

南秦岭勉略构造带中堂沟火山岩地球化学特征及其地质意义

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摘要:通过对分布于勉略构造带中段三岔子西侧中堂沟地区的火山岩进行详实的野外地质剖面调查,发现其为一套绿片岩相浅变质火山岩,岩石组合以变安山岩为主,含有少量的变玄武岩和变英安岩,主体为钙碱性系列。岩石地球化学研究表明3类岩石均具有轻稀土富集型稀土配分曲线,并显示弱的Eu负异常;微量元素方面,岩石普遍富集大离子亲石元素Cs、Rb、Ba,亏损高场强元素Nb、Ta,相对亏损P、Ti,不活动微量元素Zr、Hf、Tb、Y等既无明显的相对亏损也无显著的相对富集。在La-La/Nb、Nb-Nb/Th和La/Yb-Sc/Ni等环境判别图解中,变玄武岩和变安山岩样品点均落在岛弧火山岩范围内,并结合其岩石组合特征指示该套火山岩应形成于大陆边缘弧(活动陆缘)环境。其中变玄武岩和变安山岩岩浆起源于楔形地幔的部分熔融,且有陆壳物质的参与;变英安岩的形成则与壳源物质的部分熔融有关。

关键词:勉略构造带;中堂沟岩片;钙碱性岩石;弧火山岩;构造环境;岩浆起源

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秦岭造山带是中央造山系的重要组成部分,空间上呈狭长带状横跨中国大陆中部,是一个具有长期复杂演化历史的典型复合型大陆造山带^[1-18]。在秦岭造山带中,位于陕西省略阳—勉县—镇巴高川一线的勉略构造带是近年发现厘定的,是对秦岭造山带构造演化研究具有十分重要意义的一条古板块缝合带^[3-5,19-20]。前人曾对该带进行了大量的研究工作,涉及地层、岩石、构造、年代学、成矿等方面^[21-30],认为该构造带应为一个复杂的、由不同成因岩块组成的蛇绿构造混杂岩带^[19,32-35],并已从该构造带内解体出岛弧型火山岩^[21,31]和MORB型古洋壳残片^[21,31,36]等不同性质的岩块。三岔子地区位于勉略构造带中段,分布有超镁铁岩、堆晶辉长岩、辉绿岩

墙群、变质火山岩(包括玄武岩、玄武安山岩、安山岩、英安岩等)、放射虫硅质岩,前人普遍认为这些岩石应为勉略蛇绿构造混杂岩的一部分^[21,36-37]。但随着研究的不断深入,地球化学证据表明其中的变火山岩普遍具有岛弧火山岩的性质,因此部分学者称之为三岔子岛弧型蛇绿混杂岩^[21,37],但也有学者认为应将岛弧火山岩块从三岔子蛇绿混杂岩中解体出来,作为一个独立的火山岩块进行研究,而其中的辉长岩和辉绿岩墙等仍可视作勉略蛇绿构造混杂岩的一部分^[3,31,38]。这一岛弧火山岩究竟是代表古岛弧,还是代表大陆边缘的古岩浆弧,其形成时代是什么?这些问题一直受到学者的关注,已有学者指出三岔子火山杂岩可能代表南秦岭微陆块南侧

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活动陆缘的岩浆弧,而不是位于古勉略洋中的岛弧^[39-41]。本文在前人研究的基础上,对南秦岭勉略构造带三岔子西侧中堂沟火山岩岩片进行了详细的野外地质调查,并从岩石组合、岩相学、岩石地球化学等方面对该岩片进行系统研究,着重讨论其岩石成因及物质来源,并探讨其形成的大地构造环境,以期研究勉略构造带的构造属性及演化提供约束。

1 区域地质背景

勉略构造带包括西部勉县—略阳断裂带及其

东延的巴山弧形逆冲推覆隐伏构造带,为一个具复杂组成与构造演化的蛇绿构造混杂岩带^[3,15]。在略阳—勉县地段,地质体出露良好,是该构造混杂岩带的典型代表区段。勉略构造带北侧以武都—状元碑断裂为界与奥陶系大堡岩组相邻,南侧以康县—略阳—勉县断裂为界,与前寒武系碧口群毗邻。构造带内主要由强烈剪切变形的南华—寒武系和泥盆—石炭系逆冲推覆岩片组成,形成自北向南的叠瓦逆冲推覆构造(图1)。根据最新的研究成果,该带由老到新主要出露以下几套构造岩石地层单

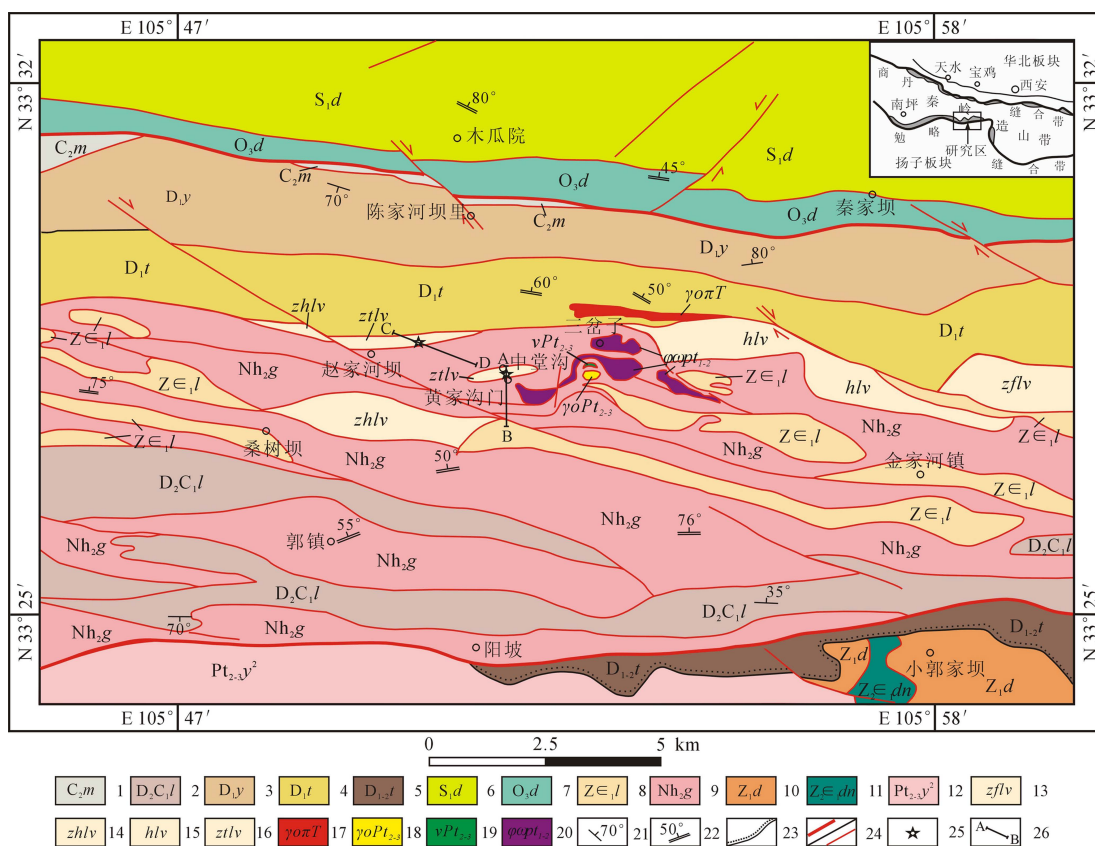


图1 南秦岭勉略构造带中堂沟地区地质构造略图

- 1—上石炭统峨河组;2—中泥盆统—下石炭统略阳组;3—下泥盆统羊汤寨组;4—下泥盆统屯寨组;5—中—下泥盆统踏坡组;
- 6—下志留统迭部岩组;7—上奥陶统大堡岩组;8—下震旦统一寒武统临江组;9—上南华统关家沟组;10—下震旦统陡山陀组;
- 11—上震旦统一寒武统灯影组;12—古元古界—新元古界阳坝岩组;13—纸房沟火山岩块;14—庄科火山岩块;15—黑沟峡火山岩块;
- 16—中堂沟火山岩片;17—李家河斜长花岗斑岩;18—偏桥沟中粒斜长花岗岩;19—偏桥沟蚀变堆晶辉长岩;20—蚀变超基性岩;
- 21—片理产状;22—层理产状;23—不整合界线;24—边界断层/次级断层;25—采样位置;26—实测剖面位置及编号

Fig.1 Schematic geological tectonic map of Zhongtanggou area of Mianlue suture zone, South Qinling

- 1—Upper Carboniferous Minjiang Formation; 2—Middle Devonian—Lower Carboniferous Lueyang Formation; 3—Lower Devonian Yangtangzhai Formation; 4—Lower Devonian Tunzhai Formation; 5—Middle and Lower Devonian Tapo Formation; 6—Lower Silurian Diebu Formation; 7—Upper Ordovician Dabao Formation; 8—Lower Sinian—Lower Cambrian Linjiang Formation; 9—Upper Nanhua Guanjiagou Formation; 10—Lower Nanhua Guanjiagou Formation; 11—Upper Sinian-Lower Cambrian Dengying Formation; 12—Paleoproterozoic-Neoproterozoic Yangba Formation; 13—Zhifanggou volcanic blocks; 14—Zhuangke volcanic blocks; 15—Heigouxia volcanic blocks; 16—Zhongtanggou volcanic blocks; 17—Lijiahe plagioclase granite porphyry; 18—Pianqiaogou medium-grained plagiogranite; 19—Pianqiaogou altered cumulus crystal gabbro; 20—Altered ultrabasic rocks; 21—Schistosity and its attitude; 22—Bedding and its attitude; 23—Unconformity; 24—Boundary fault/Secondary fault; 25—Sampling position; 26—Measured section position and its serial number

元:南华—寒武系主要由含砾泥质岩、泥质碎屑岩、火山碎屑岩、火山—沉积岩系、碳酸盐岩和镁铁质碳酸盐岩组成;泥盆系为深水浊积岩、泥质碳酸盐岩和泥质岩;石炭系为碳酸盐岩^[32-33]。带内以发育石炭—泥盆系深水浊积岩、炭硅质岩等陆缘沉积岩系,缺失奥陶—志留系岩层为其主要特征^[34]。除此之外,蛇绿岩块和变质火山岩系也以构造岩片形式卷入该构造带中(图1)。

研究区火山岩岩片分布于略阳县三岔子西侧中堂沟—黄家沟门一带,为一套绿片岩相浅变质火山岩,其岩石类型以变安山岩为主,含有少量的变玄武岩和变英安岩。本文对该地区的火山岩进行了详细的野外地质调查工作,查明其空间展布形态及位置,并在野外地质剖面上连续采集一系列样品,对其进行分析测试,探讨其地球化学特征及其地质意义。

2 火山岩岩片分布与地层概况

2.1 中堂沟地区火山岩岩片 AB 段实测剖面

中堂沟地区火山岩岩片 AB 段实测剖面如图 2 所示,剖面起点 A 坐标: N33° 21' 5.00"、E105° 51' 5.95", 终点 B 坐标: N33° 20' 6.55"、E105° 50' 9.33"。

剖面自南向北列述如下:

临江组(ZC ₁ l)	未见底
⑥灰黑色炭质千枚岩夹少量灰岩	170 m
-----断层接触-----	
关家沟组(Nh ₂ g)	1870 m
⑤深灰色—灰黑色绢云千枚岩	1000 m
-----侵入接触-----	
④深灰色细粒辉长辉绿岩脉	70 m
-----侵入接触-----	
③深灰绿—灰色绿泥绢云石英千枚岩	680 m
-----断层接触-----	
②深灰色绢云千枚岩	120 m
-----断层接触-----	
中堂沟火山岩片(ztlv)	200 m
①浅灰绿色—深灰色绿泥绿帘钠长石英片岩(变安山岩)夹灰绿色绿帘绿泥钠长片岩(变玄武岩)	200 m

2.2 中堂沟地区火山岩岩片 CD 段实测剖面

中堂沟地区火山岩岩片 CD 段实测剖面如图 3 所示,剖面起点 C 坐标: N33° 21' 7.53"、E105° 50' 9.43", 终点 D 坐标: N33° 21' 9.06"、E105° 50' 6.00"。剖面自北向南列述如下:

屯寨组(D ₁ t)	未见顶
⑤绢英千枚岩	未见顶
-----断层接触-----	

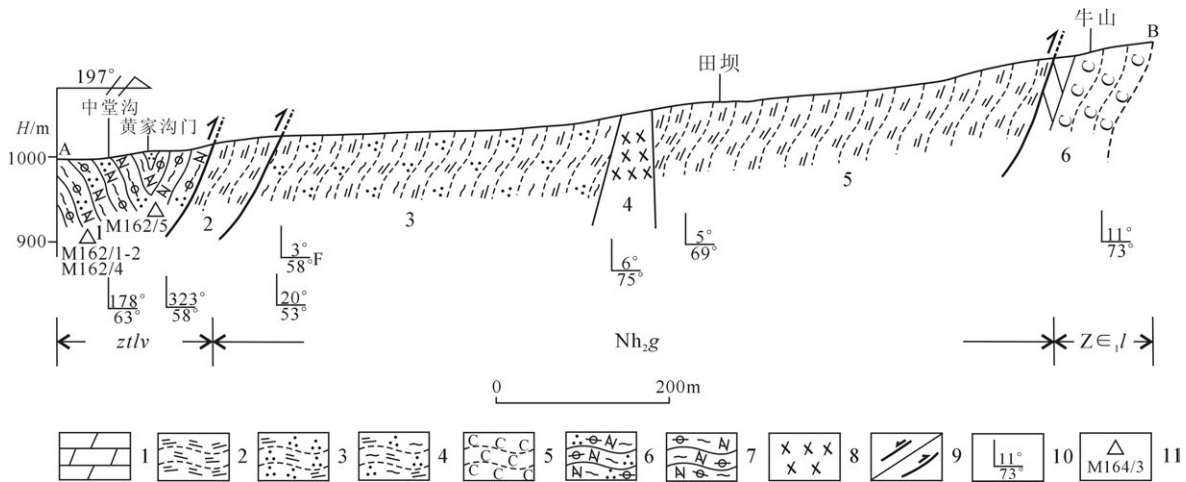


图2 南秦岭勉略构造带中堂沟地区火山岩岩片 AB 段剖面示意图

1—中厚层状灰岩;2—绢云千枚岩;3—绢英千枚岩;4—绿泥绢云石英千枚岩;5—炭质千枚岩;6—绿泥绿帘钠长石英片岩;7—绿帘绿泥钠长片岩;8—辉长辉绿岩;9—断层;10—产状;11—采样位置;ztlv—中堂沟火山岩片;Nh₂g—关家沟组;ZC₁l—临江组;F—断层产状

Fig.2 Geological section along AB segment of the volcanic rock slice from Zhongtangou area of Mianlue suture zone, South Qinling

1—Medium-thick-bedded dolomite; 2—Sericite phyllite; 3—Sericite quartz phyllite; 4—Chlorite sericite quartz phyllite; 5—Carbonaceous phyllite; 6—Chlorite epidote albite quartz schist; 7—Chlorite epidote albite schist; 8—Gabbro diabase; 9—Fault; 10—Attitude; 11—Sampling position; ztlv—Zhongtangou volcanic blocks; Nh₂g—Guanjiagou Formation; ZC₁l—Linjiang Formation; F—Fault attitude

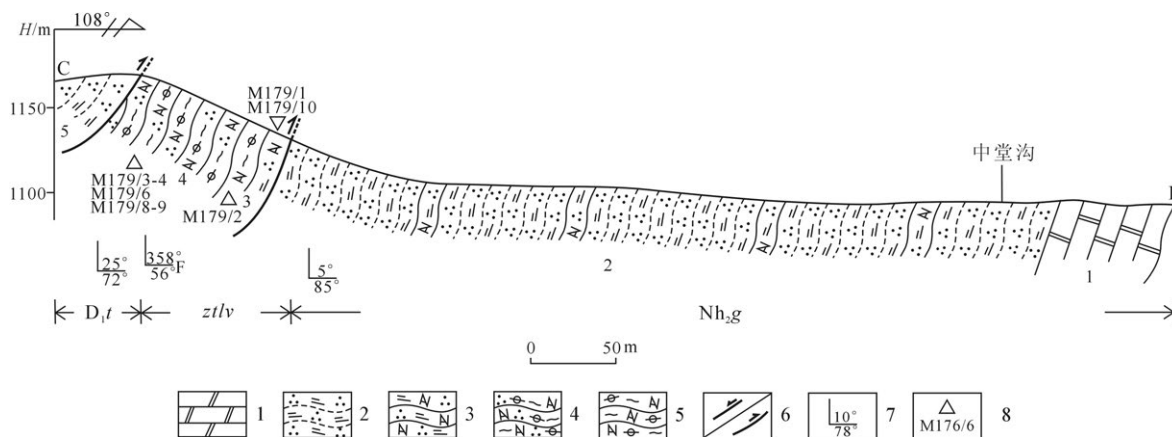


图3 南秦岭勉略构造带中堂沟地区火山岩岩片CD段剖面示意图

1—厚层块状白云岩;2—绢英千枚岩;3—绿泥绢云石英片岩;4—绿泥绿帘钠长石英片岩;5—绿帘绿泥钠长片岩;
6—断层;7—产状;8—采样位置;D₁t—屯寨组;ztlv—中堂沟火山岩片;Nh₂g—关家沟组;F—断层产状

Fig.3 Geological section along CD segment of the volcanic rock slice from Zhongtanggou area of Mianlue suture zone, South Qinling

1-Thick-bedded dolomite; 2-Sericite quartz phyllite; 3-Chlorite sericite quartz schist; 4-Chlorite epidote albite quartz schist; 5-Epidote chlorite albite schist; 6-Fault; 7-Attitude; 8-Sampling position; D₁t-Tunzhai Formation; ztlv-Zhongtanggou volcanic blocks; Nh₂g-Guanjiagou Formation; F-fault attitude

中堂沟火山岩片 (ztlv)	195 m
④灰绿色糜棱岩化绿泥绿帘钠长石英片岩(变安山岩)	160 m
③浅灰白色绢云钠长石英片岩(变英安岩)夹灰绿色绿帘绿泥钠长片岩(变玄武岩)	35 m
-----断层接触-----	
关家沟组(Nh ₂ g)	550 m
②深灰色—灰黑色绢英千枚岩夹绢云钠长石英片岩	500 m
①白色厚层块状白云岩	50 m

3 火山岩岩石学特征

研究区火山岩分布于勉略构造带三岔子西侧中堂沟—黄家沟门一带,近EW向延伸展布,长约3 km,宽50~500 m,与周围地层主要呈断层接触,为一套绿片岩相浅变质火山岩。该套火山岩岩石组合类型以变安山岩为主,含有少量的变玄武岩和变英安岩,主体为钙碱性系列,这与典型的活动大陆边缘弧岩石组合相似。

变安山岩(M162/1、M162/2、M162/4、M179/3、M179/4、M179/6、M179/8、M179/9),野外以绿泥绿帘钠长石英片岩形式出现,其样品M179/8的手标本和镜下特征如图4-a、d、g所示;岩石主体呈深灰

色—浅灰色,片状构造,变余斑状结构,主要组成矿物有钠长石(38%~42%)、石英(18%~25%)、绿泥石(17%~21%)、绿帘石(10%~15%)、变余斜长石斑晶(2%~5%)以及少量的方解石(1%~3%);其中钠长石多呈板片状或他形粒状集合体,浅灰色,斜消光,发育钠长石律双晶;石英多呈半自形—他形晶,无色,为次生交代的产物;绿泥石呈多呈鳞片粒状集合体,薄片呈浅绿色,发育一组解理;绿帘石多呈粒状集合体,灰绿色,具有高到极高正突起,糙面显著,干涉色鲜艳;绿泥石和绿帘石多呈集合体形式出现;基质暗色矿物大多发生绿泥石化和绿帘石化,具有明显的定向性,总体表现出糜棱岩化的特征;变余斜长石斑晶发生钠黝帘石化和钠长石化;方解石呈条带状交代,包裹早期的石英颗粒(图4-d)。

变玄武岩(M162/5、M179/2),野外以绿帘绿泥钠长片岩形式出现,其样品M179/2的手标本和镜下特征如图4-b、e、h所示;岩石主体呈灰绿色,片状构造,具鳞片粒状变晶结构,主要组成矿物有钠长石(45%~50%)、绿泥石(20%~25%)、绿帘石(15%~20%)以及少量的方解石(2%~5%);其中钠长石具板片状结构,干涉色I级灰—灰白,发生绿泥石化、绿帘石化和高岭土化;绿泥石呈浅绿色,多为鳞片

粒状集合体;绿帘石呈灰绿色,多为粒状集合体,具有高到极高正突起,干涉色鲜艳;绿帘石多发生绿泥石化,并与绿泥石多呈集合体形式出现;方解石多呈粒状,无色,解理极完全,高级白干涉色,呈条带状交代。

变英安岩(样品 M179/1、M179/10),野外以绢云钠长石英片岩形式出现,其样品 M179/1 的手标本和镜下特征如图 4-c、f、i 所示;岩石主体呈灰白色,

片状构造,具鳞片粒状变晶结构,主要组成矿物有石英(50%~55%)、钠长石(20%~25%)、白云母(10%~15%)、绢云母(2%~5%)、斜长石(2%~3%)以及少量的方解石(1%~2%);其中石英多呈无色,I级黄白干涉色,波状消光,发生动态重结晶,晶体边界呈锯齿状,十分清楚,部分石英颗粒表面见有小包裹体;钠长石多呈浅灰色,板片状晶形,干涉色I级灰—灰白;白云母多呈鳞片状集合体,无色,一组极完全解

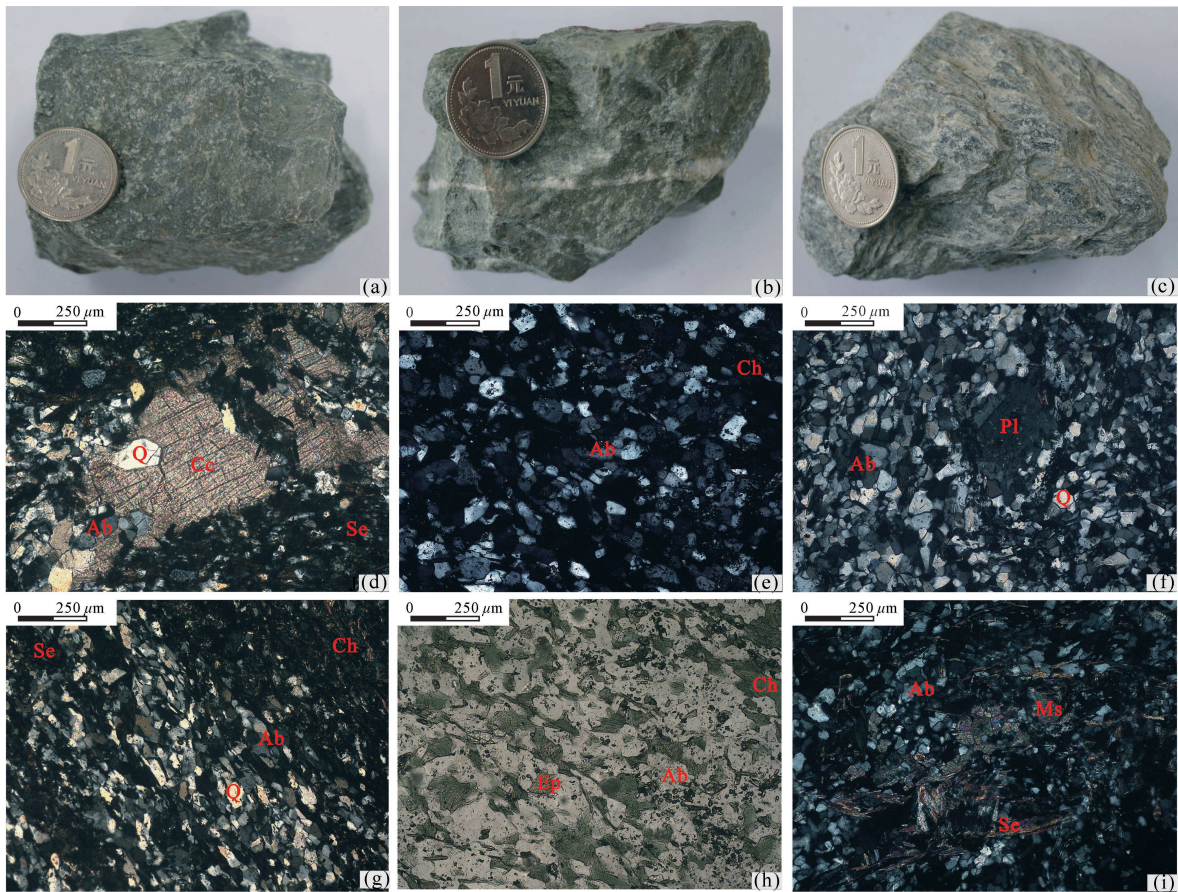


图4 南秦岭勉略构造带中堂沟火山岩野外和镜下照片

a—变安山岩手标本照片;b—变玄武岩手标本照片;c—变英安岩手标本照片;d—变安山岩中方解石呈条带状交代,包裹早期的石英颗粒;e—变玄武岩中钠长石发生绿泥绿帘石化;f—变英安岩的斜长石斑晶;g—变安山岩糜棱岩化特征;h—变玄武岩中绿帘石的绿泥石化;i—变英安岩中白云母的鳞片状集合体以及绢云母变种

(d、e、f、g、i—正交偏光;h—单偏光)

Ab—钠长石;Ch—绿泥石;Cc—方解石;Ep—绿帘石;Ms—白云母;Pl—斜长石;Q—石英;Se—绢云母

Fig.4 Field photographs and microphotographs of the volcanic rocks from Zhongtanggou area of Mianlue suture zone, South Qinling

a—Hand specimen of metamorphism andesite; b—Hand specimen of metamorphism basalt; c—Hand specimen of metamorphism dacite; d—Calcite assuming stripe shape and containing early quartz grains in the metamorphism andesite; e—Chloritized and epidotized albite in the metamorphism basalt; f—Plagioclase phenocrysts in the metamorphism dacite; g—Mylonitized andesite; h—Chloritized epidote in the metamorphism basalt; i—Muscovite existent as scaly aggregates and subjected to sericitization in the metamorphism dacite

(d, e, f, g, i—crossed nicols, h—plainlight)

Ab—Albite; Ch—Chlorite; Cc—Calcite; Ep—Epidote; Ms—Muscovite; Pl—Plagioclase; Q—Quartz; Se—Sericite

理,干涉色十分鲜艳,颗粒细小者呈绢云母变种;斜长石为板片状,无色,多发生钠黝帘石化、绢云母化、方解石化。

4 火山岩地球化学特征

4.1 测试方法

样品经表面杂质清除后,切割去除风化面,在玛瑙研钵中无污染破碎研磨到200目供化学分析。主量元素由长安大学西部矿产资源与地质工程教育部重点实验室用日本岛津XRF-1800型波长色散X射线荧光光谱仪测定,X射线荧光光谱分析熔片法按国家标准GB/T 14506.28-1993,分析精度和准确度优于2%。微量元素在长安大学西部矿产资源与地质工程教育部重点实验室采用Thermo-X7电感耦合等离子体质谱仪进行样品测定,分析精度和准确度优于10%,仪器工作参数:Power, 1200W; Nebulizer gas, 0.64 L/min; Auxiliary gas, 0.80 L/min; Plasma gas, 13 L/min。

4.2 主量元素地球化学

中堂沟火山岩化学成分及微量元素、稀土元素分析结果见表1。由于研究区火山岩大多受到变质和蚀变作用的影响,本文采用火山岩岩石-构造组合类型、稀土元素及微量元素地球化学多种手段进行研究,主要利用活动性较弱的高场强元素探讨其成因。从Zr/TiO₂-SiO₂图解(图5-a)可以看出,中堂

沟火山岩主要岩石类型为:玄武岩、安山岩、英安岩,这与镜下鉴定结果基本一致;结合AR-SiO₂图解(图5-b),表明其主体为钙碱性系列岩石。在Harker图解中,中堂沟火山岩随着SiO₂含量的增加,TiO₂、MgO、CaO、Al₂O₃、Fe₂O₃^T、Na₂O、K₂O、P₂O₅等并没有良好的线性关系(图6),暗示研究区火山岩并非同源岩浆演化的产物。

变安山岩SiO₂含量介于53.32%~58.27%,平均为56.66%;TiO₂含量介于0.96%~1.25%,平均为1.13%;K₂O含量介于0.01%~2.31%,平均为0.87%;CaO含量介于1.33%~5.73%,平均为3.98%;Na₂O含量介于3.41%~6.45%,平均为4.59%;Al₂O₃含量介于15.47%~17.31%,平均为16.30%;MgO含量介于1.88%~4.39%,平均为3.31%,总体特征与世界陆缘弧安山岩^[44]相近。

变玄武岩2个样品SiO₂含量分别为50.27%和51.92%;TiO₂含量分别为0.86%与1.22%;K₂O含量分别为0.68%和1.07%;CaO含量分别为4.09%与6.09%;Na₂O含量分别为3.16%和5.73%;Al₂O₃含量分别为13.26%与19.27%;MgO含量分别为4.54%和7.30%。变英安岩2个样品SiO₂含量分别为67.12%和67.75%;TiO₂含量分别为0.69%与0.68%;K₂O含量分别为0.22%和2.52%;CaO含量分别为2.02%与1.72%;Na₂O含量分别为2.69%和5.15%;Al₂O₃含量分别为15.00%与13.75%;MgO含量分别为1.92%和3.01%。

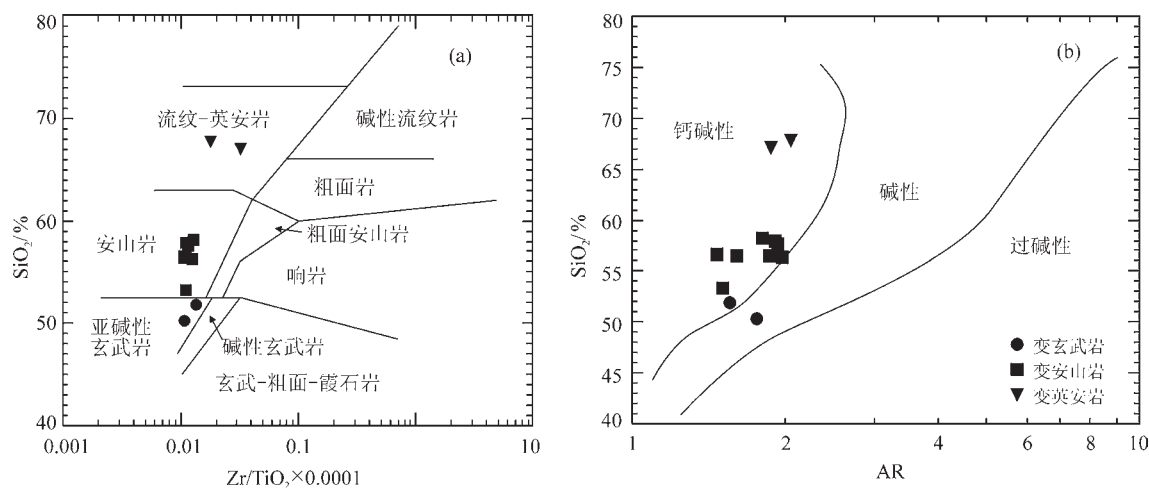


图5 火山岩Zr/TiO₂-SiO₂(a)和AR-SiO₂(b)图解
(a据文献[42];b据文献[43])

Fig.5 Zr/TiO₂-SiO₂(a) and AR-SiO₂(b) diagrams of the volcanic rocks
(a, after reference [42]; b, after reference [43])

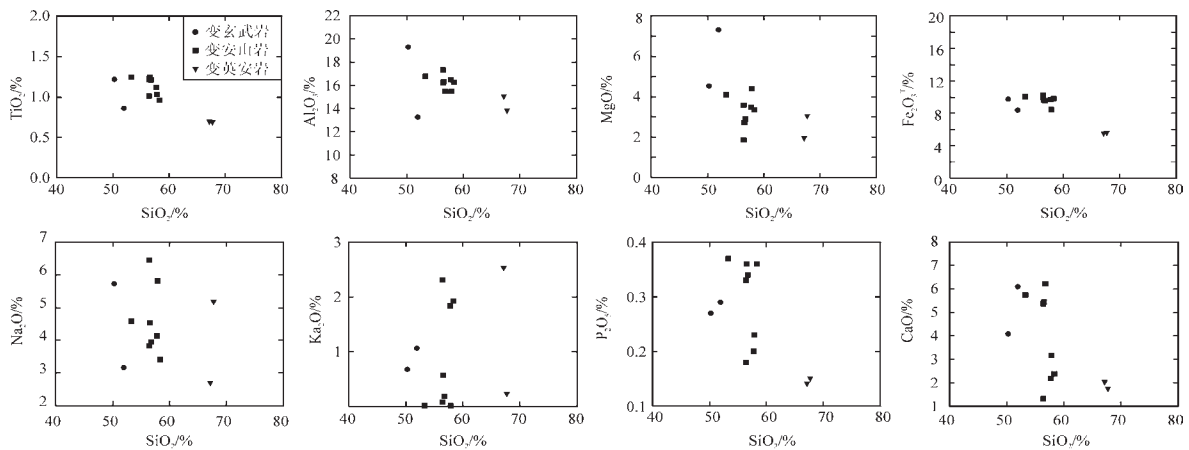


图6 火山岩主要元素Harker图解
Fig.6 Harker diagrams showing major elements of the volcanic rocks

4.3 稀土元素地球化学

从表1可见,变安山岩稀土元素总量较低,介于 62.01×10^{-6} ~ 121.23×10^{-6} ,平均为 99.25×10^{-6} ;轻重稀土分异明显, $\Sigma\text{LREE}/\Sigma\text{HREE}$ 为3.72~6.19, $(\text{La}/\text{Yb})_N$ 为2.71~6.52, $(\text{Ce}/\text{Yb})_N$ 为2.60~4.82; δEu 为0.82~0.91,平均值为0.87,具弱Eu负异常特征。在球粒陨石标准化稀土元素配分模式图上(图7),变安山岩具右倾负斜率、轻稀土富集的特征,主体与世界陆缘弧安山岩^[44]相同。

变玄武岩2个样品稀土总量较低,分别为 90.97×10^{-6} 和 112.59×10^{-6} ;轻重稀土分异明显, $\Sigma\text{LREE}/\Sigma\text{HREE}$ 分别为5.81与7.13, $(\text{La}/\text{Yb})_N$ 为5.77和7.21, $(\text{Ce}/\text{Yb})_N$ 为4.61~6.10; δEu 平均为0.85,具有弱负异常。变英安岩2个样品稀土总量同样较低,分别为 141.06×10^{-6} 和 142.16×10^{-6} ;轻重稀土分异明显, $\Sigma\text{LREE}/\Sigma\text{HREE}$ 分别为6.52与7.61, $(\text{La}/\text{Yb})_N$ 为7.30和7.85, $(\text{Ce}/\text{Yb})_N$ 为4.63~6.15; δEu 变化很小,平均为0.72,具有弱的负Eu异常。在球粒陨石标准化稀土配分图上(图7),研究区变玄武岩和变英安岩基本上具有一致的右倾负斜率稀土配分模式, LREE相对富集,具弱Eu负异常。

4.4 微量元素地球化学

研究区样品微量元素测试数据见表1,变安山岩 Th/Ta 为4.91~13.13,平均为7.38; Nb/La 为0.28~0.61,平均为0.50; Th/Yb 为1.01~1.86,平均为1.55; Ta/Yb 为0.10~0.34,平均为0.25。火山岩微量元素 N-MORB 标准化蛛网图(图8-a)表明研究区变安

山岩呈显著的“三隆起”形态,以 Rb、Ba、Th 的较强富集, Ce 和 Sm 的微弱富集为特点。表明该研究区变安山岩微量元素基本特征与世界陆缘弧安山岩^[44]相一致。

变玄武岩 Th/Ta 分别为4.64和15.32; Nb/La 分别为0.26与0.62; Th/Yb 分别为1.51和2.89; Ta/Yb 分别为0.19与0.33。变英安岩 Th/Ta 分别为7.33和12.67; Nb/La 分别为0.61与0.28; Th/Yb 分别为3.46和2.44; Ta/Yb 分别为0.47与0.19。在火山岩微量元素 N-MORB 标准化蛛网图上(图8-b),变玄武岩和

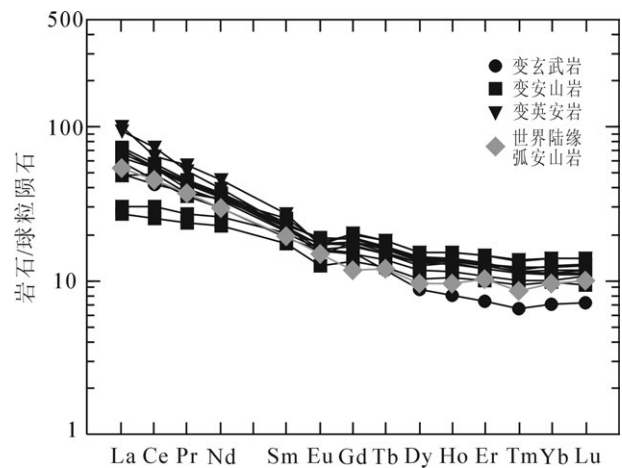


图7 稀土元素球粒陨石标准化配分型式
(世界陆缘弧安山岩据文献[44];球粒陨石标准化值据文献[45])
Fig.7 Chondrite-normalized REE patterns
(world continental margin arc andesite after reference [44];
chondrite normalized data after reference [45])

表 1 勉略缝合带中堂沟火山岩主量元素(%)和微量元素(10^{-6})分析结果
 Table 1 Major element(%) and trace element(10^{-6}) analyses of the volcanic rocks from
 Zhongtanggou area of Mianlue suture zone

分析项目	M162/5 变玄武岩	M179/2 变玄武岩	M162/1 变安山岩	M162/2 变安山岩	M162/4 变安山岩	M179/3 变安山岩	M179/4 变安山岩	M179/6 变安山岩	M179/8 变安山岩	M179/9 变安山岩	M179/1 变英安岩	M179/10 变英安岩	世界陆缘弧 安山岩 ^[4]
SiO ₂	51.92	50.27	56.40	58.27	57.71	57.91	56.70	56.47	53.32	56.52	67.12	67.75	59.90
TiO ₂	0.86	1.22	1.01	0.96	1.12	1.03	1.21	1.22	1.25	1.25	0.69	0.68	0.69
Al ₂ O ₃	13.26	19.27	17.31	16.30	16.48	15.47	15.48	16.21	16.80	16.35	15.00	13.75	17.10
Fe ₂ O ₃ ^T	8.40	9.74	10.26	9.85	9.68	8.43	9.55	9.97	10.02	9.59	5.48	5.55	—
MnO	0.14	0.17	0.17	0.43	0.41	0.22	0.14	0.11	0.23	0.15	0.09	0.11	0.14
MgO	7.30	4.54	3.59	3.37	3.47	4.39	2.91	1.88	4.11	2.73	1.92	3.01	3.30
CaO	6.09	4.09	1.33	2.38	2.18	3.16	6.23	5.36	5.73	5.43	2.02	1.72	7.20
Na ₂ O	3.16	5.73	3.83	3.41	4.14	5.81	3.96	6.45	4.58	4.52	2.69	5.15	3.90
K ₂ O	1.07	0.68	2.31	1.92	1.84	0.01	0.18	0.08	0.01	0.57	2.52	0.22	1.30
P ₂ O ₅	0.29	0.27	0.18	0.36	0.2	0.23	0.34	0.33	0.37	0.36	0.14	0.15	0.20
LOI	7.9	3.07	3.26	2.82	3.33	3.44	2.53	2.17	3.49	3.08	2.4	2.42	—
TOTAL	100.39	99.05	99.65	100.07	100.56	100.10	99.23	100.25	99.92	100.55	100.07	100.51	—
A/CNK	0.76	1.09	1.54	1.36	1.29	1.01	0.86	0.79	0.94	0.91	1.39	1.16	—
Sc	17.03	13.66	12.42	16.74	11.50	12.65	11.71	8.51	14.13	9.99	6.53	8.69	20.20
Cr	356.4	14.02	34.70	38.95	33.39	11.23	7.06	7.15	3.15	3.50	52.49	53.27	37.00
Ni	174.0	61.09	30.35	30.67	29.41	40.75	14.79	13.82	13.25	15.02	33.91	42.27	—
Cu	114.2	12.47	89.42	111.1	121.0	13.08	10.49	19.32	8.87	10.31	21.69	8.61	—
Zn	70.66	122.3	73.81	95.59	84.91	76.51	73.58	68.35	109.2	74.42	74.50	40.57	—
Ga	16.38	17.73	18.16	19.67	16.88	14.66	16.56	17.34	18.28	17.59	15.30	10.11	—
Rb	40.97	21.84	31.53	23.66	13.64	0.65	5.38	2.34	0.44	17.74	65.75	6.87	44.00
Sr	557.7	523.7	101.7	316.2	191.0	239.8	717.3	892.8	902.1	893.9	242.9	125.5	400.00
Y	12.08	20.74	14.37	24.67	18.45	17.76	20.77	20.06	21.97	21.74	21.50	24.34	22.00
Zr	114.4	129.9	126.2	122.8	128.2	112.8	129.4	129.6	136.8	135.7	219.9	121.0	117.00
Nb	3.96	12.83	3.60	4.15	3.70	11.02	12.04	12.10	12.78	12.71	17.90	8.77	9.40
Cs	8.54	1.17	2.42	2.03	1.68	0.01	0.35	0.16	0.02	1.30	3.17	0.32	—

续表 1

分析项目	M162/5		M179/2		M162/1		M162/2		M162/4		M179/3		M179/4		M179/6		M179/8		M179/9		M179/10		世界陆缘弧
	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩	变玄武岩
Ba	334.1	596.9	799.1	585.8	628.2	5.28	124.4	42.40	9.47	297.4	1009	146.2	395.00										
La	15.38	20.78	8.44	14.90	9.43	18.24	19.74	22.10	23.06	22.00	29.34	31.31	17.00										
Ce	33.90	43.31	20.22	39.63	24.54	36.33	43.17	42.62	46.93	44.98	59.92	51.75	37.00										
Pr	4.57	5.26	2.90	4.48	3.30	4.32	4.85	5.15	5.56	5.38	6.25	6.95	4.64										
Nd	20.40	21.17	13.48	20.22	15.33	17.76	19.94	20.60	22.39	21.90	23.74	26.79	18.30										
Sm	4.36	4.29	3.35	4.89	3.99	3.69	4.07	4.09	4.61	4.45	4.37	5.22	3.87										
Eu	1.17	1.25	0.91	1.30	1.17	1.14	1.27	1.27	1.34	1.38	1.06	1.24	1.11										
Gd	3.90	4.63	3.42	5.12	4.27	3.88	4.55	4.37	4.91	4.76	4.57	5.20	3.10										
Tb	0.55	0.76	0.57	0.85	0.71	0.64	0.75	0.71	0.78	0.76	0.72	0.86	0.57										
Dy	2.78	4.37	3.30	4.87	4.16	3.72	4.23	4.01	4.55	4.46	4.21	4.92	3.15										
Ho	0.57	0.97	0.74	1.09	0.92	0.81	0.96	0.93	1.00	1.00	0.96	1.10	0.70										
Er	1.52	2.63	2.07	3.07	2.47	2.21	2.59	2.48	2.73	2.66	2.61	3.05	2.20										
Tm	0.21	0.37	0.30	0.43	0.36	0.32	0.37	0.36	0.38	0.39	0.39	0.44	0.28										
Yb	1.44	2.43	2.01	2.87	2.34	2.08	2.34	2.29	2.58	2.51	2.52	2.89	2.04										
Lu	0.23	0.37	0.30	0.45	0.36	0.34	0.37	0.35	0.41	0.41	0.40	0.45	0.33										
Hf	3.36	3.53	3.99	3.67	3.87	3.17	3.56	3.58	3.77	3.77	6.29	3.30	3.44										
Ta	0.27	0.79	0.25	0.29	0.27	0.67	0.76	0.78	0.82	0.81	1.19	0.56	—										
Pb	54.49	5.61	3.64	2.96	3.35	3.56	8.22	11.83	10.42	13.40	4.18	2.37	—										
Th	4.16	3.68	2.42	3.82	2.36	3.31	4.34	4.24	4.74	4.33	8.71	7.06	—										
U	1.31	0.89	0.78	0.87	0.74	0.83	1.10	1.00	1.16	1.19	2.44	1.40	—										
ΣREE	90.97	112.59	62.01	104.17	73.54	95.50	109.19	111.31	121.23	117.03	141.06	142.16	94.40										
Σ(La/Yb) _N	7.13	5.81	3.88	4.56	3.72	5.82	5.76	6.19	5.99	5.91	7.61	6.52	—										
(La/Yb) _N	7.21	5.77	2.83	3.50	2.71	5.91	5.70	6.52	6.02	5.92	7.85	7.30	8.90										
δEu	0.85	0.85	0.82	0.79	0.86	0.91	0.90	0.91	0.86	0.91	0.72	0.72	0.87										

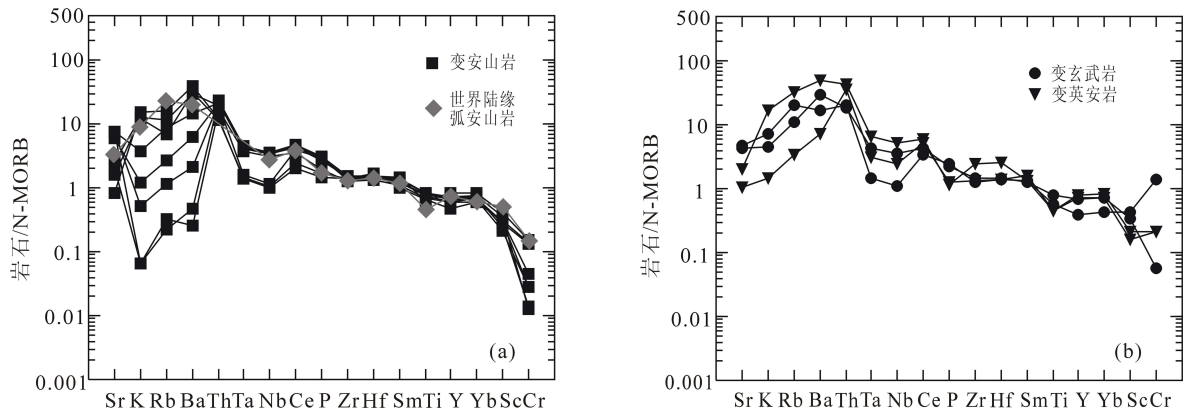


图8 火山岩微量元素N-MORB标准化蛛网图
(世界陆缘弧安山岩据文献[44]; N-MORB标准化值引自参考文献[47])

Fig.8 N-type MORB normalized trace element spidergrams
(World continental margin arc andesite after reference [44]; N-type MORB normalized data after reference [47])

变英安岩总体也具有弧火山岩的分布型式,以Rb、Ba、Th的较强富集,Ce和Sm的微弱富集为特点。综上,研究区变玄武岩和变英安岩与变安山岩微量元素特征十分相似,总体显示出弧火山岩典型的地球化学特征^[46]。

5 岩石成因及其构造环境

岩浆作用是构造活动的物质表现形式,在不同构造环境中形成的岩浆具有不同的岩石组合和地球化学特征。

中堂沟地区钙碱性火山岩组合为变玄武岩、变安山岩和变英安岩,其中以变安山岩为主体,变玄武岩和变英安岩次之,这是最常见的岛弧火山岩组合类型。其地球化学表明该区火山岩具有大离子

亲石元素(LILE)和轻稀土元素(LREE)明显富集,而高场强元素(HFSE)和重稀土元素(HREE)相对亏损的特征,具有轻稀土富集型稀土配分曲线,并显示弱的Eu负异常,以上均表明该套火山岩与火山弧型岩浆岩具有较大的相似性^[46,48]。

从AR-SiO₂图解(图5-b)中可以看出中堂沟火山岩样品主体属于钙碱性系列;La-La/Nb图解(图9-b)和Nb-Nb/Th图解(图9-c),表明该区变玄武岩为岛弧玄武岩;在Bailey^[44]针对安山岩制定的Sc/Ni-La/Yb判别图上(图9-a),变安山岩样品落入了大陆岛弧与它类洋弧环境重叠的区域,且偏向大陆岛弧一侧。研究区变玄武岩Th(3.92×10^{-6})>Ta(0.53×10^{-6}),Th/Ta比值为7.37,具有典型岛弧玄武岩地球化学特征(Th/Ta大于1.6)^[24-25,49];Hf平均含量

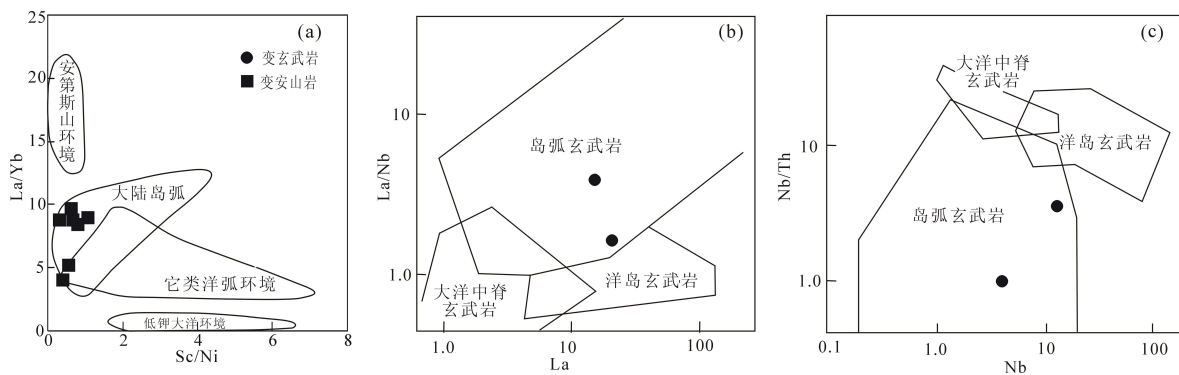


图9 火山岩Sc/Ni-La/Yb(a)、La-La/Nb(b)和Nb-Nb/Th(c)图解
(a据文献[44]; b,c据文献[50])

Fig.9 Sc/Ni-La/Yb(a), La-La/Nb(b) and Nb-Nb/Th(c) diagrams of the volcanic rocks
(a, after reference [44]; b, c, after reference [50])

为 3.45×10^{-6} , $\text{Th} \times \text{Ta} / \text{Hf}^2$ 比值为 0.175 (大于 0.035), 表现为比洋内岛弧更具有相对偏高的不相容性元素含量^[49], 结合其岩石组合特征可知中堂沟火山岩应形成于大陆边缘弧(活动陆缘)环境。

研究区变玄武岩和变安山岩样品大离子亲石元素 Ba (342.3×10^{-6})、Cs (1.77×10^{-6})、Rb (15.82×10^{-6})、K (359.805×10^{-6}), 总体比 N-MORB ($\text{Ba} \approx 6.3 \times 10^{-6}$ 、 $\text{Cs} \approx 0.007 \times 10^{-6}$ 、 $\text{Rb} \approx 0.56 \times 10^{-6}$ 、 $\text{K} \approx 600 \times 10^{-6}$)^[51] 含有较高的 LILE, 表明其岩浆源区可能受到一定程度地壳混染的影响。岛弧岩浆主要由洋壳及其沉积物在俯冲过程中形成的流体或熔体交代过的上覆地幔楔发生部分熔融而形成^[52-53]。研究区变玄武岩和变安山岩样品微量元素 Yb 和 Ta 均满足与俯冲带相关的岛弧岩浆岩区特征: $\text{Yb} < 5 \times 10^{-6}$, $\text{Ta} < 1 \times 10^{-6}$, Ta / Yb 比值小于 0.5^[54], 因此该区火山岩可能代表了受俯冲带上升流体(富 Ba、Cs、Sr、K、Rb、Th)影响的岛弧火山岩。微量元素 Th/La 比值能够说明俯冲过程中沉积物贡献的多少^[55], 该区变玄武岩和变安山岩样品 Th/La 值为 0.215, 与大陆壳的 Th/La 比值 0.204 相近^[56], 暗示其与俯冲板片所携带的沉积物有一定的关系。

微量元素 Y 和 Zr 在变质及蚀变作用过程中十分稳定, 元素 Ti 的丰度可以有效地指示火山岩源区物质组成及构造环境^[47]。中堂沟火山岩 Ti/Zr 含量介于 18.81~56.45, 平均为 48.21; Ti/Y 含量介于 167.50~426.97, 平均为 325.49, 从 Ti/Zr-Ti/Y 图解(图 10)可以看出, 变安山岩和变玄武岩火山岩样品数据点均落在壳源与 MORB 型源区之间, 说明它们既不是典型的壳源成因, 也不是典型的 MORB 型幔源成因, 而是兼具这两种源区的特征, 表明与俯冲洋壳携带的洋壳沉积物(泥页岩)及俯冲带楔形地幔源区的局部熔有直接的成因联系, 这正是弧火山岩特有的地球化学指纹^[57]。然而研究区变英安岩以富集高场强元素 Zr (170.47×10^{-6})、Hf (4.79×10^{-6})、产热元素 U (1.92×10^{-6})、Th (7.89×10^{-6}) 及不相容元素 Cs (1.75×10^{-6})、Rb (36.31×10^{-6})、Ba (577.60×10^{-6})、Sr (180.42×10^{-6}), 相对富 Pb、亏损 Nb、Ti 为特征, 且 Zr/Nb 为 12.783, Th/Nb 为 0.591, 这与大陆地壳微量元素特征相近 ($\text{Cs} \approx 2.00 \times 10^{-6}$ 、 $\text{Rb} \approx 49.00 \times 10^{-6}$ 、 $\text{Ba} \approx 456.00 \times 10^{-6}$ 、 $\text{Sr} \approx 320.00 \times 10^{-6}$ 、 $\text{U} \approx 1.30 \times 10^{-6}$ 、 $\text{Th} \approx 5.60 \times 10^{-6}$ 、 Zr / Nb 为 16.5, Th / Nb 为 0.70)^[58], 且在 Ti/Zr-

Ti/Y 图解中(图 10)样品点位于花岗岩型源区附近, 表明其岩浆起源与壳源物质的部分熔融有关。研究区变英安岩与其他火山岩组的岩石成因和物质来源明显不同, 且火山岩稀土配分型式表明变英安岩并非是变玄武岩和变安山岩结晶分异的产物, 因为若为同源岩浆系列, 变英安岩的稀土总量应明显高于变玄武岩和变安山岩, 且 Eu 负异常也比较显著^[46, 59]。

综上, 依据研究区火山岩岩石组合、微量元素特征及构造环境判别图解, 笔者认为中堂沟火山岩应形成于大陆边缘弧(活动陆缘)环境。其中变玄武岩和变安山岩岩浆起源于楔形地幔的部分熔融, 且有陆壳物质的参与; 变英安岩的形成则与壳源物质的部分熔融有关。

6 大地构造意义

南秦岭勉略古洋盆长期处于特提斯构造域中, 具有多块体中、小洋陆相互作用的东古特提斯构造的基本特征, 近东西向延展约 160 km, 向东经巴山弧、湖北随县花山直至大别南缘宿松、清水河地区, 向西经康县—文县—南坪至阿尼玛卿德尔尼, 直至东昆仑南缘。依据其岩石组合及玄武岩类型的不同, 可以将勉略构造带自西向东可以分为以下 3 个部分:

勉略缝合带西段阿尼玛卿德尔尼蛇绿岩为典型的 N-MORB 环境下生成的岩石圈残片, 表明阿

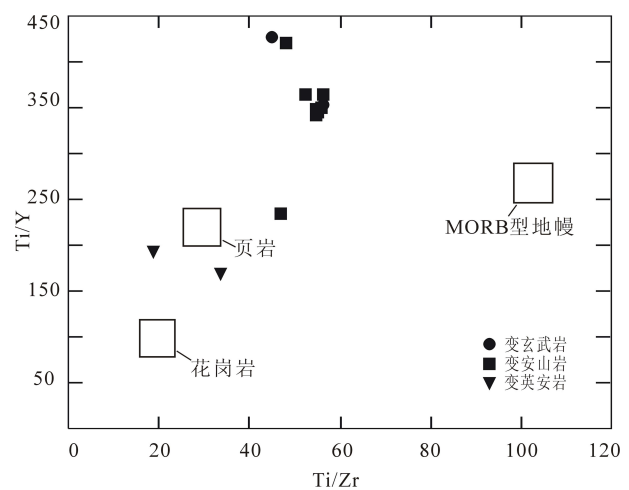


图 10 火山岩 Ti/Zr-Ti/Y 图解(据文献[57])

Fig.10 Ti/Zr-Ti/Y diagram of the volcanic rocks (after reference [57])

尼玛卿曾经存在过一个具有一定规模的成熟有限洋盆^[60-63];而康县—琵琶寺—南坪段,缝合带较为宽缓,较多地保留了洋岛火山岩及洋壳蛇绿岩(如琵琶寺蛇绿岩片)的岩石组合^[61,64-67]。

勉略缝合带中段(勉县—略阳段)火山岩分为3种类型:第一类为典型的MORB型玄武岩,分布于文家沟—庄科一带,代表本区消失了的古洋壳岩石,是洋盆扩张作用的产物,为真正的洋壳蛇绿岩组成部分^[21,39];第二类为陆缘弧火山岩块,分布于三岔子、中堂沟、桥梓沟及略阳以北的横县河一带^[21,68-69],以本论文研究的中堂沟陆缘弧火山岩为典型代表。这类火山岩与洋脊的扩张作用没有直接的成因联系,而是与洋壳俯冲消减作用有关的一套大陆边缘弧岩浆岩^[48,70];第三类为黑沟峡双峰式火山岩,玄武岩具典型MORB特征,可能是由大陆裂谷向初始洋盆转化阶段的产物^[36]。

勉略缝合带东段巴山弧两河—饶峰—五里坝地区以出露典型的陆缘弧火山岩及弧内裂隙双峰式火山岩为特征^[24-25,71-72],而随县花山构造混杂带中以周家湾陆间裂谷—初始洋变质玄武岩为特征^[73-74];大别山南缘清水河地区堆晶辉长岩系总体代表了洋壳的中下部层位^[21,39],而浠水—兰溪双峰式火山岩则是陆间裂谷—初始洋转化阶段的产物,但洋盆规模较小,并未形成典型的MORB型洋壳类型^[75]。

综上所述,南秦岭勉略缝合带自西向东不同区段出露的蛇绿岩和相关火山岩的性质和时空演化关系表明:勉略古洋盆曾经历了一个较为完整的发生、发展、演化和消亡过程;中堂沟陆缘弧火山岩的厘定,对探讨勉略构造带中段三岔子火山岩构造属性问题提供了较为可靠的野外地质资料和地化数据参考,为探讨勉略缝合带的形成与演化乃至东古特提斯域和中国大陆造山带的基本特性、特征及大陆动力学背景提供重要的基础资料。

7 结论

本文通过对勉略构造带三岔子西侧中堂沟火山岩详实的野外地质剖面调查,依据其岩石组合、岩相学、地球化学等方面的系统研究,并结合前人对三岔子岛弧火山岩研究资料的综合分析,得出以下结论:

(1)勉略构造带中堂沟火山岩为一套绿片岩相

浅变质火山岩,岩石组合以变安山岩为主,含有少量的变玄武岩和变英安岩,主体为钙碱性系列;3类岩石稀土配分曲线均为轻稀土富集右倾负斜率型,具弱Eu负异常,普遍富集大离子亲石元素Cs、Rb、Ba,亏损高场强元素Nb和Ta,相对亏损P和Ti。

(2)中堂沟火山岩岩石组合、微量元素特征及构造环境判别图解,表明该套火山岩应形成于大陆边缘弧(活动陆缘)环境。其中变玄武岩和变安山岩岩浆起源于楔形地幔的部分熔融,且有陆壳物质的参与;变英安岩的形成则与壳源物质的部分熔融有关。

(3)南秦岭勉略缝合带自西向东不同区段出露的蛇绿岩和相关火山岩的性质及其时空演化关系表明:勉略古洋盆曾经历了一个较为完整的发生、发展、演化和消亡过程;中堂沟陆缘弧火山岩的厘定,对探讨勉略构造带中段三岔子火山岩构造属性问题提供了较为可靠的野外地质资料和地化数据参考,为探讨勉略缝合带的形成与演化提供重要的基础资料,勉略洋作为东古特提斯的组成部分,它对于探讨中国大陆造山带的基本特征及大陆动力学探索具有重要意义。

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Geochemical characteristics of the volcanic rocks from Zhongtanggou area of Mianlue suture zone in South Qinling Mountains and their geological significance

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Abstract: A detailed geological cross-sectional survey was conducted for the volcanic rocks in Zhongtanggou area on the western side of Sanchazi along Mianlue suture zone. The volcanic rocks are mainly greenschist facies metamorphic rocks, which comprise mainly metamorphic andesite rocks and subordinately metamorphic basalt and metamorphic dacite rocks, belonging mainly to the calc-alkaline series. Their REE distribution patterns are characterized by LREE enrichment, right-oblique shape and depletion of Eu. Their trace elements generally have features of enrichment of Cs, Rb and Ba, obvious depletion of Nb and Ta, and slight depletion of P and Ti. Trace elements such as Zr and Hf are relatively stable. In the La–La/Nb, Nb–Nb/Th and La/Yb–Sc/Ni discrimination diagrams, the metamorphic basalt and metamorphic andesite samples mainly fall in the region of island arc volcanic rocks. These characteristics, in combination with features of volcanic rocks, indicate that the volcanic rocks in Zhongtanggou area were formed in a typical tectonic setting of island arc. The authors hold that the material source of metamorphic andesite and metamorphic basalt rocks might have been closely related to a locally depleted area in the mantle wedge with the addition of continental crustal material. The material source of metamorphic dacite was probably related to the partial melting of the crustal granitic magma.

Key words: Mianlue suture zone; rock slice of Zhongtanggou; calc-alkaline rock; arc volcanic rock; tectonic setting; magma source

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