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SHRIMP U-Pb zircon age of the Jinbaoshan ultramafic intrusion, Yunnan Province, SW China

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SHRIMP U-Pb zircon dating gives ages of 260.6 ± 3.5 Ma and 260.7 ± 5.6 Ma for serpentinised wehrlite and plag-hornblendite in the Jinbaoshan ultramafic intrusion, respectively. The results indicate that the Jinbaoshan intrusion was emplaced at ca.260 Ma and contemporaneous with the Emeishan continental flood basalts (ECFB), similar to other mafic-ultramafic intrusions of the Emeishan large igneous province (LIP). The new ages provide a geochronological constraint on the origin of the Jinbaoshan ultramafic intrusion. It confirms that the Jinbaoshan ultramafic intrusion belongs to the Emeishan LIP that formed at ca. 260 Ma.

zircon, SHRIMP, U-Pb age, ultramafic intrusion, Emeishan LIP, Ni-Cu-PGE deposit

The Jinbaoshan ultramafic intrusion is located in Midu County, Yunnan Province. It occurs in the western margin of the Yangtze Block (Figure 1). The Jinbaoshan intrusion hosts the largest magmatic PGE deposit (sulfide-poor PGE deposit) in China at present. The intrusion is a sheet-like body composed mainly of wehrlite with minor gabbros, hornblendites and pyroxenites. It intruded Devonian dolomites. The intrusion is ~5 km long, ~1 km wide and 25—170 m in vertical thickness (Figure 1).

The Jinbaoshan intrusion is considered to be an important ore-bearing intrusion in the Emeishan LIP[1]. Previous studies have suggested that it is related to the magmatism of the Emeishan continental flood basalts[2,3]. In the Jinbaoshan area, some of the associated gabbroic dykes intruded lower Permian limestone which locally occurred, and unconformably overlain by the Late Triassic shales. The stratigraphic correlation suggests that the intrusion was emplaced before the Late Triassic but after Early Permian. The field relations have been widely used as evidences for coeval relationship between the intrusive rocks and ECFB, but an accurate age is lacking. An accurate determination of the age and the associated geotectonic background for the Jinbaoshan intrusion is important for better understanding of the magmatism and associated metallogeny in the Emeishan LIP. In this paper, we report precise SHRIMP U-Pb zircon ages for the Jinbaoshan intrusion.

The zircons were separated from 2 samples. One is a serpentinised wehrlite (1309-3) from the entrance of adit 1309 and the other is a plag-hornblendite (L03) from the base of the intrusion in exploration section 1#. Sample 1309-3 represents a typical wehrlite immediately below the 1# ore seam in the intrusion. It is composed of serpentinised olivine and pyroxene with minor magnetite and other accessory minerals. Clinopyroxene commonly occurs as large poikilitic crystals enclosing olivine. The plag-hornblendite (L03) contains >60 vol% hornblende, ~20 vol% plagioclase and minor biotite and magnetite.

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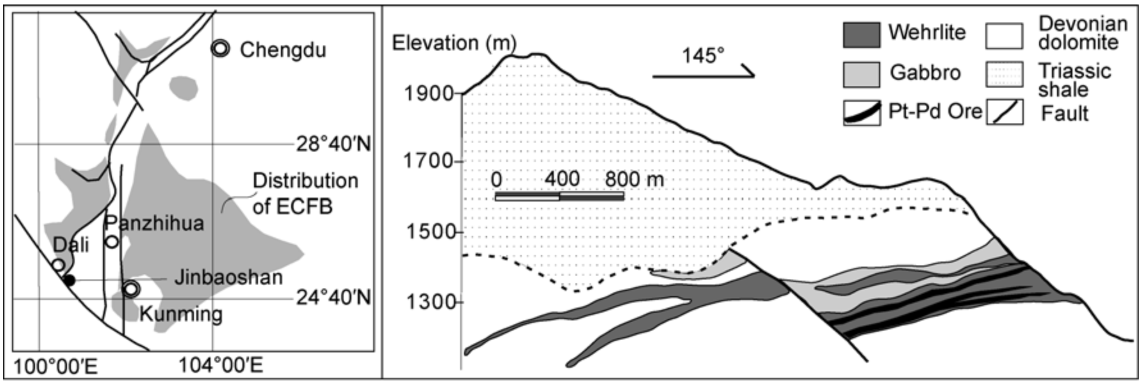

Figure 1 Location and a representative section of the Jinbaoshan intrusion (a part of the exploration section 5# in northwest side of the Lishe River, based on the unpublished report of Geological Team 3, Yunan Geological Survey).

Hornblende occurs as euhedral crystals of 3—8 mm in diameter. The plag-hornblendite is considered to be an evolved phase of the intrusion[2]. Zircons in the samples were separated by heavy-liquid and magnetic methods, followed by hand-picking under a binocular microscope. About 120 zircon grains from 10 kg of the wehrlite sample and about 200 zircon grains from 10 kg of the plag-hornblendite were found. The sizes of the zircons are 50—100 um in diameter. The grain sizes of zircons from plag-hornblendite sample are generally larger than those from the wehrlite sample.

The zircon grains from each sample were mounted randomly in target, respectively. U-Pb analyses were performed using a SHRIMP II machine in the Beijing SHRIMP Center, Chinese Academy of Geological Sciences. Inter-element fractionation of ion emission from zircon was correctd using the standard zircon TEMORA (417 Ma)[4]. The abundances of U, Th and Pb were measured based on the standard zircon SL13 (572 Ma, U = 238 ppm). Common Pb was corrected using the measured ^{204}Pb. The analytical results were processed using the ISOPLOT program of Ludwig[5]. The decay constants given by IUGS were used in age calculations. The results are listed in Table 1.

A total of 19 spot analyses were made on 19 zircon grains from the wehrlite sample (1309-3). Three of them have ^{206}Pb/^{238}U ages of 2632 ± 73 Ma, 1842 ± 40 Ma and 545.2 ± 12 Ma. These ages are much older than that inferred from the field relations described above and these three grains are therefore considered to be inherited xenocrysts from the footwall strata that the magma of the Jinbaoshan intrusion passed through. These zircon xenocrysts show clear oscillatory zoning in CL images as shown in Figure 2(a), and are characterized by low Th, U contents and low Th/U ratios. Three other zircon grains from the wehrlite sample have ^{206}Pb/^{238}U age of 242.1 ± 5.8 Ma, 240.9 ± 5.8 Ma and 242.3 ± 5.7 Ma, significantly younger than crystallization age of the sample (see below). We call them abnormal age zircons. The zircon grains with abnormal ages have some unique features in CL images such as embayment structure and thin light-grey rim as shown in Figure 2(b). They are characterized by high U and Th contents and Th/U ratios between 1.61 and 4.41. Their younger ages than the crystallization age of the intrusion may have resulted from post-crystallization Pb-loss due to post-magmatic hydrothermal alteration. The remaining 13 analyses yield a weighted mean ^{206}Pb/^{238}U age of 260.6 ± 3.5 Ma (MSWD = 1.17). The concordian ages of these zircon grains are illustrated in Figure 3(a). These zircon grains have subhedral morphology and weak oscillatory zoning or unzoned texture in the CL images as shown in Figure 2(c). They have high Th/U ratios ranging from 0.47 to 7.8. These zircons are considered to be crystallized from basaltic magma and the mean age of these zircon grains is interpreted to be the crystallization age of the sample.

A total of 9 spots were analyzed on 9 zircon grains from the plag-hornblendite sample (L03). Two analyses have young ^{206}Pb/^{238}U ages of 244.7 ± 5.9 Ma and 245.9 ± 5.9 Ma. Their CL images show a thin light-grey rim, similar to the zircon grains with abnormal ages from wehrlite sample (1309-3). The contents of U, Th of the two spots are high. Their Th/U ratios are 1.25 and 3.68, respectively. One analysis gives a discordance U-Pb age with the ^{206}Pb/^{238}U age of 266.8 ± 6.6 Ma. The remaining 6 analyses yield a weighted mean ^{206}Pb/^{238}U age of 260.7 ± 5.2 Ma (MSWD = 0.89), which is interpreted to be the crystallization age of the sample. These zircon grains, similar to the basaltic magmatic zircons from

Table 1 The SHRIMP analytical results of zircons from the Jinbaoshan intrusion[a)]

Spot	$^{206}Pb^c$ (%)	U (μg·g^{-1})	Th (μg·g^{-1})	$^{232}Th/^{238}U$	$^{206}Pb^*$ (μg·g^{-1})	$^{206}Pb/^{238}U$ age (Ma)	$^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	Err. corr.
Sample 1309-3													
1309-3-1.1	0.26	2604	2510	1.00	94.2	265.3±6.3	0.0502	1.3	0.29	2.8	0.0420	2.4	0.880
1309-3-2.1	0.24	1812	13741	7.84	61.8	250.3±6.0	0.0513	1.1	0.28	2.7	0.0396	2.4	0.910
1309-3-3.1	0.20	2849	1298	0.47	105.9	272.4±6.5	0.0510	0.9	0.30	2.6	0.0432	2.4	0.941
1309-3-4.1	0.32	2888	7111	2.54	95.2	242.1±5.8	0.0506	1.0	0.27	2.6	0.0383	2.4	0.929
1309-3-5.1	0.18	2935	14372	5.06	104.0	260.0±6.2	0.0514	0.9	0.29	2.6	0.0412	2.4	0.941
1309-3-6.1	0.17	4104	2190	0.55	150.1	268.3±6.4	0.0507	1.1	0.30	2.7	0.0425	2.4	0.913
1309-3-7.1	0.24	1585	2111	1.38	54.8	253.6±6.1	0.0516	1.3	0.29	2.8	0.0401	2.4	0.877
1309-3-8.1	0.07	2948	6632	2.32	106.2	264.7±6.3	0.0511	0.9	0.30	2.6	0.0419	2.4	0.943
1309-3-9.1	0.15	3984	7976	2.07	140.6	259.2±6.2	0.0511	0.9	0.29	2.6	0.0410	2.4	0.943
1309-3-10.1	0.41	1227	1910	1.61	40.3	240.9±5.8	0.0500	1.7	0.26	3.0	0.0381	2.5	0.818
1309-3-11.1	0.28	2215	2152	1.00	77.9	258.0±6.2	0.0495	1.6	0.28	2.9	0.0408	2.4	0.836
1309-3-12.1	7.34	167	130	0.81	77.9	2632±73	0.2895	7.2	20.1	8.0	0.5043	3.4	0.424
1309-3-13.1	0.42	98	54	0.57	27.8	1842±40	0.1111	2.1	5.07	3.3	0.3307	2.5	0.764
1309-3-14.1	0.26	2203	8822	4.14	72.7	242.3±5.7	0.0504	1.2	0.27	2.7	0.0383	2.4	0.889
1309-3-15.1	0.53	1736	1310	0.78	61.2	257.9±6.1	0.0492	2.4	0.28	3.4	0.0408	2.4	0.706
1309-3-16.1	0.33	920	769	0.86	33.7	268.4±6.3	0.0520	2.8	0.30	3.7	0.0425	2.4	0.647
1309-3-17.1	1.54	447	847	1.96	15.5	252.0±6.1	0.0501	6.3	0.28	6.7	0.0399	2.5	0.369
1309-3-18.1	3.53	146	151	1.07	5.4	261.2±7.0	0.0485	18.9	0.28	19.1	0.0413	2.7	0.143
1309-3-19.1	0.88	951	253	0.27	72.8	545.2±12	0.0692	1.4	0.84	2.8	0.0882	2.4	0.861
Sample L03													
L03-1.1	0.55	816	1961	2.48	28.7	257.6±6.4	0.0519	2.7	0.29	3.7	0.0408	2.6	.692
L03-2.1	5.29	1005	292	0.30	38.5	266.8±6.6	0.0680	7.5	0.40	7.9	0.0423	2.5	.318
L03-3.1	0.62	636	1020	1.66	23.4	268.8±6.5	0.0538	2.9	0.32	3.8	0.0426	2.5	.648
L03-4.1	1.37	302	269	0.92	11.0	264.2±6.6	0.0535	8.0	0.31	8.4	0.0418	2.6	.304
L03-5.1	0.26	2494	8885	3.68	83.1	244.7±5.9	0.0517	1.3	0.28	2.7	0.0387	2.4	.887
L03-6.1	2.13	172	203	1.21	6.2	259.1±6.7	0.0537	9.0	0.30	9.4	0.0410	2.6	.281
L03-7.1	0.51	1429	847	0.61	49.2	251.9±6.0	0.0523	1.7	0.29	3.0	0.0399	2.4	.818
L03-8.1	2.96	257	472	1.90	9.5	264.1±6.7	0.0489	12	0.28	12.6	0.0418	2.6	.206
L03-9.1	0.63	3511	4237	1.25	118.0	245.9±5.9	0.0505	3.4	0.27	4.2	0.0389	2.4	.584

a) Errors in 1σ; Pb^c and Pb^*: the common and radiogenic portions.

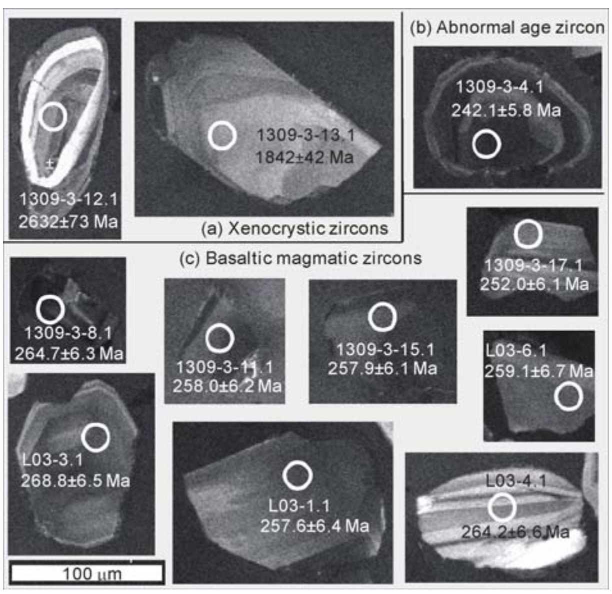

Figure 2 Representative cathodoluminescence (CL) images of zircons from the Jinbaoshan ultramafic intrusion. Circles show the spots of U-Pb analyses, the number of the spot and the corresponding U-Pb age are also shown.

wehrlite sample (1309-3), have subhedral morphology and weak oscillatory zoning or unzoned texture in CL images as shown in Figure 2(c). Their Th/U ratios range from 0.61 to 2.48. The concordian ages of this sample is shown in Figure 3(b).

In summary, the crystallization ages of the wehrlite and plag-hornbledite samples are similar. Their variations are within the analytical errors. Collectively, these two samples yield a weighted mean zircon $^{206}Pb/^{238}U$ age of 260.6 ± 2.8 Ma (n = 19, MSWD = 1.02), confirming that the Jinbaoshan intrusion was emplaced at ~260 Ma.

The tectonic setting of the Jinbaoshan intrusion has been controversial because it is located adjacent to the Sanjiang orogenic belt. Our SHIRMP analytical results show that the age of the Jinbaoshan intrusion is quite different from that of the Ailaoshan ultramafic belt which represents a suture. Jian et al.[6] reported zircon U-Pb ages of 362—328 Ma for the Shuangou ophiolite.

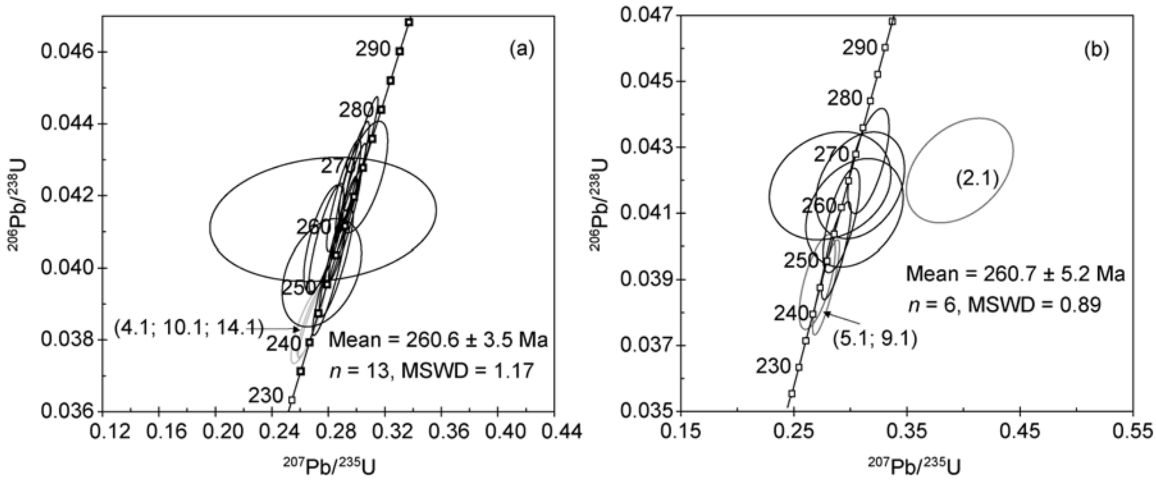

Figure 3 SHRIMP zircon U-Pb concordia diagrams for the Jinbaoshan ultramafic intrusion. Numbers in bracket are those spot analyses that are excluded from the mean calculations. (a) Sample 1309-3; (b) sample L03.

In another aspect, the plaeo Jingshajiang-Ailaoshan ocean was subducted westwards to Lanping-Simao block[7–9], so arc magmatism would not take place in the Jinbaoshan area because it was in the east side of the Ailaoshan suture. Previous studies have suggested that the rocks of the Jinbaoshan intrusion belong to tholeiite series, and have low Ba/La ratios generaly less than 10[2], indicating that the intrusion is related to intra-plate tholeiitic magmagtism rather than arc magmatism[10]. The above arguments show no link between the origin of the Jinbaoshan intrusion and tectonic activity of the Sanjiang orogenic belt. In addition, previous studies have shown that the Jinbaoshan intrusion has well geochemical relationship with the ECFB[2,3]. The zircon SHIRMP ages of the Jinbaoshan intrusion from this study are similar to the zircon SHIRMP ages of other mafic-ultramafic intrusions such as the Limahe, Panzhihua and Hongge that are coeval with the ~260 Ma ECFB[11–13]. It is clear that the Jinbaoshan intrusion is part of the Emeishan LIP.

The magmatism of the Emeishan LIP is one of the most significant geological events in late Paleozoic era on the Earth. An accurate determination of the age and duration of the Emeishan LIP is important to understand the geological and biological evolution of the Earth[14–16]. A number of dating studies have been carried out for the Emeishan LIP[15–25]. Lo et al.[20] presented the first set of high-precision $^{40}Ar/^{39}Ar$ plateau ages of ~251—253 Ma for the ECFB, showing a temporal link with the Permian-Triassic boundary event[20,26]. However, these ages are not consistent with the stratigraphic relations. The Emeishan basalts are capped by Late Permian Luopingian sediments (Xuanwei Formation)[27], which suggests that the Emeishan volcanism took place at or prior to the Middle-Late Permian. The recently updated Middle-Late Permian boundary age from Luopingian is 260.4 ± 0.4 Ma[28]. He et al.[19] obtained a mean zircon $^{206}U/^{238}Pb$ age of 260 ± 4 Ma for zircons from the silicic ignimbrite in the lowermost Xuanwei Formation and interpreted this age as the end of the Emeishan volcanism. As pointed out previously by Courtillot et al.[29], the discrepancy in Ar-Ar dating and stratigraphic data was a problem associated with the calibration of the age of monitor standards. Based on SHRIMP U-Pb analyses of zircons separated from mafic and alkaline intrusions and dykes, Zhou et al. and some other authors suggested a temporal link between the Emeishan LIP and the end-Guadalupian mass extinction. Zhou et al.[11,12] obtained a mean $^{206}U/^{238}Pb$ age of 259±3 Ma—263±3 Ma for zircons from the Xinjie, Panzhihua and Limahe intrusion. Zhong et al.[13,18] obtained zircon U-Pb ages of 259.3 ± 1.3, 260.7 ± 0.8 Ma, 261 ± 4 Ma from Hongge, Binggu intrusion and Cida granitic pluton. Recent study by Xu et al.[16] revealed that the 1st episode of felsic magmatism in the Emeishan LIP took place at ~260Ma and were triggered by advective heating associated with underplating of plume-derived magmas. Our SHRIMP U-Pb zircon age for the Jinbaoshan intrusion, together with previously reported SHRIMP zircon U-Pb ages for other intrusions in the Emeishan LIP, reinforce the notion that all these intrusions are coeval with the ECFB and formed during a major igneous event at ca. 260 Ma, coinciding with the end-Guadalupian mass extinction at the Middle-Late Permian boundary.

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