Cai JianHui$^{1,2}$, YAN GuoHan$^1$, CHANG ZhaOShan$^1$, WANG XiaoFang$^1$, SHAO HongXiang$^1$ and CHU ZhuYin$^3$

1. Faculty of Earth and Space Sciences, Peking University, Beijing 100871, China
2. Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
3. Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China


Abstract  The Wazan complex is one of representative example of Taihang-Da Hinggan tectonomagmatic belt in eastern China, which has the largest scale and the most rock types. It consists of three-stage rocks. According to the major element characteristic, REE and Nd, Sr, Pb isotopic characteristics of the Wazan complex reported in this paper, the main stage rocks (granodiorite, adamellite and few quartz diorite) have the similar petrological and geochemical characteristics to those of 

adakite with SiO$_2$≥58%, Al$_2$O$_3$≥15%, low Y content (4.20~12, 68µg/g), high Sr content (518~861µg/g) and Sr/Y ratios (60.19~178.10). LREE enrichment with (La/Yb)$_N$=34.06~76.91. HREE depletion with Yb=0.44~1.00, no obviously Eu anomaly (Eu/Eu$^*$=0.83~1.03) and relative depletion in the high field strength elements (such as Nb, Hf, Ti), $I_{ch}$=0.7060, negative $\varepsilon_{Nd}(t)$ value (−16.29~−14.27) and positive $\varepsilon_{Sr}(t)$ value (+23.7~+25.0), but obviously different from those of subduction-related adakites. These adakite-like rocks were most likely derived from the partial melting of basaltic lower crust in the thickened crust resulted from hot mantle material upwelling as several mushroom cloud and the thermally altered ground uplifting to the bottom of continental crust during late Jurassic period. But the early and the late stage ones belong to non-adakites. The early basic- to intermediate- intrusive rocks (hornblende granite, gabbro and diorite) are high Mg and Fe. LREE enrichment, Eu positive anomaly, enriched in compatible elements and low incompatible elements, $I_{ch}$=0.7065, $\varepsilon_{Nd}(t)$=−16.72~−10.92, which are the products of partial melting of subcontinental lithospheric enrich mantle and probably represent the underplating basaltic magma below the thickened continental crust during early Mesozoic era. The late alkaline intermediate- to acid-intrusive rocks (alkali-granite, quartz syenite and quartz monzonite) are characteristic of high K and Na, alkaline series high $\Sigma$REE, negative Eu anomaly, low Sr content, high Y and Yb, negative Sr anomaly, $I_{ch}$=0.7062, $\varepsilon_{Nd}(t)$=−16.25, suggesting that the formation of adakite-like rocks of the main stage result in the lithospheric delamination and cause asthenosphere to upwell to the bottom of thinned continental crust, so the rocks of the late stage are formed by the partial melting of the crust-mantle transformation belt even in the middle crust. In this paper the Rb-Sr isochronal age of granodiorite (145.7±5.3Ma) is reported. Based on the Rb-Sr isochronal age of granite and granodiorite, the main body of the Wazan complex was probably formed in late Jurassic period between 137.8Ma and 145.7Ma.

Key words  Petrological and geochemical characteristics; Genesis; Adakite-like rock; Sr, Nd and Pb isotopes; Rb-Sr isochronal age; the Wazan complex.


前言

大兴安岭构造岩浆带中生代构造岩浆活动存在长时间的多期活动，岩体的岩相以岩基为主。

大兴安岭中生代构造岩浆带中规模最大

岩体是位于太行山轴部紫荆关断裂带上的涞源

王安镇岩体是多期岩浆活动的产物

这在国内外是不多见的

本文通过对王安镇岩体三期岩石主量元素

岩石学报

P588. 14；P595

1

2
本文锆石年龄为王群面告王季亮等二长花岗岩主要出露于岩体中心部位其等时线年龄为王群面告晚期主要是富碱的中酸性岩类如钾长花岗岩、石英二长岩和石英正长岩该阶段岩石多呈分散的小岩体或脉状出现石英正长岩的等时线年龄为-37.8Ma(Yan Guohan et al., 2000)。从以上三期岩石的形成年龄来看早期为燕山早期早侏罗世主期年龄为燕山晚期早白垩世晚期的年龄为燕山晚期早白垩世。总体上形成王安镇杂岩体的岩浆活动高峰是在燕山晚期的晚侏罗世岩石学特征早、中、晚三期代表性岩石的岩石学特征如下早期角闪石岩多以闪长岩的包体形式产出黑色中细粒结构全晶质包含结构块状构造主要矿物成分为角闪石其中一种是棕色闪石含量约为35%另一种是绿色普通角闪石含量约为25%斜方辉石、橄榄石黑云母斜长石及的副矿物包括蛇纹石、绿泥石和磁铁矿从以上三期岩石的形成年龄来看早期为燕山早期早侏罗世主期年龄为燕山晚期早白垩世晚期的年龄为燕山晚期早白垩世。总体上形成王安镇杂岩体的岩浆活动高峰是在燕山晚期的晚侏罗世岩石学特征早、中、晚三期代表性岩石的岩石学特征如下早期角闪石岩多以闪长岩的包体形式产出黑色中细粒结构全晶质包含结构块状构造主要矿物成分为角闪石其中一种是棕色闪石含量约为35%另一种是绿色普通角闪石含量约为25%斜方辉石、橄榄石黑云母斜长石及的副矿物包括蛇纹石、绿泥石和磁铁矿。
图2 王安镇岩体地质略图

据石准立编改

早期闪长岩
灰黑色
似辉长辉绿结构
块状构造
主要矿物成分为斜长石
平均含量约
钾长石
普通角闪石
黑云母
石英
副矿物主要为磷灰石和磁铁矿

中主期花岗闪长岩和石英闪长岩
灰黑色
粗粒花岗结构或似斑状结构
块状构造
主要矿物成分有黑云母
含量
角闪石占
斜长石含量为
碱性长石含量
石英闪长岩中石英含量更高
可达
可
见碱性长石交代斜长石和为闪石所交代的透辉石
副矿物约
主要为磷灰石
’磁铁矿
榍石和锆石

中主期花岗岩
淡肉红色
粗粒花岗结构或似斑状结构
块状构造
其中石英含量为
钾长石和斜长石各占约
角闪石含量为
黑云母约为
副矿物为磷灰石
榍石
锆石

晚期钾长花岗岩
肉红色
花岗结构或似斑状结构
块状构造
其中石英含量为
斑晶钾长石占
基质钾长石含量为
斜长石只存在于基质中
含量约为
角闪石含量为
黑云母约为
副矿物为磷灰石
榍石
锆石

岩石学报

Fig. 2  Simplified geological map of Wanganzhen complex (after Shi Zunli, 1990, modified slightly)
本文对王安镇岩体中出露面积最大的花岗闪长岩进行岩石地球化学特征的对比研究。本文所选岩体花岗闪长岩全岩主要是正长石和中长石，中粒结构，呈细粒榍石和磁铁矿。正英岩、二长花岗岩和埃达克岩岩石地球化学特征的对比见表3。王季亮等（1989）等时线年龄为137.8Ma～145.7Ma。王安镇岩体花岗闪长岩全岩岩石地球化学特征如表3。表3 具有较高的相关性，表明这些岩石在形成后未发生明显的改变。根据王鸿桢等（2001）指出，无论是按照中国全国地层委员会，还是按照国际地质科学联合会，还是按照中国全国地层委员会和国际地质科学联合会，岩石地球化学特征表明，如表3，表明这些岩石在形成后未发生明显的改变。本文选取普通角闪石似斑状结构和图个新鲜花岗闪长岩全岩块状构造。

Table 1  The Rb-Sr isotopic determination data and calculation results of the Wanzhong complex

<table>
<thead>
<tr>
<th>Rb×10^-6</th>
<th>Sr×10^-6</th>
<th>Rb/Sr</th>
<th>Sr/85Sr</th>
<th>87Sr/86Sr</th>
<th>87Sr/86Sr (±2σ)</th>
<th>Lu</th>
<th>εSr (t)</th>
<th>(Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>97-56</td>
<td>115.10</td>
<td>887.70</td>
<td>0.37450</td>
<td>0.706783±27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>97-52</td>
<td>111.70</td>
<td>755.80</td>
<td>0.42660</td>
<td>0.706840±14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>97-50</td>
<td>150.90</td>
<td>930.70</td>
<td>0.46780</td>
<td>0.706970±24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>97-51</td>
<td>119.90</td>
<td>658.90</td>
<td>0.52340</td>
<td>0.707082±18</td>
<td></td>
<td>0.7060</td>
<td>23.7</td>
<td>145.7±5.3</td>
</tr>
<tr>
<td>98-25</td>
<td>167.40</td>
<td>636.90</td>
<td>0.75910</td>
<td>0.707554±15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98-26</td>
<td>168.60</td>
<td>626.90</td>
<td>0.77660</td>
<td>0.707625±15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>97-57</td>
<td>182.70</td>
<td>552.90</td>
<td>0.95420</td>
<td>0.707913±15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98-33</td>
<td>224.10</td>
<td>440.50</td>
<td>1.47000</td>
<td>0.709051±14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-21</td>
<td>12.9</td>
<td>1142</td>
<td>0.03262</td>
<td>0.705620±1.6</td>
<td>186.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-33</td>
<td>158.1</td>
<td>608.40</td>
<td>0.7502</td>
<td>0.707534±24</td>
<td></td>
<td>0.7062</td>
<td>26.4</td>
<td>126.4±3.4</td>
</tr>
<tr>
<td>98-2</td>
<td>158.1</td>
<td>608.40</td>
<td>0.7502</td>
<td>0.707534±24</td>
<td></td>
<td>0.7062</td>
<td>26.4</td>
<td>126.4±3.4</td>
</tr>
<tr>
<td>98-23</td>
<td>176.8</td>
<td>594.70</td>
<td>0.8584</td>
<td>0.707667±21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98-30</td>
<td>265.1</td>
<td>286.20</td>
<td>2.675</td>
<td>0.711213±23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98-38</td>
<td>254.5</td>
<td>107.00</td>
<td>6.874</td>
<td>0.718539±15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VG354</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## 表 2 岩石名称与主要的造岩元（％）及微量元素（μg/g）

### 表 2 The chemical analysis data of the granitoids from the Wanzheng complex: major element (％), tracer element(μg/g)

<table>
<thead>
<tr>
<th>岩石名称</th>
<th>角闪岩</th>
<th>辉长岩</th>
<th>闪长岩</th>
<th>花岗岩</th>
<th>石英</th>
</tr>
</thead>
<tbody>
<tr>
<td>样品号</td>
<td>6C</td>
<td>8b</td>
<td>8b</td>
<td>8b</td>
<td>8b</td>
</tr>
<tr>
<td>序号</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>SiO2</td>
<td>44.32</td>
<td>46.72</td>
<td>44.32</td>
<td>46.72</td>
<td>46.72</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56</td>
</tr>
<tr>
<td>Al2O3</td>
<td>23.50</td>
<td>23.50</td>
<td>23.50</td>
<td>23.50</td>
<td>23.50</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
</tr>
<tr>
<td>FeO</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
</tr>
<tr>
<td>MnO</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>MgO</td>
<td>3.42</td>
<td>3.42</td>
<td>3.42</td>
<td>3.42</td>
<td>3.42</td>
</tr>
<tr>
<td>CaO</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
<td>5.76</td>
</tr>
<tr>
<td>Na2O</td>
<td>1.27</td>
<td>1.27</td>
<td>1.27</td>
<td>1.27</td>
<td>1.27</td>
</tr>
<tr>
<td>K2O</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>LOI</td>
<td>2.13</td>
<td>2.13</td>
<td>2.13</td>
<td>2.13</td>
<td>2.13</td>
</tr>
</tbody>
</table>

### 总结

从表 2 可以看出，Wanzheng 复合体中的花岗岩的主量元素含量范围如下：

- SiO2: 44.32％～46.72％
- TiO2: 0.56％～0.56％
- Al2O3: 23.50％～23.50％
- Fe2O3: 5.76％～5.76％
- FeO: 5.76％～5.76％
- MnO: 0.25％～0.25％
- MgO: 3.42％～3.42％
- CaO: 5.76％～5.76％
- Na2O: 1.27％～1.27％
- K2O: 1.00％～1.00％
- P2O5: 0.10％～0.10％
- LOI: 2.13％～2.13％

这些元素的含量范围反映了Wanzheng 复合体中花岗岩的化学成分特征，体现了岩浆作用过程中的化学分异过程。
Table 3  Comparison between the typical adakite and the granitoids from the Wanganzhen complex

<table>
<thead>
<tr>
<th></th>
<th>Typical Adakite</th>
<th>Granitoids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Al₂O₃</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MgO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CaO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Na₂O+K₂O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Na₂O/K₂O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sr (×10⁻⁶)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yb (×10⁻⁶)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y (×10⁻⁶)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sr/Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>La/Yb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eu/Eu*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iₐ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>εNd</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4  Diagram of K₂O vs. SiO₂ and K₂O/Na₂O vs. SiO₂ for the Wanganzhen granitoid complex

1. Basic- to intermediate- intrusives of the early stage
2. Adakite-like rocks of the main stage
3. Alkaline intermediate- to acid-intrusives of the late stage

Defant et al., 1990; Drummond M S et al., 1990; Martin H, 1993; 1999
\[ \text{图解中} \] 

\[ \text{图中} \] 

\[ \text{Fig. 5 Chondrite-normalized REE patterns and primitive mantle-normalized distribution patterns of} \] 

\[ \text{ incompatible elements for the granitoids from the} \] 

\[ \text{Wanganzhen complex. Normalization values after Sun} \] 

\[ \text{and McDonough (1989)} \] 

\[ \text{(a), (b), (c), (d), (e), (f)} \] 

\[ \text{Sun and McDonough, 1989} \] 

\[ \text{ Fig. 5 Chondrite-normalized REE patterns and primitive mantle-normalized distribution patterns of} \] 

\[ \text{ incompatible elements for the granitoids from the} \] 

\[ \text{Wanganzhen complex. Normalization values after Sun} \] 

\[ \text{and McDonough (1989)} \] 

\[ \text{(a), (b), (c), (d), (e), (f)} \] 

\[ \text{Sun and McDonough, 1989} \]
图

图6 Sr/Y vs. Y and (La/Yb)_N vs. Yb_N diagram of the granitoids from the Wanganzhen complex

5 Nd-Sr-Pb

<table>
<thead>
<tr>
<th>岩石名称</th>
<th>Sm×10^{-6}</th>
<th>Nd×10^{-6}</th>
<th>εNd(t)</th>
<th>T_CHUR</th>
<th>T_EM</th>
<th>(Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>角闪石岩</td>
<td>20-3</td>
<td>2.7250</td>
<td>12.9500</td>
<td>0.12730</td>
<td>0.511977±9</td>
<td>-10.92</td>
</tr>
<tr>
<td>闪长岩</td>
<td>20-21</td>
<td>6.1890</td>
<td>35.9500</td>
<td>0.10410</td>
<td>0.511668±9</td>
<td>-16.72</td>
</tr>
<tr>
<td>花岗闪长岩</td>
<td>97-52</td>
<td>5.5820</td>
<td>41.4600</td>
<td>0.09600</td>
<td>0.511711±8</td>
<td>-16.29</td>
</tr>
<tr>
<td>花岗岩</td>
<td>20-33</td>
<td>3.3400</td>
<td>24.3300</td>
<td>0.08305</td>
<td>0.511804±8</td>
<td>-14.27</td>
</tr>
<tr>
<td>石英正长岩</td>
<td>98-30</td>
<td>7.0310</td>
<td>50.9800</td>
<td>0.08342</td>
<td>0.511712±15</td>
<td>-16.25</td>
</tr>
</tbody>
</table>

Table 5 The Sm-Nd isotopic determination data and calculation results of the Wanganzhen complex

<table>
<thead>
<tr>
<th>岩石名称</th>
<th>206Pb/204Pb</th>
<th>207Pb/204Pb</th>
<th>208Pb/204Pb</th>
<th>208Pb/206Pb</th>
<th>(Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>角闪石岩</td>
<td>16.437</td>
<td>15.134</td>
<td>36.381</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>闪长岩</td>
<td>17.178</td>
<td>15.297</td>
<td>37.138</td>
<td>0.2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

Table 5 The Pb isotopic determination data of K-feldspar from the Wanganzhen complex

...
Fig. 7  

Diagrams of $\varepsilon_{Nd} (t)$ vs. $\varepsilon_{Nd} (t) - \varepsilon_{Nd} (t-d)$ (a), $\varepsilon_{Nd} (t)$ vs. $\varepsilon_{Nd} (t-d)$ correlation (b) and Pb isotopic composition of K-feldspar (c)
减薄的陆壳底部

王焰等

可能是由于中生代中性岩由角闪石岩造成下地壳密度加大而发生拆沉作用

可能来自于加厚的陆壳底部

状上涌

后者可能是由于晚中生代中性岩上地幔物质低度熔融的产物

的上地幔物质低度熔融的产物

蔡剑辉等；张旗研究员对本文初稿提出了宝贵的意见

早白垩世

张旗研究员对本文初稿提出了宝贵的意见

早白垩世

张旗研究员对本文初稿提出了宝贵的意见

#### References


Geological Society, China University of Geosciences, Beijing; Geological Publishing House (in Chinese)


Chinese

Martin H. 1993. The mechanisms of petrogenesis of the Archaean continental crust—comparison with modern oricesses. Lithos, 30, 373—388


Mu Buolei, Yan Guohan. 1992. Geochemistry of Triassic alkaline or subalkaline igneous complexes in the Yan-huo area and their significane. Acta geologica sinica, 66(2); 108—121


Wang Qiang, Xu Jifeng, Zhao Zhenhua. 2001. The summary and comment on research on a new kind of igneous rock-adakite. Advance in earth sciences, 16(2); 201—208 (in Chinese with English abstract)


Yan G H,Xu B L, Mu B L et al. 2000 Alkaline intrusives at the East foot of the Taihang-Da Hinggan Mountains; chronology, Sr, Nd and Pb isotopic characteristics and their implications. Acta Geologica Sinica, 74(4);774—781
