Single Zircon LA-ICP-MS U-Pb Dating of the Guandimiao and Wawutang Granitic Plutons in Hunan, South China and Its Petrogenetic Significance

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Abstract: The Guandimao and Wawutang plutons are located at the center of Hunan, South China. The former is mainly composed of biotite monzonitic granites/granodiorites and two-mica monzonitic granites, but the latter only consists of biotite monzonitic granites. The zircon ages of 203.0±1.6 Ma (biotite monzonitic granites) and 208.0±3.2 Ma (two-mica monzonitic granites) for the Guandimao pluton and 204±3 Ma for the Wawutang pluton obtained with the LA-ICP-MS U-Pb dating indicate that they were formed during the late Indosinian. In consideration of other geochronological data from Indosinian rocks of South China and adjacent regions, it is inferred that the two plutons were derived from crustal materials by decompressional melting in a post-collisional tectonic setting during spontaneous thinning of the thickened curst. Moreover, the inherited zircon age of 1273±57 Ma from the Wawutang pluton indicates that the source of the two plutons is related to the early Proterozoic crustal basement.

Key words: zircon LA-ICP-MS U-Pb dating, granite, Indosinian movement, CL images

1 Introduction

The South China Block (SCB), located between the Qinling-Dabie and Songma Indosinian sutures, experienced successively two important tectonic movements during the Mesozoic, i.e. the Indosinian movement (early Mesozoic) and the Yanshanian movement (late Mesozoic). Therefore, the generally accepted viewpoint is that the key geological problems during the Mesozoic are essentially the dynamics and material expression of these two tectonic movements in South China (Chen et al., 2002; Xu et al., 2003). The Indosinian movement, first recognized in the early 20th century (Deprat, 1914), refers to a structural unconformable event occurring in Triassic strata in Vietnam. It is also believed that the movement is related to continental collision between the Indochina Block (ICB) and the SCB (Meng and Zhang, 2000; Carter et al., 2001).

Indosinian granites in South China are dispersedly distributed in Guangxi, Hainan, Guangdong, Jiangxi, Hunan et al., in the mass, but mostly are fairly concentrated in Hunan Province, where their outcrops are over an area of ca. 5000 km^2 (by statistics from the Regional Geological Survey Unit, 1995a, b). Recently, using the zircon in-situ dating technology (i.e. SHRIMP，LA-ICP-MS and so on), some Indosinian granitic plutons in South China have been recognized (Luo et al., 1992; Shao et al., 1995; Guo et al., 1997a; Xu et al., 2003; Deng et al., 2004; Qiu et al., 2004; Shu et al., 2004; Xu et al., 2004a; Zhang et al. 2004; Ding et al., 2005; Wang et al., 2005; Xie et al., 2005), which suggest that the effect of the Indosinian movement in South China has probably exceeded previous cognition of the researchers, drawing attention from more and more scholars to the manifestation and effect of the Indosinian movement in South China. Therefore, it is quite important to carry out accurate dating for Indosinian granites in Hunan in order to obtain the integrated tectonic framework and features of magmatic evolution for South China during the Mesozoic, and we thus select the Guandimiao (GDM) and Wawutang (WWT) granitic plutons in Hunan for the study of zircon chronology. A series of dating methods (zircon U-Pb model age, whole-rock Sm-Nd, biotite K-Ar and muscovite K-Ar) have been applied for the two plutons, and the dating results range from 183 Ma to 235 Ma

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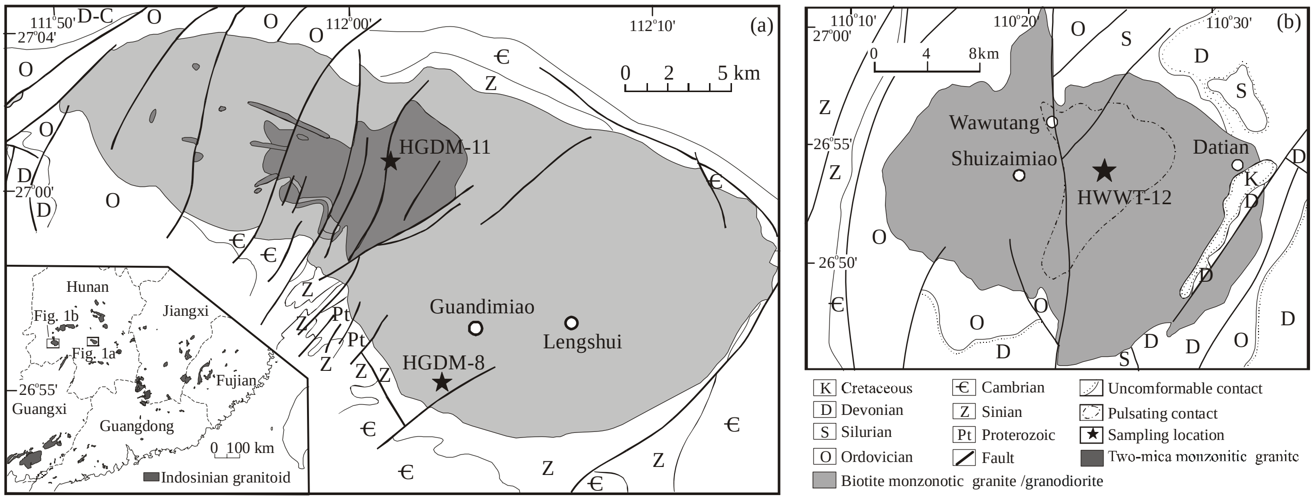

Fig. 1. Simplified geological map of the study area.
(a) Simplified geological map of the Guandimiao pluton (modified from the Regional Geological Survey Unit, 1995a); (b) Simplified geological map of the Wawutang pluton (modified from the Regional Geological Survey Unit, 1995a); inset—the map showing the distribution of Indosinian granites in South China (modified from Sun, 2006).

(Regional Geological Survey Unit, 1995a, b), corresponding to the early Yanshanian to Indosinian period. In order to ascertain the accurate ages of the two plutons (Indosinian? or Yanshaninan?), we firstly used the in-situ zircon U-Pb dating method of laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to analyze two samples from the GDM and one sample from the WWT in this paper.

2 Geological and Petrological Introduction

The GDM pluton is located at the boundaries of Hengyang, Qidong and Shaodong counties and crops out with an area of ca. 290 km^2 and extends along the E-W direction, which emplaces in the Sinian-Ordovician (Fig. 1a). The WWT pluton, exposed over an area of 500 km^2, intrudes into the Sinian, Cambrian, Ordovician and Silurian and is overlain by Cretaceous red strata in its eastern part (Fig. 1b) (Regional Geological Survey Unit, 1995a).

The GDM pluton is mainly composed of biotite monzonitic granites/granodiorites and two-mica monzonitic granites. The round dioritic enclaves, the pelitic and sandy xenoliths are generally found in biotite monzonitic granites/granodiorites. Biotite monzonitic granites/granodiorites are fine- to medium-grained rocks which consist of euhedral plagioclase with progressive rhythmic zoning (An=33–35, ca. 35–45% modal), subhedral to anhedral K-feldspar (15–20% modal), rounded quartz (ca.35% modal) which often replaces K-feldspar, euhedral flaky biotite (8–10% modal), and minor hornblende (1–2% modal). There are less or no enclaves and xenoliths in two-mica monzonitic granites, which are located at the center of the pluton (Fig. 1a) and are composed of rounded quartz (30–35% modal), perthitic K-feldspar (ca. 30% modal), euhedral and subhedral plagioclase (An=36, ca. 33% modal), subhedral to anhedral flaky biotite (5% modal), and of flaky or scaly muscovite (2–5% modal) which often grows together with biotite.

The WWT pluton mostly consists of biotite monzonitic granites, in which plagioclase and quartz phenocrysts are often discovered. Plagioclase phenocrysts with lengths of 0.8–6 cm commonly spread along the specific direction and generally contain biotite inclusions. The mafic minerals of granites are predominated by euhedral biotites (ca. 2–8% modal) and the felsic minerals mainly include K-feldspar (40–45% modal), anhedral quartz (ca. 35% modal), and euhedral to anhedral plagioclase (An=24–26, 15–20% modal), in which some show combination twins and contact twins in the thinning section.

3 Analytic Method

Representative samples of the two plutons, including HGDM-8 (biotite monzonitic granite) and HGDM-11 (two-mica granite) from the GDM pluton and HWWT-12 (biotite monzonitic granite) from the WWT pluton, are selected to conduct zircon dating. These samples are in-situ weathering granitic samples and the exact geographical coordinates measured by GPS on the sampling locations are respectively: HGDM-8: 26°54.083′ N, 112°4.089′ E; HGDM-11: 26°0.630′ N, 112°1.274′ E; HWWT-12:

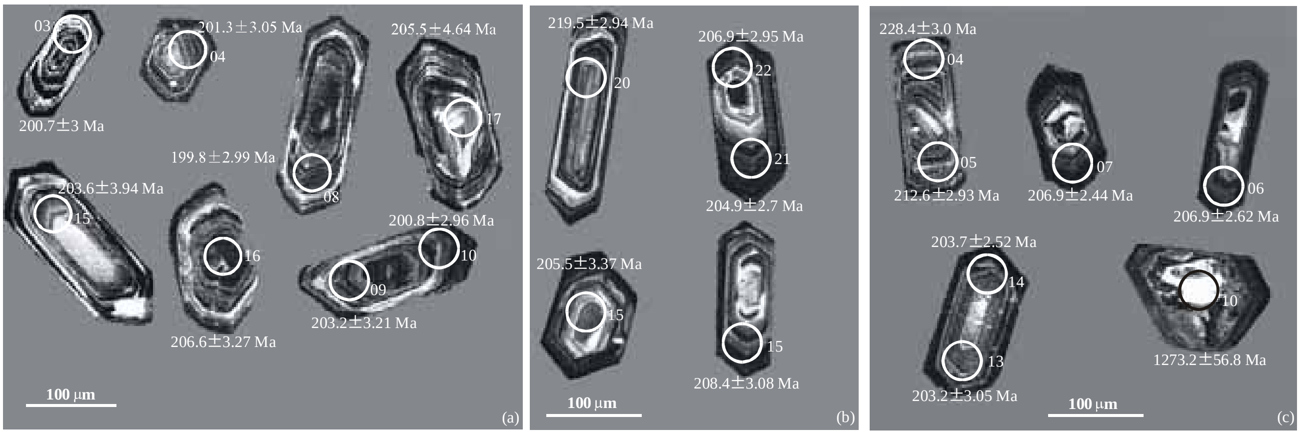

Fig. 2. CL images of representative zircons from the Wawutang and Guandimiao granites.

(a) Sample HGDM-8; (b) Sample HGDM-11; (c) Sample HWWT-12.

Illustration of label in the figure: e.g. 03/200.7±3 Ma, the former (03) denotes the measuring spot, the latter (200.7±3 Ma) denotes the age of this spot (we generally select the $^{206}Pb/^{238}U$ age for younger zircon but $^{207}Pb/^{206}Pb$ for older zircon), and they correspond to Table 1. The circles represent ambitus by laser ablation.

26°53.789′ N, 110°23.971′ E (Fig. 1). Before sampling, we cleaned off the accumulations over the weathering body in order to avoid admixture of exotic zircons, and then sampled from the semi-concreted weathering body. Zircons were separated from the weathering samples using elution, magnetic techniques and conventional heavy liquid methods, and then more than 50 zircon grains for each sample were picked out under a binocular microscope. As for the sample target, it is almost the same as that for SHRIMP analyses (Song et al., 2002). To reveal the microstructure of zircons, the cathodoluminescent (CL) imaging was carried out on a Cameca electron microprobe hosted at the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing. The analytical voltage and current for the CL were 50 kV and 15 nA, respectively.

Zircon LA-ICP-MS U-Pb dating was carried out at the Chinese Ministry of Education Key Laboratory of Continental Dynamics, Northwest University, Xi'an. The LA-ICP-MS is a combination of the GeoLas 200M laser-ablation system equipped with a 193 nm ArF-excimer laser. Helium was used as the carrier gas to enhance the transport efficiency of the ablated material. The instrument was optimized via a NIST SRM 610 for maximum sensitivity, stable signal, minimum oxide/element ratios and background. All measurements were made using the zircon TEM (417 Ma) as isotopic fractionation corrections and the zircon 91500 (1064 Ma) as the external standard for the age calculation. During the course of the measurements, the signal of ^{206}Pb and ^{207}Pb was twenty-fold higher than that of ^{204}Pb, which was very low and almost the same as the background, so we did not correct the common Pb. The operating processes and instrumental parameters are described in detail by Yuan et al. (2003). Isotopic ratios and U-Pb ages were calculated using the GLITTER (ver. 4.0, Macquarie University). The results of zircon dating are listed in Table 1.

4 CL Images and Results of Dating

Zircons from the samples (HGDM-8 and HGDM-11) of the GDM pluton mostly show euhedral doubly-terminated prismatic crystals, in most of which there develop pyramid (101) and prism (110) but prism (100) and pyramid (211) are in minority. In the CL images (Fig. 2a, b), oscillatory zones grow in most of zircons and their Th/U ratios range from 0.31 to 1.72 for HGDM-8 and 0.17 to 0.86 for HGDM-11 (Table 1), which suggests that they are igneous zircons (Corfu et al., 2003; Di et al., 2005). But part of them are usually surrounded by a thin light rim and a relatively dark outer shell which are similar to the igneous zircons having undergone metamorphic accretion (Pidgon, 1992; Vavra et al., 1999; Corfu et al., 2003; Wu et al., 2004). Therefore, the spots of dating are almost located at the oscillatory zones of zircons.

The mean weighted ages and plotting of concordia diagrams were determined by Isoplot 2.49a (Ludwig, 1991). Eighteen (18) analyses of each sample (i.e. HGDM-8 and HGDM-11) of the GDM pluton were made. On the concordia diagrams, the distributions of their plotted points either on the concordia curve (Fig. 3a) or right of it as an aclinic line (Fig. 3b), which are different from that of discordant plotted points caused by Pb loss (Li et al., 1996; Mezger et al., 1997; Chen et al., 2001) but related to difficult determination of ^{207}Pb and no influence on the ratios of $^{206}Pb/^{238}U$, denote that the U-Pb system still keeps closure and basically has no U or Pb loss and addition after crystallization of these zircons (Xu et al., 2003; Yuan et al., 2003; Ding et al., 2005). Herein, the $^{206}Pb/^{208}U$ weighted

Table1 Analytical data of LA-ICP-MS Zircon dating for the Guandimiao and Wawutang granitic plutons

Spot	Th (μg/g)	U (μg/g)	Th/U	Isotopic ratios				Age (Ma)			
				$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{232}Th$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{232}Th$
Sample of biotite monzonitic granites from GDM：HGDM-8											
HGMD8-1	4895	3602	1.36	0.06152±0.00151	0.03366±0.00045	0.28492±0.00709	0.00794±0.00009	657.3±51.9	213.4±2.8	254.6±5.6	159.8±1.9
HGMD8-3	1150	1855	0.62	0.06129±0.00231	0.03162±0.00048	0.26676±0.00995	0.0096±0.00019	649.6±79.0	200.7±3	240.1±8.0	193.1±3.8
HGMD8-4	851	1669	0.51	0.0526±0.00227	0.03171±0.00049	0.22961±0.00982	0.01048±0.00023	311.7±95.4	201.3±3.1	209.9±8.1	210.7±4.5
HGMD8-5	7537	4394	1.72	0.05611±0.00157	0.03282±0.00045	0.25347±0.00712	0.00866±0.0001	456.3±60.9	208.2±2.8	229.4±5.8	174.3±2.0
HGMD8-6	952	2008	0.47	0.07979±0.00313	0.03198±0.00052	0.35124±0.01349	0.01338±0.0003	1191.8±75.5	202.9±3.3	305.7±10.1	268.7±6.0
HGMD8-7	1254	2118	0.59	0.06558±0.00262	0.033670.00052	0.303970.012	0.012030.00024	793±81.8	213.5±3.3	269.5±9.4	241.7±4.8
HGMD8-8	1306	2867	0.46	0.05034±0.00206	0.03148±0.00048	0.21816±0.00884	0.0095±0.00021	210.5±92.2	199.8±3.0	200.4±7.4	191.1±4.2
HGMD8-9	977	2038	0.48	0.05189±0.00235	0.03202±0.00051	0.22871±0.01021	0.01017±0.00025	280.3±100.2	203.2±3.2	209.1±8.4	204.4±5.0
HGMD8-10	3577	3152	1.13	0.05503±0.00207	0.03165±0.00047	0.23974±0.00896	0.00963±0.00015	413.3±81.6	200.8±3.0	218.2±7.3	193.82.9
HGMD8-12	784	1262	0.62	0.07653±0.0038	0.03157±0.00057	0.3327±0.01611	0.01239±0.00031	1109±96	200.4±3.6	291.6±12.3	248.8±6.2
HGMD8-13	454	860	0.53	0.07086±0.00412	0.03189±0.00061	0.31117±0.01766	0.0129±0.00037	953.5±114.5	202.4±3.8	275.1±13.7	259.2±7.4
HGMD8-14	743	1591	0.47	0.086±0.00339	0.03207±0.00054	0.37972±0.01463	0.01387±0.00033	1338±74	203.5±3.4	326.8±10.8	278.5±6.6
HGMD8-15	387	1245	0.31	0.05282±0.00369	0.03208±0.00063	0.23334±0.01599	0.01193±0.00051	321.2±150.6	203.6±3.9	213±13.2	239.6±10.3
HGMD8-16	1360	2089	0.65	0.0543±0.00252	0.03257±0.00052	0.24346±0.01115	0.01155±0.00024	383.3±100.4	206.6±3.3	221.3±9.1	232.1±4.8
HGMD8-17	439	527	0.83	0.05118±0.00483	0.0324±0.00074	0.22835±0.02117	0.01123±0.00038	249±203.4	205.6±4.6	208.8±17.5	225.8±7.6
HGMD8-18	3681	2329	1.58	0.05462±0.0023	0.03185±0.0005	0.23958±0.00999	0.01032±0.00015	396.9±91.2	202.1±3.1	218.1±8.2	207.6±3.1
HGMD8-19	4018	3160	1.27	0.05171±0.00194	0.03185±0.00048	0.22678±0.00844	0.0111±0.00015	272.8±83.5	202.1±3.0	207.5±7.0	223.1±3.1
HGMD8-20	2256	2245	1	0.09109±0.00258	0.03232±0.00048	0.40538±0.01138	0.01237±0.00018	1449±53	205.1±3.0	345.5±8.2	248.5±3.6
Sample of two-mica monzonitic granites from GDM：HGDM-11											
HGDM11-01	466	841	0.55	0.05278±0.002	0.03663±0.00052	0.26655±0.00996	0.01187±0.00024	319.5±59.7	231.9±3.2	239.9±8.0	238.4±4.7
HGDM11-02	829	1228	0.68	0.05917±0.00184	0.03292±0.00044	0.26859±0.00822	0.00996±0.00017	573.5±87.2	208.8±2.8	241.6±6.6	200.3±3.4
HGDM11-03	1057	1766	0.6	0.07061±0.00181	0.03384±0.00044	0.3294±0.00835	0.01229±0.00018	946±46.0	214.5±2.7	289.1±6.4	246.8±3.6
HGDM11-05	286	778	0.37	0.04998±0.00244	0.03094±0.00047	0.21319±0.01022	0.01012±0.00029	194.1±40.8	196.4±3.0	196.2±8.6	203.4±5.8
HGDM11-06	511	925	0.55	0.05394±0.00223	0.03319±0.00048	0.24684±0.01002	0.01119±0.00024	368.3±78.0	210.5±3.0	224±8.2	224.9±4.7
HGDM11-07	368	2123	0.17	0.04581±0.00147	0.03248±0.00043	0.20517±0.00655	0.00942±0.00026	0.1±110.3	206±2.7	189.5±5.5	189.5±4.7
HGDM11-08	790	1654	0.48	0.04951±0.00142	0.03466±0.00045	0.23665±0.00672	0.01116±0.00018	172.2±89.1	219.6±2.8	215.7±5.5	224.2±5.2
HGDM11-09	707	1768	0.4	0.05253±0.00152	0.03253±0.00042	0.23566±0.00675	0.01067±0.00018	308.5±29.6	206.4±2.6	214.9±5.5	214.5±3.6
HGDM11-10	681	2034	0.33	0.0567±0.00184	0.0312±0.00042	0.24395±0.0078	0.00989±0.00021	479.2±75.5	198±2.6	221.6±6.4	198.8±3.7
HGDM11-11	398	801	0.5	0.05669±0.00329	0.03432±0.0006	0.26831±0.01525	0.01188±0.00036	478.8±83.0	217.5±3.7	241.3±12.2	238.7±4.3
HGDM11-12	1470	1701	0.86	0.0567±0.0017	0.03222±0.00043	0.25192±0.00748	0.0098±0.00014	479.2±103.3	204.4±2.7	228.1±6.1	197.1±7.1
HGDM11-13	341	771	0.44	0.04976±0.00222	0.03208±0.00048	0.22014±0.00963	0.00997±0.00025	184±15.7	203.5±3.0	202±8.0	200.6±2.8
HGDM11-14	860	1589	0.54	0.05241±0.00174	0.03309±0.00045	0.23916±0.00784	0.00946±0.00017	303.3±122.8	209.9±2.8	217.7±6.4	190.3±4.9
HGDM11-15	443	516	0.86	0.07784±0.00344	0.03239±0.00054	0.34763±0.01492	0.01048±0.00023	1143±97	205.5±3.4	302.9±11.2	210.8±3.5
HGDM11-16	541	1021	0.53	0.04596±0.00223	0.03285±0.00049	0.20822±0.00995	0.00887±0.00021	0.1±101.7	208.4±3.1	192.1±8.4	178.6±4.6
HGDM11-18	890	1229	0.72	0.04702±0.00159	0.03464±0.00047	0.22461±0.00752	0.00993±0.00016	50.1±154.2	219.5±2.9	205.7±6.2	199.8±2.1
HGDM11-20	915	1242	0.74	0.05055±0.00202	0.03262±0.00047	0.22731±0.00894	0.00963±0.00017	220.3±84.0	206.9±3.0	208±7.4	193.7±3.6

(continued)

Spot	Th (μg/g)	U (μg/g)	Th/U	Isotopic ratios				Age (Ma)			
				$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{232}Th$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{232}Th$
Sample of biotite monzonitic granites from WWT: HGDM-12											
HWWT12-01	803	2638	0.3	0.0498±0.0019	0.03207±0.00045	0.2202±0.00821	0.0099±0.00025	185.8±86.5	203.5±2.8	202.1±6.8	199.2±5.0
HWWT12-02	930	4494	0.21	0.04526±0.0012	0.0327±0.0004	0.20407±0.00533	0.00897±0.00019	0.1±21.6	207.4±2.5	188.6±4.5	180.4±3.8
HWWT12-04	463	2465	0.19	0.04509±0.00161	0.03607±0.00048	0.22424±0.00784	0.01013±0.00031	0.1±33.7	228.4±3	205.4±6.5	203.7±6.1
HWWT12-05	468	2103	0.22	0.0459±0.00189	0.03352±0.00047	0.21211±0.00857	0.01033±0.00031	0.1±87.9	212.6±2.9	195.3±7.2	207.7±6.2
HWWT12-06	359	3454	0.1	0.04321±0.00143	0.03261±0.00042	0.19422±0.00632	0.01054±0.00035	0.1	206.9±2.6	180.2±5.4	211.9±7.0
HWWT12-07	770	6741	0.11	0.04763±0.00114	0.03261±0.00039	0.21412±0.00505	0.01263±0.00028	80.3±56.7	206.9±2.4	197±4.2	253.6±5.5
HWWT12-10	166	312	0.53	0.08317±0.00247	0.19087±0.00272	2.18775±0.06299	0.0597±0.00113	1273±57	1126±7	1177±20	1172±22
HWWT12-11	535	5835	0.09	0.04306±0.00133	0.03297±0.00042	0.19563±0.00595	0.00915±0.00032	0.1	209.1±2.6	181.4±5.1	184.2±6.4
HWWT12-12	1290	5433	0.24	0.04759±0.00145	0.03024±0.00039	0.19832±0.00591	0.00768±0.00017	78.3±71.4	192.1±2.4	183.7±5.0	154.6±3.5
HWWT12-13	441	1500	0.29	0.04824±0.00228	0.03203±0.00049	0.21288±0.00985	0.00893±0.00029	111±108.1	203.2±3.1	196±8.3	179.7±5.8
HWWT12-14	671	3594	0.19	0.04625±0.00135	0.0321±0.0004	0.20458±0.00588	0.00917±0.00021	10.9±68.1	203.7±2.5	189±5.0	184.5±4.2
HWWT12-15	779	2415	0.32	0.04968±0.00198	0.03119±0.00044	0.21346±0.00833	0.00675±0.00019	180.2±90.5	198±2.8	196.5±7.0	136±3.9
HWWT12-16	432	3276	0.13	0.04568±0.0016	0.0332±0.00044	0.20893±0.00715	0.00958±0.00029	0.1±62.5	210.6±2.8	192.7±6.0	192.6±5.8
HWWT12-17	865	3588	0.24	0.04964±0.00166	0.03222±0.00043	0.22028±0.00719	0.00767±0.0002	178±76.1	204.4±2.7	202.1±6.0	154.5±4.1
HWWT12-18	623	6029	0.1	0.04651±0.00133	0.03219±0.0004	0.20618±0.00576	0.00851±0.00026	24±66.1	204.2±2.5	190.3±4.9	171.2±5.3
HWWT12-19	905	7613	0.12	0.04801±0.00113	0.03139±0.00038	0.20756±0.00479	0.00853±0.00021	98.5±55.9	199.2±2.4	191.5±4.0	171.6±4.1
HWWT12-21	424	2011	0.21	0.04806±0.00189	0.03311±0.00046	0.21917±0.00841	0.00854±0.00026	102.3±90.3	210±2.9	201.2±7.0	171.9±5.3

Note: Diameter of beam spot of laser was 40μm. The isotopic ratios and age data are all composed of measured value and absolute error (1σ).

mean ages for each sample were calculated: 203.0±1.6 Ma (MSWD=0.58) for HGDM-8 and 208.0±3.2 Ma (MSWD=4.9) for HGDM-11 by calculation of 16 (except HGDM8-01 and HGDM8-07) and 18 dating values, respectively. All the measuring points fall in the oscillatory zone, corresponding to late Indosinian epoch.

As for zircons of sample HWWT-12 from the WWT pluton, they are also euhedral doubly-terminated prismatic crystals and mostly with pyramid (101) and prism (110) developed. CL images reveal that they are typical igneous zircons with oscillatory zones and a minority of them have inherited cores, which show stronger CL images with spotted structure mantling oscillatory zones (Fig. 2c), of which Th/U =0.10–0.3. Sixteen (16) analyses were done (Table 1) and almost all the analyzed points lie on or near the concordia curve seen in Fig. 3c, which is consistent with that of zircons of no Pb loss or addition and suggests that the U-Pb system keep closure since formation of zircons. The $^{207}Pb/^{206}Pb$ age is effective for ancient zircons, which have undergone Pb loss and is selected for old zircons (>500 Ma) (Compston et al., 2001; Xu et al., 2004b). So the dating spot of HWWT11-10 is just located at the core of the zircon (Fig. 2c) and its $^{207}Pb/^{206}Pb$ age of 1273±57 Ma (Fig. 3d) might be that of the metamorphic basement (Guo et al., 1997b; Chen et al., 1998; Shen et al., 1999; Tang et al., 2004). The mean weighted age of 15 $^{206}Pb/^{238}U$ ages determined from igneous zircon yields to be 204±3 Ma (MSWD=4.3), which indicates that the WWT pluton is also formed during the Indosinian.

5 Discussion

There are different opinions about the tectonic evolution and petrogenesis of granites in South China during the Indosinian. Hsü et al. (1988) and Wang et al. (2005) considered that the Indosinian granitoids in South China were products of island-arc magmatism. However, the facts of dispersive planar-shaped distributions of Indosinian granites in SC and lack of coeval commensal igneous rocks indicate that their genesis should not be directly related to collision or subduction (Xu et al., 2003; Zhou, 2003; Ding et al., 2005). Furthermore, many researches have concluded that subduction of the Pacific plate toward the Eurasian continent took place during the late Mesozoic (Jahn, 1974; Huang et al., 1990; Jahn et al., 1990; Charvet et al., 1994; Lapierre et al., 1997; Zhou et al., 2000). Accordingly, the Indosinian movement has drawn attention from some researchers (Chen et al., 2002; Xu et al., 2003). This movement not only caused accretion of the ICB to the SCB but also resulted in formation of the Qinling orogen by collision between the North China Block (NCB) and the SCB. The SCB, just situated between the ICB and NCB,

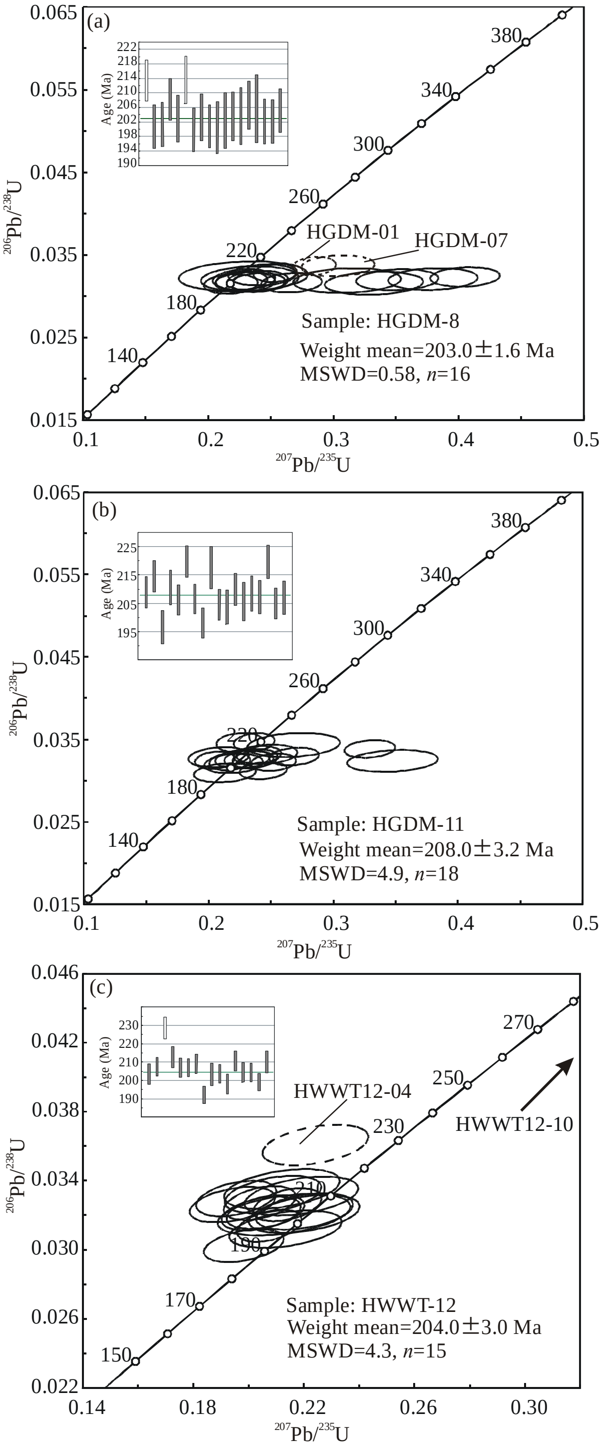

Fig. 3. Zircon U-Pb concordia diagram of the Wawutang and Guandimiao granites.

(a) Sample HGDM-8; (b) Sample HGDM-11; (c) Sample HWWT-12.

would undoubtedly be influenced by this movement and produce a series of tectonic and magmatic responses. A set of early Indosinian granites have recently been confirmed in Hainan, Guangxi and Guangdong, including the granites of the Jianfengling pluton (236–232 Ma) (Shu et al., 2004) and the Sanya syenite (237–252 Ma) (Xie et al., 2005) in Hainan, the cordierite granite and hypersthene porphyrite (230–236 Ma) in Shiwandashan-Darongshan of southeastern Guangxi (Luo et al., 1992; Deng et al., 2004), the gneissic granite (229–255 Ma) of Yunkaidashan in Guangxi (Shao, 1995), the granites of the Wuliting pluton (233–243 Ma) in southern Jiangxi (Qiu et al., 2004; Zhang et al., 2004), the granite of the Guidong pluton (236–239 Ma) (Xu et al., 2003) in northern Guangdong and the syenites from Tieshan and Yangfang (242–254 Ma) (Wang et al., 2005) in northern Fujian, indicating that the Indosinian magmatism in South China was related to the Indosinian movement occurring in the neighboring area.

The WWT and GDM plutons are just located at the hinterland of the SCB and dating results of this study reveal that they are formed during the late Indosinian. Based on statistical analysis of 83 age data of Indosinian granites in Hunan by Ding et al. (2006), ages exceeding 240 Ma are still scarce and the age peaks range from 210 Ma to 225 Ma for rocks in Hunan Province. Moreover, recent chronological study presents 224 Ma for gabbro enclaves within erupting basaltic breccia pipes from Daoxian (Guo et al., 1997a), 207–220 Ma of SHRIMMP ages for Taojiang-Dashengshan granites (Xu et al., 2004a) and 211–215 Ma of LA-ICP-MS ages for Weishan (Ding et al., 2005) in Hunan. It is obvious that the Indosinian magmatism in Huanan (or the hinterland of SC) was characterized by extensive late Indosinian magmatic movements. The ages of 203–208 Ma for the two plutons in this study are identical with the opinion mentioned above and provide new evidence for deeply discussing the nature of the Indosinian movement within the hinterland of South China (or the intraplate of SC). Tectonic movement and magmatism of the late Indosinian played a vital role during the geological evolution of this region.

The Indosinian granites in South China occur as dispersed and small plutons (see inset of Fig. 1), mainly including two kinds of granites: strongly peraluminous leucogranites (ACNK>1.1, ca. 60% of the total outcrop area of Indosinian granites in SC) and weakly peraluminous (ACNK=1.0–1.1, ca. 31%) or metaluminous (ACNK<1, ca. 9%) biotite granites and granodiorites, the former contain highly aluminous minerals such as muscovite and tourmaline (Zhou, 2003; Zhou et al., 2006). The $\varepsilon_{Nd}(t)$ (about −10) and Nd model ages (about 1.8 Ga) of Most Indosinian granites in South China are lower, indicating that Indosinian granites in South China are mainly derived from crustal materials and related to partial melting of old metamorphic basement (Chen et al., 1998; Zhou, 2003; Qiu et al., 2004; Sun et al., 2005).

The peak ages of collision between the SCB and ICB range from 243 Ma to 258 Ma (Lepvrier et al., 1997; Nam, 1998, 2001; Lan et al., 2000a, b; Carter et al., 2001; Maluski et al., 2001), which are earlier than that of metamorphism of the Qinling-Dabie orogen (226 Ma−230 Ma) (Liu et al., 2004). These chronological results reveal that the SCB compressed by the ICB moved as a whole toward the NCB during the early Permian and collided with the NCB till the middle Triassic, meanwhile the SCB was also constrained by the Qiangtang-Sibumasu and Songpan-Garzê compressed orogenic belt accreting to the Indochina-South China Block during the early-middle Triassic (ca. 240 Ma) (Carter et al., 2001), these tectonic movements led to folding of strata, thrusting nappe structure, compression of contemporary basins and crustal thickening in intraplate of the SCB (Wang et al., 2002; Zhou et al., 2003; Sun et al., 2005). Experimental and theoretical studies have proved that the crust would generally undergo relaxation of heat-stress within a time interval of 10−20 Ma after being thickened under extension mechanism, which caused crustal extension and partial melting by decompression to form granitic magma (Patiño Dounce et al., 1990). The fact of being ca. 20 Ma later than the Indosinian collision mentioned above and the Indosinian geological-geophysical model of South China constructed by Wang et al. (2002) have proved that the crustal thickening may predominate the formation of Indosinian tectonism and magmatism in Hunan. We, thereby, speculate that the GDM and WWT granitic plutons were formed under the tectonic environment of Indosinian crustal extension and thinning after crustal thickening and are assigned to post-collisional granites.

Moreover, the inherited zircon age of 1273±57 Ma obtained from the WWT pluton is identical to the ages of the basement and Nd isotopic model ages of granites in this region (Guo et al., 1997b; Chen and Jahn, 1998; Shen et al., 1999; Tang et al., 2004). This suggests that the source rocks of the two plutons are related to Proterozoic basement of SC, which proves the existence of Precambrian crystalline basement in this region. It is significant to identify the origin of Indosinian granites and the nature of the crustal basement in this region.

6 Conclusion

The Zircon LA-ICP-MS dating results of 203.0±1.6 Ma and 208.0±3.2 Ma for the GDM pluton and 204±3 Ma for the WWT pluton should represent the ages of formation for granites and indicate that they formed during the late Indosinian. In consideration of their spatial distribution (viz. the hinterland of South China) and time limit of the Indosinian movement, it is inferred that granites of the two plutons were formed under crustal extension and thinning of intraplate tectonic environment after the Indosinian collision and belonged to post-collisional intraplate granites. The measured inherited zircon age of 1273±57 Ma should represent the age of protolith and it suggests that there should exist the middle Proterozoic crystalline basement.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (No. 40372036) and the Key Project of the Ministry of Education, China (No. 306007). We are grateful to the anonymous reviewers, their constructive reviews helped to improve the manuscript. We deeply thank Wang Juncan from the No.230 Research Institute, CNNC, Changsha for his help. The CL images were directed by Xu Ping et al. from the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, and the LA-ICP-MS zircon dating was directed by Liu Xiaoming et al. from the Chinese Ministry of Education Key Laboratory of Continental Dynamics, Northwest University, Xi’an. Their assistance is all sincerely appreciated.

Manuscript received Dec. 7, 2005
accepted Aug. 22, 2006
edited by Zhu Xiling

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