

北阿尔金 HP/LT 蓝片岩和榴辉岩的 Ar-Ar 年代学及其区域构造意义

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摘要:在北阿尔金的红柳泉一带,新识别出蓝片岩和榴辉岩的出露。它们与泥质片岩、钙质片岩和石英片岩等一起构成 HP/LT 变质带,与相邻的蛇绿混杂岩呈断层接触。根据估算的温度和压力显示榴辉岩形成的峰期温压条件为 $T=430\sim 540^{\circ}\text{C}$, $P=2.0\sim 2.3\text{ GPa}$ 。分别对榴辉岩和蓝片岩中的多硅白云母和钠云母进行 $^{39}\text{Ar}-^{40}\text{Ar}$ 年代学测定,获得榴辉岩中多硅白云母的坪年龄为 $(512\pm 3)\text{Ma}$, 等时线年龄为 $(513\pm 5)\text{Ma}$; 蓝片岩中钠云母的坪年龄为 $(491\pm 3)\text{Ma}$, 等时线年龄为 $(497\pm 10)\text{Ma}$ 。这些年龄资料显示北阿尔金 HP/LT 变质带形成时代可能早于北祁连 HP/LT 变质带,反映了北阿尔金—北祁连早古生代洋壳俯冲存在穿时性。

关键词:北阿尔金; 蓝片岩; 榴辉岩; Ar-Ar 年代学

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由蓝片岩和低温榴辉岩组成的 HP/LT 变质带是古洋壳俯冲带的重要标志^[1]。在青藏高原东北缘的北祁连地区,保存有中国最完整的 HP/LT 变质带,它与相伴的蛇绿岩一起,成为北祁连早古生代缝合带的标志。已有的研究推测北祁连缝合带向西可延至北阿尔金^[2-3],并且在阿尔金山北部的红柳沟—拉配泉一带,已有蛇绿岩出露的报道^[4,5];并且在北阿尔金的贝克滩一带也报道有高压泥质岩的出露^[6,7],但一直没有蓝片岩和低温榴辉岩出露的报道。最近,笔者通过详细的野外剖面穿切和室内岩相学和矿物学工作,在由蛇纹岩、堆晶辉长岩、枕状熔岩及硅质岩等组成的蛇绿混杂岩之间,发现有石榴蓝闪石片岩(蓝片岩)和榴辉岩的出露^[8]。笔者已对这些榴辉岩和蓝片岩进行了较详细的岩石学研究^[8-10],并将通过榴辉岩和蓝片岩中多硅白云母和钠云母的 $^{39}\text{Ar}-^{40}\text{Ar}$ 同位素测定,来确定这些榴辉岩和蓝片岩可能的形成时代,并与北祁连 HP/LT 变质岩的形成时代进行对比,来讨论其区域构造意义。

1 地质背景

阿尔金山分布在青藏高原北部边缘,呈 SWW-NEE 向延伸约 800 km,北邻塔里木盆地,南为巨型的阿尔金左行走

滑断裂所限(图 1)。根据已有的区域地质和岩石构造资料^[2-4,11],在阿尔金山内可划分成 3 个近 EW 向的断裂(或剪切带)所分割的构造单元,从北向南分别为北阿尔金俯冲增生杂岩带(NATS)、中阿尔金地块(CAB)和南阿尔金俯冲—碰撞杂岩带(SAS)(图 1)。中阿尔金地块(CAB)主要为浅变质的陆缘碎屑岩和碳酸盐岩组成的金雁山群、角闪岩相变质杂岩组成的阿尔金群及不同时代的侵入岩所组成,其中碳酸盐岩中含有叠层石化石,并据此认为其时代为中新元古代^[11];阿尔金群原被认为时代为古元古代,近年来一些新的研究资料显示其主要形成于中元古代—新元古代早期^[12]。南阿尔金俯冲—碰撞杂岩带由长英质片麻岩和少量呈透镜状分布在这些片麻岩中的榴辉岩、高压麻粒岩和石榴橄榄岩等所组成,在这些岩石中已发现一些 UHP 变质作用证据^[13,14],其峰期变质时代为 500 Ma 左右^[15]。这些构造单元可分别与阿尔金断裂东南侧祁连—柴北缘相应的构造单元对比(图 1-a)^[8,9]。

北阿尔金俯冲增生杂岩带呈近 EW 向分布在红柳沟—拉配泉一带,与北侧属于塔里木地块古老变质基底的一部分的米兰群和南侧的中阿尔金地块为断层接触。主要由浅变质的火山岩、火山碎屑岩及碎屑岩等所组成,并夹有具有蛇绿岩特征的超基性岩(蛇纹岩)、基性岩墙群和基性枕状熔岩

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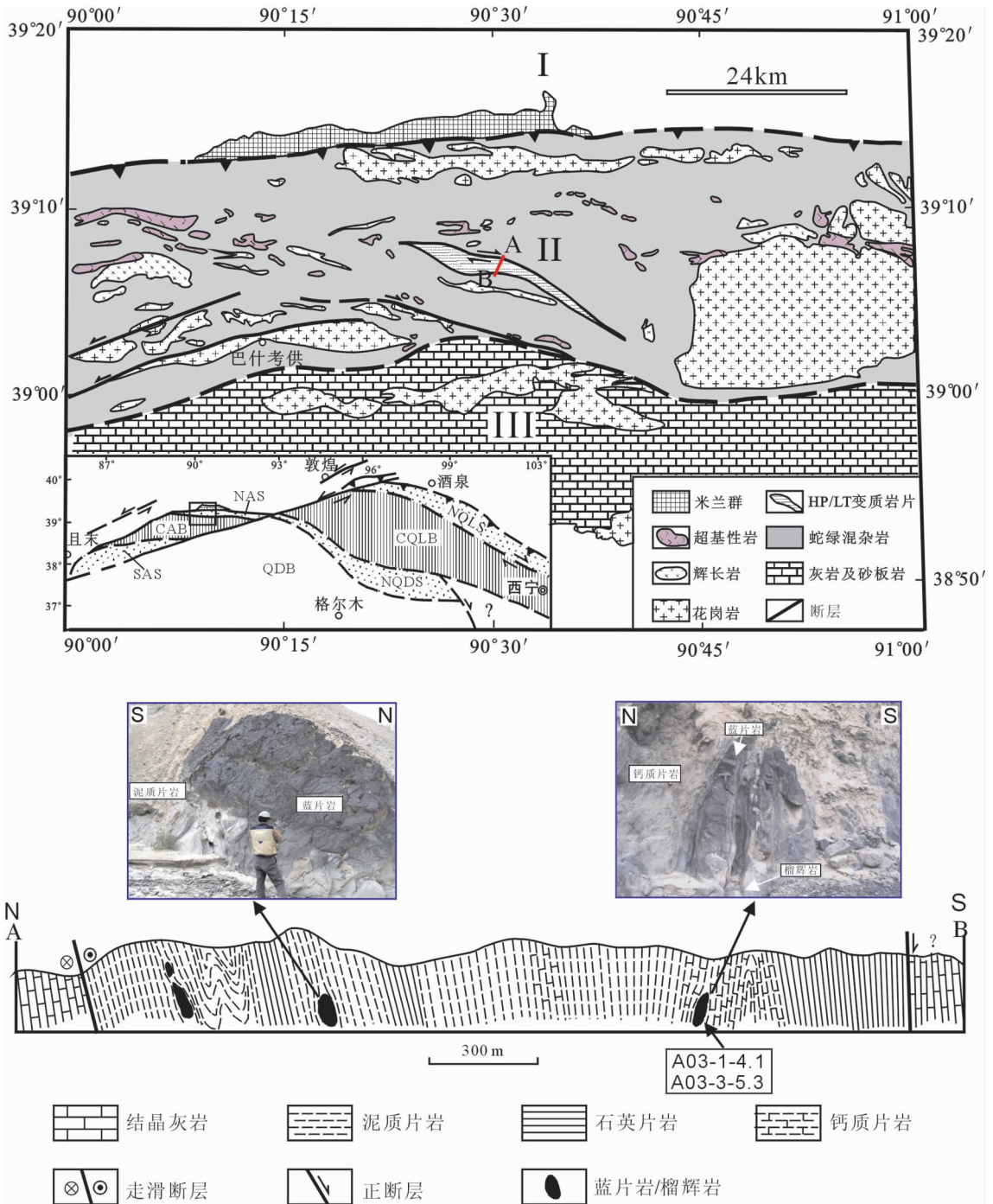


图 1 北阿尔金 HP/LT 变质岩片分布地质图(a)剖面图采样位置(b)

I—塔里木地块;II—北阿尔金俯冲增生杂岩带; III—中阿尔金地块;NAS—北阿尔金俯冲增生杂岩;NQLS—北祁连俯冲增生杂岩带; CAB—中阿尔金地块;CQLB—中祁连地块;SAS—南阿尔金俯冲碰撞杂岩带;NQDS—柴北缘俯冲碰撞杂岩带;QDB—柴达木地块

Fig.1 Distribution of the North Altyn Tagh HP/LT metamorphic terrane(a) and cross-section showing the outcrops and sample locations for this study(b)

I—Tariim block;II—North Altyn Tagh accretionary complex;III—Central Altyn Tagh block. Abbreviations;NAS—North Altyn Tagh accretionary complex;NQLS—North Qilian accretionary complex;CAB—Central Altyn Tagh block;QLB—Qilian block; SAS—South Altyn Tagh accretionary complex;NQDS—North Qaidam subduction-collision zone;QDB—Qaidam block

(图1)。已有的一些年代学证据显示其时代主要为早古生代^[4]。笔者所研究的以蓝片岩和低温榴辉岩为特征的 HP/LT 变质带呈构造岩片分布在其中。HP/LT 变质带主要由石榴蓝闪片岩(蓝片岩)、榴辉岩,含硬绿泥石、石榴子石多硅白云母片岩(泥质片岩)、石英片岩及钙质片岩(由碳酸盐矿物和少量石英和白云母所构成)等所组成,其中榴辉岩和蓝片岩主要呈透镜状分布在泥质片岩和钙质片岩之中,局部也见与泥质片岩和钙质片岩呈互层状产出,它们共同构成一个宽 2~5 km,长约 40 km 的构造岩片(图 1-a),分布在北阿尔金俯冲增生杂岩的中部,呈 NW-SE 向展布,与两侧由超基性岩、辉长岩、基性枕状熔岩及硅质岩等所组成的蛇绿混杂岩呈断层接触(图 1-a)。

2 榴辉岩和蓝片岩的岩石学特征及形成 *PT* 条件

用于 Ar-Ar 测定的榴辉岩和蓝片岩样品采自于同一露头(图 1-b),在此露头中,榴辉岩分布在蓝片岩中,呈透镜或似层状,它们的围岩为钙质片岩和云母片岩。

蓝片岩样品 Q03-1-4.1 主要由石榴子石和蓝闪石组成,具有少量的帘石类矿物、冻蓝闪石、钠云母、绿泥石、钠长石及榍石,没有发现多硅白云母。蓝闪石在基质中围绕石榴子石定向分布,构成 HP/LT 条件下的叶理(图 2-a)。蓝闪石边部局部被冻蓝闪石所替代。钠云母粒度较大,明显增生在定向分布的蓝闪石上,并与叶理斜交,其生长应晚于蓝闪石(图 2-b),部

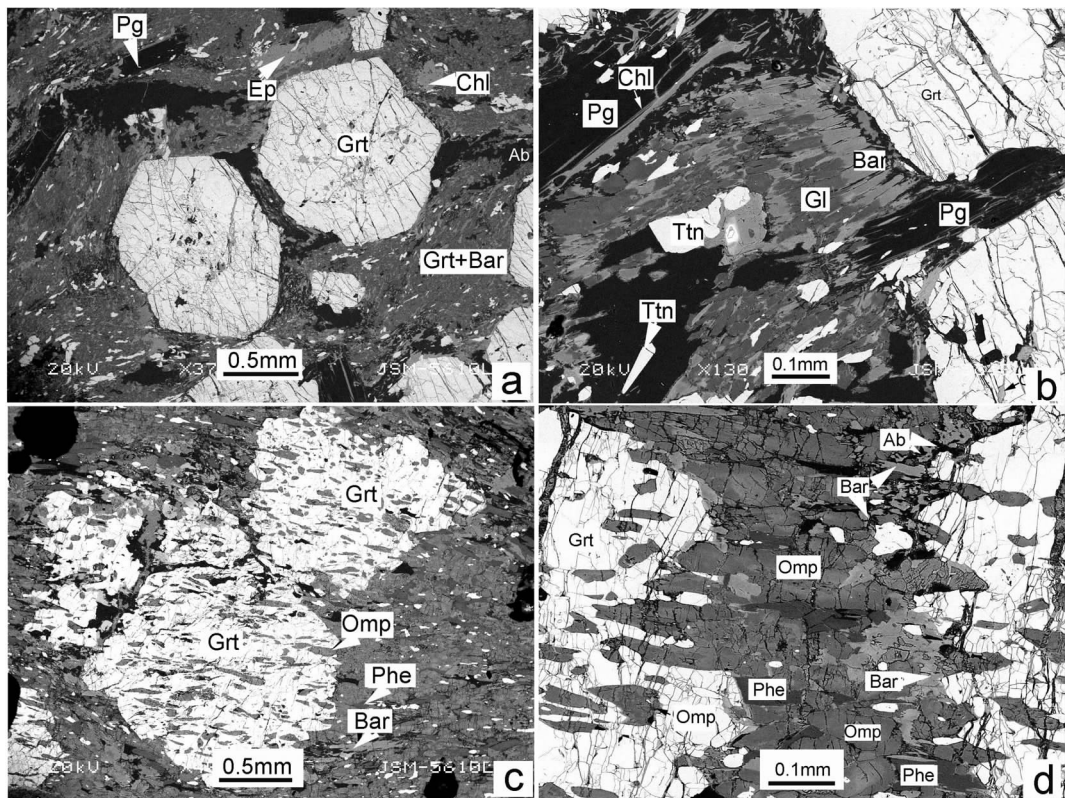


图 2 石榴蓝片岩和榴辉岩的显微结构特征(BSE 图像)

a-蓝闪石围绕石榴子石定向分布,构成蓝片岩相的叶理(A03-1-4.1);b-蓝闪石边部被冻蓝闪石所替代,钠云母斜切蓝闪石,且边部有绿泥石生长(A03-1-4.1);c-榴辉岩中基质和石榴子石中的绿辉石定向分布,并连续分布,没有发生弯曲(A03-3-5.3);d-在绿辉石和石榴子石之间具有冻蓝闪石和钠长石组成的后成合晶(A03-3-5.3, BSE 图像);Ab-钠长石;Bar-冻蓝闪石;Chl-绿泥石;Ep-绿帘石;Gl-蓝闪石;Grt-石榴子石;Omp-绿辉石;Phe-多硅白云母;Pg-钠云母;Ttn-榍石

Fig.2 BSE images of eclogite and blueschist in the North Altyn Tagh

a-Oriented distribution of glaucophane around garnet porphyroblasts, forming the foliation of blueschist (A03-1-4.1);b-Glaucophane rimmed by barroisite and cut by paragonite and chlorite growing at edges (A03-1-4.1);c-Matrix and garnet porphyroblasts in eclogite contain oriented inclusions of omphacite, phengite and quartz, which are distributed continuously and show no bending (A03-3-5.3);d-Barroisite-albite symplectite formed between omphacite and garnet (A03-3-5.3); Abbreviations: Ab-albite; Bar-barroisite; Chl-chlorite; Ep-epidote; Gl-glaucophane; Grt-garnet; Omp-omphacite; Phe-phengite; Pg-paragonite; Ttn-titanite

分钠云母边部有绿泥石生长(图 2-b)。钠云母的 Na₂O 含量为 5.8%~7.2%,K₂O 为 0.5%~1.3%。

榴辉岩样品 Q03-3-5.3 主要由石榴子石、绿辉石、冻蓝闪石、石英和多硅白云母所组成,还有少量蓝闪石、帘石类矿物、方解石、钠云母、绿泥石、钠长石和榍石。石榴子石为自形晶或半自形晶(图 2-c),绿辉石与多硅白云母和石英一起定向分布,且基质和石榴子石中的绿辉石包体具有一致的方

向,并连续分布,没有发生弯曲(图 2-c),同时也可见绿辉石等矿物围绕石榴子石分布,这反映石榴子石可能稍晚于绿辉石或两者在 HP/LT 条件下近同时结晶,并可能同时发生变形作用。石榴子石中直线状的包体分布特征反映其变形作用以共轴应变为特征,没有发生明显的旋转变形。绿辉石的硬玉分子主要变化在 Jd=(40~50)mol%^[8],从核到边,硬玉分子增加,霓石分子逐渐减少直到接近零。蓝闪石含量很少,一些

表 1 榴辉岩中多硅白云母及蓝片岩钠云母 ³⁹Ar-⁴⁰Ar 测定结果

Table 1 ³⁹Ar-⁴⁰Ar data for phengite of eclogite and paragonite of blueschist

温度(°C)	(⁴⁰ Ar/ ³⁹ Ar) _m	(³⁶ Ar/ ³⁹ Ar) _m	(³⁷ Ar/ ³⁹ Ar) _m	(³⁸ Ar/ ³⁹ Ar) _m	F	³⁹ Ar (×10 ⁻¹⁴ mol)	³⁹ Ar (Cum.)(%)	Age (Ma)	±1σ (Ma)
榴辉岩 A03-3-5.3 中的多硅白云母						W=33.00mg	J=0.006159		
400	93.2946	0.2285	0.3023	0.0948	25.7874	8.19	0.17	265.9	4.9
500	161.2582	0.4332	0.3489	0.1290	33.2708	6.42	0.30	336	11
600	54.7378	0.0266	0.6638	0.0223	46.9531	50.23	1.32	458.2	4.3
650	319.3737	1.0514	1.6612	0.2470	8.8034	1.93	1.36	95	17
730	96.8593	0.1645	0.9942	0.0503	48.3437	13.13	1.63	470.2	5.3
810	62.8052	0.0265	0.2887	0.0204	55.0116	77.85	3.21	526.4	5.2
860	58.1353	0.0205	0.2121	0.0390	52.1006	79.20	4.83	502.1	4.6
910	57.9314	0.0154	0.1175	0.0271	53.4031	120.48	7.28	513.0	4.6
960	56.1208	0.0091	0.0781	0.0238	53.4300	302.97	13.46	513.2	5.2
1000	55.0620	0.0083	0.0471	0.0256	52.6044	385.28	21.31	506.3	5.6
1050	54.3266	0.0050	0.0352	0.0167	52.8600	1166.96	45.09	508.4	4.7
1100	55.3166	0.0050	0.010	0.0163	53.8257	1762.98	81.02	516.5	4.6
1150	54.7283	0.0045	0.0310	0.0188	53.4051	679.20	94.86	513.0	4.6
1200	58.5178	0.0172	0.2315	0.0285	53.4494	124.70	97.40	513.4	4.7
1250	74.3512	0.0708	0.2886	0.0291	53.4700	67.44	98.77	513.5	4.5
1300	102.2003	0.1785	0.7592	0.0566	49.5426	42.89	99.65	480.4	4.5
1400	97.6244	0.1475	4.1399	0.0500	54.5160	17.34	100.00	522.3	7.1
蓝片岩 A03-1-4.1 中的钠云母						W=33.00mg	J=0.006163		
400	122.7158	0.3007	1.6996	0.0146	34.0295	1.66	0.42	343	12
500	161.4310	0.4610	4.3987	0.1568	25.6180	0.78	0.62	264	19
600	97.4146	0.1969	1.6140	0.0656	39.3997	2.97	1.38	392.2	7.4
700	83.4562	0.1489	1.9312	0.0590	39.6579	2.65	2.06	394.5	8.6
800	65.4999	0.0660	1.1382	0.0321	46.1192	11.89	5.10	451.3	5.0
880	61.8002	0.0437	0.3566	0.0241	48.9243	39.28	15.13	475.4	4.9
930	60.2586	0.0307	0.2212	0.0216	51.2088	58.97	30.18	494.8	4.5
980	59.8055	0.0299	0.4761	0.0274	51.0324	76.97	49.84	493.3	4.7
1030	63.0419	0.0385	0.3550	0.0330	51.7028	58.05	64.66	499.0	4.7
1080	68.2101	0.0622	0.1825	0.0599	49.8521	47.31	76.74	483.3	5.1
1130	78.9405	0.0961	0.3103	0.0354	50.5724	17.65	81.25	489.4	4.6
1210	75.6229	0.0858	0.3364	0.0324	50.2893	26.10	87.91	487.0	4.4
1290	67.9225	0.0599	0.3988	0.0273	50.2724	38.36	97.7	486.9	4.5
1370	32.1566	0.0426	1.8357	0.0270	19.7211	8.99	100.00	206.9	2.9

注:表中下标 m 代表样品中测定的同位素比值。样品 A03-3-5.3 的全年龄(Total age)为 511.0 Ma,样品 A03-1-4.1 的全年龄(Total age)为 479.8 Ma;F=⁴⁰Ar/³⁹Ar,是放射性 ⁴⁰Ar 和 ³⁹Ar 的比值。

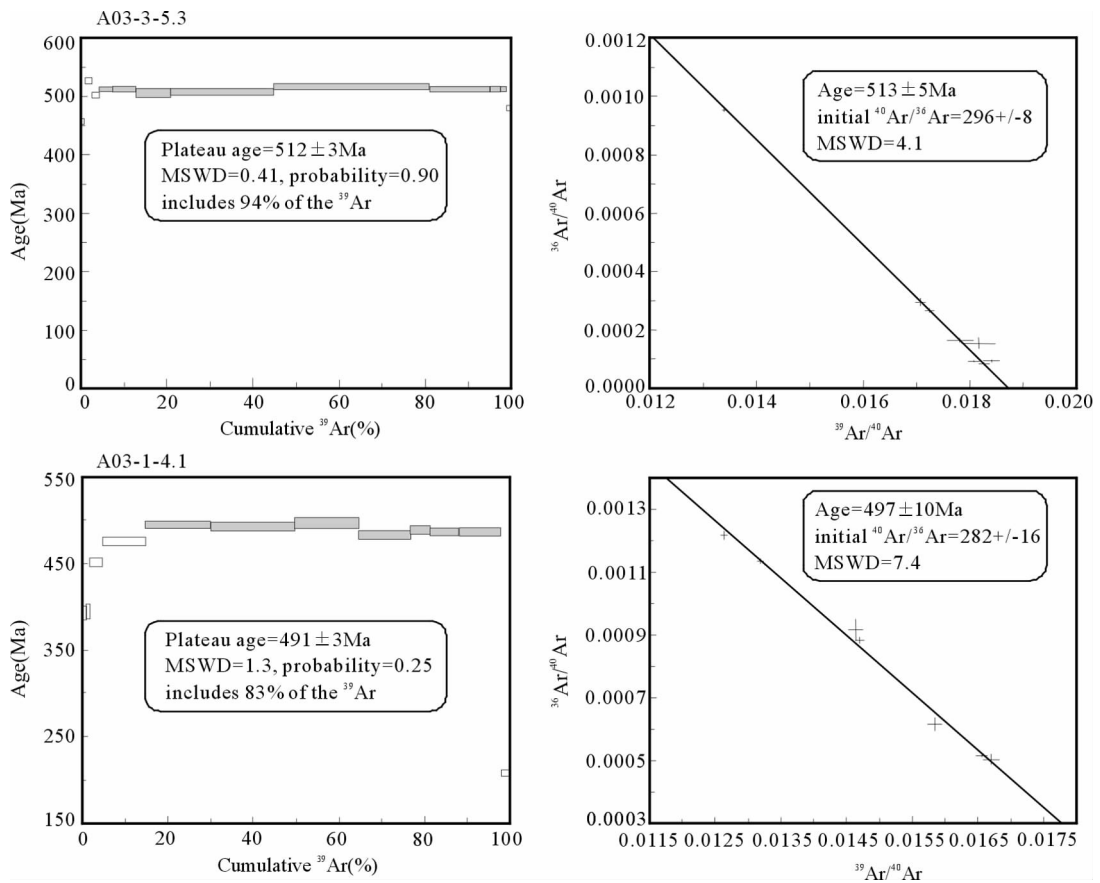


图3 北阿尔金榴辉岩中多硅白云母和蓝片岩中钠云母的年龄谱(左图)及等时线(右图)
Fig.3 Age spectra (left) and isochron diagrams (right) of phengite from eclogite sample A03-3-5.3 and paragonite from blueschist sample A03-1-4.1 in the North Altyn Tagh

以包体形式分布在石榴子石中,且与绿辉石一起定向分布;另一些蓝闪石在冻蓝闪石中呈包体出现。冻蓝闪石具有两种类型,一种粒度较大,呈斑晶增生在绿辉石组成的叶理之上,并与之斜交;另一种与钠长石组成合成合晶,替代了早期的绿辉石(图2-d)。多硅白云母粒度较小,与绿辉石共生, Si 含量 3.4~3.6 p.f.u.;绿泥石与钠长石共生,分布在绿辉石的边部沿石榴子石、绿辉石和冻蓝闪石的裂隙生长,其形成应晚于冻蓝闪石。利用石榴子石-单斜辉石-多硅白云母地质压力计^[6]和石榴子石-单斜辉石地质温度计^[7],共生的石榴子石、绿辉石和多硅白云母获得的温压条件为: $T=430\sim 540^{\circ}\text{C}$, $P=2.0\sim 2.3\text{ GPa}$ ^[8]。

3 $^{39}\text{Ar}-^{40}\text{Ar}$ 测定

从榴辉岩样品 A03-3-5.3 和蓝片岩样品 A03-1-4.1 中分别选出多硅白云母和钠云母,通过重液和磁选后,样品又在显微镜下仔细挑选,因此样品是非常纯的。Ar-Ar 同位素测定在中国地质科学院地质研究所同位素实验室完成,测定方法及流程见文献^[8]。测定结果见表1和图3。

榴辉岩的多硅白云母获得近一致的年龄谱,9个增温阶段包括94%的 ^{39}Ar 释放,获得的坪年龄为 $(512\pm 3)\text{Ma}$ (表3,图3)。反映在反等时线上,产生的 $^{40}\text{Ar}/^{36}\text{Ar}$ 截距为 296 ± 8 ,与理想大气值(295.5)一致,获得的等时线年龄为 $(513\pm 5)\text{Ma}$ (MSWD=4.1),与坪年龄一致。

蓝片岩样品 A03-1-4.1 中钠云母7个增温阶段包括83%的 ^{39}Ar 释放,获得的坪年龄为 $(491\pm 3)\text{Ma}$ (表3,图3),反映在反等时线上,产生的 $^{40}\text{Ar}/^{36}\text{Ar}$ 截距为 282 ± 16 ,与理想大气值(295.5)近一致,获得的等时线年龄为 $(497\pm 10)\text{Ma}$ (MSWD=7.4),与坪年龄在误差范围内一致。

4 讨论及地质意义

Ar-Ar 测定结果显示,榴辉岩中多硅白云母的年龄明显要大于蓝片岩中钠云母的年龄。2个样品来自于同一露头,怎样解释它们之间的年龄差异?岩相学研究显示榴辉岩中多硅白云母与绿辉石及石榴子石等矿物共生(图2-c及图2-d),为榴辉岩相条件下的变质生长矿物。当然,所计算的榴辉岩温度条件($430\sim 540^{\circ}\text{C}$)略高于白云母的K-Ar体系的封闭温

度(350±50°C)^[9],因此,榴辉岩中多硅白云母的 Ar-Ar 年龄可能代表了榴辉岩相变质作用后抬升过程中的冷却时代。不过,榴辉岩的 PT 演化显示其具有快速冷却和折返的特征^[8,9], (512±3)Ma 的年龄可能接近榴辉岩相变质时代。用于钠云母 Ar-Ar 测定的蓝片岩样品为榴辉岩的围岩,从蓝片岩石榴子石中具有绿辉石包体的特征,笔者推断蓝片岩可能为榴辉岩退变质的产物。而蓝片岩的岩相学研究表明钠云母并非与蓝闪石共生的矿物,它明显切割蓝闪石和石榴子石等矿物(图 2-a、2-b),其形成应晚于蓝闪石,可能为蓝片岩相后绿片岩相退变质阶段的产物。因此,蓝片岩中钠云母的 Ar-Ar 年龄(491±3 Ma)可能代表了岩石晚期绿片岩相叠加的时代,它不能代表蓝片岩相阶段的时代,更不能代表蓝片岩早期可能经过的榴辉岩相阶段的变质时代。

北阿尔金低温榴辉岩和蓝片岩的揭示^[9],特别是最近在北阿尔金和北祁连均发现有含硬柱石榴辉岩的发现^[9],进一步证明了北阿尔金早古生代缝合带是北祁连早古生代缝合带西延部分的推断^[2,3]。然而,笔者所获得的北阿尔金榴辉岩和蓝片岩中白色云母(多硅白云母和钠云母)的 Ar-Ar 年龄明显大于北祁连同类岩石中矿物(多硅白云母和蓝闪石)的 Ar-Ar 年龄(440~460 Ma)^[20,21],这是否反映了同一条俯冲带沿走向俯冲时间的差异(穿时性),还需今后进一步的工作。另外,由于白云母的 Ar-Ar 测定是否存在过剩氩问题也一直存在争议^[2],进一步对北阿尔金榴辉岩及蓝片岩进行更精确的年代学研究十分必要。

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³⁹Ar-⁴⁰Ar geochronology of high-pressure/low-temperature blueschist and eclogite in the North Altyn Tagh and their tectonic implications

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Abstract: Blueschists and eclogites are newly recognized in the Hongliuquan area, North Altyn Tagh. These blueschists and eclogites, together with metapelites, calcareous schists and quartz schists, form part of a coherent high-pressure (HP)/low-temperature (LT) metamorphic terrane, which occurs as a tectonic slab in faulted contact with ophiolitic mélanges. P-T estimates show that the peak pressure-temperature metamorphic conditions for the eclogites were 2.0-2.3 GPa and 430-540°C. Phengite from an eclogite sample and paragonite from a blueschist sample were selected for Ar-Ar dating. Phengite from eclogites yields an Ar-Ar plateau age of (512±3)Ma and an isochron age of (513±5)Ma, and paragonite from blueschists gives an Ar-Ar plateau age of (491±3)Ma and an isochron age of (497±10)Ma. These new age data suggest that the North Altyn Tagh HP/LT metamorphic belt probably formed earlier than the North Qilian HP/LT metamorphic belt and imply the existence of diachronism of subduction of the Early Paleozoic oceanic crust beneath the North Altyn Tagh - North Qilian.

Key words: North Altyn Tagh; blueschist; eclogite; Ar-Ar geochronology

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