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## 北祁连肃南地区阴沟群形成时代及沉积源区讨论 ——碎屑锆石 U-Pb 年龄证据

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**摘要:**北祁连造山带肃南地区是阴沟群的典型分布区, 主要由中基性火山岩、火山碎屑岩夹硅质岩、变质泥岩及砂岩组成。本文对阴沟群上部 2 件粗砂岩碎屑锆石进行 LA-ICP-MS U-Pb 年龄的测定, 分别获得最小谐和年龄( $425 \pm 2$ ) Ma、( $425 \pm 5$ ) Ma, 代表其形成时代可能为早—中志留世, 说明肃南地区原划为早奥陶世的阴沟群可能存在不同时代的物质组成, 其形成时代需要进一步的厘定。碎屑锆石谐和年龄分布特征表明, 其物源主要来自南部的中祁连地块 (800~1000 Ma、1600~1800 Ma), 其次来自北祁连岛弧和同碰撞/碰撞后花岗岩 (425~510 Ma), 而源自北部华北板块的沉积物 (老于 1800 Ma 的锆石) 则极少。

**关键词:**北祁连造山带; 碎屑锆石; 阴沟群; 物源; 锆石 U-Pb; LA-ICP-MS

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## Age and provenance of the Yingou Group in Sunan area of North Qilian Mountain: Evidence from detrital zircon U-Pb Dating

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**Abstract:** The Yingou Group is mainly distributed in Sunan area of North Qilian orogenic belt and consists of intermediate-basic volcanic rocks, pyroclast intercalated with silicalite, metamorphic mudstones and sandstones. U-Pb ages of detrital zircons from two sandstone samples in the Upper Yingou Group were measured using the LA-ICP-MS method. The ages of the youngest zircons, ( $425 \pm 2$ ) Ma and ( $425 \pm 5$ ) Ma, indicate that the deposition took place in the Early to Middle Silurian. Therefore, the age and the composition of the Yingou Group should be redefined. The concordant ages of detrital zircons show that the provenance in the Upper Yingou Group was derived mainly from the Central Qilian block (800-1000 Ma, 1600-1800 Ma), subordinately from the North Qilian arc and synorogenic granites (425-510 Ma), and rarely from the North China plate (> 1800 Ma).

**Key words:** North Qilian orogenic belt; detrital zircon; Yingou Group; provenance; zircon U-Pb; LA-ICP-MS

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北祁连造山带位于青藏高原东北缘,是中祁连地块与华北板块西部之间典型的碰撞造山带(图1)。近年来,关于北祁连造山带古老基底、洋盆性质与洋壳俯冲碰撞过程,及大地构造演化等问题,一直受到众多专家的广泛关注<sup>[1-17]</sup>。阴沟群在北祁连造山带内沿走向延伸,分布广泛,以祁连县川刺沟剖面出露最完整,主要由中基性火山岩、火山碎屑夹硅质岩、变质泥岩及砂岩组成。该地层单元由尹赞勋等创立<sup>[18]</sup>,命名为阴沟统,依据其中部层位所采的三叶虫和笔石化石,时代划为早奥陶世,1981年青海省地研所编图组将其改称为阴沟群,此方案一直沿用至今<sup>[19]</sup>。随着锆石微区原位U-Th-Pb同位素测定技术的发展,一些学者在该造山带盆地形成及其物源区构造演化研究中取得了重要研究成果<sup>[15-17,20]</sup>。然而,对阴沟群的碎屑时代和演化相对较少,且一直缺乏精确的同位素年龄数据。

本研究通过采用LA-ICP-MS技术对北祁连造山带肃南地区阴沟群上部粗砂岩样品中的锆石进行的U-Pb同位素测定,分析其年龄谱特征,取得了新的认识,进而为肃南地区早古生代构造演化提供

依据。

## 1 地质概况

北祁连造山带位于华北板块西南缘龙首山与中祁连地块之间,北界为龙首山断裂,南缘与中祁连北缘断裂相接,东端为同心—固原断裂,西端为阿尔金断裂所截切。自北向南,北祁连造山带可以划分为河西走廊弧后盆地、北祁连岛弧、海沟俯冲杂岩3个不同构造分区<sup>[2]</sup>。

自元古宙以来,北祁连造山带主要经历了大陆裂谷、板块构造和陆内造山3个阶段<sup>[8]</sup>。在古元古代中期,由于软流圈地幔柱上涌,导致大陆岩石圈开始逐渐拉伸、裂谷化。至晚寒武世,发生大陆裂解和分离,形成北祁连早古生代洋盆。至早奥陶世,北祁连洋盆开始向北俯冲、消减,形成完整的北祁连早古生代沟-弧-盆系<sup>[1-2,7,11-14]</sup>。目前在造山带中保存的奥陶纪弧后盆地、岛弧、俯冲杂岩和消减洋壳残片,就是北祁连早古生代洋盆俯冲、消减作用的产物<sup>[2,8]</sup>。至晚奥陶世—早志留世,由于洋壳的不断消减导致北祁连洋盆闭合,北部奥陶纪岛弧带与

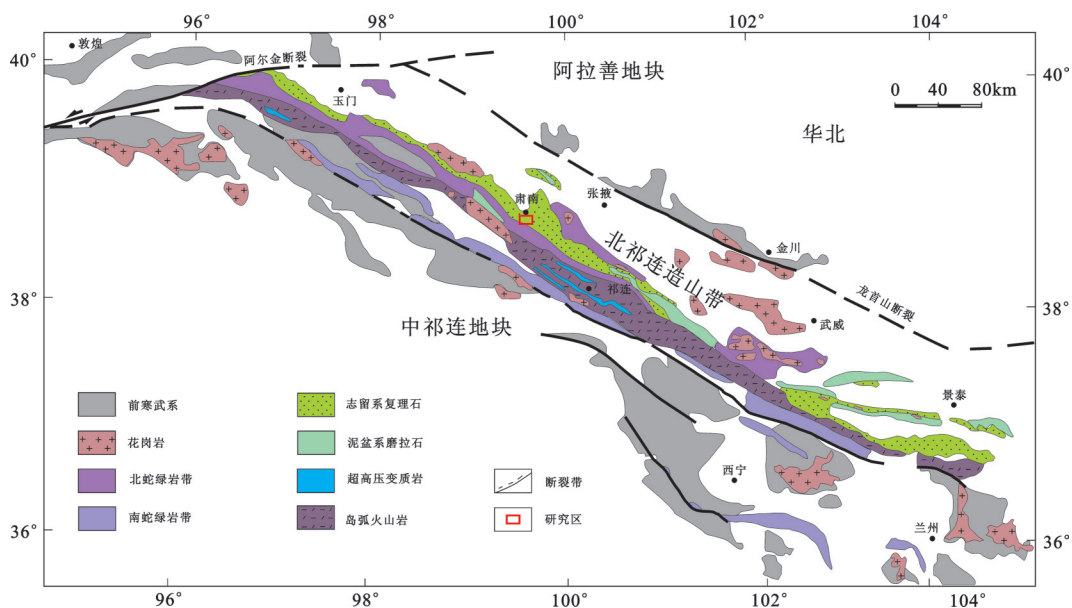


图1 北祁连造山带地质图(据文献[13]修改)

Fig.1 Geological map of the North Qilian orogen (modified after reference [13])

南部中祁连地块发生弧-陆碰撞<sup>[2,7]</sup>。泥盆纪,南部中祁连地块与北部华北大陆板块发生对接碰撞造山<sup>[21]</sup>。在北祁连河西走廊一带广泛分布的志留纪复理石和泥盆纪磨拉石,代表了北祁连同造山过程的沉积响应<sup>[2-3,6]</sup>。

北祁连肃南地区,奥陶系—泥盆系分布广泛,地层发育良好。其中奥陶系分为下奥陶统阴沟群、中奥陶统中堡群、上奥陶统妖魔山组和南石门子组,与上伏地层角度不整合接触;志留系出露完整,为一套复理石建造,以单斜层出现,自下而上可划分为鹿角沟组、肮脏沟组、泉脑沟山组、早峡组4个组,组与组之间整合接触;泥盆系为中下泥盆统老君山组,是一套陆相磨拉石沉积建造,与下伏地层角度不整合接触。本文观察剖面位于北祁连造山带中段,在甘肃省肃南县城西南部白泉门和野牛沟附近(图2~3)。

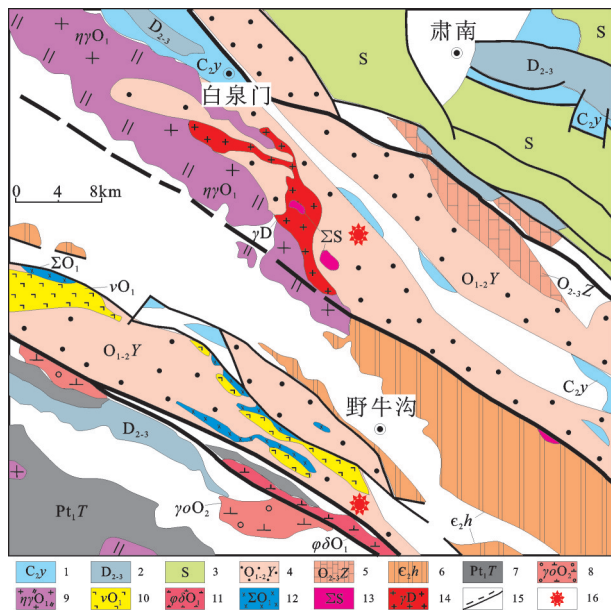


图2 肃南地区地质简图

- 1—羊虎沟组;2—中晚泥盆世地层;3—志留纪地层;4—阴沟群;  
5—中堡群;6—黑茨沟组;7—托赖岩群;8—中奥陶世斜长花岗岩;  
9—早奥陶世二长花岗岩;10—早奥陶世辉长岩;11—早奥陶世辉石  
闪长岩;12—早奥陶世超基性岩;13—志留纪超基性岩;  
14—泥盆纪花岗岩;15—断层/推测断层;16—采样位置
- Fig.2 Simplified geological map of the Sunan area  
1—Yanghugou Formation; 2—Middle-late Devonian strata; 3—Silurian strata; 4—Yingou Group; 5—Zhongbao Group; 6—Heicigou Formation;  
7—Tuolai Group; 8—Middle Ordovician plagiogranite; 9—Early Ordovician adamellite; 10—Early Ordovician gabbro; 11—Early Ordovician pyroxene diorite; 12—Early Ordovician ultrabasic rocks; 13—Silurian ultrabasic rocks; 14—Devonian granite; 15—Fault/ inferred fault; 16—Sampling location

## 2 样品采集与分析方法

本研究中的2件碎屑锆石样品(12-38-R1和12-25-R2),为肃南地区前人划为阴沟群上部的砂岩,其各自的采样位置:样品12-38-R1的点为北纬38°23'45"、东经99°28'33.05",样品12-25-R2的点为北纬38°39'27.60"、东经99°29'23"(图2~3)。锆石的分选工作由河北省廊坊市宇能岩石矿物分选技术服务有限公司完成。锆石样品靶制备及反射光、透射光拍摄在西北大学大陆动力学国家重点实验室完成,锆石阴极发光图像拍摄在中国科学院地质与地球物理研究所扫描电镜实验室完成。

锆石LA-ICP-MS U-Pb同位素分析在天津地质调查中心同位素实验室完成。分析使用的激光器型号为美国ESI公司UP193-FX ArF准分子激光器,激光波长为193 nm,脉冲宽度5 ns。束斑直径为35 μm,激光频率为8~10 Hz;预剥蚀时间和剥蚀时间分别为5 s和45 s。实验过程使用He作为载气,流速为0.85 L/min。等离子质谱仪(ICP-MS)为Thermo Fisher公司制造的Neptune。数据处理软件使用ICPMS Data Cal程序<sup>[22]</sup>和Ludwig的Isoplot程序<sup>[23]</sup>。年龄计算时以标准锆石GJ-1为外标进行同位素比值校正<sup>[24]</sup>。元素含量以标准玻璃NIST612为外标计算。

对于锆石年龄大于10亿年的数据,采用<sup>207</sup>Pb/<sup>206</sup>Pb年龄,而对于锆石年龄小于10亿年的数据,采用<sup>206</sup>Pb/<sup>238</sup>U年龄<sup>[25-26]</sup>。以<sup>206</sup>Pb/<sup>238</sup>U年龄和<sup>207</sup>Pb/<sup>206</sup>Pb年龄比值为标准选择U-Pb年龄数据<sup>[25,27-29]</sup>,谐和度介于90%~110%的数据为有效数据。

## 3 分析结果

砂岩样品12-38-R1中的碎屑锆石大小不均,大多数介于80~180 μm,形状为次圆状和柱状。阴极发光(CL)图像显示(图4-a),大部分锆石呈次圆状和柱状,可见明显的振荡环带。该样品共测得86个数据(表1),在进行年龄统计分析时,剔除了谐和度较低的18个数据,仅保留谐和度较高的68个数据。这些测点数据大多数位于U-Pb谐和线附近,少数点沿不一致线分布(图5-a)。所统计的谐和年龄(谐和度为90%~110%)在频率分布图中形成425~500 Ma、800~1000 Ma、1000~1200 Ma等多个峰值,并以800~1000 Ma为主峰值(图5-b),其中2



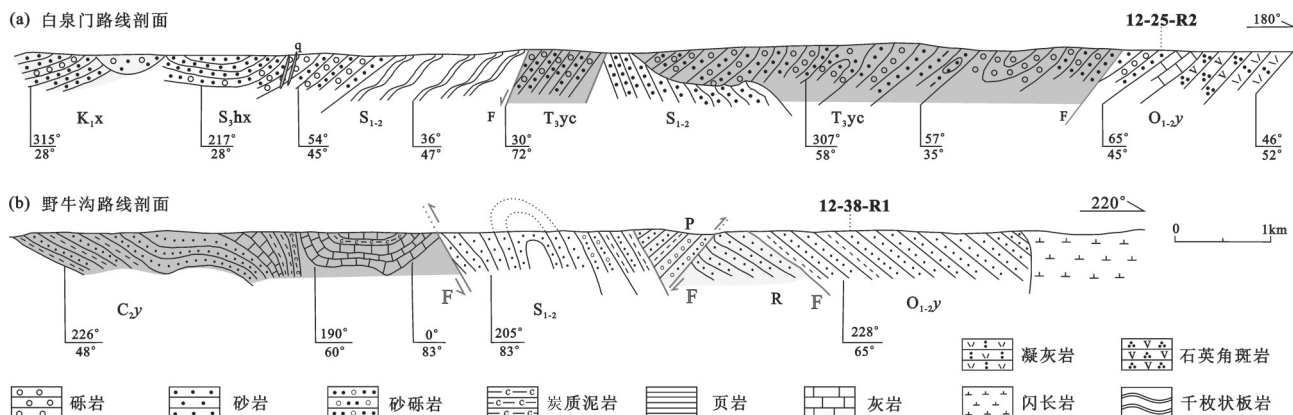


图3 肃南地区白泉门和野牛沟地质剖面图

Fig.3 Geological sections of Baimenquan and Yeniu in Sunan area, Gansu Province

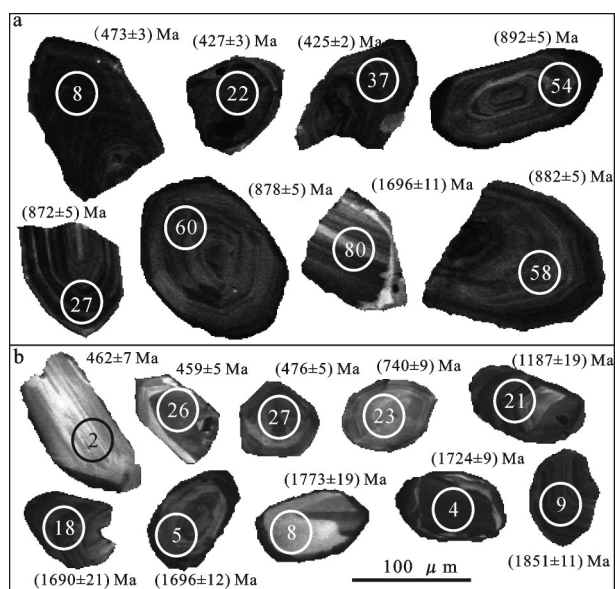


图4 北祁连造山带志留纪碎屑锆石CL图像

(数字代表测点位置和测点号, a—12-38-R1, b—12-25-R2)

Fig.4 Cathodoluminescence images of Silurian zircons in the North Qilian orogenic belt

(The numerals represent the positions and the serial number of measuring points, a—12-38-R1, b—12-25-R2)

个较年轻锆石年龄为(425±2) Ma、(427±3) Ma。

样品 12-25-R2 的碎屑锆石大小不等, 大多数介于 50~120 μm, 形状为次圆状和柱状。阴极发光 (CL) 图像显示 (图 4-b), 大部分锆石为次圆状和次棱角状, 呈无环带或面状分带, 可能为变质成因或经历部分熔融的锆石, 少部分锆石呈弱振荡环带。对该样品共进行 70 个测点分析, 剔除谐和度较差的

24 个点, 对剩下的 46 个点进行年龄统计, 分析数据见表 1。这些测点数据大多数位于 U-Pb 谐和图的谐和线附近, 少数点沿不一致线分布 (图 5-c)。其谐和年龄值 (谐和度为 90%~110%) 介于 425~1983 Ma (图 5-d), 在年龄频率分布图上主体形成 425~550 Ma、700~800 Ma、1600~1800 Ma 等多个峰值, 并以 425~550 Ma 为主峰值 (图 5-d), 其中 2 个较年轻锆石年龄为 (425±5) Ma、(427±4) Ma。

## 4 讨论

### 4.1 阴沟群形成时代的厘定

尹赞勋等<sup>[19]</sup>根据在阴沟群中部层位所采集的三叶虫和笔石化石将其时代界定为早奥陶世, 这是目前地层时代界定的唯一依据。以后地质工作者均沿用这一观点, 但未能提供更详细的证据。而碎屑锆石 U-Pb 年龄能够判断地层时代的下限。本文通过对前人划为阴沟群上部粗砂岩进行碎屑锆石的同位素分析, 结果显示, 样品 12-38-R1 两个较年轻锆石年龄分别为 (425±2) Ma (谐和度 104%)、(427±2) Ma (谐和度 100%), 样品 12-25-R2 两个较年轻锆石年龄分别为 (425±5) Ma (谐和度 104%)、(427±4) Ma (谐和度 105%)。这些数据谐和度高, 表明阴沟群上部砂岩形成时代不是前人原定义的早奥陶世, 而可能为早—中志留世。肃南地区原划为早奥陶世的阴沟群可能存在不同时代的物质组成, 其形成时代需要进一步的厘定。

### 4.2 沉积物源区

北祁连造山带及其邻区前泥盆纪岩浆及其变

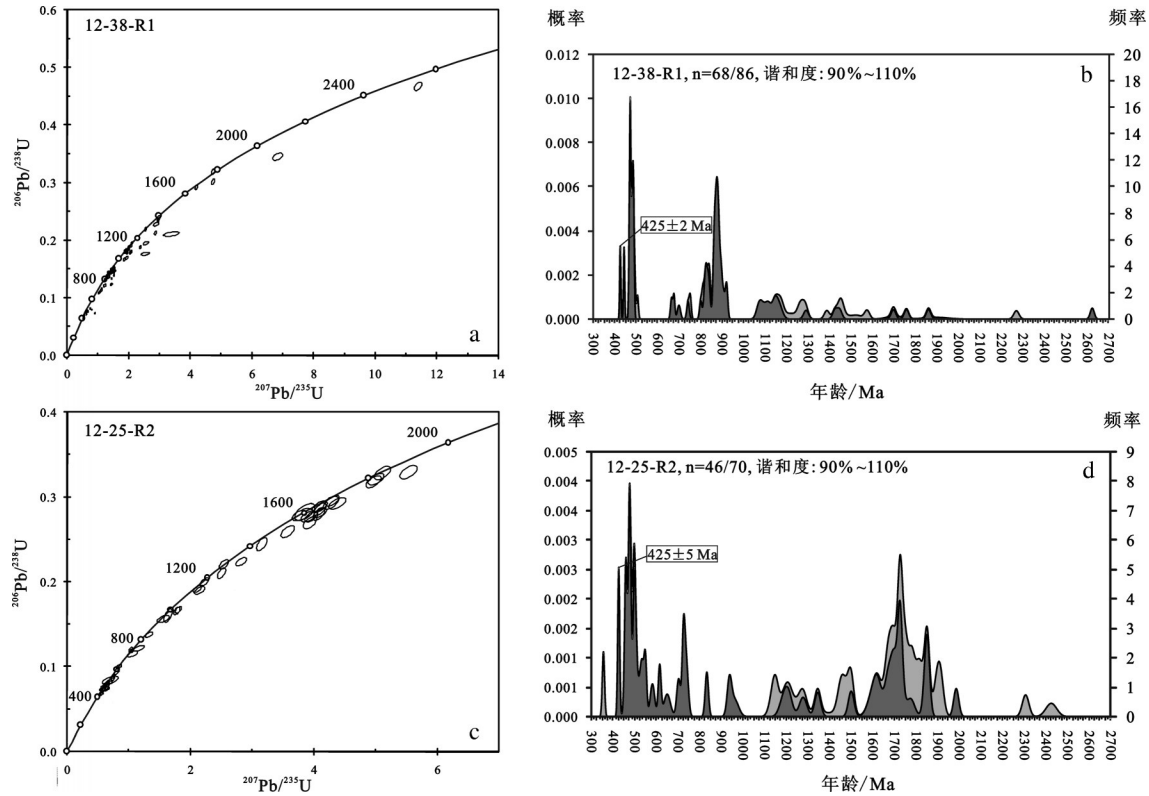


图5 锆石U-Pb谐和图和年龄频谱图

(深灰色区域为谐和度介于90%~110%的锆石年龄频谱图,浅灰色区域为所有锆石年龄频谱图;  
n指谐和度介于90%~110%的年龄数据/所有年龄数据)

Fig.5 Zircon U-Pb concordia diagrams and age spectra

The dark grey area shows zircon age spectra with concordant degree between 90%–110%, the light gray area for the all;  
“n” refers to the number of the zircons with concordant degree between 90%–110% / the total

质事件比较复杂。北祁连山带内部岩浆事件主要与北祁连洋消减产生的岛弧岩浆作用(460~510 Ma)以及同碰撞/碰撞后花岗岩(420~460 Ma)有关<sup>[30]</sup>。此外,北祁连蛇绿岩和裂谷火山岩年龄主要集中在500~700 Ma<sup>[31, 32]</sup>。同时,与北祁连洋壳俯冲产生的高压变质年龄集中在460~490 Ma<sup>[9-14]</sup>。中祁连地块基底区域岩浆事件主要集中在630~1000 Ma、1000~1200 Ma、1200~1600 Ma、1600~1800 Ma,尤其以800~1000 Ma的岩浆事件为主<sup>[33-38]</sup>。阿拉善地块(华北板块)区域岩浆事件则主要集中在1700~1800 Ma、2300~2400 Ma、2500~2600 Ma、2900~3000 Ma,其中在600~1600 Ma基本上没有岩浆活动的记录<sup>[39-47]</sup>。

从样品12-38-R1的年龄分布特征来看,800~1000 Ma和425~510 Ma的锆石年龄最为集中,所占比例最多(分别为39.1%和30.4%),其他年龄值零星分布。锆石年龄存在860 Ma的主峰值和472 Ma的

次峰年龄值。从锆石CL图像特征上看(图4-a),大多数472 Ma和860 Ma左右的锆石具有岩浆锆石振荡环带构造,颗粒较大,形态呈自形长板状,表明源区经历了岩浆事件。结合区域地质分析,表明800~1000 Ma的碎屑锆石很可能来自中祁连地块,为其主要的物源区,425~510 Ma的锆石大多数来自于北祁连岛弧(460~510 Ma),仅有少部分可能来自同碰撞/碰撞后花岗岩(420~460 Ma),而来自于华北地块的沉积物极少(老于1800 Ma的锆石)。

从样品12-25-R2的年龄分布特征来看,1600~1800 Ma和425~510 Ma的锆石年龄最为集中,所占比例最多(分别为31.1%和26.7%),其他年龄值零星分布。锆石年龄存在475 Ma的主峰值和726 Ma、1726 Ma 2个次峰年龄值。从锆石CL图像特征上看(图4-b),大多数475 Ma、726 Ma和1726 Ma左右的锆石具有变质锆石特征,部分具有岩浆锆石振

表 1 阴沟群上部粗砂岩(12-38-R1、12-25-R2)碎屑锆石 U-Pb 同位素数据  
 Table 1 U-Pb isotopic data for detrital zircons from the upper Yingou Group sandstone (sample 12-38-R1, 12-25-R2)

点号	含量/ $10^{-6}$				同位素比值				表面年龄/Ma				谐和度				
	Pb	Th	U	Tb/U	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$			
样品号: 12-38-R1																	
1	34	40	236	0.17	0.0702	0.0005	1.4186	0.0084	0.1466	0.0009	933	15	897	5	882	5	102
2	14	36	67	0.54	0.1041	0.0021	2.5383	0.0565	0.1768	0.0011	1699	37	1283	29	1050	7	162
3	48	45	361	0.12	0.0781	0.0006	1.4403	0.0081	0.1338	0.0008	1149	14	906	5	809	5	112
4	27	32	205	0.16	0.0687	0.0006	1.2777	0.0094	0.1350	0.0009	888	18	836	6	816	5	102
5	48	92	333	0.28	0.0719	0.0005	1.4220	0.0079	0.1435	0.0008	983	14	898	5	864	5	104
6	33	210	147	1.43	0.0805	0.0008	1.8514	0.0159	0.1668	0.0011	1209	21	1064	9	995	7	122
7	29	22	202	0.11	0.0752	0.0009	1.5067	0.0171	0.1454	0.0008	1073	24	933	11	875	5	107
8	37	127	483	0.26	0.0575	0.0006	0.6043	0.0066	0.0762	0.0005	511	25	480	5	473	3	101
9	32	27	228	0.12	0.0706	0.0005	1.4263	0.0078	0.1466	0.0009	945	14	900	5	882	6	102
10	49	78	144	0.54	0.1137	0.0007	4.7304	0.0218	0.3018	0.0020	1859	11	1773	8	1700	11	109
11	44	61	422	0.14	0.0681	0.0004	1.0185	0.0072	0.1085	0.0008	871	13	713	5	664	5	107
12	43	70	295	0.24	0.0693	0.0005	1.3679	0.0070	0.1431	0.0009	909	14	875	4	862	5	102
13	52	71	371	0.19	0.0704	0.0004	1.3829	0.0061	0.1425	0.0009	940	12	882	4	859	5	103
14	11	25	51	0.48	0.0948	0.0013	2.5524	0.0352	0.1953	0.0011	1524	26	1287	18	1150	7	133
15	31	85	215	0.39	0.0670	0.0005	1.2639	0.0072	0.1368	0.0009	839	14	830	5	826	5	100
16	27	97	337	0.29	0.0612	0.0005	0.6538	0.0043	0.0775	0.0005	647	17	511	3	481	3	106
17	37	36	68	0.53	0.1766	0.0010	11.3799	0.0520	0.4675	0.0030	2621	9	2555	12	2473	16	106
18	19	64	248	0.26	0.0584	0.0007	0.6151	0.0068	0.0763	0.0005	546	25	487	5	474	3	103
19	23	20	176	0.11	0.0676	0.0005	1.2898	0.0097	0.1384	0.0008	856	16	841	6	835	5	101
20	44	63	124	0.51	0.1075	0.0006	4.7299	0.0234	0.3192	0.0021	1757	11	1773	9	1786	12	98
21	32	34	255	0.13	0.0665	0.0004	1.2115	0.0075	0.1321	0.0009	823	14	806	5	800	6	101

续表1

点号	含量/ $10^{-6}$			同位素比值				表面年龄/Ma				谐和度			
	Pb	Th	U	Th/U	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		
22	21	147	278	0.53	0.5223	0.0049	0.0684	0.0004	427	23	427	4	427	3	100
23	37	40	249	0.16	1.4969	0.0078	0.1532	0.0010	953	13	929	5	919	6	101
24	32	119	426	0.28	0.6194	0.0037	0.0751	0.0005	596	15	489	3	467	3	105
25	56	40	316	0.13	2.0695	0.0101	0.1801	0.0011	1277	12	1139	6	1067	6	120
26	110	91	841	0.11	1.3650	0.0079	0.1374	0.0010	988	11	874	5	830	6	105
27	61	43	439	0.10	1.3755	0.0071	0.1448	0.0009	896	14	879	5	872	5	101
28	89	84	639	0.13	1.3506	0.0056	0.1433	0.0009	879	13	868	4	863	5	101
29	26	23	215	0.11	1.2145	0.0186	0.1218	0.0010	995	22	807	12	741	6	109
30	44	180	183	0.99	2.0921	0.0109	0.1947	0.0012	1146	12	1146	6	1147	7	100
31	32	97	422	0.23	0.5981	0.0039	0.0760	0.0005	495	17	476	3	472	3	101
32	47	111	632	0.18	0.6179	0.0036	0.0760	0.0005	567	17	489	3	472	3	104
33	137	174	1755	0.10	0.7458	0.0077	0.0816	0.0007	816	14	566	6	506	4	112
34	54	59	295	0.20	1.8985	0.0089	0.1829	0.0012	1076	12	1081	5	1083	7	99
35	30	33	215	0.15	1.3129	0.0071	0.1442	0.0009	808	14	851	5	868	5	98
36	57	63	231	0.27	2.9561	0.0203	0.2384	0.0018	1424	11	1396	10	1378	10	103
37	23	180	310	0.58	0.5501	0.0077	0.0681	0.0004	553	31	445	6	425	2	105
38	23	99	284	0.35	0.6617	0.0059	0.0761	0.0004	711	21	516	5	473	3	109
39	30	28	206	0.14	1.4456	0.0071	0.1472	0.0009	964	14	908	4	885	5	103
40	16	17	153	0.11	1.0532	0.0109	0.1105	0.0007	903	21	730	8	675	4	108
41	69	61	388	0.16	1.8881	0.0080	0.1805	0.0011	1092	11	1077	5	1070	7	102
42	59	108	314	0.34	1.8585	0.0089	0.1798	0.0011	1068	12	1066	5	1066	7	100
43	15	55	96	0.57	1.3253	0.0145	0.1394	0.0009	898	24	857	9	841	5	102
44	166	129	1223	0.11	1.5184	0.0080	0.1396	0.0009	1169	14	938	5	842	6	111
45	67	116	331	0.35	2.3724	0.0099	0.1881	0.0011	1456	11	1234	5	1111	7	131

续表1

点号	含量/ $10^{-6}$				同位素比值				表面年龄/Ma				谐和度				
	Pb	Th	U	Th/U	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$		$1\sigma$	$1\sigma$		
46	45	142	598	0.24	0.0005	0.0603	0.6264	0.0047	0.0754	0.0005	614	19	494	4	468	3	105
47	40	69	357	0.19	0.0006	0.0703	1.1092	0.0093	0.1144	0.0012	937	17	758	6	698	7	108
48	105	302	555	0.54	0.0005	0.0827	2.0452	0.0079	0.1794	0.0011	1261	12	1131	4	1064	7	119
49	43	112	212	0.53	0.0005	0.0791	1.9553	0.0098	0.1792	0.0011	1175	13	1100	6	1063	6	111
50	39	169	447	0.38	0.0009	0.0724	0.7955	0.0087	0.0797	0.0005	996	24	594	6	494	3	120
51	100	43	574	0.07	0.0005	0.0778	1.9451	0.0092	0.1812	0.0010	1143	12	1097	5	1074	6	106
52	39	174	495	0.35	0.0004	0.0613	0.6515	0.0039	0.0770	0.0005	651	15	509	3	478	3	106
53	33	26	251	0.10	0.0007	0.0707	1.3272	0.0132	0.1361	0.0008	950	21	858	9	822	5	104
54	27	25	181	0.14	0.0008	0.0741	1.5158	0.0165	0.1484	0.0009	1043	23	937	10	892	5	105
55	54	30	386	0.08	0.0005	0.0757	1.5080	0.0077	0.1445	0.0008	1087	13	934	5	870	5	107
56	41	128	527	0.24	0.0006	0.0601	0.6431	0.0060	0.0776	0.0005	609	22	504	5	482	3	105
57	53	190	318	0.60	0.0004	0.0691	1.4251	0.0069	0.1496	0.0010	901	13	899	4	899	6	100
58	35	29	240	0.12	0.0009	0.0755	1.5271	0.0189	0.1467	0.0009	1082	25	941	12	882	5	107
59	40	151	291	0.52	0.0008	0.0841	1.4334	0.0132	0.1236	0.0008	1295	17	903	8	751	5	120
60	42	51	287	0.18	0.0006	0.0711	1.4301	0.0120	0.1459	0.0009	960	19	902	8	878	5	103
61	42	151	564	0.27	0.0005	0.0582	0.6072	0.0038	0.0757	0.0004	536	17	482	3	470	3	102
62	81	99	459	0.22	0.0005	0.0766	1.9008	0.0082	0.1800	0.0012	1110	12	1081	5	1067	7	104
63	56	380	735	0.52	0.0005	0.0620	0.6107	0.0043	0.0714	0.0004	675	19	484	3	445	3	109
64	23	45	92	0.49	0.0011	0.0917	2.8848	0.0355	0.2281	0.0013	1462	23	1378	17	1324	8	110
65	34	303	366	0.83	0.0005	0.0581	0.6328	0.0045	0.0789	0.0005	535	19	498	4	490	3	102
66	20	60	127	0.47	0.0010	0.0710	1.4252	0.0193	0.1456	0.0009	958	27	900	12	876	5	103
67	40	157	496	0.32	0.0005	0.0580	0.6291	0.0038	0.0786	0.0005	532	18	496	3	488	3	102
68	7	57	16	3.55	0.0037	0.1159	3.3719	0.1064	0.2111	0.0016	1893	57	1498	47	1235	9	153
69	84	174	326	0.53	0.0005	0.0910	2.9501	0.0124	0.2352	0.0015	1446	11	1395	6	1362	9	106



续表1

点号	含量/10 <sup>-6</sup>			Th/U	同位素比值				表面年龄/Ma				谐和度				
	Pb	Th	U		<sup>207</sup> Pb/ <sup>206</sup> Pb	<sup>207</sup> Pb/ <sup>235</sup> U	<sup>206</sup> Pb/ <sup>238</sup> U	1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb	1σ	<sup>207</sup> Pb/ <sup>235</sup> U	1σ		<sup>206</sup> Pb/ <sup>238</sup> U	1σ		
70	133	218	577	0.38	0.0973	0.0006	2.8620	0.0150	0.2133	0.0014	1574	12	1372	7	1246	8	126
71	47	329	540	0.61	0.0601	0.0005	0.6477	0.0046	0.0782	0.0005	606	19	507	4	485	3	104
72	59	192	750	0.26	0.0579	0.0005	0.6264	0.0041	0.0784	0.0005	528	18	494	3	487	3	101
73	27	237	331	0.72	0.0568	0.0005	0.5570	0.0047	0.0711	0.0004	485	21	450	4	443	3	102
74	52	36	282	0.13	0.0769	0.0005	1.9943	0.0130	0.1881	0.0012	1119	13	1114	7	1111	7	101
75	10	36	129	0.28	0.0599	0.0011	0.6429	0.0112	0.0778	0.0005	600	39	504	9	483	3	104
76	182	2452	2065	1.19	0.0882	0.0005	0.9008	0.0035	0.0741	0.0005	1386	12	652	3	461	3	301
77	19	39	130	0.30	0.0744	0.0007	1.4893	0.0123	0.1452	0.0008	1053	19	926	8	874	5	106
78	30	18	208	0.09	0.0713	0.0006	1.4635	0.0100	0.1488	0.0009	967	17	915	6	894	5	102
79	26	45	134	0.34	0.0789	0.0006	2.0759	0.0127	0.1909	0.0011	1168	15	1141	7	1126	7	104
80	57	156	160	0.97	0.1040	0.0006	4.1856	0.0169	0.2920	0.0017	1696	11	1671	7	1651	10	103
81	80	25	226	0.11	0.1433	0.0010	6.8239	0.0666	0.3453	0.0025	2268	12	2089	20	1912	14	119
82	36	78	225	0.35	0.0712	0.0006	1.5076	0.0106	0.1535	0.0009	964	17	933	7	921	5	101
83	110	93	608	0.15	0.0786	0.0005	2.0066	0.0094	0.1852	0.0011	1162	14	1118	5	1095	7	106
84	32	76	173	0.44	0.0823	0.0009	1.9230	0.0205	0.1695	0.0010	1252	20	1089	12	1009	6	124
85	35	28	239	0.12	0.0723	0.0007	1.5072	0.0155	0.1511	0.0009	996	20	933	10	907	5	103
86	113	216	478	0.45	0.0839	0.0005	2.5377	0.0107	0.2194	0.0013	1290	12	1283	5	1279	7	101
样品号: 12-23-R2																	
1	79	149	275	0.54	0.0935	0.0006	3.1528	0.0350	0.2445	0.0031	1499	13	1446	16	1410	18	106
2	15	59	180	0.33	0.0592	0.0023	0.6074	0.0263	0.0744	0.0011	576	86	482	21	462	7	104
3	61	59	525	0.11	0.0636	0.0006	1.0432	0.0138	0.1189	0.0010	729	21	725	10	724	6	100
4	172	162	571	0.28	0.1056	0.0005	4.0761	0.0384	0.2801	0.0030	1724	9	1650	16	1592	17	108
5	80	77	261	0.29	0.1040	0.0007	4.0946	0.0411	0.2856	0.0029	1696	12	1653	17	1620	16	105
6	64	95	206	0.46	0.1110	0.0008	4.1640	0.0436	0.2720	0.0025	1817	13	1667	17	1551	14	117

续表1

点号	含量/ $10^{-6}$				同位素比值				表面年龄/Ma				谐和度				
	Pb	Th	U	Th/U	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{207}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{207}\text{Pb}$		$^{206}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$		
7	81	227	336	0.68	0.0805	0.0007	2.2230	0.0271	0.2002	0.0019	1210	17	1188	15	1176	11	103
8	46	38	148	0.25	0.1084	0.0011	4.3733	0.0575	0.2926	0.0028	1773	19	1707	22	1655	16	107
9	126	100	370	0.27	0.1132	0.0007	4.9641	0.0491	0.3181	0.0029	1851	11	1813	18	1780	16	104
10	99	129	570	0.23	0.0781	0.0006	1.8003	0.0204	0.1672	0.0016	1149	14	1046	12	997	9	115
11	80	74	228	0.33	0.1130	0.0008	5.0002	0.0530	0.3210	0.0027	1848	13	1819	19	1795	15	103
12	19	38	136	0.28	0.0874	0.0037	1.4808	0.0762	0.1228	0.0025	1370	82	923	47	747	15	183
13	210	200	736	0.27	0.1057	0.0008	3.9333	0.0443	0.2699	0.0030	1726	15	1621	18	1540	17	112
14	41	79	199	0.40	0.0819	0.0011	2.1479	0.0355	0.1901	0.0019	1244	27	1164	19	1122	11	111
15	96	169	395	0.43	0.0913	0.0009	2.8185	0.0358	0.2238	0.0020	1454	18	1360	17	1302	11	112
16	32	27	414	0.06	0.0602	0.0011	0.6449	0.0142	0.0778	0.0009	609	41	505	11	483	5	105
17	123	57	509	0.11	0.1112	0.0013	3.6236	0.0404	0.2363	0.0020	1820	21	1555	17	1367	12	133
18	114	173	362	0.48	0.1036	0.0012	3.9560	0.0431	0.2768	0.0024	1690	21	1625	18	1575	14	107
19	52	111	165	0.67	0.1157	0.0011	4.0869	0.0515	0.2563	0.0023	1890	16	1652	21	1471	13	129
20	37	122	321	0.38	0.0676	0.0010	0.9879	0.0224	0.1060	0.0024	855	32	698	16	650	15	107
21	79	235	341	0.69	0.0796	0.0008	2.1050	0.0276	0.1918	0.0016	1187	19	1150	15	1131	9	105
22	27	108	138	0.79	0.0720	0.0016	1.5529	0.0396	0.1564	0.0017	986	46	952	24	937	10	102
23	19	46	141	0.32	0.0693	0.0020	1.1623	0.0367	0.1217	0.0014	907	59	783	25	740	9	106
24	94	199	316	0.63	0.0999	0.0009	3.5709	0.0449	0.2593	0.0029	1622	17	1543	19	1486	16	109
25	114	95	407	0.23	0.1099	0.0009	4.0666	0.0464	0.2684	0.0029	1798	14	1648	19	1533	17	117
26	27	182	312	0.58	0.0561	0.0019	0.5708	0.0207	0.0738	0.0008	457	75	459	17	459	5	100
27	23	128	265	0.48	0.0560	0.0017	0.5916	0.0209	0.0766	0.0009	452	69	472	17	476	5	99
28	122	449	432	1.04	0.0863	0.0006	2.5004	0.0278	0.2102	0.0025	1344	14	1272	14	1230	15	109
29	44	51	577	0.09	0.0589	0.0008	0.6499	0.0108	0.0800	0.0008	564	29	508	8	496	5	102
30	46	53	693	0.08	0.0591	0.0007	0.5578	0.0090	0.0684	0.0007	571	25	450	7	427	4	105

续表1

点号	含量/ $10^{-6}$				同位素比值				表面年龄/Ma				谐和度					
	Pb	Th	U	Th/U	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$				
31	148	206	2014	0.10	0.0005	0.0564	0.0005	0.5929	0.0085	0.0762	0.0007	468	20	473	7	474	4	100
32	246	206	790	0.26	0.0007	0.1053	0.0007	4.2929	0.0448	0.2958	0.0025	1719	12	1692	18	1670	14	103
33	70	152	389	0.39	0.0008	0.0738	0.0008	1.6322	0.0290	0.1605	0.0032	1035	23	983	17	960	19	102
34	155	349	363	0.96	0.0008	0.1128	0.0008	5.1056	0.0554	0.3284	0.0032	1845	13	1837	20	1830	18	101
35	52	83	218	0.38	0.0011	0.1028	0.0011	3.0086	0.0416	0.2122	0.0021	1676	19	1410	19	1241	12	135
36	144	108	508	0.21	0.0010	0.1024	0.0010	3.9159	0.0538	0.2774	0.0026	1668	18	1617	22	1578	15	106
37	63	86	446	0.19	0.0010	0.0697	0.0010	1.3244	0.0248	0.1379	0.0012	919	29	856	16	833	7	103
38	71	62	718	0.09	0.0010	0.0607	0.0010	0.8382	0.0188	0.1001	0.0011	629	37	618	14	615	7	101
39	144	135	491	0.28	0.0013	0.0988	0.0013	3.8079	0.0677	0.2794	0.0029	1602	25	1594	28	1589	16	101
40	77	99	251	0.40	0.0013	0.0989	0.0013	3.8518	0.0670	0.2825	0.0041	1603	24	1604	28	1604	23	100
41	35	97	347	0.28	0.0012	0.0617	0.0012	0.8037	0.0177	0.0944	0.0017	665	40	599	13	582	10	103
42	15	78	179	0.44	0.0027	0.0601	0.0027	0.6098	0.0303	0.0736	0.0011	608	98	483	24	458	7	106
43	83	103	357	0.29	0.0007	0.0833	0.0007	2.5349	0.0317	0.2207	0.0023	1277	17	1282	16	1285	13	99
44	75	140	252	0.56	0.0010	0.1170	0.0010	3.8728	0.0448	0.2401	0.0024	1911	15	1608	19	1387	14	138
45	18	47	212	0.22	0.0023	0.0590	0.0023	0.6583	0.0273	0.0809	0.0010	568	84	514	21	501	6	102
46	104	507	359	1.41	0.0008	0.0931	0.0008	2.5698	0.0312	0.2002	0.0018	1490	16	1292	16	1176	11	127
47	181	140	668	0.21	0.0007	0.1071	0.0007	3.8105	0.0408	0.2581	0.0025	1750	13	1595	17	1480	14	118
48	63	113	284	0.40	0.0008	0.0915	0.0008	2.5090	0.0303	0.1988	0.0026	1458	17	1275	15	1169	15	125
49	56	134	201	0.67	0.0011	0.1075	0.0011	3.4032	0.0445	0.2296	0.0037	1758	18	1505	20	1332	21	132
50	121	180	452	0.40	0.0007	0.1087	0.0007	3.5342	0.0366	0.2357	0.0022	1778	12	1535	16	1364	13	130
51	297	107	1067	0.10	0.0007	0.1057	0.0007	4.0989	0.0417	0.2813	0.0023	1726	12	1654	17	1598	13	108
52	13	55	126	0.43	0.0042	0.0600	0.0042	0.6970	0.0528	0.0842	0.0019	605	150	537	41	521	12	103
53	37	143	300	0.48	0.0020	0.0663	0.0020	1.0529	0.0334	0.1152	0.0014	816	63	730	23	703	9	104
54	103	101	384	0.26	0.0010	0.1166	0.0010	4.0883	0.0484	0.2543	0.0038	1905	16	1652	20	1461	22	130

续表 1

点号	含量/ $10^{-6}$				同位素比值				表面年龄/Ma				谱和度				
	Pb	Th	U	Th/U	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$	$1\sigma$	$1\sigma$	$1\sigma$
55	26	46	112	0.41	0.1030	0.0016	2.9750	0.0542	0.2096	0.0024	1678	29	1401	26	1227	14	137
56	61	51	201	0.25	0.1028	0.0009	4.0929	0.0498	0.2888	0.0027	1675	17	1653	20	1636	15	102
57	173	308	427	0.72	0.1218	0.0008	5.5301	0.0585	0.3292	0.0032	1983	12	1905	20	1835	18	108
58	95	220	338	0.65	0.1568	0.0023	4.2798	0.0860	0.1979	0.0033	2422	25	1689	34	1164	20	208
59	34	117	477	0.25	0.0582	0.0015	0.5474	0.0161	0.0682	0.0008	537	56	443	13	425	5	104
60	69	63	945	0.07	0.0573	0.0007	0.6078	0.0088	0.0769	0.0008	503	25	482	7	478	5	101
61	97	109	1123	0.10	0.0620	0.0007	0.7393	0.0110	0.0865	0.0013	675	23	562	8	535	8	105
62	256	980	385	2.55	0.1463	0.0013	7.3640	0.0900	0.3650	0.0048	2303	15	2157	26	2006	26	115
63	301	127	1013	0.13	0.1057	0.0009	4.2740	0.0509	0.2933	0.0030	1727	16	1688	20	1658	17	104
64	96	205	780	0.26	0.0621	0.0006	1.0270	0.0126	0.1199	0.0013	679	20	717	9	730	8	98
65	69	91	749	0.12	0.0610	0.0007	0.7484	0.0119	0.0889	0.0010	640	26	567	9	549	6	103
66	29	109	338	0.32	0.0721	0.0011	0.7849	0.0135	0.0790	0.0011	988	31	588	10	490	7	120
67	71	111	409	0.27	0.0776	0.0007	1.7753	0.0213	0.1658	0.0019	1138	18	1036	12	989	11	115
68	30	51	374	0.14	0.0582	0.0011	0.6520	0.0128	0.0813	0.0012	536	41	510	10	504	7	101
69	168	219	714	0.31	0.1065	0.0010	3.1269	0.0388	0.2130	0.0020	1740	17	1439	18	1245	12	140
70	30	177	488	0.36	0.0610	0.0013	0.4772	0.0110	0.0567	0.0008	640	44	396	9	356	5	111

注:表中所列误差均为 $1\sigma$ 误差。



荡环带构造, 锆石颗粒较小, 形态呈他形、均质, 表明源区发生了一定程度的变质作用, 同时也伴随有岩浆活动。结合区域热事件分析对比发现, 1600~1800 Ma的碎屑锆石最有可能来自南部的中祁连地块。425~510 Ma的锆石与北祁连岛弧(460~510 Ma)和同碰撞/碰撞后岩浆活动时间一致。另外, 极少有来自于华北地块的锆石(老于1800 Ma的锆石)。

综合来看, 肃南地区阴沟群上部沉积物主要来自南部的中祁连地块, 其次来自北祁连岛弧和同碰撞/碰撞后花岗岩, 而源自北部华北板块的沉积物则极少。

## 5 结 论

(1) 运用LA-ICP-MS方法, 对北祁连造山带肃南地区阴沟群上部2件粗砂岩进行锆石U-Pb测年。其中最小谐和年龄值425 Ma, 代表了该砂岩形成时代可能为早一中志留世, 而不是前人原定义的早奥陶世。这表明北祁连造山带肃南地区原划为早奥陶世的阴沟群可能存在不同时代的物质组成, 其形成时代需要进一步的厘定。

(2) 碎屑锆石谐和年龄分布特征表明, 其沉积物主要来自南部的中祁连地块(800~1000 Ma、1600~1800 Ma), 其次来自北祁连岛弧和同碰撞/碰撞后花岗岩(425~510 Ma), 而源自北部华北板块的沉积物(老于1800 Ma的锆石)则极少。

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