

丁正江, 孙丰月, 李国华, 等. 胶东邢家山地区燕山早期钼钨成矿母岩锆石 U-Pb 年龄及其意义[J]. 中国地质, 2015, 42(2): 556-569.  
Ding Zhengjiang, Sun Fengyue, Li Guohua, et al. Accurate zircon U-Pb dating of Early Yanshanian molybdenum-tungsten mother rocks in Xingjiashan area of Jiaodong Peninsula and its significance[J]. Geology in China, 2015, 42(2): 556-569(in Chinese with English abstract).

## 胶东邢家山地区燕山早期钼钨成矿母岩 锆石 U-Pb 年龄及其意义

丁正江<sup>1,2</sup> 孙丰月<sup>3</sup> 李国华<sup>2</sup> 纪攀<sup>2,3</sup> 孔彦<sup>2</sup>

(1. 中国地质大学(北京), 北京 100083; 2. 山东省第三地质矿产勘查院, 山东烟台 264004;  
3. 吉林大学地球科学学院, 吉林 长春 130061)

**摘要:** 对从幸福山花岗岩中挑出的岩浆锆石进行了 LA-ICP-MS 分析, 得出了由 15 个点组成的加权平均值为(157±2) Ma 的年龄。此 15 个测试点均处于岩浆锆石的振荡环带上, 且此年龄与邢家山钼钨矿辉钼矿 Re-Os 年龄一致, 代表该花岗岩的结晶年龄。本次测试所得到的另外 2 组捕获锆石年龄(2798±13) Ma 和(2250±18) Ma 暗示该岩浆源区可能存在的新太古代-古元古代侵入岩基底, (230±6) Ma 则可能暗示着该区存在三叠纪的岩浆活动。中生代以来(190~110 Ma), 中国东部构造岩浆活动特征较为一致, 与之相对应存在多期成矿作用。胶东地区广泛出露的玲珑花岗岩与幸福山花岗岩岩石地球化学特征及年龄基本一致, 可能该区也存在着大规模的钼多金属成矿作用, 只是大部分为后期构造抬升所剥蚀, 邢家山钼钨矿是保存下来的代表。也说明, 栖霞-福山地区中生代以来剥蚀程度相对较小, 矿床保存条件较好, 故应重视该区中浅成矿床(斑岩-矽卡岩型、卡林型、造山型浅成矿床等)的寻找。

**关键词:** 锆石 U-Pb 年龄; 燕山早期; 钼钨矿床; 邢家山; 胶东地区

**中图分类号:** P597; P618.6 **文献标志码:** A **文章编号:** 1000-3657(2015)02-0556-14

## Accurate zircon U-Pb dating of Early Yanshanian molybdenum-tungsten mother rocks in Xingjiashan area of Jiaodong Peninsula and its significance

DING Zheng-jiang<sup>1,2</sup>, SUN Feng-yue<sup>3</sup>, LI Guo-hua<sup>2</sup>, JI Pan<sup>2,3</sup>, KONG Yan<sup>2</sup>

(1. China University of Geoscience (Beijing), Beijing 100083; 2. Shandong No. 3 Exploration Institute of Geology and Mineral Resources, Yantai 264000, Shandong, China; 3. College of Earth Sciences, Jilin University, Changchun 130061, Jilin, China)

**Abstract:** This paper presents the magma zircon LA-ICP-MS U-Pb isotopic dating results of the Xingfushan granites. The weighted mean age (157±2 Ma) was obtained from 15 test points on the oscillatory zones. Inferred from the same test positions and the coincident dating result with Re-Os isotopic age of molybdenite from the Xingjiashan molybdenum-tungsten deposit, the

收稿日期: 2014-04-02; 改回日期: 2014-09-23

基金项目: 国土资源部金矿成矿过程与资源利用重点实验室、山东省金属矿产成矿地质过程与综合利用重点实验室开放课题(2013009)与山东省财政科研类项目(鲁勘字[2007]56号)联合资助。

作者简介: 丁正江, 男, 1977年生, 高级工程师, 矿物学、岩石学、矿床学专业; E-mail: ytdzhj@126.com。

通讯作者: 孙丰月, 男, 1963年生, 博士, 教授, 从事矿床地质、区域成矿作用研究; E-mail: sunfeng0669@sina.com。

granites here crystallized in this period. The other two captured zircons from the same assay at the separate age of (2798±13) Ma and (2250±18) Ma imply possible existence of Neoproterozoic–Paleoproterozoic intrusive basement, whereas No. 7 point at the age of (230±6) Ma implies possible Triassic magmatic activity. The consistent features of the tectono–magmatic activities in eastern China since Mesozoic (190–110 Ma) produced the corresponding varied metallogenesis here. The common granites of Linglong and Xingfushan units in Jiaodong Peninsular share almost the same geochemical features and ages, suggesting that this area might have hosted large–scale molybdenum polymetallic metallogenesis. Under heavy regional denudation by late tectonic uplifting, the left Xingjiashan molybdenum–tungsten deposit typically shows less denudation in Qixia–Fushan area since Mesozoic and better metallogenic condition, so more importance should be attached to the prospecting for hypabyssal deposits (porphyry–skarn, Carlin and organic hypabyssal deposits) here.

**Key words:** zircon U–Pb age; Early Yanshanian; molybdenum–tungsten deposit; Xingjiashan; Jiaodong Peninsular

**About the first author:** DING Zheng–jiang, male, born in 1977, senior engineer, majors in mineralogy, petrology and economic geology; E–mail: ytdzhj@126.com.

**About the corresponding author:** SUN Feng–yue, male, born in 1963, doctor, professor, engages in the study of mineral deposits and regional metallogenesis; E–mail: sunfeng0669@sina.com.

## 1 前 言

长期以来,对胶东地区中生代成矿作用的研究基本集中于对该区金矿的研究,仅有少数专家学者涉及了该区同时期铜钼铅锌银等成矿作用,并且目前为止基本上形成了较为一致的观点,即胶东地区中生代成矿集中于135~110 Ma,认为这与华南、华北板块碰撞造山以及太平洋板块的俯冲作用过程有关<sup>[1-3]</sup>。故而,也就形成了一个在成因上较为一致的看法,即该区金及多金属成矿基本上是与该区燕山晚期郭家岭花岗岩的侵入有关,为与该期岩浆活动紧密相关的岩浆期后热液矿床;近期,也有一些研究者提出了胶东地区金及多金属矿成矿与该区燕山晚期伟德山花岗岩(~115 Ma)有关,无论在时间上还是与空间上均具有“远为金、近为铜钼多金属”的特点<sup>[4]</sup>。本文所涉及的烟台市福山区邢家山钼钨矿床为一斑岩–矽卡岩型矿床,其成矿母岩为幸福山斑状中细粒含黑云二长花岗岩<sup>[1,5,6]</sup>。山东地矿局三队(1982)曾获得该岩体黑云母 K–Ar 法年龄 124.27~163.24 Ma,原山东地质局 805 队(1968)同样方法获得年龄为 133 Ma 和 158 Ma,结合野外产状特征及与围岩接触关系一致认为其成岩时代为中生代燕山晚期,归属于该区伟德山花岗岩<sup>①</sup>。但笔者前期在找矿过程中发现,邢家山钼钨矿床矿体多见为燕山晚期诸岩脉所穿切等系列问题,遂对该区

钼钨矿成矿时间产生疑问,并采取了矿石中的辉钼矿进行了单矿物 Re–Os 法测年<sup>[6]</sup>,获得了辉钼矿 Re–Os 同位素模式年龄范围为(156±2)~(161±2) Ma,显示该矿床成矿年龄应为燕山早期。但注意到,该区钼矿化与外围中生代燕山晚期成矿之栖霞市尚家庄斑岩型钼矿(该钼矿成矿母岩牙山花岗岩黑云母 <sup>40</sup>Ar–<sup>39</sup>Ar 法、锆石 U–Pb 法年龄为(116±0.5)~(117.7±2.9) Ma)<sup>[2,4]</sup>产出标高大致相当,考虑到成矿与剥蚀问题,二者似乎应为同时代产物。为慎重起见,笔者又采取了邢家山钼钨矿床成矿母岩——幸福山花岗岩进行单颗粒锆石 U–Pb 法精确测年,以正确厘定该矿床成矿年龄,为后期该区相关研究及找矿工作思路的拓展提供依据。

## 2 矿床成矿背景及矿床特征

### 2.1 区域成矿背景

胶东地区处于华北板块与扬子板块结合部位,以桃村断裂为界,其北西部分属于华北板块东南缘,桃村断裂南东侧部分位于苏鲁—大别超高压变质带之上<sup>[3]</sup>(图 1)。整个胶东出露岩性,前寒武纪结晶基底变质岩系与晚期岩浆岩面积大致相当,而福山北部—栖霞一带以前寒武纪变质岩系为主,这可能与该区地壳抬升的程度有关<sup>[7]</sup>。其中,前寒武纪变质岩,以其金丰度较高而被多数学者认为是该区金矿的原始矿源层;中生代燕山晚期郭家岭花岗岩

①山东省第三地质矿产勘查院. 山东省烟台市烟台等五幅区域地质调查报告. 2000.

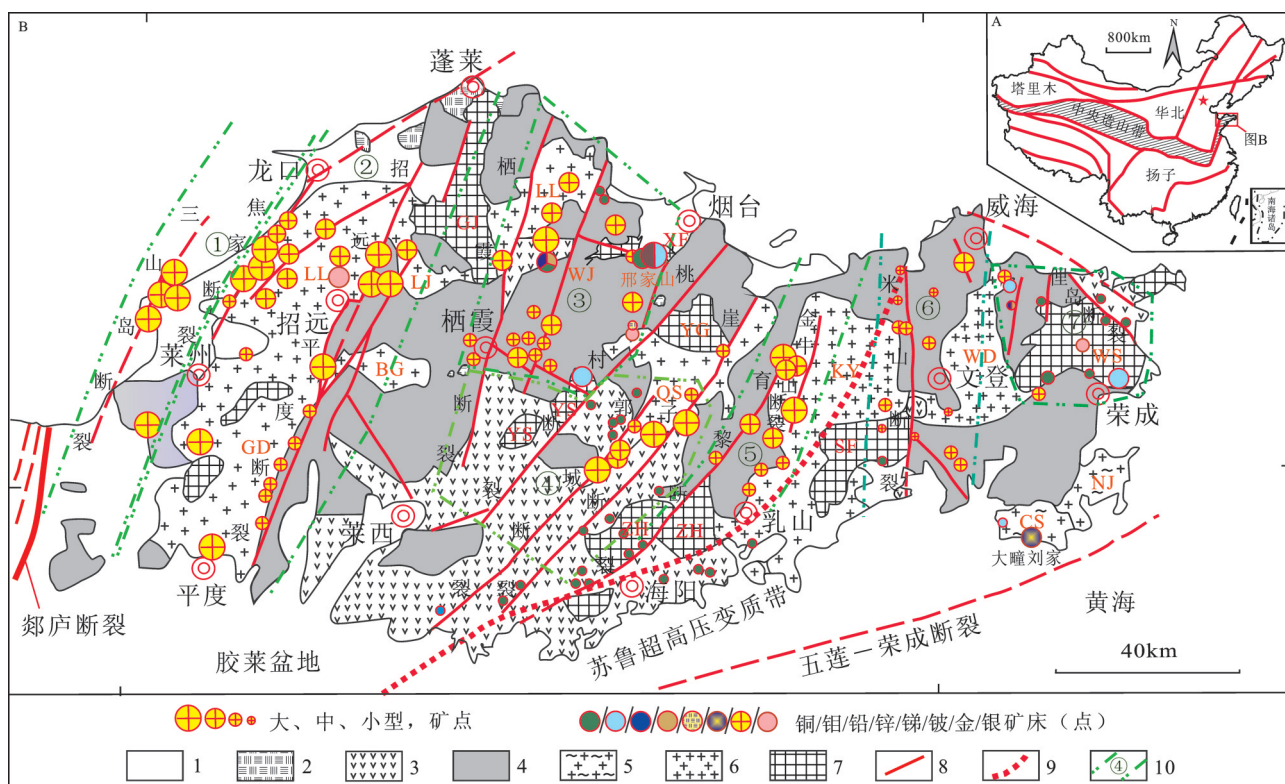


图1 胶东地区地质简图及主要有色、贵金属矿分区带分布图(据文献[8])

1—新生代沉积物; 2—新生代玄武岩; 3—白垩纪砂岩/火山岩; 4—前寒武纪基底; 5—三叠纪花岗岩; 6—侏罗纪花岗岩; 7—白垩纪花岗岩; 8—主要断裂构造; 9—推测变质带边界; 10—成矿区带界线及编号;

中生代侵入岩: LL—玲珑岩体; GD—郭家店岩体; LJ—滦家河岩体; BG—毕郭岩体; XF—幸福山岩体; QS—鹊山岩体; WD—文登岩体; NJ—宁津岩体; KY—昆嵛山岩体; GL—郭家岭岩体; YS—牙山岩体; YG—院格庄岩体; HY—海阳岩体; SF—三佛山岩体; WS—伟德山岩体; WJ—王家庄岩体; CS—槎山岩体;

成矿区(带): ①—莱州西北部成矿带; ②—招远—平度成矿带; ③—栖霞—蓬莱—福山成矿区; ④—胶莱盆地东北缘成矿区; ⑤—牟平—乳山成矿带; ⑥—威海—文登成矿带; ⑦—荣成成矿区

Fig. 1 Geological sketch map and zoning map of main nonferrous-precious metal deposits in Jiaodong Peninsula (modified after reference [8])

1—Cenozoic sediments; 2—Cenozoic basalt; 3—Cretaceous sandstone/lava; 4—Precambrian basement; 5—Triassic granite; 6—Jurassic granite; 7—Cretaceous granite; 8—Main fracture structure; 9—Inferred boundary of metamorphic belt; 10—Boundary and code of mineralization zone;

Mesozoic intrusive rocks: LL—Linglong rock body; GD—Guojiadian rock body; LJ—Luanjiahe rock body; BG—Biguo rock body; XF—Xingfushan rock body; QS—Queshan rock body; WD—Wendeng rock body; NJ—Ningjin rock body; KY—Kunyushan rock body; GL—Guojialing rock body; YS—Yashan rock body; YG—Yuangezhuang rock body; HY—Haiyang rock body; SF—Sanfoshan rock body; WS—Weideshan rock body; WJ—Wangjiazhuang rock body; CS—Chshan rock body

Mineralization district (belt): ①—Northwestern Laizhou mineralization belt; ②—Zhaoyuan—Pingdu mineralization belt;

③—Qixia—Penglai—Fushan mineralization zone; ④—Mineralization zone at the northeast edge of the Jiaolai Basin;

⑤—Muping—Rushan mineralization belt; ⑥—Weihai—Wendeng mineralization belt; ⑦—Rongcheng mineralization zone

被认为是导致该区燕山晚期(135~110 Ma)<sup>[4]</sup>金矿成矿大爆发的原因。

烟台市福山区邢家山地区, 处于胶东栖霞—蓬莱—福山金及多金属成矿区东部(图1)。区域上地层主要出露古元古代粉子山群, 新元古代蓬莱群, 中生代莱阳群、青山群, 及新生代第四系。其中, 粉子山群为一套碎屑岩及不纯碳酸盐岩沉积建造, 该

地层从下部到上部依次赋存有杜家崖(金银, 中型)、邢家山(钼钨, 特大型)、王家庄(铜锌, 大型)和隆口(金, 小型)等矿床。区域侵入岩主要为中生代燕山期幸福山岩体和伟德山岩体及各类岩脉, 其中幸福山斑状中细粒含黑云二长花岗岩呈岩株状小面积出露, 与成矿直接相关。区域内发育的近EW向吴阳泉超壳断裂, 延深大、活动时间长, 为深源岩浆及

流体活动提供了重要通道,其次级NE向断裂为重要控矿断裂。

### 2.2 斑岩分布及钨钼矿床特征

幸福山斑岩体局限分布于东西向构造与北东向断裂交汇部位(图2)。岩体展布长轴方向为北西300°,具周边外倾趋势,边缘呈岩枝状脉侵入围岩,长度约2700 m,宽约1100 m,面积约1.30 km<sup>2</sup>。岩体

侵入于粉子山群变质岩中,北西部内、外接触带中普遍发育强烈的矽卡岩化和硅化、碳酸盐化等蚀变,以钨钼为主的多金属矿化均赋存于该蚀变带内。自接触带向北西方向金属元素组合有明显的水平分带,即Mo+Zn+Mn→Mo+W→W+Cu→Pb+Zn<sup>①</sup>。从其蚀变特征、金属元素组合或有色金属矿床产出部位可以看出,与幸福山岩体存在密切的成因联系。邢家山

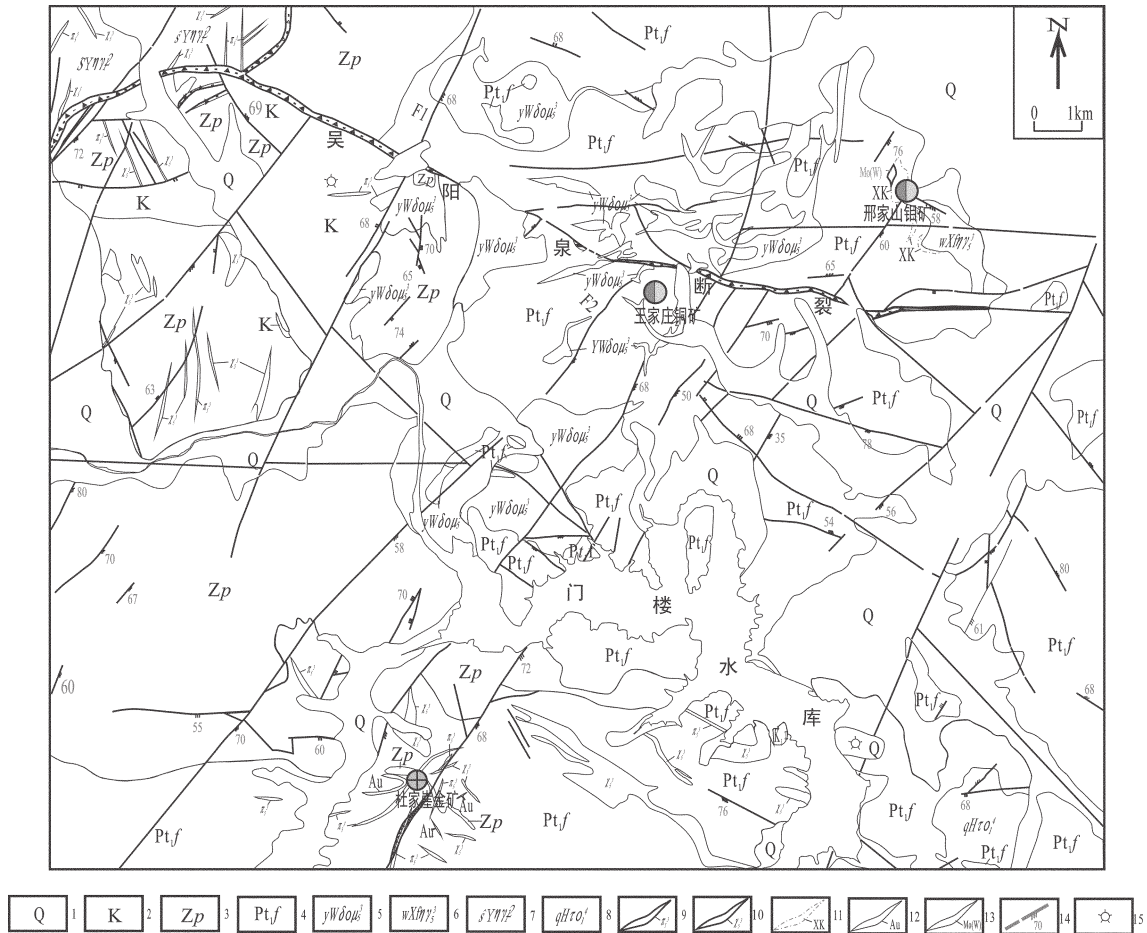


图2 福山北部地区区域地质图(据文献[1])

- 1—第四系; 2—中生代莱阳群、青山群火山盆地沉积; 3—新元古代蓬莱群千枚岩、板岩夹石英岩等; 4—古元古代粉子山群含炭变粒岩、片岩、大理岩、透闪岩等; 5—中生代燕山晚期王家庄单元石英闪长玢岩; 6—中生代燕山晚期幸福山单元二长花岗斑岩; 7—古元古代吕梁期燕子介单元片麻状细粒含黑云二长花岗岩; 8—新太古代五台—阜平期回龙单元条带状细粒含角闪黑云英云闪长岩; 9—中酸性脉岩; 10—中基性脉岩; 11—矽卡岩化带; 12—金矿体; 13—钨(钼)矿体; 14—断层及产状; 15—古火山机构

Fig.2 Regional geological map of northern Fushan (modified after reference [1])

- 1—Quaternary; 2—Volcanic basin deposits of Mesozoic Laiyang Group and Qingshan Group; 3—Phyllite, slate intercalated with quartzite, etc. of Neoproterozoic Penglai Group; 4—Granulite containing carbonaceous leptite, schist, marble, tremolite, etc. of Paleoproterozoic Fenzishan Group; 5— Quartz diorite porphyry of Mesozoic Late Yanshanian Wangjiazhuang Unit; 6—Mozonitic granite porphyry of Mesozoic Late Yanshanian Xingfushan Unit; 7—Genessic fine-grained monzonitic granite containing biotite of Paleoproterozoic Luliang Period Yanzikuang Unit; 8—Fine-grained biotite tonalite containing amphibole of Neoproterozoic Wutai-Fuping Period Huilongkuang Unit; 9—Intermediate-acidic vein rock; 10—Intermediate-basic vein rock; 11—Skarn belt; 12—Gold orebody; 13—Molybdenum (tungsten) orebody; 14—Fault and its attitude; 15—Paleovolcanic edifice

①山东省第三地质矿产勘查院.山东省烟台市烟台等五幅区域地质调查报告.2000.

钼钨矿床位于近东西向吴阳泉断裂带东段北侧,矿体主要赋存在幸福山岩体内部及其与粉子山群的内外接触带中(图2)。受城市规划影响,矿区已勘查地段主要为矽卡岩型矿化,斑岩内体矿体因为居民区压矿无法勘查,仅在局部钻探施工并控制了斑岩型钼矿体<sup>[1]</sup>。现已查明共133个钼钨矿体(其中钼钨共生矿体22个,单独钼矿体85个,单独钨矿体26个);多呈似层状、透镜状产出,产状与地层产状基本一致,膨缩变化大,常见切层现象,整体上倾角较缓,10°~30°;钼矿体规模大小不一,长200~2200 m,厚1.17~185.47 m,矿体总厚度400余米;矿体间距一般在10 m以内,最大101 m。矽卡岩型矿石以透闪透辉矽卡岩型和石榴透辉矽卡岩型为主(约占91%),包括钼钨矿(辉钼矿+闪锌矿+黄铁矿)、钨钨矿(白钨矿+辉钼矿+磁黄铁矿)、钼钨矿(辉钼矿+白钨矿+磁黄铁矿)。矿石中主要金属矿物有辉钼矿、白钨矿、磁黄铁矿、黄铁矿、黄铜矿、赤铁矿、褐铁矿;主要脉石矿物为透辉石、石英、方解石、钾长石、白云母、石榴子石、符山石、绿泥石、黝帘石、绢云母等。矿石常见自形、半自形、他形粒状结构、充填结构、交代蚕食结构、固溶体出溶结构、碎裂结构;主要呈浸染状、细脉-脉状、条带状、角砾状、块状等构造(图3)。矿石中Mo含量多在 $0.03 \times 10^{-2} \sim 0.30 \times 10^{-2}$ ,最高为 $1.51 \times 10^{-2}$ ,矿区平均 $0.07 \times 10^{-2}$ ;WO<sub>3</sub>含量一般在 $0.20 \times 10^{-2} \sim 0.40 \times 10^{-2}$ ,最高为 $1.88 \times 10^{-2}$ ,矿区平均为 $0.20 \times 10^{-2}$ 。矿体围岩为大理岩、白云石大理岩、硅质白云石大理岩、二云片岩、斑状中细粒含黑云二长花岗岩等,发育矽卡岩化、硅化、钾长石化、黝帘石化-绿帘石化、钠长石化、绿泥石化、碳酸盐化、绢云母化等。矿化可分为3个成矿阶段,即早期矽卡岩化钼钨多金属硫化物阶段、中期石英-辉钼矿多金属硫化物、晚期石英-碳酸盐阶段。矿床类型为斑岩-矽卡岩型矿床,幸福山岩体为其成矿母岩<sup>[1,4,5]</sup>。

### 2.3 钼钨成矿母岩岩石学特征

邢家山钼钨成矿母岩为斑状中细粒含黑云二长花岗岩,取样分析(样号XFS1201),样品采自邢家山钼钨出露点以东约200 m一建筑工地揭露的岩体露头,地理坐标37°30′30″N,121°13′50″E。岩石SiO<sub>2</sub>含量平均68.56%,属于酸性花岗岩类(表1)。与

中国花岗岩平均值<sup>[9]</sup>比较其SiO<sub>2</sub>、CaO、K<sub>2</sub>O含量略偏高,K<sub>2</sub>O/Na<sub>2</sub>O≈1.2,Fe<sub>2</sub>O<sub>3</sub>+FeO含量偏低,其余氧化物含量基本一致,属钙碱性岩石(图4),中浅部侵位。根据区调成果<sup>①</sup>微量元素中,与酸性岩类世界平均值<sup>[9]</sup>对比,该岩石亲石元素Ti、Mn、Cr含量较低,Ba、Sr其余较高;亲铜元素Pb含量较高,Cu、Ni、Zn其余较低;亲铁元素Mo含量高出10倍以上,其余较低。Nb、Zr明显偏低,不及1/2。从稀土配分曲线可以看出,属轻稀土富集,右倾型(图5),钨略显正异常,δEu>0.7,属下地壳或太古宙沉积岩部分熔融形成的岩浆岩类。为上地幔与下地壳部分熔融形成的混熔岩浆成因,即壳幔混熔型花岗岩。成因温度为750~800℃,压力0.05 GPa。

## 3 样品采集与分析方法

### 3.1 样品特征

本次用于U-Pb同位素分析的1件(样号XFS1201)。岩性为斑状中细粒含黑云二长花岗岩,岩石风化呈黄白色(图6-A),新鲜浅灰-灰褐色,似斑状结构,基质不等粒花岗岩结构,块状构造、斑杂状构造、“似文象”构造。主要矿物成分:斑晶含量37.1%,其中石英11.80%、斜长石19.9%、钾长石4.7%、角闪石0.7%,粒度1.25~3.35 mm;基质含量62.9%,其中钾长石39.05%、斜长石2.5%、石英19.58%、黑云母1.2%、绿帘石0.7%、磷灰石0.1%、榍石0.07%、方解石0.2%,粒度为0.035~0.65 mm。岩石构造不均一性明显,细-微粒状、团块状与密斑状,呈结构“云朵状”弥散分布,相互间为渐变关系。普遍见石英呈条纹条带状出溶,多为(0.3~1.5) cm×(12~30) cm(宽×长)的密集状大致平行小脉体,局部含量达50%(图6-B)。

### 3.2 分析方法

锆石的挑选在河北省廊坊区域地质调查研究所实验室利用标准重矿物分离技术分选完成。制靶时,先在双目镜下仔细挑选出表面平整光洁且具不同长宽比例、不同柱锥面特征、不同颜色的锆石颗粒,然后将这些锆石粘在双面胶上,用无色透明环氧树脂固定,待环氧树脂固化之后对其表面抛光至锆石中心。原位分析之前,利用阴极发光(CL)图像详细研究锆石的晶体形貌和内部结构特征,选择

①山东省第三地质矿产勘查院.山东省烟台市烟台等五幅区域地质调查报告.2000.

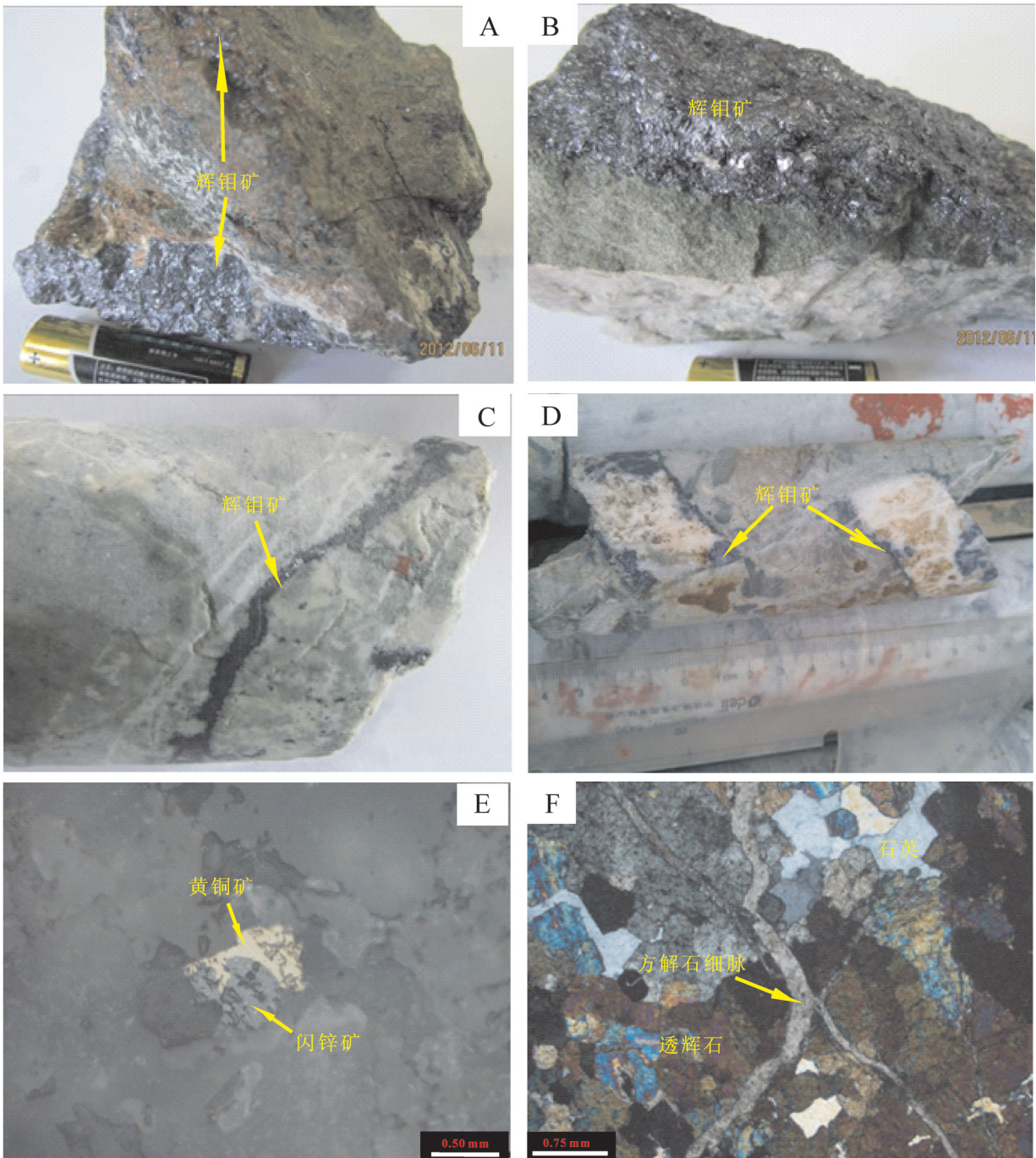


图3 邢家山钼钨矿床矿石特征

A—矽卡岩型矿石, 辉钼矿呈脉状、团块状、浸染状分布; B—矽卡岩型矿石, 辉钼矿呈脉状发育, 见后期碳酸盐脉; C—细脉状辉钼矿沿大理岩裂隙充填; D—辉钼矿与碳酸盐共生, 并被后期构造所错动; E—黄铜矿与闪锌矿共生, 闪锌矿中溶出黄铜矿(固溶体出溶结构); F—透辉岩中发育后期方解石细脉

Fig.3 Sample characteristics from the Xingjiashan Mo-W deposit

A—Skarn ore with molybdenite of veined, mass and dissemination forms; B—Skarn ore with molybdenite veins in late carbonate veins; C—Molybdenite of veinlets in marble fracture; D—Molybdenite together with carbonate, faulted by late tectonic movements; E—Chalcopyrite together with sphalerite, chalcopyrite dissolved out from sphalerite—exsolution texture of solid solution; F—Calcite veinlet of late period in diopside

表1 幸福山花岗岩岩石化学成分(%)<sup>①</sup>  
Table 1 Chemical composition of Xingfushan granite rock (%)<sup>①</sup>

样品号	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	H <sub>2</sub> O <sup>+</sup>	P <sub>2</sub> O <sub>5</sub>	CO <sub>2</sub>	总和
XFS-H1	69.01	0.38	16.00	0.49	1.47	0.04	0.49	2.90	3.59	4.79	0	0.10		99.26
XFS-H2	77.31	0.14	11.79	0.64	0.68	0.02	0.19	0.35	1.48	6.16	0.9	0.10		99.85
XFS-H3	78.10	0.14	11.28	0.22	0.77	0.02	0.22	0.35	1.19	6.10	1.10	0.08		99.57
XFS-H4	71.96	0.232	14.00	0.08	2.56	0.04	0.47	2.58	3.14	3.85	0.34	0.11		99.36
XFS-H5	68.56	0.16	15.04	0.35	1.32	0.02	0.4	3.37	3.61	4.34	1.12	0.07	1.20	99.56
平均值	72.90	0.21	13.62	0.36	1.36	0.03	0.35	1.91	2.60	5.05	0.71	0.09	0.24	99.52
中国花岗岩(黎彤)	71.27	0.25	14.25	1.24	1.62	0.08	0.80	1.62	3.79	4.03	0.56	0.16	0.33	100.00
中国花岗闪长岩(黎彤)	64.98	0.52	16.33	1.89	2.49	0.09	1.94	3.70	3.67	2.95	0.83	0.32	0.29	100.00
中国石英闪长岩(黎彤)	60.51	0.73	16.70	2.87	3.49	0.14	2.54	4.86	3.68	2.65	0.88	0.46	0.75	100.00

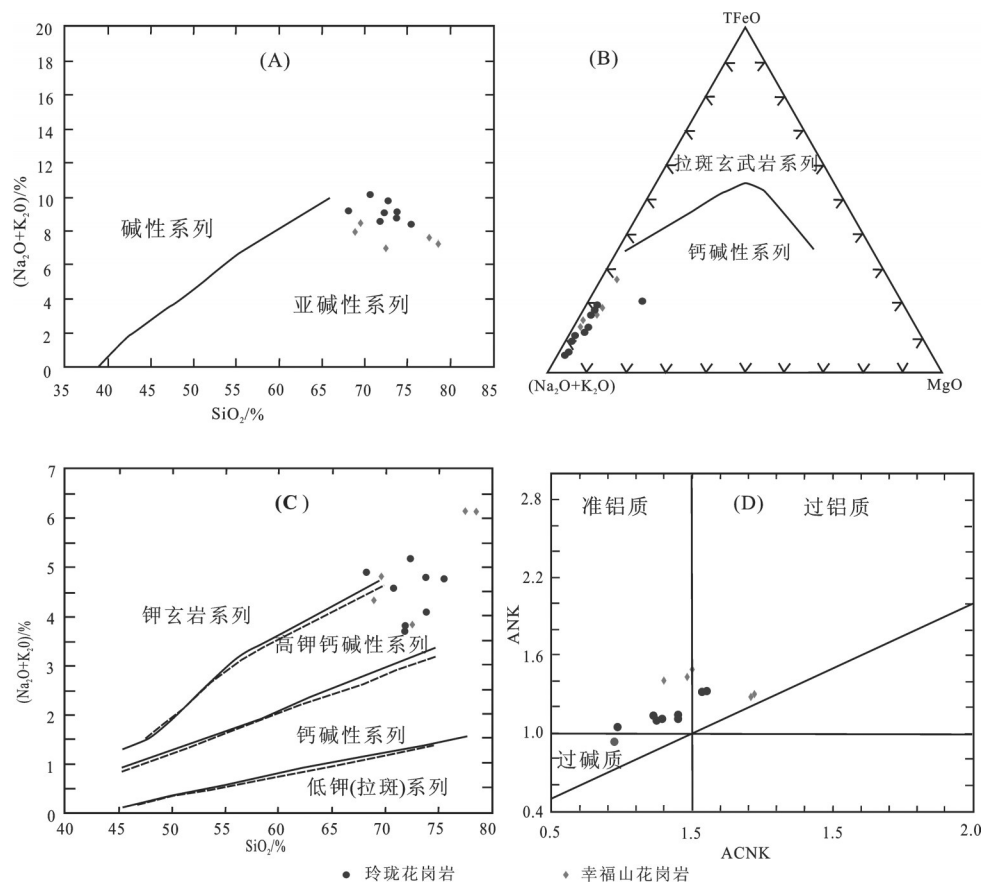


图4 幸福山花岗岩地球化学图解(据①绘制, 玲珑花岗岩数据及底图转引自[10])

A—硅-碱图解; B—(Na<sub>2</sub>O+K<sub>2</sub>O)—MgO—TFeO图解; C—SiO<sub>2</sub>—K<sub>2</sub>O图解; D—ACNK—ANK图解

Fig.4 Geochemical diagrams of Xingfushan granites (after ①; data of Linglong granites and base map after reference [10])

A—Silicon-alkaline diagram; B—(Na<sub>2</sub>O+K<sub>2</sub>O)—MgO—TFeO diagram; C—SiO<sub>2</sub>—K<sub>2</sub>O diagram; D—ACNK—ANK diagram

①山东省第三地质矿产勘查院. 山东省烟台市烟台等五幅区域地质调查报告. 2000.

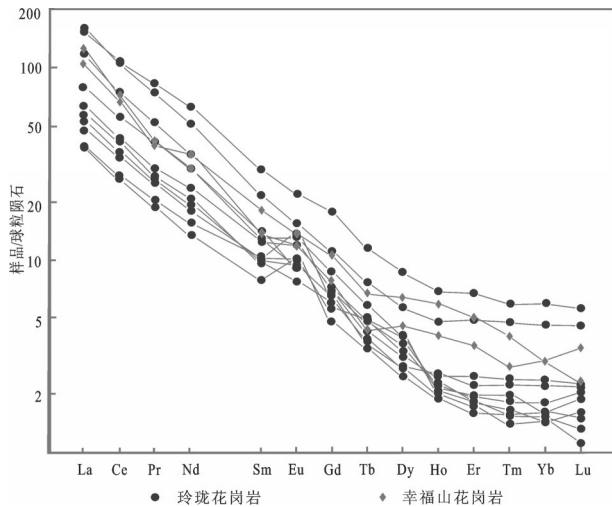


图5 花岗岩球粒陨石标准化蛛网图(据①,底图据[10] 修编)  
Fig.5 Chondrite-normalized spidergram of granites (after ①, base map after reference [10])

同位素分析的最佳点。锆石制靶、CL照相和锆石U-Pb年龄测定和微量元素分析均在西北大学教育部大陆动力学重点开放实验室利用LA-ICP-MS分析完成。锆石U-Pb同位素定年采用ComPex102ArF准分子激光器(波长193 nm)和带有

动态反应池的四级杆Elan6100DRC型ICP-MS进行锆石U和Pb测定。试验中采用He作为剥蚀物质载气,用美国国家标准技术研究院研制的人工合成硅酸盐玻璃标准参考物质NIST SRM610进行仪器最佳化,本次测试采用的激光剥蚀束斑直径为32 μm,采样方式为单点剥蚀,每测定5个样品点,加测标样一次。具体测试过程详见文献[11, 12]。锆石年龄采用国际标准锆石91500作为外标,<sup>29</sup>Si作为内标元素(锆石中SiO<sub>2</sub>含量为32.8%)<sup>[13]</sup>;普通铅校正采用Anderson推荐的方法<sup>[14]</sup>;样品的同位素比值及元素含量计算采用ICPMSDATECAL程序<sup>[15, 16]</sup>年龄计算及谐和图的绘制采用Isoplot 3.0软件<sup>[17]</sup>。

#### 4 锆石特征及测年结果

样品(XFS1201)锆石呈无色或浅黄褐色,以长柱或等轴状自形晶为主,粒径变化较大,在110~300 μm,长短轴之比在1:1~2.5:1。锆石阴极发光图像显示,大部分锆石具有典型岩浆锆石的韵律环带<sup>[18, 19]</sup>(图7),显示为典型岩浆锆石特征<sup>[20]</sup>。根据该样品锆石的内部结构,总计选取20个锆石微区开展锆石U-Pb测年分析,分析结果(表2)显示,该样品锆石的U

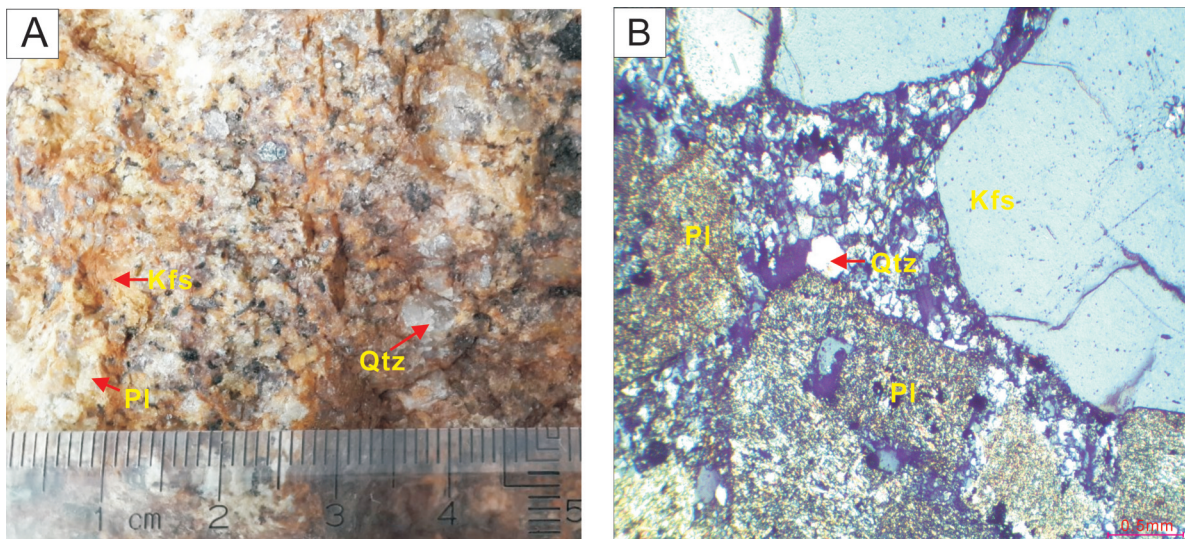


图6 幸福山花岗岩照片  
A-岩石标本照片; B-岩石显微照片; Qtz-石英; Kfs-钾长石; Pl-斜长石(绢云母化)  
Fig.6 Xingfushan granites  
A-Rock sample; B-Rock microphotograph; Qtz-Quartz; Kfs-Potash feldspar; Pl-Plagioclase

①山东省第三地质矿产勘查院.山东省烟台市烟台等五幅区域地质调查报告.2000.



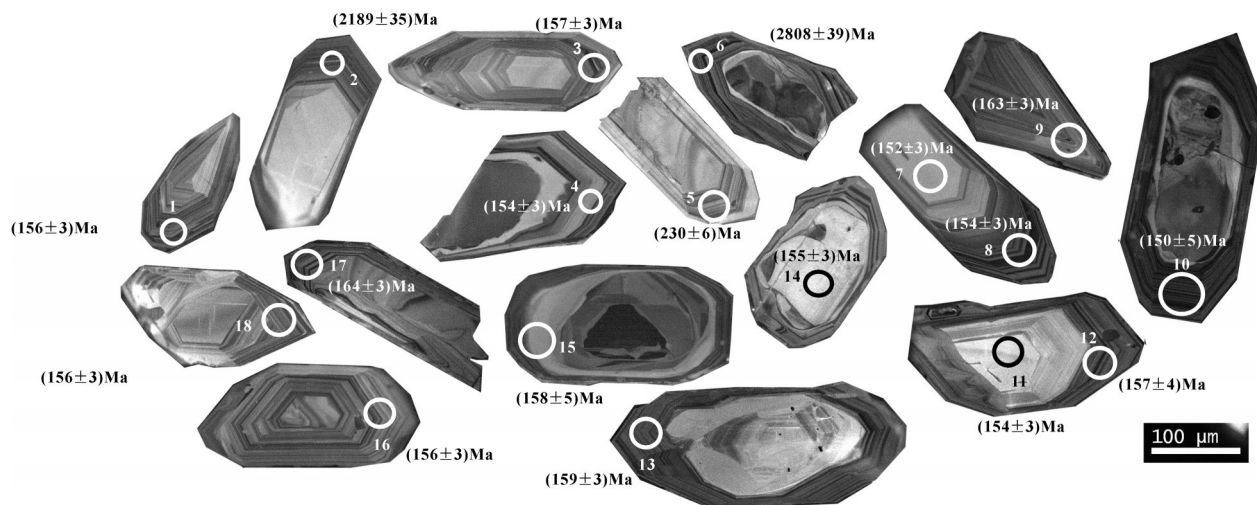


图7 幸福山岩体锆石阴极发光图像  
Fig.7 Zircon CL images of samples from Xingfushan area

表2 幸福山花岗岩锆石普通铅校正后的LA-ICP-MS同位素数据  
Table 2 LA-ICP-MS isotopic data of zircons from Xingfushan granites after common lead correction

点号	Th		U		$^{207}\text{Pb}/^{206}\text{Pb}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		$^{207}\text{Pb}/^{206}\text{Pb}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		$^{208}\text{Pb}/^{232}\text{Th}$	
	$10^{-6}$	Th/U	比值	$1\sigma$	比值	$1\sigma$	比值	$1\sigma$	年龄/Ma	$1\sigma$	年龄/Ma	$1\sigma$	年龄/Ma	$1\sigma$	年龄/Ma	$1\sigma$	年龄/Ma	$1\sigma$
1	40.05	319.22	0.13	0.04796	0.00354	0.16227	0.01114	0.02453	0.00046	97	117	153	10	156	3	121	5	
2	42.35	239.64	0.18	0.14185	0.00482	7.91041	0.18597	0.40434	0.00771	2250	18	2221	21	2189	35	631	51	
3	29.35	31.52	0.93	0.05129	0.00299	0.17467	0.00908	0.02469	0.00044	254	87	163	8	157	3	195	11	
4	48.05	133.6	0.36	0.04648	0.00605	0.15483	0.01968	0.02415	0.00050	23	222	146	17	154	3	137	10	
5	96.44	571.8	0.17	0.04911	0.00696	0.24598	0.03394	0.03632	0.00098	153	250	223	28	230	6	245	13	
6	34.08	37.69	0.90	0.19662	0.00610	14.80247	0.26800	0.54589	0.00931	2798	13	2803	17	2808	39	1506	33	
7	90.55	330.06	0.27	0.05337	0.00501	0.17536	0.01570	0.02383	0.00049	345	165	164	14	152	3	137	9	
8	25.41	36.03	0.71	0.05049	0.00480	0.16779	0.01524	0.02410	0.00048	218	168	157	13	154	3	151	10	
9	107.53	221.35	0.49	0.05209	0.00437	0.18382	0.01459	0.02559	0.00049	289	145	171	13	163	3	164	11	
10	80.74	547.77	0.15	0.05040	0.00720	0.16380	0.02262	0.02357	0.00078	213	246	154	20	150	5	153	8	
11	83.28	533.75	0.16	0.04765	0.00678	0.15912	0.02215	0.02421	0.00053	82	245	150	19	154	3	163	21	
12	24.16	247.68	0.10	0.04727	0.01192	0.16064	0.04017	0.02464	0.00063	63	386	151	35	157	4	167	24	
13	173.55	352.98	0.49	0.04836	0.00531	0.16630	0.01765	0.02493	0.00051	117	199	156	15	159	3	140	23	
14	62.61	209.98	0.30	0.05067	0.00251	0.17016	0.00715	0.02435	0.00043	226	64	160	6	155	3	141	7	
15	109.61	254.25	0.43	0.04930	0.00945	0.16895	0.03178	0.02485	0.00083	162	307	159	28	158	5	145	9	
16	97.91	330.52	0.30	0.05241	0.00784	0.17700	0.02598	0.02449	0.00053	303	289	165	22	156	3	154	16	
17	84.74	270.52	0.31	0.04844	0.00299	0.17206	0.00960	0.02575	0.00046	121	93	161	8	164	3	181	14	
18	35.79	195.94	0.18	0.04853	0.00471	0.16360	0.01518	0.02444	0.00050	125	169	154	13	156	3	159	14	

含量在  $31.52 \times 10^{-6} \sim 571.80 \times 10^{-6}$ , Th 含量在  $24.16 \times 10^{-6} \sim 173.55 \times 10^{-6}$ , Th/U 比值均大(等)于 0.1、小于 1, 具有岩浆锆石的特点<sup>[20, 21]</sup>。除 2 个测试点可能因为污染出现  $^{208}\text{Pb}/^{232}\text{Th}$  年龄为负值外, 其他 18 个测试点  $^{206}\text{Pb}/^{238}\text{U}$  年龄明显分为 3 组, 其中点 2 和点 6 年龄较老, 分别为  $(2250 \pm 18) \text{ Ma}$  和  $(2798 \pm 13) \text{ Ma}$  (岩浆源区可能存在老的基底); 点 5 年龄值为  $(230 \pm 6) \text{ Ma}$ ; 其余 15 个点年龄集中于  $(150 \pm 5) \text{ Ma} \sim (164 \pm 3) \text{ Ma}$ , 年龄加

权平均值为  $(157 \pm 2) \text{ Ma}$  ( $1\sigma$ , MSWD=1.3, 95% conf.) (图 8), 应为该花岗岩的结晶年龄。

## 5 讨论

### 5.1 花岗岩形成时代

利用进行锆石 U-Pb 年龄技术, 目前来看已经成为对成岩成矿进行年代限定的较为可信的几种放射性同位素测年方法之一, 已广泛应用到各类岩石矿石

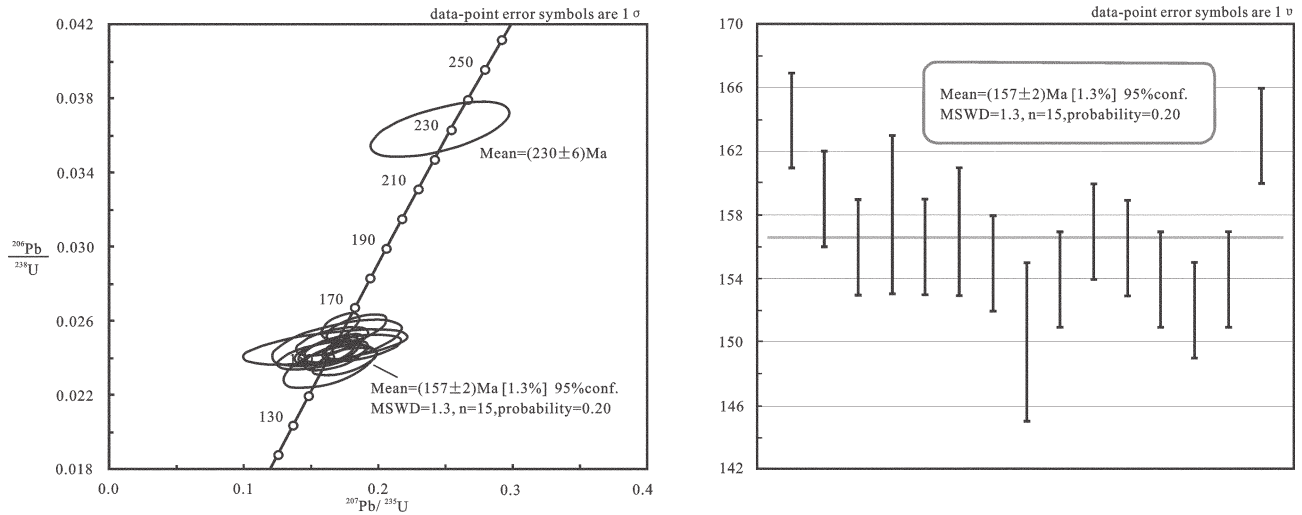


图8 幸福山花岗岩XFS1201样品LA-ICP-MS锆石U-Pb年龄谐和图(a)和加权平均值图(b)

Fig.8 LA-ICP-MS zircon U-Pb concordia diagram of Xingfushan granite sample XFS1201 (a) and weighted mean diagram (b)

形成年代的研究中。本文对从幸福山花岗岩中挑出的18粒锆石进行了LA-ICP-MS分析,得出了由15个点组成的加权平均值(157±2) Ma的年龄。

此15个测试点均处于岩浆锆石的振荡环带上,且此年龄与丁正江等<sup>[6]</sup>测得的邢家山钼钨矿辉钼矿Re-Os年龄(辉钼矿Re-Os法加权平均年龄为(158.91±1.91) Ma, Re-Os等时线年龄为(158.70±2.06) Ma),在误差范围内一致,说明(157±2) Ma可以代表该花岗岩的结晶年龄。这与胶东地区广泛出露的玲珑花岗岩年龄(160~150 Ma)<sup>[10, 22-24]</sup>基本一致。而本次测试所得到的另外2个(2798±13) Ma和(2250±18) Ma年龄,可能为捕获锆石年龄,暗示该岩浆源区可能存在老的侵入岩基底(前者对应于新太古代栖霞TTG岩系,后者对应于早元古代);点5年龄值为(230±6) Ma,则可能暗示着该区存在三叠纪的岩浆活动。

## 5.2 区域燕山早期成矿与找矿潜力问题

有研究认为,胶东地区侏罗纪以来的花岗岩基本上以NE—NNE向延伸分布为特征,这与辽东、吉林、黑龙江东部地区特征大致一致,推测中国东部地区构造岩浆活动可能受同一构造体系所影响,即中生代太平洋板块构造俯冲作用的影响<sup>[10, 11, 25]</sup>。这些地区花岗岩在岩石地球化学上也具有相似性,成岩与成矿时间上具有较好的对应性<sup>[10, 26-29]</sup>,与燕山早期(J<sub>2</sub>-J<sub>3</sub>)钙碱性侵入岩有关的斑岩型矿床,如大黑

山、福安堡、霍吉河、多宝山、岔路口、鹿鸣等斑岩型钼矿(180~160 Ma)<sup>[30-38]</sup>。事实上,甚至南中国地区也存在着同时期的与斑岩有关的铜钼矿床,如江西德兴(铜)、福建永定山口(钼)、江西新安(钼)、园岭寨(钼)、安徽东源(钨钼矿)、湖南黄沙坪(铅锌钨钼多金属)等<sup>[39-48]</sup>。这说明,在侏罗纪期间,中国东部确实广泛存在着以钼为主的钼铜多金属矿化。通过对比发现,邢家山钼钨矿床成矿母岩幸福山花岗岩与胶东西部广泛出露的玲珑花岗岩,地球化学特征较为一致,它们应是区域上具有密切成因联系的不同地壳层次的花岗质侵入体(图3)。推测,作为同期次具有相同地球化学特征的玲珑花岗岩,可能在侵位过程中也形成了一些规模钼多金属矿化。目前该花岗岩基大面积出露,表明其定位成岩后该地壳遭受了大规模抬升和剥蚀,致使上部斑岩所形成的矿床已被剥蚀殆尽,而邢家山钼钨矿可能因为区域性差异剥蚀所幸存下来的这个时期成矿的一个代表<sup>[6]</sup>。

在邢家山斑岩-矽卡岩型钼钨矿床南西方向约40 km、同是桃村断裂西侧还发现了中生代燕山晚期栖霞尚家庄中型斑岩型钼矿床((116.4±1.6) Ma)<sup>[49, 50]</sup>。研究表明,斑岩-矽卡岩型矿床一般成矿深度为4~5 km,即二者成矿深度大致相当。问题在于,上述2个斑岩(-矽卡岩)型矿床,一个是约160 Ma成矿,一个是约116 Ma成矿,时代相差约45 Ma,但二者标

高却大体一致。这说明,二者自成矿以来剥蚀量基本相等(4~5 km),也就是说,假定二者都是持续抬升剥蚀的话,邢家山地区剥蚀速率相对较小,大约相当于尚家庄地区剥蚀速率的3/4(116/160)左右,显示了该区较好的保存条件。这与孙丰月等(1995)提出的胶东西部地区(桃村断裂以西)中生代以来差异抬升是一致的<sup>[7]</sup>。同时,该区广泛出露的厚达几千米的古元古代和震旦纪变质岩层(图1)也说明了这一点。由此来看,挟持于栖霞断裂、桃村断裂之间的栖霞—福山地区可能相当于胶北隆起与苏鲁大别造山带之间的一个应力转换带,在整个区域演化中,表现的相对平静,仅在边缘或断裂发育处释放出少量成岩成矿的信号。这是否暗示着该区深部具有大的找矿潜力?

## 6 结 论

(1)幸福山花岗岩锆石LA-ICP-MS U-Pb加权平均年龄为(157±2) Ma,与邢家山钼钨矿形成时间一致,可以代表该花岗岩的结晶年龄。其地球化学特征与玲珑花岗岩类似。

(2)胶东地区存在着中生代燕山早期斑岩型钼多金属成矿作用,胶东西部可能存在着与玲珑花岗岩有关的该期大规模成矿,邢家山钼钨矿床仅是其中代表。栖霞—福山地区中生代以来剥蚀程度相对较小,矿床保存条件较好,具有寻找斑岩—矽卡岩型矿床的潜力。

**致谢:** 审稿专家及责任编辑杨艳老师对论文提出了宝贵修改意见,在此一并致以诚挚的谢意!

### 参考文献(References):

- [1] 丁正江,孙丰月,刘殿浩,等.烟台福山北部地区金及多金属矿成矿系列[J].山东国土资源,2011,27(1):1-6.  
Ding Zhengjiang, Sun Fengyue, Liu Dianhao, et al. Metallogenic series of gold and polymetal from the northern Fushan area in Yantai[J]. Land and Resources in Shandong Province, 2011, 27(1): 1-6(in Chinese with English abstract).
- [2] 张田,张岳桥.胶东半岛中生代侵入岩浆活动序列及其构造制约[J].高校地质学报,2007,13(2):323-336.  
Zhang Tian, Zhang Yueqiao. Geochronological sequence of Mesozoic intrusive magmatism in Jiaodong Peninsula and its tectonic constraints[J]. Geological Journal of China Universities, 2007, 13(2): 323-336(in Chinese with English abstract).
- [3] 宋明春主编.山东省大地构造格局和地质构造演化[M].北京:地质出版社,2009:1-173.  
Song Mingchun. Shandong Geotectonic Framework and Evolution[M]. Beijing: Geological Publishing House, 2009: 1-173(in Chinese).
- [4] 李杰.胶东地区钼-铜-铅锌多金属矿成矿作用及成矿模式——兼论与胶东金成矿作用的关系[D].成都:成都理工大学,2012:1-127.  
Li Jie. Molybdenum-Copper-Lead-Zinc Polymetallic Mineralization and Metallogenic Model in Jiaodong Peninsular and its Relationship with Gold Mineralization [D]. Chengdu: Chengdu University of Technology, 2012: 1-127(in Chinese with English abstract).
- [5] 孙丰月,丁正江,刘殿浩,等.初论胶东福山北部地区斑岩成矿系统[J].黄金,2011,336(1):14-19.  
Sun Fengyue, Ding Zhengjiang, Liu Dianhao, et al. Primary study on porphyry metallogenic system of the northern Fushan area in Jiaodong Peninsular[J]. Gold, 2011, 336(1): 14-19(in Chinese with English abstract).
- [6] 丁正江,孙丰月,刘建辉,等.胶东邢家山钼钨矿床辉钼矿Re-Os同位素测年及其地质意义[J].岩石学报,2012,28(9):2721-2732.  
Ding Zhengjiang, Sun Fengyue, Liu Jianhui, et al. Re-Os dating of molybenites from the Xingjiashan molybdenum-tungsten deposit in Jiaodong Peninsular and its geological significance[J]. Acta Petrologica Sinica, 2012, 28(9): 2721-2732(in Chinese with English abstract).
- [7] 孙丰月,石准立,冯本智.胶东金矿地质及幔源C-H-O流体分异成岩成矿[M].长春:吉林人民出版社,1995:1-170.  
Sun Fengyue, Shi Zhunli, Feng Benzhi. Geology of Gold Deposits in Jiaodong Peninsular and Mantle-derived C-H-O Fluids Differential Ore-and-rock Forming[M]. Changchun: Jilin People's Publishing House, 1995: 1-170(in Chinese).
- [8] 丁正江,孙丰月,刘福来,等.胶东伟德山地区铜钼多金属矿锆石U-Pb法测年及其地质意义[J].岩石学报,2013,(02):607-618.  
Ding Zhengjiang, Sun Fengyue, Liu Fulai, et al. U-Pb dating of zircons from the Weideshan molybdenum copper polymetallic deposits in Jiaodong Peninsular[J]. Acta Petrologica Sinica, 2013, (02): 607-618(in Chinese with English abstract).
- [9] 黎彤,袁怀雨,吴胜昔.中国花岗岩类和世界花岗岩类平均成分对比研究[J].大地构造与成矿学,1998,22(1):29-34.  
Li Tong, Yuan Huaiyu, Wu Shengxi. Comparison and study of

- granitoid average composition between China and the world[J]. *Geotectonica et Metallogenia*, 1998, 22(1): 29-34(in Chinese with English abstract).
- [10] 林博磊, 李碧乐. 胶东玲珑花岗岩的地球化学、U-Pb 年代学、Lu-Hf 同位素及地质意义[J]. *成都理工大学学报(自然科学版)*, 2013, (02): 147-160.
- Lin Bolei, Li Bile. Geochemistry, U-Pb chronology, Lu-Hf isotope of Linglong granites in Jiaodong Peninsular and its geological significance[J]. *Journal of Chengdu University of Technology(Science of Technology Edition)*, 2013, (02): 147-160 (in Chinese with English abstract).
- [11] Williams I S. U-Th-Pb geochronology by ion microprobe[C] // McKibben M A, Shanks W C, Ridley W I (eds.). *Applications of Microanalytical Techniques to Understanding Mineralizing Processes. Reviews in Economic Geology*, 1998, 7: 1-35.
- [12] Yuan HL, Gao S, Liu XM, et al. Accurate U-Pb age and trace element determinations of zircon by laser ablation inductively coupled plasma mass spectrometry[J]. *Geoanalytical and Geostandard Research*, 2004, 28(3): 353-370.
- [13] 于晓飞, 孙丰月, 李碧乐, 等. 西昆仑大同地区加里东期成岩、成矿事件: 来自 LA-ICP-MS 锆石 U-Pb 定年和辉钼矿 Re-Os 定年的证据[J]. *岩石学报*, 2011, 27(6): 1770-1778.
- Yu Xiaofei, Sun Fengyue, Li Bile, et al. Caledonian diagenetic and metallogenic events in Datong district in the western Kunlun: Evidences from LA-ICP-MS zircon U-Pb dating and molybdenite Re-Os dating[J]. *Acta Petrologica Sinica*, 2011, 27(6): 1770-1778(in Chinese with English abstract).
- [14] Andersen T. Correction of common lead in U-Pb analyses that do not report  $^{204}\text{Pb}$  [J]. *Chemical Geology*, 2002, 192(1/2): 59-79.
- [15] Liu Y S, Gao S, Hu Z C, et al. Continental and oceanic crust recycling-induced melt-peridotite interactions in the trans-North China orogen: U-Pb dating, Hf isotopes and trace elements in zircons from mantle xenoliths[J]. *Journal of Petrology*, 2010, 51(1/2): 537-571.
- [16] Liu Y S, Hu Z C, Gao S, et al. In situ analysis of major and trace elements of anhydrous minerals by LA-ICP-MS without applying an internal standard[J]. *Chemical Geology*, 2008, 257(1/2): 34-43.
- [17] Ludwig K. User's Manual for Isoplot 3.00: A Geochronological Toolkit for Microsoft Excel[M]. Berkeley Geochronology Center Special Publication, 2003, 4: 1-70.
- [18] Belousova EA, Griffin WL, O'Reilly SY, et al. Igneous zircon: Trace element composition as an indicator of source rock type[J]. *Contributions to Mineralogy and Petrology*, 2002, 143: 602-622.
- [19] Rubatto D. Zircon trace element geochemistry: Partitioning with garnet and the link between U-Pb ages and metamorphism[J]. *Chemical Geology*, 2002, 184: 123-138.
- [20] 吴元保, 郑永飞. 锆石成因矿物学研究及其对 U-Pb 年龄解释的制约[J]. *科学通报*, 2004, 49(16): 1589-1604.
- Wu Yuanbao, Zheng Yongfei. Study on zircon genetic mineralogy and its restrict to the implication of U-Pb age[J]. *Chinese Science Bulletin*, 2004, 49(16): 1589-1604(in Chinese).
- [21] 谢桂青, 胡瑞忠, 蒋国豪, 等. 锆石的成因和 U-Pb 同位素定年的某些进展[J]. *地质地球化学*, 2001, 29(4): 64-70.
- Xie Guiqing, Hu Ruizhong, Jiang Guohao, et al. Zircon genesis and some progress of U-Pb isotope dating[J]. *Geology and Geochemistry*, 2001, 29(4): 64-70(in Chinese with English abstract).
- [22] Qiu Y M, Groves D I, McNaughton N J, et al. Nature, age and tectonic setting of granitoid-hosted, orogenic gold deposits of the Jiaodong Peninsula, eastern North China craton, China[J]. *Miner. Dep.*, 2002, 37: 283-305.
- [23] Wang D Z, Zhang G T, Qiu J S. The tectonic constraint on the late Mesozoic A-type granitoid in eastern China[J]. *Geological Journal of China Universities*, 1995, 1(2): 13-20.
- [24] 苗来成, 罗镇宽, 黄佳展, 等. 山东招掖金矿带内花岗岩类侵入体锆石 SHRIMP 研究及其意义[J]. *中国科学(D辑)*, 1997, 3: 207-213.
- Miao Laicheng, Luo Zhenkuan, Huang Jiazhan, et al. Study on zircon SHRIMP of granitoid intrusions in the Zhaoye gold metallogenic belt of Shandong Province and its significance[J]. *Science in China (Series D)*, 1997, 3: 207-213 (in Chinese with English abstract).
- [25] 黄凡, 陈毓川, 王登红, 等. 中国钼矿主要矿集区及其资源潜力探讨[J]. *中国地质*, 2011, 38(5): 1111-1134.
- Huang Fan, Chen Yuchuan, Wang Denghong, et al. A discussion on the major molybdenum ore concentration areas in China and their resource potential[J]. *Geology in China*, 2011, 38(5): 1111-1134(in Chinese with English abstract).
- [26] 胡受奚, 赵懿英, 徐金方. 华北地台金成矿地质[M]. 北京: 科学出版社, 1997: 1-220.
- Hu Shouxi, Zhao Yiyang, Xu Jinfang. *Gold Metallogeny of North China Platform*[M]. Beijing: Science Press, 1997: 1-220(in Chinese).

- [27] 徐洪林, 张德全, 孙桂英. 胶东昆崙山花岗岩的特征、成因及其与金矿的关系[J]. 岩石矿物学杂志, 1997, 16(2): 131-143.  
Xu Honglin, Zhang Dequan, Sun Guiying. Characteristics and diagenesis of granites from Kunyu Mountain in Jiaodong Peninsular, and its relationship with gold deposits[J]. Acta Petrologica et Mineralogica, 1997, 16(2): 131-143(in Chinese with English abstract).
- [28] 孙景贵, 胡受奚, 凌洪飞. 胶东金矿区高钾-钾质脉岩地球化学与俯冲-壳幔作用研究[J]. 岩石学报, 2000, 16(3): 401-412.  
Sun Jinggui, Hu Shouxi, Ling Hongfei. Study on the geochemistry and subduction-crust mantle interaction of the high potassium-potassium like rocks in gold deposits concentration zone of east Shandong, China[J]. Acta Petrologica Sinica, 2000, 16(3): 401-412(in Chinese with English abstract).
- [29] 陈衍景, Franco P, 赖勇, 等. 胶东矿集区大规模成矿时间和构造环境[J]. 岩石学报, 2004, 20(4): 907-922.  
Chen Yanjing, Franco P, Lai Yong, et al. Metallogenic time and tectonic setting of the Jiaodong gold province, eastern China[J]. Acta Petrologica Sinica, 2004, 20(4): 907-922(in Chinese with English abstract).
- [30] 葛文春, 吴福元, 周长勇, 等. 兴蒙造山带东段斑岩型Cu、Mo矿床成矿时代及其地球动力学意义[J]. 科学通报, 2007, 52(20): 2407-2417.  
Ge Wenchun, Wu Fuyuan, Zhou Changyong, et al. Geochronology of porphyry Cu & Mo deposits in the Xingmeng Orogenic Belt and its geodynamic significance [J]. Chinese Science Bulletin, 2007, 52(20): 2407-2417(in Chinese).
- [31] 李立兴, 松权衡, 王登红, 等. 吉林福安堡铜矿中辉钼矿铼-钨同位素定年及成矿作用探讨[J]. 岩矿测试, 2009, 28(3): 283-287.  
Li Lixing, Song Quanheng, Wang Denghong, et al. Re-Os dating of molybdenite from the Fu'anpu molybdenum deposit of Jilin Province and discussion on its metallogenesis[J]. Rock and Mineral Analysis, 2009, 28(3): 283-287(in Chinese with English abstract).
- [32] 王成辉, 松权衡, 王登红, 等. 吉林大黑山超大型铜矿辉钼矿铼-钨同位素定年及其地质意义[J]. 岩矿测试, 2009, 28(3): 269-273.  
Wang Chenghui, Song Quanheng, Wang Denghong, et al. Re-Os dating of molybdenite from the Daheishan molybdenum deposit of Jilin Province and its geological significance[J]. Rock and Mineral Analysis, 2009, 28(3): 269-273 (in Chinese with English abstract).
- [33] 李向文, 王可勇, 钱烨, 等. 吉林大黑山铜矿床成矿流体地球化学特征及其地质意义[J]. 岩石学报, 2013, 29(9): 3173-3182.  
Li Xiangwen, Wang Keyong, Qian Ye, et al. The geochemical characteristics of oreforming fluids of Daheishan molybdenum deposit and its geological significance, Jilin Province [J]. Acta Petrologica Sinica, 2013, 29(9): 3173-3182(in Chinese with English abstract).
- [34] 陈静. 黑龙江小兴安岭区域成矿背景与有色、贵金属成矿作用[D]. 长春: 吉林大学, 2011.  
Chen Jing. Metallogenic Setting in Lesser Khingan Mountains Area of Heilongjiang Province and Metallogenesis of Nonferrous-precious Metals[D]. Changchun: Jilin University, 2011(in Chinese with English abstract).
- [35] 刘军, 武广, 钟伟, 等. 黑龙江省多宝山斑岩型铜(钼)矿床成矿流体特征及演化[J]. 岩石学报, 2010, 26(5): 1450-1466.  
Liu Jun, Wu Guang, Zhong Wei, et al. Fluid inclusion study of the Duobaoshan porphyry Cu(Mo) deposit, Heilongjiang Province, China[J]. Acta Petrologica Sinica, 2010, 26(5): 1450-1466(in Chinese with English abstract).
- [36] 刘军, 武广, 王峰, 等. 黑龙江省岔路口斑岩铜矿床流体包裹体和稳定同位素特征[J]. 中国地质, 2013, 40(4): 1231-1251.  
Liu Jun, Wu Guang, Wang Feng, et al. Fluid inclusions and stable isotope characteristics of the Chalukou porphyry Mo deposit in Heilongjiang Province[J]. Geology in China, 2013, 40(4): 1231-1251(in Chinese with English abstract).
- [37] Li B L, Shen X. Discussion on Middle Jurassic metallogenic mechanism of Au-Mo polymetallic hydrothermal deposits in eastern Jilin[J]. Global Geology, 2012, 15(1): 19-25.
- [38] 汪志刚. 吉林东部中生代内生金属矿床成矿作用研究[D]. 长春: 吉林大学, 2012.  
Wang Zhigang. Study on Mineralization of Mesozoic Endogenous Metal Deposits in Eastern Jilin Province[D]. Changchun: Jilin University, 2012(in Chinese with English abstract).
- [39] 王强, 赵振华, 简平, 等. 德兴花岗闪长斑岩 SHRIMP 锆石 U-Pb 年代学和 Nd-Sr 同位素地球化学[J]. 岩石学报, 2004, 20(2): 315-324.  
Wang Qiang, Zhao Zhenhua, Jian Ping, et al. SHRIMP zircon geochronology and Nd-Sr isotopic geochemistry of the Dexing granodiorite porphyries[J]. Acta Petrologica Sinica, 2004, 20(2): 315-324 (in Chinese with English abstract).
- [40] 姚军明, 华仁民, 屈文俊, 等. 湘南黄沙坪铅锌铜多金属矿床辉钼矿的 Re-Os 同位素定年及其意义[J]. 中国科学(D辑),

- 2007, 4: 471-477.
- Yao Junming, Hua Renmin, Qu Wenjun, et al. Re-Os isotopic dating of molybdenite from the Huangjiaping Lead-zinc-tungsten-molybdenum deposit in Hunan Province and its significance[J]. Science in China (Series D), 2007, 4: 471-477(in Chinese with English abstract).
- [41] 罗锦昌, 陈郑辉, 屈文俊. 福建省永定山口钼矿铼-钨同位素定年及其地质特征[J]. 岩矿测试, 2009, 28(3): 254-258.
- Luo Jinchang, Chen Zhenghui, Qu Wenjun. Re-Os dating of molybdenite from the Shankou molybdenum deposit in Yongding Country of Fujian Province and its geological significance[J]. Rock and Mineral Analysis, 2009, 28(3): 254-258 (in Chinese with English abstract).
- [42] 曾载淋, 刘善宝, 邓茂春, 等. 江西广昌新安钼矿床地质特征及其铼-钨同位素测年[J]. 岩矿测试, 2011, 30(2): 144-149.
- Zeng Zailin, Liu Shanbao, Deng Maochun, et al. Geological characteristics and Re-Os Dating of the Xin'an Molybdenum Deposit in Jiangxi Province[J]. Rock and Mineral Analysis, 2011, 30(2): 144-149(in Chinese with English abstract).
- [43] 周雪桂, 吴俊华, 屈文俊, 等. 赣南园岭寨钼矿辉钼矿 Re-Os 年龄及其地质意义[J]. 矿床地质, 2011, 30(4): 690-698.
- Zhou Xuegui, Wu Junhua, Qu Wenjun, et al. Re-Os dating of molybdenites from Yuanlingzhai molybdenum deposit in southern Jiangxi Province and its geological significance[J]. Mineral Deposits, 2011, 30(4): 690-698(in Chinese with English abstract).
- [44] 杜保峰, 魏俊浩, 王启, 等. 中国东部钼矿成矿背景与成岩-成矿时差讨论[J]. 矿床地质, 2010, 29(6): 935-955.
- Du Baofeng, Wei Junhao, Wang Qi, et al. Metallogenic setting and discussion of time difference of diagenesis-metallogenesis from Mo deposits in Eastern China[J]. Mineral Deposits, 2010, 29(6): 935-955(in Chinese with English abstract).
- [45] 郭保健, 毛景文, 李厚民, 等. 秦岭造山带秋树湾铜钼矿床辉钼矿 Re-Os 定年及其地质意义[J]. 岩石学报, 2006, 22(9): 2341-2348.
- Guo Baojian, Mao Jingwen, Li Houmin, et al. Re-Os dating of the Qiushuwan molybdenite deposit in Qinling Orogenic Belt[J]. Acta Petrologica Sinica, 2006, 22(9): 2341-2348(in Chinese with English abstract).
- [46] 黄典豪, 杜安道, 吴澄宇, 等. 华北地台钼(铜)矿床成矿年代学研究——辉钼矿铼-钨年龄及其地质意义[J]. 矿床地质, 1996, 15(4): 365-373.
- Huang Dianhao, Du Andao, Wu Chengyu, et al. Metallogenic chronology study of Mo(Cu) deposits in North China Platform[J]. Mineral Deposits, 1996, 15(4): 365-373(in Chinese with English abstract).
- [47] 杜玉雕, 余心起, 刘家军, 等. 皖南东源钼钨成矿流体特征和成矿物质来源[J]. 中国地质, 2011, 38(5): 1334-1346.
- Du Yudiao, Yu Xinqi, Liu Jiajun, et al. Characteristics of ore-forming fluids and sources of ore-forming materials in the Dongyuan W-Mo deposit, southern Anhui Province[J]. Geology in China, 2011, 38(5): 1334-1346(in Chinese with English abstract).
- [48] 刘晓菲, 袁顺达, 吴胜华. 湖南金船塘锡铋矿床辉钼矿 Re-Os 同位素测年及其地质意义[J]. 岩石学报, 2012, 28(1): 39-51.
- Liu Xiaofei, Yuan Shunda, Wu Shenghua. Re-Os dating of the molybdenite from the Jinchuantang tin-bismuth deposit in Hunan Province and its geological significance[J]. Acta Petrologica Sinica, 2012, 28(1): 39-51(in Chinese with English abstract).
- [49] 李杰, 宋明春, 王美云, 等. 胶东尚家庄钼矿床 Re-Os 同位素年龄及其地质意义[J]. 中国地质, 2013, 40(5): 1612-1621.
- Li Jie, Song Mingchun, Wang Meiyun, et al. The molybdenite Re-Os age and genetic analysis of the Shangjiashuang Mo deposits in Jiaodong area[J]. Geology in China, 2013, 40(5): 1612-1621(in Chinese with English abstract).
- [50] 薛玉山, 柳振江, 成少博, 等. 胶东邢家山大型钼矿地质地球化学特征及成因意义[J]. 中国地质, 2014, 41(2): 540-561.
- Xue Yushan, Liu Zhenjiang, Cheng Shaobo, et al. Geological-geochemical characteristics of the Xingjiashan Mo deposit in Jiaodong and their geological significance[J]. Geology in China, 2014, 41(2): 540-561(in Chinese with English abstract).