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SHRIMP U-Pb geochronology of the detrital zircons from the Longshoushan Group and its tectonic significance

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Sixty-two geologically meaningful U-Pb dates were obtained by using SHRIMP technique for the detrital zircons in three metasedimentary rocks from stratigraphically uppermost parts of the Longshoushan Group in the present study. Eighty percents of these dates range from 1.7 Ga to 2.2 Ga with a peak at 1.8—2.0 Ga and twenty percents from 2.3 Ga to 2.7 Ga. The youngest detrital zircon is dated at 1724±19 Ma which is interpreted as the maximum depositional age of the metasedimentary rocks. Therefore, the age for the diagenesis and lithification of the original sedimentary rocks of the Longshoushan Group before the metamorphism must be younger than 1724±19 Ma. Comparison of the age histograms of these detrital zircons with the ages of the igneous rocks on the surrounding older massifs suggests that the sediments of the Longshoushan Group were most likely derived from the Alaxa Block and Tarim Craton. This implies that the affinity between Alaxa Block and Tarim Craton was strong and that they might have been a unified craton during middle-early Proterozoic time.

Longshoushan Group, SHRIMP, detrital zircons, U-Pb geochronology, metasedimentary rocks

1 Introduction

The term "Longshoushan Group" was first proposed by the First Regional Survey Team, Bureau of Geology, Gansu Province, in 1967. It comprises a set of NWW-SEE trending Precambrian metamorphic rock units in the area bounded by 38°—40°N latitude and 99°—103°E longitude[1]. It is exposed in a long and narrow belt of about 500 km long and 30 km wide, starting from Jinta in Gansu Province, stretching southeastward through Heli Mountain, Gaotai County, and Shandan to Longshou Mountain and Jinchang (Figures 1 and 2). Because the exposure area of the Longshoushan Group is at the junction of three geological terranes, Tarim Craton, North China Craton and Qilian Fold Belt, the geological age of the Longshoushan Group is particularly important for understanding the geotectonics and geological evolution of the entire northwest China and thus has attracted the attention of many geological investigators for many years[2−7].

Geological ages of the Longshoushan Group have been debated for more than two decades. Many previous data either lacked the detailed original data required for discussion or were self contradictory, therefore, they were of little value. However, the previous data reported in literature pertinent to the geological age of the Longshoushan Group are summarized below. Discovery of the Conophyton stramotolite within the Dunzigou Group[1,8] in the Jixian System and the Longshoushan Group, which unconformably underlies the Dunzigou Group, was consequently considered as pre-Jixian System. Besides, absence of the Changcheng System in the Longshou Mountain area[8] further placed the Longshoushan Group into pre-Changcheng System. In other

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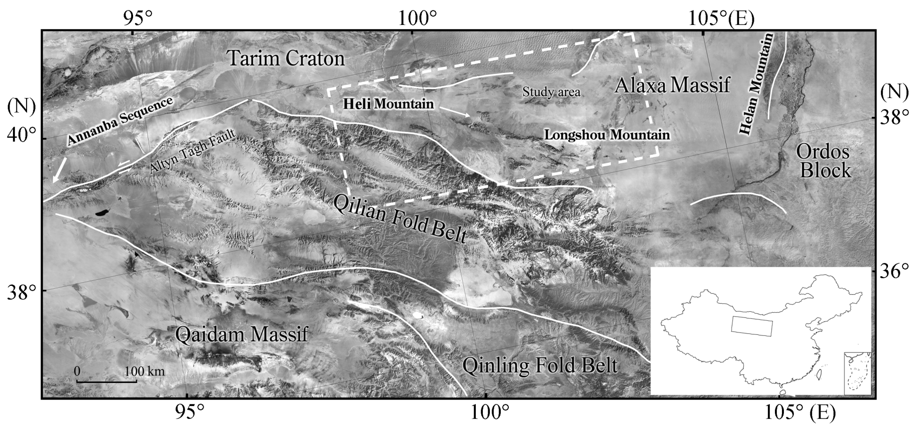

Figure 1 Satellite images of the studied and adjacent areas. Major structural lines and geotectonic divisions are shown. Rectangle outlined by the white dash line is the studied area and is enlarged in Figure 2. Digital topography from Landsat-1 (1972—1978) database.

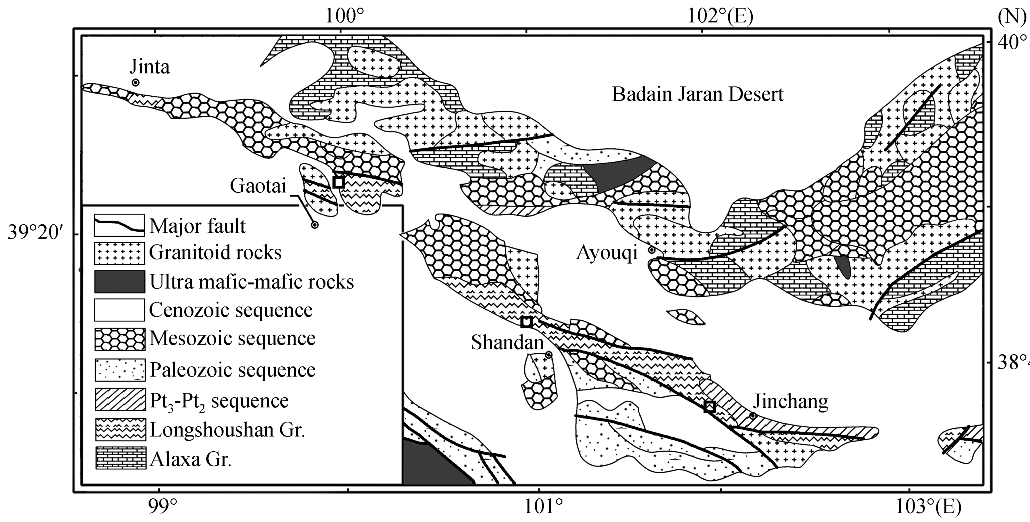

Figure 2 Simplified geological map of the studied area, showing the distribution of the Longshoushan Group and the related rock formations. □, Sample locality.

words, the age for the sedimentation and solidification of the Longshoushan Group was older than 1800 Ma, the lower age limit for the Changcheng System[9]. For the metasedimentary rocks of the Longshoushan Group, there are four muscovite K-Ar dates of 1319 Ma, 1690 Ma, 1697 Ma and 1711 Ma[8], and one biotite K-Ar date of 1600 Ma[10]. In addition, the muscovite K-Ar dates are 1740 Ma and 1786 Ma[11] respectively for the pegmatitic granite and gneissic granite which intruded into the Longshoushan Group. These K-Ar isotopic dates indicate that age of the regional metamorphism which had acted on the rocks of the Longshoushan Group subsequent to their sedimentary lithification was older than 1786 Ma. Whole-rock Rb-Sr isochrone dates are 1949 Ma, 2147 Ma, 2331 Ma, and 2065 Ma respectively for the intrusive hornblend-biotite-plagioclase gneiss, plagiogranite, pegmatitic plagiogranite, and migmatite[1,8,10]. The Rb-Sr dates were interpreted as the ages of the metamorphosed igneous protolithis of the Longshoushan Group. Recently, more reliable U-Pb age data were obtained for single-grain zircons by isotopic dilution technique. For example, Xiu et al.[6,7] determined the U-Pb ages for zircons separated from the granitic gneiss and trondhjemite of the Longshoushan Group and reported the upper and lower interception ages of 1914±9 Ma and 577±174 Ma respectively for the granitic gneiss and 2015±16 Ma and 452±16 Ma for the trondhjemite. For the zircons in the plagioclase amphibolite from the Longshoushan Group, Lu[5] obtained U-Pb ages of 2034±16 Ma and 758±47 Ma respectively for the upper and lower interception points. The upper interception age is generally considered as the age of protolith of metaigneous rocks, while the lower interception age is thought to be the age of subsequent metamorphism. Accordingly, the ages of these igneous rocks in the Longshoushan Group prior to metamorphism were likely 1914—2034 Ma. An Sm-Nd isotope age of 1508 Ma was reported by Gansu Bureau of Geology and Mineral Resources in 1997[10], which was taken to represent the metamorphic age of the Longshoushan Group, but is hard to compare with other metamorphic ages mentioned above.

Regarding the geological ages of the provenance of the sediments for the Longshoushan Group, there are Sm-Nd model ages (T_{DM}) of 2090—3060 Ma and 2004—2680 Ma reported respectively by Chung[12] and Wan et al.[13] and T_{DM} ages of 2486—3186 Ma reported by Compiling Committee of Stratigraphy of China[1] and Tang et al.[14−16]. In summary, it is difficult to suggest a reasonable lithification age and a metamorphic age for it. It is generally acknowledged that U-Pb age of detrital zircon is a very good indicator of affinity of sediments, paleogeography, paleoplates, and history of accretion[17 − 19]. Recently, important accomplishments were made by determining the ages of the detrital zircons from the North China Craton and Ordos Block[9,17,20−22]. In the present study, the metasedimentary rock samples of the Longshoushan Group were collected from Heli Mountain and Longshou Mountain areas and the SHRIMP technique was used to determine U-Pb ages of the detrital zircons. These ages will not only provide new constraints on the lithification and metamorphic ages for the Longshoushan Group but also be used to trace their sedimentary provenance and their geological significance.

2 Stratigraphy and rock association of the Longshoushan Group

Longshoushan Group is exposed mostly in the Heli Mountain and Longshou Mountain areas. It is unconformably overlain by the Dunzigou Group and is in fault contact with the older Alaxa Group[8]. The Longshoushan Group suffered, in general, a low-amphibolite facies regional metamorphism and migmatization during the Luliang orogeny and was strongly deformed. The protoliths of the Longshoushan Group were chiefly shaly and sandy clastic and carbonate rocks of shallow marine environment; Besides, there were also minor amount of mafic volcanic rocks and dacite[1]. The Longshoushan Group exposed in the Heli Mountain area and that in Longshou Mountain area were correlated and, on the basis of previous work[1,8,10,11], the Longshoushan Group is divided into, from bottom upward, A, B, C, and D formations (Figure 3).

2.1 Qilingou Formation

This formation constitutes the lowest part of the Longshoushan Group. The type locality is located at Qilingou, Shandan County. It consists of banded, Augen migmatites interbedded with plagioclase amphibolite, gneiss, and thinly-bedded marble and serpentinized marble. The degree of metamorphism was low-amphibolite facies and the protoliths were a set of intermediate-mafic volcanic and sedimentary rocks.

2.2 Baijiazui Formation

This formation is distributed chiefly in the middle segment of Longshou Mountain with type locality at Shiquangou, north of Jinchang. It mainly consists of interbedding marble and biotite gneiss, garnet bearing two-mica quartz schist, and plagioclase amphibolite. The degree of metamorphism was low-amphibolite facies and the protolite was a sequence of marine continental clastic rocks and Mg-rich marble.

2.3 Tamagou Formation

This formation is exposed all over the Heli Mountain and Longshou Mountain areas and a cross section along Dunzigou, Jinchang is most representative. It chiefly consists of two-mica quartz schist, plagioclase amphibolite, plagioclase leucoleptite, and minor amount of marble, dolomite, biotite-plagioclase gneiss, and quartzite. The degree of metamorphism was high greenschist facies and the protoliths were carbonate and flyschoid rocks.

2.4 Shijingkuo Formation

This formation is distributed mostly in the southern part of the Heli Mountain. The best representative cross-section is found at Chibaogou, Gaotai County. It consists of leucoleptite, quartzite, and metadacite in the lower part, mica-quartz schist and gneiss in the middle part, and leptite gneiss, and crystalline limestone in the upper part. The degree of metamorphism was mainly low-greenschist facies, and the protoliths were marine

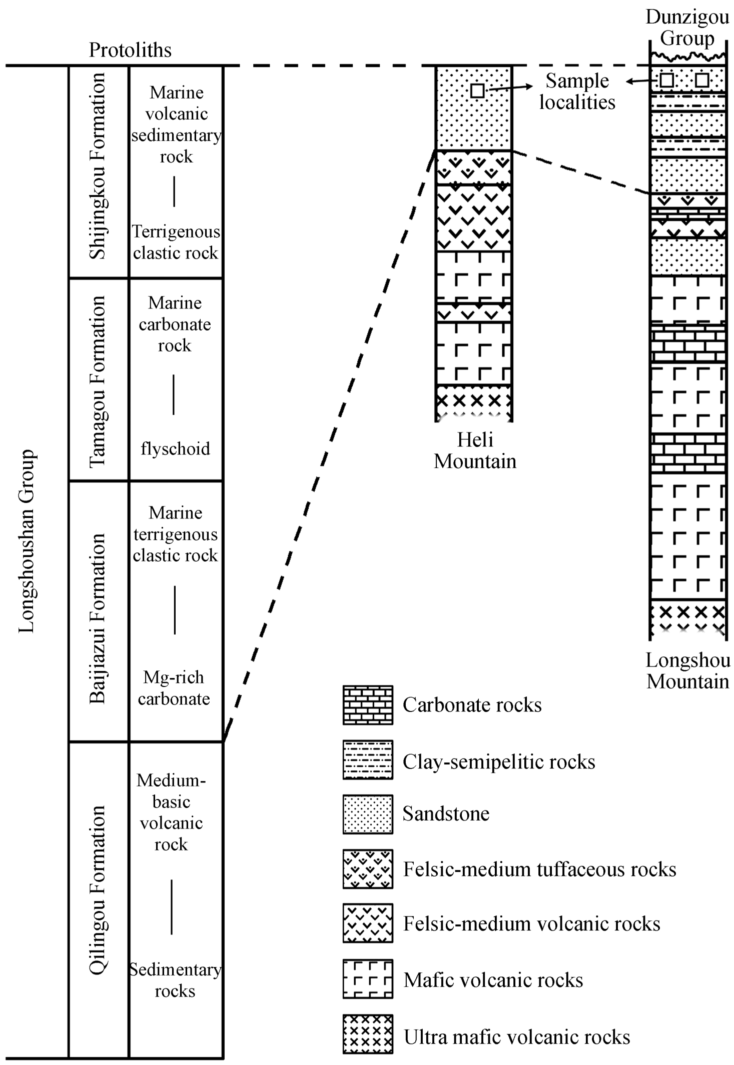

Figure 3 Stratigraphic column of the Longshoushan Group and the correlation of the Longshoushan Group exposed in the Longshou Mountain and Heli Mountain areas.

sedimentary-volcanic and continental clastic rocks.

3 Characteristics of the samples

Large amount of metasedimentary rocks of the Longshoushan Group were collected from Heli Mountain and Longshou Mountain areas. Three metasedimentary rocks, of which the sampling localities are shown in Figure 2, were selected for the present SHRIMP study. The sample 89-2405B (39°35.2′N, 99°57.8′E) was collected in the Heli Mountain, about 20 km north of Gaotai County, Gansu Province. It is a two-mica schist and consists mainly of quartz (80%), mica (15%), and trace feldspar. Micas were slightly chloritized. It is typically a clastic sedimentary rock. The sample SD2-14 (38°56.5′N, 101°11.6′E) is a muscovite quartz schist and consists mainly of quartz (85%), muscovite (10%), and little feldspar. The protolith was apparently sandstone. The quartz grains were elongated and aligned, and show wavy extinctions, indicating that the rock suffered ductile deformation. The Sample 87-1001H (38°33.4′N, 102°02.5′E) is also a two-mica schist and consists chiefly of quartz (55%), chlorite (25%), and mica (20%). The alternating bands of coarse and fine quartz grains and aligned mica and chlorite flakes suggest that the protoliths were shaly sandstone.

4 Determination of U-Pb ages of zircon with SHRIMP

4.1 Method and procedure of the determination

The rock samples were crushed, ground, and sorted. The zircon grains were separated by using heavy liquid, magnetic separator, and finally by hand-picking under microscope. The zircon grains were first embedded in epoxy resin and then exposed to the surface by grinding and polishing. The polished surfaces of the zircon grains were examined and photoed with transmitting and reflecting lights under an optical microscope and with cathodoluminescence through a scanning electron microscope (Figure 4). Concentration and ratio of U-Th-Pb isotopes of the zircon grains were determined with an

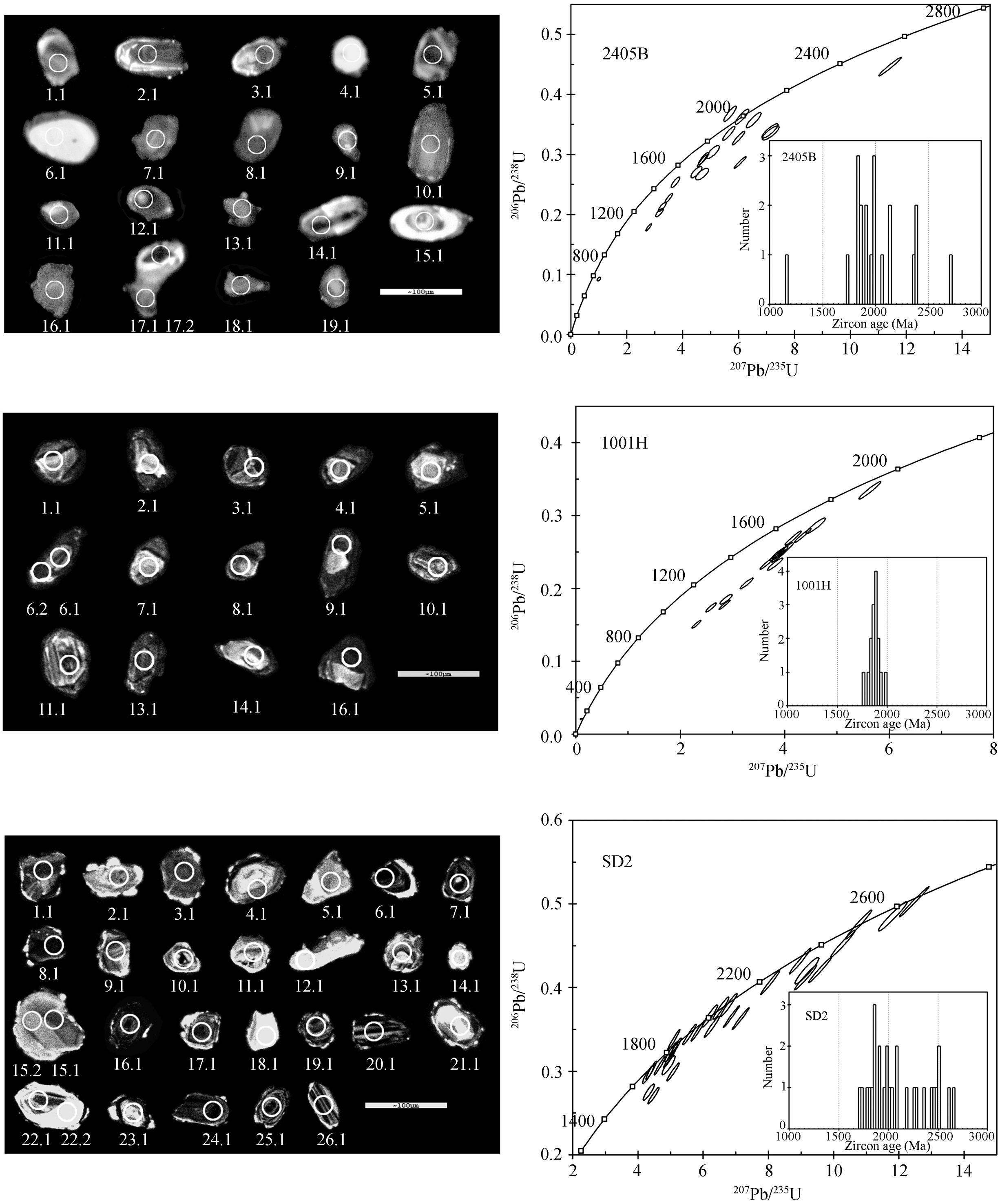

Figure 4 Left: Cathodoluminescence images of the detrital zircons from the Longshoushan Group. The numbers below the zircons are the analyzed spots. Right: Concordia diagrams of the SHRIMP U-Pb zircon ages for the Longshoushan Group. The insets are the histograms for the distribution of $^{207}Pb/^{206}Pb$ ages.

ion microprobe at Ion Microprobe Center, Chinese Academy of Geological Sciences, Beijing, China, following procedures recommended by Compston et al.[23]. Standard zircon SL13 (572 Ma, concentration of U = 238 μg/g) was used in measurement of the concentration of U, Th, and Pb of the samples. Standard TEM (417 Ma) was used to calibrate the Pb/U and UO/U values[24] and to calculate the age of the sample zircons with ISOPLOT software program[25]. Common lead is calibrated with the measured ^{204}Pb.

4.2 Results of age determination

Sixty-three point measurements on fifty-nine zircon grains from three metasedimentary rocks are made. The positions of measuring points are shown in Figure 4 and the analytical data are given in Table 1. In the sample 89-2405B, the zircon grains are about 50－100 μm in size and are rounded or subrounded, typical of detrital zircons (Figure 4). Images of cathodoluminescence show no zonings inside the zircon grains (Figure 4). Twenty point measurements were made on nineteen zircon grains, among which the points 17.1 and 17.2 were made respectively on the margin and core of a zircon grain (Figure 4). The age of the margin (point 17.1) is clearly much younger than the others (Table 1), suggesting a Pb loss due to subsequent geological processes, and is therefore discarded. The ^{207}Pb/^{206}Pb ages of the rest nineteen measuring points on the zircon grains range from 1794 Ma to 2702 Ma with Th/U ratios between 0.08 and 0.77.

Table 1 The U-Pb SHRIMP analytical result of detirtal zircon from Longshoushan Group

Spot	^{206}Pb^{c} (%)	U (ppm)	Th (ppm)	Th/U	^{206}Pb* (ppm)	^{206}Pb/^{238}U age (Ma)	^{207}Pb/^{206}Pb age (Ma)	^{208}Pb/^{232}Th age (Ma)	Discordant (%)
1.SD2-14 Shandan									
SD2-1.1	0.29	439	154	0.35	154	2195±44	2275±7	912±33	3
SD2-2.1	0.36	257	107	0.42	66.6	1696±36	1734±13	1351±40	2
SD2-3.1	0.10	314	394	1.25	82.7	1723±36	1808±10	1635±40	5
SD2-4.1	0.15	244	131	0.54	74.1	1950±40	2081±10	1992±51	6
SD2-5.1	0.15	179	70	0.39	74.9	2550±51	2620±10	2340±64	3
SD2-6.1	0.13	793	377	0.48	249	2007±41	2180±6	1595±39	8
SD2-7.1	0.10	584	25	0.04	170	1875±39	1792±10	1010±95	–5
SD2-8.1	0.19	644	230	0.36	201	1995±41	2263±7	1836±47	12
SD2-9.1	0.72	458	406	0.89	107	1543±33	1955±14	625±21	21
SD2-10.1	0.09	291	277	0.95	113	2407±48	2506±8	2649±64	4
SD2-11.1	0.24	203	93	0.46	65.6	2053±42	2049±11	2082±56	0
SD2-12.1	0.43	152	101	0.66	42.4	1805±38	1844±18	1191±37	2
SD2-12.1	0.50	289	233	0.81	74.7	1686±35	2001±12	601±20	16
SD2-14.1	0.69	195	127	0.65	70.8	2258±48	2439±15	1754±61	7
SD2-15.1	0.11	216	167	0.77	58.7	1767±37	1869±11	1752±43	5
SD2-16.1	1.77	537	361	0.67	129	1562±33	1868±19	1398±50	16
SD2-15.2	0.08	226	151	0.67	63.8	1828±38	1860±11	1788±48	2
SD2-17.1	0.05	281	277	0.99	102	2265±46	2509±7	2289±56	10
SD2-18.1	0.29	152	106	0.69	38.8	1673±36	1724±19	1735±47	3
SD2-19.1	0.14	408	182	0.45	152	2312±47	2354±7	2509±63	2
SD2-20.1	0.04	480	277	0.58	207	2625±51	2652±5	2757±66	1
SD2-21.1	0.18	185	52	0.28	58.2	2011±42	1999±14	1917±85	–1
SD2-22.1	0.06	200	107	0.53	65.2	2073±43	2095±11	2224±56	1
SD2-22.2	0.27	69	65	0.94	18.2	1725±38	1905±21	1751±48	9
SD2-23.1	0.25	256	273	1.06	91.0	2223±45	2465±8	1477±51	10
SD2-24.1	0.21	392	134	0.34	118	1925±40	1981±8	1851±48	3
SD2-25.1	0.10	358	296	0.83	146	2506±50	2500±7	2464±61	0
SD2-26.1	0.24	415	128	0.31	123	1904±39	1922±11	821±38	1
2.87-1001H Jinchang									
1001H-1.1	0.35	375	66	0.18	48.7	904±20	1819±15	1086±40	50
1001H-2.1	0.50	411	63	0.15	61.6	1033±23	1766±18	714±56	42
1001H-3.1	0.19	335	37	0.11	78.6	1553±33	1890±10	1533±60	18
1001H-3.1	0.34	363	63	0.17	64.8	1211±27	1876±14	765±45	35

(*to be continued on the next page*)

(*continued*)

Spot	$^{206}Pb^c$ (%)	U (ppm)	Th (ppm)	Th/U	$^{206}Pb^*$ (ppm)	$^{206}Pb/^{238}U$ age (Ma)	$^{207}Pb/^{206}Pb$ age (Ma)	$^{208}Pb/^{232}Th$ age (Ma)	Discordant (%)
1001H-5.1	0.59	262	61	0.23	52.9	1351±29	1935±16	1406±59	30
1001H-6.1	0.29	420	74	0.18	84.9	1357±29	1853±12	1402±50	27
1001H-6.2	0.16	351	32	0.09	74.6	1424±31	1851±11	1162±58	23
1001H-7.1	0.38	295	47	0.16	63.3	1430±31	1869±15	1828±72	24
1001H-8.1	0.28	529	113	0.21	111	1410±30	1887±11	1513±46	25
1001H-9.1	0.10	352	28	0.08	81.4	1536±33	1836±12	1901±81	16
1001H-10.1	0.46	552	115	0.21	84.5	1053±23	1901±11	990±37	45
1001H-11.1	0.21	196	56	0.29	56.4	1860±39	1986±11	1989±56	6
1001H-13.1	0.82	486	94	0.19	77.9	1093±24	1845±23	1116±60	41
1001H-14.1	0.63	240	53	0.22	59.3	1619±36	1904±18	2290±96	15
1001H-16.1	0.29	417	56	0.13	91.2	1457±31	1876±15	340±80	22
3.89-2405B Gaotai									
2405B-1.1	0.89	467	36	0.08	149	2017±40	1836±21	2100±310	−10
2405B-2.1	1.12	955	155	0.16	148	1056±22	1851±18	1024±76	43
2405B-3.1	0.70	326	219	0.67	94.4	1861±37	1990±19	2010±55	6
2405B-4.1	1.50	184	143	0.77	54.5	1876±38	2371±22	1886±66	21
2405B-5.1	0.77	692	184	0.27	176	1656±33	1918±21	1531±69	14
2405B-6.1	0.92	364	45	0.12	115	1993±39	1990±22	2083±200	0
2405B-7.1	2.26	570	134	0.23	102	1187±25	1851±29	1384±110	36
2405B-8.1	0.32	468	147	0.32	132	1824±36	2137±15	1911±57	15
2405B-9.1	1.35	783	124	0.16	184	1539±31	1963±31	1565±150	22
2405B-10.1	0.43	452	173	0.38	174	2377±46	2702±8	2760±76	12
2405B-11.1	1.07	521	150	0.29	115	1454±30	1749±27	1465±72	17
2405B-12.1	0.50	709	91	0.13	177	1636±33	1921±13	1406±99	15
2405B-13.1	0.85	597	108	0.18	118	1319±27	1829±20	1120±90	28
2405B-14.1	1.32	174	73	0.42	46.2	1708±35	1976±31	1682±94	14
2405B-15.1	0.71	135	55	0.41	41.8	1965±40	2136±22	2082±80	8
2405B-16.1	0.74	869	197	0.23	215	1621±32	2382±10	1600±70	32
2405B-17.1	3.26	902	199	0.22	73.8	567±12	1170±66	870±76	52
2405B-17.2	1.88	468	273	0.58	87.0	1238±26	1825±28	1154±49	32
2405B-18.1	2.10	308	73	0.24	72.3	1520±32	2061±40	1103±180	26
2405B-19.1	1.17	373	123	0.33	109	1862±37	2394±27	2383±110	22

The zircon grains from the sample SD2-14 are 50－100 μm in size and a total of 27 point measurements were made on 26 grains. According to the grain size, shape, and characteristics of cathodoluminescent images of the zircon grains, two distinct groups can be distinguished. The zircon grains of the first group are clearly of detrital, for they are rounded and show no or indistinct zonings (Figure 4), characteristics of long distance transportation and abrasion. Eleven point measurements were made on these zircon grains and their $^{207}Pb/^{206}Pb$ ages range from 2200 Ma to 2650 Ma with Th/U ratios between 0.35 and 1.06. The zircon grains of the second group are long ellipsoid and show occasionally zonings (Figure 4). Sixteen point measurements were made on these zircon grains and their $^{207}Pb/^{206}Pb$ ages range from 1724 Ma to 2095 Ma, clearly younger than the zircon grains of the first group. Their Th/U ratios fall between 0.04 and 1.23.

The zircon grains from the sample 87-1001H are about 100 μm across and show no or indistinct oscillatory zonings. They are mostly ellipsoidal, but some are spherical (1.1, 3.1 and 10.1 in Figure 4) or show cracks (8.1, 13.1 and 16.1 in Figure 4), resulting from weathering, erosion, and transportation during sedimentary processes, being typical features of detrital grains. Fifteen point measurements were made on fourteen grains and their $^{207}Pb/^{206}Pb$ ages range from 1766 Ma to 1986 Ma with Th/U ratios between 0.08 and 0.30. Points 6.1 and 6.2 were made on the margin and core of a zircon grain (Figure 4), but their ages are essentially identical (1853±13 Ma and 1651±11 Ma).

5 Discussion

5.1 Ages of formation of the Longshoushan Group

The lithification age of the Longshoushan Group was first considered by the Bureau of Geology, Gansu Province, to be pre-Changcheng System, because it is unconformably overlain by the Dunzigou Group of the Jixian System and the Changcheng System is in general absent in the Longshou Mountain area[1,8]. Besides, the whole-rock Rb-Sr ages and zircon U-Pb ages presented in the previous section[1,5−8,10] suggest that the ages of the protoliths of the metaigneous rocks in the Longshoushan Group fall approximately between 1914 Ma and 2147 Ma. The present study has provided new age information to re-evaluate the geological ages of the Longshoushan Group. In the present study, SHRIMP determination of U-Pb ages of the detrital zircons in the metasedimentary rocks from uppermost part of the Longshoushan Group has yielded 63 geologically meaningful ages. The ages are distributed between 1.7 Ga and 2.7 Ga (Table 1), with the youngest one being 1724±19 Ma. The age 1724±19 Ma is thought to be the maximum age of the completion of the sedimentary process and therefore the lithification age of the Longshoushan Group is reasonably inferred to be younger than 1724±19 Ma. This is different from the consideration of the some previous workers that the lithification of the Longshoushan Group was completed earlier than 1800 Ma[1,6,7].

The previous K-Ar isotopic studies suggested that the age of regional metamorphism acting on the Longshoushan Group subsequent to its lithification must be older than 1319−1786 Ma[8,10,11]. The present study has assessed a maximum age of 1724±19 Ma for the lithification for the Longshoushan Group, and thus the age of regional metamorphism subsequent to lithification must be younger than 1724±19 Ma. This view can partially be reconciled with the K-Ar isotope ages.

5.2 Provenance of the Longshoushan Group, as inferred from the age characteristics of detrital zircons

It is generally believed that detrital sediments bear geological characteristics of the source area, because detrital sediments were derived from all parts of the source area and were thoroughly mixed during sedimentary processes (transportation, sedimentation, and diagenesis). Particularly, because zircon is rigid and durable and has a closure temperature of higher than 750℃[26], detrital zircons can still preserve their original compositional characteristics during diagenesis, metamorphism, or even crustal anatexis. Therefore, U-Pb ages of detrital zircons can be used to study thermal events of source area and also to trace source areas for sediments. The age histograms of sixty-two geologically meaningful U-Pb ages of detrital zircon obtained in the present study for the Longshoushan Group are shown in Figure 5(a). It is seen that majority of ages, about 80%, fall between 1.7 Ga and 2.2 Ga, with a peak at 1.8−2.0 Ga and the rest are distributed between 2.3 Ga and 2.7 Ga. Based on the frequency distribution of detrital zircon ages (Figure 5(a)) and the surrounding older massifs, the sources of the sediments are discussed for the metasedimentary rocks of the Longshoushan Group as follows. The Longshou Mountain area is elongated and narrow, and geologically was a middle Proterozoic fault-fold belt surrounding the southern margin of the Alaxa Craton. It is also located at the junction of the Alaxa and Tarim Cratons. The Longshoushan Group is stratigraphically the basement of the Longshou Mountain fault-fold belt[11]. The Alaxa Craton was formed in the late Archean and consists mainly of greenstone-granitoid association of the age 2690−2750 Ma[27,28]. Subsequent to its formation, several thermal-tectonic events occurred, during which the granitoids had been melted and recrystallized for many times with two major periods, 1700−2856 Ma and 100−500 Ma, as shown by K-Ar geochronological studies[11]. Thus, it is inferred that the early-Proterozoic to the late Archean (1.7−2.7 Ga) sediments of the Longshoushan Group were very likely derived from the Alaxa Block. Morever, Guo[29] and Gehrel et al.[30] reported 1934±6 Ma and 1.7−2.9 Ga magmatism on the Tarim Craton respectively. What is worth noting is the frequency distribution of the ages of the detrital zircon from the Annanba Group, also a middle Proterozoic rocks at the northeastern margin of the Tarim Craton, which ranges from 1.7 Ga to 2.6 Ga with a peak at 1.8−2.0 Ga (Figure 5(b))[18], very similar to that of the detrital zircon of the Longshoushan Group. Accordingly, it is inferred that parts of the sediments of the Longshoushan Group could probably be received from the Tarim Craton.

5.3 Regional geological significance

Frequency distributions of the ages of the detrital zircons of six middle Proterozoic formations from different terranes, Longshoushan Group, Annanba Group, Chuozishan Group at Helan Mountain, Jining Complexes, Wulashan Complexes, and Changcheng System at Ming Tombs in Beijing are shown in Figure 5.

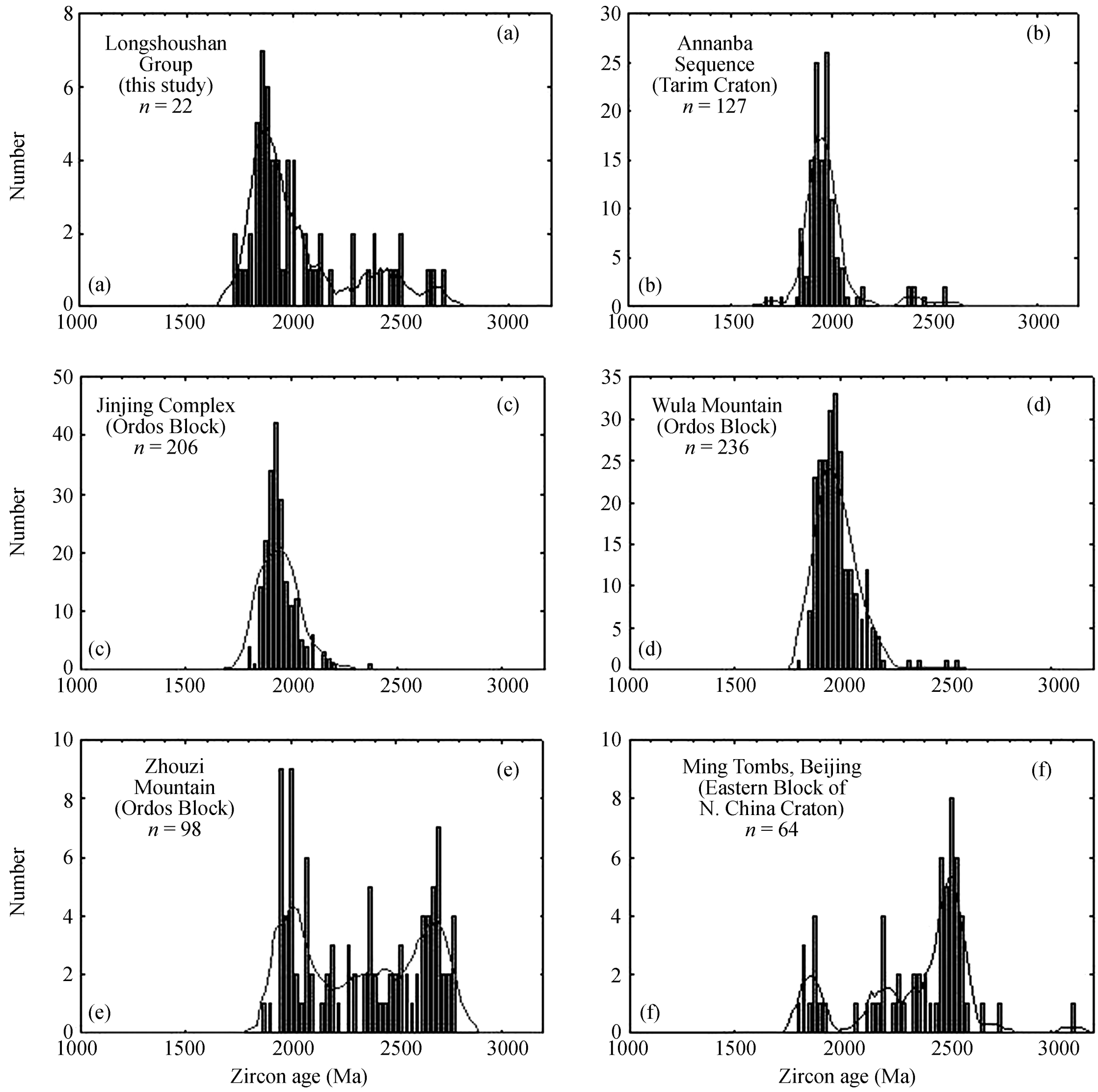

Figure 5 The histograms for the distribution of $^{207}Pb/^{206}Pb$ ages of the detrital zircons from the Longshoushan Group, Annanba sequence, Jining complex, Wulashan complex, Zhouzishan complex and Ming Tombs. (a) This study; (b) from ref. [18]; (c) from ref. [21]; (d) from ref. [22]; (e) from ref. [17]; (f) from ref. [9].

Important differences are found by comparing these frequency distributions. The ages of the detrital zircons of the Changcheng System belonging to the eastern blocks of the North China Craton (Figure 6) are distributed between 1.8 and 2.8 Ga, mostly between 2.4 and 2.8 Ga (Figure 5(f)). The Jining Complexes and Wulashan Complexes, both of which are located at the northern margin of the Ordos terrane (Figure 6), have similar frequency distribution for their detrital zircon ages. They chiefly range from 1.8 Ga to 2.2 Ga with very little Archean detrital zircons (Figure 5(c) and (d)). Note that the Changcheng System, Jining Complexes and Wulashan Complexes have no 1.7—1.8 Ga detrital zircons or sediments. The 1.7—1.8 Ga detrital zircons or clastic sediments are also absent in the Zhuozishan Group (Figure 5(e)), which is located at western margin of the Ordos Block (Figure 6). By a strong contrast, the Longshoushan Group, located at southern margin of the Alaxa massif, and the Annanba Group, located at northeastern margin of the Tarim Craton (Figure 6), are characterized by detrital zircon of the ages 1.7—1.8 Ga in their frequency distributions in addition to a peak age at 1.8—2.0 Ga (Figure 5(a) and (b)). In other words, the sources of sediments for the Longshoushan Group and Annanba Group were likely the same, but were different from those for the Changcheng System, Jining Com-

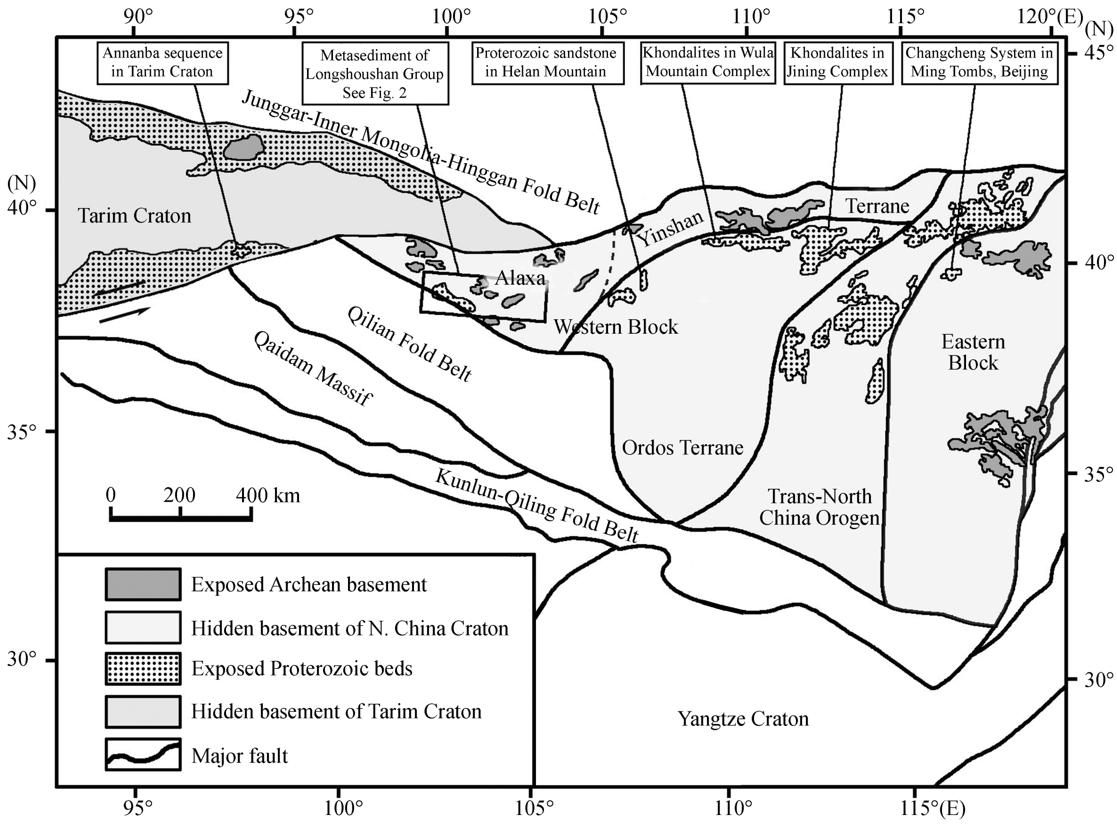

Figure 6 Simplified geotechonic map of central, northern and northwestern China[22].

plexes, Wulashan Complexes, and Zhuozishan Group. The Longshoushan Group and Annanba Group respectively received simultaneously their sediments from Alaxa massif and Tarim Craton, implying that the Alaxa massif showed a stronger affinity with the Tarim Craton than with the Ordos Block and the eastern block of the North China Craton, and further that the Alaxa massif, in paleogeography, might be connected with the Tarim Craton to be, in fact, a unified continent in the middle-early Proterzoic time.

Li et al.[31,32] reported a zircon U-Pb age of 825 Ma for the Jinchuan ultramafic intrusion in the Longshoushan Group, which was interpreted to have related to the fragmentation of Rodinia supercontinent. Note that this period of magmatism was also present on the Tarim Craton, but was absent on the North China Craton[33,34]. Therefore, this discovery also led the present authors to suggest a stronger affinity of the Alaxa Block toward the Tarim Craton than toward the North China Craton. In addition, it has been reported that the structural units on the two sides of the Altyn Tagh fault could be correlated. The Alaxa craton and Qilian terrane on the east side could be correlated with the Dunhuang block and Altyn terrane respectively[35].

Ge and Liu[36] and Wang and Chen[37] presented paleontogical, stratigraphical, paleogeographical, and thermal-tectonic evidence to advocate that the Alaxa, Tarim, central Qilian, and Qaidam Cratons were a unified continent during Neoproterozoic-early Paleozoic period and proposed a name “Western China Craton” for this unified continent. They further considered that this newly recognized “Western China Craton” was part of the East Gondwana continent. Part of this consideration is endorsed by the present study. The U-Pb ages of the detrital zircon of the Longshoushan Group, obtained in the present study, also suggest that the Alaxa Craton and Tarim Craton were likely a unified continent, but in the mid-early Proterozoic time. To understand whether or not the central Qilian and Qaidam Craton were connected with the Alaxa and Tarim Cratons to form a single piece of continent and were also part of the East Gondwana continent, further studies of the ages of the detrital zircons from the central Qilian and Qaidam Cratons are urgently demanded.

6 Conclusions

(1) The youngest detrital zircon in the three metasedimentary rocks collected from the uppermost part of the Longshoushan Group was dated back to 1724 ± 19 Ma. Thus, lithification age should be younger than 1724 ± 19 Ma.

(2) Consideration of the frequency distribution of the age of the detrital zircons and the surrounding older terranes suggests that the sediments of the Longshoushan Group were principly derived from the Alaxa and Tarim Cratons.

(3) The Alaxa Craton shows a stronger affinity toward the Tarim Craton, and both Cratons could be correlated together and could have been a unified continent during the middle-early Proterozoic.

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