by Mao Jingwen¹, Zhang Zuoheng¹, Bernd Lehmann², Zhang Zhaochong³,
Yang Jianmin¹ and Wang Zhiliang¹

The Yeniutan granodiorite in Sunan County, Gansu Province, China: petrological features, geological setting and relationship to tungsten mineralization

¹ Institute of Mineral Deposits, Chinese Academy of Geological Sciences, Beijing 100037, China

² Institute of Mineralogy and Mineral Resources, Technical University of Clausthal, D-38678 Clausthal-Zellerfeld, Germany

³ Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

The 460 Ma-old Yeniutan granodiorite intrusion is spatially and temporally associated with the Ta'ergou tungsten deposit, one of the recently explored large tungsten resources in northwest China. It is located in the North Qilian Caledonian-aged belt and consists of a granodiorite main phase cut by dikes of biotite granite. The country rock is the Early Proterozoic Beidahe Group and Ordovician volcanic rocks which are overprinted by a 500~800 m wide thermal metamorphic aureole. The granodiorite has a coarse-grained and pseudoporphyrict texture and is composed of variable amounts of amphibole, pyroxene, biotite, plagioclase, quartz and alkali feldspar perthite. Accessory minerals are sphene, magnetite, zircon, apatite and allanite. The biotite granite is fine- to medium-grained, and is composed of plagioclase, K-feldspar, quartz and biotite with accessory apatite, zircon and thorite.

The SiO₂ content of the granodiorite ranges from 57 to 63 wt%, the Al index (Na+K/Al) varies from 0.43 to 0.58. The SiO₂ content of the biotite granite ranges from 65 to 66 wt% and its Al index varies from 0.43 to 0.58. The two granitic rocks share similar characteristics of trace elements and rare earth elements. Their contents of compatible components such as V, Ba, Co, Ni, Cr and Sr are high, the Rb content ranges from 20 to 188 ppm, and their Rb/Sr ratios are mainly between 0.3 and 0.6. The REE content of the granodiorite ranges from 141 to 241 ppm, the La/Yb ratio varies from 10 to 31, δEu from 0.6 to 0.8. The total REE amount of the biotite granite is about 160 ppm, the La/Yb ratio varies from 19 to 36, and δEu from 0.5 to 0.9. All geochemical indicators reflect an evolution from pseudoporphyrict granodiorite to biotite granite at a generally low degree of fractionation.

Sr and O isotope data indicate a high degree of contamination and assimilation in the upper crust.

Unlike most tungsten granite suites in which the latest intrusive unit is genetically associated with tungsten mineralization, the main-phase granodiorite of the Yeniutan intrusion is related to tungsten mineralization. With the regional geological evolution as the background and in light of geochemical data, zircon U-Pb and other dating, the Yeniutan granodiorite and its related tungsten mineralization are deduced to have formed in a pre-collisional rather than a collisional setting.

Introduction

China is currently the source of about three quarters of all tungsten mined in the world and has around 40 % of the global tungsten reserves (USGS, 1999). In the past ten years, the two large tungsten deposits of Ta'ergou and Xiaoliugou with metal reserves of more than 200,000 tons W at an average grade of 0.67% and 0.75%, respectively, have been discovered in the Sunan and Subei counties, Gansu province, NW China (Song Shuhe, 1994; Mao Jingwen et al., 1999a, 1999b, 1999c). Both of them consist of quartz-wolframite type and skarn type mineralization, dominated by the former one. Due to carbonate layers that are rare in the Precambrian amphibole-facies metamorphic rocks, the major host rocks for both Yeniutan granitic intrusion and related mineralization, skarn type W mineralization is widespread in the area, but not extensive. These two world-class deposits and the great prospecting potential make the North Qilian orogenic belt the most important tungsten metallogenetic belt in northwest China.

Most world-class tungsten deposits are associated with granitoids in a collisional setting (Mitchell and Garson, 1981; Sawkins, 1990; Seltmann et al., 1994; Shatov et al., 1996) or in a post-collisional extensional setting (Marignac and Cuney, 1999; Breiter et al., 1999). Our recent research also indicates that the well-known South China tungsten-tin province with dozens of world-class tungsten and tin deposits is developed in a Mesozoic extensional setting. However, the world-class tungsten deposits in the western sector of the North Qilian Caledonian orogenic belt may occur in a pre-collisional period. This paper describes the petrology, mineralogy and geochemistry of the Yeniutan granitic intrusion and tries to probe into its

characteristics, petrological evolution, tectonic setting and relationship to tungsten mineralization.

Geological characteristics of the Yeniutan granitic intrusion

Lying in Sunan county, Gansu Province, the Yeniutan granitic intrusion is located geologically in the western sector of the North Qilian Caledonian orogen and geographically in the northeastern margin of the Tibetan plateau. Mao Jingwen et al. (2000) has described the related regional geological setting.

The Yeniutan intrusion is 33 by 5–10 kilometers large, and the outcrop exposure is about 220 km² (Figure 1). The intrusion intruded into the Early Proterozoic Beidahe Group and Ordovician strata. It displays an outwards dipping contact with the country rocks at 50°–70°. The intrusive contact is clearly defined, and the thermometamorphic zone in the east side of the intrusion is about 500–800 meters wide. Andalusite, tremolite, epidote and diopside hornfels can be recognized. There is also marble and skarn formation and silicification developed.

The intrusion consists dominantly of granodiorite. The grain size of minerals in the granodiorite ranges from coarse to very coarse in the central part of the intrusion to medium-grained in the marginal phase. Many biotite granite dikes and small stocks intrude the granodiorite intrusion irregularly (Figure 2). The grain size of minerals in the biotite granite changes progressively from medium or medium to fine-grained in the central phase to fine-grained along the margins. The two granitic intrusive phases are followed by a large number of dikes and quartz veins, including tourmaline pegmatite veins, quartz diorite porphyrite dikes, diorite porphyrite dikes, granite dikes and

W-bearing quartz veins which developed both within the granodiorite intrusion and in the surrounding country rocks.

The pseudoporphyritic granodiorite can be divided into amphibole and pyroxene granodiorite variants. There is no clear lithological or intrusive boundary between the two kinds of rocks. The amphibole granodiorite is mainly composed of hornblende (25%), biotite (7%), plagioclase (50%), alkali feldspar perthite (5%), quartz (10%), and sphene (2%). Some amphibole shows clinopyroxene pseudomorphs. The radioactive minerals such as zircon are mainly enclosed in biotite or plagioclase. Perthite appears as phenocrysts, possesses cross-hatched twinning, and usually encloses amphibole, biotite and plagioclase (An30–40, An10–12). Polysynthetic twins of plagioclase are clearly developed, the central parts of a few plagioclase crystals have been strongly altered and changed into clinozoisite-sericite, while the outside part is frequently unaltered. The accessory mineral assemblage consists of sphene, magnetite, zircon, apatite and allanite. Sphene occurs as coarse grained euhedral crystals, but most of them are contained in amphiboles with fractured or anhedral habit. Apatite appears as short and fine columnar crystals scattered among or inside the rock-forming minerals. Zircon is commonly contained in dark minerals.

The pyroxene pseudoporphyritic granodiorite consists mainly of plagioclase (An33–46), alkali feldspar perthite, orthoclase, hornblende, pyroxene and quartz. Plagioclase appears as perfect elliptical and tabular crystals and is mostly fresh; a few crystals have been altered into sericite and clinozoisite assemblage. It seems that there is more clinozoisite in the center and more sericite in the margin of the altered plagioclase. There are great amounts of quartz and biotite enclaves in perthite, and rare orthoclase enclaves characterized by Carlsbad twin are hosted in biotite. Biotite, containing much apatite and zircon, shows pleochroism. Pyroxene appears light brown or colorless, coarse and short columnar under the microscope and is partly replaced by amphibole. Amphibole is euhedral with long

columnar crystal shape, or replaces pyroxene. Quartz is fine-grained and interstitial to other minerals. In the light of textural and metasomatic relationships the rock-forming mineral sequence is: pyroxene→biotite and amphibole→plagioclase→potassium feldspar→quartz. The modal contents are pyroxene 5%, biotite 5%, amphibole 10%–15%, plagioclase 50%–55%, potassium feldspar 15% and quartz 10%. Sphene is the major accessory mineral and the dominant assemblage is sphene-zircon-apatite.

According to grain size, the biotite granite can be divided into fine and medium-grained variants. The mineral assemblage and the proportion of major rock-forming minerals are almost the same in both granite types. Both are composed of plagioclase, potassium feldspar, quartz and biotite. The modal contents are plagioclase (An27–51) 45%–50%, potassium feldspar 10%–20%, quartz 30%–35%, and biotite 15%–20%. Plagioclase appears in euhedral-subhedral crystals with fine and dense polysynthetic twins. Most of them are fresh; a few have been altered into clinozoisite-sericite. Potassium feldspar occurs in perfect elliptical or platy shape and has generally been sericitized. It is mostly composed of perthite characterized by orthoclase, and also of microcline characterized by cross-

Figure 1 Geological map of the Yeniutan intrusion (Modified after the geological map on 1:200,000 scale).

Figure 2 Geological section of the Yeniutan granodiorite intrusion (after Gansu Bureau of Geology and Mineral Resources, 1972).

hatched twins. Biotite has been altered into muscovite or chlorite along cleavage planes. Biotite hosts many inclusions of short columnar euhedral apatite, thorite and zircon. The biotite has a ragged shape, and often occurs as flakes within feldspar and quartz. Quartz occurs as automorphic crystals and is interstitial to plagioclase. It is worth pointing out that besides the secondary muscovite from replacement of biotite, there is also some minor muscovite appearing as independent crystals. A few small fine-grained tourmaline veins cut the biotite granite.

The Yeniutan intrusion is related to tungsten mineralization. The Ta'ergou skarn-wolframite quartz vein type deposit is located in the endo- and exocontact in the areas of Ta'ergou and Shidonggou (Figure 1), and is the largest tungsten deposit in Northwest China (Zhang Zuoheng et al., 1998, Mao Jingwen et al., 1999c). There are also the Renganggou and the Qinghe small-size skarn iron deposits, which are situated to the northeast exocontact of the intrusion (Figure 1).

Petrochemistry

Major elements

Twenty-four specimens of granitic rocks were selected for bulk analyses in the National Research Center of Geoanalysis by the XRF method. The results are listed in Table 1.

The SiO_2 content of the granodiorite ranges from 57 to 65 wt% and the A/CNK index varies from 0.8 to 1.3, and is mostly lower than 1, indicating metaluminous composition. The Al index ($\text{Na}+\text{K}/\text{Al}$) ranges from 0.5 to 0.8, the Rittmann δ value ranges from 0.8 to 3.0, which reflects the calc-alkaline character of the rocks.

The data show that the SiO_2 content of biotite granite ranges from 65 to 66 wt%. The aluminum saturation index ($\text{Al}/\text{Ca}+\text{Na}+\text{K}$) is around 1.1, and the Al index ($\text{Na}+\text{K}/\text{Al}$) ranges from 0.4 to 0.6, the Rittmann index δ ranges from 1.0 to 2.3. The biotite granite is a low-alkali rock. Its SiO_2 content ranges from 67 to 71 wt% and the other three indices range from 1.07 to 1.25, 0.49 to 0.66, 1.03 to 2.06, respectively. The diagrams of SiO_2 vs other main oxides and the differentiation index (D.I.) (Figure 3) show that the MgO, TiO_2 , MnO, P_2O_5 , CaO, $\text{FeO}+\text{Fe}_2\text{O}_3$ contents decrease as the SiO_2 contents increase from granodiorite to biotite granite while the changes of $\text{Na}_2\text{O}+\text{K}_2\text{O}$, Na_2O and K_2O contents display a scatter distribution.

Trace elements

Twenty-four specimens from the Yeniutan granitic rocks have been analyzed in the National Research Center of Geoanalysis. Most elements are analyzed

with the ICP-AES method and Rb by XRF. All the data are listed in Table 2.

In contrast to many other W-bearing granites, the trace element contents of the Yeniutan granitic rocks display a relatively low degree of fractionation. The contents of compatible elements such as V, Ba, Co, Ni, Cr and Sr are high, and the Rb content is intermediate (from 20 to 188 ppm). The Li content ranges from 11–50 ppm. Moreover, Li content increases from granodiorite to biotite granite. The Rb/Sr ratios of the two main rock units in the Yeniutan intrusion are very close to each other, mostly between 0.3 and 0.6, which is different from most W-Sn bearing granites. The latter are usually highly enriched in Rb and poor in Sr, their Rb/Sr ratio is generally higher than 1, or even higher than 100. For instance, the Rb/Sr ratios of the Xihuashan granites related to the Xihuashan tungsten deposit range from 22 to 84 (Le Bel et al., 1984), those of the Qianlishan granites associated with the Shizhuoyuan W-Sn-Mo-Bi deposit range from 11 to 136 (Mao Jingwen et al., 1995), and those of the Sandaozhuang W-Mo related granite range from 1.5 to 2.2 (Li Shimei, 1983). The Th/U ratio of granodiorite in the Yeniutan granitic intrusion varies from 4.39 to 18.16 with a mean of 9.78, and that of biotite granite varies from 2.51 to 5.35 with a mean of 3.46. This phenomenon, i.e. Th/U ratio is getting lower from early to late granitic rocks, indicates that both granitic rocks share the same source and belong to the same granite suite.

Although two large granite-related deposits have been found in the research area, the contents of W, Be, Mo and Bi in the granitic rocks do not show any anomaly. The contents of Mo, W, Bi and Be in the rocks are essentially coincident with their Clarke values in average granites of the world. Although tin of the Yeniutan granitic rocks is 1 to 2 ppm higher than the Clark value of its corresponding rock, there is no tin mineralization known in the area.

TiO_2 behaves compatibly during the magmatic evolution of granites (Lehmann, 1990, 1994), so it is a suitable component to indicate magmatic differentiation processes. The diagrams of TiO_2 vs Ni, Li, V and Ba (Figure 4) show that TiO_2 is positively correlated

Figure 3 Diagram of SiO_2 vs MgO, TiO_2 , MnO, P_2O_5 , CaO, $\text{Na}_2\text{O}+\text{K}_2\text{O}$, and D.I. in Yeniutan granitic rocks.

Table 1 Petrochemical composition of granitoids in the Yeniutan intrusion (wt%).

Type of rocks	Fine-grained biotite granite				Medium-grained biotite granite				Granodiorite			Granodiorite														
Sample number	Ym-2	Ym-3	Ym-9	Ym-10	Ym-5	Ym-6	Ym-7	Ym-8	Ym-13	Ym-15	Ym-16	Ym-18	Ym-19	Qh-1	Qh-2	Qh-3	Qh-5	Qh-7	Qh-9	Th-1	Th-2	Th-3	Th-4	Th-5		
SiO ₂	65.63	65.14	65.21	66.37	71.18	71.48	67.35	70.33	63.66	60.41	58.99	62.40	61.06	62.31	62.46	61.54	62.83	60.10	60.43	64.60	63.61	61.68	60.23	57.33		
TiO ₂	0.59	0.47	0.62	0.51	0.23	0.25	0.47	0.38	0.63	0.87	0.81	0.69	0.74	0.71	0.65	0.69	0.66	0.75	0.75	0.68	0.63	0.75	0.65	0.89		
Al ₂ O ₃	15.65	15.93	14.99	15.33	15.02	14.98	14.86	14.76	15.22	15.36	15.54	15.24	15.41	14.77	14.74	14.91	14.74	14.97	14.70	15.94	15.16	14.69	14.55	15.32		
MgO	2.19	1.79	2.04	1.77	0.57	0.61	1.69	1.60	2.38	2.97	3.12	2.86	2.91	2.78	2.61	2.83	2.60	3.11	3.17	2.25	2.23	2.98	3.31	3.72		
Fe ₂ O ₃	0.74	0.50	0.66	1.11	0.68	0.42	0.87	0.67	0.87	1.19	1.01	1.15	1.09	0.77	0.80	0.93	0.52	0.83	0.89	0.47	1.13	0.64	0.74	0.97		
FeO	4.93	4.31	6.07	5.01	2.42	2.56	4.16	3.83	4.35	5.16	5.41	5.87	5.90	4.94	4.58	4.83	5.42	5.42	5.42	4.94	4.54	5.37	4.93	6.14		
MnO	0.13	0.08	0.09	0.09	0.06	0.06	0.11	0.09	0.13	0.15	0.14	0.50	0.13	0.13	0.11	0.12	0.13	0.13	0.14	0.11	0.13	0.13	0.12	0.16		
CaO	4.07	3.28	4.27	3.75	2.14	2.29	3.14	2.56	4.42	5.66	5.03	4.60	4.63	4.69	4.44	4.99	4.43	5.24	5.31	3.70	4.14	4.44	5.13	6.15		
Na ₂ O	3.09	2.74	2.40	3.18	3.15	3.68	2.61	2.61	2.53	2.59	2.23	2.38	2.55	2.47	2.65	2.65	2.71	2.71	2.38	2.79	2.69	2.51	3.14	2.69		
K ₂ O	2.29	4.38	2.34	2.12	4.11	3.48	3.64	2.68	4.60	2.53	6.06	6.91	5.09	4.31	4.19	4.10	4.53	4.09	4.30	2.63	4.24	4.73	3.68	3.79		
P ₂ O ₅	0.27	0.39	0.24	0.27	0.07	0.06	0.20	0.18	0.28	0.34	0.35	0.34	0.33	0.31	0.27	0.30	0.27	0.34	0.35	0.32	0.24	0.32	0.29	0.38		
H ₂ O ⁺	1.30	1.28	1.18	1.10	0.82	0.66	1.84	1.28	0.90	1.72	1.06	1.28	1.66	1.14	1.53	0.94	0.69	1.28	1.24	0.76	0.93	0.72	2.26	1.24		
CO ₂	0.35	0.71	0.35	0.10	0.48	0.52	0.14	0.05	0.22	0.19	0.14	0.31	0.02	-	-	-	-	-	-	-	-	-	-	-		
F	0.10	0.09	0.07	0.08	0.03	0.03	0.07	0.09	0.10	0.12	0.09	0.08	0.07	0.03	0.09	0.10	0.09	0.10	0.11	-	-	-	-	-		
Cl	0.01	0.02	0.04	0.04	0.03	0.02	0.02	0.03	0.05	0.03	0.04	0.02	0.02	0.01	0.01	0.01	0.01	-	-	-	-	-	-	-		
sum	100.60	100.61	99.91	99.72	100.67	100.68	100.30	100.47	100.34	100.29	99.04	100.75	99.97	99.91	99.64	99.41	99.57	99.86	99.80	99.30	99.76	98.96	99.03	98.78		
D.I.	65.02	70.34	61.73	67.08	82.60	77.23	70.94	73.06	65.52	56.99	59.19	62.69	61.63	63.26	64.97	62.75	65.71	59.74	59.67	64.05	65.68	63.54	61.52	54.22		
A/CNK	1.05	1.05	1.05	1.07	1.11	1.07	1.07	1.25	0.89	0.89	0.80	0.77	0.85	0.86	0.87	0.83	0.85	0.81	0.81	1.18	0.92	0.85	0.79	0.78		
Al	0.48	0.58	0.43	0.49	0.64	0.66	0.55	0.49	0.66	0.46	0.66	0.75	0.63	0.59	0.60	0.59	0.64	0.59	0.58	0.47	0.60	0.63	0.63	0.56		
δ	1.28	2.29	1.01	1.20	2.06	1.80	1.61	1.03	2.46	2.15	3.26	2.47	2.78	2.36	2.34	2.39	2.59	2.62	2.48	1.35	2.75	2.31	2.58	2.96		

Table 2 Trace element contents of granitoids in the Yeniutan intrusion (ppm).

Type of rocks	Fine-grained biotite granite				Medium-grained biotite granite				Granodiorite				Granodiorite											
Sample number	Ym-2	Ym-3	Ym-9	Ym-10	Ym-5	Ym-6	Ym-7	Ym-8	Ym-13	Ym-15	Ym-16	Ym-18	Ym-19	Th-1	Th-2	Th-3	Th-4	Th-5	Qh-1	Qh-2	Qh-3	Qh-5	Qh-7	Qh-9
Ba	434.60	616.90	349.80	348.20	282.80	673.40	656.30	325.40	743.90	677.00	1370.00	1204.00	830.00	491.80	780.50	976.30	875.30	840.30	796.40	719.50	804.40	828.90	818.40	863.30
Be	2.96	2.65	2.35	1.30	<1.00	1.10	2.87	2.25	2.60	2.32	2.41	2.82	3.42	2.23	3.66	3.20	3.58	3.09	3.56	2.65	2.78	3.98	4.40	2.94
Co	10.15	8.36	13.60	9.01	3.35	6.09	7.46	6.37	9.49	10.41	11.92	11.11	10.02	9.19	9.77	12.79	10.96	14.31	11.31	22.84	28.81	10.78	51.52	58.05
Cr	46.97	45.22	48.51	44.41	11.76	27.62	44.35	40.21	46.64	55.58	30.12	54.32	48.87	62.23	62.83	66.30	57.47	81.91	67.00	60.85	67.21	63.26	63.13	69.30
Cu	45.18	11.39	65.95	50.93	<2.00	11.00	34.55	16.35	19.11	20.11	20.04	44.36	15.66	35.76	26.70	28.83	19.41	32.12	22.08	29.49	26.90	97.78	36.68	24.77
Ga	10.62	6.57	14.67	13.98	<5.00	12.54	11.78	11.68	11.00	11.40	11.85	9.58	10.66	21.44	15.13	22.89	18.66	24.03	16.84	20.30	20.46	17.96	23.84	24.36
Li	46.15	33.86	44.93	50.67	20.79	24.94	25.64	41.28	32.58	27.04	31.55	38.84	27.73	67.87	42.42	37.83	25.19	38.53	34.05	23.52	18.38	42.26	39.16	26.40
Ni	5.11	8.10	7.64	7.82	<4.00	6.84	5.58	4.65	16.45	12.51	9.52	7.97	7.35	9.94	11.27	9.49	8.62	12.20	9.12	10.62	10.08	9.06	10.26	10.21
Pb	77.20	123.30	74.23	101.40	91.50	70.50	87.60	82.90	62.60	58.70	64.60	65.80	53.56	<13.00	40.98	27.08	19.76	26.97	22.58	26.98	21.69	28.52	18.43	21.18
Sr	343.10	244.30	257.90	305.90	73.26	167.50	318.40	240.60	294.50	421.20	420.00	305.70	374.10	356.50	398.20	484.00	186.00	474.10	136.60	401.60	410.50	422.80	454.40	453.40
Th	3.02	4.86	3.51	5.29	8.56	3.61	7.28	5.87	15.86	14.31	11.51	12.54	12.80	10.42	25.43	25.81	12.16	3.99	8.78	14.14	21.29	18.41	15.61	15.61
V	93.68	78.22	116.7	85.41	16.32	33.98	76.81	68.59	103.40	126.10	134.40	118.50	111.70	100.20	103.60	133.50	116.90	161.40	127.20	111.30	129.70	112.70	138.90	136.90
Zn	74.05	84.90	112.9	81.90	22.91	42.50	69.77	67.99	73.95	82.98	89.86	83.59	80.01	83.08	86.40	85.77	74.18	96.09	78.75	69.16	76.20	77.88	72.37	74.60
Zr	42.86	37.96	84.77	84.77	38.46	96.32	69.11	49.53	48.14	62.12	65.10	48.50	58.64	-	-	-	-	-	-	-	-	-	-	-
W	1.70	0.90	<0.50	<0.50	0.80	0.80	0.60	1.40	<0.50	<0.50	<0.50	0.60	<0.50	2.20	1.20	1.20	1.10	0.70	0.50	2.80	2.00	1.30	2.10	2.80
Sn	9.00	7.60	4.80	4.80	7.30	5.20	10.0	8.90	5.20	4.70	1.40	9.00	8.20	5.00	3.60	5.00	5.40	5.00	8.00	7.20	6.40	7.90	6.40	5.40
U	1.20	1.50	1.40	1.80	1.60	1.40	1.50	1.60	2.00	2.10	1.70	1.80	2.00	1.00	1.40	2.60	0.70	2.80	2.00	1.00	2.00	3.00	1.60	2.40
Nb	9.00	10.00	11.00	11.00	5.00	7.00	11.00	9.00	11.00	14.00	10.00	7.00	12.00	13.00	12.00	12.00	8.00	11.00	10.00	8.00	9.00	10.00	11.00	12.00
Rb	125.00	159.00	144.00	112.00	98.00	90.00	159.00	138.00	168.00	126.00	188.00	180.00	161.00	171.00	176.00	168.00	79.00	151.00	187.00	154.00	138.00	186.00	151.00	148.00
Rb/Sr	0.36	0.65	0.56	0.37	-	0.54	0.50	0.57	0.57	0.30	0.45	0.59	0.43	0.48	0.44	0.35	0.42	0.32	0.43	0.38	0.34	0.44	0.33	0.33
Co/Ni	1.99	1.03	1.78	1.15	-	0.89	1.34	1.37	0.58	0.83	1.18	1.39	1.36	0.92	0.87	1.35	1.27	1.17	1.24	2.15	2.86	1.19	5.02	5.69
Se	6.57	4.57	11.4	9.18	3.61	3.01	6.33	6.97	12.25	11.67	14.37	12.74	12.93	11.05	11.68	13.98	11.99	15.88	13.79	11.79	15.00	11.91	15.12	16.47
Y	20.21	18.74	19.37	25.76	15.17	14.65	19.52	16.21	23.79	20.76	21.80	27.01	22.90	26.40	23.76	26.53	17.65	20.82	27.25	22.83	28.34	24.55	25.66	28.39
Th/U	2.52	3.24	2.51	2.94	5.35	2.58	4.85	3.67	7.93	6.81	6.77	6.97	6.40	10.40	18.16	9.93	17.37	1.43	4.39	14.14	10.63	6.14	9.76	6.50

with Ni, V and Ba, except for Li. The contents of V, Bi, Ba and TiO₂ decrease synchronously as the rock evolves from granodiorite to biotite granite. Like Na₂O and K₂O, Li does not show any regularity during magmatic evolution.

Rare earth elements

Twenty-three samples of the granitic rocks have been chosen to perform REE analyses in the National Research Center of Geo-analysis by the ICP-AES method. The results are listed in Table 3.

The REE contents of the granodiorite range from 141 to 241 ppm. The La/Yb ratio varies from 10 to 31, δEu from 0.6 to 0.8. The chondrite-normalized REE patterns (Figure 5) are moderately steep with a weak negative Eu anomaly. Although the REE contents of the granodiorite samples vary greatly, the REE patterns are quite similar to each other. The samples labeled from TH-1 to TH-5 are collected in succession along a cross-section through the intrusion, and their REE characteristics are very close. The La/Yb ratio ranges from 15-26, the La/Sm ratio from 4.8 to 7.3, and δEu from 0.6 to 0.7.

The total amount of the REE contents of biotite granite in the Yeniutan intrusion is about 160 ppm, only one sample (YM-2) reaching 204 ppm. The La/Yb ratio is rather high and varies from 19 to 36, the La/Sm ratio from 6.5 to 10, and δEu from 0.5 to 0.9. The chondrite-normalized REE patterns (Figure 6) are moderately steep with depletion of HREE. The depletion of Eu in biotite granite is weaker than that in granodiorite.

In general, granitoids in the same evolutionary series from early to late stage display a decline in the La/Yb ratio and Eu depletion. However, the granodiorite and biotite granite in the Yeniutan granitic rock series resemble each other, although the rock-forming

mineral assemblage and major-element composition are different, which may indicate that there is no obvious cogenetic differentiation relationship between the granitic rocks.

Table 3 REE contents of granitoids in Yeniutan intrusion (ppm).

Type of rocks	Biotite granite							Granodiorite				Granodiorite											
Sample number	Ym-2	Ym-5	Ym-6	Ym-7	Ym-8	Ym-9	Ym-10	Ym-13	Ym-15	Ym-16	Ym-18	Ym-19	Th-1	Th-2	Th-3	Th-4	Th-5	Qh-1	Qh-2	Qh-3	Qh-5	Qh-7	Qh-9
La	53.99	40.61	43.41	50.46	42.24	30.13	41.68	50.35	55.42	45.30	44.26	44.62	42.82	45.48	61.89	37.52	30.36	27.47	38.13	42.77	41.65	36.92	40.45
Ce	86.56	63.66	69.02	76.17	68.90	48.54	67.18	82.51	79.48	83.02	68.49	71.51	78.35	73.63	100.30	65.67	54.15	52.38	65.40	73.88	71.61	65.00	69.31
Pr	9.47	7.14	7.73	8.25	7.95	5.60	7.37	9.33	9.27	8.70	7.60	8.48	10.11	9.69	12.70	9.13	6.75	7.26	8.66	10.51	9.53	9.14	9.39
Nd	29.69	23.08	24.45	26.27	25.95	21.77	24.47	31.31	30.53	29.36	26.44	28.76	30.38	27.73	37.08	26.07	24.39	24.33	26.52	31.52	27.71	27.36	30.30
Sm	6.41	4.52	4.96	5.02	4.97	4.61	5.22	6.07	5.83	6.16	5.74	5.97	8.85	6.96	8.47	7.69	5.73	7.16	6.43	7.96	7.08	7.41	7.70
Eu	1.11	1.19	1.18	0.94	0.87	1.15	1.34	1.28	1.41	1.43	1.28	1.35	1.42	1.30	1.35	1.22	1.24	1.41	1.19	1.55	1.34	1.38	1.40
Gd	6.26	3.87	4.24	5.21	4.88	5.09	5.32	6.43	6.07	6.22	6.54	6.58	5.92	0.83	5.70	0.55	0.58	0.83	0.66	8.62	5.93	7.06	7.35
Tb	0.91	0.55	0.49	0.71	0.48	0.71	0.81	0.91	0.76	0.62	0.78	0.85	0.92	0.83	0.83	0.55	0.58	0.83	0.66	1.02	0.85	0.71	0.89
Dy	4.19	2.91	3.07	3.56	3.17	3.89	4.57	4.35	4.01	4.16	4.69	4.18	5.46	4.34	5.13	3.33	3.92	4.94	4.18	5.27	4.51	4.77	5.27
Ho	0.80	0.58	0.57	0.72	0.44	0.74	0.97	0.90	0.78	0.80	1.02	0.89	1.10	0.97	1.10	0.71	0.80	1.06	0.90	1.13	0.96	1.03	1.14
Er	2.37	1.44	1.60	2.06	1.61	2.03	2.62	2.74	2.33	2.33	3.08	2.43	2.98	2.78	3.11	2.12	2.23	3.10	2.60	3.24	2.74	2.88	3.24
Tm	0.31	0.19	0.18	0.29	0.20	0.26	0.36	0.40	0.30	0.29	0.40	0.37	0.43	0.39	0.46	0.30	0.33	0.42	0.37	0.43	0.38	0.39	0.45
Yb	1.69	1.33	1.20	1.72	1.34	1.56	1.98	2.32	1.80	1.88	2.77	2.15	2.38	2.42	2.42	1.79	1.95	2.66	2.29	2.75	2.43	2.46	2.71
Lu	0.28	0.21	0.10	0.17	0.12	0.14	0.27	0.42	0.28	0.24	0.36	0.36	0.37	0.36	0.40	0.26	0.30	0.38	0.35	0.40	0.34	0.37	0.41
sum	204.04	151.28	163.20	181.55	163.12	126.22	164.16	199.32	198.27	163.15	173.45	178.50	191.45	183.80	240.94	161.80	138.24	141.02	163.19	190.55	177.06	166.88	180.01
La/Yb	31.95	30.53	36.17	29.34	31.52	19.31	21.05	21.70	30.79	24.10	15.98	20.75	17.99	18.79	25.57	20.96	15.50	10.33	15.55	17.14	15.01	14.93	14.98
La/Sm	8.42	8.98	8.75	10.05	8.50	6.54	7.89	8.29	9.51	7.35	7.71	7.47	4.84	6.53	7.31	4.88	5.30	3.84	5.37	5.88	4.98	5.25	6.69
δ Eu	0.58	0.93	0.84	0.61	0.51	0.80	0.85	0.69	0.79	0.77	0.70	0.72	0.61	0.62	0.61	0.60	0.73	0.64	0.63	0.67	0.63	0.62	0.64

Figure 4 Diagram of TiO_2 vs Ni , V , Li and Ba .

phenomena in mind and as a result of backscattered electron imaging on the zircon, all grains are considered to be primarily magmatic with no xenocrystic sectors.

All the analyses are listed in Table 6 and plotted in Figure 7. $^{206}\text{Pb}/^{238}\text{U}$ surficial age for the No.1, No.2 and No.3 grains range from 459.1 to 460.3Ma with a mean of $459.6 \pm 2.5\text{Ma}$, which can be considered to be the magmatic crystallization age. No.4 and No.5 grains have the surficial age varying from 423.8 to 439.8Ma, which may represent the disturbed age.

Five zircons from the granodiorite define a discordant line with an upper intercept of 469Ma (Figure 7). Although MSWD of 0.061 of the discordant line is quite low, the errors for it are high. The analyses of the former three grains plotted at almost the same point

Figure 5 Chondrite-normalized REE pattern of granodiorite along a section.

in the line give a precise age of $459.6 \pm 2.5\text{Ma}$ which also approaches the upper intercept of 469Ma.

Discussion

A special type of W-related granitoid

As mentioned above, there are two large-size tungsten deposits or tungsten-polymetallic deposits explored in the research area, i.e. the Ta'ergou and the Xiaoliugou deposit. They are spatially and temporally related to the Yeniutan intrusion and the Xiaoliugou intrusion, respectively. At the current level of knowledge, it is difficult to set up the geological and geochemical criteria for tungsten-bearing and tungsten-barren granitoids in the western part of the North Qilian region. High CaO , FeO and MgO as well as K_2O and Na_2O , higher K_2O content than Na_2O content and low SiO_2 content are the main characteristics of the Yeniutan intrusion. The Yeniutan intrusion comprises two main intrusive units, i.e. granodiorite and later biotite granite dikes. The Ta'ergou tungsten deposit is spatially and temporally related to the granodiorite, although its differentiation index, REE patterns, La/Yb ratios and δEu reveal a relatively low degree of differentiation.

According to granite source, tungsten-tin deposit-related granites are divided into S- and I-types. S-type tungsten-bearing granites are extensively developed in China. This type of tungsten and tin granites is characterized by high silicon, aluminum, alkaline metals and volatile components. They usually intrude in multiple stages. Silicon, alkalis, volatile components such as F and B, incompatible elements such as Rb, Li, Ga, and metallic elements such as Be, Nb, Ta, W, Sn and Mo are gradually concentrated from early to late intrusive stages. Tungsten and tin mineralizations are generally asso-

Figure 6 Chondrite-normalized REE pattern of biotite granite.

Figure 7 U-Pb concordia plots for the Yeniutan granodiorite.

ciated with the latest stages of granite plutons (Groves and McCarthy, 1978; Higgins et al., 1985; Lehmann, 1987, 1990; Mao Jingwen, 1989). The chondrite-normalized REE patterns are characterized by strong depletion in Eu, and a seagull-like distribution shape. Although a lot of criteria for recognition, such as the diagrams of $\text{SiO}_2/10(\text{CaO}+\text{MgO})-(\text{Na}_2\text{O}+\text{K}_2\text{O})$ and $(\text{FeO}+\text{MgO})-\text{CaO}-(\text{Na}_2\text{O}+\text{K}_2\text{O})$, the ratios of K/Rb, Rb/Sr, Rb/Ba and K/Cs, have been set up to distinguish ore-bearing granite intrusions, these criteria do not fit the Yeniutan granitic rocks. The Yeniutan intrusion is not peraluminous, and has low SiO_2 and Al_2O_3 contents. The CIPW norm is corundum-deficient (Table 1), and both granodiorite and biotite granite belong to calcium-rich granitic rocks. Even though, the composition projection in ACF diagram (Figure 8) shows that the Yeniutan is S-type granite. This conclusion is also supported by oxygen isotope data (Table 5) characterized by high values of $\delta^{18}\text{O}$ and the initial strontium value of 0.7154 (Zou and Huang, 1988). However, the projection of $\delta^{18}\text{O}_{\text{‰}}$ (SMOW) vs SiO_2 (wt %) (Figure 9) implies that the granodiorite and biotite granite in the Yeniutan intrusion belong in I-type and S-type, respectively, and are evidently different from the Sn-W granites in South China. Chappell et al. (1998) pointed out that with fractional crystallization, Th abundance increases in I-type granites, and decreases in S-type granites. The evolution trend of Th/U ratio in the Yeniutan granitic rocks is very similar to that in the Qianlishan granite suite genetically associated with the Shizhuoyuan W-Sn-Mo-Bi deposit (Mao Jingwen and Li Hongyan, 1995; Mao Jingwen et al., 1996), which is proved to be of typical S-type.

I-type granite-related tungsten deposits are quite rare in China. Typical examples are the Sandaozhuang W-Mo deposit in Henan Province, the Yangchuling porphyry W deposit in Jiangxi Province and the Lianhua porphyry W deposit in Guangdong Province. The granite related to the Sandaozhuang W-Mo deposit occurs as a small stock (0.12 km²) (Song Shuhe, 1994). The rocks are silicon- and alkali-rich (SiO_2 content ranging from 70 to 76 wt%, $\text{Na}_2\text{O}+\text{K}_2\text{O}$ content from 7-10 wt%) and strongly differentiated. The initial strontium value is 0.707 and the $\delta^{18}\text{O}$ ranges from 7.2 to 9‰, which indicates that the rock-forming materials are from a deep source. There are also many I-type granite-related W deposits and W-Mo deposits in central Kazakhstan (Shatov et al., 1996). Most of the tungsten granites there are similar to the light-colored granite of Sandaozhuang. By contrast, we propose to emphasize the obvious difference between the Yeniutan and the typical I-type tungsten-bearing granites.

The evolutionary succession of the Yangchuling intrusion is quartz diorite occurring as xenolith→granodiorite→granodiorite porphyry→adamellite porphyry from early to late (Zhang Yuxue, 1982). The Yangchuling porphyry tungsten deposit shows a clear spatial-temporal relationship to adamellite porphyry and granodiorite porphyry. In this rock succession, SiO_2 contents range from 66 to 67 wt%, and 69 to 70 wt%, respectively, and $\text{K}_2\text{O}+\text{Na}_2\text{O}$ content from 6.5 to 7.4 wt%. They all belong to metaluminous and peralkaline granite. The chondrite-normalized REE patterns show right-inclined shape and are weakly Eu depleted. These data are almost coincident with the data of the Yeniutan intrusion and suggest that the ore-forming materials and metallogenic mechanism have similarities in some degree. Furthermore, the Yeniutan granitic rocks and other I type tungsten granites comprise almost the same accessory mineral assemblage characterized by magnetite, thus defined as magnetite granite series by Ishihara (1977). As Ishihara (1984, 1998) and Sillitoe and Thompson (1998) have summarized, W and W-Mo mineralization is spatially and temporally related to magnetite series granitoids owning high redox state, whereas Sn, W-Sn and polymetallic tin deposits to ilmenite series granitoids owning low redox state. This could also explain why tin mineralization did not occur although both the granodiorite and the biotite granite in the Yeniutan granitic intrusion have high abundance of tin. Rb/Sr ratio is a useful tool to trace the granite source. The ratio of the Yeniutan granitic intrusion is quite low, which is close to I-type granite rather than S-type granite.

According to the data discussed above, it can be concluded that the tungsten-bearing Yeniutan granitic intrusion is characterized by low silicon, high alkaline and basic components, and displays some unique characteristics in petrology, petrochemistry, and REE geochemistry. It is enriched either in incompatible elements, i.e. Ga, Li

Figure 8 ACF diagram for the Yeniutan granitic rocks.

$A=(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3-\text{Na}_2\text{O}-\text{K}_2\text{O})$; $C=(\text{CaO}-3.3\text{P}_2\text{O}_5)$; $F=(\text{FeO}+\text{MgO}+\text{MnO})$

Figure 9 SiO_2 vs $\delta^{18}\text{O}$ diagram for the Yeniutan granitic intrusion.

Table 4 Basic characteristics of tungsten-tin granites.

Diagenetic type	S-type	I-type		Yeniutan granitic intrusion
Typical intrusion or region	Nanling region and Erzgebirge region	Yangchuling Intrusion in south China	Sandaozhuang intrusion in North China and Kazakhstan region	
Lithologic characters	biotite granite, light-colored granite	granodiorite, adamellite, granite	granodiorite, light-colored granite	granodiorite
Outcropped area (km ²)	10~100		0.1~2.8	220
SiO ₂ (%)	72~78	60~70	73~78	57~65
Na ₂ O+K ₂ O (%)	7~9	5~7.5	7~10	5.1~9.3
Accessory mineral assemblage	zircon, magnetite, ilmenite, monacite	zircon, magnetite, rutile, apatite, allanite		sphene, zircon, apatite, magnetite
Strontium initial value	0.712~0.755	0.703~0.707		0.7154
Mineralization elements assemblage	W, Sn, Pb, Zn, Bi, Li, REE	W, Mo		W, Mo, Be

and Rb or in large ions of Ti, Sr, Ba, Co, Ni, V and Th but is poor in U. The La/Yb ratio is higher than that of both I- and S-type granite, but δEu values are less reduced. The intrusion possesses the ordinary characteristics of I-type granite but Sr isotope data show that the rocks are derived from a crustal source. So it can be concluded that the rocks display transitional characteristics between I- and S-type. The basic characteristics of the three types of granites are listed in Table 4.

The classification of I- and S-type granite proposed by Chappell and White (1974) and based on source characteristics has greatly promoted the studies of granite. However, in recent years it has become evident that the end-member granites of I- or S- type are rare and that most granites are between the former two. Even in the same granitic suite, differentiation can produce transitions from one type to another. The tungsten and tin granites are all end- or near end-member granites of either I- or S- type granite which has experienced strong differentiation and evolution. The rock-forming material source of the Yeniutan intrusion is between the I- and S-type granite and the degree of differentiation and magmatic evolution is low. In fact, it is a rare type of tungsten-related granite intrusion. It is probably derived from the depth, but has incorporated a great amount of crustal materials by contamination and assimilation.

Relationship of the Yeniutan granitic intrusion to the Ta'ergou tungsten deposit

The magmatic evolution of rare-metal mineralized granitic intrusions during intracrustal fractionation is controlled by fractional crystallization (Lehmann, 1994). In fact, all tungsten-tin granites, including S-type, I-type, and M-type, display strong fractionation, and the related tungsten-tin mineralizations are related to the ultimate stage of granite evolution.

However, the Yeniutan granitic intrusion is an exception. What is the relationship of the Yeniutan granitic intrusion to the Ta'ergou tungsten deposit? There are three possibilities. First, the Yeniutan is a special tungsten-bearing granitic rock, and is different from highly fractionated S-type and I-type ore-bearing granite. It is probable that it experienced strong fractionation, but we cannot recognize this with the present criteria. Mao et al. (2000) described three granite belts in the western sector of the North Qilian Caledonian orogen, i.e. biotite granite belt in the north, granodiorite belt in the south margin, and syenite belt in the south margin. However, the granodiorite is the only one with spatial-temporal relationship to mineralization. Although the biotite granite in the northern belt shows strong differentiation and formed within a collisional setting, there are not any tungsten and/or tin miner-

alizations around them. The other possibility is that the magma assimilated a great amount of Early Proterozoic metamorphic rocks during emplacement, which transformed it into ore-bearing granitic rocks. However, the latter hypothesis is contradicted by the low content of tungsten.

Second, the Yeniutan granitic intrusion acted as a "heat machine", which heated formation fluids to form a series of convective circulation systems. These fluid systems leached tungsten and other metallic elements from the host rocks, and then discharged them along the fractures or marble layers in the Early Proterozoic metamorphic rocks. Zou and Huang (1988) reported that the average content of WO₃ in the schist, amphibolite and slate is 66

ppm (258 samples) in the research area, and among these rocks plagioclase amphibolite has the highest tungsten abundance ranging from 112 to 215 ppm. It is worth pointing out that all sampling locations are far away from the tungsten mineralizations so far known.

Table 5 Oxygen isotope data for Yeniutan granitic rock.

Sample No.	Granitic types	$\delta^{18}\text{O}_{\text{SMOW}}$ (per mil)
YM-13	Granodiorite	9.8
YM-15	Granodiorite	9.3
YM-16	Granodiorite	9.3
YM-18	Granodiorite	9.7
YM-19	Granodiorite	9.3
YM-20	Granodiorite	9.3
YM-21	Granodiorite	8.7
YM-22	Granodiorite	9.4
YM-2	Biotite granite	9.9
YM-3	Biotite granite	10.6
YM-5	Biotite granite	11.5
YM-6	Biotite granite	12.1
YM-7	Biotite granite	10.2
YM-8	Biotite granite	11.8
YM-9	Biotite granite	10.8
YM-10	Biotite granite	10.2

Third, the ore-bearing fluids were derived from a deep source, and moved up along the NWN-trending fault which controls the distribution of the granodiorite intrusions. At last, they formed ore deposits at the contact zones by metasomatism and deposition.

Analyses on petrogenetic setting of the granitoid

The chemical composition of rocks can be used as a tool to identify geotectonic setting. Peacock (1931) put forward the alkali-lime index to identify the rock type. Then, Shand (1951) divided granites into peraluminous, metaluminous and peralkaline ones. He used major elements to recognize that calcalkaline granite originated from volcanic arc magma, peralkaline granite from intraplate and peraluminous granite formed in a continent collision environment through anatexis of sedimentary rocks. Debon & Le Fort (1982) proposed diagrams of a group of "characteristic minerals" based on the early work of De La Roche (1978), using chemical components and min-

Table 6 U-Pb zircon data for Yeniutan granodiorite (No.GH-7).

Samples		Concentration		Content of common Pb in the samples (μg)	Atomic ratio of isotopes					Surficial ages (Ma)		
No.	Weight analysis (μg)	U (10^4)	Pb (10^4)		$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{207}\text{Pb}$	$^{207}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{207}\text{Pb}$
1	20	564	45	0.061	866	0.1195	0.07382 $\pm$ 63	0.5720 $\pm$ 70	0.05621 $\pm$ 45	459.1	459.3	460.5
2	20	374	42	0.210	185	0.2767	0.07385 $\pm$ 89	0.5724 $\pm$ 110	0.05621 $\pm$ 78	459.3	459.6	460.8
3	20	536	42	0.052	971	0.0903	0.07401 $\pm$ 67	0.5746 $\pm$ 74	0.05631 $\pm$ 45	460.3	461.0	464.7
4	15	472	34	0.018	1707	0.1071	0.07036 $\pm$ 103	0.5402 $\pm$ 113	0.05568 $\pm$ 76	438.3	438.5	439.8
5	15	469	31	0.001	24651	0.0921	0.06795 $\pm$ 62	0.5199 $\pm$ 67	0.05550 $\pm$ 45	423.8	425.1	432.3

Figure 10 Diagram of SiO_2 (wt%) vs Nb (ppm).

eral assemblages to discriminate tectonic environments. Pearce et al. (1984) proposed the trace element discrimination diagrams to imply ocean ridge granites (ORG), volcanic arc granites (VAG) and collision granites (COLG). Nearly at the same time, Batchelor and Bowden (1985) suggested the tectonic granite types of mantle differentiation, pre-collision, syncollision period, late orogenic and anorogenic granites distinguished by multi-elements. Using different methods to trace the genetic environment of granites has become more and more popular since the mid-1980's. Hong Dawei et al. (1995) collected the data of important and typical alkaline rocks over the world and set up the diagrams of trace elements to recognize anorogenic (AA) and post-orogenic (PA) types of rocks.

Based on the work of former researchers, we try to discriminate the rock-forming settings of the Yeniutan intrusion with chemical and trace element analyses as follows:

(1) The data of the Yeniutan intrusion are plotted within the volcanic arc field in the diagram of SiO_2 vs Nb (Figure 10). Although some points are plotted at the boundary between intraplate and volcanic arc, the low content of Rb (79-188 ppm) reveals that the intrusion is derived from a volcanic arc source.

(2) According to the diagrams of Y vs Nb and (Y+Nb) vs Rb (Figure 11) after Pearce et al. (1984), it is further shown that Yeniutan granitic rocks have a volcanic arc or volcanic arc + syncollision source.

(3) The diagram of R_1 vs R_2 (Figure 12) shows that Yeniutan intrusion is pre-collision granite and formed during subduction.

Furthermore, we dated the granodiorite in the Yeniutan intrusion as 459.6 ± 2.5 Ma by the single zircon U-Pb method. A Rb-Sr isochron on muscovite of wolframite quartz veins in the Ta'ergou section yielded an age of 441 ± 17 Ma (Zou and Huang, 1988). Re-Os isotopic dating for the molybdenite from the Xiaoliugou tungsten deposit is 462 ± 13 Ma (2σ) of isochronal age (Mao Jingwen et al., 1999b). The three groups of age data reveal directly or indirectly that the Yeniutan and the Xiaoliugou granodiorite intrusions formed in Middle-Late Ordovician. In light of previous studies of tectonic evolution and dating on volcanic rocks and intrusive rocks in the eastern and middle sectors of North Qilian Caledonian orogen, Zuo and Wu (1997) and Xia Linqi et al. (1998) proposed that North Qilian began to split out in late Sinian (679-574 Ma), the subduction and arc evolution occurred during Late Cambridge and Middle Ordovician (522-469 Ma), and the plates started to collide between the Late Ordovician and Early Silurian (469-445 Ma). The studies on the volcanic rocks in the western sector of North Qilian Caledonian orogen by Zhang Jianxin et al. (1997) proved that subduction happened during 466 and 440 Ma. Zhang Dequan et al. (1995) obtained the precise data of rock-forming age ranging from 420 to 404 Ma for the Jinfosi granite, which is believed to be a product of collision period in the north belt of the western sector of the North Qilian Caledonian orogen. So it can be concluded that all data clearly show that the granodiorite rocks, represented by the Yeniutan intrusion, and the related tungsten mineralization formed in a pre-collision period.

Figure 11 Diagrams of Y vs Nb and (Y+Nb) vs Rb.

Figure 12 Diagram of R_1 vs R_2 (After Batchelor et al., 1985).

Conclusions

The Yeniutan granodiorite intrusion is spatially and temporally associated with tungsten mineralization, but its petrology, petrochemistry and evolution history do not fit the usual patterns of tin-tungsten bearing rocks. The main conclusions of this preliminary study are summarized as follows:

(1) For both crust-derived and crust-mantle-derived tungsten granites, their main characteristic is that they underwent strong differentiation. However, the degree of differentiation and evolution of the Yeniutan granitic rocks is quite low. It is composed of two rock-forming stages, i.e. granodiorite and equigranular biotite granite, but it is the early stage granodiorite that is in spatial-temporal relationship to the Ta'ergou tungsten deposit.

(2) Geochemical and trace element data of the Yeniutan granitic rocks reflect a situation between I- and S- type granites, i.e. a transitional nature. And it is also a typical magnetite series granitoid.

(3) Petrochemistry and isotopic dating indicate that Yeniutan granitic rocks formed in a pre-collision setting. The intrusion assimilated and contaminated a great amount of upper crustal material during emplacement.

Acknowledgments

This work was financially supported by Major State Basic Research Program of People's Republic of China (No. G1999043200), and the special fund from the former Ministry of Geology and Mineral Resource (No. 9617). It is also a part of the achievements made by the Scientific & Technological Prospecting Project financially supported by National Planning Committee of China (JG9471902). This paper is a contribution to IGCP-373 project. The authors wish to express thanks to Dr. Reimar Selmann and Prof. Hong Dawei for their constructive suggestions.

References

- Batchelor, R. A., and Bowden, P., 1985, Petrogenetic interpretation of granitoid rock series using multication parameters. *Chemical Geology* 48, 43-45.
- Breiter K., Förster, H.-J., and Seltmann, R., 1999, Variscan silicic magmatism and related tin-tungsten mineralization in the Erzgebirge-Slavkoský les metallogenic province. *Mineralium Deposita* 34, 503-521.
- Chappell, B.W., and White, A.J.R., 1974, Two contrasting granite types. *Pacific Geol.* 8, 173-174.
- Chappell, B.W., Bryant, C.J., White, A.J.R., and Williams, I.S., 1998, High- and low-temperature I-type granites. *Resource Geology* 48, 225-235.
- Debon, F., and Le Fort P., 1982, A cratonic classification of common rocks and their magmatic associations: principles, method, application. *Bulletin de Mineralogie* III, 493-510.
- Groves, D.I., and McCarthy, T.S., 1978, Fractional crystallization and the origin of tin deposits in granitoids. *Mineralium Deposita* 13, 11-22.
- Higgins, N.C., Solomon, M., and Varne R., 1985, The genesis of the Blue Tier batholith, northeastern Tasmania, Australia. *Lithos.* 18, 129-149.
- Hong Dawei, Wang Shiguang, Han Baofu, and Jin Manyuan, 1995, The classification of tectonic setting and discrimination of alkali granite. *Science in China (B series)* 25, 418-426.
- Ishihara, S., 1997, The magnetite-series and ilmenite-series granitic rocks. *Mining Geology* 27, 293-305.
- Ishihara, S., 1984, Granitoid series and Mo/W mineralization in East Asia. *Rept. Geol. Surv. Japan* 263, 173-208.
- Ishihara, S., 1998, Granitoid series and mineralization in the Circum-Pacific Phanerozoic granitic belts. *Resource Geology* 48, 219-224.
- Le Bel, L., Li Yiadou, and Sheng Jifu, 1984 Granitic evolution of the Xihuashan-Dangping (Jiangxi, China) tungsten-bearing system. *TMPM Tschermaks Min. Petr. Mitt.* 33, 149-167.
- Lehmann, B., 1987, Tin granites, geological heritage, and magmatic differentiation. *Geol. Rdsch.* 76, 177-185.
- Lehmann, B., 1990, *Metallogeny of tin*. Springer, Berlin/Heidelberg/New York, 211p.
- Lehmann, B., 1994, Granite-related rare metal mineralization: a general geochemical framework. *in* Seltmann, Kämpf & Möller eds, *Metallogeny of Collisional Orogens*; Czech Geological Survey, Prague, pp.342-349.
- Li Shimei, 1983, A discussion on the origin of small Mo-W-related intermediate-acid intrusions in Luanchuan region, Henan province. *Henan Geology*, no.1, pp. 1-9.
- Marignac, C., and Cuney, M., 1999, Ore deposits of the French Massif Central: insight into the metallogenesis of the Variscan collision belt. *Mineralium Deposita* 34, 472-504.
- Mao Jingwen, 1989, The igneous rock series and tin polymetallic minerogenic series in the Tengchong area, Yunnan province. *Acta Geologica Sinica* 62, 175-187.
- Mao Jingwen, Li Hongyan, 1995, Evolution of the Qianlishan granite stock and its relation to the Shizhuyuan polymetallic tungsten deposit. *International Geology Review* 37, 63-80.
- Mao Jingwen, Li Hongyan, Shinazaki, H, Raimbault, L, and Guy, B, 1996, Geology and metallogeny of the Shizhuyuan skarn-greisen deposit, Hunan Province, China. *International Geology Review* 38, 1020-1039.
- Mao Jingwen, Zhang Xiaoyu, Zhang Zhaochong, Ren Fengshou, Zuo Guochao, Zhang Zuoheng, Yang Jianmin, Wang Zhiliang, and Ye Dejin, 1999a, Temporal—spatial distribution and metallogenesis of polymetallic deposits in the western part of the Qilian. *Acta Geologica Sinica*, v.73, no.2, pp. 230-241.
- Mao Jingwen, Zhang Zhaochong, Zhang Zuoheng, and Du Andao, 1999b, Re-Os isotopic dating of molybdenites in the Xiaoliugou W (Mo) deposit in the Northern Qilian Mountains and its geological significance. *Geochimica Cosmochimica Acta* 63, 1815-1818.
- Mao Jingwen, Zhang Zuoheng, and Yang Jianmin, 1999c, Geological characteristics and genesis of Ta'ergou tungsten deposit, North Qilian, Gansu Province. *in* Stanley, R. J., et al., eds, *Mineral Deposits: Processes and Processing*, A. A. Balkema/Rotterdam/Brookfield, pp.381-384.
- Mao Jingwen, Zhang Zuoheng, Yang Jianmin, and Zhang Zhaochong, 2000, Geology and geochemistry of the Hanshan shear zone gold deposit in Gansu Province, China. *Mineralium Deposita*, vo.35, no.1, pp.63-71.
- Mitchell, A.H.G., and Garson, M.S., 1981, *Mineral deposits and global tectonic settings*. London, New York, Toronto, Sydney, San Francisco: Academic Press, 350p.
- Pearce, J.A., Harris, N.B.W., and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *J. Petrol.* 25, 956-983.
- Sawkins, F.J., 1990, *Metal deposits in relation to plate tectonics*. Springer-Verlag, 2nd edition, 461p.
- Seltmann, R., Kämpf, H., and Möller, P., 1994, *Metallogeny of collisional orogens*. Prague, Czech Geological Survey.
- Shatov, V., Seltmann, R., and Kremenetsky, A., 1996, Granite-related ore deposits of Central Kazakhstan and adjacent areas. St. Petersburg, Glagol Publishing House.
- Sillitoe, R.H. and Thompson, F.H., 1998, Intrusion-related gold deposits: types, tectonic-magmatic settings and difficulties of distinction from orogenic gold deposits. *Resource Geology* 48, 237-250.
- Song Shuhe, 1994, *Mineral deposits of China (Middle Volume)*. Beijing, Geological Publishing House.
- USGS (1999) U.S. Geological Survey, *Mineral Commodity Summaries*, January 1999, 184-185.
- Xia Linqi, Xia Zuchun, Ren Youxiang, Zuo Guochao, and Qiu Jiaxiang, 1998, Volcanism and related metallogenesis in Qilian Mt and its surrounding regions. Beijing, Geological publishing House, 215p (in Chinese).
- Zhang Dequan, Sun Guiying and Xu Hongli, 1995, Petrology and isotope chronology of the Jinfosi pluton, Qilian Mts., Gansu. *Acta Geoscientia Sinica*, no.4, pp.375-385.
- Zhang Jianxin, Xu Zhiqin and Chen Wen, 1997, A tentative discussion on the ages of the subduction-accretionary complex / volcanic arcs in the middle sector of the North Qilian Mountains. *Acta Petrologica et Mineralogica*, vol.16, no.2, pp.119-128.
- Zhang Yuxue, 1982, A discussion on the geochemistry and origin of the Yangchuling porphyry W-Mo deposit. *Geochemistry*, no.2, pp. 122-132.
- Zhang Zuoheng, Mao Jingwen, Yang Jianmin, Wang Zhiliang, and Zhang Zhaochong, 1998, Study on the ore-forming fluids and hydrogen, oxygen and sulfur isotopes of the Ta'ergou quartz vein-type tungsten deposit. *Mineral Deposits* 17(supplement), 791-794.
- Zou Zhiping, and Huang Chuanjian, 1988, The geology of Ta'ergou tungsten deposit in North Qilian Mountains, Gansu. (Unpublished data).
- Zuo Guochao, and Wu Hanquan, 1997, A bisubduction-collision orogenic model of Early-Paleozoic in the middle part of north Qilian area. *Advancement on Earth Science*. vol.12, no.4, pp.315-323.

Mao Jingwen is Professor of Economic Geology in the Institute of Mineral Deposits, Chinese Academy of Geological Sciences. He works on tin-tungsten deposits and related granites. Since 1993, he has been studying gold deposits, especially orogenic gold deposits and their tectonic settings. At present he is leading the Major State Basic Research Program of People's Republic of China entitled "Large-Scale Metallogenesis and Prediction of Highly Dense Mineralized Areas".

Zhang Zuoheng is Assistant Professor of Economic Geology in the Institute of Mineral Deposits, Chinese Academy of Geological Sciences. His research concerns granite-related tungsten deposits and gold deposits. Currently he is working in Prof. Mao's research group.