



# High-temperature geochronology constraints on the tectonic history and architecture of the ultrahigh-pressure Dabie-Sulu Orogen

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[1] New U/Pb zircon and Th/Pb monazite ages are presented from the giant Sulu ultrahigh-pressure (UHP) terrane. Combined with Sm/Nd ages, Rb/Sr ages, inclusion relationships, and geologic relationships, they help define the timing of peak recrystallization, the timing of subsequent amphibolite-facies metamorphism, and the architecture of the Dabie-Sulu suture zone between the collided Sino-Korean and Yangtze cratons. The data indicate a ~15 Myr record of UHP recrystallization, the first clearly documented for a giant UHP terrane; this requires that continental subduction in the Dabie-Sulu orogen involved multiple UHP tectonic or recrystallization events. A 244–236 Ma “precursor” UHP event, seen only in the Dabie Shan, was followed by a second, ~230–220 Ma “main” UHP event, which was itself terminated by a 220–205 Ma amphibolite-facies overprint. Older eclogite-facies events seen in the Qinling segment of this orogenic belt raise the possibility that these rocks have undergone (U)HP metamorphism three or four times, but at present, there is no geochronological evidence in the Dabie-Sulu area to support this. The subduction of the lower, Yangtze plate did not proceed in a simple fashion: The ages of inherited zircon cores demonstrate that a ribbon continent of Yangtze affinity escaped subduction and became wedged against the Sino-Korean plate hanging wall. **Citation:** Hacker, B. R., S. R. Wallis, L. Ratschbacher, M. Grove, and G. Gehrels (2006), High-temperature geochronology constraints on the tectonic

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## 1. Introduction

[2] Ultrahigh-pressure (UHP) terranes are defined by the presence of regionally developed metamorphic coesite and are composed of crustal rocks that were subducted to and exhumed from mantle depths >100 km. The Qinling-Dabie-Sulu orogen of China contains one of Earth's three giant UHP terranes. Several features render this UHP orogen one of the best for understanding the generation and exhumation of UHP rocks: (1) UHP rocks cover an area exceeding 10,000 km<sup>2</sup>; (2) the presence of carbonates, phosphates, basalts, and quartzites proves that the UHP rocks represent in part a subducted supracrustal sequence [Rolfó *et al.*, 2004] and are not simply over-thickened lower crust; and (3) well-documented peak metamorphism of 650–850°C and 4 GPa [Hacker *et al.*, 1997; Zhang and Liou, 1998; Mattinson *et al.*, 2004; Proyer *et al.*, 2004] shows that this terrane was subducted to and exhumed from depths of 135 km.

[3] Central to resolving the physical and chemical processes involved in the genesis and exhumation of UHP terranes is constraining the sequence of events. Simple questions like the following remain poorly answered: “How rapid was continental subduction?” “How many UHP event(s) were there?” “How long did the UHP event(s) last?” In the specific case of the giant Qinling-Dabie-Sulu UHP terrane, we know that it developed during northward subduction of the Yangtze Craton beneath the Sino-Korean Craton in the Triassic [Hacker *et al.*, 2000], but important controversies include the following: Exactly when in the Triassic did the UHPM occur? Were UHP subduction and exhumation coeval everywhere along the length of the orogen, implying a short-lived subduction and exhumation event of regional extent, or were they diachronous? Are some of the eclogites assumed to be Triassic actually remnants of early (U)HP metamorphic events? Where is the suture between the upper and lower plates in the collision zone? This paper addresses these issues with new U/Pb zircon and monazite ages from the Sulu area, introduced below. We present both multicollector inductively coupled plasma mass spectrometry (ICP) and secondary ion mass spec-

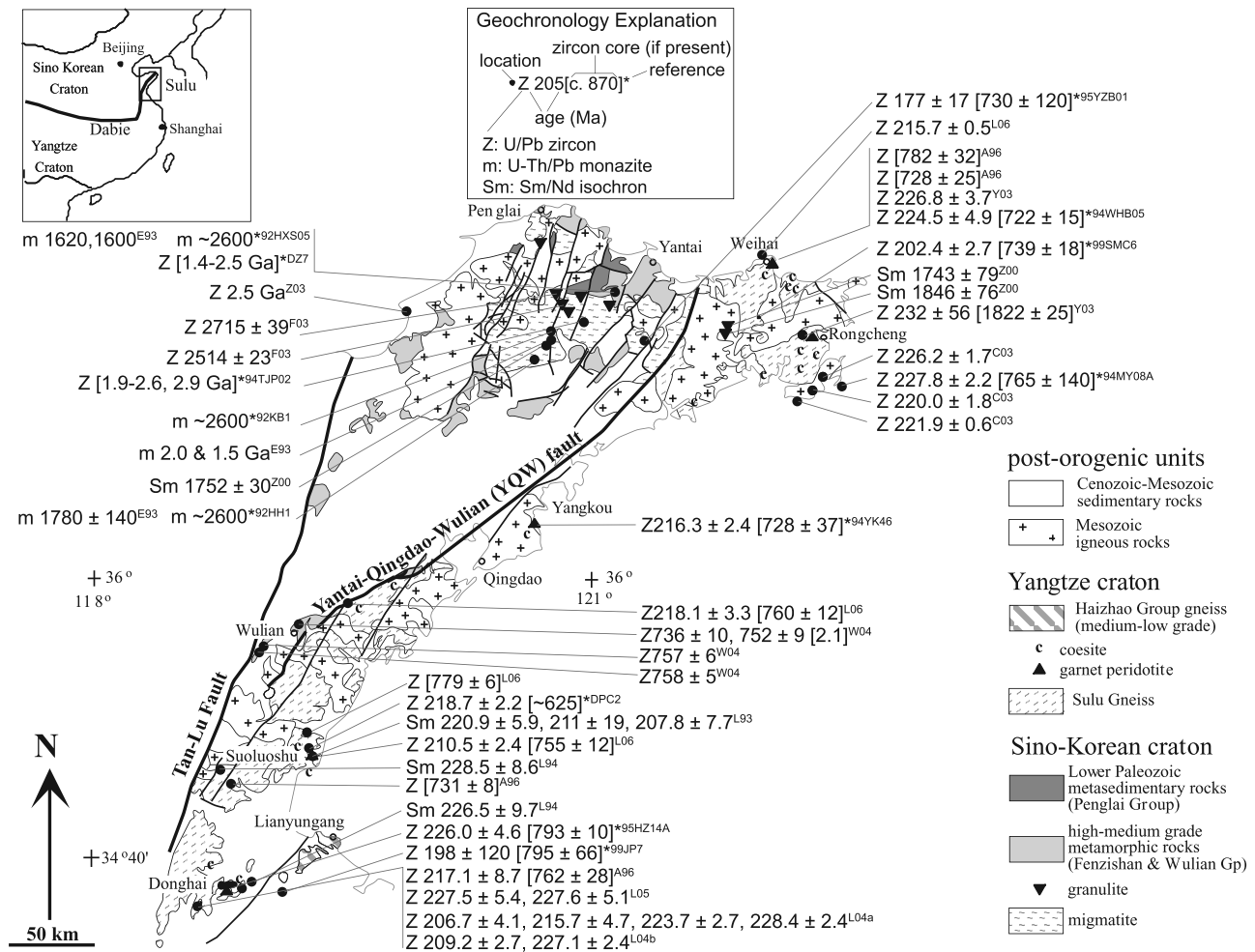
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**Figure 1.** Geology of the Shandong area [after *Regional Geological Survey of Jiangsu*, 1984; *Regional Geological Survey of Shandong*, 1991; *Faure et al.*, 2003; *Wu et al.*, 2004], emphasizing high-temperature geochronology. Coesite and coesite pseudomorphs locales from *Zhang and Liou* [1998]. High-pressure granulite blocks from *Zhai et al.* [2000] and *Faure et al.* [2003]. References: asterisk, this study; A96 [Ames et al., 1996]; C03 [Chen et al., 2003b]; E93 [Enami et al., 1993]; F03 [Faure et al., 2003]; L93 [Li et al., 1993]; L94 [Li et al., 1994]; L04a [Liu et al., 2004a]; L04b [Liu et al., 2004b]; L05 [Liu et al., 2005]; L06 [Leech et al., 2006]; W04 [Wu et al., 2004]; Y03 [Yang et al., 2003b]; Z00 [Zhai et al., 2000]; Z03 [Zhou et al., 2003].

trometry (SIMS) ages and compare them with an isotopically and regionally broader data set.

## 2. Geology of Sulu

[4] The Shandong peninsula in eastern China contains one of the great HP and UHP regions on Earth (Figure 1). It is separated into two domains separated by the Yantai-Qingdao-Wulian (YQW) fault system. Northwest of this fault the basement rocks are banded mafic to felsic gneisses. These gneisses are dominantly amphibolite facies but locally preserve granulite-facies relics [Zhai et al., 2000]; no eclogite is known. Ultramafic rocks are rare and exclusively spinel peridotite. The basement gneisses are overlain by a series of medium-grade to unmetamorphosed rocks of Archean(?), Proterozoic, and lower Paleozoic age known

as the Jiaodong, Fenzishan, Jingshan-Wulian, and Penglai groups [Wu et al., 2004]. Differentiating among these groups is difficult, but the Wulian and Penglai groups have Sinian fossils [Zhou et al., 1995], generally low-grade metamorphism, and the same heterogeneous rock types (see below), even though they are exposed in different regions (Wulian in the southwestern and Penglai in the northeastern Shandong peninsula).

[5] Southeast of the YQW fault the basement rocks ("Sulu gneiss") are dominantly banded felsic gneisses containing ultramafic and mafic blocks with local coesite-eclogite parageneses. In some regions the felsic gneisses preserve features characteristic of granites [Wallis et al., 1997] and in other regions are intercalated with lenses of dolomitic marble and schist [Kato et al., 1997], but no clear evidence proves a metasedimentary or meta-igneous origin

for all the gneisses. The UHP and HP eclogites and garnet peridotites reached conditions of 650–850°C and 4 GPa; this UHP metamorphism was followed by a strong amphibolite- to granulite-facies overprint at 750°C and 1 GPa that nearly erased the record of the UHP event [Zhang *et al.*, 1995; Banno *et al.*, 2000; Nakamura and Hirajima, 2000]. Rocks on both sides of the YQW fault are intruded by numerous granitoid bodies of chiefly Jurassic to Cretaceous age [Yang *et al.*, 2005b] and unconformably overlain by dominantly volcanoclastic Mesozoic to Cenozoic sediments.

[6] Traditionally the metamorphic differences across the YQW fault, in particular the absence of eclogite to the northwest, have been taken as evidence that the Yangtze Craton and the Sulu UHP-HP terrane are restricted to the southeast side of the fault and that the Sino-Korean Craton is restricted to the northwest side. However, the basement rocks on both sides of the YQW fault have a strong amphibolite-facies overprint that largely obscures earlier metamorphic assemblages, and both sides contain local granulite-facies rocks [Banno *et al.*, 2000; Nakamura and Hirajima, 2000]. Faure *et al.* [2001, 2003] used this similarity to challenge the traditional interpretation, suggesting that some of the amphibolite-facies rocks northwest of the YQW fault are retrogressed eclogite. They used their new interpretation to suggest that the suture lies west of the YQW fault and that the entire Shandong peninsula is a regional sheet of low- to medium-grade metamorphic rocks overlying UHP/HP rocks. If correct, this constitutes a major reinterpretation and requires revision of all tectonic models explaining the formation and exhumation of the Sulu UHP rocks. We agree in this paper that rocks northwest of the YQW are of Yangtze craton affinity, but we suggest instead that they belong to the Qinling microcontinent [Ratschbacher *et al.*, 2003, 2004] that was rifted from the Yangtze craton in the Proterozoic and thereby escaped the Triassic UHP metamorphism.

### 3. New Geochronology

[7] We measured U-Pb and Th-Pb ages from Sulu zircons and monazites to understand the orogen architecture and the causal events, taking care to study rocks giving extensive areal coverage of both sides of the YQW fault and localities that have played an important role in revealing the UHP petrological history (see Figure 1 and the auxiliary material for analytical methods).<sup>1</sup> We chose to focus on the quartz-feldspathic gneisses that host the eclogites because they are volumetrically dominant and have seen limited U/Pb study; undeformed or weakly deformed igneous rocks were not dated.

[8] Sample 94TJP02 is a strongly foliated biotite-granite gneiss with well-developed compositional layering from north of the YQW fault. This sample was examined to evaluate whether the effects of the UHP reached this far north. Abundant, pink-yellow-colorless zircons show cathodoluminescent (CL) oscillatory zoning to higher U rims,

but little resorption and no sector zoning, suggestive of igneous crystallization (Figure 2). Although differences in precision exist between the SIMS and ICP data (Figures 3–5), the combined results indicate (re)crystallization between 2.9 and 2.5 Ga and subsequent (re)crystallization around 1.9–1.8 Ga. The CL textures and Th/U ratios of 0.1–0.6 imply that both crystallization events are magmatic [cf. Hoskin and Schaltegger, 2003].

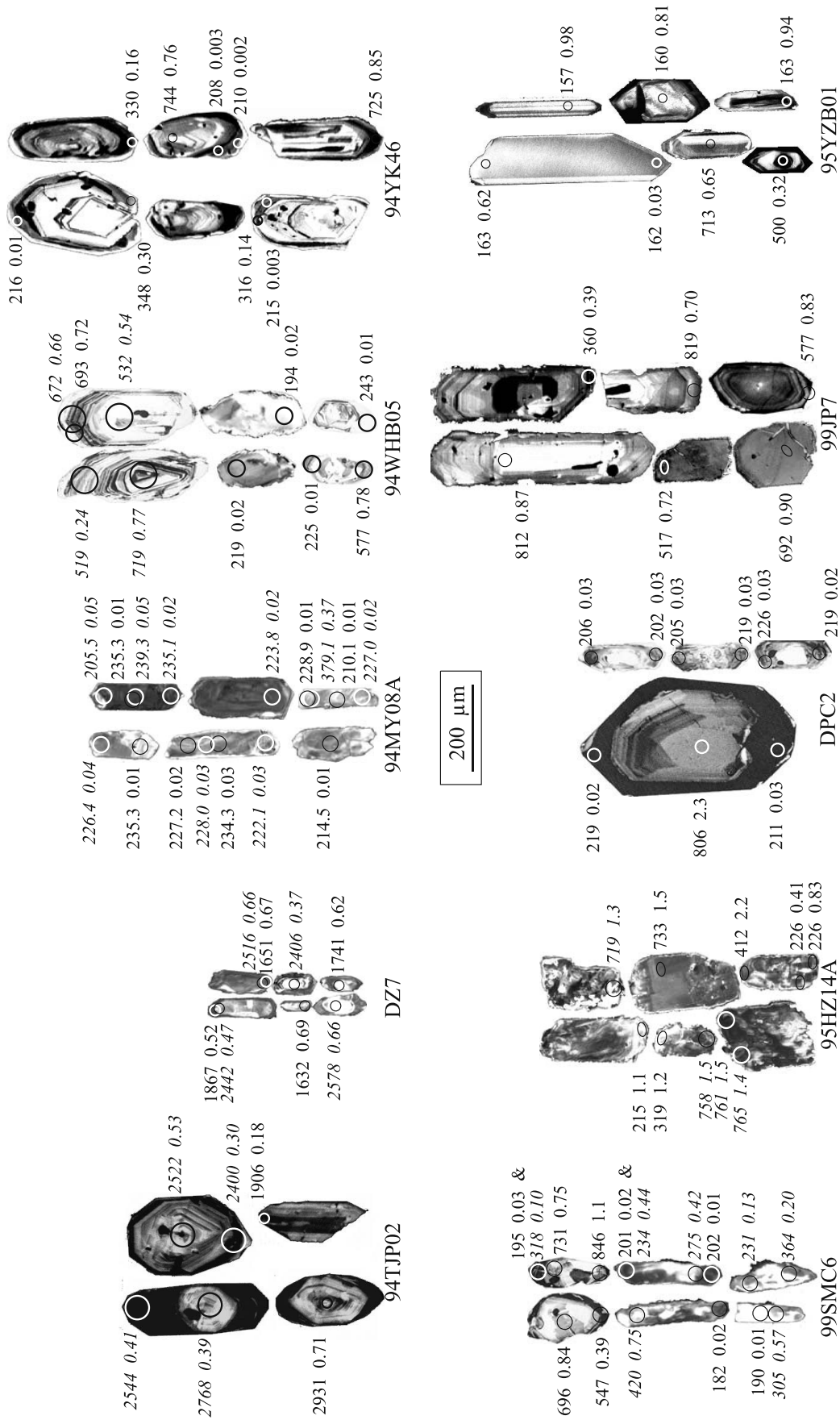
[9] DZ7 is an orthogneiss with quenched melt intruded along decimeter- to centimeter-scale shear zones. This sample is also from north of the YQW fault. The presence of clear partial melting zones associated with deformation [see Wallis *et al.*, 1999, Figures 5a and 5b] suggests dating of these samples may allow determination of melting and its associated tectonic event. Zircons extracted from the former melt have cathodoluminescent, partly oscillatory cores overgrown by dark mottled rims (Figure 2). A discordia defined by combined ICP + SIMS results indicates initial (re)crystallization at ~2.5 Ga followed by (re)crystallization around 1.4 Ga (Figure 3b). The ICP results derive from relatively large zircon volumes whereas the SIMS results targeted only the thin overgrowths present on some of the zircons. If the ICP analyses alone are used to constrain the upper intercept, a concordia age (in the sense of Ludwig [1998]) of  $2486 \pm 36$  Ma is obtained (Figure 3b inset). Forcing the upper intercept to  $2486 \pm 36$  Ma and projecting through the SIMS data gives a lower intercept of  $1418 \pm 62$  Ma. Th/U ratios of ~0.6 suggest that these events were igneous.

[10] The sample 95YZB01 is a strongly deformed granitic orthogneiss located immediately northwest of the YQW fault. It lacks the clear compositional layering of the previous two samples. It contains sparse pale brown to pale red zircons for which CL images show oscillatory zoned grains with no obvious rims (Figure 2). Relatively high Th/U ratios of ~0.8 suggest that these grains are igneous. ICP  $^{206}\text{Pb}/^{238}\text{U}$  spot ages on 11 grains range from 149 to 713 Ma. A discordia fit to all the data yields an upper intercept of  $730 \pm 120$  Ma and a lower intercept of  $177 \pm 17$  Ma (Figure 3c). The younger spot ages form a single subpopulation with a concordia age of  $160.4 \pm 2.3$  Ma (inset). We interpret this as the crystallization age of the granite; the strong fabric of this rock implies that tectonism continued through the Late Jurassic in this area.

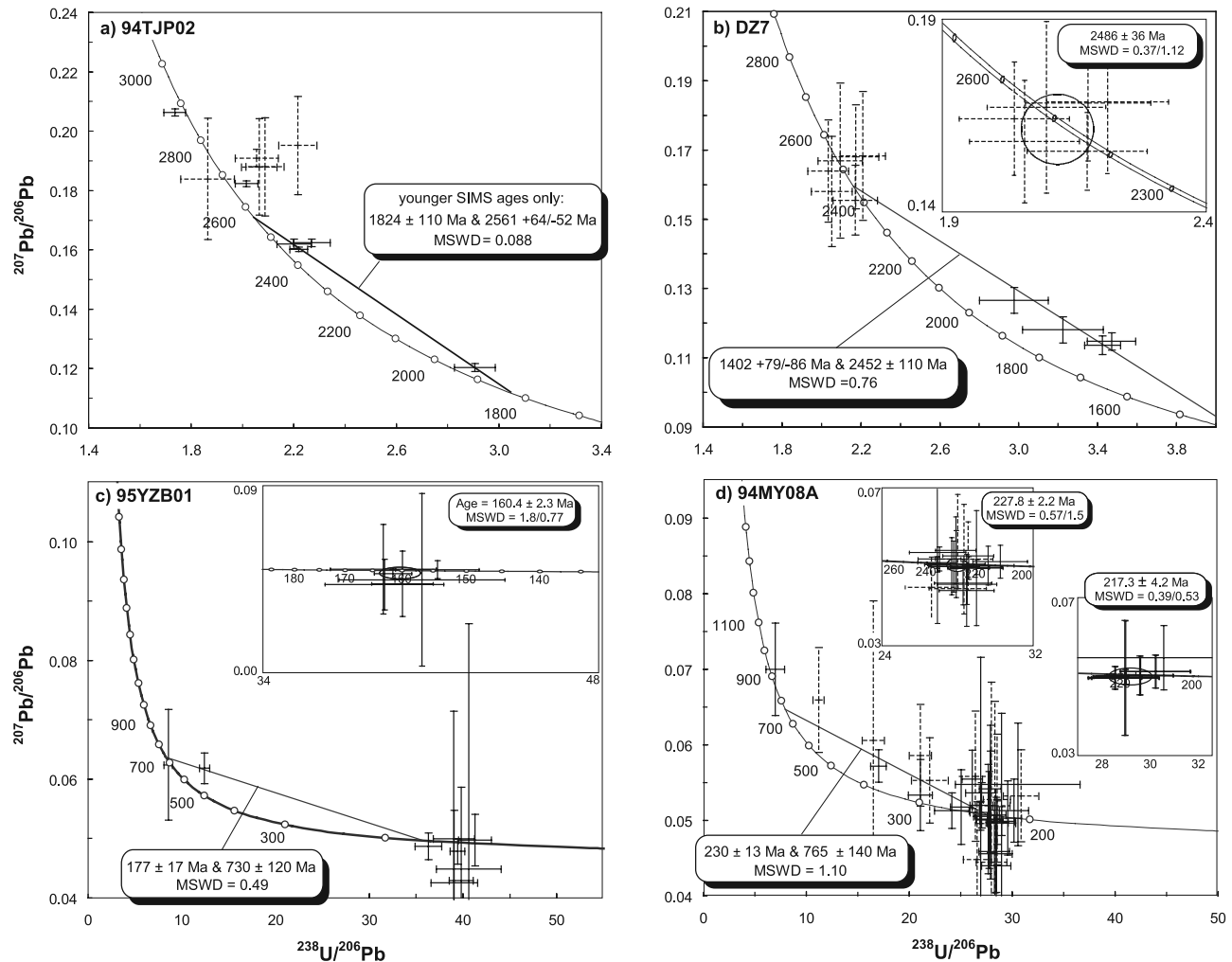
[11] The sample 94MY08A is a compositionally layered granitic orthogneiss from the northern part of the UHP domain. It contains large K-feldspar grains up to 20 cm in size [see Wallis *et al.*, 1999, Figure 5e]. A first, folded foliation is truncated by a second foliation, implying a complex tectonic history and hinting at an origin older than the less deformed Jurassic granite sample 95YZB01. The zircon grains show patchy or mottled CL (Figure 2). The oldest spot from a high Th/U core has a concordant  $^{206}\text{Pb}/^{238}\text{U}$  age of 862 Ma. A discordia fit to all the data yields intercepts of  $765 \pm 135$  Ma and  $230 \pm 13$  Ma (Figure 3d) confirming a Precambrian origin for this gneiss. Most of the  $^{206}\text{Pb}/^{238}\text{U}$  spot ages are younger than ~270 Ma (Figure 4a) and have Th/U ratios of 0.01–0.06, suggesting that they are metamorphic. Twenty of these ages (excepting only the youngest,

<sup>1</sup>Auxiliary material data sets are available at [ftp://ftp.agu.org/apend/tc/2005tc001937](http://ftp.agu.org/apend/tc/2005tc001937). Other auxiliary material files are in the HTML.





**Figure 2.** Cathodoluminescence images of typical zircons. SIMS data are shown in normal text, and ICP data are italicized. First number is age in Ma, and second number is Th/U ratio.



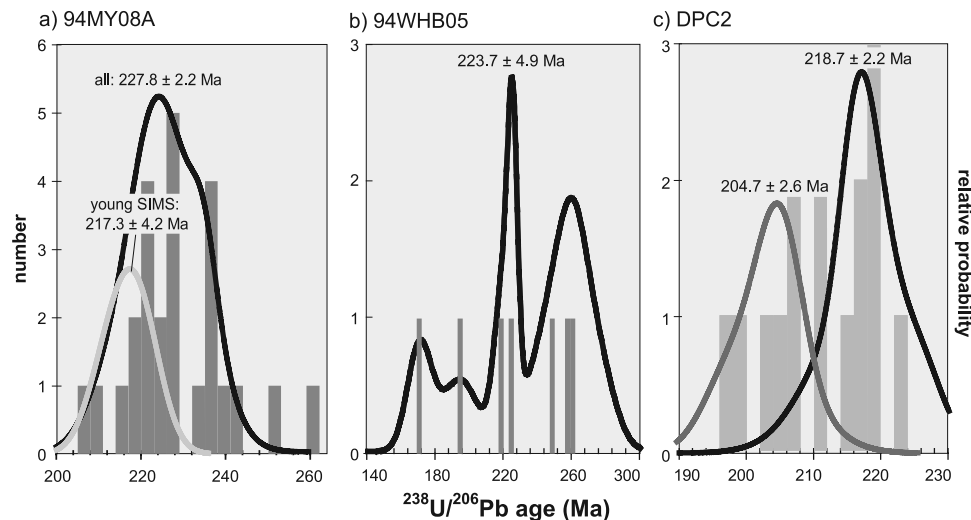
**Figure 3.** Tera-Wasserburg presentations of U/Pb isotopic data corrected using measured  $^{204}\text{Pb}$ . ICP data are dashed; SIMS data are solid lines. Error crosses are  $2\sigma$ . Where two MSWDs are given for concordia ages, they correspond to the “concordance” and “concordance plus equivalence” tests of Isoplot.

206 Ma) from ICP and SIMS analyses define a single population with a concordia age of  $227.8 \pm 2.2$  Ma (Figure 3d). The youngest group of five SIMS ages yields a slightly younger concordia age of  $217.3 \pm 4.2$  Ma; these analyses do not show distinctly different U contents, Th/U ratios, or CL response compared to the ICP analyses, and may give younger ages simply because SIMS consumes  $\sim 2$  orders of magnitude less zircon and is therefore more likely to capture the effects of small amounts of Pb loss. Because these five SIMS analyses were obtained from the near-rim regions, we interpret these results as reflecting Pb loss subsequent to the recrystallization age yielded by the bulk of the zircon and the ICP analyses. For this reason, we use the concordia age for the remaining 15 spots of  $229.5 \pm 5.6$  Ma (mean square weighted deviation (MSWD) = 0.52) as the best peak metamorphic age for this sample.

[12] The sample 94WHB05 is a strongly deformed, compositionally layered biotite–K-feldspar augen gneiss from Weihai in the northern part of the UHP domain. This

region shows local evidence for partial melting [Wallis *et al.*, 1999, Figure 5c]. The zircons show oscillatory-zoned cores with mottled CL rims (Figure 2). Thirty-one  $^{206}\text{Pb}/^{238}\text{U}$  ICP spot ages on 16 grains range from 171 to 792 Ma. A discordia fit to all the data yields intercepts of  $670 \pm 52$  Ma and  $225 \pm 22$  Ma (Figure 5a). Five of the oldest spot ages from grain cores yield a concordia age of  $722 \pm 15$  Ma. Three of these youngest points give a concordia age of  $224.5 \pm 4.9$  Ma and the two most precise ages have a weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  age of  $223.7 \pm 4.9$  Ma (Figure 4b). Although the geologic significance of ages calculated from these low Th/U (0.01–0.02) spots is difficult to assess given the meager number of Mesozoic spot ages, continued Pb loss into the Late Triassic is indicated. Both Cretaceous and Triassic ages have been reported from this region [Wallis *et al.*, 1999].

[13] The sample 94YK46 is a phengite–K-feldspar granitic gneiss from Yangkou in the northern part of the UHP domain showing weak compositional layering. The



**Figure 4.** Histograms and relative frequencies of young  $^{238}\text{U}/^{206}\text{Pb}$  ages from three samples. The older and younger ages for 94MY08A and DPC2 are interpreted to reflect peak metamorphism and Pb loss, respectively.

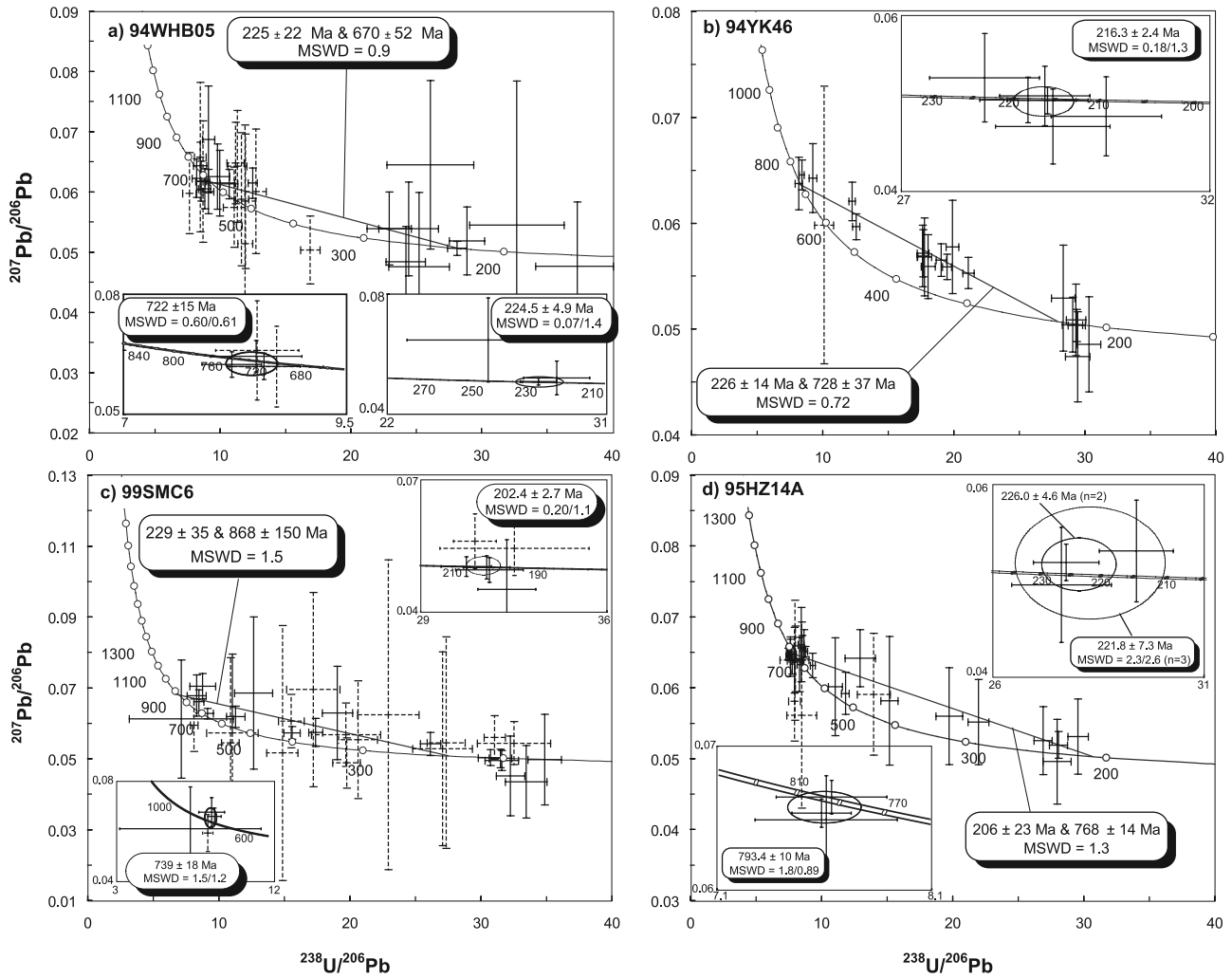
Yangkou area is best known for studies of the Yangkou unit [Wallis *et al.*, 1997] that preserves coesite as a matrix mineral, implying low fluid activity during and after UHP metamorphism [Liou and Zhang, 1996]. Probably as a result of this low fluid activity, zircon shows very little evidence for new growth associated with the UHP metamorphism [Wallis *et al.*, 2005]. The sample used in the present study comes from outside the Yangkou unit and is more likely to have undergone zircon growth related to the UHP metamorphism. The zircons are abundant, pale yellow to orange to colorless, inclusion-free grains. CL images show oscillatory-zoned cores overgrown by thin rims with relatively flat CL response (Figure 2). Twenty ICP  $^{206}\text{Pb}/^{238}\text{U}$  spot ages on 17 grains range from 188 to 744 Ma. A discordia fit to all the data yields intercepts of  $728 \pm 37$  Ma and  $226 \pm 14$  Ma (Figure 5b). The six youngest, low Th/U grains give a concordia age of  $216.3 \pm 2.4$  Ma. All grains older than 223 Ma show a positive linear correlation between Th/U and  $^{206}\text{Pb}/^{238}\text{U}$  spot age, whereas all six younger grains have a fixed Th/U ratio of 0.013 (Figure 6a); there is no correlation between age and U content, which is low, at 100–500 ppm. It is probable therefore that the U-Pb ages older than 223 Ma are from analyses of domains with mixed <223 Ma and ~750 Ma zircon.

[14] The sample 99SMC6 is a biotite–K-feldspar gneiss with compositional layering showing two stages of deformation from close to Rongcheng in the northern part of the UHP domain. This gneiss locally contains garnet and textural evidence for partial melting and is cut by small undeformed dikes. CL images show mottled overgrowths on cores with oscillatory zoning (Figure 2). Thirty-one ICP  $^{206}\text{Pb}/^{238}\text{U}$  spot ages on 26 grains range from 182 to 846 Ma. Like sample 94YK46, there is a positive correlation between Th/U and age for grains older than 206 Ma and a fixed Th/U ratio of  $\leq 0.02$  for younger grains (Figure 6b). In similar fashion to 94YK46, this implies that most  $^{206}\text{Pb}/^{238}\text{U}$  spot

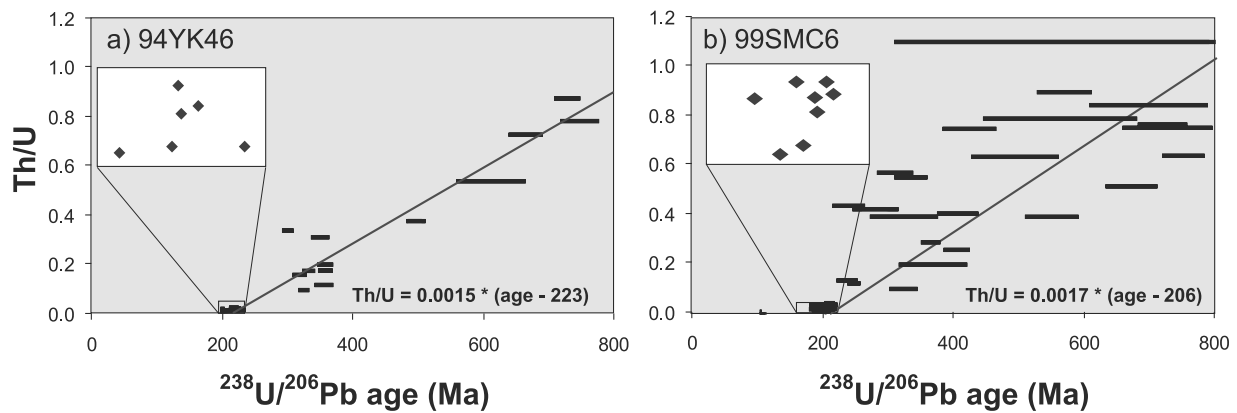
ages are mixtures of ~206 Ma and ~750 Ma zircon age domains. A discordia fit to all the data yields intercepts of  $868 \pm 150$  Ma and  $229 \pm 35$  Ma (Figure 5c). The four oldest spot ages from grain cores yield a concordia age of  $\sim 739 \pm 18$  Ma. Of the eight spot ages with low Th/U, the oldest six have a concordia age of  $202.4 \pm 2.7$  Ma; their high U contents of 1700–2900 ppm suggest that they are affected by Pb loss.

[15] The sample 95HZ14A is a mica–K-feldspar deformed granite from Donghai in the southern part of the UHP domain. There is very little evidence for either partial melting or late stage igneous intrusion in this region. It is, however, unclear whether these deformed granites can be correlated with the compositionally layered gneiss in the northern part of the UHP region. The sample contains orange, partly rounded zircons, with oscillatory-zoned cores overgrown by <10  $\mu\text{m}$  thick rims with variable and mottled CL response (Figure 2). Twenty-nine ICP  $^{206}\text{Pb}/^{238}\text{U}$  spot ages on 25 grains range from 214 to 814 Ma. A discordia fit to all the data yields intercepts of  $768 \pm 14$  Ma and  $\sim 206 \pm 23$  Ma (Figure 5d). Three of the oldest spot ages from grain cores have a concordia age of  $793.4 \pm 10$  Ma. The three youngest low Th/U spots yield a concordia age of  $221.8 \pm 7.3$  Ma. Two points have a concordia age of  $226.0 \pm 4.6$  Ma, in closer agreement with the better constrained results from samples 94MY08A and 94WHB05. These results show that the original pre-UHP basement complex contained local granite bodies.

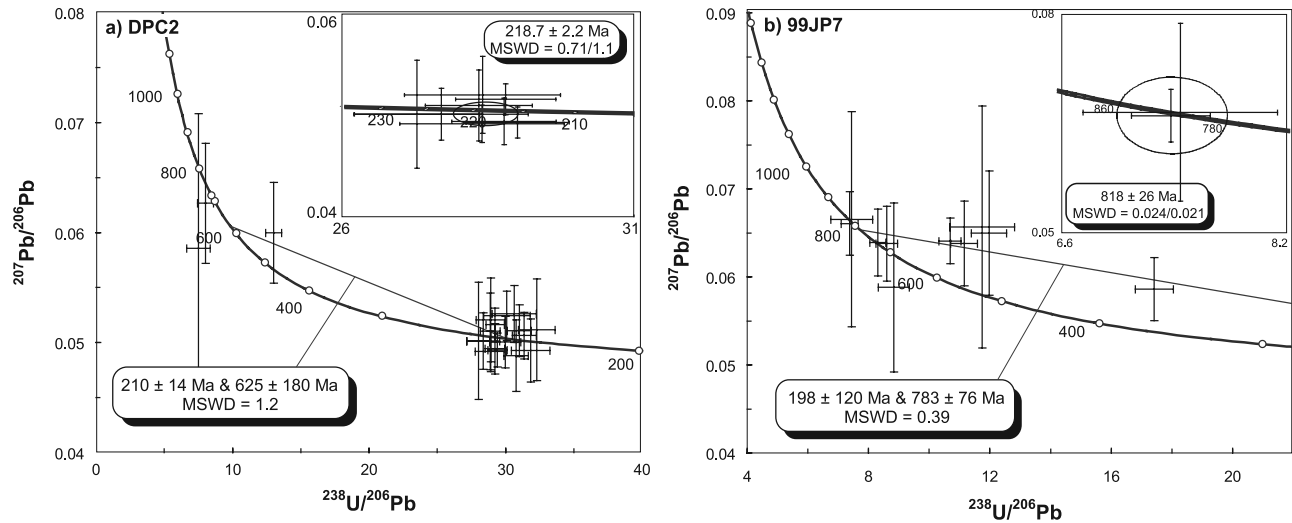
[16] DPC2 is a granitic orthogneiss with well-defined compositional layering from Suoluoshu in the southern part of the UHP domain. At least two phases of folding are preserved. Local centimeter-scale garnet clusters and aegirine are found in the gneiss. CL images of the zircons show mottled, diffusely luminescent rims on cores with oscillatory zoning (Figure 2). There is a sharp discontinuity in Th/U ratios from ~1 in the cores to <0.03 in the rims.



**Figure 5.** Tera-Wasserburg presentations of U/Pb isotopic data corrected using measured  $^{204}\text{Pb}$ . ICP data are dashed; SIMS data are solid lines. Error crosses are  $2\sigma$ . Where two MSWDs are given for concordia ages, they correspond to the concordance and concordance plus equivalence tests of IsoPlot.



**Figure 6.** Clear correlation between  $\text{Th}/\text{U}$  and  $^{238}\text{U}/^{206}\text{Pb}$  age in samples 94YK46 and 99SMC6 suggesting analysis of overlapping age domains.



**Figure 7.** Tera-Wasserburg presentations of U/Pb isotopic data corrected using measured  $^{204}\text{Pb}$ . ICP data are dashed; SIMS data are solid lines. Error crosses are  $2\sigma$ . Where two MSWDs are given for concordia ages, they correspond to the concordance and concordance plus equivalence tests of Isoplot.

Nineteen ICP  $^{238}\text{U}/^{206}\text{Pb}$  spot ages on 16 grains range from 197 to 806 Ma. A discordia fit to all the spot ages gives intercepts of  $625 \pm 180$  Ma and  $210 \pm 14$  Ma (Figure 7a). The two oldest spot ages from grain cores yield a concordia age of  $764 \pm 43$  Ma. The  $^{206}\text{Pb}/^{238}\text{U}$  ages from the low Th/U analyses show two subpopulations, each defined by eight analyses (Figure 4c). The two groups have concordia ages of  $218.7 \pm 2.2$  Ma and  $204.7 \pm 2.6$  Ma, and show no differences in U content.

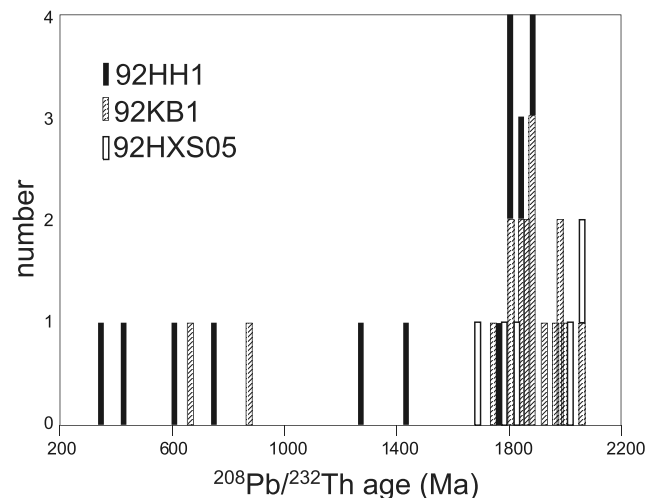
[17] The sample 99JP7 is a quartzfeldspathic schist likely derived from a granite near Lianyungang. Field observations suggest this schist overlies the main gneiss region, probably along an unconformable contact. It has abundant, frosted, inclusion-rich, whitish opaque to clear zircons. CL images show oscillatory-zoned, mottled grains with no evident rims (Figure 2). Most of the ICP analyses yield relatively high Th/U ratios of  $\sim 0.6$ , suggesting that these grains are igneous; one grain has a slightly lower Th/U rim. The two oldest spot ages from grain cores yield a concordia age of  $818 \pm 26$  Ma. A discordia fit to all the data yields intercepts of  $783 \pm 76$  Ma and  $198 \pm 120$  Ma (Figure 7b). These data indicate igneous crystallization at  $\sim 818$  Ma and probable Jura-Triassic Pb loss. These results suggest the sedimentary cover to the Sulu gneiss was also involved in the Triassic orogeny and metamorphism.

[18] Enami *et al.* [1993] described in detail four monazite-bearing sillimanite–K-feldspar–garnet–biotite schists from SW of Yantai that they dated using an electron microprobe. We dated monazite from three similar schists, 92HH1, 92HXS05, and 92KB1, from the same area. The monazites are commonly intergrown with and locally completely included by grains of aligned biotite; texturally distinct cores are observed in some grains. A broad range in monazite Th/Pb ages from 2068 Ma to 347 Ma (Figure 8) suggests, at the minimum, a post-347 Ma overprint of a pre-2068 Ma metamorphism. As a means of unraveling the

timing of the UHP and subsequent amphibolite-facies events, however, the monazite ages are not helpful, and not discussed further.

#### 4. Discussion

[19] Our new data and the entire Sm/Nd, U/Pb, Th/Pb, and Rb/Sr data set from the Sulu-Dabie area can be combined to address the questions posed in the introduction: the timing of UHP and overprinting events, including assessing whether there were multiple UHP events, whether the UHP metamorphism might have been diachronous, and the location of the suture between the colliding plates.



**Figure 8.** The  $^{232}\text{Th}/^{208}\text{Pb}$  ages for monazites 92HH1, 92HXS05, and 92KB01.



#### 4.1. Interpretation of the New U/Pb Zircon Ages From Sulu

[20] Protolith ages for two samples are  $\sim 2.5$  Ga and the best constrained ages from the remaining samples are  $\sim 818$  Ma to  $\sim 728$  Ma; the significance of these ages is discussed in a subsequent section. The Mesozoic metamorphic zircon recrystallization ages are more difficult to evaluate because the limited amount of recrystallization gravely restricts the opportunities for measuring spot ages, the measured  $^{238}\text{U}/^{206}\text{Pb}$  ratios have a large spread, the  $^{207}\text{Pb}/^{206}\text{Pb}$  ratios have large uncertainties, and concordia has minimal curvature in the Mesozoic. Sample 94MY08A gave the best constrained age, from 15 equivalent and concordant isotopic ratios, of  $229.5 \pm 2.6$  Ma. Three other samples (99SMC6, 95HZ14A, DPC2) gave equivalent spot ages, but also older and younger ages that we have argued above reflect incomplete recrystallization and subsequent Pb loss, respectively. Thus, from our new data set,  $229.5 \pm 2.6$  Ma is the best age for the UHP metamorphism in Sulu.

#### 4.2. Sm/Nd Age of the UHP Metamorphism

[21] Sm/Nd ages afford the advantage that grains known to be stable only at high pressure can be analyzed to form an isochron. There are now about two dozen Sm/Nd ages from Dabie-Sulu. Table S2 shows all of these isochrons that have MSWD values less than expected for the population size [Wendt and Carl, 1991]; as noted in Table S2, some ages have been recalculated using Isoplot. About half are two-point isochrons for which isotopic equilibrium among the constituent grains cannot be assessed, but about half are composed of 3 or more phases such that it is possible to assess equilibrium. Figure 9 (bottom) shows that these ages span a 36 Myr range from  $246 \pm 6$  Ma to  $210 \pm 9$  Ma, with a distribution that suggests four subpopulations of  $\sim 240$  Ma,  $\sim 228$  Ma,  $\sim 220$  Ma and  $\sim 212$  Ma, regardless of whether one considers the entire data set, only the two-point ages, or only the three-point ages, and regardless of whether one computes weighted mean ages or median ages. The ages of these peaks are clearly influenced to an uncertain extent by the finite number of data, but they bear importantly on the questions posed earlier. Which of these ages are credible? Do these subpopulations signify discrete (re)crystallization events at high pressure?

[22] The oldest three-point age is from a garnet pyroxenite and might be a mixed age reflecting an older history [cf. Brueckner *et al.*, 1996]. If so, one might consider eliminating the “240 Ma” data set from further consideration; we will see below, however, that the existence of this age group is supported by similarly old zircons. A few localities (italicized in Figure 9) have yielded both Sm/Nd and Rb/Sr ages, which can help assess whether the Sm/Nd ages are credible, based on the expectation that the Sm/Nd ages should be older than the Rb/Sr ages: (1) From Zhubian in Sulu, Li *et al.* [1994] reported a Sm/Nd age of  $228.5 \pm 8.6$  Ma and a muscovite Rb/Sr age of  $223.9 \pm 0.9$  Ma; at Qinglongshan (Sulu) their Sm/Nd age is  $226.5 \pm 9.7$  Ma and their phengite Rb/Sr age is  $219.5 \pm 0.5$  Ma. (2) From Shuanghe in Dabie, Chavagnac *et al.* [2001] reported

Sm/Nd ages of  $238 \pm 4$  and  $229 \pm 4$  Ma; from the same locale, Li *et al.* [2000] measured Sm/Nd ages of  $241.9 \pm 3.2$ ,  $226.5 \pm 3.2$  and  $226.3 \pm 3.2$  Ma, and a Rb/Sr phengite age of  $219.0 \pm 6.6$  Ma. (3) From Huangzhen in Dabie, Li *et al.* [2004] reported a multipoint Sm/Nd age of  $236.1 \pm 8.4$  Ma and a Rb/Sr age of  $230 \pm 14$  Ma. (4) From Bixiling in Dabie, Chavagnac and Jahn [1996] measured eight Sm/Nd ages from  $225 \pm 7$  Ma to  $210 \pm 9$  Ma and Rb/Sr phengite ages of  $214 \pm 6$  Ma,  $212 \pm 5$ , and  $198 \pm 4$  Ma. Four of these Sm/Nd ages, from 215 to 210 Ma, are essentially two-point isochrons as the whole rock and clinopyroxene separates have nearly identical Sm/Nd. This observation, combined with a phengite age as old as 214 Ma, suggests that at Bixiling the oldest, seven-point Sm/Nd age of  $225 \pm 7$  Ma is the best approximation of the age of the eclogite-facies event and that the younger Sm/Nd ages have been reset by subsequent events. This interpretation is also supported by the Bixiling U/Pb zircon data discussed below and suggests that the “212 Ma” Sm/Nd data set reflects post-UHP resetting. In aggregate, this reasoning implies that throughout Sulu and Dabie the best Sm/Nd constraints on the age(s) of the UHP event(s) are the three-point isochrons older than  $\sim 225$  Ma (the youngest Sm/Nd age with a corresponding Rb/Sr age) or older than  $\sim 225$ –219 Ma (the older Rb/Sr ages).

#### 4.3. Zircon Age of the UHP Metamorphism and the Amphibolite-Facies Overprint

[23] U/Pb zircon ages measured from eclogite, eclogite-bearing gneiss, and garnet peridotite from the UHP terranes of Dabie and Sulu are summarized in Figure 9 and Table S3. To facilitate comparison with the data of this study, and to screen out low-quality analyses, all the SIMS zircon ages in Table S3 are concordia ages (in the sense of Ludwig [1998]) from common-Pb corrected concordant spot analyses only; for some data sets this resulted in rejection of a large number of spot ages.

[24] The inferred metamorphic recrystallization ages range from  $246 \pm 10$  Ma to  $202.4 \pm 2.7$  Ma and can be broken into three subpopulations of  $\sim 239$  Ma,  $\sim 226$  Ma, and  $\sim 216$  Ma (Figure 9). The ages of these peaks are median ages computed by weighting all of the ages equally; the weighted mean ages of these same peaks are not significantly different, but are unduly dominated by single high-precision analyses. The peak ages are influenced to an uncertain extent by the finite number of data; their uncertainties, in particular, have limited geologic significance because of the size of the data set.

[25] The  $\sim 239$  Ma group of zircon ages includes results from two separate studies of rocks from Shuanghe (Dabie), and from two different studies of rocks from Shima (Dabie). This, combined with (1) the fact that the Sm/Nd ages from Shuanghe are the same as the zircon ages and  $\sim 10$  Myr older than elsewhere (see above) and (2) zircon-inclusion textures described below, lends considerable confidence to the interpretation that the 239 Ma group of zircon ages represents (re)crystallization at UHP. The middle, 226 Ma, group of U/Pb zircon ages is split away from younger ages because (1) a series of post-UHP shoshonitic plutons that



intrude the UHP gneiss in NE Sulu have crystallization ages of 226–220 Ma (special ornament in Figure 9) [Chen *et al.*, 2003b; Yang *et al.*, 2005a], (2) strongly deformed potassic dikes of a similar age are interpreted to be associated with the UHP metamorphism [Wallis *et al.*, 2005], and (3) a cobble from northern Dabie contains zircons with coesite-bearing mantles dated as ~239 Ma and coesite-bearing rims dated as ~226 Ma [Wan *et al.*, 2005]. The 226 Ma age group comes from both Dabie and Sulu and corresponds to the ~228 Ma group of Sm/Nd ages.

[26] The 216 Ma group of ages comes mostly from localities of similar geographic distribution to the 226 Ma group of ages, although three come from more westerly parts of Dabie (Banzhu and Hong'an in Figure 9). Four observations suggest that the 216 Ma group of zircon ages represents amphibolite-facies (re)crystallization after the UHP metamorphism. (1) A sample from Dabie (Wumiao) consists of 238–220 Ma metamorphic zircons overgrown by 220–214 Ma rims developed at amphibolite facies [Maruyama *et al.*, 1998]. (2) Five samples from Sulu (Donghai) have coesite-bearing zircon domains with ages of 242–220 Ma and quartz-bearing zircon domains with ages of 219–205 Ma [F. Liu *et al.*, 2004a, 2004b, 2005]. (3) A series of 226 to 220 Ma shoshonitic plutons intrude the UHP gneiss in NE Sulu [Chen *et al.*, 2003b; Yang *et al.*, 2005a]. (4) We interpreted the difference between our SIMS + ICP age of  $227.1 \pm 2.7$  Ma and SIMS age of  $217.3 \pm 4.2$  Ma for UHP gneiss 94MY08A to reflect rim Pb loss, although the agreement of this “Pb-loss” age with the zircon overgrowth ages of Maruyama *et al.* and Liu *et al.* may be coincidental. If this reasoning that the 216 Ma group of U/Pb zircon ages reflects post-UHP amphibolite-facies metamorphism is correct, the Sm/Nd ages that are younger than ~220 Ma therefore also reflect local amphibolite-facies reequilibration.

#### 4.4. Summary of the Radiochronology of the UHP Rocks

[27] In combination, the Sm/Nd and U/Pb data indicate (1) UHP eclogite-facies recrystallization in the Dabie Shan, but not in Sulu, at ~244–236 Ma; (2) UHP recrystallization at ~230–220 Ma in Dabie and in Sulu; and (3) amphibolite-facies recrystallization beginning at ~220 Ma and continuing on down to ~205 Ma in both Dabie and Sulu. This is the first giant UHP terrane for which a significant span in ages has been documented; equivalent or longer times spans have been documented a UHP domain of unknown size in the northeast Greenland Caledonides [McClelland *et al.*, 2006]. This surprisingly long time span could be the result of (1) daughter-product inheritance, (2) daughter-product loss, (3) multiple subduction events of the same unit, (4) multiple subduction events of different tectonic units, or (5) a long residence time at UHP conditions. We now assess these possibilities in detail.

[28] 1. It is reasonable to imagine that the 244–236 Ma zircon ages might be artifacts produced by incomplete resetting of inherited (e.g., 750 Ma) grains by the 230–220 Ma event, because the technique we employed of using only concordia ages for SIMS data has the potential to skew

such ages toward older values because of the minimal curvature in concordia and the large uncertainty in SIMS  $^{207}\text{Pb}/^{206}\text{Pb}$  measurements. One could argue that the 244–236 Ma Sm/Nd ages are similarly too old because of the presence of older inclusions. However, these explanations are unlikely simply because the Sm/Nd and U/Pb ages both show a very similar range from 246 Ma or 244 Ma to 236 Ma, followed by a distinct interregnum of ~5 Myr.

[29] 2. Is the 230–220 Ma “event” an artifact produced by variable daughter-product loss induced by an amphibolite-facies overprint of a 244–236 Ma UHP event? This possibility is more difficult to discount. Because some Sm/Nd ages derived from (U)HP minerals are as young as 211–210 Ma, a time that we know produced amphibolite-facies zircon (re)crystallization, all the Sm/Nd ages might be too young. Moreover, the zircon ages form a continuum from ~231 Ma down to ~209 Ma, suggesting Pb loss or protracted recrystallization. In contrast, the preservation of UHP zircon domains of different ages, 239 Ma and 226 Ma [Wan *et al.*, 2005], combined, again, with the ~5 Myr separation in age between the 244–236 Ma and 230–220 Ma groups, implies that the 230–220 Ma ages reflect a real UHP event.

[30] 3. If we accept that the data require two separate periods of recrystallization at UHP conditions separated by a minimum of ~5 Myr and an average of ~12–13 Myr, one possible explanation is that two distinct tectonic units were subjected to UHP conditions at different times. This explanation can be ruled out, however, because the same area in Dabie that recorded the 244–236 Ma event also has given younger zircon and Sm/Nd ages.

[31] 4. Alternatively, a single tectonic unit in Dabie may have been subjected multiple times to UHP conditions. At present there are no data that allow this hypothesis to be evaluated.

[32] 5. Finally, could a single terrane be subjected to UHP conditions for 12–13 Myr, with different portions of the unit recording various periods of UHP recrystallization? This is unlikely if the terrane remained in the footwall of the subduction zone because even a relatively slow subduction rate of 50 mm/yr would lead to a pressure increase of 5–20 GPa in 12–13 Myr, and a subduction rate of 20 mm/yr would be too slow for most of the plate to avoid heating to mantle temperatures (the characteristic diffusion distance for 12–13 Myr is ~20 km). A more promising scenario for a lengthy period of recrystallization at UHP conditions would be if the subducted terrane were underplated to the hanging wall, refrigerated by ongoing subduction, and then exhumed.

#### 4.5. Diachroneity of the UHP Metamorphism

[33] There is a clear geographic difference between the ages of the eclogite-facies events in Dabie and Sulu. The oldest precise Sm/Nd and U/Pb ages from Sulu are  $228.5 \pm 8.6$  Ma and  $228.4 \pm 2.4$  Ma, respectively, whereas there are 16 ages from Dabie that are significantly older (Figure 9). Many of the older ages come from the Shuanghe or Maowu-Shima-Huangzhen areas in Dabie (Table S2). This implies



that this area was either the first to (re)crystallize at UHP or suffered the least resetting.

#### 4.6. Devonian or Carboniferous Eclogite in Sulu?

[34] In addition to the well-known Triassic UHP and HP eclogites of the Qinling-Dabie-Sulu orogen, eclogites with Paleozoic ages have been discovered in Qinling and Dabie [Ratschbacher *et al.*, 2006]. Coesite- and diamond-bearing eclogites in western Dabie (Hong'an) yielded U/Pb zircon SHRIMP ages of  $507 \pm 37$  Ma and  $511 \pm 35$  Ma [Yang *et al.*, 2003a] and a Sm/Nd garnet-hornblende-omphacite-rutile-whole rock age of  $400 \pm 16$  Ma [Hu *et al.*, 1996]. Ages of  $\sim 315$  Ma have also been determined from eclogites in this area [Jian *et al.*, 1997, 2001; Gao *et al.*, 2002; Sun *et al.*, 2002; X. Liu *et al.*, 2004]. Ratschbacher *et al.* [2003] suggested that these pre-Triassic UHP metamorphism(s) resulted from aborted subduction of a "Qinling microcontinent" beneath the Sino-Korean craton and from Devonian-Triassic subduction south of that microcontinent. Eclogites of these ages have not been found in Sulu, but we argue below that the Qinling microcontinent is preserved in Sulu.

#### 4.7. Location of the Suture

[35] Significant differences in the tectonic histories of the Sino-Korean and Yangtze cratons mean that the ages of inherited zircons (Figure 10) can be used to determine the location of the suture within Sulu, as was done for Dabie [Hacker *et al.*, 1998] and for the entire Qinling-Dabie orogen [Ratschbacher *et al.*, 2003] (Figure 11). The Sino-Korean Craton consists of two Archean blocks separated by the early Proterozoic Trans-North China Orogen, overprinted by arcs and rifts at its southern and northern margins [e.g., Kusky and Li, 2003; Wilde *et al.*, 2004]. Precambrian U/Pb zircon ages of the Sino-Korean Craton cluster at  $\sim 3.8$  Ga,  $3.4$ – $3.0$  Ga, and  $2.2$ – $2.0$  Ga, with the bulk of the ages at  $\sim 2.5$  Ga (99 data with a mean at  $\sim 2502$  Ma) and  $1.9$ – $1.75$  Ga (21 data with a mean at  $\sim 1805$  Ma) (Figure 10a). The latter two events characterize the Wutai-Fuping arc system and the final assembly of the Sino-Korean Craton, respectively [e.g., Guan *et al.*, 2002; Wilde *et al.*, 2004]. The Sino-Korean Craton was then affected by early Paleozoic ( $\sim 480$  to  $400$  Ma) arc formation and orogeny along its southern margin (Figure 10a) [Ratschbacher *et al.*, 2003, 2006].

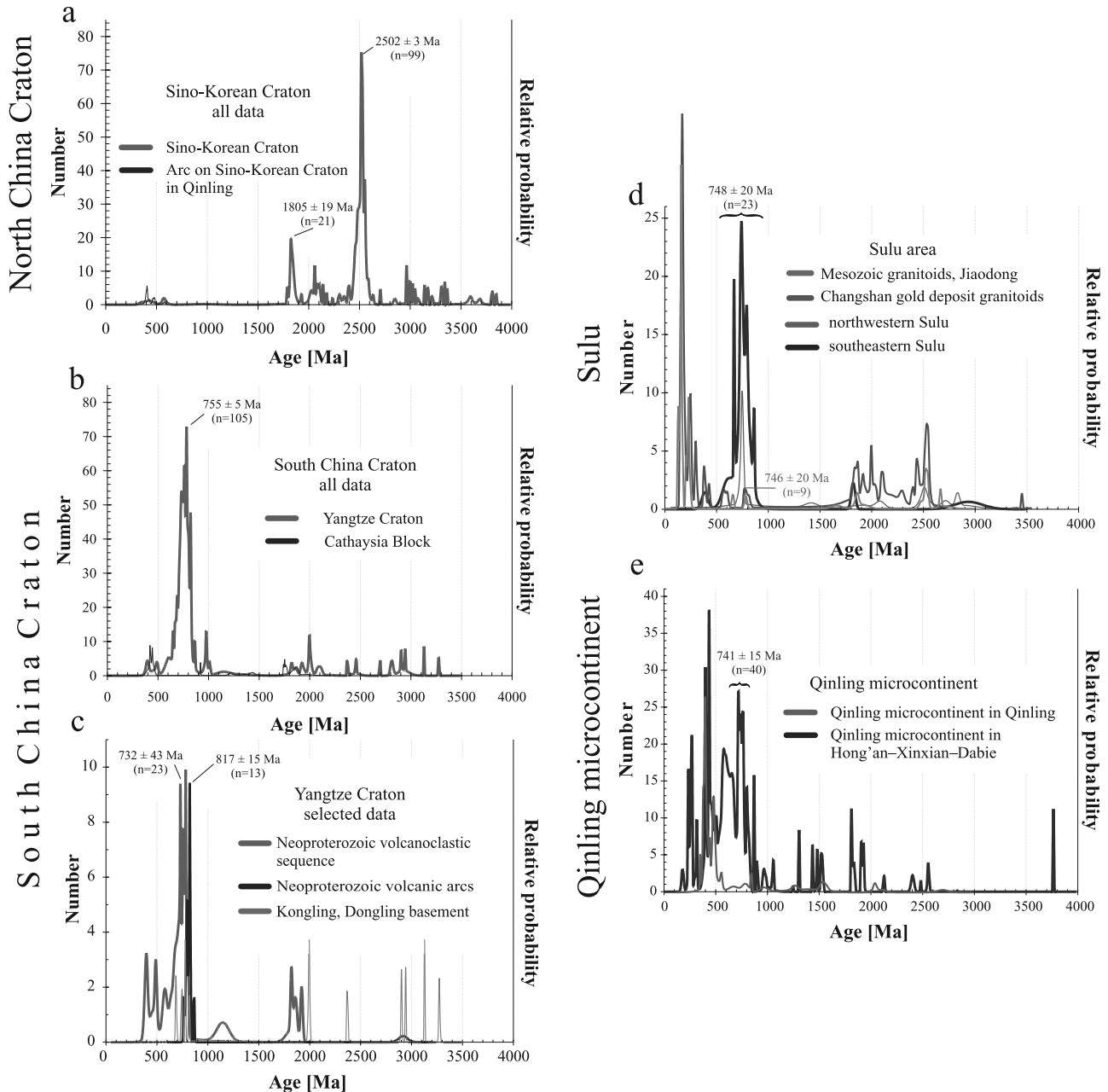
[36] In contrast, the Precambrian U/Pb zircon ages of the Yangtze Craton cluster at  $3.3$ – $2.9$  Ga,  $2.0$ – $1.7$  Ga, and  $\sim 1.0$  Ga, with the majority of the ages at  $0.85$ – $0.65$  Ga (105 data with a mean at  $\sim 755$  Ma, Figure 10b). The Neoproterozoic ages most likely date two distinct events that are difficult to separate based only on age. Most of the dated rocks have not been characterized geochemically, but 13 ages from petrochemically well-studied arc rocks along the northern and western Yangtze Craton (Panxi-Hannan arc of Zhou *et al.* [2002]) and the suture between the Yangtze and Cathaysia (Huanan Block) cratons [e.g., Li, 1999] give a mean age of  $\sim 817$  Ma (Figure 10c). The younger event ( $\sim 732$  Ma for 23 well-studied rocks) corresponds to rifting of Rodinia [Gao *et al.*, 1990; Li *et al.*, 1995, 1999] (Figure 10c). These age groups are also found in the Yangtze Craton

outside the Qinling-Dabie-Sulu orogen (Figure 10c) [Qiu *et al.*, 2000; Grimmer *et al.*, 2003]. In summary, the Neoproterozoic arc and rifting magmatism are diagnostic of the Yangtze Craton (Figures 10b and 10c), and the Sino-Korean Craton is best recognized by the  $\sim 480$  to  $400$  Ma arcs and orogenies that affected its southern edge (Figures 10a and 10e) [Ratschbacher *et al.*, 2003].

[37] On the basis of the identification of retrogressed eclogites and similarities in structural orientation and kinematics, Faure *et al.* [2001, 2003] suggested that the Shandong Peninsula northwest of the YQW fault is part of the Yangtze Craton and was affected by the Triassic UHP metamorphism. Retrogressed eclogites crop out within the Sino-Korean Craton  $\sim 500$  km west of Sulu [Zhao *et al.*, 2001], however, so the presence of eclogites does not signal Yangtze craton per se. A better test is to use zircon ages. The most common Precambrian zircon ages in Sulu and Dabie are circa  $750$  Ma, and such ages clearly occur southeast and northwest of the YQW fault in Sulu (Figures 1 and 10d). The Neoproterozoic ages northwest of the YQW fault come from gneissic granites interpreted to constitute the lower part of the Wulian Group, from inherited zircons in Jurassic-Cretaceous gold-bearing granites, and from detrital grains in carbonates (Figure 10d) [Wang *et al.*, 1998; Zhang *et al.*, 2003; Zhou *et al.*, 2003; Wu *et al.*, 2004; Tang *et al.*, 2006]. These ages, combined with the absence of early Paleozoic ( $\sim 480$ – $400$  Ma) ages characteristic of the arcs and orogenies along the southern margin of the Sino-Korean Craton, demonstrate that the Wulian Group is part of the Yangtze Craton.

[38] As discussed above, we interpret our monazite and zircon data (as well as that of Ishizaka *et al.* [1994]) from the gneissic migmatites beneath the Wulian-Fenzishan-Penglai groups northwest of the YQW fault to indicate (re)crystallization events at  $\sim 2.7$ – $2.5$  Ga and  $\sim 1.9$  Ga that were only weakly overprinted by a Phanerozoic metamorphism; this contrasts with the strong Triassic UHP and amphibolite-facies metamorphism SE of the YQW fault. In addition, SIMS U/Pb zircon ages obtained by Faure *et al.* [2003] from two samples of the host gneiss to the retrogressed-eclogite(?) boudins are in this same age range. Ishizaka *et al.* [1994] obtained a  $1.81$  Ga Rb/Sr whole rock age on this host gneiss, and Zhai *et al.* [2000] dated three high-pressure granulites from this area, obtaining Sm/Nd ages of  $\sim 1.85$ ,  $1.75$ , and  $1.74$  Ga. Ages of  $\sim 2.5$ ,  $2.0$ , and  $1.8$  also occur as inherited components in the Jurassic-Cretaceous granites of the Shandong Peninsula (Figure 10d) [Wang *et al.*, 1998; Zhang *et al.*, 2003]. Ages of both  $2.5$  Ga and  $1.8$  Ga coincide with the ages of known granulite-facies events in the Sino-Korean Craton [Zhai *et al.*, 2000] and suggest that the gneissic migmatite unit is part of the Sino-Korean Craton. However, both age groups also occur in the Yangtze Craton (Figure 10b), though not in granulites, and thus do not unambiguously tie the gneissic migmatite unit to the Sino-Korean Craton. In addition, one upper intercept age (our sample 95YZB01) and three lower intercept ages of foliated migmatite [Faure *et al.*, 2003] hint at a  $\sim 775$  Ma event in gneissic migmatites. Thus the gneissic migmatite unit requires further dating to define its provenance.





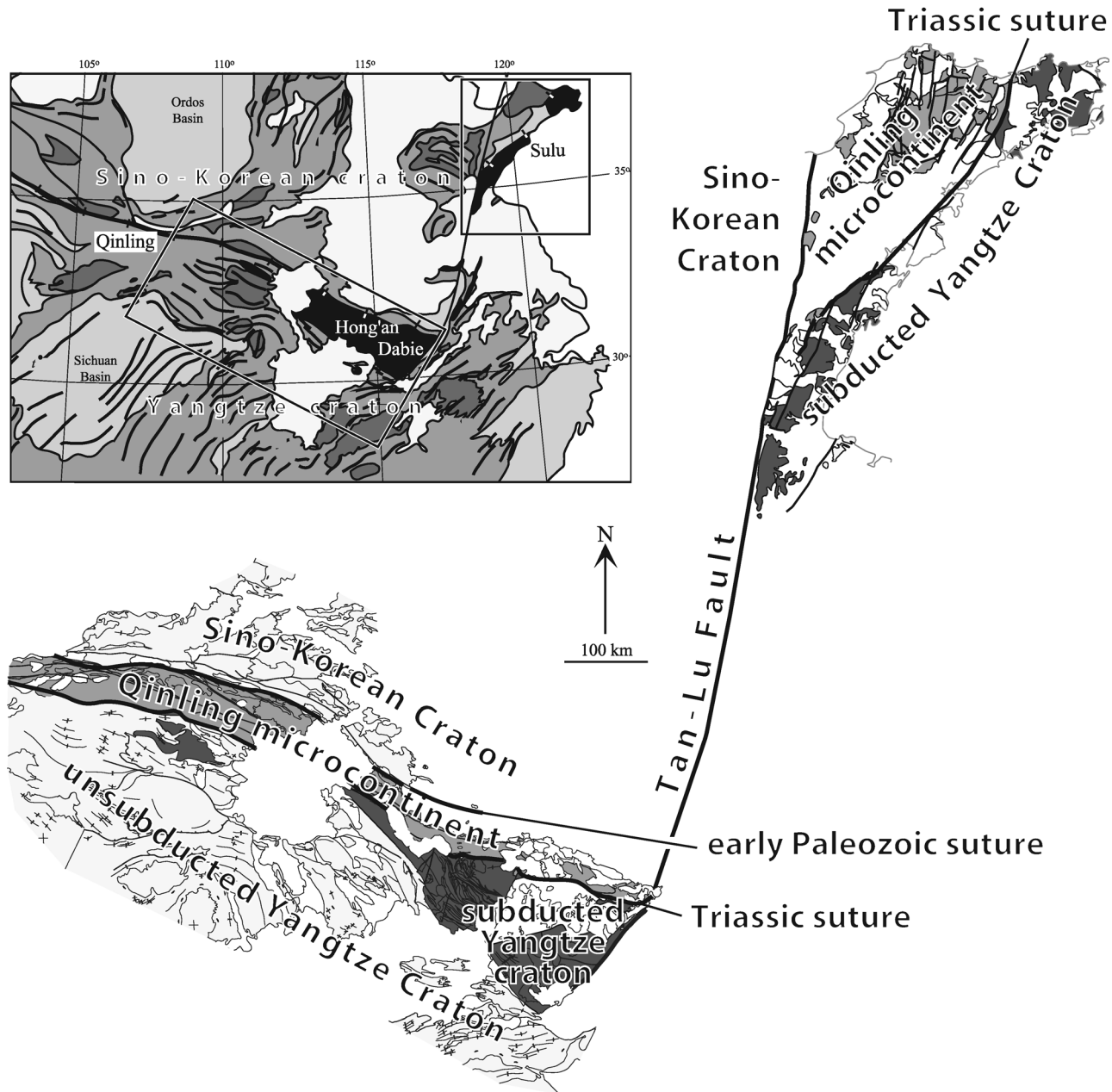
**Figure 10.** Pre-Triassic zircon ages from the (d) Sulu area compared to (a) the Sino-Korean Craton and the Ordovician-Devonian arc along its southern margin (arc data only from Qinling). (b) Data from the South China Craton split into the two major blocks. (c) Yangtze craton data, divided based on geotectonic setting and region. (e) Data of the Qinling microcontinent. Data in Figure 10d are from the compilation by Ratschbacher *et al.* [2006].

[39] There are three possible ways to explain the geology of northwestern Sulu in terms of Sino-Korean versus Yangtze affinity.

[40] 1. The Wulian-Fenzishan-Penglai groups are parts of the Yangtze Craton thrust northwestward over Sino-Korean basement (the gneissic migmatite); this would place the Triassic suture along the YQW, as in most current tectonic models. Wallis *et al.* [1999] and Faure *et al.* [2003] demonstrated top NW kinematics throughout Sulu, but that

deformation is due to exhumation, rather than crustal thickening.

[41] 2. The entire northwestern Sulu area is part of the Yangtze Craton, and the Triassic suture lies northwest of Sulu. The relationship of the Wulian-Fenzishan-Penglai groups to the gneissic migmatite in Sulu resembles that observed in Dabie between the volcanoclastic Changpu and Ganghe “cover units” and the depositionally underlying “Yangtze basement gneisses”; that cover is dated at ~761 Ma



**Figure 11.** Architecture of the Qinling-Dabie-Sulu orogen, emphasizing how the once subducted UHP portion of the Yangtze craton is separated from the Sino-Korean hanging wall by the Qinling ribbon microcontinent. Rock units younger than Triassic are unshaded.

(U/Pb zircon) and was interpreted as part of the Neoproterozoic rift sequence of the Yangtze Craton [Oberhänsli *et al.*, 2002; Schmid *et al.*, 2003]. Unfortunately, the basement gneisses are undated and poorly characterized, prohibiting a direct comparison with the gneissic migmatite of northwestern Sulu. Ages of  $\sim 2.5$  Ga and  $\sim 1.8$  Ga occur in Dabie but cannot be clearly associated with “Yangtze gneisses” beneath the Neoproterozoic rift sequence. Speculatively, an orthogneiss at Bixiling with a  $2458 \pm 76$  Ma upper intercept SIMS zircon age (sample CF96-39 of Chavagnac *et al.* [2001]), close to the study area of Schmid *et al.* [2003] and a granulite within the northern Orthogneiss

Unit in northern Dabie with a  $2456 \pm 7$  Ma Pb/Pb zircon evaporation age may constitute the closest Dabie equivalents to the gneissic migmatite in Sulu.

[42] In Dabie, the Triassic suture between the Yangtze and Sino-Korean cratons does not coincide with the northern boundary of the UHP-HP rocks, but actually lies 10–50 km farther north, such that the Sino-Korean Craton and the UHP part of the Yangtze Craton are separated by an unsubducted part of the Yangtze Craton (Luzhenguang Complex [Hacker *et al.*, 1998; Chen *et al.*, 2003a; Hacker *et al.*, 2004]). It is possible that a similar situation exists in Sulu: the Wulian-Fenzishan-Penglai groups and probably the gneissic migma-

tite units correspond to this unsubducted part of the Yangtze Craton. In this model, the UHP-HP rocks of the Qinling-Dabie-Sulu orogen developed by intracontinental subduction and exhumation.

[43] 3. We prefer a third scenario that resolves controversies about the age of the Sino-Korean/Yangtze Craton collision (Figure 11). We propose that there was an early Paleozoic collision between the Qinling microcontinent and the southern margin of the Sino-Korean Craton, and then a Triassic collision of this collage with the Yangtze Craton [Ratschbacher *et al.*, 2006]. The Qinling microcontinent is a long and narrow ribbon continent that extends at least through Qinling and Dabie. Here we suggest that it continues into Sulu and constitutes the basement and cover north of the YQW fault. In Qinling and Dabie, the Qinling microcontinent is characterized by the  $\sim 1.0$  Ga Jinningian orogeny,  $\sim 0.8$ – $0.7$  Ga arc formation and rifting, and  $\sim 470$ – $400$  Ma arc formation (Figure 10) [Ratschbacher *et al.*, 2006]. Thus the Qinling microcontinent's Proterozoic history ties it to the Yangtze Craton, from which it rifted at  $\sim 0.75$  Ga when Rodinia broke apart (see above). Its Paleozoic arc, mid-late Paleozoic fore-arc basin, and its separation from the Yangtze Craton by an oceanic mélange, render the Qinling microcontinent distinct [Ratschbacher *et al.*, 2006].

[44] How does this scenario apply to Sulu? The Wulian Group has already been correlated lithologically with the Luzhenguang and Foziling complexes of Dabie [Zhou *et al.*, 2002]. The basal sections are both  $\sim 0.75$  Ga gneissic granites [Zhou *et al.*, 2002; Chen *et al.*, 2003a] and are intercalated with and/or overlain by a mafic series in the Wulian Group and in the Luzhenguang complex (where it is  $\sim 0.75$  Ga [Hacker *et al.*, 2000]). The “upper” part of the Wulian Group is quartzite, carbonaceous slate, phyllite, and marble. The Foziling complex in Dabie consists of marble overlain by monotonous siliciclastic rocks interpreted as a forearc sequence [Ratschbacher *et al.*, 2006]. Migmatites are rare in the Luzhenguang and have not been dated, however, detrital zircon ages of 1.5, 1.8–1.9, and 2.5 Ga in the Foziling and Luzhenguang groups [Chen *et al.*, 2003a] suggest that basement with ages similar to the gneissic migmatite of Sulu was present in the hinterland. In summary, we propose that the migmatitic basement in Sulu is the basement of the Qinling microcontinent, and the Wulian Group is the Neoproterozoic cover (which has Sinian fossils [Zhou *et al.*, 1995]) of that microcontinent plus an overlying forearc sequence.

[45] Where is the 470–400 Ma arc in Sulu? Such arc rocks are ubiquitous as plutons in Qinling and represented by volcanic rocks in northern Hong'an (Figure 10e), but occur in Dabie only as recycled detritus in the fore-arc basin rocks. Thus the arc may not have been present or may have undergone greater exhumation in the east. The  $\leq 70^\circ$  counterclockwise rotation of the Sino-Korean Craton with respect to the Yangtze Craton during collision [Zhao and Coe, 1987; Gilder *et al.*, 1999] implies that the intervening Paleotethys ocean narrowed eastward, perhaps restricting arc formation in the east.

## 5. Conclusions

[46] New U/Pb zircon and U-Th/Pb ages from monazite were presented from the Sulu UHP domain. Our best zircon determination of the UHP event in Sulu is  $229.5 \pm 2.6$  Ma; the monazite ages are insufficiently reset and not helpful in determining the age(s) of the UHP metamorphism. All Triassic Sm/Nd ages and all U/Pb zircon ages from the Sulu and Dabie UHP terranes fall in three groups. The  $\sim 230$ – $220$  Ma group of ages is considered the “main” UHP event, based on (1) inclusion relationships in zircons, (2) the absence of older Rb/Sr ages, and (3) the presence of a 226–220 Ma post-UHP intrusive suite, and the agreement between U/Pb and Sm/Nd ages. Younger ages of  $\sim 220$ – $205$  Ma represent amphibolite-facies recrystallization, based on (1) inclusion relationships in zircons; (2) the association, in some samples, with higher U concentrations in the younger ages; (3) the patterns of older Rb/Sr ages, (4) the presence of a 226–220 Ma post-UHP intrusive suite, and (5) the fact that many of the Sm/Nd ages are younger than the U/Pb ages. The oldest group of ages, 244–236 Ma, come exclusively from Dabie. The distinct time gap between these ages and the 230–220 Ma peak implies two distinct UHP recrystallization events. Widespread  $\sim 750$  Ma zircons, reveal that like the Dabie Shan, a low-pressure crustal sliver of Yangtze affinity was trapped north of the deeply subducted part of the Yangtze Craton in Sulu and escaped subduction.

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