The Source System of Mesozoic Magmatism in Middle and Lower Yangtze Valleys and Adjacent Areas—A Geochemical Tracer Study *

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Abstract: The mechanism that controls regional mineralization must be governed by a series of geochemical reactions in relation to the source system of magmatism. In this respect, the geological bodies must have been overprinted by various kinds of tracers in terms of either chemical elements or isotopes. For this reason, the problem may be better approached by treating the lithosphere as a whole with due considerations given to the various tracer elements and isotopes and the various media of the magmatism (magmatic as well as sedimentary rocks). Presented in this paper are the results of this attempt based on a great wealth of available data concerning the source system of Mesozoic magmatism in the Middle and Lower Yangtze Valleys and adjacent areas.

Key words: **the source system of Mesozoic magmatism; geochemical tracer; the Middle and Lower Yangtze Valleys and adjacent areas**

Introduction

Mineralizations in the region studied, characterized by endogenic Cu, Fe, S, Au, etc., have been shown to be closely related in time and space to, and governed to a large extent by, Mesozoic magmatism. As suggested by modern theory of metallogenesis, mineralization is a form of lithospheric movement at shallow depths in the crust and is controlled by the chemistry, structure and thermal character of the lithosphere. Since the 1980's, the petrology and geochemistry of deep-seated rocks have received increasing attention, in conjunction with the traditional geophysical techniques, in extracting information about deep lithosphere. In this respect, promising opportunities are provided by the magmatic and volcanic rocks and deep xenoliths that exist at shallow depths in the area studied. In this systematic multi-element and multi-medium study of geochemical tracers emphasis is put on the three types of Mesozoic granites, i.e., the intermediate-acid stocks related to Cu- and Fe-mineralization; the granite batholiths and the A-type granites.

Isotopic Tracers of Nd and Sr

Many Nd and Sr isotope data are available for the various types of granites in the area studied (Chen Jiangfeng et al., 1993; Xing Fengming et al., 1993). For convenience of comparison,

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the original data for granites of different enrichment coefficients ($f_{Sm/Nd}$, $f_{Rb/Sr}$) and intrusion ages were converted to modern equivalents at $T=0$: $\varepsilon_{Nd(0)}$ and $\varepsilon_{Sr(0)}$.

Granites south of the Yangtze River (Jiangnan granites)

These granites are granite and granite diorite of the calc-alkalic series, with intrusion ages in 140 Ma and 130 – 120 Ma ago. They are plotted into a horizontal band in $\varepsilon_{Nd(0)}$ vs. $\varepsilon_{Sr(0)}$ diagram, showing a narrow range in $\varepsilon_{Nd(0)}$ between -7 – -8 while $\varepsilon_{Sr(0)}$ varies widely between 70 and 16000 (Fig. 1). It is also clear from Fig. 1 that granites of the Jinning Period show a similar distribution pattern and that the phyllites of the Shangxi Group are plotted well within this band with $\varepsilon_{Nd(0)}$ ranging between -8.4 – -9.4 and $\varepsilon_{Sr(0)}$ between 41 – 590 (Xing Fengming et al., 1993).

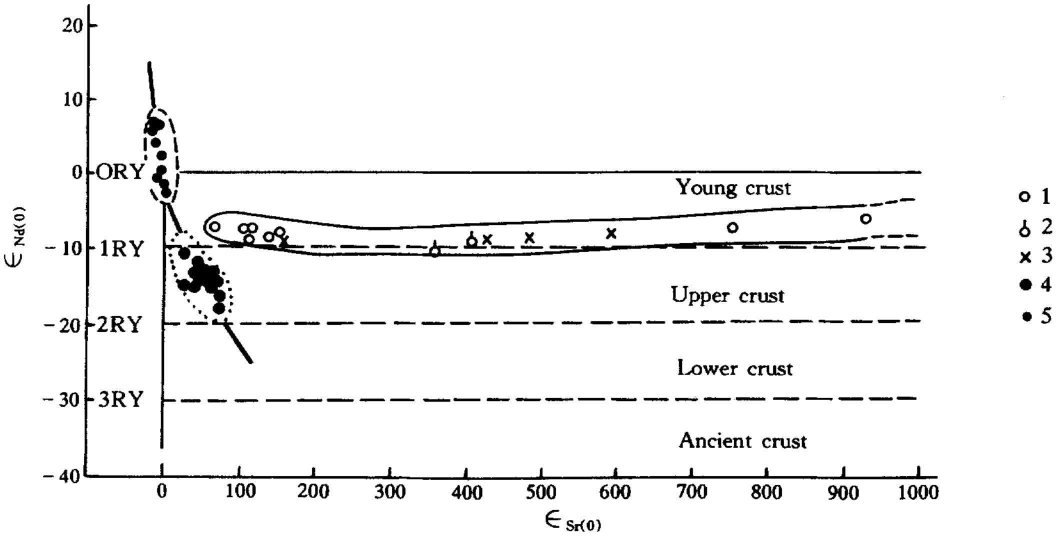

Fig. 1. $\varepsilon_{Nd(0)}$-$\varepsilon_{Sr(0)}$ diagram of geological bodies in the Middle and Lower Yangtze Valleys and adjacent areas. 1. Yenshanian granite; 2. Jinning granite; 3. Middle Proterozoic phyllite; 4. intermediate-acid stock related to mineralization; 5. Cenozoic alkaline basalt.

This indicates that: (1) granites of the Yenshanian and Jinning periods may have been derived from the crust because crustal material is the only source which is characterized by relatively constant values of $\varepsilon_{Nd(0)}$($f_{Nd/Sm}$) and widely variable $\varepsilon_{Sr(0)}$($f_{Rb/Sr}$); (2) the source of these granites may be further limited to the upper crust because the lower crust is more negative in $\varepsilon_{Nd(0)}$ and much lower in $\varepsilon_{Sr(0)}$; (3) the granite and the Middle Proterozoic low-grade metamorphic rocks (the flysch formation of argillaceous-arenaceous composition) may have a common source. The former is a product of remelting of pre-existing rocks in terrestrial crust and the latter resulted from re-sedimentation of the terrestrial crust.

Intermediate-acid stocks along the Yangtze River

These stocks consist mostly of alkali-calcic assemblage of diorite—quartz-diorite—granodiorite. They are the parent rocks of Cu(Au) and Fe mineralization with widely spreading ages of intrusion (170 – 90 Ma). In comparison with the granites mentioned above, they are concentrated in a small field in the plot, with $\varepsilon_{Nd(0)}$ between -8.6 – -17.99 (mostly -13 – -15)

and much more restricted $\epsilon_{Sr(0)}$ values between 30 and 70. They shift considerably to the lower right from mantle xenoliths ($\epsilon_{Nd(0)}$: $-5 - +5$; $\epsilon_{Sr(0)}$: $-16 - +26$), suggesting contamination between mantle magma and ancient crust which is characterized by more negative $\epsilon_{Nd(0)}$. Furthermore, partial melting of these stocks must have taken place in the lower crust because that is the only region with more negative $\epsilon_{Nd(0)}$ and less positive $\epsilon_{Sr(0)}$.

Isotopic Tracer of Pb

Because the source implications of lead isotope data should be better interpreted on a broader scale of time and space, feldspar lead isotopes were analyzed on three granite samples from the Dabie Uplift to supplement the collected data of Mesozoic granites from the region studied. To eliminate errors caused by time, the data were represented as deviations relative to contemporaneous mantle lead (Zhu Bingquan, 1985) and plotted on a three-dimensional topographic $V_1 - V_2$ diagram to emphasize the control of local lithosphere (Fig. 2). Information brought about by the diagram may be outlined as follows.

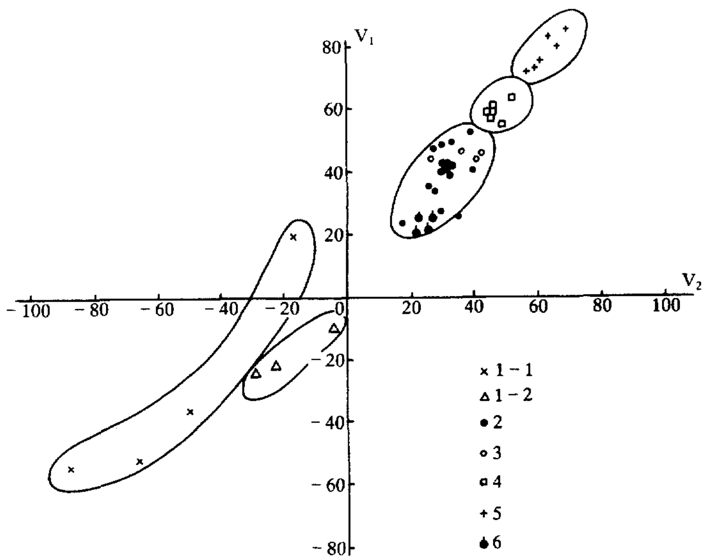

Fig. 2. V_1-V_2 diagram of feldspar lead isotopes of Yenshanian granites, Middle and Lower Yangtze Valleys and adjacent areas. 1-1. Dabie granite; 1-2. granite at Hongzhen, Chuxian and Guandian; 2. ore-bearing intermediate-acid stock; 3. A-type granite; 4. granite south of the Yangtze River; 5. granite of South China; 6. ultramafic peridotite xenolith.

(1) Feldspar lead isotopic composition of granites in South China (Nanling) is characterized by high U and Th (V_1: 70 − 85, V_2: 60 − 70) while those from the Dabie Uplift show low U/Pb and Th/Pb ratios (V_1: +20 − −60, V_2: −20 − −90). Granites in the Yangtze Block are intermediate in this character between the granites in the two regions mentioned above.

(2) In the Yangtze Block, granites south of the Yangtze River (the Jiangnan granites) have V_1 50 − 60 and V_2 45 − 55 which are in contrast with the V_1 30 − 45 and V_2 20 − 40 of the intermediate-acid stocks related to Cu and Fe mineralizations. This strongly suggests that they were derived from different sources. The source regions of the Jiangnan granites are relatively

high in U and Th and the crust there has differentiated to a higher extent with apparent enrichment of Si-Al components, thus resulting in higher values of V_1 and V_2. This is consistent with the indications of the Nd and Sr isotopes mentioned above. The source regions of the small stocks, on the other hand, are low in U and Th and are much more basic. Furthermore, the mantle features of these small stocks are also indicated by the fact that the lherzolite xenoliths and their alkaline basalt hosts at Panshishan, Luhe County, Jiangsu, also fall within the same field.

(3) Lead isotopic compositions of granites from Hongzhen, Chuxian and Guandian at the northeast margin of the Yangtze Block southeast of the Tancheng-Lujiang Fault deviate obviously from the general trend (V_1: $-10 - -25$, V_2: $-5 - -30$), suggesting that their source regions have been influenced to a considerable extent by the North China-Dabie Block.

(4) The A-type granites are plotted in the same field with the small stocks, but it is uncertain at present whether this may indicate a common source or not. Currently, the source of A-type granites is differently interpreted by: 1) the residual source model (Collins, 1982); and 2) partial melting of crustal igneous rocks of tonalitic (quartz-mica-dioritic) to granitic compositions (Creaser, 1991).

REE Tracer

REE characters of granites may provide important information about source and petrogenesis based on systematic analysis of REE data of other geological bodies in the region and on comparison with other tracer systems.

(1) The inference that the Jiangnan granites, which were derived from some argillaceous and arenaceous gneisses via partial melting, may have a common source as the Middle Proterozoic flysch rocks of similar compositions is supported by the very similar REE compositions and partition characters between them (see Table 1 and Fig. 3A):

	Granite south of the Yangtze River	Middle Proterozoic argillaceous-arenaceous rock
La/Yb	10 - 30	10 - 15
$(La/Yb)_N$	6 - 13	6 - 8
ΣREE'	140 - 200	145 - 187
δEu	0.70	0.70 - 0.86

Similar REE features can also be seen between the Jiuling plagioclase granite and the Xiuning granodiorite of the Jinning Period (Fig. 3B).

(2) The small stocks of intermediate-acid compositions related to Cu-and Fe-mineralizations possess very similar REE characters, with La/Yb 25 - 50, $(La/Yb)_N$ 15 - 30, δEu 0.8 - 1 and a right-declined partition model free of Eu anomaly (Fig. 3C). These reflect that their source regions must be characterized by the existence of a typical assemblage of biotite, amphibole and plagioclase and higher abundances of K, Rb and Ba, lower level of Sr and the absence of, or very weak, Eu anomaly.

(3) Owing to complex petrogenesis, the REE compositions of A-type granites are characterized by: 1) high total REE with significant negative anomalies of Eu; and 2) HREE are also high, giving rise to a seagull-shaped partition model as shown in Fig. 3D.

What is obvious from the above discussions is that the three types of granites are different

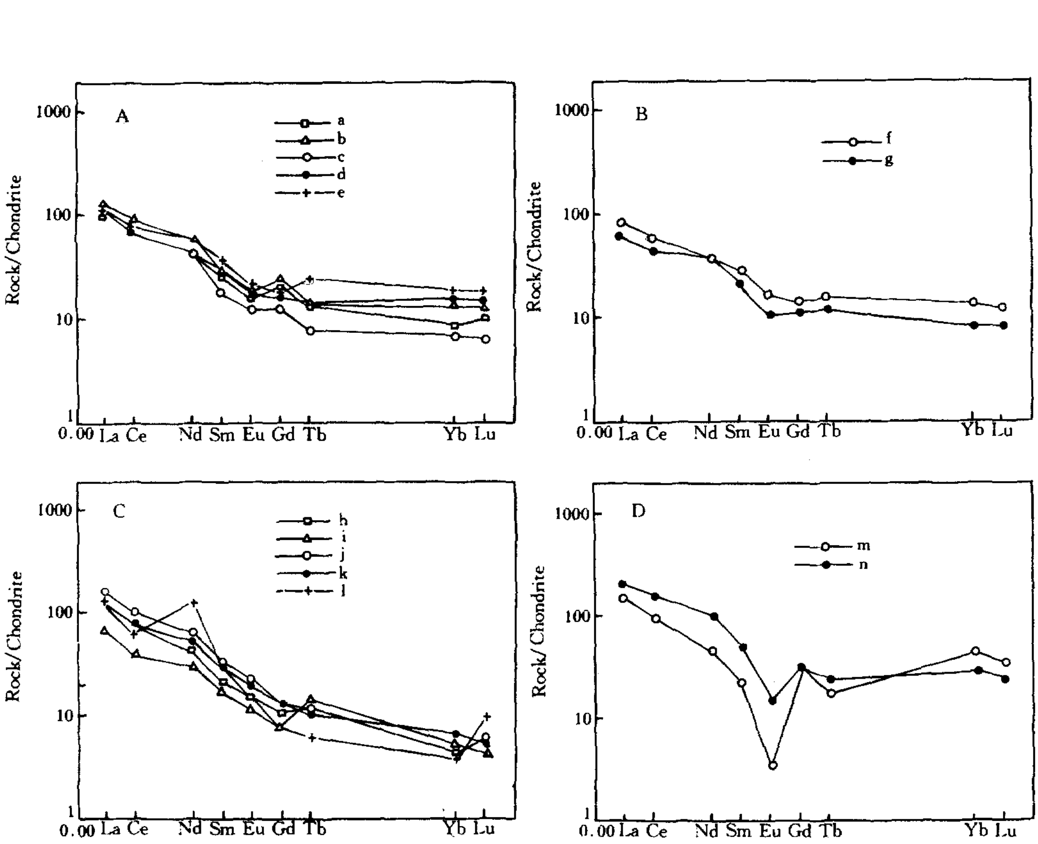

Fig. 3. REE characters of geological bodies in the Middle and Lower Yangtze Valleys and adjacent areas. A. Yenshanian granite and Middle Proterozoic metamorphic series; B. Jinning granite; C. ore-bearing intermediate-acid stock along the Yangtze River; D. A-type granite. a. Taiping monzonitic granite; b. Qingyang granodiorite; c. Jiuhuashan potash feldspar granite; d. Jiangnan Middle Proterozoic clastic rock; e. Jiangnan Middle Proterozoic argillaceous rock; f. Jiuling plagioclase granite; g. Xiuning granodiorite; h. Fengshandong granodiorite porphyry; i. Chengmenshan granodiorite porphyry; j. Yueshan quartz-diorite; k. Tongguanshan quartz-diorite; l. Anjishan granodiorite porphyry; m. Huayuangong potash feldspar granite; n. Dalongshan potash feldspar granite.

from each other in source region. Granites south of the Yangtze River are derived from argillaceous-arenaceous crust while the source regions of the small stocks are dominated by rocks with the typical biotite-amphibole-plagioclase assemblage. Moreover, they are also distinct from each other in the manner of petrogenesis.

(4) According to Treuil and Joron (1975), the plotting of La/Sm against La abundance is instructive for petrogenetic process (partial melting or differential crystallization) of granites. As can be seen from Fig. 4, both the Jiangnan granites and the ore-bearing stocks are generated largely through equilibrium partial melting. The Jiangnan granites show a good linear correlation (line 2) while the small stocks are more scattered in two bands. The slope of one band is close to line 2 and that of the other band may be defined by line 1. Plots along the steeper line

are mostly those related to Cu-mineralization and those along the gentle slope line are those related to Fe-mineralization. Differential crystallization may have also been involved in both of the two trends at shallow depths. It is also clear from Fig. 4 that the A-type granites are plotted along a horizontal line, suggesting that they were generated predominantly by differential crystallization. In conjunction with the characters of their source regions, it can be inferred that the A-type granites may have undergone differential crystallization in the order of basic→intermediate→intermediate-acid→acid (basic), which may account for their enrichment in REE and depletion in Eu.

Table 1. REE compositions ($\times 10^{-6}$) of geological bodies, the Middle and Lower Valleys of the Yangtze River and adjacent areas

	Locality/ stratigraphy	Rock type	La	Ce	Nd	Sm	Eu	Gd	Tb	Yb	Lu	La/Yb	$(La/Yb)_N$	ΣREE'	δEu
Ⅰ	Tieshan	Quartz-diorite	54.4	103.6	42.7	7.3	1.51	4.4	0.63	1.20	0.17	45.3	27.0	215.91	0.82
	Echeng	Granodiorite	54.6	91.2	79.5	4.6	0.94	3.4	0.58	2.04	0.30	26.8	15.9	237.16	0.76
	Fengshandong	Granodiorite porphyry	38.6	66.3	26.6	4.3	1.13	3.3	0.62	0.84	0.18	46.0	27.4	141.87	0.97
	Chengmenshan	Granodiorite porphyry	22.5	36.7	18.4	3.5	0.84	2.5	0.71	0.92	0.13	24.5	14.6	86.20	0.90
	Wushan	Granodiorite porphyry	46.8	87.1	32.9	5.2	1.28	3.5	0.73	0.87	0.15	53.8	31.8	178.53	0.94
	Yueshan	Quartz-diorite	49.1	93.1	37.0	6.6	1.62	4.0	0.58	0.94	0.14	52.2	31.3	193.08	0.97
	Shizishan	Quartz-diorite	38.2	69.3	28.1	5.3	1.37	3.8	0.60	1.80	0.27	21.2	12.6	148.74	0.97
	Tongguanshan	Quartz-diorite	39.7	75.7	32.1	5.9	1.54	4.0	0.58	1.24	0.17	32.0	19.1	160.93	1.00
	Fenghuangshan	Granodiorite	50.4	104.9	50.2	9.6	2.58	6.4	0.89	1.61	0.21	31.3	18.5	226.79	1.03
	Anjishan	Granodiorite porphyry	37.0	60.0	75.0	6.0	1.05	2.7	0.30	0.74	0.30	50.0	29.6	183.09	0.74
Ⅱ	Taiping	Monzonitic granite	31.3	66.1	26.4	5.18	1.17	6.2	0.70	1.56	0.31	20.1	11.9	138.92	0.70
	Qingyang	Granodiorite	41.4	82.5	35.5	5.59	1.36	7.7	0.64	2.63	0.40	15.7	9.4	177.72	0.70
	Jiuhuashan	Potash feldspar granite	42.8	67.0	27.6	4.10	0.98	8.0	0.51	2.41	0.44	17.76	10.55	153.84	0.58
Ⅲ	Jiuling	Plagioclase granite	25.0	51.5	20.6	5.37	1.17	4.31	0.75	2.50	0.37	10.0	5.9	111.57	0.78
	Xiuning	Granodiorite	19.3	41.3	21.5	4.37	0.77	3.46	0.59	1.52	0.25	12.7	7.5	93.06	0.63
Ⅳ	Huayuangong	Potash feldspar granite	47.9	91.2	27.2	4.67	0.25	9.70	0.87	7.85	1.04	6.1	3.6	196.68	0.12
	Dalongshan	Potash feldspar granite	68.7	152.0	62.1	10.2	1.09	9.46	1.16	5.33	0.76	12.9	7.6	310.80	0.37
Ⅴ	Shuangjiaoshan Group	Greywacke	32.0	63.8	18.6	5.71	1.16	4.58	0.78	2.74	0.42	11.68	6.93	129.79	0.66
		Fine sandstone	33.3	64.0	28.7	6.01	1.21	5.26	0.46	3.15	0.44	10.57	6.28	142.53	0.71
		Greywacke	32.8	63.5	26.5	5.90	1.14	5.21	0.69	3.13	0.41	10.48	6.22	139.28	0.67
	Shangxi Group	Phyllitic siltstone	34.7	61.0	28.8	6.14	1.27	5.05	0.72	2.67	0.47	12.99	7.72	140.88	0.74
		Siltstone	39.1	71.0	30.7	6.80	1.38	4.77	0.89	3.09	0.50	12.65	7.51	158.19	0.71
	Shuangjiaoshan Group	Silty slate	40.3	80.4	44.8	7.96	1.77	6.13	1.33	3.38	0.56	11.92	7.00	186.63	0.80
		Slate	38.6	73.3	20.4	7.19	1.50	6.89	1.57	3.89	0.57	9.92	6.25	153.84	0.72
		Slate	40.6	77.0	32.8	7.27	1.64	5.90	1.01	3.12	0.53	13.01	7.94	169.87	0.80
		Slate	42.1	78.6	45.1	7.65	1.55	7.11	1.98	3.82	0.58	11.02	6.60	187.49	0.69
	Shangxi Group	Black slate	35.1	63.1	32.6	6.82	1.48	4.00	1.02	3.28	0.55	10.70	6.36	147.95	0.85
		Green slate	35.1	65.7	30.4	6.42	1.46	4.49	0.94	2.87	0.49	12.23	7.28	147.89	0.87
		Phyllitic slate	34.4	68.7	26.7	6.50	1.39	3.71	0.95	3.03	0.52	11.35	6.75	145.90	0.86
		Silty slate	35.1	69.4	31.2	6.87	1.46	6.18	1.05	3.22	0.55	10.90	6.47	155.05	0.74

Ⅰ. Intermediate-acid stocks related with Cu- and Fe-mineralizations along the Yangtze River (from Zhai Yusheng, Mao Jianren et al., 1992, 1990); Ⅱ. Yenshanian granites; Ⅲ. granites of the Jinning Period; Ⅳ. A-type granites; Ⅴ. Middle Proterozoic low-grade metamorphic series.

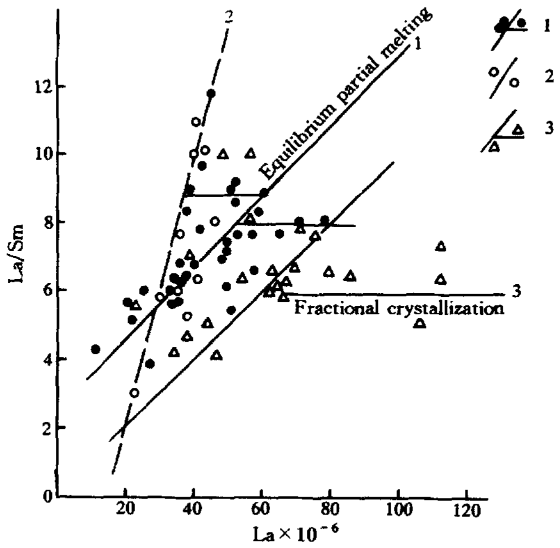

Fig. 4. Equilibrium partial melting and differential crystallization of granites. 1. Ore-bearing intermediate-acid stock; 2. granite batholith south of the Yangtze River; 3. A-type granite.

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