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Isotopic characteristics of shoshonitic rocks in eastern Qinghai-Tibet Plateau: Petrogenesis and its tectonic implication

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Abstract The Cenozoic magmatic rocks of shoshonitic series in the eastern Qinghai-Tibet Plateau include potassic alkaline plutonic rocks, volcanic rocks, lamprophyres and acidic porphyries. Analytical results show that these different lithological rocks are extremely similar in Sr, Nd and Pb isotopic compositions with the range of 0.705 187—0.707 254 for $^{87}Sr/^{86}Sr$, 0.512 305—0.512 630 for $^{143}Nd/^{144}Nd$, 18.53—18.97 for $^{206}Pb/^{204}Pb$, 15.51—15.72 for $^{207}Pb/^{204}Pb$ and 38.38—39.24 for $^{208}Pb/^{204}Pb$. They are isotopically similar to the EMII end-member. This indicates that mantle metasomatism must have taken place in their source region. The formation of these particular rocks is related to crustal thinning and mantle upwelling in a large-scale strike-slip and pull-apart fault zone at about 40 Ma in northern and eastern Qinghai-Tibet Plateau.

Keywords: isotopic characteristics, magmatic rocks, shoshonitic series, eastern Qinghai-Tibet Plateau.

The Cenozoic shoshonitic rocks in the eastern Tibet are distributed along the Ailao Mountain-Jinsha River fault zone and its two sides. The rocks consist of both intrusive and eruptive series, and display wide compositions ranging from ultrabasic, basic, intermediate to acidic. The samples investigated in this study include potassic alkaline plutonic rocks, volcanic rocks, lamprophyres and acidic porphyries, for which some Sr, Nd and Pb[1—4] isotope data have previously been reported. Due to their uniformity in temporal-spatial distribution, these rocks are regarded as the same series in this study. On the other hand, these rocks are closely associated with the large and super-large deposits of Cu, Mo and Au. Therefore, it is important to undertake isotopic studies on them in order to characterize the nature of their source materials, and to understand its petro genesis as well as the mechanism of associated mineralization.

1 Sr-Nd-Pb isotopic characteristics

1.1 Samples and sample locations

The rocks studied include potassic alkaline plutonic rocks (malignite, shonkinite and diopside syenite), volcanic rocks (tephrite, shoshonite, latite and trachyte), lamprophyres (alkali-minette and minette) and acidic porphyries (quartz monzonitic porphyry, monzonitic granoporphyry, syenite-granoporphyry and alkali-feldspar granoporphyry). They were collected from north to south: Nangqen, Yulong, Zalagar, Mangzong, Doxarsumdo, Mamupu, Zongguo, Xiaoqiaotou, Gaoxingcun, Shitoncun, Wozhong, Xiaogu’ancun, 91#, Midu and Laowangzhai (fig. 1).

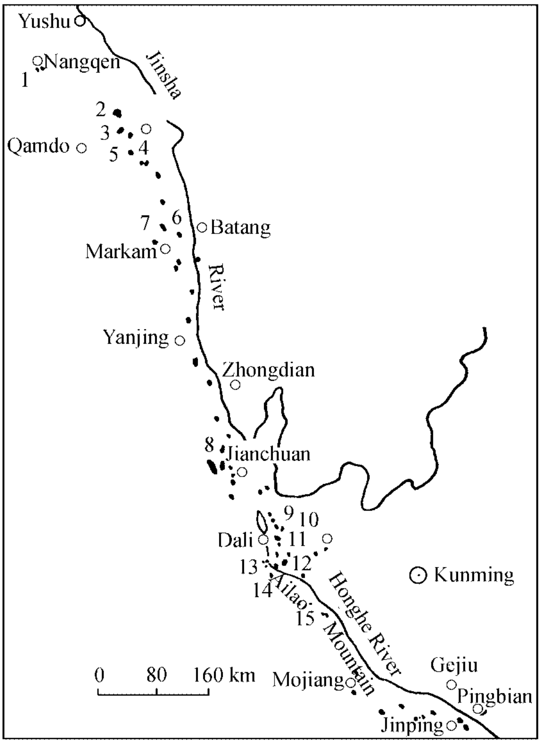

Fig. 1. A map showing the sampling localities. 1, Nangqen; 2, Yulong; 3, Zalagar; 4, Mangzong; 5, Doxarsumdo; 6, Mamupu; 7, Zongguo; 8, Xiaoqiaotou; 9, Gaoxingcun; 10, Shitoucun; 11,. Wozhong; 12, Xiaoguancun; 13, 91#; 14, Midu; 15, Laowangzhai.

1.2 Analytical method

The samples have been analyzed for Sr, Nd and Pb isotopic compositions in the Isotopic Geochemistry Laboratory of Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. Spikes of ^{84}Sr and ^{146}Nd were added to the precisely weighted samples. The samples were then dissolved in $HF+HNO_3$ in Teflon. Sr and REE are separated by cation resin. The separation of Nd and Pb was made by HDEHP and HBr-anion resin, respectively. Sr, Nd and Pb isotope ratios were measured on a mass spectrometer VG-354. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios were normalized to 0.119 4 and 0.348 417, respectively. The analyses of standards during this period give 0.710 340 ± 20 for $^{86}Sr/^{87}Sr$ of NBS-987 and 0.511 860±10 for $^{143}Nd/^{144}Nd$ of La Jolla. Lead isotopic ratios were corrected for mass fractionation using NBS-981 as a calibration standard. Analytical precision is about 0.02%. The analytical results are given in table 1. Since the samples are very young (30 Ma[2]), the isotopic ratios are not corrected for the time effect and there is no significant difference between modern and initial Sr-Nd isotopic ratios.

1.3 Sr, Nd and Pb isotopic characteristics

The different rocks of the shoshonitic series have extremely similar isotopic compositions to $^{143}Nd/^{144}Nd$ ranging from 0.512 305 to 0.512 630 and $^{87}Sr/^{86}Sr$ ratio varying from 0.705 187 to

0.707 254. The variation in Pb isotopic ratios is very small (18.53—18.97 for $^{206}Pb/^{204}Pb$, 15.51—15.72 for $^{207}Pb/^{204}Pb$ and 18.53—18.97 for $^{206}Pb/^{204}Pb$). These results show that the different rocks of the shoshonitic series from eastern Tibet are nearly homogeneous in Sr, Nd and Pb isotopic compositions, suggesting that they may be cogenetic in origin. Similar isotopic compositions have been found for the Cenozoic volcanic and plutonic rocks of Kerguelen Island [5,6]. It is clear from fig. 2 that the different rock types of the shoshonitic series from eastern Tibet are all plotted in a small area, overlapping those of Cenozoic magmatic rocks in the East Africa rift[7] and Kerguelen Island. They are significantly different from MORB[8]. High $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratios suggest that their source region must have been metasomatized in the past.

Table 1 Sr,Nd and Pb isotopic data of shoshonitic rocks in eastern Tibet and its neighboring region

No.a)	Sample	Nd ($\times10^{-6}$)	$^{143}Nd/^{144}Nd$	ε_{Nd}	Sr ($\times10^{-6}$)	$^{87}Sr/^{86}Sr$	ε_{Sr}	Pb ($\times10^{-6}$)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1	96-2	84.88	0.512 528 ± 9	–2.18	1 332.3	0.706 139 ± 14	23.3	69.48	18.716 ± 24	15.642 ± 26	38.872 ± 65
2	96-8	126.42	0.512 597 ± 11	–0.84	974.6	0.705 739 ±	17.6	11.34	18.908 ± 17	15.608 ± 14	38.996 ± 35
3	96-21	296.89	0.512 507 ± 13	–2.59	6 600.1	0.705 192 ± 17	9.8	39.97	18.783 ± 17	15.613 ± 19	38.729 ± 53
4	83-284	72.41	0.512 427 ± 19	–4.15	989.5	0.706 765 ± 8	32.2	22.28	18.971 ± 18	15.669 ± 20	38.996 ± 21
5	82-136	64.93	0.512 509 ± 9	–2.56	1 002.2	0.705 817 ± 21	18.7	21.32	18.867 ± 26	15.661 ± 24	38.963 ± 28
6	82-141	39.99	0.512 485 ± 8	–3.02	750.6	0.705 997 ± 9	21.2	22.46	18.870 ± 19	15.648 ± 29	38.955 ± 33
7	83-404	47.39	0.512 522 ± 9	–2.30	627.8	0.706 329 ± 14	26.0	35.32	18.883 ± 13	15.629 ± 10	38.921 ± 18
8	83-375	43.31	0.512 532 ± 11	–2.11	276.3	0.705 453 ± 2	13.5	30.52	18.852 ± 14	15.634 ± 15	38.915 ± 18
9	83-99	130.89	0.512 496 ± 11	–2.81	1 585.4	0.705 962 ± 8	20.6	22.85	18.960 ± 23	15.721 ± 30	39.236± 25
10	83-110	70.68	0.512 496 ± 10	–2.81	1 545.3	0.706 191 ± 6	24.0	41.40	18.825 ± 19	15.659 ± 19	38.958 ± 19
11	83-85	95.31	0.512 552 ± 16	–1.72	2 281.1	0.705 187 ± 9	9.8	56.75	18.861 ± 9	15.659 ± 11	38.965 ± 17
12	83-778	49.50	0.512 517 ± 8	–2.40	1 603.7	0.706 519 ± 11	28.7	53.96	18.678 ± 24	15.601 ± 25	38.664 ± 28
13	86-192	25.97	0.512 544 ± 39	–1.87	1 003.5	0.706 360± 14	26.4	29.28	18.576 ± 11	15.514 ± 9	38.382 ± 23
14	86-152	49.53	0.512 536 ± 13	–2.03	615.4	0.705 677 ± 7	16.7	6.96	18.865 ± 68	15.562 ± 68	39.120 ± 79
15	86-4	48.07	0.512 544 ± 9	–1.87	1 527.7	0.705 911 ± 9	20.0	26.14	18.656 ± 15	15.610 ± 13	38.644 ± 21
16	86-99	37.75	0.512 305 ± 23	–4.89	1 221.0	0.707 119 ± 6	37.2	45.57	18.532 ± 3	15.523 ± 14	38.492 ± 18
17	86-76	92.45	0.512 596 ± 7	–0.86	2 588.6	0.706 324 ± 5	25.9	47.67	18.813 ± 13	15.675 ± 16	39.082 ± 35
18	86-177	33.20	0.512 403 ± 25	–4.62	1 106.0	0.706 497 ± 5	28.3	28.40	18.564 ± 11	15.552 ± 13	38.408 ± 16
19	86-33	33.57	0.512 630± 10	–0.20	986.3	0.706 759 ± 6	32.1	16.36	18.730 ± 6	15.599 ± 5	38.776 ± 14
20	95-3	86.36	0.512 597± 9	–0.84	1 526.2	0.707 254 ± 16	39.1	25.61	18.811 ± 15	15.613 ± 20	38.541 ± 21

a) Numbers 4—8 from ref. [4]; 1—3, Nangqen; 4, Yulong; 5, 6, Zalagar; 7, Mangzong; 8, Doxarsumdo; 9, 10, Mamupu; 11, Zongguo; 12, Xiaoqiaotou; 13, Wozhong; 14, 15, Gaoxingcun; 16, Shitoucun; 17, 91#; 18, Xiaogu'ancun; 19, Midu; 20, Laowangzhai; 1, diopside syenite-porphyry; 2, 18, 19, latite; 3, 9, 16, 20, minette; 4, quartz monzonitic porphyry; 5, 8, monzonitic granoporphyry; 6, syenite-granoporphyry; 7, alkali-feldspar granoporphyry; 10, 12, diopside alkali-feldspar syenite; 11, trachyte; 13, shonkinite; 14, malignite; 15, tephrite; 17, pyrope-bearing alkali-minette.

2 Discussion

2.1 Attribute of acidic porphyries

The acidic porphyries investigated in this paper include ore-bearing porphyries and their co-existing typical potassic alkaline plutonic and volcanic rocks. They are characterized by high alkali content, high-K and high K_2O/Na_2O ratio (>1)[10] and thus belong to the potassic alkaline se-

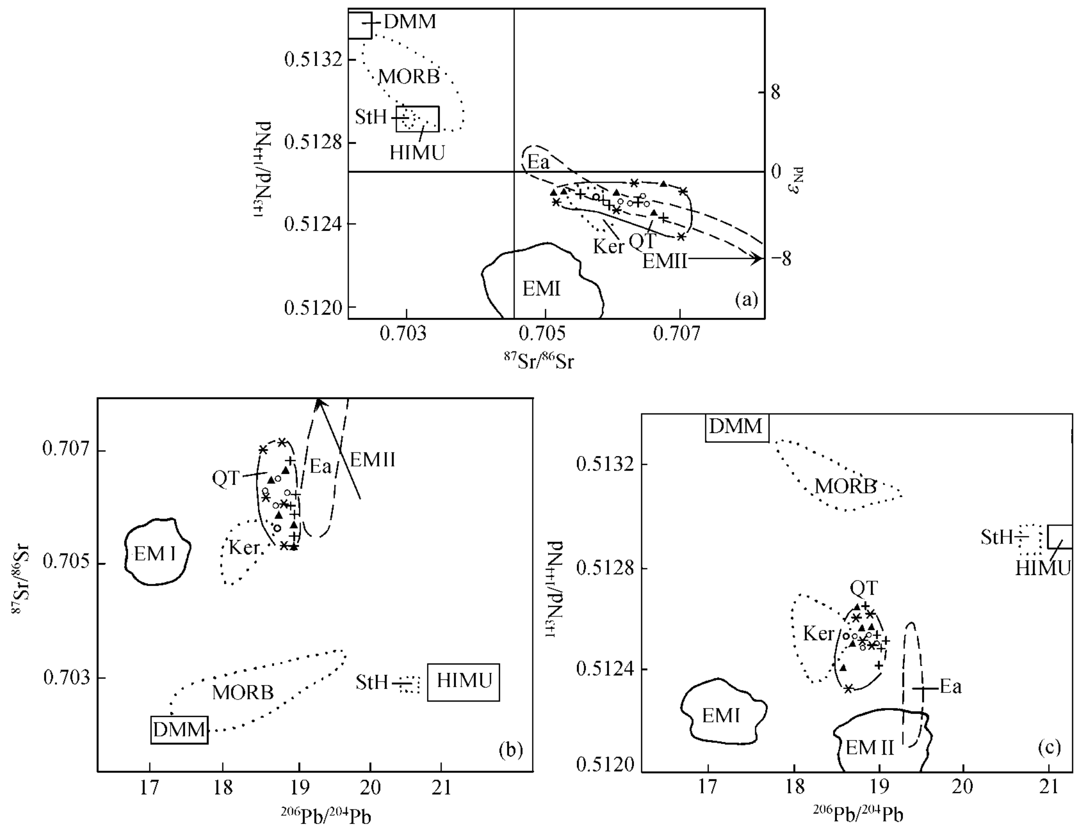

Fig. 2. Sr-Nd-Pb covariation diagrams. (a) Sr-Nd, (b) Pb-Sr and (c) Pb-Nd diagram. MORB, Oceanic basalts; Ea, East Africa Rift; Ker, Kerguelen Island; DMM, EMI, EMII, HIMU end-members of mantle[9]; QT, Eastern Qinghai-Tibet plateau and their neighboring region; 1, plutonic rocks; 2, volcanic rocks; 3, lamprophyres; 4, acidic porphyries.

ries. Moreover, there are no alkaline ferromagnesian minerals in syenites and granites. This makes them different from sodic alkaline series which generally contain ferromagnesian minerals. These acidic porphyries thus can be classified as a part of potassic alkaline plutonic rocks. It is worth indicating that the nomenclature of the acidic porphyry in this paper is specially designated and is distinct from the common syenitic and quartz syenitic porphyry typical of alkaline plutonic rocks.

2.2 Tectonic setting of shoshonitic rocks

On the basis of geochemical characteristics, the shoshonitic rocks have been divided into five subgroups which are believed to occur in five different tectonic settings[11]: i.e. within-plate, continental arc, post-collisional arc, oceanic (island) arc, initial and late oceanic arc. In the following, the possible tectonic settings at which the shoshonitic rocks occur are discussed on the basis of geological and geophysical data.

1) Since the late Eocene, a large thick red molasse, gypsum and saline-bearing formations of Gonjo, Baofengsi, Meile and Jinsichang groups, the coal-bearing subformations, the Lawula and

Jianchuan formation of alkaline basalts and trachytes were accumulated in a series of faulted basin along the Jinsha River-Red River. The total thickness of these formations is greater than 8 200 m. 2) In the Tertiary faulted basins between Red River and Jinsha River, a series of lakes developed. From south to north, the Erhai Lake, Zibai Lake, Jianhu Lake and the Manghu Lake in eastern Tibet form a bead-like distribution pattern which is similar to the morphology [12] in the East Africa Rift. 3) The remote sensing data[13] on the Gonjo group of the Eogene System show that an expand area of sedimentation was formed in the Tertiary inherited faults around the center of the Manghu Lake. The fact that the biggest tectonic lake (Manghu Lake) in eastern Tibet is located in the center of the Tertiary sedimentary system strongly suggests that this sedimentary center continues to subside during the Quaternary period. 4) The drilling data[14] indicate that the sediments in the Gonjo faulted basin become thinner from west to east, pointing to an asymmetric distribution feature. There are three-level faults on the west side for the Tertiary Dali basin from the foot of Cangshan Mountain to the Erhai Lake. The electric data[15] show a total offset of the fault movement of about 500 m. Its asymmetric feature also suggests a pull-apart characteristics. Positive Bouguer gravity anomalies are found at Jianchuan, Heqing and the side of west Lijiang, and trend northwardly. This contrasts with the regional background of negative gravity anomaly. Although these geophysical features may be related to the presence of high density basalt layer, they more likely reflect crustal thinning and the gravity features of the rift valley. 5) On the basis of the geophysical data[16], the faulted basin along the Red River-Jinsha River is coincident with a zone of mantle upwelling. The depth to the Moho beneath this zone is shallower by 2—3 km than those of the adjacent regions. 6) There is a marked, nearly south-north trend linear magnetic anomaly along the joint zone of the Jinsha River[17]. The aeromagnetic intensity increases discontinuously from east to west with a variation range of 30—80 γ. The eastern side of the joint zone is characterized by negative magnetic values close to zero. In contrast, the Qamdo block to the west side displays positive values. The anomaly distribution pattern forms a NS trend short-axis shape to the east of the joint zone. But it becomes NNW-trend linear shape to the west. The difference in the magnetic anomaly between the two sides of the joint zone suggests that there is a large-scale intra-plate fault system along the Jinsha River. Moreover, the electrical and magnetic sounding data suggest a discontinuity of the upper mantle beneath the joint zone of the Jinsha River, which subsides in the northeastern side but uplifts in the southwestern side. It is possible that the upper mantle in this region is stretched.

The above-mentioned geological, geomorphic and geophysical data all suggest that the possible tectonic setting is an intra-plate strike-slip and pull-apart fault zone or initial rift at which the shoshonitic rocks formed along the Jinsha-Red River zone.

2.3 Petrogenetic mechanism

The ages of Cenozoic shoshonitic rocks in this region vary between 40 Ma and 30 Ma[2]. These ages are roughly coincident with or slightly later than the time of collision between the Indian and Eurasian continents at the Yarlung Zangbo River suture zone. It can therefore be concluded that initiation of the large-scale strike slip-pull apart fault zone along the Red River-Jinsha River-Kekexili is related to continuous northward movement of the Indian Plate, which is in-turn blocked by ancient basements of Tarim and Qaidam. The place where basins formed is also characterized by crustal thinning and mantle upwelling. This provides favorable conditions to melt metasomatized mantle resulting in the formation of shoshonitic rocks. This is also the reason why the Cenozoic shoshonitic rocks in this region commonly occur as groups and are closely associated with the Tertiary faulted basins.

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References

1. Ding Chaojian, Wang Zeng, Shentu Baoyong, Nd, Sr isotopic characteristics of main mineralization rock bodies for the Yulong Cu (Mo) ore belt in eartern Tibet, Contribution to the Geology of the Qinghai-Xizang (Tibet) Plateau (20) (in Chinese), Beijing: Geological Publishing House, 1990, 226—230.
2. Zhang Yuquan, Xie Yingwen, Geochronology of Ailaoshan-Jinshajiang alkali-rich intrusive rocks and their Sr and Nd isotopic characteristics, Science in China, Ser. D, 1997, 40 (5): 522.
3. Ma Hongwen, Petrology and Mineralization of Granites in Yulong Porphyry Copper Belt (in Chinese), Tibet, Wuhan: China University of Geosciences Press, 1990, 112—119.
4. Zhang Yuquan, Xie Yingwen, Qiu Huaning et al., Shoshonitic series: Sr,Nd and Pb isotopic compositions of ore-bearing porphyry for Yulong copper ore belt in the eastern Tibet, Scientia Geological Sinica (in Chinese), 1998, 33 (3): 359.
5. Dosso, L., Murthy, V. R., A Nd isotopic study of the Kerguelen Island: Inference on riched oceanic mantle sources, Earth Planet Sci. Lett., 1980, (48): 268.
6. Lameyre, J., Marot, A., Ziminesv et al., Chronological evolution of the Kerguelen Island, syenite-granite ring complex, Nature, 1976, GB(26): 306.
7. Vollmer, R., Norry, M. J., Possible origin of K-rich volcanic rocks from Virunga, East Africa, by metasomatism of continental crustal materical: Pb Nd and Sr isotopic evidences, Earth Planet Sci. Lett., 1983, (64): 374.
8. Sun, S. S., McDonough, W. F., Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes, in Magmatism in the Ocean Basins, (eds. Saunders, A. D., Norry, M. J.), Geological Society Special Publication, 1989, 42: 313.
9. Hart, S. R., A large-scale isotope anomaly in the southern Hemisphere mantle, Nature, 1984, 309: 753.
10. Zhang Yuquan, Xie Yingwen, Liang Huaying et al., Petrogenesis series and ore-bearing porphyries of the Yulong ccopper ore belt in eastern Tibet, Geochimica(in Chinese), 1998, 27 (3): 236.
11. Muller, D., Rock, N. M. S., Groves, D. I., Geochemical discrimination between shoshonitic and potassic volcanic rocks from different tectonic setting: a pilot study, Mineral. Petrol., 1992, (46): 259.
12. Liu Huairen, Observation in East Africa Rift, Tectonic Evolution and Mineralization of the Tethys in Western China (ed. Chengdu Institute of Geological and Mineral Resources, Chinese Academy of Geological Sciences)(in Chinese), Chengdu: Electron University of Science and Technology Publishing House, 1991, 366.
13. He Yunzhong, Remote sensing geological characteristics and looking for ore deposit in Yulong porphyry copper zone, Eastern Tibet, Tibet Geology (in Chinese), 1992, (1): 22.
14. Tang Renli, Luo Huaisong, The Geology of Yulong Porphyry Cu (Mo) Ore Belt, Tibet (in Chinese), Beijing: Geological Publishing House, 1995, 1—40.
15. Yan Xianfu, Geological characteristics of certain rift basin in Yunnan Province and their apply effect for geophisic survey, Yunnan Geology(in Chinese), 1982, 1 (1): 47.
16. Fei Ding, On the structural feature and the oceanization in the north part of South China Sea , Acta Geophysical Sinica(in Chinese), 1983, 26 (5): 459.
17. Yu Wenjie, Geological features of the middle section of the joint zone in Jinsha River, Tibet Geology, 1993, (2): 26.