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浙西北平水铜矿细碧角斑岩成岩年龄及其地质意义

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摘要: 文章对浙西北平水铜矿赋矿围岩双溪坞群平水组细碧角斑岩中锆石进行了 LA-ICP-MS U–Pb 同位素年龄测定。结果显示锆石 Th/U 比值为 0.42~2.28, 明显高于 Th/U 比值小于 0.1 的变质成因的锆石, 为典型岩浆成因锆石。几乎所有的锆石颗粒样品都投影在谐和曲线上及其附近, 细碧岩年龄加权平均值为 $(952 \pm 5) \text{ Ma}$ ($n=18$, MSWD=0.19), 角斑岩年龄加权平均值为 $(954 \pm 8) \text{ Ma}$ ($n=15$, MSWD=0.51); 结合锆石自形、发育岩浆环带等特点, 该年龄是平水组细碧角斑岩的形成年龄。结合前人研究及地质事实, 本次研究确定双溪坞群平水组细碧角斑岩的成岩年龄为新元古代(950 Ma 左右); 认为江南造山运动发生的上、下限虽还没有最终限定, 但它东端的造山运动很可能介于 1.0~0.9 Ga; 钦杭成矿带北东段地区有寻找同类矿床的潜力。

关 键 词: 平水铜矿; 细碧角斑岩; LA-ICP-MS; 新元古代; 地质意义

中图分类号: P597^{+.3}

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Chronology and geological significance of spillite–keratophyre in Pingshui Formation, northwest Zhejiang Province

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Abstract: This paper reports LA-ICP-MS zircon U–Pb ages of spillite–keratophyre in Pingshui Formation, northwest Zhejiang Province. The Th/U ratios in the range of 0.42–2.28 show that the zircon is a typical magmatic mineral. Analytical results show that the weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of the spillite is $(952 \pm 5) \text{ Ma}$ ($n=18$, MSWD=0.19), and that of the keratophyre is $(954 \pm 8) \text{ Ma}$ ($n=$

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15, MSWD=0.51). Combined with previous studies and geological facts, the authors hold that the diagenetic epoch of the spillite-keratophyre in the Pingshui Formation was the Neoproterozoic (about 950 Ma). It is further suggested that the amalgamation between the Yangtze and Cathaysia Blocks in the eastern segment of the Jiangnan orogen was completed between 1.0 Ga and 0.9 Ga. It can be inferred that the Pingshui area and even Qin-Hang metallogenic belt have the potential in search for VMS deposits.

Key words: Pingshui copper deposit; spillite-keratophyre; LA-ICP-MS; Neoproterozoic; geological significance

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浙江平水铜矿是浙江省最大的铜矿床,为典型的火山成因块状硫化物矿床(VMS),其位于钦杭成矿带北东段浙西北地区^[1]。钦杭成矿带大致自西南端的广西钦州湾、经湘东和赣中延伸到东北端浙江杭州湾,整体呈北东向反S状弧形展布,全长近2000 km,宽100~150 km。钦杭结合带不仅是一条巨型的构造-岩浆活动带,而且也是有利的成矿作用带。在这条长约2000 km的古板块结合带上,已探明的大、中型矿床达400余处,其中包括德兴、银山、金山、永平、东乡、芙蓉、黄沙坪、柿竹园、芙蓉、锡矿山、水口山、黄沙坪、东坡、佛子冲等大型-超大型金属矿床(田)^[2-4]。浙西北地区也位于成矿地质条件优越的钦杭成矿带北东段,但是,区内目前仅发现了中型的平水铜矿、小型的建德铜矿和小型的横山金矿等;浙西北地区矿化异常和矿化点非常发育,具有进一步寻找大型矿床的潜力。平水铜矿已连续开采了30余年,前人对平水铜矿在地质特征、成矿流体、矿床成因及成岩成矿年代学等方面已经进行了大量、详细的研究^[5-12],但主要集中在矿床成因和成矿模式等方面;而在某些方面研究依旧薄弱,制约区域找矿,如:与成矿关系密切的细碧角斑岩的成岩时代以及成矿构造背景等方面仍没有最终确定。因此,本文选择浙西北地区的平水铜矿,对其细碧角斑岩采用精确的LA-MC-ICP-MS锆石U-Pb法进行年代学制约,揭示浙西北地区平水组细碧角斑岩的成岩时代和产出构造背景,为找矿勘查提供依据。

1 地质概况

研究区位于钦杭成矿带北东段的绍兴平水地区

(图1-a)。出露地层主要为中新元古界双溪坞群平水组,主要岩性为细碧角斑岩系,局部夹晶屑凝灰岩、泥质硅质岩、砂岩等。区域内出露的主要侵入岩为新元古代早期中酸性的西裘岩体(原称平水岩体)和桃红岩体。Ye et al.^[13]对桃红和西裘2个岩体的SHRIMP年代学和地球化学研究表明,桃红岩体(913 ± 15 Ma)与西裘岩体(905 ± 14 Ma)的形成时代基本一致,且均形成于活动大陆边缘环境,为同期幔源岩浆分异形成的典型I型花岗岩。本地区褶皱构造不发育,主要是由平水组构成的倾向北西的单斜构造;断裂较多,主要呈北东走向,如矿区内的F₁断层(图1-b)。

平水铜矿矿体产于平水组火山旋回第一旋回和第二旋回的间隙期内,位于第一旋回上部的火山岩中,直接容矿岩石是一套细碧角斑岩组合。矿床由19条铜矿体及1条硫矿体组成。一号铜矿体是区内最大的矿体,长1000余米,矿体平均厚8.81 m,倾斜延伸在750 m以上,矿体产状较陡,走向北东40°~60°,沿走向和倾斜均呈舒缓状弯曲。矿体形态简单,呈层状、似层状、透镜状,除三号矿体与顶板细碧质碎屑熔岩呈低角度喷发不整合外,其余矿体和顶底板围岩整合并与围岩同步褶皱,具层控特征(图1-c)。矿石片理亦和围岩片理一致。矿石构造主要为块状、条带状、浸染状,矿石结构主要为细粒他形-半自形结构、破碎结构,矿石矿物主要是黄铁矿、黄铜矿、少量闪锌矿、磁铁矿,脉石矿物主要为石英、方解石、绿泥石、石膏和重晶石等。

2 样品采集和测试方法

2.1 样品采集和描述

本文选择矿体直接顶底板的平水组细碧岩和

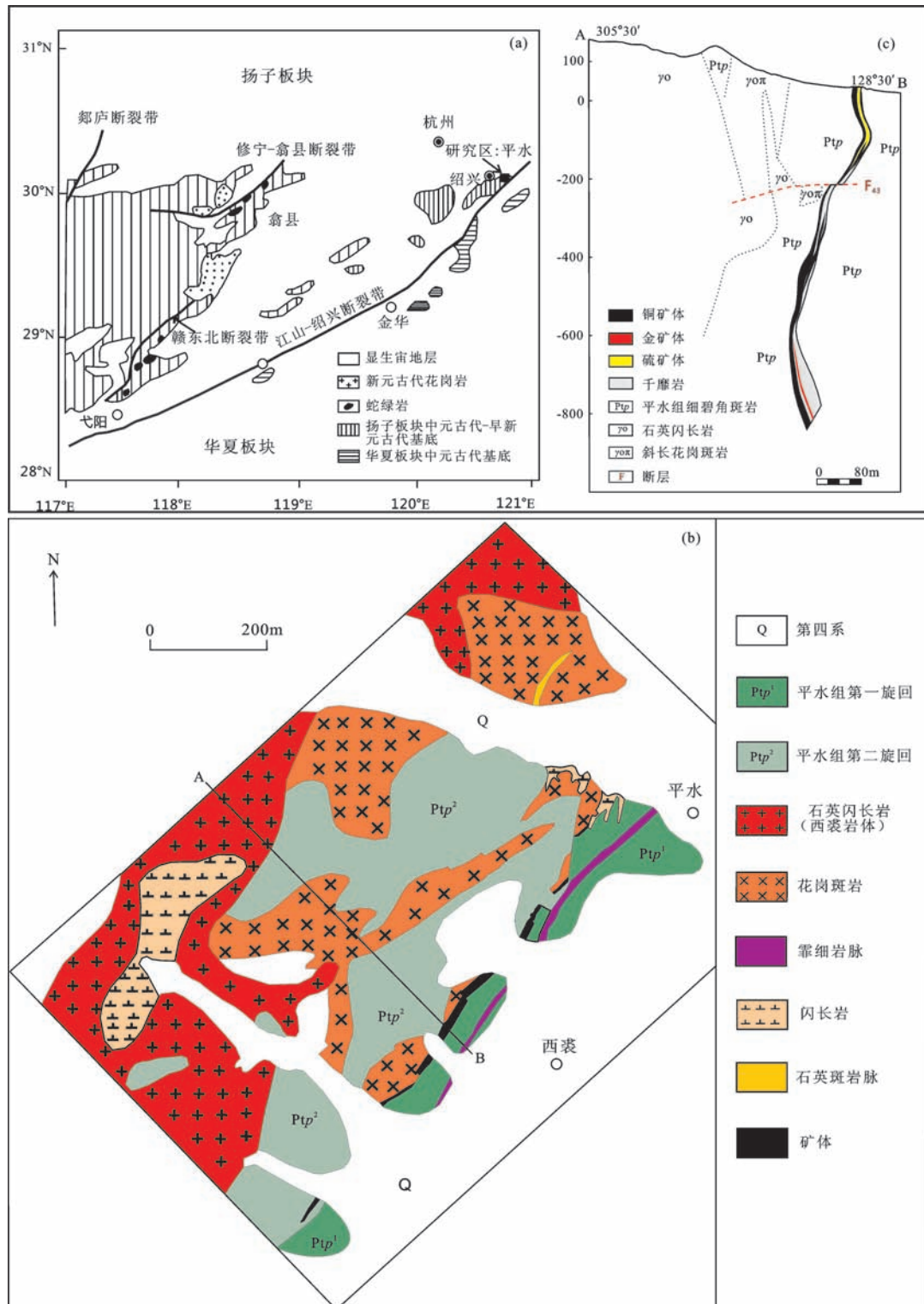


图1 平水铜矿构造位置及地质简图(据文献[11-12]修改)

a—构造背景示意图; b—平水铜矿矿床地质简图; c—剖面图

Fig. 1 Tectonic background schematic map and geological sketch map of the Pingshui copper deposit (modified after references [11-12])

a—Tectonic background schematic map; b—Geological sketch map of the Pingshui copper deposit; c—Geological section

角斑岩作为研究对象;细碧岩样品采自矿区-505中段1线矿体底板位置;角斑岩样品采自剖面露头,地理坐标 $29^{\circ}53'27''\text{N}$ 、 $120^{\circ}36'43''\text{E}$ 。细碧岩:主要呈斑状结构,矿物成分主要是钠更长石(70%~80%)和辉石(10%~15%)为主,可见少量铁矿和蚀变矿物,斑晶成分主要为辉石,镜下未见橄榄石及其蚀变假象,绿帘石、绿泥石和辉石常充填于由长柱状钠更长石组成的格架空隙中。细碧岩样品普遍发生了绢云母化和绿泥石化(图2-a、c、d)。角斑岩:多呈灰

绿色,斑状结构,基质霏细结构或显微花岗岩结构;斑晶含量占15%~25%,多以石英与斜长石为主,铁镁质矿物含量较少,未见钾长石。斑晶石英多呈熔蚀或淬冷特征,一些颗粒具波状消光,斑晶斜长石(0.5~1.3 mm)多为宽板状(长宽比1:3左右),镜下聚片双晶发育,部分受到蚀变影响。基质主要由长石和石英组成,含少量钛铁矿,粒度0.01~0.1 mm。所有样品均发育不同程度的片理化构造,同时受到后期轻微的绿泥石化、绿帘石化以及碳酸盐化改造(图

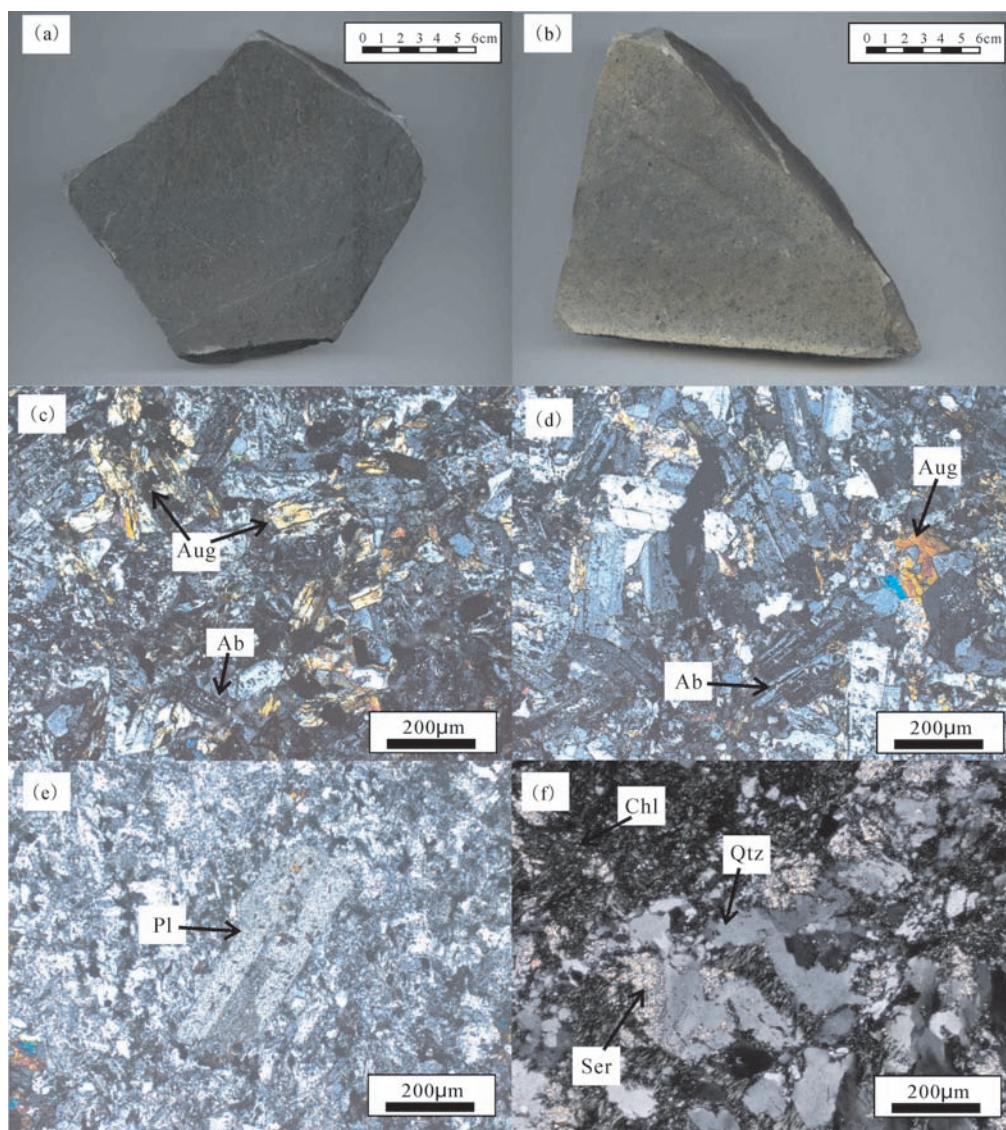


图2平水组细碧角斑岩手标本及镜下照片

Aug—辉石;Ab—钠长石;Pl—斜长石;Qtz—石英;Chl—绿泥石;Ser—绢云母

Fig. 2 Samples and microscopic photos of Pingshui spillite-keratophyre
Aug—Pyroxene; Ab—Albite; Pl—Plagioclase; Qtz—Quartz; Chl—Chlorite; Ser—Sericite

2-b、e、f)。

2.2 测试方法

样品经人工破碎后,按常规的重力和磁选方法分选出锆石,最后在双目显微镜下挑选。将待测样品锆石颗粒置于环氧树脂中制靶,然后磨至一半,用于阴极发光CL图像和LA-ICP-MS U-Pb同位素分析。在显微镜观察的基础上,选择合适的样品进行了阴极发光研究,特别避开锆石内部的包裹物以及锆石内部裂隙,以进行下一步的激光原位剥蚀测试。

阴极发光CL图像在西北大学大陆动力学国家重点实验室完成,锆石LA-ICP-MS U-Pb分析在南京大学内生金属矿床成矿机制国家重点实验室完成。采用仪器为Agilent 7500a ICP-MS。其工作参数为:等离子气体Ar 16 L/min,辅助气体Ar 1 L/min,剥蚀物质载气He 0.9~1.2 L/min。激光剥蚀系统波长213 nm,激光脉冲频率5 Hz,宽度5 ns,剥蚀孔径40 μm ,剥蚀时间80 s,背景测量时间40 s,脉冲能量为10~20 J/cm²,²⁰⁶Pb、²⁰⁷Pb、²⁰⁸Pb、²³²Th和²³⁸U的停留时间依次为15、30、10、10和15 ms。应用锆石标样GJ-1进行同位素分馏校正,均一的GEMOC/GJ-1GJ-1锆石标样的测试值为(601±12) Ma^[14];此外,在分析中加入“未知”标样Mud Tank(分析值(735±12) Ma)^[15],用于监控测试的重现性和仪器的稳定性,实验室对GJ-1和Mud Tank锆石标样的测试结果与其他实验室的测试结果一致。质谱的分析数据通过即时分析软件GLITTER计算获得相应的同位素比值、年龄以及误差,上述数据采用Andersen的方法进行普通铅校正^[16],校正后的最终结果应用Isoplot程序完成年龄计算和谐和图的绘制。

2.3 测定结果

LA-ICP-MS锆石U-Pb定年的样品为细碧岩和角斑岩。锆石定年结果见表1和图3。锆石阴极发光图像(CL)显示,锆石颗粒长度为100~150 μm ,具有典型的岩浆锆石震荡环带。锆石具有U含量 $101\times 10^{-6}\sim 1529\times 10^{-6}$,Th含量 $78\times 10^{-6}\sim 3676\times 10^{-6}$,Th/U比值为0.42~2.28(表1)。Th/U比值与典型的岩浆锆石一致,明显高于Th/U比值小于0.1的变质成因的锆石。CL图像也表现出典型的岩浆生长韵律环带结构(图3)。利用Ludwig Isoplot V.206进行

了谐和曲线和加权平均年龄的投影和计算,几乎所有的锆石颗粒样品都投影在谐和曲线上及其附近,表明这些锆石颗粒形成后U-Pb同位素体系是封闭的,基本上没有U或Pb的丢失或加入。

大多数U-Pb定年结果集中在谐和线附近。细碧岩²⁰⁶Pb/²³⁸U年龄加权平均值为(952±5) Ma ($n=18$, MSWD=0.19),角斑岩年龄加权平均值为(954±8) Ma ($n=15$, MSWD=0.51)(图3)。结合锆石自形、发育岩浆环带等特点,该年龄被解释成平水组细碧角斑岩的形成年龄。

3 讨论与认识

3.1 成岩时代

浙西北双溪坞群主要出露于绍兴市平水、富阳章村以及诸暨陈蔡地区西北部。双溪坞群自下而上划分为平水组、北坞组、岩山组和章村组。根据岩石组合差异,可以把双溪坞群火山-沉积岩系划分为早晚2个火山-沉积旋回。早期旋回以绍兴平水组为代表,以细碧-角斑岩为特征。晚期旋回以富阳章村为代表,以英安质凝灰岩、熔结凝灰岩为主,为中酸性陆相火山岩^[17-18]。

双溪坞群的年代学研究随着同位素定年技术的提高在不断进步,已获得的数据有:绍兴平水组有890~970 Ma^[19](Sm-Nd法)、(978±44) Ma^[18](Sm-Nd法)、1012 Ma^[20](Sm-Nd法)、(906±10) Ma^[10](锆石U-Pb法);北坞组有(926±15) Ma^[21](锆石U-Pb法);富阳章村组有875~904 Ma^[17](TIMS单颗粒锆石U-Pb法)、(1154±122) Ma^[22](全岩Sm-Nd等时线法)、(891±12) Ma^[21](锆石U-Pb法)。考虑到定年方法的适用性和可靠性,目前普遍认为北坞组的年龄为926 Ma,章村组的年龄为891 Ma。平水组的年龄仍存在争议,20世纪90年代以前发表的测年数据跨度太大,可能因测试方法陈旧等原因而精度不够;而Chen et al.(2009)^[10]得到的角斑岩的成岩年龄为906 Ma,但是其²⁰⁶Pb/²³⁸U U-Pb年龄不谐和,范围跨度较大,为878~999 Ma;而且906 Ma的年龄比上覆北坞组的年龄还年轻,也比侵入其中的桃红岩体和西裘岩体(结晶年龄905~913 Ma)^[13]年轻,这与地质事实不符。本文通过LA-ICP-MS锆石U-Pb定年法得到细碧岩的结晶年龄为(952±5) Ma,角斑岩的结晶年龄为(954±8) Ma,U-Pb年龄均很谐和,定年方法

表1 平水组细碧角斑岩的LA-ICP-MS 锆石U-Th-Pb 分析结果
Table 1 Zircon LA-ICP-MS U-Pb isotope dating results of Pingshui spillite-keratophyre

分析样点	²³² Th	²³⁸ U	Th/U	同位素比值			表面年龄/ Ma		
	/10 ⁻⁶			²⁰⁷ Pb/ ²⁰⁶ Pb(1σ)	²⁰⁷ Pb/ ²³⁵ U(1σ)	²⁰⁶ Pb/ ²³⁸ U(1σ)	²⁰⁷ Pb/ ²⁰⁶ Pb(1σ)	²⁰⁷ Pb/ ²³⁵ U(1σ)	²⁰⁶ Pb/ ²³⁸ U(1σ)
样品 ps523									
1	602	361	1.67	0.0706±0.0010	1.5385±0.0239	0.1582±0.0020	945±30	946±10	947±11
2	467	292	1.6	0.0700±0.0010	1.5541±0.0238	0.1611±0.0020	928±29	952±9	963±11
3	786	436	1.8	0.0688±0.0013	1.5039±0.0282	0.1586±0.0021	892±37	932±11	949±12
4	416	291	1.43	0.0700±0.0010	1.5295±0.0234	0.1585±0.0020	929±29	942±9	948±11
5	573	642	0.89	0.0703±0.0011	1.5446±0.0255	0.1594±0.0020	937±32	948±10	953±11
6	308	178	1.73	0.0725±0.0013	1.5792±0.0292	0.1581±0.0021	999±36	962±11	946±12
7	277	161	1.72	0.0701±0.0012	1.5368±0.0276	0.1590±0.0021	932±35	945±11	951±11
8	455	285	1.59	0.0707±0.0014	1.5424±0.0302	0.1583±0.0021	947±39	947±12	948±12
9	818	445	1.84	0.0697±0.0011	1.5232±0.0244	0.1586±0.0020	919±31	940±10	949±11
10	755	332	2.28	0.0697±0.0012	1.5400±0.0272	0.1603±0.0021	919±34	947±11	959±12
11	235	210	1.12	0.0696±0.0010	1.5314±0.0234	0.1597±0.0020	916±29	943±9	955±11
12	548	331	1.66	0.0685±0.0011	1.5162±0.0250	0.1605±0.0021	885±32	937±10	960±12
13	1511	824	1.83	0.0701±0.0009	1.5453±0.0217	0.1599±0.0020	932±26	949±9	956±11
14	404	247	1.63	0.0694±0.0011	1.5145±0.0257	0.1582±0.0021	912±33	936±10	947±11
15	476	301	1.58	0.0682±0.0011	1.4951±0.0244	0.1590±0.0020	875±32	928±10	951±11
16	589	314	1.88	0.0701±0.0012	1.5398±0.0272	0.1593±0.0021	932±35	946±11	953±11
17	234	158	1.48	0.0708±0.0015	1.5465±0.0323	0.1585±0.0022	952±42	949±13	948±12
18	545	300	1.81	0.0694±0.0012	1.5243±0.0276	0.1593±0.0021	912±36	940±11	953±12
样品 ps105									
1	478	488	0.98	0.0709±0.0018	1.5157±0.0408	0.1551±0.0027	954±52	937±16	930±15
2	78	101	0.78	0.0713±0.0024	1.5698±0.0534	0.1597±0.003	966±68	958±21	955±17
3	1577	1391	1.13	0.0719±0.0013	1.5755±0.0319	0.1589±0.0025	984±35	961±13	951±14
4	723	822	0.88	0.0742±0.0017	1.6147±0.0402	0.1579±0.0027	1046±47	976±16	945±15
5	573	417	1.37	0.0693±0.0013	1.5176±0.0328	0.1588±0.0026	908±38	938±13	950±15
6	3676	1671	2.2	0.0712±0.0016	1.5481±0.0381	0.1578±0.0027	962±46	950±15	945±15
7	477	1270	0.38	0.0701±0.0012	1.5462±0.0313	0.1600±0.0026	931±35	949±12	957±15
8	615	471	1.31	0.0703±0.0013	1.5846±0.0342	0.1636±0.0027	936±38	964±13	977±15
9	1060	1144	0.93	0.0708±0.0017	1.556±0.0407	0.1594±0.0028	953±49	953±16	953±16
10	843	707	1.19	0.0719±0.0028	1.5764±0.0609	0.1591±0.0033	982±77	961±24	952±18
11	454	1087	0.42	0.0701±0.0013	1.5648±0.0331	0.1619±0.0027	931±37	956±13	967±15
12	711	614	1.16	0.0689±0.0017	1.5189±0.0399	0.1599±0.0028	896±50	938±16	956±16
13	1323	1529	0.87	0.0703±0.0013	1.5446±0.0332	0.1594±0.0026	937±38	948±13	953±15
14	1257	1202	1.05	0.0706±0.0015	1.554±0.0358	0.1596±0.0027	947±41	952±14	955±15
15	1019	792	1.29	0.0704±0.0018	1.569±0.0432	0.1617±0.0029	939±53	958±17	966±16

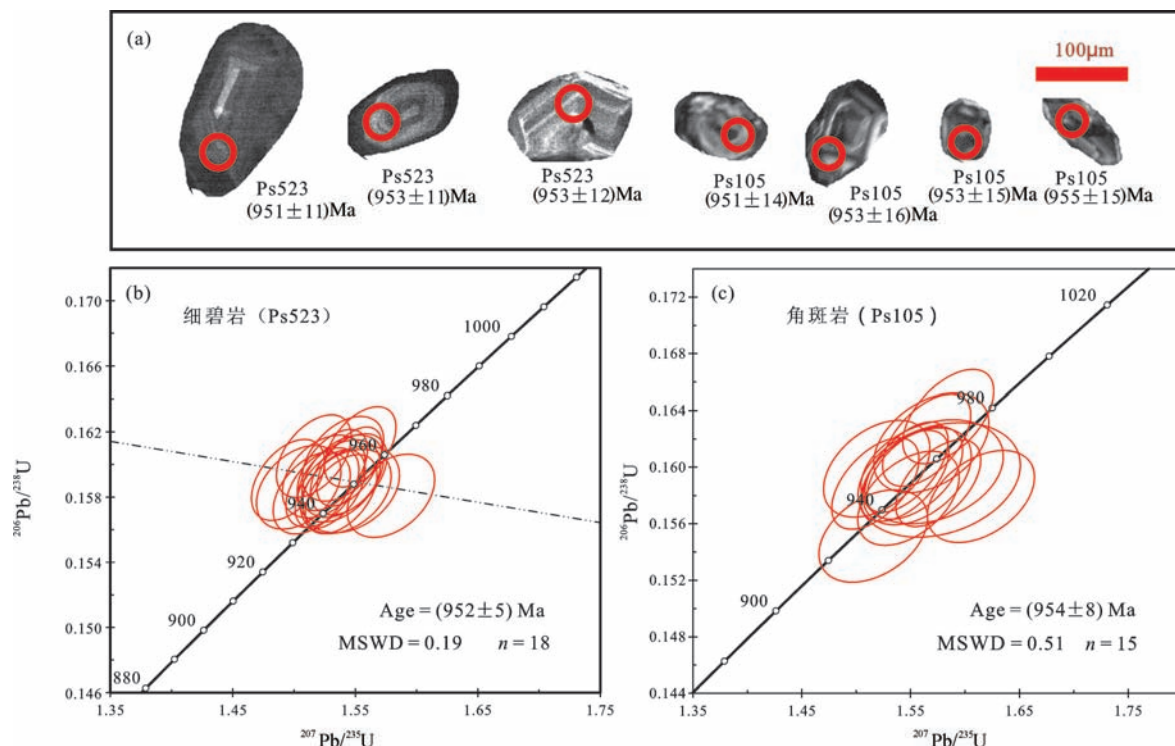


图3 平水组细碧角斑岩锆石CL图和ICP-MS U-Pb谐和线图

Fig. 3 Zircon CL images and LA-ICP-MS U-Pb concordia diagram of Pingshui spilite-keratophyre

可靠;而且,大约950 Ma的成岩年龄与地质事实相符。因此,通过本文详细的锆石年代学研究,确定双溪坞群平水组细碧角斑岩的成岩年龄为950 Ma左右。

3.2 构造背景

近年来的地质学、岩石学和年代学研究表明,扬子地块和华夏地块在新元古代时期发生俯冲和碰撞作用,形成了一个联合的统一大陆,其碰撞拼贴带在东北端就为江—绍断裂带^[21],但其碰撞时间仍存在争议,主要有2种观点:一种观点认为是从中元古代到新元古代(1.1~0.9 Ga)^[13, 23-28];另一种观点认为是在新元古代中期(0.86~0.8 Ga)^[29-36]。前人研究表明双溪坞群火山岩和平水地区同造山的花岗闪长岩(西裘岩体和桃红岩体)是典型的岛弧岩浆活动^[13],本文得到的双溪坞群最老的成岩年龄为952~954 Ma,结合区域上川南回龙沟同构造花岗片麻岩的成岩年龄为1007 Ma和约1.0 Ga的赣东北蛇绿岩及伴生的约970 Ma的埃达克质花岗岩指示当时属于俯冲环境^[37]。因此,本文研究结果表明江南造山运动发生的上、下限虽还没有最终限定,但它东端的造山运动很可能发生于1.0~0.9 Ga。

3.3 区域找矿意义

火山成因块状硫化物矿床是硫化物以层状形式形成的矿物聚集体,它主要沉淀于海底或者近海底,在空间上、时间上和成因上与同时代的火山作用密切相关^[38];矿体常与围岩地层整合产出,围岩成岩年龄常代表其成矿年龄;因此平水组细碧角斑岩的成岩年龄可以对平水铜矿成矿年龄进行了一个很好的限定,其成矿年龄应该是在新元古代(950 Ma左右)。江西弋阳(铁砂街)铜矿同样位于钦杭成矿带北东段,前人研究表明弋阳铜矿是典型的火山成因块状硫化物矿床,其围岩同样为细碧角斑岩,成岩成矿年龄也是新元古代^[39]。并且,平水铜矿和弋阳铜矿均是形成于岛弧环境^[39]。同时,从全球范围看,火山成因块状硫化物矿床空间上常呈带(区)成群分布,形成总体储量可观的矿田、矿带^[38]。因此,平水铜矿成岩年龄的最终确定,为区域找矿,特别是为在钦杭成矿带北东段寻找同类矿床提供了重要依据。

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及相关人员的热情帮助,南京大学武兵老师在测试期间提供了技术保障,论文修改过程中审稿专家和编辑部李亚萍老师提出了宝贵修改意见,在此表示衷心的感谢!

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