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Enrichment of Mantle-derived Fluids in the Formation Process of Granitoids: Evidence from the Himalayan Granitoids around Kunjirap in the Western Qinghai-Tibet Plateau

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Abstract Taking the Himalayan granitoids around Kunjirap in the western Qinghai-Tibet plateau as an example, the authors present in this paper the characteristics of the granitoids rich in mantle-derived fluid components and discuss their rock-forming mechanism. The research results indicate that the rock assemblage of the studied granitoids involves diopside syenite-diopside granite-biotite (monzonitic) granite, consisting mainly of K-feldspar, oligoclase, quartz, iron-phlogolite, diopside and edenite. The rocks are rich in mantle-derived fluid components of volatiles including F, alkali metal elements such as K, Na, Rb, Sr and Ba, and radiogenic heat-producing elements such as U and Th. They were generated by the influx of mantle-derived fluids into the lower crust to give rise to partial melting during the lithosphere thinning in the Qinghai-Tibet plateau.

Key words: mantle-derived fluid, granitoid, western Qinghai-Tibet plateau

1 Introduction

Lithogeny and metallogeny of mantle-derived fluids have become a research frontier attracting attention of international geologists. The classic theory did not touch upon such a question, that is, whether mantle-derived fluids could pass through the upper mantle and Moho into the crust to be involved in lithogeny and metallogeny. Research results in recent years (e.g. Cao and Zhu, 1995) have indicated that the Bayan Obo REE deposit in Inner Mongolia, northern China is a seldom seen deposit associated with mantle-derived fluid metasomatism, and that the Qieganbulake vermiculite ore deposit in Weili County, Xinjiang is a supperlarge non-metallic deposit associated with mantle-derived fluid metasomatism. Our researches demonstrate the rock-forming process of granitoids during the influx of mantle-derived fluids into the crust.

Litvinovsky and Podladehikov (1993) suggested that crustal anatexis was closely related to the influx of mantle volatiles, and underlined that in a closed system crustal anatexis would require very high temperatures (>900℃) in the absence of enough volatiles in the lower crust, which is unrealistic. They proposed a model indicating that granitoids were generated by the influx of a large quantity of heat and enough volatiles into the crust during underplating. Cao (1996) also proposed that the enrichment of mantle-derived volatiles (CO_2, H_2O, F, P, S, Cl, B etc.) and mobile flux elements (K, Na, Li, Rb, Sr, Ba etc.) in crustal rocks should be studied.

Taking the Himalayan granitoids around Kunjirap in the western Qinghai-Tibet plateau as an example, this paper presents the characteristics of granitoids rich in mantle-derived fluid components and discusses their rock-forming mechanism.

2 Tectonic Settings and Granitoid Distribution

There are four suture zones in the western Qinghai-Tibet plateau (e.g., Pan, 1994; Deng, 1995), from north to south: (1) the Oytag-Küda suture zone, generated in the Ordovician (Jiang et al., 1999); (2) the Mazar-Kengxiwar suture zone, generated in the Late Permian (Jiang and Yang, 2000a); (3) the Hongshanhu-Qiaoer Tianshan suture zone, generated in the Late Jurassic (Jiang and Yang, 2000b); and (4) the Bangong Co-Nujiang suture zone, generated in the Late Cretaceous (Jiang and Yang, 2000c). The Himalayan granitoids occur mainly in the vicinity of the Hongshanhu-Qiaoer Tianshan suture zone (Fig. 1).

The Kuzigan (KU), Karibasheng (KA), and Zankan (ZA) plutons are studied in this paper. The KU pluton trends NW-SE, 32 km in length, 5–8 km in width and 192 km^2 in area. It was intruded into Permian strata in the west and overlain by Quaternary sediments in the east. It comprises early-stage diopside syenite with a K-feldspar $^{40}Ar/^{39}Ar$ age of 52 Ma and late-stage diopside granite with a K-feldspar $^{40}Ar/^{39}Ar$ age of 18.2 Ma (Pan, 1996), the latter being intruded into the former. The KA granitoid body trends NW-SE, 90 km in length, 10–20 km in width and 1366 km^2 in area. It was intruded into Permian strata in the west, into Proterozoic strata in the north, and into the KU pluton in the south, and was overlain by Quaternary sediments in the east. The western part of the rockbody is composed of porphyroid granite, while the eastern part consists of biotite (monzonitic) granite with a biotite $^{40}Ar/^{39}Ar$ age of 11.45 Ma (Pan, 1996). The ZA pluton trends NW-SE and covers an area of 1366 km^2. It was intruded into Proterozoic strata and consists mainly of diopside syenite with a K-feldspar $^{40}Ar/^{39}Ar$ age of 11.58 Ma (Pan, 1996). All the rockbodies in the study were formed in the Miocene, corresponding to the age of large-scale volcanism in the Qinghai-Tibet plateau (Turner et al., 1996), except the early-stage diopside syenite of the KU pluton that was generated in the Paleocene.

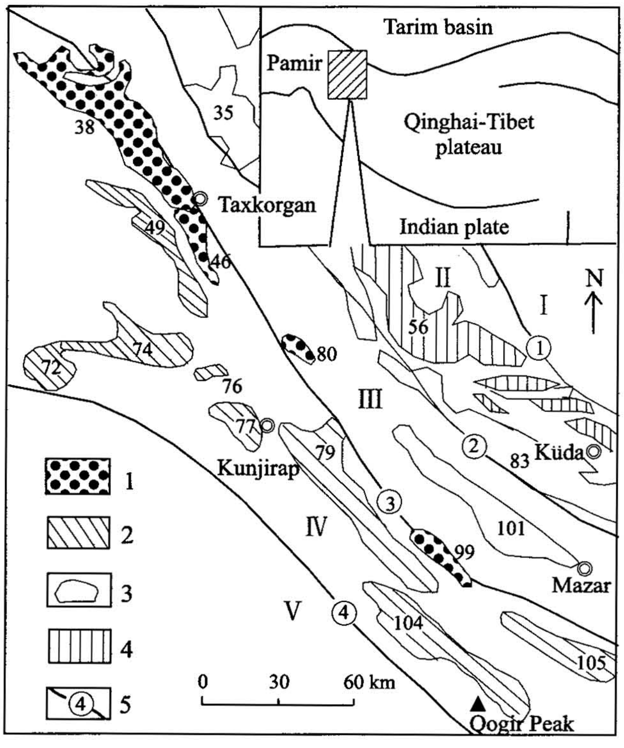

Fig. 1. Sketch map showing the distribution of granitoids in the western Qinghai-Tibet plateau.

1. Himalayan period: Karibasheng (38), Kuzigan (46), Zankan (80), Taturugou (99); 2. Late Yanshanian; 3. Indosinian-Early Yanshanian; 4. Early Caledonian; 5. suture zones: ① Oytag-Küda suture zone; ② Mazar-Kengxiwar suture zone; ③ Hongshanhu-Qiaoer Tianshan suture zone; ④ Bangong Co-Nujiang suture zone. I – Tarim basin; II – western Kunlun terrane; III – Taxkorgan terrane; IV – Karakorum terrane; V – Gandise terrane.

3 Characteristics of Granitoids

3.1 Petrography and mineral chemistry

Biotite monzonitic granite or biotite granite is composed mainly of K-feldspar, plagioclase, quartz, biotite and minor amphibole with medium-grained granitic texture and massive structure. The contents of dark-coloured minerals are generally no more than 10%. The diopside granite is composed mainly of K-feldspar (60–75%), quartz (23–28%), plagioclase (5–10%), diopside (1–2%) and minor amphibole with medium-grained granitic texture and massive structure. The diopside syenite consists mainly of K-feldspar (60–80%), diopside (10–30%) and minor amphibole with medium-grained texture and massive structure.

Results of electron microprobe analyses (Table 1) indicate that the studied biotites are enriched in MgO and lean in FeO, plotted in the iron-phlogolite field in the classification diagram for biotite (Forster, 1960). The high Fe^{3+}/Fe^{2+} ratios (1.05–2.24) are another notable feature of biotite compositions, suggesting a high-temperature and oxidized environment for these granitoids. The studied amphiboles show relatively high CaO and low TiO_2 contents, and are also rich in MgO, belonging to edenite according to Leake's classification (1978) for calcic amphiboles. The pyroxenes from the KU pluton show Wo content of 45.3–46.2%, En content of 28.9–39.0% and Fs content of 14.8–25.8% (Table1), constituting diopside (Morimoto, 1988). The

Table 1 Electron microprobe analyses (%) of main rock-forming minerals

Pluton	KA	KA	KA	KA	KU	KU	KU	KA	KA	KA	KA
Sample	T1-1	T1-1	T1-1	T1-1	*	*	*	T1-1	T1-1	T1-1	T1-1
Rock type	bmg	bmg	bmg	bmg	dg	ds	dg	bmg	bmg	bmg	bmg
Mineral	bio	bio	bio	bio	amp	pyr	pyr	Pla_c	Pla_r	K-fel	K-fel
SiO_2	38.101	37.900	38.754	38.800	45.72	52.95	52.87	63.965	62.207	65.806	65.017
TiO_2	2.147	2.223	1.910	2.181	0.49	0.48	0.09	0	0	0	0
Al_2O_3	13.195	13.400	13.424	12.640	7.57	0.79	0.66	22.419	23.369	19.216	19.123
FeO	16.773	16.800	17.010	16.964	17.29	8.55	13.86	0.101	0.107	0	0
MnO	0.371	0.311	0.408	0.304	0.79	0.22	0.69	0.006	0	0.037	0
MgO	14.405	13.764	13.732	14.041	11.77	12.86	9.13	0.002	0	0	0
CaO	0	0	0	0.043	10.31	21.23	19.92	3.585	4.321	0.033	0.021
Na_2O	0.118	0.192	0.104	0.094	2.94	0.97	1.23	9.024	9.985	1.432	1.487
K_2O	10.177	10.466	9.799	10.122	1.26	0	0	0.196	0.283	13.988	14.220
P_2O_5	0	0.077	0.039	0	n.a.	n.a.	n.a.	0	0.004	0.058	0
Sum	95.453	95.289	95.311	95.384	97.36	98.07	98.44	99.298	100.28	100.57	99.868
$Mg/(Mg+Fe^{2+})$	0.83	0.83	0.75	0.78	0.60	46.2(Wo)	45.3(Wo)	81.1(Ab)	79.5(Ab)	13.4(Ab)	13.7(Ab)
Mg/(Mg+Fe)	0.61	0.59	0.59	0.60	0.56	39.0(En)	28.9(En)	17.8(An)	19.0(An)	0.2(An)	0.1(An)
Fe^{3+}/Fe^{2+}	2.08	2.24	1.05	1.37	0.19	14.8(Fs)	25.8(Fs)	1.1(Or)	1.5(Or)	86.4(Or)	86.2(Or)

KA – Karibasheng; KU – Kuzigan; bmg – biotite monzonitic granite; dg – diopside granite; ds – diopside syenite; bio – biotite; amp – amphibole; pyr – pyroxene; pla – plagioclase (r – rim; c – core); K-fel – K-feldspar; n.a. – not analyzed.

* from Zhang et al. (1994); the others determined at the State Key Laboratory for Mineral Deposits Research of Nanjing University.

plagioclases are mainly oligoclase with an An content of 17.8–19.0%. The K-feldspars show a high content of Or (86.2–86.4%) with minor amounts of Ab (13.4–13.7%) and negligible amounts of An (0.1–0.2%).

3.2 Geochemistry

In the QAP diagram (Fig. 2), compositions of the studied granitoids are plotted in the fields of monzogranite, syenogranite, alkali-feldspar granite, alkali-feldspar syenite and alkali-feldspar quartz syenite. All the diopside syenite, diopside granite and biotite (monzonitic) granite show very high alkali contents with K_2O+Na_2O contents > 8%, averaging 9.83% (Table 2). In a plot of AR (Alkalinity Ratio) vs. SiO_2 (Fig. 3), all data are plotted in the alkaline rock field except for two that fall in the peralkaline rock field, suggesting that the rocks belong to the alkaline series.

The diopside syenite, diopside granite and biotite (monzonitic) granite are all rich in REE, with the highest being 778.45 ppm and the average 600.46 ppm (Table 2), especially in LREE with the LREE/HREE ratios ranging from 6.5 to 17.4 and La_N/Yb_N ratios from 41.9 to 174.7. In addition, the rocks are also obviously rich in LILE (e.g. average Rb 348 ppm, Ba 3519 ppm and Sr 1560 ppm) and radiogenic heat-producing elements (average Th 94.9 ppm and U12.1 ppm) as well as volatile F (highest 6480 ppm and average 3078 ppm).

The $\delta^{18}O$ value (determined in this study at the Nanjing Institute of Geology and Mineral Resources, Chinese Academy of Geological Sciences), $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios (determined in this study at the Institute of Geology, Chinese Academy of Geological Sciences) of the KA biotite monzonitic granite are 11.88‰, 0.709229 and 0.512256, respectively, with the calculated $\varepsilon_{Nd}(t) = -7.28$ and $t_{DM} = 997$ Ma. The results obtained by Zhang et al. (1994) indicate that the $^{87}Sr/^{86}Sr$ ratios of the KU diopside granite and diopside syenite are 0.71002 and 0.70948, respectively. The Sr and Nd isotopic compositions mentioned above are very similar to those of Himalayan volcanic rocks in the Qinghai-Tibet plateau ($^{87}Sr/^{86}Sr$ = 0.7076–0.7106, $^{143}Nd/^{144}Nd$ = 0.512224–0.512371, $\varepsilon_{Nd}(t) = -5.2$– -8.1, t_{DM} = 820–1030 Ma) (Turner et al., 1996).

4 Granitoids being Rich in Mantle-derived Fluid Components

At present researchers of the world have commonly considered that the mantle of the earth is actually a giant reservoir of mantle fluids composed of CO_2, H_2O, CH_4, H_2, F, P, S, Cl, B, alkali metals and rare earth elements (REE), as well as other incompatible elements

Table 2 Chemical compositions (%) and trace element contents ($\times 10^{-6}$) of Himalayan granitoids around Kunjirap in the western Qinghai-Tibet plateau

Pluton	KA	KA	KA	KA	ZA	KU	KU	KU
Sample	S-2	9002	T1-1	14008	25004	14013	19002	14014
Rock type	bg	bmg	bmg	bmg	ds	ds	ds	dg
SiO_2	69.47	66.54	71.85	70.87	53.48	60.91	62.80	70.12
TiO_2	0.33	0.69	0.24	0.32	1.12	0.39	0.15	0.37
Al_2O_3	14.59	14.56	13.74	14.56	13.01	15.05	14.78	14.42
Fe_2O_3	1.16	2.98*	1.04	1.65*	6.04*	4.60*	2.01*	2.32*
FeO	0.88		0.78					
MnO	0.03	0.05	0.03	0.02	0.15	0.12	0.06	0.04
MgO	0.54	0.99	0.38	0.43	4.06	0.84	0.28	0.36
CaO	1.98	3.49	1.80	1.97	5.94	5.08	3.30	2.14
Na_2O	3.62	3.46	3.78	3.32	3.10	3.22	3.07	3.61
K_2O	5.18	4.79	4.56	4.70	8.13	7.78	10.95	5.36
P_2O_5	0.14	0.39	0.12	0.09	1.10	0.03	0.23	0.09
LOI	0.45	n.a.	0.43	n.a.	n.a.	n.a.	n.a.	n.a.
Total	98.37	97.94	98.75	97.93	96.13	98.02	97.63	98.83
Na_2O+K_2O	8.80	8.25	8.34	8.02	11.23	11.00	14.02	8.97
K_2O/Na_2O	1.43	1.38	1.21	1.42	2.62	2.42	3.57	1.48
Fe_3O_2/FeO	1.32		1.33					
A/CNK	0.96	0.85	0.95	1.03	0.53	0.65	0.64	0.93
Sc	3.03	n.a.	2.21	n.a.	16.5	n.a.	2.35	n.a.
V	52.3	47.5	42.2	25.5	104.0	69.4	26.8	36
Cr	41.1	28.7	35.2	17.3	79.5	30.9	7.5	19.5
Zn	40.1	59.3	31.5	36.1	1580	140	78.8	43.8
Rb	188	n.a.	193	n.a.	621	n.a.	391	n.a.
Ba	6960	3130	4080	1820	4040	4020	1730	2370
Sr	1860	2060	972	930	1520	2090	1780	1270
Th	n.a.	125.0	n.a.	49.8	73.8	191.0	50.9	79.0
U	n.a.	12.8	n.a.	9.8	6.8	16.4	15.1	11.8
Nb	12.1	30.2	9.17	15.0	47.0	30.8	26.7	26.4
Zr	209	376	183	182	465	392	136	326
Y	17.1	28.9	11.1	10.0	50	48.0	23.5	31.7
F	n.a.	2210	n.a.	1840	6480	2500	2700	2740
La	178	n.a.	127	n.a.	168	n.a.	312	n.a.
Ce	254	n.a.	175	n.a.	315.2	n.a.	76.4	n.a.
Pr	24.2	n.a.	15.5	n.a.	25.08	n.a.	8.53	n.a.
Nd	94.5	n.a.	57.8	n.a.	141.38	n.a.	160.26	n.a.
Sm	13.3	n.a.	8.06	n.a.	19.73	n.a.	10.86	n.a.
Eu	2.59	n.a.	1.44	n.a.	5.27	n.a.	2.68	n.a.
Gd	8.22	n.a.	4.95	n.a.	28.29	n.a.	10.4	n.a.
Tb	1.11	n.a.	0.73	n.a.	6.29	n.a.	2.47	n.a.
Dy	3.80	n.a.	2.32	n.a.	9.06	n.a.	3.93	n.a.
Ho	0.81	n.a.	0.54	n.a.	2.54	n.a.	0.96	n.a.
Er	1.76	n.a.	1.19	n.a.	3.84	n.a.	1.58	n.a.
Tm	0.32	n.a.	0.22	n.a.	0.68	n.a.	0.31	n.a.
Yb	1.30	n.a.	0.95	n.a.	2.38	n.a.	1.06	n.a.
Lu	0.21	n.a.	0.16	n.a.	0.71	n.a.	0.28	n.a.
REE	601.22		406.96		778.45		615.22	
LREE/HREE	16.36		17.36		6.50		12.83	
La_N/Yb_N	81.3		79.4		41.9		174.7	
δEu	0.76		0.70		0.76		0.84	

Notes: bg – biotite granite; ZA – Zankan; other symbols same as in Table 1.
* total iron; Samples S-2 and T1-1 were determined at the Nanjing Institute of Geology and Mineral Resources with conventional wet chemical methods for major elements, AAS for Rb and ICP-AES for the others; the other samples were determined in the Central Laboratory of the Xinjiang Bureau of Geology and Mineral Resources by ICP-AES for REE, LRF for U, ion electrode method for F, and XRF for the others.

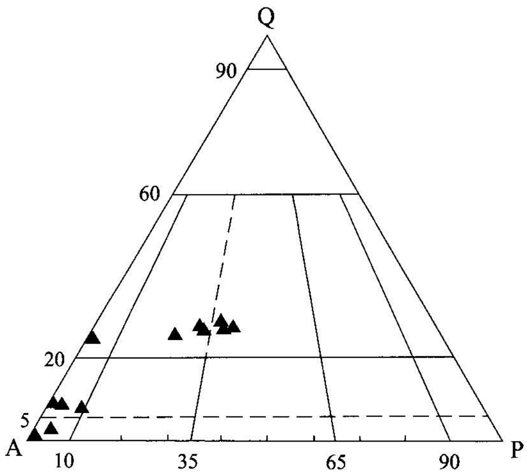

Fig. 2. QAP diagram of Le Maitre (1989).
4 samples from Zhang and Xie (1994).

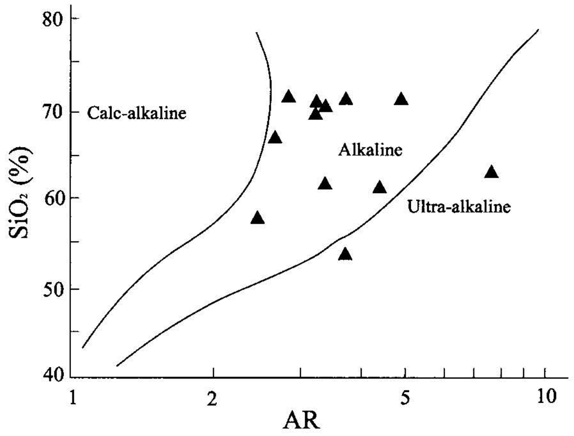

Fig. 3. AR vs SiO_2 diagram of Wright (1969).
4 samples from Zhang and Xie (1994).

(Bi, 1996). The source regions of granitoids in the study area are generally found in the thickened lower crust (see below for more discussion). The high $\delta^{18}O$ value (11.88‰) and negative Nb and Ti anomalies of these plutons in primitive mantle-normalized trace element diagrams suggest that the source rocks of the granitoids are likely metasediments. However, geochemical characteristics of these granitoids indicate that they are rich in mantle-derived fluid components of volatiles such as F, alkali metal elements such as K, Na, Rb, Sr and Ba, and REE. They are much more concentrated in comparison with the crustal Clark values and acid rocks, but similar to the Himalayan volcanic rocks that were derived from enriched mantle (Turner et al., 1996) (Table 3). The extreme similarities in regard to Sr, Nd isotope compositions and Rb/Sr ratios between the granitoids and the Himalayan volcanic rocks further indicate that such elements as Rb, Sr, Sm and Nd could have been largely derived from the mantle.

Here, it is worthy to have a discussion on the origin of U and Th. Generally, U and Th have been considered to be of crustal origin. Recent researches (e.g. Bao and Zhang, 1998; Jiang and Yang, 2000d), however, have revealed that there is an enrichment zone of U and Th beneath the lithosphere, and that late-orogenic granitoids contain much higher U and Th, which are mainly derived from the enrichment zone compared with granitoids of other tectonic types. U and Th are radiogenic heat-producing elements and the main energy source of the formation and evolution of the Earth's crust (Hou and Ouyang, 1974). The enrichment of U and Th in the crust is due to gradual migration of U and Th from the interior of the earth (below the upper mantle) to the exterior. In the mantle that contains volatiles, U and Th find their way directly into the enrichment zone in the form of high-valence compounds and complexes; whereas in the interior of the earth where there are no volatiles, U and Th would first sink to the Earth's core as low-valence stable compounds or metals, and then be converted to

Table 3 Comparison of average compositions of granitoids in the studied area and other rocks

Rock type	No. of samples	K_2O (%)	Na_2O (%)	Rb (ppm)	Sr (ppm)	Ba (ppm)	U (ppm)	Th (ppm)	F (ppm)	REE (ppm)	Rb/Sr	References
HG	8*	6.43	3.40	348	1560	3519	12.1	94.9	3078	600.5	0.22	This study
HVR	56	4.34	3.61	181	1425	1693	4.7	53.9		658.1	0.13	Turner et al, 1996
CCV		2.05	3.10	78	480	390	1.7	5.8	450	158	0.16	Li, 1976
AR		4.03	3.73	300	300	830	3.5	18	800	250	1.00	Li, 1976

HG – Himalayan granitoids; HVR – Himalayan volcanic rocks; CCV – crustal Clark values; AR – acid rocks.
* No. of samples is 4 for Rb and REE and 6 for U, Th and F.

high-valence compounds and complexes that could migrate easily at the core-mantle boundary by reacting with residual volatiles or their ions derived from the mantle and subducted lithospheric slab, and finally be driven to the enrichment zone by ascending plumes. The heat produced by U and Th in the enrichment zone would cause rocks to melt. As a result, the rocks in the enrichment zone become plastic, thus causing convection of the mantle and drifting of the lithosphere. The radioactive energy of U and Th in the enrichment zone can also produce magmas. The magmas tend to ascend along the ocean ridge, generating new ocean crust and promoting drift of the ocean plate. In the subduction zone of the plate, the solid lithospheric plate would bring materials from the continental crust, which contain water and volatiles, into the mantle and the core-mantle boundary (Wang, 1997). These water and volatile ions can react with U and Th in the interior of the earth and promote them to migrate into the enrichment zone. It is obvious that the heat-producing elements such as U and Th beneath the lithosphere would be fully concentrated during the period of 30–50 Ma, i.e. from continental collision to late orogeny. Thus, in the process of late-orogenic lithospheric delamination, U and Th in the enrichment zone would migrate upward along with the asthenosphere and emptied into the continental crust to generate granitoids enriched in heat-producing elements. The granitoids in the study area, generated in a late-orogenic environment (see below for further discussion) and containing large amounts of U and Th (Tables 2 and 3), could have resulted from the influx of U, Th and volatiles from the enrichment zone into the crust. Because U and Th tend to migrate strongly from high-temperature facies to low-temperature facies in the presence of volatiles or their ions (Bao and Zhang, 1998), the Himalayan granitoids show much higher U and Th contents than volcanic rocks (Table 3). To sum up, we think that U and Th are also important components of the mantle-derived fluids and could be enriched in the crust.

5 Origin of Granitoids Rich Mantle-derived Fluid Components

Both material source and heat source need to be discussed for studying the origin of any granitoids. The depth to the source region of biotite monzogranite is estimated to be 46.2 km using the Ab-Or-Q-H_2O diagram of Tuttle (1958). The source region of syenite magma could be even deeper. Researches of experimental petrology and facies equilibrium (Deng et al., 1996) indicated that syenite magma could be formed at a pressure of 1.5 GPa (about 50 km) and show negative Eu anomalies because of the presence of plagioclase in the melting systems, or would not show negative Eu anomalies because of the absence of plagioclase on the solidus line at a pressure of 1.7 GPa (about 57 km). In the study area, the presence of slightly negative Eu anomalies (δEu from 0.76 to 0.84) in syenites indicates that the depth of their source region could be 50–57 km. The Himalayan volcanic rocks in the Qinghai-Tibet plateau hardly show negative Eu anomalies (δEu = 0.94), suggesting that the depth of their source region is >57 km. The granitoid source regions are almost in the thickened lower crust since the crust thickness is about 55 to 60 km in the Himalayan granitoid distribution area, whereas the source region of volcanic rocks is located in the lithospheric mantle. This is in agreement with the conclusion that volcanic rocks are derived from partial melting of the lithospheric mantle (Turner et al., 1996).

Except the early portion of the KU pluton, the Himalayan granitoids (20 to 10 Ma), associated with the post-collisional volcanism on the Qinghai-Tibet plateau (Turner et al., 1996), were formed after the India-Asia collision. In addition, they are all low-Ti (TiO_2<2%) rocks, suggesting that the post-collisional extension did not approach the within-plate rifting stage. This is further illustrated by the R_1-R_2 multi-cation diagram (Fig. 4), in which data from the granitoids are plotted in the late-orogenic field. The continent-continent subduction occurred after the collision between the Indian and Asian plates. However, a tomographic analysis shows that the Indian plate did not subduct into the lower portion of the plateau on the northern side of the Yarlung Zangbo suture zone, but subduct at a large angle into the deep mantle of southern Tibet, which implies that this subduction cannot directly provide heat source for the Himalayan volcanic rocks and granitoids in the interior of the Qinghai-Tibet plateau, and moreover, both volcanic rocks and granitoids belong to the alkaline series rather than the calc-alkaline series. Then, what is the mechanism that can provide heat source for these rocks? Just as Turner et al. (1992) pointed out, the most

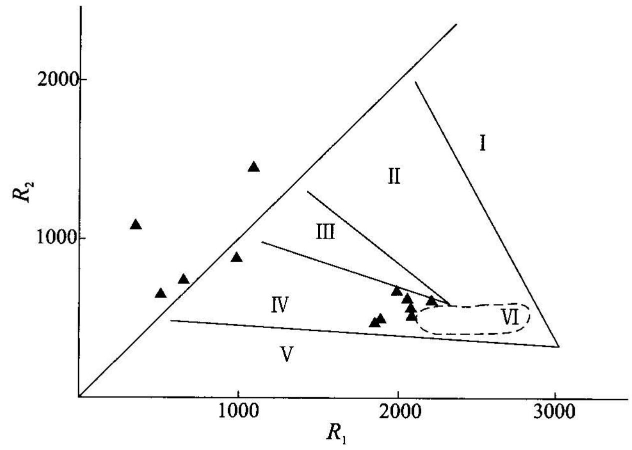

Fig. 4. R_1-R_2 multiple cation diagram (Batchelor et al., 1985).

I. Mantle plagiogranite; II. active plate margin granite; III. post-collision uplift granite; IV. late orogenic granite; V. anorogenic granite; VI. syn-collision granite.

The 4 samples are from Zhang and Xie (1994).

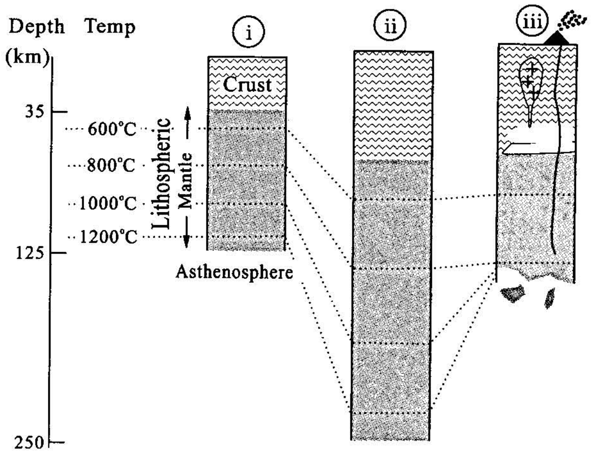

Fig. 5. Petrogenesis model for Himalayan granitoids in the Qinghai-Tibet plateau (after Turner et al., 1996).

i – Eocene; ii – Oligocene; iii – Miocene and later.

plausible means of attaining temperatures high enough for the melting was to thin the lithosphere through mantle convection. Accompanied with lithospheric thinning, partial melting and underplating would occur in the enriched lithospheric mantle, and in a favourable condition magmas could extrude to generate widespread volcanic rocks in the interior of the Qinghai-Tibet plateau. In the meanwhile, the underplating caused influx of a large quantity of heat and enough volatiles, mobile flux elements as well as radiogenic heat-producing elements into the lower crust. This gave rise to partial melting and intrusion, thus generating the Himalayan granitoids rich in mantle-derived fluid components. Figure 5 illustrates simply the process mentioned above, i.e., the collision between the Indian and Asian plates took place in the Eocene, and homogenous thickening of the lithosphere proceeded until the Oligocene (Turner et al., 1996). Since the Miocene, the lithosphere has been thinned, and the enriched lithospheric mantle experienced partial melting and extrusion to generate the Himalayan volcanic rocks. In the meanwhile, an enrichment of associated mantle-derived fluids in the lower crust occurred, bringing about the Himalayan granitoids rich in mantle-derived fluid components in the study area.

6 Conclusions

The rock assemblage of the Himalayan granitoids around Kunjirap in the western Qinghai-Tibet plateau is diopside syenite-diopside granite-biotite (monzonitic) granite, consisting mainly of K-feldspar, oligoclase, quartz, iron-phlogolite, diopside and edenite. The rocks are rich in mantle-derived fluid components of volatiles such as F, alkali metal elements such as K, Na, Rb, Sr and Ba, and radiogenic heat-producing elements such as U and Th. They were generated by the influx of mantle-derived fluids into the lower crust to give rise to partial melting during the lithosphere thinning in the Qinghai-Tibet plateau.

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