Geochronology, genesis and landscape of Yanshanian granite in Guangzhou area, central Guangdong Province of China

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Abstract

Based on field geological investigation and zircon U–Pb isotope dating of granites in Guangzhou, central Guangdong, the formation age, petrogenesis and weathering characteristics of granites are discussed. The LA-ICPMS zircon U–Pb ages of Huolushan and Liugianshan granites in central Guangdong are 159.1 ± 3.5 Ma and 156.2 ± 4.4 Ma, respectively. These granites show low crystallization temperature (~ 800 °C) and negative low $\epsilon_{\text{Hf}}(t)$ values (-9.4 and -9.8), with two-stage model ages of 1241–1666 Ma, indicating that they were derived from partial melting of the Proterozoic crust. According to the geological and geomorphological characteristics of the granite area in central Guangdong, it is considered that lithology is the material basis of the granite landscape. Structural factors such as joints and faults are important controlling factors. The climatic and hydrological conditions in the granite area also play an important role in the formation of granite landforms.

Keywords Guangzhou · Granite · Geochronology · Lu–Hf isotope · Geomorphologic landscape

1 Introduction

South China preserves evidence of large-scale magmatism and is known for extensive mineralization. They enjoy a high reputation both in terms of resource type and aesthetic value e.g., [2, 6, 20, 39]. The mineralization of a large number of polymetallic deposits such as tungsten and tin is considered to be highly correlated with the Mesozoic granitic magmatism e.g., [12, 17, 25, 26, 37, 44]. At the same time, REE-rich granite regolith is a significant host for the ion-adsorption type Rare Earth Elements (REE) ore resources in South China [9]. After the formation of granite, as long as the overlying rock is stripped, a large area of granite rock mass is exposed [30]. When the granite is close to the ground or exposed, the protruding corners of the large rock gradually become smoother, forming a spherical-like weathering body [32]. The resulting

spherical weathering of granite is a widely distributed geomorphic element, especially in humid granitic areas. Regarding the safety factor of its stability, the predecessors have performed analysis based on mechanical calculations and physical tilt tests [23]. Some scholars believe that the tectonic and lithological controls for granite geomorphology is very important. For example, long-term uplift and subsidence are often responsible for the spatial pattern of major landforms. Lithological differences appear to have a significant influence on landform development in the long-term, controlling the rates of various exogenous processes [22]. In tectonically quiet regions, the shape of the granite landscape is controlled by the erosion resistance of the rock. Erosion is highly dependent on the release of particles from weathered rock and a degree of dissolution [7]. The weathering of granite in ultra-arid and low-temperature environments is mainly controlled by oxidation,

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including veins formed by thermal expansion and contraction and oxide alterations inside the rock [13].

Among the granites located in many forest parks in Guangzhou area, central Guangdong Province of South China, the spherical weathering is a common geological phenomenon. Regarding the formation age and the genesis of these granites, the predecessors paid more attention to the migmatite-gneiss suite in the study area [38, 40]. However, previous studies less involved the granite rock mass and the common granite geomorphology. In this study, the author collects representative samples to discuss the diagenetic age and rock genesis, and investigates the granite characteristics to explore the role of granite in the formation of geological relics and the significance of tourism geology. In this way, people can receive a knowledge experience when they appreciate the magic of nature.

2 Regional geology and petrology

South China preserves the record of intense tectonic–magmatic activities with associated widely distributed granites in the Mesozoic, especially in the Nanling Range. The extensive granitic magmatism has generated a large number of Jurassic and Cretaceous granites. The exposed area exceeds more than 30,000 km² and a small amount of Triassic granite with an exposed area of 3260 km² in Nanling area and its neighboring areas (Fig. 1a; [45]). A large number of polymetallic ore deposits formed during the Mesozoic, especially tungsten and tin mineralization. They are related to the extensive Mesozoic magmatic activities e.g., [3, 14, 21]. Guangzhou area is located in the Southern China fold system. Influenced by the Caledonian, Indosinian, Yanshanian and Himalayan cycle, folds and fractures of different scales were developed within the range. Among them, the Northeast Guangcong fault and the East–West Shougouling fault are the most prominent [47]. The granites in the study area mainly include the complex granites formerly known as the Luogang rock mass (Fig. 1b; [38]).

The studied monzonitic granite (samples: GZ-2 and GZ-3) were collected from the Huolushan and Liupianshan in the western part of Luogang rock mass and the northeastern part of Guangzhou. They commonly show porphyritic texture and massive structure (Fig. 2a and b). The mineral assemblage is mainly composed of plagioclase, K-feldspar, quartz, biotite and muscovite. Myrmekite is common between plagioclase and K-feldspar (Fig. 2c and d).

3 Analytical methods

In this study, the LA-ICP-MS zircon U–Pb dating technique was used to determine the zircon U–Pb age and in situ Lu–Hf isotope of representative rock samples from the Huolushan and Liupianshan granites in Guangzhou area, central Guangdong Province of south China. Zircons were sorted from fresh samples by gravity separation, magnetic separation and other separation techniques. Under the binocular microscope, no cracks, no inclusions, transparent and clean zircon were selected and immobilized on glass panels with epoxy resin. Then they were polished. Subsequently, reflected light and transmitted light photomicrography and cathodoluminescence (CL) image were performed to examine their internal structures. Zircon U–Pb and Lu–Hf isotope analysis were undertaken using Neptune multi-collector ICPMS equipped with 193 nm ArF excimer laser in Guangzhou Institute of Geochemistry (GIG), Chinese Academy of Sciences (CAS). The specific analysis procedure is described in the literature [41, 42]. The zircon U–Pb isotope ratio was calculated using the TEMORA as external standard. Fractional calibration and calculation were performed using ICPMS DataCal (8.4) [18]. Data processing was performed using the Ludwig 2001 SQUID 1.02 and ISOPLLOT programs [19].

4 Results

4.1 Zircon U–Pb age

The zircon U–Pb isotopic composition is shown in Table 1. The typical zircon CL image and age concordia plot are shown in Figs. 3 and 4.

The zircon grains in the sample GZ-2 display the shape of idiomorphic crystal with oscillatory zoning. A total of sixteen spots were selected for the zircon U–Pb isotope analysis. Two of the spots (GZ-2-03 and GZ-2-15) may be zircons from the wall rock captured by the upwelling magma, and their ²⁰⁶Pb/²³⁸U ages are 247.3 ± 8.8 Ma and 220.2 ± 7.2 Ma, respectively. Eight of the remaining spots were distributed over the concordant curve and the weighted average of ²⁰⁶Pb/²³⁸U was 159.1 ± 3.5 Ma (MSWD = 0.89). These analysis spots show Th/U ratios greater than 0.1. Therefore, the crystallization age of this sample was 159.1 ± 3.5 Ma.

The zircon grains separated in the sample GZ-3 exhibited strong oscillatory zonations. The ²⁰⁶Pb/²³⁸U age of the GZ-3-14 is 795.2 ± 23.1 Ma, which may be zircon captured from the wall rock during the magma

Fig. 1 **a** Regional distribution of the Mesozoic igneous rocks in the southeastern SCB (modified after [29]) and **b** Geological map of the eastern and northeastern parts in Guangzhou area, central Guangdong Province of China (modified after [38])

emplacement. The remaining fourteen spots show Th/U ratios of 0.10–0.93 and yield a weighted average of $^{206}\text{Pb}/^{238}\text{U}$ age of 156.2 ± 4.4 Ma. Combining the chronological results with the CL image analysis, we believe that 156.2 ± 4.4 Ma represents the crystallization age of the sample.

4.2 Zircon Hf isotopes

The zircon in situ Lu–Hf isotopic results are listed in Table 2.

In-situ Lu–Hf isotope analysis of eight zircon grains from the Huolushan granite (GZ-2) shows that the calculated $\epsilon_{\text{Hf}}(t)$ is -13.0 to -5.3 , with an average of -9.4 , and the two-stage model age T_{DM2} ranges from 1241 to 1618 Ma, according to $t = 159.1$ Ma, as shown in Figs. 5a and 6a.

Fourteen zircon grains were carried out by in situ Lu–Hf isotope analysis on Liupianshan granite (GZ-3), with $^{176}\text{Hf}/^{177}\text{Hf} = 0.282282 \sim 0.282470$. According to the formation age of $t = 156.2$ Ma, $\epsilon_{\text{Hf}}(t) = -14.0$ to -7.3 , average -9.8 , the

Fig. 2 The outcrop photographs (a–b) and corresponding photomicrographs (c–d) of the granites collected from Huolushan and Liupianshan in Guangzhou area, central Guangdong Province of China. Abbreviations: Pl, plagioclase; Kf, K-feldspar; Qtz, quartz; Bt, biotite

two-stage model age T_{DM2} is between 1339–1666 Ma, as shown in Figs. 5b and 6a.

5 Discussion

5.1 Formation age and petrogenesis

The Huolushan and Liupianshan granites are distributed in the eastern part of Guangzhou, formerly known as the Luogang rock mass [4, 16, 46]. For the Luogang rock mass, some scholars have identified the Indosinian I-type granites formed in the Triassic [5], while others have identified the Jurassic crustal anatexic Yanshanian granites [4]. This shows that the Luogang rock mass is a complex rock mass formed by multi-stage sub-magmatic invasion. For Yanshanian granites in Guangzhou, the age data obtained by early scholars mainly used Rb–Sr isotope dating, and the age range was concentrated at 203–155 Ma [4]. Since the Rb–Sr dating is usually reset or affected by late tectonic thermal events, these ages and their errors are in a larger range.

In this paper, zircon U–Pb dating was carried out on the samples of the Huolushan and Liupianshan granites from

the west side of the Luogang rock mass. The results show that the crystallization age of Huolushan granite (GZ-2) is 159.1 ± 3.5 Ma, and the crystallization age of Liupianshan granite (GZ-3) is 156.2 ± 4.4 Ma. This shows that they were formed in the late Jurassic. This period is one of the most significant periods of magmatic activity in the geological history of South China, and the number of granites and their corresponding metallogenic events is numerous. The Fogang rock mass located in the northeastern part of the Luogang rock mass is the largest complex rock foundation exposed in the Nanling area. Analogously, Li et al. [15] yielded consistent ages ranging from 159 ± 3 Ma to 165 ± 2 Ma by SHRIMP U–Pb zircon analyses for four samples from the Fogang Batholith. Huang et al. [11] studied the granite rock mass distributed in the southwest coastal area of Guangdong Province, and obtained the embedding age of 166–159 Ma. Zhang et al. [43] collected 12 granitic intrusions from coastal to inland areas in eastern Guangdong Province, and obtained their zircon U–Pb ages of 165–154 Ma. These age data indicate that the Jurassic granite is widely distributed in the south of China from the coast to the inland.

According to the analysis below, we proposed that the Huolushan and Liupianshan granite were likely produced

Table 1 U-Pb isotopic ratios and ages of zircons from the granites collected from Guangzhou area in central Guangdong Province, China

Content		Th/U	Isotopic ratios						Age(Ma)				Concordance (%)
Th (ppm)	U (ppm)		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	
2490	2338	1.07	0.04970	0.00230	0.17694	0.00832	0.02590	0.00086	165.4	7.2	164.8	5.4	99
798	1624	0.49	0.05035	0.00234	0.16953	0.00794	0.02425	0.00078	159.0	6.9	154.4	4.9	97
621	1501	0.41	0.05131	0.00257	0.27657	0.01481	0.03912	0.00141	247.9	11.8	247.3	8.8	99
1266	2868	0.44	0.04744	0.00207	0.15785	0.00688	0.02408	0.00076	148.8	6.0	153.4	4.8	96
939	2487	0.38	0.05043	0.00230	0.17319	0.00807	0.02485	0.00082	162.2	7.0	158.2	5.1	97
1217	3230	0.38	0.04916	0.00211	0.16884	0.00730	0.02485	0.00080	158.4	6.3	158.2	5.0	99
320	602	0.53	0.07520	0.00499	0.26815	0.01822	0.02560	0.00085	241.2	14.6	163.0	5.3	61
507	878	0.58	0.04814	0.00289	0.16852	0.00998	0.02537	0.00082	158.1	8.7	161.5	5.2	97
919	531	1.73	0.07094	0.00454	0.21097	0.01404	0.02197	0.00082	194.4	11.8	140.1	5.1	67
1277	937	1.36	0.05530	0.00331	0.16661	0.00971	0.02196	0.00074	156.5	8.4	140.0	4.7	88
968	773	1.25	0.05543	0.00286	0.23138	0.01197	0.03021	0.00099	211.3	9.9	191.8	6.2	90
575	1333	0.43	0.04737	0.00245	0.17193	0.00883	0.02627	0.00084	161.1	7.6	167.2	5.3	96
2684	2759	0.97	0.05057	0.00228	0.14163	0.00645	0.02024	0.00065	134.5	5.7	129.2	4.1	95
816	1200	0.68	0.06851	0.00417	0.24398	0.01521	0.02548	0.00084	221.7	12.4	162.2	5.3	69
785	721	1.09	0.05141	0.00273	0.24560	0.01300	0.03474	0.00115	223.0	10.6	220.2	7.2	98
933	1496	0.62	0.04974	0.00226	0.16968	0.00778	0.02468	0.00079	159.1	6.7	157.2	4.9	98
1043	10791	0.10	0.05064	0.00207	0.16754	0.00665	0.02393	0.00075	157.3	5.8	152.5	4.7	96
686	919	0.75	0.05399	0.00299	0.15804	0.00822	0.02199	0.00075	149.0	7.2	140.2	4.7	93
897	1973	0.45	0.04291	0.00201	0.15276	0.00725	0.02569	0.00082	144.3	6.4	163.5	5.2	87
723	992	0.73	0.04930	0.00248	0.17845	0.00906	0.02630	0.00086	166.7	7.8	167.3	5.4	99
1103	3557	0.31	0.04657	0.00200	0.16681	0.00726	0.02590	0.00084	156.6	6.3	164.8	5.3	94
1025	2371	0.43	0.05320	0.00280	0.17901	0.00947	0.02426	0.00078	167.2	8.2	154.5	4.9	92
774	1878	0.41	0.04702	0.00231	0.16593	0.00808	0.02557	0.00082	155.9	7.0	162.8	5.1	95
524	1343	0.39	0.04781	0.00229	0.16863	0.00820	0.02539	0.00083	158.2	7.1	161.6	5.2	97
698	752	0.93	0.05722	0.00344	0.19714	0.01169	0.02496	0.00081	182.7	9.9	158.9	5.1	86
1066	3024	0.35	0.05034	0.00213	0.17663	0.00797	0.02520	0.00085	165.2	6.9	160.5	5.3	97
395	773	0.51	0.05207	0.00276	0.17800	0.00943	0.02476	0.00081	166.3	8.1	157.7	5.1	94
513	1384	0.37	0.04933	0.00238	0.15629	0.00735	0.02295	0.00074	147.4	6.5	146.3	4.6	99
489	2621	0.19	0.07068	0.00250	1.29184	0.04571	0.13128	0.00406	842.1	20.3	795.2	23.1	94
449	919	0.49	0.05554	0.00286	0.18476	0.00968	0.02392	0.00077	172.1	8.3	152.4	4.9	87
1168	2506	0.47	0.05343	0.00224	0.17763	0.00731	0.02404	0.00076	166.0	6.3	153.2	4.8	91

Fig. 3 CL images of representative zircons from Huolushan and Liupianshan granites. The small ellipses indicate the LA-ICP-MS analytical spots for U-Pb isotopes and large circles denote the LA-ICP-MS analytical spots for Lu-Hf isotopes. Numbers near the analytical spots are the U-Pb ages (within parentheses) and $\epsilon_{\text{Hf}}(t)$ values [within square brackets]

Fig. 4 LA-ICPMS Zircon U-Pb concordia age plots for the granites collected from Huolushan and Liupianshan in Guangzhou area, central Guangdong Province of China

by partial melting of Proterozoic ancient crust. (1) In-situ zircon Lu–Hf isotope analysis results in this study show that the granites from the Huolushan and Liupianshan in Guangzhou area have relatively homogeneous zircon Hf isotopic compositions with lower $\varepsilon_{\text{Hf}}(t)$ values ranging from -14.0 to -5.3 and two-stage model ages of 1666 – 1241 Ma, similar to those of basement rocks in eastern Cathaysia Block (Fig. 6a), which represents by highly evolved Proterozoic crust [27], implying that they could have originated from basement rocks in the Cathaysia Block. (2) Geochemical data show that the Huolushan and Liupianshan granite has aluminum supersaturation and initial value of $^{87}\text{Sr}/^{86}\text{Sr} > 0.7100$, which indicates that they belong to continental remelted granite [4]. (3) Crystallization temperature of zircons from the the Huolushan and Liupianshan granite is calculated using Ti-in zircon thermometer of Watson et al. [33]. The calculation results show that the average crystallization temperature of zircons is ~ 800 °C (Fig. 6b), similar to those of S-type granite generating from ancient crust, but different from those of typical A-type granite with high crystallization temperature [24, 28] and adakitic rock deriving from mafic lower crust or juvenile arc crust [1].

5.2 Geomorphological landscape and controlling factors

Many granitic rock eggs were seen in the area of the Huolushan and Liupianshan granite in Guangzhou, central Guangdong Province of China (Fig. 7). The large and stacking of granitic rock eggs were related with both spherical weathering and water scouring. After the formation

of granite body, the pressure relaxes when exposed near the ground or rising. Under the weathering action of physical, chemical and biological factors, spherical layered rock blocks are peeled off along the joint plane. The relics of rock blocks are dominated by quartz, feldspar and other minerals [30, 31]. Specifically, the spherical weathering of granite in Guangzhou area is mainly controlled by the following factors.

Firstly, lithology is the material basis of the granite landscape. Lithological differences revealed in grain size, mineralogical composition and water impermeability. The massive and dense crystal structure allows the weathering to proceed only on the surface of the rock, from the exterior to the inner layer. The impermeability allows the rainfall to runoff on the surface of the rock, enhancing water erosion of the rock. The effect is that when the weathering shell on the rock mass is denuded, the flowing water is infiltrated along the joints, and the huge granite body is separated to become the initial state of the huge stone egg topography. With the deepening of weathering, the angular edges of the massive rock mass fall off and the square-shaped rock mass changes to a smooth shape [39]. In addition, different minerals in the rock mass have different weathering resistance. The common rock-forming minerals in the Huolushan and Liupianshan granite mainly include quartz, feldspar, and mica. In general, the weathering resistance of quartz and feldspar is stronger than that of mica. This is why most of the spherical weathering bodies have quartz and potassium feldspar residual spots in the study area (Fig. 7a and b). Some scholars agree that the truly outstanding landscape and silica are consistent with the high-potassium granite bodies [8]. The rock mass

Table 2 Lu-Hf isotopic data of zircons extracted from the granites collected from Guangzhou area in central Guangdong Province, China

Spot	Age (Ma)	$^{176}\text{Yb}/^{177}\text{Hf}$	1σ	$^{176}\text{Lu}/^{177}\text{Hf}$	1σ	$^{176}\text{Hf}/^{177}\text{Hf}$	1σ	$^{176}\text{Hf}/^{177}\text{Hf}_i$	$\epsilon_{\text{Hf}}(0)$	$\epsilon_{\text{Hf}}(t)$	1σ	$T_{\text{DM}}\text{Hf}_1$ (Ma)	$T_{\text{DM}}\text{Hf}_2$ (Ma)	Hf DM (t)	T_{DM}^c (Ma)	$f_{\text{Lu/Hf}}$
GZ-2																
GZ-2-01	159.1	0.113130	0.002089	0.003069	0.000054	0.282415	0.000018	0.282405	-12.6	-9.48	0.6	1253	1447	0.283137	1810	-0.91
GZ-2-02	159.1	0.046162	0.000507	0.001345	0.000015	0.282407	0.000018	0.282403	-12.9	-9.56	0.6	1206	1451	0.283137	1815	-0.96
GZ-2-04	159.1	0.028419	0.000151	0.000795	0.000003	0.282374	0.000016	0.282372	-14.1	-10.66	0.6	1234	1505	0.283137	1884	-0.98
GZ-2-05	159.1	0.026160	0.000140	0.000740	0.000002	0.282437	0.000016	0.282435	-11.9	-8.44	0.6	1145	1396	0.283137	1745	-0.98
GZ-2-06	159.1	0.031311	0.000171	0.000908	0.000006	0.282412	0.000016	0.282409	-12.7	-9.33	0.5	1185	1439	0.283137	1801	-0.97
GZ-2-08	159.1	0.025156	0.000060	0.000714	0.000003	0.282309	0.000016	0.282307	-16.4	-12.98	0.6	1323	1618	0.283137	2029	-0.98
GZ-2-12	159.1	0.033214	0.000076	0.000933	0.000002	0.282414	0.000014	0.282411	-12.7	-9.29	0.5	1184	1437	0.283137	1798	-0.97
GZ-2-16	159.1	0.016558	0.000411	0.000447	0.000010	0.282525	0.000015	0.282523	-8.7	-5.30	0.5	1015	1241	0.283137	1547	-0.99
GZ-3																
GZ-3-01	156.2	0.054039	0.000193	0.002054	0.000008	0.282411	0.000014	0.282405	-12.8	-9.56	0.5	1224	1448	0.283139	1813	-0.94
GZ-3-02	156.2	0.025995	0.000065	0.000708	0.000004	0.282430	0.000017	0.282428	-12.1	-8.76	0.6	1154	1409	0.283139	1762	-0.98
GZ-3-04	156.2	0.026237	0.000126	0.000753	0.000002	0.282464	0.000014	0.282462	-10.9	-7.55	0.5	1108	1349	0.283139	1686	-0.98
GZ-3-05	156.2	0.060906	0.000227	0.001618	0.000007	0.282447	0.000019	0.282443	-11.5	-8.22	0.7	1157	1382	0.283139	1728	-0.95
GZ-3-06	156.2	0.026214	0.000055	0.000759	0.000001	0.282470	0.000015	0.282468	-10.7	-7.34	0.5	1100	1339	0.283139	1673	-0.98
GZ-3-07	156.2	0.034816	0.000080	0.000981	0.000002	0.282428	0.000016	0.282426	-12.2	-8.83	0.5	1165	1412	0.283139	1767	-0.97
GZ-3-08	156.2	0.022967	0.000113	0.000640	0.000001	0.282384	0.000017	0.282383	-13.7	-10.35	0.6	1215	1487	0.283139	1862	-0.98
GZ-3-09	156.2	0.028040	0.000044	0.000799	0.000002	0.282423	0.000014	0.282420	-12.3	-9.01	0.5	1167	1421	0.283139	1778	-0.98
GZ-3-10	156.2	0.034107	0.000116	0.000957	0.000003	0.282282	0.000019	0.282279	-17.3	-14.00	0.7	1368	1666	0.283139	2090	-0.97
GZ-3-11	156.2	0.036833	0.000257	0.001065	0.000009	0.282380	0.000018	0.282377	-13.8	-10.53	0.6	1234	1496	0.283139	1874	-0.97
GZ-3-12	156.2	0.028187	0.000256	0.000764	0.000004	0.282362	0.000014	0.282360	-14.5	-11.15	0.5	1250	1526	0.283139	1912	-0.98
GZ-3-13	156.2	0.023546	0.000044	0.000672	0.000002	0.282402	0.000017	0.282400	-13.1	-9.74	0.6	1192	1457	0.283139	1824	-0.98
GZ-3-15	156.2	0.018456	0.000204	0.000521	0.000004	0.282367	0.000014	0.282366	-14.3	-10.95	0.5	1235	1517	0.283139	1900	-0.98
GZ-3-16	156.2	0.038879	0.000105	0.001107	0.000002	0.282360	0.000017	0.282357	-14.6	-11.27	0.6	1265	1532	0.283139	1920	-0.97

Fig. 5 Histograms of $\epsilon_{\text{Hf}}(t)$ values of zircons from the granites collected from Huolushan and Liupianshan in Guangzhou area, central Guangdong Province of China

Fig. 6 Diagrams of zircon $\epsilon_{\text{Hf}}(t)$ values versus crystallization ages (a) and Ti-in-zircon crystallisation temperatures versus crystallization ages (b) for the granites collected from Huolushan and Liupianshan

in Guangzhou area, central Guangdong Province of China. The Hf isotope evolution for the crustal basement of the eastern Cathaysia Block is indicated by the shaded region [10, 35]

has better integrity and stronger weathering resistance, and it seems to be more conducive to the shaping of the landscape with ornamental value.

Secondly, structural factors such as joints and faults are important controlling factors for granite landform. In fact, granite is plutonic igneous rock formed by the condensation of magma in the deep underground. The reason why we have seen so many granite landforms must have experienced structural uplift to near-surface or full exposure. The terrain ups and downs caused by the active lifting or faulting can form a landform-type layout. As a result, the development of granite joints is very obvious, which provides a geological basis for the spherical weathering of granite. The fault structures are well developed in the study area, and the deformation stages of the Shougouling fault zone are from Late Triassic to Quaternary [36, 47]. In

the later geological history, many rhombic jointed tectonic systems destroyed the robustness and impermeability of the granite itself. Groundwater and chemical weathering and biological weathering can be penetrated vertically or horizontally [39]. This also coincides with the joint and brittle crack observed in the field. (Figure 7d and e). On the granite hills with thick weathering crusts, strong cut valleys are often formed. At the top of the granite mountainous terrain, the surface weathered soils are washed away, and are scattered into large stone eggs by spherical peeling.

Finally, the climatic and hydrological conditions in the granite area also play an important role in the formation of granite landforms. It can be highly weathered under hot and humid conditions, because most of the chemical reactions occur at high temperatures. In the dry and cold

Fig. 7 Characteristics of Huolushan and Liupianshan granites in Guangzhou area, central Guangdong Province of China. **a** The bright part of high weathering degree granite are quartz particles with strong resistance to weathering; **b** Huge particle feldspar porphyroclasts; **c** Rounded shape of the egg-shaped stone; **d** Joints of the developments in spherical weathering body **e** Brittle crack of spherical weathering body; **f** Layer peeling in a regular round of spherical weathering body

climate, physical weathering mainly occurs and breaks into small fragments [34]. Guangzhou area is located on the subtropical coast. The Tropic of Cancer passes through the south-central region. It is a maritime subtropical monsoon climate with sufficient light and heat, simultaneous water and heat and abundant rainfall. In addition, Guangzhou area is often hit by typhoons. The granite is washed by rain, and the fine-grained minerals on the surface are washed away by a large amount. This has evolved into a scouring groove for a long time, which provides favorable external environmental conditions for the formation of globular weathering.

6 Conclusions

Through the LA-ICP-MS zircon U–Pb dating technology, the formation ages of the Huolushan and Liupianshan monzonitic granites in Guangzhou area, central Guangdong Province of China were 159.1 ± 3.5 Ma and

156.2 ± 4.4 Ma, respectively. They correspond to the large-scale magmatism of the Late Jurassic. The average values of zircon $\epsilon_{\text{Hf}}(t)$ are -9.4 and -9.8 , and the two-stage model ages are 1241–1618 Ma and 1339–1666 Ma, respectively. They were likely produced by partial melting of Proterozoic ancient crust. Regarding the spherical weathering characteristics of granite in the study area, they are controlled by many factors. Lithology is the material basis of the granite landscape. Structural factors such as joints and faults are important controlling factors. The climatic and hydrological conditions in the granite area also play an important role in the formation of granite landforms.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interests regarding the publication of this paper.

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