Chinese Science Bulletin

© 2008 SCIENCE IN CHINA PRESS

Springer

Timing of the Wudangshan, Yaolinghe volcanic sequences and mafic sills in South Qinling: U-Pb zircon geochronology and tectonic implication

LING WenLi[1,2], REN BangFang[1,2], DUAN RuiChun[1,2], LIU XiaoMing[1,3], MAO XinWu[4], PENG LianHong[4], LIU ZaoXue[4], CHENG JianPing[1] & YANG HongMei[1,2]

[1] Faculty of Earth Sciences, China University of Geosciences, Wuhan 430074, China;
[2] State Key Laboratory of Geological Process and Mineral Resources, China University of Geosciences, Wuhan 430074, China;
[3] State Key Laboratory of Continental Geodynamics, Northwest University, Xi'an 710069, China;
[4] Geological Survey of Hubei Province, Wuhan 430022, China

The Wudangshan, Yaolinghe volcanic-sedimentary sequences and doleritic-gabbroic sills comprise the largest exposed Precambrian basement in South Qinling. Zircons separated from 5 volcanic-pyroclastic samples of the Wudangshan Group, 2 volcanic samples of the Yaolinghe Group and one sample for the mafic sills were used for U-Pb dating by laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS). The results reveal that the Wudangshan volcanic sequence was formed at (755±3) Ma (a weighted mean from the 5 samples, MSWD=0.47), whereas the Yaolinghe volcanic suite and the mafic sill were crystallized at (685±5) (2 samples, MSWD=0.36) and (679±3) Ma (MSWD=1.6), respectively, which are equal to each other within analysis errors. These ages are markedly younger than those previously documented for the rocks. The newly obtained ages for the Wudangshan and Yaolinghe Groups are identical to those of the bottom Liantuo and slightly older than those of the Nantuo Formations, respectively, lower strata of the Nanhua (middle to late Neoproterozoic) stratotype section in eastern Three Gorges, Yangtze craton. A range of inherited magmatic zircons was recognized with ages of 830 to 780 Ma, which are typical of Neoprotzrozoic magmatisms recorded along the margins and interior of the Yangtze craton. Thus, there is Neoproterozoic basement comprising 830—780 Ma igneous suites in South Qinling; the inherited zircons were detrital sediments derived from the northern margin of the Yangtze craton. Accordingly, it is suggested that the South Qinling is a segment of the Yangtze craton before the Qinling Orogeny.

Wudangshan Group, Yaolinghe Group, mafic sills, U-Pb zircon dating, northern margin of Yangtze craton

The Yangtze and North China cratons were welded along the Qinling-Dabie-Sulu orogen belt during early Mesozoic[1]. Continental geodynamic significance is highlighted by eclogite-facies metamorphic suites in the Dabie-Sulu orogenic belt, with fast deep subduction and exhumation of continental crust[2]. When studies on the geodynamic processes of continental deep subduction and exhumation in the Dabie-Sulu belt were carried out, zircon-recorded protolith ages for the Jinning period (830—780 Ma) have been taken frequently as indicators of the Neoproterozoic subducted and exhumated northern margin of the Yangtze craton[3,4]. Observation shows that both along margins and within the interior area of the Yangtze craton the Jinning magmatism was widely recorded. However, whether the South Qinling is part of the Yangtze margin is not clear from existing observations.

The Qinling and Dabie-Sulu orogens are isolated by

Received February 26, 2007, accepted April 19, 2007
doi: 10.1007/s11434-008-0269-6
†Corresponding author (email: wlling@cug.edu.cn)
Supported by the National Natural Science Foundation of China (Grant Nos. 40373015, 40173016, 40472099 and 40521001) and Program of Innovative Research Team of China University of Geosciences (Wuhan)

the Nanyang Basin and display distinct metamorphic grades. Thus, the South Qinling is an excellent proxy to investigate the protolith features of the high pressure-ultrahigh pressure metamorphic rocks. The South Qinling is one of the dominant tectono-units in Qinling orogen, and has been inferred as a segment of the Yangtze craton involved into the orogen[5]. The Wudangshan, Yaolinghe volcanic-sedimentary successions and the mafic sills in the region comprise the largest Precambrian basement in South Qinling. Given a direct contact with the Sinian strata (635—542 Ma), the suites are considered to be formed at late Proterozoic. Evidently, knowledge on timing and tectonic setting of these suites is essential to understand geological history of the South Qinling and its affiliation with the Yangtze craton as well as a linkage of the Neoproterozoic magmatism along the Yangtze margins with the breakup of the supercontinent Rodinia. This paper presents a zircon U-Pb geochronological study on the Wudangshan, Yaolinghe volcanic sequences and the mafic sills in South Qinling coupled with discussions of affiliation of the South Qinling with the Yangtze craton as well as linkage of the magmatic activities with Rodinia breakup.

1 Geological setting

In South Qinling, the Wudangshan succession is widely outcropped in northwestern Hubei Province from regions of Yunxi, Shiyan and Danjiangkou to Zhushan and Fangxian with an area of ~8000 km^2. The Wudangshan Group consists of greenschist facies volcanic-sedimentary sequence, and is subdivided into the Yangping and Shuangtai Formations dominated by clastic sedimentary and volcanic-sedimentary strata, respectively. The Yangping Formation is composed chiefly of quartzofeldspathic sandstone intercalated with silty mudstone and muddy siltstone, whereas the Shuangtai Formation mainly comprises silicic volcanics with subordinate mafic layers and fine-grained sedimentary sequence. The silicic volcanic rocks consist of dacitic-rhyolitic lavas and pyroclastic tuff, while the mafic layers are dominated by lavas of basalt to basaltic andesite with minor pyroclastic tuff. The Yaolinghe Group is restricted to the northern and western rimes of the Wudang inlier in regions of the Yunxi-Yunxian and Deshengpu-Zuxi, respectively. There is a debate on whether the Yaolinghe strata contacts the Wudangshan strata by ductile shear zone or conformable surface. The Yaolinghe succession also experienced a greeschist metamorphism, and is dominated by basaltic lavas with minor mafic tuff as well as interbedded silicic volcanic and fine-grained sedimentary beds. The doleritic-gabbroic sills emplaced into the Wudangshan and Yaolinghe strata along planes approximately paralleling bedding surfaces and possessed a greenschist metamorphic facies as well. The mafic sills are highly variable from several hundred meters to less than one meter in width. Due to subsequent intensive deformation, contacting surfaces between the sills and their wall rocks are irregular but show coherent schistosity. Both the Wudangshan, Yaolinghe successions and the mafic sills are overlain by sedimentary sequences of the Sinian Doushantuo and Dengying Formations.

2 Samples and analysis method

Considering an extensive outcrop area of the Wudangshan volcanic sequence coupled with some documented data suggesting noticeably diverse ages for the volcanic rocks colleted from southern and northern regions of the Wudang terrain[6], in this study, 5 large samples for U-Pb zircon dating were collected from 5 cross sections located at Xinhe of the Danjiangkou City to the east, Baxianguan of the Wudang Town to the north, Santai and Nankou of the Zhushan County to the west and Langkou of the Fangxian County to the south, respectively in order to avoid sampling bias (Figure 1). Two samples of the Yaolinghe volcanic sequence were collected at Guihua of the Yunxian County to the north and Deshengpu of the Zhushan County to the west. Two samples of the mafic sills were collected at Nankou of the Zhushan County to the south and Xinhe of the Danjiangkou City to the east, respectively. However, owing to that only two zircon grains were separated from the Xinhe sill and displayed discordant U-Pb isotopic composition (with $^{206}Pb/^{238}U$ apparent ages of (680±7) and (768±6) Ma, respectively), the data are not reported formally here.

The samples (~20—60 kg) were crushed using tungsten carbide mill and heavy minerals were concentrated using washing plate. Zircons were purified under binocular microscope by handpick. Prior to U-Pb isotopic analysis cathodoluminescence (CL) photos were made on the zircon crystals for guiding spot selection during the *in situ* measurement. U-Pb zircon analysis was carried out at the State Key Laboratory of Continental Geodynamics, Northwest University in Xi’an using inductively coupled plasma-mass spectrometry (ICP-MS).

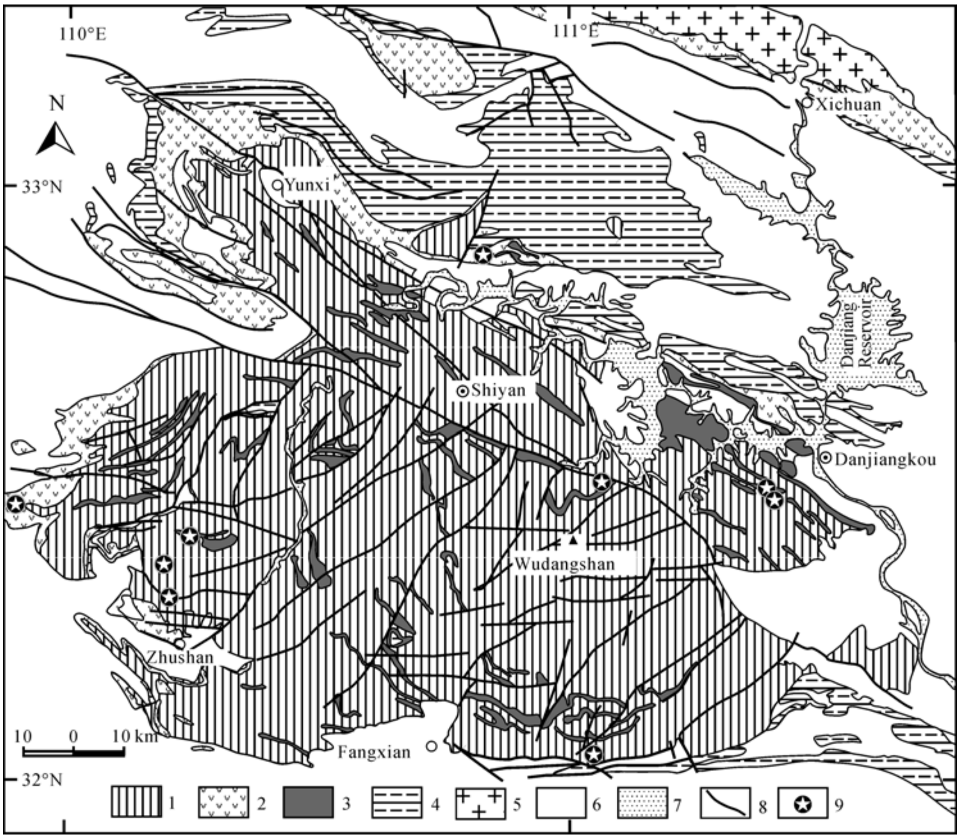

Figure 1 Sketchy geological map of Wudang area in South Qinling. 1, Wudangshan Group; 2, Yaolinghe Group; 3, Mafic sill; 4, Sinian; 5, Intermediate-felsic intrusion; 6, Phanerozoic; 7, Reservoir; 8, Fault; 9, Sampling location.

The GeoLas 200M laser-ablation system equipped with a 193 nm ArF-excimer laser (ComPex102, Lambda Physik) was used in connection with Agilent7500a ICP-MS. All analyses were performed using zircon 91500 as the external standards of U-Pb isotope, and NIST SRM610 and ^{29}Si as elemental external and internal standards, respectively along with a laser spot ~30 μm. Detailed technique parameters and analysis procedure were described elsewhere[7,8]. The isotopic ratios and element contents were calculated using GLITTER (Ver 4.0, Macyuarie University), whereas the apparent and discordia U-Pb ages were calculated by the ISOPLOT program (Ver 2.49).

3 U-Pb zircon geochronology

The Wudangshan and Yaolinghe samples for U-Pb dating were collected from meta-rhyolite and volcanoclastic tuff intercalated with the meta-basalts. The meta-rhyolite rocks (WD05-50, WD06-06, WD05-34 and WD06-04) display evident blastorhyotaxitic structure and aphanitic texture with rock-forming minerals of plagioclase (25%—60%), quartz (30%—40%), potassium feldspar (7%—30%) and minor magnetite (<0.6%). Their SiO_2 content is 75.37%, 77.55%, 77.04% and 77.72% (wt, the same below) with corresponding ε_{Nd}(750 Ma) values of +6.01, +3.82, +0.71 and +2.00, respectively (the present authors' un-published data, the same below). The tuff samples (WD06-02, WD06-07 and WD06-09) contain 5% — 30% volcanoclastics dominated by quartz and feldspar (0.5—2 mm in size) with aphanitic cements. The rock-forming minerals comprise plagioclase (40%—65%), quartz (25%—35%), potassium feldspar (4.5%—20%) and minor opaque mineral of magnetite (1%—3%). The tuffs have SiO_2 content of 72.18%, 73.85% and 73.45% and relevant ε_{Nd}(750 Ma) values of –7.12, –0.27 and –0.43, respectively. The mafic sample is meta-gabbro with blasto-ophitic texture (SiO_2 = 47.20%, ε_{Nd} = +3.75). U-Pb isotopic composition and apparent ages of the zircons are presented in Table 1 in the electronic version.

3.1 Wudangshan volcanics

Sample WD05-50 was obtained from the southern region (Langkou, Fangxian County, 32°02.699′N, 111°02.600′E), and 42 zircon grains were analyzed. All grains define a discordia line composed of 31 concordant and 11 variable degree discordant zircons and yield an upper intercept age of (757±5) Ma (MSWD=0.79, 95% confidence, the same below). This age is equivalent to the weighted average $^{206}Pb/^{238}U$ age of (755±3) Ma (MSWD=1.19) given by 31 concordant zircons within analysis error (Figure 2(a)), and accordingly is considered as the age of igneous protolith.

Sample WD06-02 was collected from the eastern region (Xinhe, Danjiangkou City, 32°28.339′N, 111°26.317′E) and 39 grains were measured. Among the grains, 30 zircons are concordant, while 9 zircons display a small amount of Pb loss (Figure 2(b)). The concordant grains fall into two populations with weighted average $^{206}Pb/^{238}U$ ages of (757±2) (MSWD = 1.13, n = 23) and (817±11) Ma (MSWD = 3.5, n = 7), respectively. The age given by the 23 concordant grains is indiscriminable from that of WD05-50 within analysis error. Along with CL images of clear oscillatory zoning and stubby euhedral shape for these grains, the age is suggested for the timing of the magmatism. Grains of the second population display CL pictures with low-CL but euhedral core surrounded by thin oscillatory zoned rim, and thus are considered as inherited origin. Higher MSWD and larger error for the average age indicate that the second group of concordant zircons ($^{206}Pb/^{238}U$ age ranging of (802±7) to (833±5) Ma) likely comprises grains with a certain extent of distinct ages.

Sample WD06-06 was taken from the northern region (Baxianguan in the Wudangshan scenic area, 32°26.148N′, 111°03.673′E) and 25 grains were analyzed. Twenty grains give concordant isotopic composition and can also be divided into two populations (Figure 2(c)). The first group consists of 18 grains and gives an average age of (752±3) Ma (MSWD=0.38) which is interpreted as magmatic timing. Whereas the second group of 2 grains yields $^{206}Pb/^{238}U$ ages of (805±12) and (813±8) Ma, respectively which are indicative of ages for inherited zircons.

WD06-07 was sampled from the western region (Santai, Zhushan County, 32°18.433′N, 110°12.740′E), and 22 grains were measured (Figure 2(d)). All zircons are discordant and define a discordia line with an upper intercept age of (769±33) Ma (MSWD = 0.22), which within analysis error equals the volcanic rock forming ages given by the above samples.

WD06-09 was also brought about from the western region (Nankou, Zhushan County, 32°23.727′N, 110°11.752′E), and 42 grains were analyzed. Apart from 4 evident Pb-loss grains, the remained 36 grains delineate a discordia line yielding an upper intercept age of (749±8) Ma (MSWD=0.93), which is identical to a weighted average age of (752±4) (MSWD=0.94) by 11 concordant zircons (Figure 2(e)). Two broadly concordant inherited zircons give $^{206}Pb/^{238}U$ ages of (820±6) and (833±6) Ma, respectively.

3.2 Yaolinghe volcanics

Samples WD06-04 and WD05-34 were collected from the northern (Guihua, Yunxian County, 32º54.571′N, 110°49.833′E) and western (Desheng, Zhushan County, 32°28.581′N, 109º51.352′E) regions. Zircons of 47 grains from WD05-34 were analyzed. Among them, 22 concordant grains yield a weighted average age of (686±3) Ma (MSWD=0.85), whereas the remained discordant grains show variable degrees of Pb loss with $^{206}Pb/^{238}U$ apparent ages less than 680 Ma (Figure 2(f)).

Only 7 grains of zircon were separated from WD06-04 and 6 grains are concordant (Figure 2(f)). Five concordant grains give a weighted average age of (682±6) Ma (MSWD=0.31), whereas the remained grain has a $^{206}Pb/^{238}U$ age of (800±5) Ma. Accordingly, ages of (682±6) and (800±5) Ma are interpreted as timings of volcanism and inherited zircon forming, respectively.

3.3 Mafic sill

The meta-gabbroic sample WD05-26 was obtained in the vicinity of Taoyuan Village (32°25.342′N, 110°12.868′E), and 40 grains were measured. Concordant zircons comprise 29 grains and fall into 4 populations on the concordia diagram (Figure 2(g)). The first population of 18 grains give a weighted average age of (679±3) Ma (MSWD=1.6), while the second and the third populations consist of 3 grains and one grain, and yield $^{206}Pb/^{238}U$ ages of (734±17) Ma (MSWD=1.4) and (822±8) Ma, respectively. Given a geological contact that the mafic sill emplaced into the Wudangshan wall rock, it is feasible to infer the grains with ages of (734±17) and (822±8) Ma being inherited zircons originating from the Wudangshan volcanics and some earlier basement, respectively. Six younger concordant grains give an average age of (579±3) Ma (MSWD=0.46). Since this age is even younger than the Sinian cover overlying

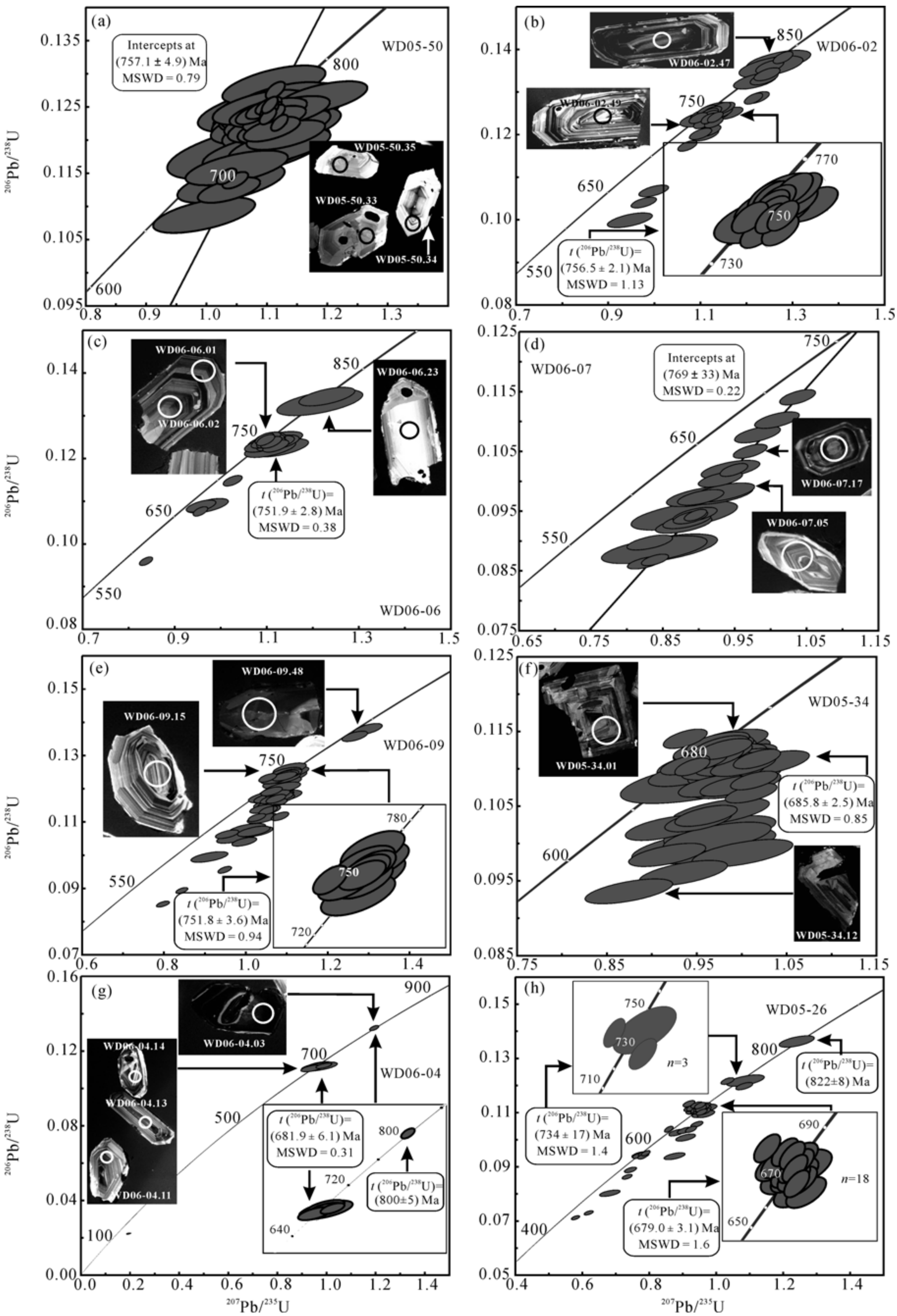

Figure 2 Zircon U-Pb concordia diagrams for Wudangshan (a)—(e), Yaolinghe (f)—(g) volcanic rocks and mafic sill (h).

the mafic sills, it is considered indicative of a late tectonothermal event. Accordingly, the age of (679±3) Ma is explained as the timing of the mafic intrusive suite. Besides, one grain with $^{206}Pb/^{238}U$ age of (635±4) Ma likely results from a weak tectonothermal activity.

4 Discussion

A weighted average age (755±3) Ma (MSWD=0.47, 95% confidence) for the Wudangshan volcanic suite is acquired based upon the ages of volcanic protolith from the above 5 Wudangshan samples. Similarly, an average age (685±5) Ma (MSWD=0.36, 95% confidence) of samples WD06-04 and WD05-34 is obtained for the Yaolinghe volcanic sequences. This age in fact is indistinguishable from that of the mafic sill ((679±3) Ma) within analysis error, which is congruous to the observation that the Yaolinghe alkali basalt exhibits similar geochemistry to the doleriteic-gabbroic sills[9−11].

Geochronological study of igneous suites in Wudang area has been carried out since 1980s. However, the documented data by conventional U-Pb zircon dating show a wide range of 2417 to 315 Ma, and even more dispersive ages by Rb-Sr and K-Ar (^{40}Ar-^{39}Ar) methods were reported[12]. For instance, the Yaolinghe basaltic suite was dated at (1005±122) and (782±164) Ma, respectively using Sm-Nd method by Zhang et al.[13] and Zhou et al.[9]. Zhang et al.[6] argued that most of the Wudangshan volcanic rocks were formed at ~1.9 Ga, whereas those exposed at the south region are coeval with the Yaolinghe volcanic sequence. These controversial consequences are likely due to an experience of intensive multi-deformation and metamorphism in the South Qinling, which resulted in variable degree opening of Rb-Sr, K-Ar and even Sm-Nd systems. It is also expectable that deformation and metamorphism in the Qinling orogen induced variable Pb-loss in zircons as those observed from the samples WD06-07 and WD05-26. Evidently, additional reason for the confusedly documented data might come from improperly interpretation to the inherited zircons.

A single-grain zircon U-Pb dating by ID-TIMS for the Wudangshan upper volcanoclastic sequence was reported recently[14]. Among 5 analyzed grains, 3 concordant zircons give a weighted average $^{206}Pb/^{238}U$ age of (744±36) Ma. Though there exists a larger error in age estimation, this age is identical to that obtained by this study within analysis error, and was explained as the timing of the upper Wudangshan succession by the authors. However, a $^{207}Pb/^{206}Pb$ apparent age of (1593±49) Ma from a discordant grain was interpreted as the timing of the lower Wudangshan strata[14].

Based on previous dates, most workers including authors of this paper inferred that the Wudangshan and Yaolinghe volcanic sequences and the mafic sills were formed during the Jinningian of 830 to 780 Ma[11] or earlier. Although this work reveals that these igneous suites are rather younger, the Jinning inherited zircons recognized from these igneous samples indicate that there are unroofed Jinning basements in South Qinling or the Yangping Formation received sedimentary deposits at least partly originating from the Yangtze craton. Thus, it is rational to suppose that the Wudang area in South Qinling was a constituent part of today's northern margin of Yangtze craton during the Jinningian period.

The Huangling intrusive complex is situated at central Yangtze craton. Most suites of the complex were dated at 820—790 Ma, whereas the bimodal Xiaofeng suite gave an age of (744±22) Ma[15] which is identical to the SHRIMP zircon U-Pb age (748±12) Ma of the bottom tuff layer from the Liantou Formation, the lowermost stratum in the Nanhua-Sinian stratotype section[16]. Despite the identical age between the Wudangshan succession and lower Liantuo tuff layer, the large thickness for both the volcanic and sedimentary sequences of the Wudangshan strata (tectono-stratigraphic thickenss >2000 m)[1)] illustrates a difference in sedimentary development from the Liantou stratum (70—50 m)[17] in eastern Three Gorges. It is evident that more detailed regional rift-sedimentation events were recorded in the Wudangshan area. The coeval Yaolinghe alkali basalt and the mafic sill show similar geochemical features typical of magmas sourced by asthenospheric mantle in extensional setting[10,11], and their ~680 Ma age is slightly older than that of the Nantou Formation (663—635 Ma)[18−20] in the Three Gorges stratigraphic section. The differences between the Yaolinghe and Nantuo successions are exhibited by the distinct sedimentary thickness (tectono-stratigraphic strata >1500 m[1)] and 150—

1) Hubei Institute of Regional Geology and Mineral Resources. Regional geological survey report of Maps Baishangguan, Yuanjiashan, Diaojiadian, Yutidian, Liziping, Wudanhshan Town and Dingjiaying (scale 1∶50000). 1997

90 m[17], respectively) and the Nantuo stratum is dominated by gravel-bearing tillites without volcanic layers. Therefore, the Yaolinghe sequence is not only incomparable with the Nantuo Formation, but indicates that an important tectono-magmatic event occurred, restricted to northern margin of the Yangtze craton.

The Jinning magmatic activities of 830—745 Ma in the Yangtze craton have been considered as surface expression of a Neoproterozoic mantle superplume, and the age ranges of 830—795 and 780—745 Ma corresponded with the periods of rifting and breakup of Rodinia supercontinent, respectively[21]. Magmatisms of 830—790 Ma have been widely documented along the other Yangtze margins[21−24] and their interior region[15], whereas ~755 Ma igneous suites including dioritic-gabbroic dykes[21,25], adakitic intrusive complex[26] and gabbroic plutons[27] have been recognized in Kangdian Rift, western margin of the Yangtze craton as well as bimodal eclogite-gneiss suite in the Dabie-Sulu orogen[1−4]. From a series of zircon U-Pb dates, Zheng et al.[3] conclude that the bimodal suite in the Dabie-Sulu belt was formed at (758±15) Ma. By a combination with zircon Hf and O isotope stusies, Zheng et al.[28] suggest that the parental mafic melts originated from depleted mantle and experienced a rapid re-building within a setting of rifted continental margin. The Wudangshan and Yaolinghe mafic volcanic rocks are characterized by a lithlogical association of alkali and tholeiitic basalts. The alkali basalts are characterized by high Ti content and lacking HFSE depletion except for a few samples in Nb and Ta from the Wudangshan sequence. The TiO_2 content of Wudangshan and Yaolinghe alkali basalts and the alkali sills is 2.3%—4.5%, 2.5%—6.6% and 1.6%—4.2% with corresponding ε_{Nd} (750 Ma) value of +6.6 to +8.9, +3.5 to +7.6 and +2.2 to +5.1, respectively (the present authors' unpublished data, the same below). Coupled with ε_{Nd} (750 Ma) values of +3.3 to +5.5 and +3.0 to +6.6 for the Wudangshan tholeiitic basalt and the tholeiitic sill, respectively, it is indicative that these igneous suites were formed in a within-plate rift setting during 755—680 Ma and melts originating from deep depleted mantle participated in the magmatisms. Considering the general correlation between Nd and Hf isotopes[29], it shows that the tholeiitic suites in South Qinling and the protolith of the Dabie eclogite were derived from mantle rocks with analogous degree depletion. Therefore, it is likely that ~755 Ma igneous suite in Dabie orogen extended continuously westward into the South Qinling. Li et al.[30] reported a study of the elemental and Nd-Hf isotopic geochemistry for the Mundine Well doleriteic-gabbroic dykes in northwestern Australia and revealed an OIB affinity for the dykes. Accordingly, it was advocated that both the Kangdian and Mundine Well mafic dykes resulted from the Rodinia breakup. It is not clear at present whether the ~755 Ma South Qinling-Dabie igneous belt stretched in succession reaching the western margin of the Yangtze craton. However, a comprehensive comparison in geochemistry between the ~755 Ma igneous suites along the Yangtze margins and the Mundine Well mafic dykes is critical to understand the development of the Rodinia breakup.

It is noteworthy that ~680 Ma magmatism in South Qinling has not been documented elsewhere in Yangtze craton. Thus, it indicates that the rift-related magmatic activities had lasted a longer period in South Qinling. Coupled with the observations of magmatic evolution from tholeiitic to alkali and thick, rapid proximate sedimentation, the ~755—680 Ma magmatisms in South Qinling might play an important role resulting the complete departure of the South China block from the Rodinia.

5 Conclusion

The Wudangshan volcanic suite was formed at (755±3) Ma, whereas the Yaolinghe volcanic sequence and the mafic sill were formed at (685±50) and (679±3) Ma, respectively which are coeval within analysis error. The obtained ages are obviously younger than most of previously documented dating data. Thus, the Wudangshan and Yaolinghe volcanic-sedimentary successions are comparable to and slightly older than the Liantuo and Nantuo Formations, respectively. Inherited zircons of 830—780 Ma, typical of the Yangtze Jinningian magmatisms, from the igneous suites reveal that there are Yangtze-type Neoproterozoic basements in South Qinling or the Yangtze craton provided the sedimentary provenance. Consequently it suggests that the South Qinling was a constituent part of the present northern margin of the Yangtze craton. A ~755 Ma bimodal igneous belt extended from the Dabie orogen westward into the South Qingling, while the ~680 Ma alkali-tholeiitic baslts in South Qinling might indicate a final magmatic event along the margin of the Yangtze craton before a complete breakup of the South China block from the Rodinia.

The paper has benefited from scientific comments of two anonymous reviewers. The authors appreciate the discussions with Deng Qianzhong, Cheng Tielong and He Renliang of the Geological Survey of Hubei Province and their assistance in the field.

1 Cong B L. Ultrahigh-Pressure Metamorphic Rocks in the Dabieshan-Sulu Region of China. Beijing: Science Press, 1996
2 Zheng Y F, Fu B, Gong B, et al. Stable isotope geochemistry of ultrahigh pressure metamorphic rocks from the Dabie-Sulu orogen in China: Implications for geodynamics and fluid regime. Earth Sci Rev, 2003, 62: 105—161[doi]
3 Zheng Y F, Wu Y B, Chen F K, et al. Zircon U-Pb and oxygen isotope evidence for a large-scale ^{18}O depletion event in igneous rocks during the Neoproterozoic. Geochim Cosmochim Acta, 2004, 68: 4159—4179
4 Xue H M, Dong S W, Liu X C. U-Pb Zircon Dating of granitic gneisses in eastern Dabie Mountains, Central China. Sci Geol Sin (in Chinese with English abstract), 2002, 37(2): 165—173
5 Zhang G W, Zhang Z Q. Nature of main Tectono-Lithostratigraphic units of the Qinling Orogen: Implications for the tectonic evolution. Acta Petrol Sin (in Chinese with English abstract), 1995, 11(2): 101—114
6 Zhang Z Q, Zhang G W, Tang S H, et al. The age of metamorphic rocks of the Wudang Group. Chin Geol (in Chinese with English abstract), 2002, 29(2): 117—125
7 Yuan H L, Gao S, Liu X M, et al. Accurate U-Pb age and trace element determinations of zircon by laser ablation inductively coupled plasma mass spectrometry. Geostan Geoanal Res, 2004, 28: 353—370[doi]
8 Liu X M, Gao S, Ling W L, et al. Identification of 3.5 Ga detrital zircons from Yangtze craton in south China and the implication for Archean crust evolution. Progr Nat Sci, 16(6): 663—666
9 Zhou D W, Zhang C L, Liu L, et al. Sm-Nd dating of basic dykes from Wudang block and a discussion of related questions. Acta Geosci Sin (in Chinese with English abstract), 1998, 19(1): 25—30
10 Zhang C L, Zhou D W, Jin H L, et al. Study on the Sr, Nd, Pb and O isotopes of basic dyke swarms in the Wudang block and basic volcanics of the Yaolinghe Group. Acta Petrol Sin (in Chinese with English abstract), 1999, 15(3): 430—437
11 Ling W L, Cheng J P, Wang X H, et al. Geochemical features of the Neoproterozoic igneous rocks from the Wudang region and their implications for the reconstruction of the Jinning tectonic evolution along the south Qinling orogenic belt. Acta Petrol Sin (in Chinese with English abstract), 2002, 18(1): 25—36
12 Chen J B, Qin Z Y, Wang S Q, et al. Geological Features of the Wudang Group. Tianjin: Tianjin Science and Technology Interpretation Press, 1991
13 Zhang Z Q, Zhang G W, Fu G M, et al. Geochronology of metamorphic strata in the Qinling Mountains and its tectonic implications. Sci China Ser D-Earth Sci, 1996, 39(3): 283—292
14 Cai Z Y, Lou H, Xiong, X L, et al. A discussion on the age of the meta-sedimentary rocks in the upper part of the Wudang group: Constrained by the grain-zircon U-Pb dating. J Stratigr (in Chinese with English abstract), 2006, 30(1): 60—63
15 Ling W L, Gao S, Cheng J P, et al. Neoproterozoic magmatic events within the Yangtze continental interior and along its northern margin and their tectonic implication: Constraint from the ELA-ICPMS U-Pb geochronology of zircons from the Huangling and Hannan complexes. Acta Petrol Sin (in Chinese with English abstract), 2006, 22(2): 387—396
16 Ma G G, Li H Q, Zhang Z C. An investigation of the age limits of the Sinian System in South China. Bull Yichang Inst Geol Mineral Res (in Chinese with English abstract), 1984, 8: 1—29
17 Research Team of the Three Gorges' stratigraphy of Hubei Geological Bureau. Stratigraphy and paleontology of the Sinian to Permian in eastern Three Gorges. Beijing: Geological Publish House, 1978
18 Zhou C M, Tucker R S, Xiao H, et al. New constraints on the ages of Neoproterozoic glaciation in South China. Geology, 2004, 32: 437—440[doi]
19 Chu X, Todt W, Zhang Q, et al. U-Pb zircon age for the Nanhua-Sinian boundary. Chin Sci Bull, 2005, 50: 716—718[doi]
20 Condon D, Zhu M, Bowring S, et al. U-Pb Ages from the Neoproterozoic Doushantuo Formation, China. Science, 2005, 308: 95—98[doi]
21 Li Z X, Li X H, Kinny, P D, et al. Geochronology of Neoproterozoic syn-rift magmatism in the Yangtze craton, South China and correlations with other continents: Evidence for a mantle superplume that broke up Rodinia. Precambr Res, 2003, 122: 85—109[doi]
22 Li Z X, Zhang L, Powell C M. South China in Rodinia: Part of the missing link between Australia—East Antarctica and Laurentia? Geology, 1995, 23: 407—410[doi]
23 Li X H. U-Pb zircon ages of granites from the southern margin of the Yangtze Block: Timing of Neoproterozoic Jinning: Orogeny in SE China and implications for Rodinia Assembly. Precambr Res, 1999, 97: 43—57[doi]
24 Wu R X, Zheng Y F, Wu Y B, et al. Reworking of juvenile crust: Element and isotope evidence from Neoproterozoic granodiorite in South China. Precambr Res, 2006, 146: 179—212[doi]
25 Lin G C, Li X H, Li W X. SHRIMP U-Pb zircon age, geochemistry and Nd-Hf isotopes of the Neoproterozoic mafic dykes from western Sichuan: petrogenesis and tectonic implications. Sci China Ser D-Earth Sci, 2006, 36(7): 630—645
26 Zhou M F, Yan D P, Wang C, et al. Subduction-related origin of the 750 Ma Xuelongbao adakitic complex (Sichuan Province, China): Implications for the tectonic setting of the giant Neoproterozoic magmatic event in South China. Earth Planet Sci Lett, 2006, 248: 271—285[doi]
27 Zhao J H, Zhou M F. Geochemistry of Neoproterozoic mafic intrusions in the Panzhihua district (Sichuan Province, SW China): Implications for subduction-related metasomatism in the upper mantle. Precambr Res 2007, 152: 27—47[doi]
28 Zheng YF, Zhao Z F, Wu Y B, et al. Zircon U-Pb age, Hf and O isotope constraints on protolith origin of ultrahigh-pressure eclogite and gneiss in the Dabie orogen. Chem Geol, 2006, 231: 135—158[doi]
29 White W M, Patchett P J. Hf-Nd-Sr and incompatible element abundances in island arcs: Implications for Magma origins and crust-Mantle evolution. Earth Planet Sci Lett, 1984, 67: 167—185[doi]
30 Li X H, Li Z X, Wingate M T D, et al. Geochemistry of the 755 Ma Mundine Well dyke swarm, northwestern Australia: Part of a Neoproterozoic mantle superplume beneath Rodinia? Precambr Res, 2006, 146: 1—15[doi]

Table 1 Zircon U-Pb isotopic data of the Wudangshan, Yaolinghe volcanic rocks and mafic sill

No.	Measured ratios					Apparent ages (Ma)		
	$^{207}Pb/^{206}Pb \pm 1\sigma$	$^{207}Pb/^{235}U \pm 1\sigma$	$^{206}Pb/^{238}U \pm 1\sigma$	$^{208}Pb/^{232}Th \pm 1\sigma$	Th/U	$^{207}Pb/^{206}Pb \pm 1\sigma$	$^{206}Pb/^{238}U \pm 1\sigma$	$^{207}Pb/^{235}U \pm 1\sigma$
WD05-50								
1	0.0647±0.0007	1.101±0.009	0.1235±0.0008	0.0394±0.0002	1.38	764±24	751±5	754±5
2	0.0644±0.0026	1.102±0.043	0.1241±0.0015	0.0408±0.0009	0.65	755±83	754±8	754±21
3	0.0665±0.0039	0.995±0.056	0.1085±0.0018	0.0398±0.0010	0.82	822±117	664±10	701±29
4	0.0668±0.0040	1.088±0.063	0.1181±0.0020	0.0446±0.0014	0.55	831±120	720±11	747±31
7	0.0657±0.0041	1.109±0.068	0.1225±0.0022	0.0418±0.0012	0.82	796±127	745±12	758±33
8	0.0656±0.0040	1.122±0.067	0.1241±0.0020	0.0421±0.0014	0.64	793±124	754±12	764±32
10	0.0680±0.0027	1.131±0.043	0.1206±0.0015	0.0401±0.0008	0.95	868±80	734±9	768±21
11	0.0639±0.0010	1.102±0.015	0.1251±0.0009	0.0382±0.0003	0.86	738±32	760±5	754±7
13	0.0653±0.0042	1.118±0.071	0.1242±0.0022	0.0394±0.0012	0.95	783±131	755±13	762±34
15	0.0671±0.0032	1.128±0.051	0.1219±0.0017	0.0396±0.0009	1.16	840±95	742±10	767±24
16	0.0655±0.0009	1.032±0.011	0.1144±0.0008	0.0374±0.0002	1.78	789±27	698±5	720±5
17	0.0662±0.0028	1.134±0.047	0.1242±0.0016	0.0426±0.0010	0.66	813±86	755±9	770±22
20	0.0652±0.0008	1.114±0.010	0.1240±0.0008	0.0401±0.0003	1.40	780±25	754±5	760±5
21	0.0640±0.0007	1.104±0.009	0.1252±0.0008	0.0404±0.0002	1.56	740±23	760±5	755±4
24	0.0683±0.0035	1.120±0.056	0.1189±0.0019	0.0398±0.0009	1.18	878±103	724±11	763±27
26	0.0646±0.0033	1.121±0.055	0.1258±0.0019	0.0429±0.0012	0.64	762±103	764±11	764±26
29	0.0655±0.0042	1.115±0.070	0.1235±0.0022	0.0474±0.0016	0.62	789±130	751±13	760±34
30	0.0649±0.0009	1.107±0.013	0.1237±0.0009	0.0403±0.0003	1.66	771±30	752±5	757±6
31	0.0634±0.0008	1.113±0.011	0.1274±0.0009	0.0427±0.0003	1.21	720±26	773±5	760±5
32	0.0646±0.0049	1.110±0.083	0.1248±0.0025	0.0499±0.0021	0.56	760±153	758±14	758±40
33	0.0658±0.0035	1.115±0.058	0.1229±0.0019	0.0449±0.0012	0.74	800±108	748±11	761±28
34	0.0669±0.0040	1.123±0.065	0.1217±0.0021	0.0376±0.0010	1.34	836±120	740±12	765±31
36	0.0657±0.0032	1.126±0.054	0.1243±0.0018	0.0455±0.0013	0.62	797±100	755±10	766±26
38	0.0648±0.0039	1.119±0.066	0.1252±0.0021	0.0402±0.0014	0.60	769±123	760±12	762±32
39	0.0631±0.0012	1.076±0.019	0.1238±0.0010	0.0411±0.0004	1.05	711±41	752±6	742±9
41	0.0635±0.0011	1.090±0.017	0.1245±0.0009	0.0391±0.0003	1.58	724±36	756±5	748±8
42	0.0639±0.0035	1.103±0.059	0.1253±0.0020	0.0426±0.0011	0.83	738±113	761±11	755±29
43	0.0663±0.0007	1.120±0.009	0.1225±0.0008	0.0403±0.0002	1.48	817±23	745±5	763±4
44	0.0664±0.0034	1.119±0.056	0.1222±0.0018	0.0428±0.0011	0.76	819±104	743±11	762±27
45	0.0645±0.0008	1.106±0.012	0.1244±0.0009	0.0413±0.0003	1.33	758±27	756±5	756±6
47	0.0643±0.0008	1.104±0.010	0.1244±0.0008	0.0417±0.0003	1.29	752±25	756±5	755±5
48	0.0628±0.0033	1.111±0.057	0.1283±0.0019	0.0454±0.0012	0.69	701±108	778±11	759±27
49	0.0631±0.0031	1.086±0.051	0.1248±0.0018	0.0431±0.0012	0.61	712±100	758±10	747±25
51	0.0658±0.0036	1.049±0.056	0.1157±0.0017	0.0393±0.0011	0.82	799±111	706±10	728±28
52	0.0669±0.0023	1.036±0.034	0.1123±0.0013	0.0402±0.0007	0.83	836±71	686±7	722±17
53	0.0656±0.0056	1.069±0.089	0.1182±0.0029	0.0493±0.0021	0.65	793±170	720±16	738±44
54	0.0684±0.0030	1.190±0.050	0.1263±0.0017	0.0408±0.0008	1.08	879±88	767±10	796±23
55	0.0667±0.0011	1.047±0.014	0.1138±0.0008	0.0374±0.0003	1.39	829±33	695±5	727±7
56	0.0655±0.0021	1.112±0.035	0.1231±0.0013	0.0401±0.0006	1.15	791±67	748±8	759±17
58	0.0661±0.0020	1.108±0.031	0.1215±0.0012	0.0397±0.0005	1.14	810±61	739±7	757±15
59	0.0651±0.0037	1.116±0.062	0.1244±0.0021	0.0427±0.0014	0.63	776±116	756±12	761±30
60	0.0665±0.0039	1.039±0.059	0.1133±0.0019	0.0392±0.0012	0.77	823±118	692±11	724±29
WD06-02								
1	0.0673±0.0009	1.280±0.014	0.1380±0.0010	0.0441±0.0004	0.65	845±28	833±5	837±6
3	0.0660±0.0012	1.137±0.017	0.1248±0.0009	0.0366±0.0003	0.85	807±36	758±5	771±8
4	0.0673±0.0013	1.111±0.019	0.1198±0.0009	0.0369±0.0005	0.54	846±38	729±5	759±9
5	0.0642±0.0009	1.095±0.013	0.1237±0.0009	0.0387±0.0003	0.76	748±30	752±5	751±6

(*To be continued on the next page*)

(*Continued*)

No.	Measured ratios					Apparent ages (Ma)		
	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{208}Pb/^{232}Th\pm1\sigma$	Th/U	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$
6	0.0654±0.0010	1.105±0.014	0.1225±0.0009	0.0379±0.0003	1.01	788±31	745±5	756±7
7	0.0669±0.0026	1.253±0.046	0.1358±0.0017	0.0408±0.0010	0.74	835±78	821±10	825±21
8	0.0651±0.0022	1.110±0.036	0.1237±0.0014	0.0413±0.0008	0.81	777±70	752±8	758±17
10	0.0665±0.0010	1.147±0.015	0.1251±0.0009	0.0388±0.0003	0.87	823±32	760±5	776±7
11	0.0644±0.0010	1.114±0.015	0.1255±0.0009	0.0392±0.0003	0.68	756±32	762±5	760±7
12	0.0657±0.0010	1.143±0.014	0.1261±0.0009	0.0391±0.0003	0.83	798±31	766±5	774±7
13	0.0671±0.0026	1.269±0.047	0.1372±0.0017	0.0482±0.0011	0.74	841±78	829±10	832±21
16	0.0675±0.0012	1.239±0.020	0.1331±0.0010	0.0418±0.0005	0.66	854±37	805±6	818±9
17	0.0646±0.0010	1.104±0.015	0.1240±0.0009	0.0389±0.0004	0.65	761±34	754±5	755±7
18	0.0671±0.0012	1.117±0.018	0.1207±0.0009	0.0385±0.0004	0.71	842±37	735±5	762±9
20	0.0690±0.0011	1.224±0.017	0.1286±0.0009	0.0391±0.0003	0.88	900±33	780±5	812±8
21	0.0652±0.0012	1.119±0.018	0.1245±0.0009	0.0383±0.0004	0.82	779±37	757±5	762±8
22	0.0643±0.0011	1.104±0.017	0.1245 0.0009	0.0391±0.0004	0.82	751±37	757±5	755±8
23	0.0663±0.0009	1.132±0.011	0.1239±0.0008	0.0384±0.0003	0.82	814±27	753±5	769±5
24	0.0679±0.0016	0.997±0.021	0.1065±0.0009	0.0367±0.0005	0.84	866±47	653±5	703±11
25	0.0663±0.0010	1.071±0.014	0.1172±0.0008	0.0364±0.0003	1.03	816±32	714±5	739±7
28	0.0656±0.0009	1.119±0.012	0.1237±0.0008	0.0354±0.0003	0.71	794±27	752±5	762±6
29	0.0689±0.0025	0.945±0.032	0.0996±0.0012	0.0349±0.0008	0.44	894±73	612±7	676±17
30	0.0651±0.0015	1.130±0.023	0.1259±0.0011	0.0403±0.0007	0.40	779±46	764±6	768±11
33	0.0652±0.0010	1.124±0.014	0.1252±0.0009	0.0401±0.0004	0.56	779±31	760±5	765±7
34	0.0647±0.0010	1.120±0.014	0.1255±0.0009	0.0400±0.0003	0.77	766±32	762±5	763±7
35	0.0667±0.0010	1.129±0.013	0.1227±0.0009	0.0396±0.0003	0.65	829±30	746±5	767±6
36	0.0663±0.0010	1.152±0.015	0.1261±0.0009	0.0402±0.0004	0.62	815±32	766±5	778±7
38	0.0682±0.0014	0.976±0.018	0.1037±0.0008	0.0325±0.0004	1.18	876±42	636±5	692±9
39	0.0673±0.0012	1.245±0.019	0.1341±0.0010	0.0432±0.0004	0.63	848±36	811±6	821±9
42	0.0665±0.0011	1.141±0.015	0.1245±0.0009	0.0400±0.0004	0.44	821±33	756±5	773±7
43	0.0687±0.0009	1.215±0.014	0.1283±0.0009	0.0390±0.0003	0.58	889±28	778±5	808±6
44	0.0676±0.0012	1.164±0.019	0.1249±0.0010	0.0418±0.0004	0.80	857±37	758±5	784±9
45	0.0647±0.0010	1.109±0.015	0.1243±0.0009	0.0392±0.0004	0.55	765±34	755±5	758±7
46	0.0653±0.0009	1.119±0.013	0.1242±0.0009	0.0411±0.0003	0.70	785±30	755±5	763±6
47	0.0668±0.0012	1.251±0.020	0.1359±0.0010	0.0415±0.0004	0.96	830±37	821±6	824±9
48	0.0665±0.0011	1.100±0.016	0.1200±0.0009	0.0372±0.0003	0.82	822±34	730±5	753±8
49	0.0650±0.0009	1.118±0.014	0.1248±0.0009	0.0392±0.0003	0.85	775±30	758±5	762±6
50	0.0656±0.0013	1.127±0.020	0.1245±0.0010	0.0410±0.0005	0.74	795±41	757±6	766±10
51	0.0667±0.0018	1.218±0.031	0.1325±0.0013	0.0427±0.0009	0.56	829±56	802±7	809±14
WD06-06								
1	0.0651±0.0010	1.109±0.015	0.1236±0.0009	0.0365±0.0003	0.72	777±33	752±5	758±7
2	0.0641±0.0009	1.097±0.013	0.1242±0.0009	0.0414±0.0004	0.61	744±30	755±5	752±7
3	0.0647±0.0014	1.107±0.022	0.1242±0.0010	0.0422±0.0005	0.62	763±45	755±6	757±11
4	0.0663±0.0035	1.215±0.062	0.1330±0.0020	0.0457±0.0010	1.13	814±107	805±12	808±29
5	0.0655±0.0019	1.114±0.030	0.1234±0.0012	0.0396±0.0006	0.82	789±59	750±7	760±15
6	0.0644±0.0014	1.101±0.023	0.1242±0.0010	0.0410±0.0004	1.51	753±46	754±6	754±11
7	0.0641±0.0013	1.100±0.019	0.1246±0.0010	0.0431±0.0006	0.45	743±41	757±6	754±9
8	0.0647±0.0014	1.105±0.022	0.1239±0.0010	0.0433±0.0006	0.50	764±44	753±6	756±10
9	0.0654±0.0014	1.110±0.021	0.1231±0.0010	0.0446±0.0006	0.44	787±44	749±6	758±10
10	0.0634±0.0009	0.836±0.010	0.0956±0.0007	0.0303±0.0002	0.70	722±29	589±4	617±5

(*To be continued on the next page*)

(*Continued*)

No.	Measured ratios					Apparent ages (Ma)		
	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{208}Pb/^{232}Th\pm1\sigma$	Th/U	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$
11	0.0645±0.0009	0.955±0.010	0.1074±0.0007	0.0346±0.0002	1.49	758±28	658±4	681±5
12	0.0645±0.0018	1.095±0.029	0.1231±0.0012	0.0415±0.0006	0.81	758±59	749±7	751±14
13	0.0637±0.0009	1.094±0.013	0.1245±0.0009	0.0416±0.0003	0.69	733±30	757±5	751±6
14	0.0649±0.0010	1.025±0.014	0.1146±0.0008	0.0386±0.0003	0.76	772±32	699±5	717±7
15	0.0647±0.0015	1.105±0.023	0.1239±0.0011	0.0413±0.0006	0.52	763±48	753±6	756±11
16	0.0658±0.0020	1.121±0.033	0.1235±0.0013	0.0435±0.0008	0.62	801±63	751±7	763±16
17	0.0670±0.0025	1.131±0.040	0.1224±0.0014	0.0471±0.0011	0.48	839±75	744±8	768±19
19	0.0661±0.0012	1.119±0.019	0.1228±0.0010	0.0419±0.0004	0.71	810±39	747±5	762±9
20	0.0647±0.0021	0.970±0.030	0.1087±0.0011	0.0371±0.0006	0.84	765±68	665±7	688±16
21	0.0638±0.0015	0.956±0.021	0.1086±0.0009	0.0366±0.0004	0.85	737±50	665±5	681±11
23	0.0664±0.0023	1.231±0.040	0.1344±0.0015	0.0496±0.0008	0.99	819±70	813±8	815±18
24	0.0657±0.0023	1.106±0.037	0.1222±0.0014	0.0431±0.0008	0.72	796±72	743±8	756±18
25	0.0653±0.0024	1.118±0.040	0.1241±0.0014	0.0396±0.0009	0.62	785±76	754±8	762±19
26	0.0647±0.0012	1.103±0.017	0.1237±0.0009	0.0388±0.0005	0.48	764±37	752±5	755±8
27	0.0641±0.0012	1.093±0.019	0.1237±0.0010	0.0421±0.0005	0.64	745±40	752±6	750±9
WD06-07								
5	0.0678±0.0039	0.880±0.049	0.0941±0.0016	0.0298±0.0007	1.10	863±116	580±9	641±27
7	0.0665±0.0015	1.009±0.021	0.1102±0.0009	0.0320±0.0004	0.57	821±46	674±5	709±10
8	0.0672±0.0021	0.944±0.027	0.1019±0.0010	0.0314±0.0006	0.53	845±62	625±6	675±14
9	0.0687±0.0042	0.837±0.049	0.0883±0.0015	0.0351±0.0012	0.59	891±120	546±9	618±27
11	0.0687±0.0019	0.883±0.022	0.0932±0.0009	0.0284±0.0004	0.95	891±55	575±5	643±12
13	0.0661±0.0016	0.982±0.021	0.1077±0.0009	0.0335±0.0004	0.83	810±48	660±5	695±11
14	0.0689±0.0017	0.895±0.021	0.0942±0.0008	0.0276±0.0004	0.61	895±50	580±5	649±11
15	0.0694±0.0044	0.847±0.052	0.0885±0.0016	0.0279±0.0007	1.23	911±125	547±10	623±29
16	0.0692±0.0024	0.931±0.030	0.0976±0.0011	0.0313±0.0007	0.53	904±68	600±6	668±16
17	0.0672±0.0012	0.972±0.016	0.1049±0.0008	0.0311±0.0003	1.04	844±38	643±5	689±8
18	0.0673±0.0018	0.831±0.021	0.0896±0.0008	0.0335±0.0005	0.50	848±55	553±5	614±12
19	0.0660±0.0012	1.038±0.017	0.1140±0.0009	0.0339±0.0004	0.60	808±37	696±5	723±8
20	0.0674±0.0017	0.902±0.021	0.0972±0.0009	0.0269±0.0003	1.60	849±52	598±5	653±11
21	0.0673±0.0016	0.930±0.020	0.1002±0.0009	0.0279±0.0004	0.76	848±49	615±5	668±11
22	0.0676±0.0011	0.949±0.013	0.1018±0.0007	0.0292±0.0003	0.66	857±33	625±4	678±7
24	0.0672±0.0024	0.902±0.031	0.0973±0.0011	0.0308±0.0007	0.52	845±74	598±7	653±17
25	0.0694±0.0015	0.824±0.016	0.0861±0.0007	0.0210±0.0002	1.64	911±44	533±4	611±9
26	0.0689±0.0022	0.879±0.026	0.0925±0.0010	0.0274±0.0005	0.74	895±63	570±6	640±14
27	0.0687±0.0014	0.888±0.016	0.0938±0.0007	0.0288±0.0002	2.74	889±41	578±4	645±9
28	0.0702±0.0012	0.838±0.013	0.0866±0.0006	0.0245±0.0002	0.95	934±35	536±4	618±7
29	0.0691±0.0023	0.934±0.029	0.0980±0.0011	0.0328±0.0006	0.66	903±66	603±6	670±15
30	0.0690±0.0010	0.895±0.010	0.0941±0.0006	0.0277±0.0002	0.76	898±29	580±4	649±6
WD06-09								
2	0.0696±0.0020	1.025±0.027	0.1067±0.0010	0.0346±0.0006	0.63	918±57	654±6	716±14
3	0.0670±0.0016	1.065±0.024	0.1153±0.0010	0.0370±0.0005	0.78	837±49	703±6	736±12
4	0.0644±0.0014	1.104±0.022	0.1243±0.0010	0.0382±0.0005	0.62	756±45	755±6	755±10
5	0.0675±0.0011	1.054±0.015	0.1132±0.0008	0.0353±0.0003	0.86	854±33	691±5	731±7
6	0.0667±0.0024	1.079±0.038	0.1174±0.0014	0.0352±0.0008	1.03	829±74	715±8	743±18
8	0.0666±0.0011	1.073±0.016	0.1167±0.0009	0.0379±0.0003	1.11	826±35	712±5	740±8
9	0.0667±0.0010	1.080±0.014	0.1174±0.0009	0.0358±0.0004	0.49	830±32	716±5	744±7
10	0.0669±0.0019	1.076±0.028	0.1167±0.0011	0.0353±0.0006	0.66	835±57	711±6	742±14
11	0.0696±0.0016	0.995±0.020	0.1037±0.0009	0.0327±0.0003	1.36	916±45	636±5	701±10

(*To be continued on the next page*)

(*Continued*)

No.	Measured ratios					Apparent ages (Ma)		
	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{208}Pb/^{232}Th\pm1\sigma$	Th/U	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$
12	0.0668±0.0017	1.078±0.025	0.1171±0.0011	0.0375±0.0004	1.32	831±51	714±6	743±12
13	0.0691±0.0019	1.018±0.027	0.1069±0.0010	0.0331±0.0005	1.05	901±56	655±6	713±13
15	0.0646±0.0016	1.095±0.025	0.1231±0.0011	0.0395±0.0004	1.06	760±50	748±6	751±12
16	0.0642±0.0013	1.093±0.020	0.1236±0.0009	0.0396±0.0003	1.20	748±42	751±5	750±10
17	0.0658±0.0018	1.090±0.029	0.1202±0.0012	0.0382±0.0005	1.03	799±57	732±7	748±14
18	0.0662±0.0014	1.078±0.020	0.1180±0.0010	0.0375±0.0004	1.17	813±42	719±6	742±10
21	0.0722±0.0010	0.947±0.011	0.0952±0.0007	0.0391±0.0003	1.18	991±28	586±4	677±6
22	0.0678±0.0012	1.060±0.016	0.1134±0.0009	0.0380±0.0003	0.93	862±35	692±5	734±8
24	0.0683±0.0014	1.298±0.023	0.1379±0.0011	0.0431±0.0005	0.62	877±41	833±6	845±10
26	0.0638±0.0017	1.107±0.027	0.1258±0.0012	0.0384±0.0005	1.19	735±55	764±7	757±13
27	0.0680±0.0017	1.040±0.024	0.1108±0.0010	0.0359±0.0006	0.53	870±51	678±6	724±12
28	0.0644±0.0019	1.107±0.031	0.1247±0.0012	0.0369±0.0004	1.86	753±61	758±7	757±15
29	0.0642±0.0014	1.097±0.021	0.1239±0.0010	0.0361±0.0003	1.36	749±44	753±6	752±10
35	0.0665±0.0023	0.909±0.030	0.0991±0.0011	0.0321±0.0006	0.79	823±71	609±6	657±16
36	0.0665±0.0018	1.058±0.027	0.1154±0.0011	0.0370±0.0005	0.76	824±56	704±6	733±13
37	0.0661±0.0019	1.070±0.030	0.1175±0.0012	0.0370±0.0006	0.71	809±60	716±7	739±15
38	0.0648±0.0012	1.063±0.017	0.1190±0.0009	0.0367±0.0003	1.27	767±38	725±5	735±9
39	0.0643±0.0022	1.094±0.036	0.1234±0.0014	0.0396±0.0007	0.96	752±72	750±8	751±18
41	0.0648±0.0020	1.088±0.032	0.1217±0.0012	0.0382±0.0005	0.90	769±63	740±7	748±15
42	0.0671±0.0021	0.970±0.028	0.1049±0.0011	0.0324±0.0005	0.68	840±63	643±6	688±14
43	0.0633±0.0015	1.072±0.023	0.1228±0.0010	0.0399±0.0005	0.69	718±49	747±6	740±11
45	0.0620±0.0010	1.052±0.015	0.1231±0.0009	0.0384±0.0004	0.49	674±34	749±5	730±7
46	0.0652±0.0014	0.953±0.019	0.1060±0.0009	0.0349±0.0004	1.04	781±45	649±5	680±10
47	0.0675±0.0021	1.002±0.030	0.1076±0.0011	0.0332±0.0005	1.01	854±65	659±6	705±15
48	0.0677±0.0012	1.266±0.020	0.1357±0.0010	0.0423±0.0005	0.41	859±37	820±6	831±9
49	0.0680±0.0011	0.796±0.011	0.0849±0.0006	0.0248±0.0002	0.84	869±33	525±4	594±6
50	0.0638±0.0016	1.096±0.026	0.1246±0.0011	0.0413±0.0005	0.95	736±53	757±6	752±12
51	0.0653±0.0015	1.052±0.022	0.1170±0.0010	0.0359±0.0005	0.57	783±48	713±6	730±11
52	0.0662±0.0014	1.038±0.019	0.1137±0.0009	0.0342±0.0004	0.92	814±42	694±5	723±10
53	0.0660±0.0012	1.061±0.018	0.1165±0.0009	0.0387±0.0004	0.51	808±39	711±5	734±9
54	0.0670±0.0011	1.026±0.014	0.1111±0.0008	0.0353±0.0003	1.15	838±33	679±5	717±7
55	0.0686±0.0010	0.842±0.010	0.0890±0.0006	0.0216±0.0002	0.96	888±29	550±4	620±5
56	0.0655±0.0024	1.061±0.037	0.1175±0.0013	0.0386±0.0006	1.26	790±75	716±8	734±18
WD05-34								
1	0.0596±0.0012	0.937±0.016	0.1140±0.0009	0.0347±0.0004	0.75	591±41	696±5	671±9
2	0.0708±0.0026	0.935±0.033	0.0959±0.0011	0.0315±0.0006	0.90	950±73	590±7	670±17
3	0.0629±0.0019	0.975±0.028	0.1124±0.0011	0.0351±0.0006	0.51	705±62	687±6	691±14
4	0.0680±0.0026	0.976±0.036	0.1042±0.0012	0.0379±0.0008	0.60	869±78	639±7	692±19
5	0.0630±0.0025	0.961±0.037	0.1107±0.0013	0.0362±0.0008	0.61	709±83	677±8	684±19
6	0.0623±0.0016	0.973±0.023	0.1134±0.0010	0.0349±0.0005	0.67	684±54	692±6	690±12
8	0.0671±0.0019	0.952±0.025	0.1029±0.0010	0.0336±0.0006	0.58	841±57	631±6	679±13
9	0.0669±0.0024	0.993±0.034	0.1077±0.0012	0.0375±0.0008	0.54	835±72	660±7	701±17
10	0.0625±0.0021	0.941±0.030	0.1093±0.0011	0.0303±0.0005	0.77	690±69	668±7	673±16
11	0.0697±0.0031	0.976±0.042	0.1015±0.0014	0.0324±0.0009	0.57	921±89	623±8	691±21
12	0.0679±0.0026	0.874±0.032	0.0934±0.0011	0.0223±0.0004	3.21	864±78	576±7	638±18

(*To be continued on the next page*)

(*Continued*)

No.	Measured ratios					Apparent ages (Ma)		
	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{208}Pb/^{232}Th\pm1\sigma$	Th/U	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$
13	0.0641±0.0019	0.987±0.027	0.1117±0.0011	0.0345±0.0006	0.64	745±60	683±6	697±14
14	0.0666±0.0016	0.987±0.022	0.1076±0.0009	0.0332±0.0005	0.61	824±50	659±5	697±11
15	0.0679±0.0013	1.014±0.017	0.1084±0.0008	0.0358±0.0004	0.81	865±39	663±5	711±9
16	0.0649±0.0019	0.989±0.027	0.1105±0.0011	0.0366±0.0006	0.55	771±59	676±6	698±14
17	0.0652±0.0020	0.983±0.029	0.1094±0.0011	0.0305±0.0005	0.71	780±63	669±6	695±15
18	0.0676±0.0022	0.917±0.028	0.0983±0.0010	0.0285±0.0005	0.89	858±66	605±6	661±15
19	0.0622±0.0016	0.951±0.022	0.1109±0.0010	0.0356±0.0005	0.60	682±53	678±6	679±12
20	0.0620±0.0017	0.962±0.025	0.1125±0.0010	0.0362±0.0006	0.51	675±59	687±6	685±13
21	0.0631±0.0018	0.973±0.026	0.1119±0.0011	0.0366±0.0006	0.54	710±59	684±6	690±13
22	0.0701±0.0030	0.973±0.040	0.1007±0.0013	0.0351±0.0009	0.56	930±86	619±8	690±21
23	0.0687±0.0014	1.011±0.019	0.1067±0.0009	0.0331±0.0003	1.00	890±43	653±5	709±10
24	0.0658±0.0017	1.002±0.024	0.1104±0.0010	0.0373±0.0005	0.55	801±53	675±6	705±12
25	0.0737±0.0029	1.001±0.037	0.0986±0.0012	0.0361±0.0008	0.63	1032±77	606±7	704±19
26	0.0652±0.0018	0.967±0.025	0.1076±0.0010	0.0363±0.0006	0.62	780±57	659±6	687±13
27	0.0647±0.0020	0.995±0.029	0.1116±0.0011	0.0363±0.0007	0.52	765±64	682±7	702±15
28	0.0653±0.0019	1.000±0.027	0.1111±0.0011	0.0339±0.0006	0.51	785±59	679±6	704±14
29	0.0627±0.0017	0.975±0.026	0.1128±0.0011	0.0350±0.0006	0.49	699±58	689±6	691±13
30	0.0627±0.0014	0.977±0.020	0.1130±0.0009	0.0367±0.0005	0.66	698±47	690±5	692±10
31	0.0615±0.0013	0.937±0.018	0.1105±0.0009	0.0327±0.0003	0.87	657±45	675±5	671±10
32	0.0629±0.0020	0.985±0.029	0.1136±0.0011	0.0367±0.0007	0.45	705±65	694±7	696±15
34	0.0642±0.0019	0.974±0.027	0.1100±0.0011	0.0385±0.0007	0.52	748±61	673±6	690±14
35	0.0650±0.0022	0.915±0.029	0.1020±0.0011	0.0344±0.0006	0.71	776±70	626±7	660±16
37	0.0622±0.0010	0.945±0.013	0.1102±0.0008	0.0333±0.0003	1.35	680±34	674±5	675±7
38	0.0672±0.0017	0.960±0.023	0.1036±0.0009	0.0322±0.0004	0.83	844±53	636±5	683±12
39	0.0632±0.0014	0.981±0.020	0.1126±0.0009	0.0371±0.0005	0.65	713±47	688±5	694±10
41	0.0627±0.0023	0.974±0.034	0.1126±0.0013	0.0397±0.0009	0.46	699±75	688±7	691±17
42	0.0622±0.0018	0.968±0.026	0.1128±0.0011	0.0406±0.0007	0.51	682±60	689±6	688±13
43	0.0629±0.0016	0.966±0.024	0.1114±0.0010	0.0371±0.0006	0.46	705±55	681±6	687±12
45	0.0634±0.0023	0.981±0.033	0.1123±0.0012	0.0367±0.0007	0.57	722±74	686±7	694±17
46	0.0645±0.0023	0.987±0.034	0.1110±0.0013	0.0382±0.0009	0.46	757±74	678±7	697±17
49	0.0676±0.0020	1.032±0.029	0.1107±0.0011	0.0367±0.0007	0.54	857±60	677±6	720±14
50	0.0625±0.0015	0.969±0.022	0.1123±0.0010	0.0331±0.0004	1.08	693±51	686±6	688±11
53	0.0622±0.0018	0.971±0.026	0.1131±0.0011	0.0373±0.0007	0.46	682±59	691±6	689±13
54	0.0663±0.0013	1.017±0.017	0.1112±0.0009	0.0359±0.0004	0.81	816±39	680±5	713±9
56	0.0639±0.0041	0.955±0.060	0.1083±0.0020	0.0387±0.0016	0.45	739±131	663±12	681±31
57	0.0698±0.0040	0.958±0.053	0.0995±0.0016	0.0464±0.0016	0.40	921±114	612±10	682±28
WD06-04								
2	0.0631±0.0033	0.970±0.048	0.1115±0.0017	0.0392±0.0010	0.69	712±106	682±10	689±25
3	0.0656±0.0008	1.195±0.012	0.1322±0.0009	0.0413±0.0003	0.64	793±27	800±5	798±6
4	0.0629±0.0021	0.968±0.031	0.1117±0.0012	0.0360±0.0007	0.67	705±70	682±7	688±16
6	0.0641±0.0015	0.988±0.022	0.1119±0.0010	0.0366±0.0005	0.68	744±49	684±6	698±11
11	0.0626±0.0023	0.969±0.034	0.1123±0.0013	0.0353±0.0008	0.52	695±77	686±7	688±18
13	0.0617±0.0021	0.940±0.030	0.1105±0.0012	0.0352±0.0005	0.98	663±71	676±7	673±16
14	0.0647±0.0019	0.191±0.005	0.0214±0.0002	0.0076±0.0001	1.83	764±62	136±1	177±5

(*To be continued on the next page*)

(*Continued*)

No.	Measured ratios					Apparent ages (Ma)		
	$^{207}Pb/^{206}Pb \pm 1\sigma$	$^{207}Pb/^{235}U \pm 1\sigma$	$^{206}Pb/^{238}U \pm 1\sigma$	$^{208}Pb/^{232}Th \pm 1\sigma$	Th/U	$^{207}Pb/^{206}Pb \pm 1\sigma$	$^{206}Pb/^{238}U \pm 1\sigma$	$^{207}Pb/^{235}U \pm 1\sigma$
WD05-26								
3	0.0637±0.0012	0.905±0.015	0.1030±0.0008	0.0313±0.0003	0.97	731±39	632±5	654±8
4	0.0633±0.0011	0.960±0.015	0.1101±0.0008	0.0333±0.0003	1.51	717±36	673±5	683±8
5	0.0623±0.0010	0.958±0.013	0.1116±0.0008	0.0349±0.0003	1.28	683±34	682±5	682±7
6	0.0621±0.0017	0.946±0.025	0.1106±0.0011	0.0340±0.0003	4.58	677±58	676±6	676±13
7	0.0614±0.0009	0.950±0.011	0.1123±0.0008	0.0345±0.0002	1.67	652±30	686±5	678±6
8	0.0625±0.0011	0.952±0.014	0.1104±0.0008	0.0336±0.0003	1.56	693±36	675±5	679±7
9	0.0619±0.0011	0.945±0.015	0.1108±0.0009	0.0342±0.0003	2.01	670±38	677±5	676±8
10	0.0601±0.0009	0.781±0.010	0.0944±0.0007	0.0287±0.0002	1.29	605±33	582±4	586±6
11	0.0606±0.0009	0.941±0.011	0.1126±0.0008	0.0352±0.0002	2.38	625±31	688±5	673±6
12	0.0620±0.0012	0.958±0.017	0.1121±0.0009	0.0335±0.0003	2.47	675±41	685±5	682±9
13	0.0648±0.0010	0.941±0.012	0.1053±0.0008	0.0322±0.0002	1.87	768±31	646±4	674±6
14	0.0617±0.0011	0.616±0.009	0.0725±0.0005	0.0223±0.0002	1.43	663±36	451±3	488±6
15	0.0603±0.0011	0.779±0.012	0.0937±0.0007	0.0295±0.0002	2.19	616±37	577±4	585±7
18	0.0625±0.0020	0.957±0.030	0.1111±0.0012	0.0368±0.0005	1.27	691±68	679±7	682±15
20	0.0648±0.0023	1.087±0.038	0.1216±0.0014	0.0396±0.0006	1.28	769±74	740±8	747±18
21	0.0604±0.0012	0.928±0.017	0.1114±0.0009	0.0358±0.0003	2.68	617±42	681±5	666±9
22	0.0635±0.0015	0.957±0.020	0.1093±0.0009	0.0342±0.0003	2.60	725±48	668±5	682±11
24	0.0658±0.0012	1.084±0.017	0.1195±0.0009	0.0384±0.0003	2.57	800±36	728±5	745±8
26	0.0618±0.0020	0.680±0.020	0.0798±0.0008	0.0191±0.0002	2.38	668±66	495±5	527±12
29	0.0656±0.0015	0.908±0.020	0.1005±0.0009	0.0332±0.0004	0.93	793±48	617±5	656±10
30	0.0625±0.0013	0.881±0.016	0.1023±0.0008	0.0351±0.0002	4.32	691±42	628±5	642±9
31	0.0644±0.0013	0.968±0.017	0.1091±0.0009	0.0360±0.0003	1.50	753±41	668±5	688±9
32	0.0618±0.0010	0.732±0.010	0.0859±0.0006	0.0257±0.0002	1.65	667±33	531±4	558±6
36	0.0622±0.0012	0.947±0.016	0.1104±0.0009	0.0352±0.0003	2.23	680±40	675±5	676±8
37	0.0604±0.0009	0.778±0.010	0.0934±0.0007	0.0259±0.0002	1.79	619±32	576±4	584±6
38	0.0622±0.0009	0.954±0.011	0.1112±0.0008	0.0341±0.0002	3.14	682±29	680±5	680±6
39	0.0606±0.0011	0.932±0.015	0.1116±0.0009	0.0377±0.0003	1.57	623±38	682±5	669±8
40	0.0620±0.0009	0.949±0.012	0.1111±0.0008	0.0351±0.0002	1.49	673±31	679±5	678±6
41	0.0593±0.0010	0.578±0.008	0.0706±0.0005	0.0209±0.0001	2.38	579±35	440±3	463±5
42	0.0593±0.0013	0.769±0.015	0.0940±0.0008	0.0308±0.0003	2.12	578±45	579±5	579±9
43	0.0589±0.0009	0.917±0.011	0.1129±0.0008	0.0358±0.0002	1.63	565±31	690±5	661±6
44	0.0662±0.0020	1.241±0.035	0.1361±0.0014	0.0457±0.0006	1.27	811±61	822±8	819±16
45	0.0604±0.0008	0.787±0.009	0.0946±0.0007	0.0282±0.0002	2.01	618±29	583±4	590±5
46	0.0617±0.0009	1.033±0.013	0.1214±0.0009	0.0386±0.0003	1.47	665±31	739±5	720±7
47	0.0647±0.0009	0.923±0.011	0.1035±0.0007	0.0331±0.0002	2.01	765±30	635±4	664±6
49	0.0678±0.0017	0.874±0.020	0.0935±0.0009	0.0354±0.0003	2.14	862±51	576±5	638±11
51	0.0631±0.0009	0.956±0.011	0.1099±0.0008	0.0349±0.0002	1.99	712±29	672±4	681±6
52	0.0600±0.0008	0.857±0.009	0.1035±0.0007	0.0329±0.0002	2.36	605±27	635±4	628±5
53	0.0609±0.0011	0.742±0.012	0.0884±0.0007	0.0273±0.0002	1.98	634±38	546±4	563±7
54	0.0593±0.0011	0.766±0.012	0.0937±0.0007	0.0350±0.0003	1.39	579±38	577±4	578±7