Shoshonitic intrusive suite in SE Guangxi: Petrology and geochemistry

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Abstract A NE-direction Mesozoic shoshonitic intrusive suite in SE Guangxi has been identified in terms of geological, petrological and geochemical investigations. The shoshonitic intrusives are characterized by enrichment of LILE, HFSE and LREE and no obvious Nb-Ta depletion, similar to those potassic rocks formed in within-plate and rifting environments. Unlike most shoshonitic rocks forming in arc settings, the SE Guangxi shoshonitic intrusives were likely generated during regional lithosphere extension induced by upwelling of asthenosphere mantle.

Keywords: **shoshonitic rocks, petrology, element geochemistry, Guangxi.**

The shoshonitic rocks are geochemically defined by high total alkalies ($K_2O+Na_2O>5\%$), high K_2O/Na_2O ratios (>0.6 at SiO_2=50%, >1.0 at SiO_2=55%), low TiO_2 (generally <1.3%), high but variable Al_2O_3 (14%—19%), and a strong enrichment in LILE and LREE[1], including volcanic rocks (absarokite, shoshonite and banakite) and intrusive rocks (mostly potassic monzonite and syenite). Most

Cenozoic shoshonitic rocks are derived from metasomatized mantle source. They are commonly formed in arc settings, including initial and late oceanic arc, continental arc and postcollisional arc settings[2,3], with a few forming in within-plate environment[4]. Shoshonitic rocks, therefore, have significant implications to petrogenesis and regional tectonic evolution. Meanwhile, shoshonitic rocks are closely associated with mesothermal gold and porphyry gold-copper mineralizations[4], and thus can potentially serve as a rock-marker for exploring mineral deposits.

We have recently identified a number of shoshonitic monzonites and syenites in SE Guangxi, which comprise a NE-trending shoshonitic intrusive suite. This note reports the preliminarily petrological and geochemical results of these shoshonitic intrusives.

1 Geological background

The studied shoshonitic intrusive occurred mainly in SE Guangxi, north to Pingle-Hexian (24°40′N), south to Bobai (22°00′N), west to Guiping-Hengxian (109°30′E), and east to Cenxi-Wuzhou and part of Huazhou in western Guangdong (110°41′E), along the Bobai-Cenxi Fault and eastern and western flanks of the Shiwandashan Basin. These intrusives are mostly quartz syenites, syenites and monzonites, including Mashan Pluton at Henxian, Xishan Pluton at Guiping, Qinghu Pluton at Luchuan-Huazhou, Maqigang Pluton at Bobai, Nandu Pluton at Cenxi, and Luorong Pluton at Wuzhou. A few of intermediate of felsic intrusives also show shoshonitic affinity, such as Tong'an and Niumiao Plutons at Pingle, Lisong Pluton at Hexian, and Yangmei Pluton at Cenxi. All the shoshonitic intrusives are distributed roughly in a NE-direction (fig. 1). They intruded into the Paleozoic strata, with Mashan Pluton intruding into the Darongshan Granite of late Hercian-early Indosinian age[6].

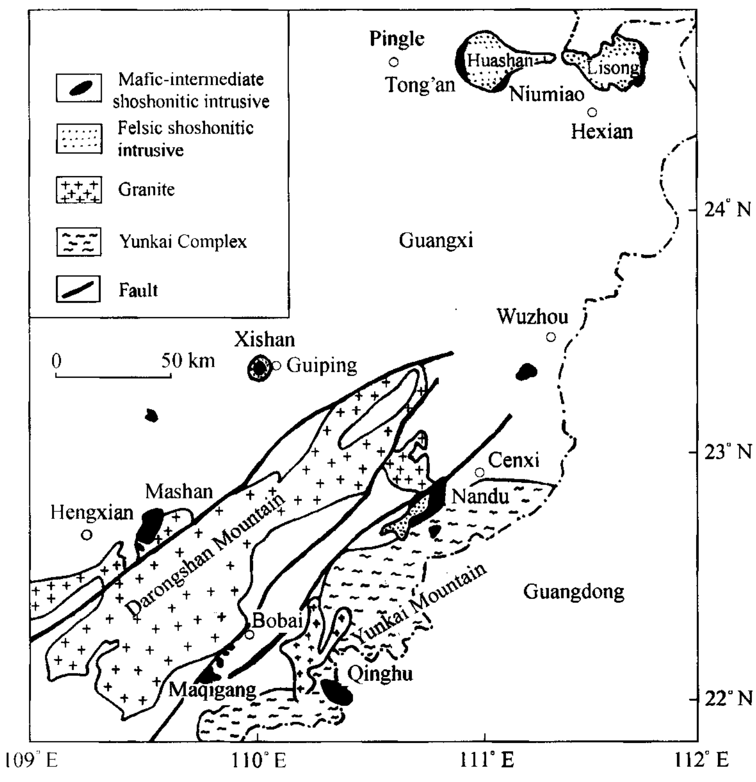

Fig. 1. Simplified geological map of SE Guangxi showing the distribution of the Mesozoic shoshonitic intrusives.

2 Petrography

The plutons investigated are mostly potassic composite. Based on the field occurrence and petrographic observations, the dominant rock types of these plutons are hornblende- and/or pyroxene-bearing syenites and monzonites, as well as a few of hornblende pyroxenite and diorite. All the plutons are undeformed.

Most syenites are equigranular and coarse grained (several to ten millimeters in diameter). Mafic minerals are unequally concentrated. They consist mainly of clinopyroxene (5%—10%), hornblende (5%—15%), K-feldspar (barbierite (35%—85%), plagioclase (5%—30%) and quartz (<5%) with or without biotite (<1%). Monzonites are pink, equigranular and medium to coarse grained, K-feldsapr, plagioclase and quartz are the most abundant rock-forming minerals (>85%). Mafic minerals (mainly hornblende with trace amount of biotite and pyroxene) occur as blebs along the boundaries of light-colored minerals.

A few of felsic plutons showing shoshonitic affinity are closely associated with the shoshonitic monzonites and syenites, such as the Xishan, Yangmei, Huashan and Lisong Plutons. They are mainly composed of 20%—40% plagiocalse (An=10—40), 25%—50% K-feldspar, 15%—40% quartz, 1%—8% biotite and <1%—5% hornblende. All the felsic plutons are mineralogically characterized by high contents of feldspars and ubiquitous occurrence of hornblende. The rock types of these plutons are mainly quartz monzonite and alkali granite.

3 Element geochemistry

Major and trace element data for representative samples of the shoshonitic intrusives are listed in table 1. These samples show variable SiO_2 contents of 50% to >70% and high alkalies (K_2O+Na_2O>6%). On the TAS diagram with modification of some boundaries for the plutonic rocks proposed by Middlemost[7], the shoshonitic intrusives fall into the field of monzodiorite, monzonite, syenite, quartz monzonite (fig. 2). The dominant rock types are monzonite and quartz monzonite. The Huashan Granite has high SiO_2 contents (>70%) and falls into the (alkali) granite, whilst the Xishan, Yangmei and Lisong plutons have slightly lower SiO_2 contents (<70%) and are plotted within the quartz monzonite field. Some composite intrusives have a wide range of SiO_2 contents, for instance, the Mashan, Qinghu and Nandu Plutons have SiO_2 contents of 47.78%—75.47%, 50.42%—74.38% and 52.10%—72.12%, respectively. All the intrusives have low MgO contents (0.4%—3.9%), indicating a significant crystal fractionation.

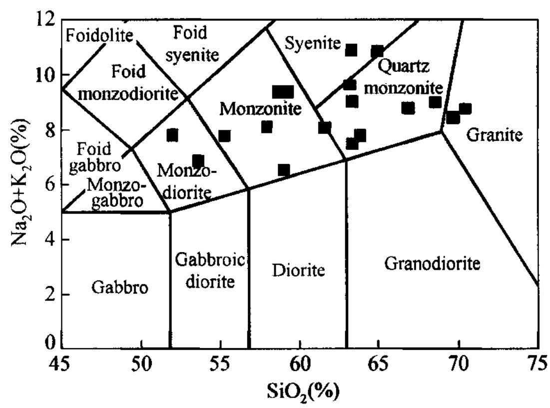

Fig. 2. Total alkali .versus silica (TAS) diagram for chemical classification[7].

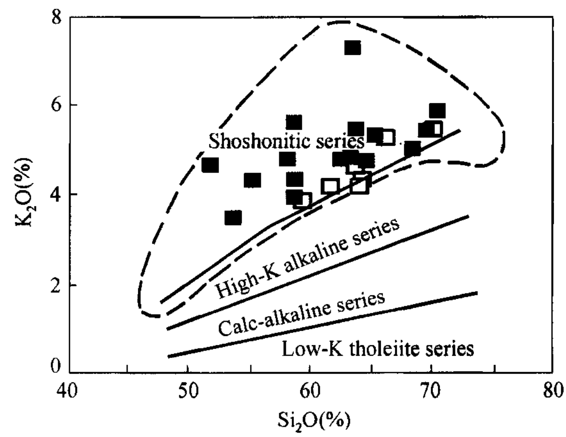

Fig. 3. SE Guangxi shoshonitic intrusives plotted on K_2O vs. SiO_2 diagram. The dashed line shows a range of shoshonitic rocks compiled by Morrison[1]. Solid squares are results of this study; open squares are results of the Cretaceous volcanics and the Luorong Pluton[6].

On the K_2O-SiO_2 diagram, most samples have unique high K_2O contents (>4%) over a wide range of SiO_2 contents ranging from 50% to 70%, and are plotted within the shoshonitic series (fig. 3). Their moderate K_2O/Na_2O ratios of 0.8—2.0 further suggest that they are shoshonitic rather than calc-alkaline or ultra-potassic in character.

Fig. 4 shows the primitive mantle-

Table 1 Major (%) and trace element (μg/g) analyses for the SE Guangxi shoshonitic intrusives

Sample	HK-2	HK-3	HK-12	HK-16	HK-21	HK-34	HK-40	HK-59	HK-62	HK-65	HK-67	HK-26*	HK-28	HK-71	HK-76*	1536-1	HK-55	HK-58
Rock	Mashan	Mashan	Maqigang	Qinghu	Qinghu	Nandu	Nandu	Niumiao	Niumiao	Tong'an	Tong'an	Yangmfei	Yangmfei	Xishan	Xianshan	Lisong	Huashan	Huashan
SiO_2	58.77	65.16	63.6	63.27	58.68	58.02	55.33	58.78	51.79	62.43	64.40	53.79	63.83	68.55	63.30	66.87	69.67	70.44
TiO_2	0.83	0.44	0.97	0.68	1.02	1.65	1.72	1.55	2.10	1.12	1.14	2.11	0.81	0.44	0.57	0.55	0.44	0.38
Al_2O_3	19.96	17.07	15.10	16.98	17.57	15.83	16.27	14.50	16.16	15.78	14.81	16.47	15.89	15.02	16.56	15.65	13.91	14.93
Σe_2O_3	6.18	3.47	6.09	3.55	5.76	7.64	8.08	8.05	10.04	6.45	6.35	9.30	5.03	3.13	4.49	4.20	3.97	3.23
MnO	0.11	0.09	0.10	0.06	0.12	0.11	0.13	0.11	0.16	0.09	0.09	0.13	0.11	0.07	0.12	0.07	0.06	0.05
MgO	0.85	0.50	1.26	0.60	1.35	2.29	2.55	3.86	3.63	1.40	1.45	2.87	1.06	0.50	0.71	0.67	0.47	0.41
CaO	3.92	1.75	3.23	2.43	4.20	4.48	5.65	5.67	6.38	3.38	3.06	5.47	2.28	1.72	1.78	2.04	1.48	1.48
Na_2O	3.81	5.17	2.90	4.82	5.17	3.21	3.45	2.76	3.15	3.47	3.09	4.14	3.58	3.79	3.58	3.79	3.01	2.93
K_2O	5.63	5.34	4.60	4.80	4.33	4.78	4.31	3.95	4.64	4.76	4.69	3.42	5.54	5.11	7.27	4.98	5.41	5.84
P_2O_5	0.16	0.14	0.30	0.18	0.30	0.49	0.53	0.34	0.58	0.27	0.26	0.59	0.32	0.14	0.17	0.22	0.14	0.13
V	110	16.0	58.4	43.4	68.2	119	136	143	181	81.6	77.0	163	39.9	24.5	25.6	25.4	25.0	23.0
Cr	3.89	3.22	15.2	13.6	10.1	12.6	7.75	96.3	15.7	7.25	8.06	1.64	9.02	7.48	11.0	3.08	8.11	6.23
Rb	132	171	143	232	183	154	142	213	242	265	268	133	225	213	316	267	382	317
Sr	795	414	308	458	652	665	638	468	452	383	327	769	450	307	210	215	128	162
Y	19.4	27.2	37.3	19.8	29.2	32.2	30.9	31.4	40.6	35.6	40.8	26.9	32.8	]26.9	75.9	43.5	41.2	35.1
Zr	898	258	447	385	522	309	284	275	257	338	356	310	334	259	619	284	298	253
Nb	17.6	62.5	35.4	76.0	77.4	81.7	71.2	42.8	70.9	51.9	50.9	62.3	87.6	54.6	110	36.3	44.8	35.1
Cs	2.87	1.50	19.7	6.56	4.11	7.45	8.56	20.0	18.4	21.6	18.4	5.04	7.54	4.50	7.08	11.7	37.7	16.5
Ba	1940	906	1118	670	645	888	795	721	477	918	571	1007	708	750	561	526	588	875
La	29.8	56.5	64.0	60.5	53.3	77.0	65.4	59.7	53.2	61.4	71.0	59.8	36.5	52.8	21.7	49.2	90.9	64.2
Ce	58.2	97.0	121	123	100	141	122	112	115	120	133	111	89.0	96.8	63.4	99.0	165	120
Pr	6.73	11.7	13.6	11.2	11.3	16.2	14.5	12.6	13.9	14.0	15.6	12.8	10.5	10.6	9.93	12.0	17.6	13.0
Nd	25.6	43.1	49.1	36.9	39.9	58.0	53.3	45.9	52.0	50.1	55.5	47.1	41.8	35.9	44.2	43.0	59.0	45.4
Sm	4.42	7.36	9.11	5.87	7.07	10.3	9.32	8.21	10.3	8.85	10.0	8.28	8.13	6.48	12.5	8.23	10.1	8.21
Eu	2.98	2.12	2.10	1.33	2.01	2.24	2.24	1.87	1.72	1.85	1.56	2.43	1.56	1.37	1.34	1.31	1.11	1.45
Gd	3.58	6.86	8.24	5.41	6.41	8.79	8.76	7.45	9.07	8.37	9.41	7.49	6.57	578	11.5	7.27	8.83	7.50
Tb	0.57	0.90	1.17	0.71	0.89	1.19	1.10	0.99	1.33	1.09	1.24	0.92	1.02	0.85	2.01	1.23	1.27	1.09
Dy	3.32	4.95	6.83	4.05	4.89	6.37	5.58	5.41	7.18	5.93	6.79	4.80	5.61	4.81	13.2	6.95	7.21	6.29
Ho	0.66	0.91	1.28	0.77	0.93	1.12	1.05	1.02	1.34	1.13	1.26	0.87	1.05	0.88	2.46	1.40	1.34	1.19
Er	1.81	2.55	3.70	2.11	2.53	3.14	2.85	2.71	3.68	3.07	3.56	2.28	2.86	2.59	7.18	3.98	4.08	3.41
Tm	0.33	0.39	0.53	0.36	0.40	0.44	0.41	0.42	0.55	0.47	0.51	0.35	0.46	0.38	1.16	0.67	6.60	0.49
Yb	2.00	2.27	3.39	2.16	2.40	2.66	2.40	2.38	3.19	2.80	2.97	1.97	2.67	2.42	7.64	4.20	3.86	3.09
Lu	0.33	0.35	0.52	0.32	0.34	0.40	0.35	0.36	0.45	0.40	0.43	0.28	0.39	0.38	1.16	0.62	0.58	0.47
Hf	20.3	6.27	10.6	9.63	10.9	7.45	6.69	7.01	6.01	8.47	8.95	7.28	8.22	7.00	17.2	7.58	8.64	7.15
Ta	1.62	4.13	2.11	5.68	4.92	4.72	3.94	3.07	4.76	3.37	3.21	3.42	4.74	5.49	15.2	4.09	4.12	2.82
Th	9.04	13.3	18.2	33.4	24.7	17.7	9.00	28.4	12.2	30.5	33.8	16.8	8.12	25.2	26.9	35.9	71.5	46.7
U	3.01	5.91	3.78	25.1	9.01	3.69	2.23	9.28	5.74	10.2	7.80	2.91	4.07	6.39	13.0	16.6	20.2	10.2

Analytical precision is 2%—5% for major elements, and better than 3% for trace elements. major and trace elements were analyzed using XRF at the Department of Geology, Taiwan University and using ICP-MS at Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. * Enclaves.

normalized trace element patterns for the shoshonitic intrusives. All samples have similar "humped" patterns characterized by variable enrichment in all the trace elements apart from Ba, Sr, P and Ti showing different degrees of negative anomaly due to crystal fractionation. Felsic samples (HK-3, HK-16 and HK-65) show pronounced P and Ti depletion due to significant fractionation of apatite and ilmennite, but have significant enrichment of Th and slight enrichment of Zr and Hf relative to mafic ones. All samples have similar REE patterns without evident Eu negative anomalies (δEu=0.91—0.54). It is noted that, unlike most shoshonitic rocks occurring in arc settings, the SE Guangxi shoshonitic intrusives have no evident Nb-Ta depletion (Nb/La=0.59 — 1.45), resembling many alkali basalts formed in oceanic islands and continental rift areas. The "humped" trace element patterns and absence of evident Nb-Ta depletion suggest that these shoshonitic intrusives were most likely formed in within-plate environments.

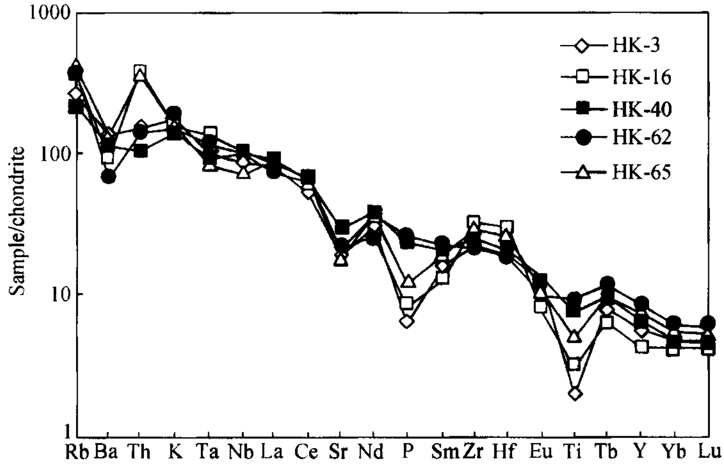

Fig. 4. Primitive mantle-normalized trace element patterns[18].

4 Discussion

The SE Guangxi shoshonitic intrusives intruded into the Paleozoic strata. The Mashan Pluton intruded into the Darongshan Granite of late Hercian-early Indosinian age[6]. Thus, it is likely that these shoshonitic rocks are Mesozoic in age, consistent with a few published K-Ar ages[6]. The precise age data, however, are still lack, with exception of a precise U-Pb zircon age of (158±2) Ma reported for the Qinghu Pluton[9].

Zhu et al.[10] reported Rb-Sr isochron ages of 210.5 and 164.7 Ma for the Tong'an and Niumiao Monzonites and the Huashan Granite, respectively. Based on the two Rb-Sr dates, they considered the former and latter belonging to the Indosinian and early Yanshanian magmatism, respectively. It is noted, however, that the Rb-Sr age of 210.5 Ma is mainly controlled by the biotite point which is obviously deviated from the linear trend of other mineral and whole-rock samples. Recalculation of their Rb-Sr data for Tong'an and Niumiao Monzonites using ISOPLOT[11], omitting the biotite and sphene data points that are significantly deviated from others, gives an imprecise isochron age of (112±45) Ma (MSWD=45.8). Recalculation of the Rb-Sr data for Huashan Granite yields an age of (160±14) Ma (MSWD=30.7), which is consistent within errors with the U-Pb zircon age of the Qinghu Pluton. It has been considered that the Tong'an and Niumiao Monzonites are probably older than the Huashan Granite based on the field relations[6]. On the other hand, we noted that Rb-Sr data of both the Tong'an and Niumiao Monzonites and Huashan Granite can define a single isochron age of (165±6) Ma (MSWD=102) (similarly omitting the biotite and sphene data points). Considering that all these intrusives are shoshonitic in character and have similar Sr-Nd isotopic compositions[9], we tentatively consider that the three plutons were contemporaneously formed in the early Yanshanian stage.

Nd isotopic data for the Qinghu Pluton[12] and Nd-Sr-O isotopic data for Tong'an and Niumiao Monzonites and Huashan Granite[10] have been reported. The Qinghu Pluton has high positive $\varepsilon_{Nd}(T)$ value of +4.8 similar to those of early Cretaceous mafic dikes ($\varepsilon_{Nd}(T)$=+4 to +5) in northern Guangdong[13], indicating derivation from a depleted mantle source. In contrast, the Tong'an and Niumiao Monzonites and Huashan Granite have more evolved Sr and Nd isotopic composition [$\varepsilon_{Nd}(T)$ ≈−2 to −3, $(^{87}Sr/^{86}Sr)_i$≈0. 707 to 0. 708], suggesting that they were derived from an enriched lithospheric mantle source, or contaminated by crustal components.

Shoshonitic rocks are commonly formed in arc settings, including initial and late oceanic arc, continental arc and postcollisional arc settings[2,3]. Only a few are formed in within-plate environment[4]. The shoshonitic rocks forming in arc settings have unique enrichment of LILE and LREE and significant depletion of Ta-Nb-Ti[4,5]. The shoshonitic rocks forming in the oceanic within-plate settings, such as Gough and Tristan da Cunha Islands[14], show typical OIB-type geochemical characters, whilst shoshonitic rocks forming in the continental within-plate settings may have arc-type geochemical features, such as Colorado[15], Borneo (Central Kalimantan, Indonesia)[16] and Lachlan Fold Belt (SE Australia)[17], or OIB-type features, such as Virunga Province (East Africa Rift)[18].

Within-plate potassic magma is commonly generated during the extension and thinning of the lithosphere and upwelling of the asthenosphere. LILE enrichment within the lithosphere mantle may result from metasomatism of underplating of plume-induced magma, or the long-term heterogeneity of the lithosphere. Nevertheless, potassic magma is generated by very small degree of partial melting of the phlogopite-bearing lithospheric mantle[19]. The SE Guangxi shoshonitic intrusives showing OIB-type trace element features indicate that they were formed in a within-plate setting, rather than an arc setting. Relatively high and variable $\varepsilon_{Nd}(T)$ values (+4.8 to −3) and absence of significant Nb-Ta negative anomaly suggest that the parent magma of the SE Guangxi shoshonitic intrusives was probably derived from interaction between an asthenosphere-derived melt and the overlying lithospheric mantle.

Gilder et al.[20] recently recognized that some Mesozoic granites in SE China possess exceptionally high Sm and Nd concentrations and relatively high $\varepsilon_{Nd}(T)$ values (−4 to −8), and form a NE-trending "Shi-Hang" zone that coincides with two prominent Mesozoic basins. They postulated the "Shi-Hang" zone to demarcate displaced terranes to the southeast from relatively stable land to the northwest. Meanwhile, Chen and Jahn[21] identified more rocks of such isotopic characteristics in SE China, and they form two NE-trending low T_{DM} and high $\varepsilon_{Nd}(T)$ values relative to the surrounding regions. The two zones roughly coincide with the "Shi-Hang" zone, but they are not continuous and separated by the N-S-striking Wanyangshan-Zhuguangshan granitic composites. Identification of a high Sm-Nd and $\varepsilon_{Nd}(T)$ zone by Gilder et al.[20] and low-T_{DM} zones by Chen and Jahn[21] is very important but its tectonic significance is still not clear. Our identification of the NE-trending shoshonitic intrusive suite along the Shiwandashan Basin and its northeast extension indicates that lithosphere extension and thinning caused by upwelling of asthenosphere mantle might occur in SE Guangxi (probably extending to southern Hunan). Upwelling of an asthenosphere-derived melt and/or very small degrees of partial melting of phlogopite-bearing lithospheric mantle not only resulted in the generation of shoshonitic magma, but also induced the extensive melting of overlying crust and formation of the Mesozoic high $\varepsilon_{Nd}(T)$-low T_{DM} granitic zone. Further work is needed to understand the tectonic setting of the Mesozoic crust-type granites in the Nanling region.

5 Conclusions

Mesozoic monzodiorites, monzonites, syenites and quartz monzonites as well as associated alkali granites along the Shiwandashan Basin and its northeastern extension in SE Guangxi show uniquely high total alkalies (K_2O+Na_2O=6.71%—10.85%), high K_2O/Na_2O ratios (0.8—2.0), belong to shoshonitic series. They form a NE-trending shoshonitic intrusive suite. These shoshonitic rocks are characterized by enrichment of LILE, HFSE and LREE and no obvious Nb-Ta depletion, similar to those potassic rocks formed in within-plate and rifting environments. Unlike most shoshonitic rocks forming in arc settings, the SE Guangxi shoshonitic intrusives were likely generated during lithosphere extension induced by upwelling of asthenospheric mantle.

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