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<th><strong>Title</strong></th>
<th>Petrogenesis of charnockites from western Junggar, Xinjiang, China; 西准噶尔紫苏花岗岩成因岩石学研究</th>
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</thead>
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<tr>
<td><strong>Author(s)</strong></td>
<td>Zhang, LF; Xian, WS; Sun, M</td>
</tr>
<tr>
<td><strong>Citation</strong></td>
<td>Xinjian Geology, 2004, v. 22 n. 1, p. 36-42; 新疆地质, 2004, 第22卷第1期, pp. 36-42</td>
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紫苏花岗岩成因岩石学研究

张立飞

1. 北京大学地球与空间科学学院
2. 香港大学地球科学系

摘要：紫苏花岗岩呈岩体形式侵入于石炭纪地层中，又为碱长花岗岩侵入。紫苏花岗岩由斜方辉石、单斜辉石、铁橄榄石、条纹长石、石英组成，以正εNd为特征（εNd=+4.8~+5.8）。矿物组成、结构和野外产状表明：这些紫苏花岗岩是火成成因的。温压计算估测其结晶条件是 T=700~800 ℃, P=420~575 kPa。紫苏花岗岩中有小的富云母包体和巨大的条带状捕虏体。前者被认为是残留体，后者与其围岩——火山碎屑岩相当。残留体中较低的εNd正值（εNd=+2.6~+3.5）要求新生的下部地壳是紫苏花岗岩的主要源岩：来自这些源岩的紫苏花岗岩的母岩浆在结晶前与一些来自于亏损地幔中的融体混合。该地区体积巨大的碱性花岗岩可能也来自相同的岩浆源，只不过它是在较浅的地壳深度上结晶的。

关键词：新疆；西准噶尔；紫苏花岗岩；富云母包体；碱性花岗岩

紫苏花岗岩是一种含有紫苏辉石的特殊类型的花岗岩，通常出现在前寒武纪高级变质岩区，如世界上几个典型的前寒武纪克拉通地区都有紫苏花岗岩出露[1]。显生宙的紫苏花岗岩比较少见，特别是含有橄榄石的岩浆型紫苏花岗岩，目前有报道的只有澳大利亚显生宙紫苏花岗岩[2]。我国在广东云开大山一带发现过加里东期紫苏花岗岩[3]，但它是含有石榴石等特征变质矿物的变质成因的紫苏花岗岩[3]，至今尚没有显生宙岩浆型紫苏花岗岩的报道[1]。根据笔者在西准噶尔庙尔沟地区工作发现了岩浆型紫苏花岗岩[4]，并较详细的报道了新疆西准噶尔庙尔沟含橄榄石的紫苏花岗岩体的岩石学和地球化学特征。

1 区域地质概况

为晚期的庙尔沟碱长花岗岩（240~270 Ma）侵入，因此西准噶尔庙尔沟含橄榄石的紫苏花岗岩形成时代应为古生代晚期。

2. 野外产状和岩石学特征

紫苏花岗岩出露在新疆西准噶尔地区最大的庙尔沟岩体的东南部和北部边缘。在紫苏花岗岩体中含有几米长的条带状围岩凝灰质火山岩捕虏体和小的扁豆状的麻粒岩相富云母包体。

紫苏花岗岩呈青黑色、块状，中粗粒花岗结构，特征矿物包括紫苏辉石（15%）、普通辉石（10%）、条纹长石（10%）、斜长石（40%）、石英（10%）、角闪石（10%）、黑云母（3%）、铁橄榄石（<2%）和一些副矿物。

紫苏辉石呈粗粒自形粒状，含少量Fe-Ti氧化物包裹体，与普通辉石、铁橄榄石呈平衡结构；橄榄石并不常见，经常被Fe-Ti氧化物包围；角闪石可达10%，似是辉石的次生矿物；条纹长石、反条纹长石（总量~10%）呈粗粒自形-半自形，与斜长石和它形石英平衡共生（斜长石组分一般是An20~An30）；其他组成矿物包括黑云母（3%）和副矿物磁铁矿/钛铁矿、榍石和锆石等。

3. 矿物化学

矿物成分的电子探针分析是在中国科学院地质研究所岩石圈开放实验室的Cameca SX51型电子显微镜上进行的，加速电压15 kV，定向束流20 nA（表1，图2A）[20]，计数器时间10~20 s，最后结果用PAP矫正。

### 表1 西准噶尔紫苏辉石的代表性成分

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<td>0.17</td>
<td>0.13</td>
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<td>0.21</td>
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<td>0.81</td>
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<td>1.27</td>
<td>1.08</td>
<td>0.84</td>
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<td>0.61</td>
<td>0.63</td>
<td>0.77</td>
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<td>MgO</td>
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<td>12.1</td>
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<td>K₂O</td>
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<td>99.9</td>
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<td>100.2</td>
<td>99.3</td>
<td>100.3</td>
<td>100.6</td>
<td>100.3</td>
<td>100.2</td>
<td>99.5</td>
<td>100.3</td>
<td>100.3</td>
</tr>
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</table>

O       96
Si⁺⁺ 1.99 2.02 1.98 1.98 1.98 1.97 1.97 1.98 1.98 1.98 1.98 1.98 1.98 1.98
Al³⁺ 0.01 0.00 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
Fe²⁺ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
Fe³⁺ 0.01 0.00 0.01 0.02 0.02 0.04 0.03 0.04 0.04 0.04 0.04 0.04 0.04 0.04
Mg²⁺ 0.71 0.74 0.98 0.98 0.58 0.58 0.66 0.71 0.39 0.43 0.43 0.43 0.43 0.43
Fe⁴⁺ 1.17 1.11 0.93 0.94 1.31 1.31 1.22 1.15 0.76 0.68 0.68 0.68 0.68 0.68
Ca²⁺ 0.03 0.04 0.03 0.03 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
Ca²⁺ 0.07 0.07 0.05 0.04 0.06 0.06 0.05 0.06 0.07 0.08 0.08 0.80 0.80 0.80
Ca²⁺ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.03 0.03 0.03 0.03 0.03 0.03
K⁺  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
Cations 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00
Wo  3.44 3.71 2.42 1.75 2.77 2.43 2.97 3.68 43.8 40.8 40.8 40.7 42.5 42.6 43.0
En  35.6 38.0 49.2 49.1 29.1 28.7 32.7 35.3 14.6 19.7 21.7 21.9 20.8 28.9
Fs  61.0 58.3 48.4 49.1 68.1 68.9 64.3 61.0 41.5 39.5 37.7 35.6 36.7 28.1

图2 紫苏花岗岩中辉石化学成分图解

(A) —— Diopside Hedenbergite
(B) —— Ensoilte Fs

### Table 2
The representative analyses of various minerals from charnockites, Western Junggar

| Mineral    | SiO₂ | TiO₂ | Al₂O₃ | FeO* | MnO | MgO | CaO | Na₂O | K₂O | Fe₂O₃ | Mg/(Mg+Fe²⁺) | Ca/(Ca+Na) | Na/(Ca+Na) | K/(Ca+Na) | TiO₂/Mg   | Al₂O₃/Mg   | FeO*Mg       | MnO/Mg     | MgO/Fe²⁺ | CaO/Fe²⁺ | Na₂O/Fe²⁺ | K₂O/Fe²⁺ | Al₂O₃/FeO* | Fe₂O₃/FeO* |
|------------|------|------|-------|------|-----|-----|-----|------|-----|-------|--------------|-------------|------------|------------|-----------|----------|----------|----------|----------|---------|----------|----------|----------|---------|----------|----------|
| Black mica | 4.14 | 1.54 | 0.62  | 2.20 | 0.34| 0.78| 0.61| 0.34 | 0.7 | 0.78  | 0.00          | 0.00        | 0.00       | 0.00       | 0.00     | 0.00     | 0.00     | 0.00     | 0.00    | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     |
| Orthoclase | 3.80 | 0.99 | 1.67  | 2.05 | 0.15| 0.15| 0.14| 0.14 | 0.15| 0.14  | 0.00          | 0.00        | 0.00       | 0.00       | 0.00     | 0.00     | 0.00     | 0.00     | 0.00    | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     |

### Table 3
Major and trace elements for charnockites from Western Junggar

| Element  | SiO₂ | TiO₂ | Al₂O₃ | FeO* | MnO | MgO | CaO | Na₂O | K₂O | Fe₂O₃ | Mg/(Mg+Fe²⁺) | Ca/(Ca+Na) | Na/(Ca+Na) | K/(Ca+Na) | TiO₂/Mg   | Al₂O₃/Mg   | FeO*Mg       | MnO/Mg     | MgO/Fe²⁺ | CaO/Fe²⁺ | Na₂O/Fe²⁺ | K₂O/Fe²⁺ | Al₂O₃/FeO* | Fe₂O₃/FeO* |
|----------|------|------|-------|------|-----|-----|-----|------|-----|-------|--------------|-------------|------------|------------|-----------|----------|----------|----------|----------|---------|----------|----------|----------|---------|----------|----------|
| SiO₂      | 61.26| 61.39| 61.29 | 64.46| 65.29| 64.62| 60.20| 61.29| 64.62| 60.20 | 61.26          | 61.39       | 61.29      | 61.29      | 61.29    | 61.29   | 61.29    | 61.29   | 61.29   | 61.29   | 61.29   | 61.29   | 61.29   |

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6.34%~8.41%, MgO+FeO=3.70%~7.77%.

在标准的QAP图上[15], 西准噶尔紫苏花岗岩投在紫苏花岗岩紫苏石英二长岩区(图3)[15]. 这些紫苏花岗岩的主要元素组成类似于Ardey紫苏花岗岩侵入体和Toro紫苏花岗质杂岩[16,17].

图3 QAP分类图

图4 QAP diagram of charnockitic rocks

图4 原始地幔标准化图解

Table 4 Sm/Nd isotope data for charnockites from Western Junggar

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<th>Nd×106</th>
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Nd ±113] 0.51275~0.51282, εNd(T) = +4.8~5.9[8]. Nd同位素亏损地幔模式计算年龄为690~790 Ma, 采用直线方程, 假设Nd(T)在4.55 Ga时为10, 则现在的Nd(T) = +10.

5 P-T条件估算

紫苏花岗岩结晶P-T条件估算


利用Wood and Banno的二辉石中Ca-Mg转换的二元模式温度计估算的紫苏花岗岩的结晶温度为T=709~826℃[19]; 根据Lindsley的二辉石Di-En-Hd-Fs四边形表示的三元模式地质温度计的估算紫苏花岗岩中与斜方辉石共生的单斜辉石形成温度介于700~800℃之间(图2B). 含铁橄榄石紫苏花岗岩的最低压力可以用富铁橄榄石-斜方辉石之间Fe-Mg的分配计算. 根据Muller经过校正的方程式[21]: 

\[ P = -41.224 + 23.709X_{\text{OpxFe}} + 18.263X_{\text{OlpFe}} + 0.0143 \times T(\text{℃}) \]

该方程的适用范围是700~800℃, 计算紫苏花岗岩结晶的最低压力为3.78~4.88 kPa, 相当于15~20 km的深度. 根据Davidson and Lindsley的地质压力计[22], 利用四元(FeO-MgO-CaO-SiO2)三相(辉石-橄榄石-石英)平衡组合中的XFe计算压力, 计算在800℃时紫苏花岗岩的形成压力是378~575 kPa. 这些不同方法计算结果接近, 紫苏花岗岩的结晶温度为700~820℃, 压力为378~525 kPa, 相当于15~20 km的深度.
Fig. 5 Chondrite normalized REE patterns for charnockites (a) and surmicaceous enclaves (b)

1. 321.2; 2. 207.3; 3. 841.5; 4. 271.6; 5. 114.7; 6. 981; 7. 159.8; 8. 1931; 9. 1932

6.1

Al

Fe-Ti

P-T (730–830 °C, 633–788 kPa)

Bi+Q=Opx+Kfd+Ilm+Fe-Ti

REE

εNd

LREE

Eu

6.2

Al

Fe-Ti

REE

εNd

LREE

Eu
In the Late Carboniferous, following the collision of the Siberian Craton with the Middle China Craton, the relative elevation of the lithosphere resulted in magma generation from a different source. The magma was evolved from a mantle plume that led to the generation of Hercynides lavas.

Some of the melts derived from the dehydrated mantle plume were injected into the lower crust, resulting in the generation of granitoids with a negative Sr isotopic signature. These melts were mixed with residues from the lower crust, which had been generated from the differentiation of the granitoids. The resulting rocks were characterized by a negative Sr isotopic signature and a positive Nd isotopic signature, indicating a hybridization between the melts from the mantle plume and the residues from the lower crust.

The study of the isotopic compositions of the rocks and their petrogenesis can provide insights into the tectonic processes that led to the generation of these granitoids. The results of this study can be used to complement the tectonic models proposed for the collision of the Siberian Craton and the Middle China Craton, and to gain a better understanding of the processes of crustal formation and evolution.

6.3

7

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PETROGENESIS OF CHARNOCKITES FROM WESTERN JUNGGAR, XINJIANG, CHINA

ZHANG Li-fei¹, XIAN Wei-sheng¹,², SUN Min¹²
(¹, School of Earth and Space Sciences, Peking University, Beijing, China;
², Department of Earth Sciences, The University of Hong Kong, Hong Kong, SAR, China)

Abstract: Charnockites occur as giant enclaves or pendants (?) in the Miaogou Batholith, Western Junggar region. These rocks are composed of ortho- and clinopyroxenes, fayalite, perthite, antiperthite, and quartz, and are characterized by positive εNd values (+4.8~+5.9). Mineral assemblage, texture and field occurrence indicate an igneous origin for the charnockites. Temperature and pressure estimations give 700~800 °C and 4~5 kb crystallization conditions. The charnockites enclose small surmicaceous enclaves and large banded angular xenoliths. The former are considered as restites, while the latter are equivalent to the country pyroclastic rocks. The positive but lower εNd values (+2.6~+3.5) for the restites require that the juvenile lower crust was the dominant source for charnockitic magma, and parental magma of the charnockites from this source was mixed with some melt from dePLETED mantle, before crystallization. The voluminous alkaline granites in the region were probably from the same magma source, but crystallized at upper crust depth.

Key words: Xinjiang; Western Junggar; Charnockite; Surmicaceous enclave; alkaline granite