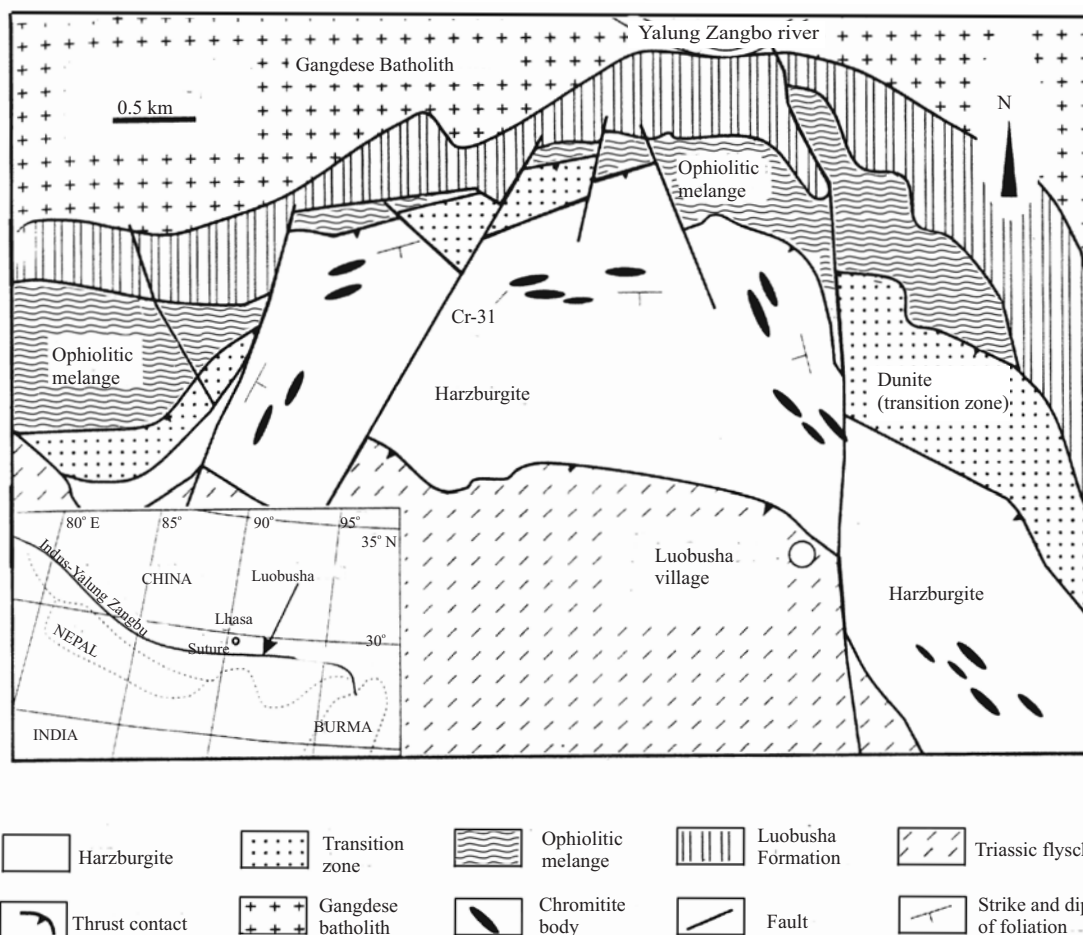


Fig. 1. Geological map of the Luobusha ophiolite showing the distribution of chromitite ore bodies (after Zhou et al., 1996).

iron silicides have been identified, for example: native Si, FeSi, FeSi₂ (Li et al., 2007) and Fe_{0.84}Si₂ (luobusaite) (Bai et al., 2006). 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). The samples were hand-washed, air-dried, and crushed carefully to avoid any possible anthropogenic contamination. 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 naquite 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 FeSi specimens studied are clearly of natural origin.

4 Appearance and Physical Properties

Naquite occurs as grains or tabular crystals generally between 15 and 50 μm across; some grains measure up to 100 μm (Fig. 2). Naquite is steel gray in color. It has a metallic lustre, is opaque, and gives a grayish-black streak. The mineral is brittle with a conchoidal fracture and seems to lack any cleavage. The estimated Mohs hardness is 6.5, and the calculated density is 6.128 g/cm^3 . The composition is Fe 65.65, Si 32.57 and Al 1.78 wt%. Reflectivity measurements were made in air, using an MPV-3 instrument with WC as a standard. The reflectance values for naquite 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, based on the average result of analyses of four samples, are given in Table 2.

The typical composition is usually close to the ideal formula. However, Al was detected in sample 97-24-1 (between 1.78 and 1.68 wt%) (Fig. 3). The empirical formula of naquite is based on the analytically determined average values recalculated to the total of 2 atoms per formula unit. The empirical formula (based on 2 atoms *pfu*) is Fe_{0.994}Al_{0.054}Si_{0.952}.

The simplified formula is FeSi, which has the ideal composition Fe 66.54, Si 33.46, for a total of 100.00 wt%.

Table 1 Reflectance values for naquite

R (%)	λ (nm)	R (%)	λ (nm)
35.6	400	42.7	560
36.7	420	42.4	580
38.0	440	41.6	589 (COM)
40.0	460	43.1	600
40.6	470 (COM)	43.0	620
41.6	480	42.2	640
41.0	500	42.5	650 (COM)
41.0	520	43.0	660
41.0	540	43.6	680
42.23	546 (COM)	43.1	700

Table 2 Chemical composition of naquite by EPMA

Sample No.	97-24-1-3	97-24-1-4	97-13-1-1	97-13-1-2
Fe	65.65	65.85	68.14	67.95
Si	32.57	32.47	31.86	32.05
Al	1.78	1.68		
Total	100.00	100.00	100.00	100.00

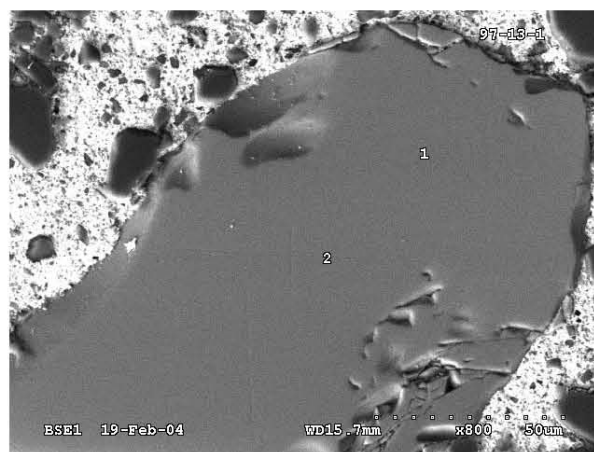


Fig. 2. Back-scattered electron image of naquite. The chemical composition of measurement points of 1 and 2 of sample 97-13 are listed in Table 2.

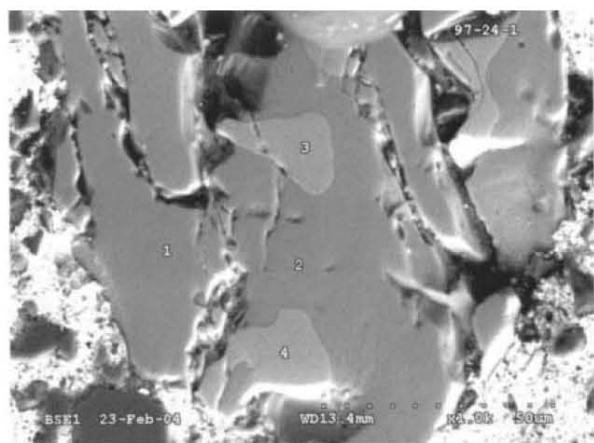


Fig. 3. Back-scattered electron image of naquite inclusions up to 25 μm across (3, 4) in luobusaite (1, 2). The chemical composition of measurement points 3 and 4 of sample 97-24 are listed in Table 2.

6 X-ray Powder Diffraction

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 by the Li et al. (2005) method. The powder pattern was obtained using GADDS software (Häming, 2000), which is shown Fig. 4, and data are listed in Table 3 (in Å for MoK α). From unit cell refinement, the crystallography parameters of naquite are cubic, space group: $P2_13$, $a=4.486(4)$ Å, $V=90.28(6)$ Å³, $Z=4$.

7 Discussion

There have been many reports of native element minerals, intermetallic alloy minerals and inclusions in chromite (Melville, 1892; Hansen and Anderko., 1958; Bird and Weathers, 1975; Keil et al., 1982; Essene and Fisher, 1986; Rudashevsky et al., 1987; Melcher et al.,

1997). Intergrowth of metallic minerals and with UHP minerals have been revealed in Tibetan samples. An occurrence of diamond as inclusions in Os–Ir alloy and 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 naquite 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 requiring 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. Note, however, that naquite was successfully synthesized at low pressure (Ouyang et al., 2006).

Table 3 X-ray powder data for naquite (sample No. 97-8-2)

I/I_0	d_{meas}	d_{calc}	hkl
40	3.1742	3.1721	110
43	2.5917	2.5900	111
23	2.2485	2.2430	200
100	2.0076	2.0062	210
65	1.8307	1.8314	211
27	1.3531	1.3525	311
36	1.1990	1.1989	321

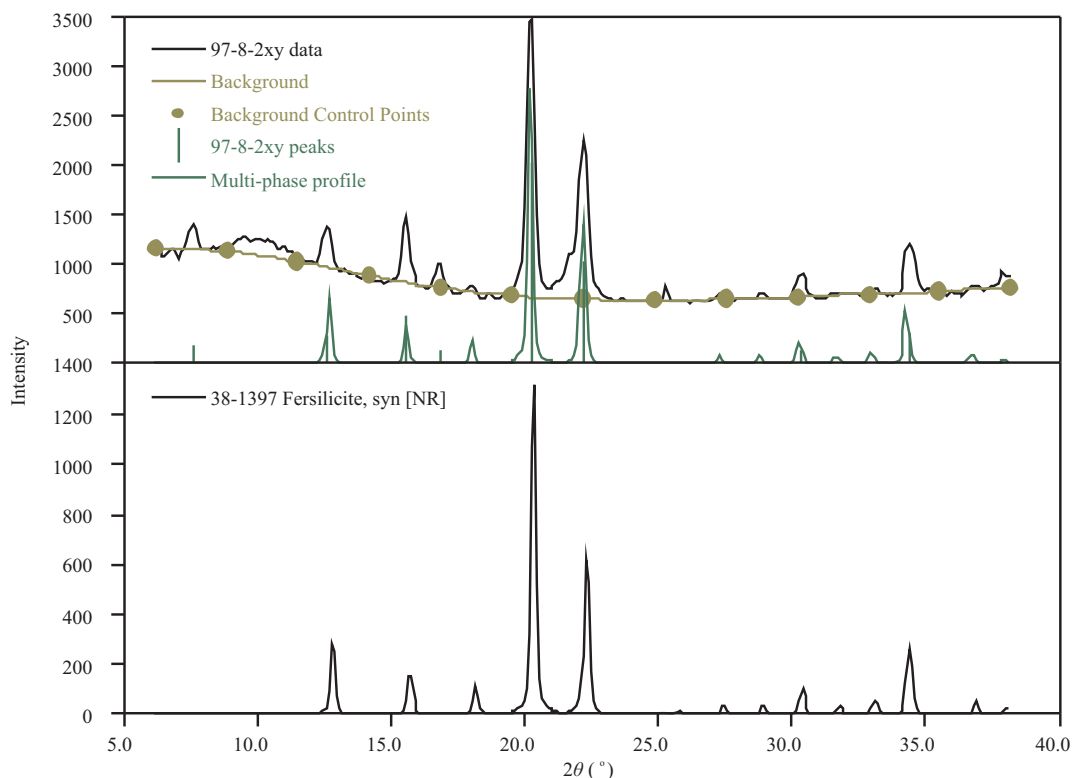


Fig. 4. X-ray powder diffraction trace of naquite (sample No. 97-8-2; upper section) compared with its search-match result for synthetic FeSi (lower section; ICDD38-1397; “fersilicite”).

Although the presence of naquite does not therefore imply a high-pressure environment, we consider that naquite is a stable mineral in the range of the upper mantle because its phase transition pressure must be 24 GPa from the NaCl structure to the CsCl structure (Dobson et al., 2002). Blocks of the mantle containing exotic minerals were presumably picked up by later boninitic melts from which the chromitites precipitated, transported to a shallow depth and partially digested in the melt, with insoluble residues incorporated into the chromitite (Robinson et al., 2004).

Naquite (FeSi) is a new species within the important iron silicide minerals. The discovery frequency and occurrence quantity of naquite are more than luobusaite in the Luobusha chromitite, Tibet. It has been previously reported (Gevork'yan, 1969) and was not approved as a new mineral species by CNMNC-IMA. Since 1969 'fersilicite' has been reported many times with respect to localities, crystallography and physical properties (Yu, 1984; Hu et al., 1995; Wartchow et al., 1997; Mahesh et al., 2004), but in most cases, its natural occurrence was not accurately described. In the Luobusha chromite, the intergrowth between naquite and luobusaite is obvious (Fig. 3). Therefore the natural occurrence of naquite is confirmed.

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