$^{40}\text{Ar}/^{39}\text{Ar}$ Constraints on the tectonic history and architecture of the ultrahigh-pressure Sulu orogen

B. R. HACKER,¹ S. R. WALLIS,² M. O. MCWILLIAMS³ AND P. B. GANS¹

¹Department of Earth Science, University of California, Santa Barbara, 93106-9630 CA, USA (hacker@geol.ucsb.edu)

²Department of Earth and Planetary Sciences, Graduate School of Environmental Studies, Nagoya University, 464-8602 Nagoya, Japan

³CSIRO Exploration & Mining, Technology Court, Pullenvale, 4069 Qld, Australia

ABSTRACT New $^{40}\text{Ar}/^{39}\text{Ar}$ ages are presented from the giant Sulu ultrahigh-pressure (UHP) terrane and surrounding areas. Combined with U-Pb ages, Sm-Nd ages, Rb-Sr ages, inclusion relationships, and geological relationships, they help define the orogenic events before, during and after the Triassic collision between the Sino-Korean and Yangtze Cratons. In the Qinling microcontinent, tectonism occurred between 2.0 and 1.4 Ga. The UHP metamorphism occurred in the Yangtze Craton between 240 and 222 Ma; its thermal effect on the Qinling microcontinent was limited to partial resetting of K-feldspar $^{40}\text{Ar}/^{39}\text{Ar}$ ages. Subsequent unroofing at rates of 5–25 km Myr⁻¹ brought the UHP terrane to crustal levels where it underwent a relatively short amphibolite facies metamorphism. The end of that metamorphism is marked by $^{40}\text{Ar}/^{39}\text{Ar}$ ages in the 219–210 Ma range, implying cooling at crustal depths at rates of 50–200 °C Myr⁻¹. Ages in the 210–170 Ma range may reflect protracted cooling or partial resetting by Jurassic or Cretaceous magmatism. Jurassic 166–149 Ma plutonism was followed by cooling at rates of c. 15 °C Myr⁻¹, suggesting relatively deep crustal conditions, whereas Cretaceous 129–118 Ma plutonism was succeeded by cooling at rates of c. 50 °C Myr⁻¹, suggesting relatively shallow crustal depths.

Key words: Ar/Ar; cooling rates; Sulu terrane; tectonism; ultrahigh-pressure.

INTRODUCTION

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 of > 100 km. The Qinling–Dabie–Sulu orogen of China contains one of Earth's three giant UHP terranes. Several features make this UHP orogen one of the best for understanding the generation and exhumation of UHP rocks: (i) UHP rocks cover an area exceeding 10 000 km²; (ii) the presence of carbonates, phosphates, basalts and quartzites proves that the UHP rocks represent in part a subducted supracrustal sequence (Rolfo *et al.*, 2004) and are not simply overthickened lower crust and (iii) well-documented peak metamorphism of 650–850 °C and 4 GPa (summary in Hacker, 2006) shows that this terrane was subducted to and exhumed from depths of 135 km.

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: 'How rapid was exhumation of the UHP rocks?' 'What physical property changes happened during subduction and exhumation?' 'How have the UHP rocks changed since being exhumed to crustal levels?' remain poorly answered. In the specific case of the giant Qinling–Dabie–Sulu UHP terrane, it

is known 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: exactly when in the Triassic did the UHPM occur? When were the rocks exhumed to crustal levels? How did the Triassic UHPM affect the Sino-Korean craton? What has been the *P–T* history of the UHP rocks since subduction? This study addresses these issues by presenting new $^{40}\text{Ar}/^{39}\text{Ar}$ ages from the Sulu area and comparing them with a isotopically broader data set.

GEOLOGY OF SULU

The Shandong peninsula in eastern China contains one of the great HP and UHP regions on Earth (Fig. 1) (Cong, 1996; Hacker *et al.*, 2004). It is separated into two domains by the Yantai–Qingdao–Wulian (YQW) fault system. North-west (NW) of this fault are rocks that Hacker *et al.* (2006) identified as the 'Qinling microcontinent', based on the spatial distribution of U-Pb ages and degree of metamorphism. The microcontinent basement rocks consist of amphibolite facies, and locally granulite facies, banded mafic to felsic gneisses (Zhai *et al.*, 2000) overlain by medium-grade to unmetamorphosed rocks of Archean(?), Proterozoic and lower Palaeozoic age known as the Jiaodong, Fenzishan, Jingshan–Wulian and Penglai Groups

Fig. 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).

(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). Rocks affiliated with the Qinling microcontinent are locally exposed south-east (SE) of the YQW fault, where they presumably lie tectonically on top of the Sulu gneiss (Faure *et al.*, 2001, 2003).

South-east 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 during continental subduction; 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 & Hirajima, 2000). The Sulu terrane has been subdivided into four slices based on structures and metamorphic grade (Xu *et al.*, 2006); Fig. 1 shows simply a UHP and an HP unit.

The pre-Mesozoic rocks on both sides of the YQW fault are intruded by numerous igneous bodies of Triassic to Cretaceous age (Yang *et al.*, 2005b) and unconformably overlain by dominantly volcanoclastic Mesozoic to Cenozoic sedimentary rocks.

GEOCHRONOLOGY PREAMBLE

Numerous geochronology studies on the Shandong Peninsula rocks shed light on the subduction and exhumation history of the UHP rocks. U/Pb studies through to about 2005 were reviewed by Hacker *et al.* (2006), and subsequent studies – along with Sm-Nd and Lu-Hf work – are reviewed here. Much $^{40}\text{Ar}/^{39}\text{Ar}$ dating has been done in the Sulu area. $^{40}\text{Ar}/^{39}\text{Ar}$ ages have the advantage of high precision and the ability to reconstruct cooling histories, but they have the disadvantage that they may be susceptible to excess ^{40}Ar that is not always recognizable (Li *et al.*, 1994; Hacker & Wang, 1995; Giorgis *et al.*, 2000). Moreover, K-bearing phases have closure temperatures low enough to be partially reset by later thermal events and may yield spectra with intermediate ages that are not diagnostic of either their formation or subsequent cooling event. Finally, deformation can lead to Ar loss or gain. All of these issues complicate the interpretation of $^{40}\text{Ar}/^{39}\text{Ar}$ spectra, such that it is the combination of $^{40}\text{Ar}/^{39}\text{Ar}$ dating of multiple minerals with different closure temperatures with other isotopic ages that permits the best interpretations. For the purposes of this paper we assume nominal closure temperatures

of 600–500 °C for hornblende, 450–350 °C for K-white mica, 350–250 °C for biotite, 450–350 °C for high-*T* steps of K-feldspar and 200–100 °C for low-*T* steps of K-feldspar; this is a simplification, but the complex and incompletely measured thermal history of the Sulu area does not yet warrant a more detailed approach. All $^{40}\text{Ar}/^{39}\text{Ar}$ ages for which isotopic ratios have been published have been recalculated in an attempt to introduce conformity; none have been updated to follow the recommendations of Renne *et al.* (1998), which would make them all ~1% older than stated.

Nearly, all attempts to date the UHP metamorphism in Sulu have been through SIMS U-Pb dating of zircon. For this study, all published U-Pb zircon data were re-evaluated to place all analyses on an equal footing and to screen out low-quality analyses. All the zircon ages reported here are single-population (low MSWD) *concordia ages* (sensu Ludwig, 1998) from common-Pb corrected *concordant spot analyses only*; for some datasets this resulted in rejection of a large number of spot ages. This removes problems associated with interpretation of discordant data (especially reversely discordant data), but cannot overcome issues associated with small degrees of inheritance or Pb loss.

Researchers have made valiant efforts to use zircon inclusions and zircon chemistry to assess whether zircon grew at (U)HP or low pressure, but even the best studies face three problematic issues inherent to zircon: (i) some inclusions are insufficiently diagnostic of pressure. Garnet in mafic rocks, for example, indicates pressures > 1 GPa, but not necessarily more; the same is true for rutile. Plagioclase is stable up to pressures of at least 1.6 GPa at 800 °C in mafic rocks. The only fool-proof (U)HP indicator minerals are omphacite + garnet or coesite. For this study, we evaluated the meaning of inclusions based on the following simple rules for MORB, as calculated by *Perple_X* (Connolly, 2005): garnet indicates > 1 GPa, plagioclase < 1.6 GPa, amphibole < 2 GPa, epidote < 2.2 GPa, rutile > 0.8 GPa, coesite > 2.7 GPa, etc. (ii) some dated zircon domains contain no inclusions; (iii) recrystallization can blur even the best inclusion data. For example, the presence of plagioclase in a zircon domain (e.g. mantle or rim) precludes the possibility that the domain grew at (U)HP, but it does not preclude the possibility that the domain grew at low pressure and then recrystallized at HP; likewise, the presence of garnet or omphacite in a zircon domain does not preclude the possibility of high-pressure zircon growth followed by low-pressure zircon recrystallization.

NEW GEOCHRONOLOGY

Thirty six $^{40}\text{Ar}/^{39}\text{Ar}$ ages from hornblende, K-white mica, biotite and K-feldspar separates of 26 Sulu rocks (Tables 1 & S1; Appendix S1) were measured, taking care to study samples from both sides of the YQW

fault and from localities that have played an important role in revealing the UHP history. Samples were analysed at Stanford University and the University of California Santa Barbara using Staudacher-type resistance furnaces and MAP-216 mass spectrometers (for details see Hacker & Wang, 1995; Calvert *et al.*, 1999). The neutron fluence standard was Taylor Creek sanidine, with an assumed age of 27.92 ± 0.16 Ma (2σ , excluding decay-constant uncertainty). Uncertainties quoted in this paper are either 2σ or 95% confidence level.

Precambrian ages

A mix of K-feldspar, biotite and hornblende was analysed from seven orthogneisses of the Qinling micro-continent (Fig. 2). One sample – 92HXS05 biotite – was analysed twice in the two different laboratories and gave spectra with monotonically increasing ages; such spectra might be compatible with cooling after *c.* 1700 Ma. Only two samples, a hornblende 94MJY01 and K-feldspar 92XS04, displayed relatively simple spectra with weighted mean ages of 1802 ± 10 and 662.6 ± 0.9 Ma respectively. The remaining five samples gave complex spectra suggestive of excess ^{40}Ar (e.g. no plateau) or gave isochrons indicative of excess ^{40}Ar (e.g. trapped components with $^{40}\text{Ar}/^{36}\text{Ar}$ ratios greater than atmosphere). The interpreted ages (three total fusion, two isochron) for these samples range from 1620 ± 20 to 380 Ma.

Mesozoic ages

Twenty-five separates gave Triassic–Cretaceous $^{40}\text{Ar}/^{39}\text{Ar}$ ages (Fig. 3). One hornblende (92CD3) with a complicated spectrum has an isochron age of 141 Ma. Four K-white mica have more-complicated spectra that are either hump shaped (95HZ14a & 95LYG07) or have monotonically increasing step ages (94YK46 & 95YTST01f). The isochron ages were used for the former and the latter interpreted to reflect protracted cooling from the time of the high-temperature step age to the time of the low-temperature step age. A fifth K-white mica sample (95ZY10) gave a relatively flat spectrum with a plateau age of 283.1 ± 1.9 Ma. Three biotite samples yielded relatively flat spectra with plateau ages of 209, 207 and 151 Ma (94BC13, 94MY08A, 99MC06B); five more gave more-complicated spectra for which the weighted mean ages of 216, 158, 125, 116 and 68 Ma were taken (94DYJ19, 94WHB05, 99DPC2, 95HZ14A, 94HYS13). Two complicated spectra have total gas age of 113 and 100 Ma (95LYG07, 92WQ-G). One K-feldspar (94WHB05) gave a saddle-shaped spectrum with an isochron age of 108 Ma. Five K-feldspar samples (92NZ13, 94YK46, 95CLSW, 95YZB1, 99JP7) gave monotonically increasing spectra (except for the first steps of some samples) interpreted to reflect protracted cooling from the time of the high-temperature step age to the time of the low-temperature step age. The least interpretable spectra (94BC13, 95HZ14a) are

Table 1. Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ data.

Sample name	Mineral	Sample mass (mg)	J	TFA (Ma)	WPMA (Ma)	$\pm 2\sigma$	% ^{39}Ar	IA (Ma)	$\pm 2\sigma$	$^{40}\text{Ar}/^{36}\text{Ar}$	MSWD	Preferred age (Ma)	$\pm 2\sigma$	$\pm 2\sigma$ total	Lab
92CD3	hbl	15.1	0.00353090	148	146.1	0.4	36	141.2	3.6	1506 $\pm$ 770	3.5	141.2	3.6	3.8	SU
92HFS01	bt	2.4	0.00346229	904	n/a	n/a	n/a	n/a	n/a	n/a	n/a	904	n/a	n/a	SU
92HFS01	kfs	0.5	0.00345681	380	~275 Ma	n/a	n/a	n/a	n/a	n/a	n/a	~275	n/a	n/a	SU
92HH1	bt	2.2	0.00345080	782	n/a	n/a	n/a	n/a	n/a	n/a	n/a	782	n/a	n/a	SU
92HXS05#1	bt	1.7	0.00348220	1463	1685	14	36	n/a	n/a	n/a	n/a	1685	14	19	SU
92HXS05#2	bt	0.3	0.01578694	1472	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1700	100	100	UCSB
92KB1	bt	0.4	0.01581700	901	n/a	n/a	n/a	736	36	856 $\pm$ 347	2.9	736	36	36	UCSB
92LJ06	bt	1.7	0.00344419	2319	n/a	n/a	n/a	1620	220	62223 $\pm$ 14000	0.63	1620	220	220	SU
92NZ13	kfs	1.9	0.00343563	294	n/a	n/a	n/a	n/a	n/a	n/a	n/a	305 $\rightarrow$ 206	n/a	n/a	SU
92WQ-G	bt	0.5	0.01580409	100	111	7	n/a	n/a	n/a	n/a	n/a	100	~10	~10	UCSB
92XS04	kfs	0.8	0.00349418	649	662.6	0.9	94	n/a	n/a	n/a	n/a	662.6	0.9	5.1	SU
94BC13	kfs	3.0	0.00354865	235	n/a	n/a	n/a	n/a	n/a	n/a	n/a	214 $\rightarrow$ 127	n/a	n/a	SU
94BC13	bt	0.2	0.01577202	209	209.7	1	80	207.9	2.9	449 $\pm$ 422	0.45	209.7	1.1	1.9	UCSB
94DYJ19	bt	3.3	0.00354168	209	216.3	0.5	34	215.8	1.7	528 $\pm$ 670	0.01	215.8	1.7	2.4	SU
94HYS13	bt	0.1	0.01580064	70	67.6	2.4	30	80	22	244 $\pm$ 119	0.68	67.6	2.4	2.5	UCSB
94MJY01	hbl	7.4	0.00347430	1750	1802	10	91	n/a	n/a	n/a	n/a	1802	10	17	SU
94MY08a	bt	2.4	0.00352480	194	207.0	1.8	84	n/a	n/a	n/a	n/a	207.0	1.8	2.4	SU
94WHB5	kfs	1.1	0.00349905	145	n/a	n/a	n/a	107.8	3.4	461 $\pm$ 16	1.5	107.8	3.4	3.5	SU
94WHB5	bt	0.6	0.00350457	147	157.8	4.6	35	160	10	284 $\pm$ 43	3.4	157.8	4.6	4.8	SU
94YK46	kfs	0.9	0.00348885	133	n/a	n/a	n/a	n/a	n/a	n/a	n/a	196 $\rightarrow$ 110	n/a	n/a	SU
94YK46	ms	0.4	0.01580827	193	n/a	n/a	n/a	n/a	n/a	n/a	n/a	201 $\rightarrow$ 189	n/a	n/a	UCSB
95CLSW	kfs	2.9	0.00341801	116	n/a	n/a	n/a	n/a	n/a	n/a	n/a	122 $\rightarrow$ 88	n/a	n/a	SU
95HZ14a	bt	0.4	0.00339946	110	115.7	4.4	42	96	95	353 $\pm$ 350	0.16	115.7	4.4	4.5	SU
95HZ14a	ms	1.1	0.00339352	201	200	10	96	197.4	8	1388 $\pm$ 1300	3.1	197.4	8	8.1	SU
95HZ14a	kfs	2.9	0.00340552	186	n/a	n/a	n/a	n/a	n/a	n/a	n/a	207 $\rightarrow$ 188	n/a	n/a	SU
95LYG07	ms	3.1	0.00337741	222	221.5	1	45	225.4	1.1	169	53	221.5	1.0	2.0	SU
95LYG07	bt	0.1	0.01582294	113	n/a	n/a	n/a	n/a	n/a	n/a	n/a	113	~10	~10	UCSB
95YST01f	ms	0.1	0.01582075	175	174.9	0.7	40	173.5	9.4	10004	2382	195 $\rightarrow$ 150	n/a	n/a	UCSB
95YZB1	kfs	3.2	0.00342889	90	n/a	n/a	n/a	n/a	n/a	n/a	n/a	135 $\rightarrow$ 110	n/a	n/a	SU
95ZY10	ms	0.1	0.01579711	283	283.1	1.9	61	279.6	1.4	421 $\pm$ 35	1.2	279.6	1.4	2.6	UCSB
99DPC2	bt	2.3	0.00341088	121	124.7	1	n/a	n/a	n/a	n/a	n/a	124.7	1.1	1.5	SU
99JP7	kfs	3.5	0.00338764	191	188.3	0.3	n/a	n/a	n/a	n/a	n/a	190 $\rightarrow$ 177	n/a	n/a	SU
99SMC06	bt	2.4	0.00351480	146	150.7	0.8	99	146.3	6.5	1312 $\pm$ 1500	1	150.7	0.8	1.4	SU

J, irradiation parameter; TFA, total fusion age; % ^{39}Ar , fraction ^{39}Ar used in computing WPMA and IA age; WPMA, weighted mean plateau age (italic = weighted mean age); $^{40}\text{Ar}/^{36}\text{Ar}$, isochron intercept; MSWD, mean square of weighted deviates; h $\rightarrow$ l (e.g. 207 $\rightarrow$ 188), spectrum with a range of step ages from a high-temperature step age (h) to a low-temperature step age (l)

saddle-shaped, with no meaningful isochron; these are provisionally interpreted to reflect protracted cooling from the time of the high-temperature step age to the time of the youngest step age. As a group – except for 92NZ13 – these six samples have step ages that range from 214 to 88 Ma. Two of the samples (95HZ14a, 99JP7) have spectra implying Triassic–Jurassic cooling, two (94BC13, 94YK46) have spectra consistent with Triassic/Jurassic to Cretaceous cooling and two (95CLSW, 95YZB1) gave only Cretaceous ages.

DISCUSSION

Our new data and the entire Sm–Nd, Lu–Hf, U–Pb, Th–Pb, Rb–Sr, K–Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ data set from the Sulu area can be combined to address the questions posed in the introduction: the timing of the UHP event, the exhumation event, and the subsequent overprinting events – including assessing the thermal history of the Qinling microcontinent and the P – T history of rocks during and after UHP exhumation.

Precambrian orogenesis

Monazite as old as 2.6 Ga (Hacker *et al.*, 2006) and zircon core ages of 2.9–2.5 Ga (Faure *et al.*, 2003;

Zhang *et al.*, 2003; Hacker *et al.*, 2006) constitute the earliest record of (Archean) orogeny exposed on the Shandong Peninsula (Fig. 4). A subsequent Paleoproterozoic granulite facies event is indicated by monazite of 2.0–1.5 Ga (Enami *et al.*, 1993), zircon of 1.9–1.4 Ga (Hacker *et al.*, 2006; Huang *et al.*, 2006), Sm–Nd garnet ages of *c.* 1.7 and *c.* 1.8 Ga (Zhai *et al.*, 2000) and a Rb–Sr biotite age of 1.3 Ga (Ishizaka *et al.*, 1994). $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende ages of 1805 Ma (Faure *et al.*, 2003) and 1802 Ma (this study) and biotite spectra decreasing from *c.* 1700 Ma (this study) reflect either very slow cooling (*c.* 1 °C Myr^{−1}) following this event or subsequent Ar loss. The preservation of these $^{40}\text{Ar}/^{39}\text{Ar}$ ages indicates that the major Triassic UHP orogeny and the Mesozoic magmatism were insufficient for complete isotopic resetting. Considerably younger ages – 904, 901 and 782 Ma for biotite (this study) presumably reflect partial resetting by younger thermal events.

The final significant Precambrian orogenic event was at *c.* 750 Ma, as indicated by zircon crystallization ages of plutons and recrystallization ages of gneisses (Ames *et al.*, 1996; Wu *et al.*, 2004; Hacker *et al.*, 2006; Huang *et al.*, 2006; Leech *et al.*, 2006; Zhang *et al.*, 2006; Tang *et al.*, 2008). Subsequent cooling is marked by a $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende age of 719 $\pm$ 4 Ma (Wu *et al.*, 2004), a Rb–Sr biotite age of

Fig. 2. Age spectra, K/Ca spectra and inverse isochrons for dated samples with Precambrian ages. Isochrons presented only for samples without a plateau and with a meaningful isochron. K/Ca ratios > 10 000 not shown. WMPA, weighted mean plateau age; WMA, weighted mean age; TFA, total fusion age; MSWD, mean square of weighted deviates. Uncertainties include only error in (J); for total error see Table 1. (a) Spectrum for 92HFS01 biotite suggests excess ^{40}Ar , but likely a Precambrian age. (b) Spectrum for 92HFS01 K-feldspar suggests Triassic resetting. (c) Spectrum for 92HH1 biotite suggests excess ^{40}Ar , but likely a Precambrian age. (d) Spectra for 92HXS05 biotite suggest initial cooling at $c. 1.7$ Ga followed by subsequent resetting. (e) Spectrum for 92KB-1 biotite suggests excess ^{40}Ar , confirmed by (f) inverse isochron with an age of 736 Ma. (g) Spectrum for 92LJ06 biotite suggests excess ^{40}Ar , confirmed by (h) inverse isochron with an age of 1620 Ma. (i) Spectrum for 94MJY01 hornblende has a plateau age of 1802 Ma. (j) Spectrum for 92XS04 K-feldspar has a plateau age of 663 Ma.

Fig. 3.

Fig. 3. Age spectra, K/Ca ratios and inverse isochrons for dated samples with Mesozoic ages. Isochrons presented only for samples without a plateau and with a meaningful isochron. K/Ca ratios > 10 000 not shown. WMPA, weighted mean plateau age; WMA, weighted mean age; TFA, total fusion age; MSWD, mean square of weighted deviates. Uncertainties include only error in (J); for total error see Table 1. (a) Spectrum for 92CD3 hornblende has plateau age of 146 Ma and (b) a poorly fit isochron age of 141 Ma. (c) Spectrum for 92NZ13 K-feldspar suggests cooling from 305 to 206 Ma. (d) Spectrum for 92WQ-G biotite composed of step ages c. 100 Ma. (e) Spectrum for 94BC13 biotite has WMPA of 210 Ma, confirmed by (f) inverse isochron. (g) Spectrum for 94BC13 K-feldspar suggests cooling from 214 to 127 Ma (h) Spectrum for 94YK46 suggests cooling from 214 to 127 Ma (i) Spectrum for 94DYJ19 biotite suggests excess ^{40}Ar , confirmed by (j) inverse isochron with an age of 215.8 Ma. (k) Spectrum for 94HYS13 biotite yields a WMPA of 67.6 Ma equivalent to (l) inverse isochron. (m) Spectrum for 94MY08A biotite suggests excess ^{40}Ar , confirmed by (n) inverse isochron with an age of 213.3 Ma. (o) Spectrum for 94WHB05 biotite yields a WMPA of 157.8 Ma equivalent to (p) inverse isochron. (q) Spectrum for 94WHB05 K-feldspar suggests excess ^{40}Ar , confirmed by (r) inverse isochron with an age of 107.8 Ma. (s) Spectrum for 94YK46 K-feldspar suggests cooling from 122 to 88 Ma. (t) Spectrum for 95HZ14a K-feldspar suggests possible cooling from 207 to <188 Ma. (u) Spectrum for 95CLSW K-feldspar suggests cooling from 122 to 88 Ma. (v) Spectrum for 95HZ14a K-feldspar suggests cooling from 135 to 110 Ma. (w) Spectrum for 95HZ14a biotite has WMA of 115.7 Ma, confirmed by (x) inverse isochron. (y) Spectrum for 95HZ14a muscovite has step ages of c. 200 Ma, compatible with (z) isochron age of 197.4 Ma. (aa) Spectrum for 95LYG07 biotite has TFA of 113 Ma. (bb) Spectrum for 95YB1 K-feldspar suggests cooling from 135 to 110 Ma. (cc) Spectrum for 99JP7 K-feldspar yields step ages from 190 to 177 Ma and a WMPA of 188.3 Ma equivalent to (dd) inverse isochron. (ee) Spectrum for 95LYG07 muscovite yields an internally discordant spectrum with a WMA of 221.5 Ma and a (ff) poorly fit isochron of 225.4 Ma. (gg) Spectrum for 95YTST01f muscovite suggests step ages from 195 to 150 Ma, a WMPA of 174.9 Ma and an (hh) equivalent isochron for the same steps. (ii) 95ZY10 muscovite yields a plateau suggesting excess ^{40}Ar , confirmed by (jj) inverse isochron age of 279.6 Ma. (kk) Spectrum yields a WMA of 125 Ma, confirmed by (ll) an inverse isochron. (mm) Spectrum for 99SMC06b biotite gives a WMPA of 150.7 Ma.

Fig. 4. Ages related to Precambrian orogenesis. Ages in Ma with 2σ uncertainties, unless noted as Ga. Ages with uncertainties > 10 Ma are excluded, except for specific, important instances. Samples localities from this study are labelled. A96 (Ames *et al.*, 1996), C92 (Chen *et al.*, 1992), C03 (Chen *et al.*, 2003), C05 (Chu, 2005), E93 (Enami *et al.*, 1993), F03 (Faure *et al.*, 2003), G04 (Guo *et al.*, 2004), H04 (Hu *et al.*, 2004), H06 (Hacker *et al.*, 2006), HZZWZL06 (Huang *et al.*, 2006), I92 (Ishiwatari *et al.* (1992) in Ishizaka *et al.*, 1994), I94 (Ishizaka *et al.*, 1994), L03 (Li *et al.*, 2003), L05 (Liu *et al.*, 2005), L06 (Leech *et al.*, 2006), Li93 (Li *et al.*, 1993), Li94 (Li *et al.*, 1994), LXXS04 (Liu *et al.*, 2004a), LXX04 (Liu *et al.*, 2004b), LJKX06 (Liu *et al.*, 2006a), LGLXL06 (Liu *et al.*, 2006b), S08 (Schmidt *et al.*, 2008), T08 (Tang *et al.*, 2008), W04 (Wu *et al.*, 2004), W05 (Wallis *et al.*, 2005), WLY06 (Webb *et al.*, 2006), X06 (Xu *et al.*, 2006), Y03 (Yang *et al.*, 2003), Y05 (Yang *et al.*, 2005b), YCWWCLF05 (Yang *et al.*, 2005a), Z00 (Zhai *et al.*, 2000), Z03 (Zhang *et al.*, 2003), Z06 (Zhang *et al.*, 2006), Z07 (Zhao *et al.*, 2007), ZZGWCCW06 (Zhao *et al.*, 2006b), ZLZL06 (Zhao *et al.*, 2006a), ZCWLSLS03 (Zhang *et al.*, 2003).

730 ± 15 Ma (Ishizaka *et al.*, 1994), a $^{40}\text{Ar}/^{39}\text{Ar}$ biotite age of 782 Ma (this study) and $^{40}\text{Ar}/^{39}\text{Ar}$ K-feldspar ages of 653 ± 8 Ma and 662.6 ± 0.9 Ma (this study). All of these ages – bar one – are NW of the YQW fault in the Qinling Microcontinent; the preservation of these 0.8–0.7 Ga metamorphic ages indicates that the thermal effects of the Triassic UHP orogeny were insufficient for isotopic resetting of the Qinling microcontinent; this is different from Dabie where the Qinling microcontinent was heated to higher temperatures during the Triassic (Hacker *et al.*, 2004). The 662.6 Ma K-feldspar $^{40}\text{Ar}/^{39}\text{Ar}$ age from SE of Weihai within what is nominally part of the Sulu UHP terrane suggests the possibility that an outlier of the Qinling microcontinent is exposed

there, similar to the gabbro and overprinted granulites south of Weihai with zircon ages of 373 ± 65, 339 ± 59 and 459 ± 47 Ma (Chu, 2005; Zhang *et al.*, 2006).

UHP metamorphism: 245–222 Ma

Zircon with low pressure, pre-(U)HP inclusions provide the best constraint on when the prograde (pre-UHP) metamorphism began; the best data are 247.1 ± 5.9 and 244.5 ± 3.9 Ma (Liu *et al.*, 2006b) (Fig. 5). The most convincing data sets on zircon with (U)HP inclusions have ages of 245.4 ± 6 Ma (Liu *et al.*, 2006a), 233.7 ± 2.8, 233.2 ± 2.6 Ma (Liu *et al.*, 2006b), 228.4 ± 2.4, 223.7 ± 2.7 Ma (Liu

Triassic UHP metamorphism

Best ages in boldface

Fig. 5. Ages related to Triassic UHP metamorphism (see caption to Fig. 4). Most characteristic data (i.e. samples with precise ages, clear outcrop relations or clear thin section textures – as mentioned in text) are in boldface.

et al., 2004a), 227.6 ± 5.1 , 227.5 ± 5.4 Ma (Liu *et al.*, 2005), 227.1 ± 2.4 Ma (Liu *et al.*, 2004b) and 225 ± 2 Ma (Zhao *et al.*, 2007). Another five eclogites, two peridotites and a dunite have zircon ages in this range: 242 ± 8 , 238 ± 3 , 236.5 ± 5 , 234.2 ± 3.6 , 232 ± 7 , 231.6 ± 2.5 , 231.3 ± 5 , 226.8 ± 3.7 Ma (Yang *et al.*, 2003; Liu *et al.*, 2006a; Zhao *et al.*, 2006a), as do two gneisses (233.9 ± 2.6 and 231.6 ± 2.5 Ma, Tang *et al.*, 2008). The individual spot data in these studies have sufficient precision to render these ages distinct from one another, indicating that the UHP event in Sulu lasted 20 ± 7 Myr (245.4 ± 6 to 225 ± 2 Ma), just as in Dabie (Hacker *et al.*, 2006; Wu *et al.*, 2006). There are four Sm–Nd ages for the UHP event, a garnet–clinopyroxene age of 220.7 ± 5.9 Ma, a garnet–phengite–whole-rock age of 228.5 ± 8.6 Ma, a four-point garnet–clinopyroxene–phengite–whole-rock age of 226.5 ± 9.5 Ma (Li *et al.*, 1993, 1994), and a garnet–clinopyroxene–whole-rock age of 220.7 ± 7.1 Ma (Schmidt *et al.*, 2008). Three Lu–Hf

garnet–clinopyroxene ages are similar: 222.7 ± 1.6 , 221.4 ± 1.2 and 219.6 ± 1.4 Ma (Schmidt *et al.*, 2008).

There are three biotite $^{40}\text{Ar}/^{39}\text{Ar}$ ages similar to the UHP zircon – 254 to 232 Ma – from the HP zone at Lianyungang (Xu *et al.*, 2006). It could be concluded that the HP zone was below 300°C at that time, and Liu & Li (2008) used such logic to argue that the peak metamorphism occurred before 253 Ma in the HP zone and from 240–220 Ma in the UHP zone. Note, however that these biotite ages are all older than a K-white mica age from nearby, suggesting that they may be affected by excess ^{40}Ar . In fact, the zircon data by themselves exhibit no difference in the age of the UHP event from north (Weihai) to south (Donghai). Whether there is an age gradient in the time of the UHP–HP metamorphism or heterogeneous excess ^{40}Ar needs further examination.

There are a few other cooling ages older than 220 Ma: biotite Rb–Sr ages of *c.* 220 Ma (Ishiwatari

Post-UHP magmatism & amphibolite facies overprint

Fig. 6. Ages related to post-UHP magmatism and amphibolite facies overprint (see caption of Fig. 4).

et al. (1992) in Ishizaka *et al.*, 1994) and 222.4 ± 4.7 Ma (Ishizaka *et al.*, 1994), a hornblende $^{40}\text{Ar}/^{39}\text{Ar}$ age from an eclogite of 221.4 ± 3.9 Ma (Lin *et al.*, 2005) and a phengite from eclogite of 222 ± 4 Ma (Faure *et al.*, 2003). Because these minerals and isotopic systems have closure temperatures significantly below that of the UHP metamorphism, these ages either have no geological significance or indicate unrecognized structural complexity.

Post-UHP amphibolite facies metamorphism and magmatism: 222–205 Ma

The end of the UHP metamorphism is marked by granitic plutons and dykes in the northern part of Sulu; these igneous bodies are undeformed to weakly deformed (Chen *et al.*, 2003; Wallis *et al.*, 2005; Yang *et al.*, 2005a) (Fig. 6). Four zircon ages from these bodies, with uncertainties < 2 Ma, range from 226.2 ± 1.7 to 220.0 ± 1.8 Ma (Chen *et al.*, 2003; Wallis *et al.*, 2005); a fifth age, from a K-feldspar-rich dyke, is 206.7 ± 1.9 Ma (Wallis *et al.*, 2005). It is

possible that these magmatic ages are influenced by inherited zircon; e.g. Chen *et al.* (2003) preferred a 205 ± 5 Ma age for one of the plutons, but this age could equally well reflect Pb loss in light of the hornblende $^{40}\text{Ar}/^{39}\text{Ar}$ age of 214.6 ± 1.9 Ma and K-feldspar age of 215.0 ± 0.7 Ma on one of the same plutons (Yang *et al.*, 2005a). Together, these ages indicate an unambiguous end to the UHP metamorphism – and possibly the climax of the post-UHP metamorphism – in the northern part of Sulu at c. 222 Ma. This is 0–10 Myr after the end of the UHP event, depending on which ages are considered to mark UHP metamorphism. This implies exhumation from ~ 100 to < 50 km at rates of $5\text{--}25$ km Myr^{-1} , but better studies involving more precise geochronology on single outcrops is required. There are no equivalent dated plutons from southern Sulu, but the prevalence of $^{40}\text{Ar}/^{39}\text{Ar}$ ages in the 220–210 Ma age range implies that southern Sulu experienced a similar magmatic event.

SIMS has been used to date zircon domains with post-UHP, amphibolite facies inclusions. The clearest

results are 215.7 ± 4.7 and 206.7 ± 4.1 Ma (Liu *et al.*, 2004a), 213 ± 5 Ma (Liu *et al.*, 2006a), and 209.2 ± 2.7 Ma (Liu *et al.*, 2004b). Other SIMS zircon ages from gneiss that are likely to be part of the amphibolite facies event include 224.5 ± 4.9 , 226.0 ± 4.6 , 227.8 ± 2.2 , 218.7 ± 2.2 , 216.3 ± 2.4 Ma (Hacker *et al.*, 2006), 215.7 ± 0.5 and 218.1 ± 3.3 Ma (Leech *et al.*, 2006). Eclogite ages, whether zircon (e.g. 218 ± 5 Ma, Zhao *et al.*, 2006a) or Sm-Nd (216 ± 10 and 215 ± 9 Ma, Zhao *et al.*, 2006b), that fall in this time frame must reflect daughter-product loss.

A large number of $^{40}\text{Ar}/^{39}\text{Ar}$ ages indicate that closure to Ar began throughout Sulu by 219 Ma: hornblende ages are 212.9 ± 1.3 Ma (Webb *et al.*, 2006) and 213.7 ± 2 Ma (Li *et al.*, 2003); K-white mica ages are 218.0 ± 2.9 Ma (Li *et al.*, 2003), 218.8 ± 2.7 , 213.8 ± 2.7 Ma (Xu *et al.*, 2006), 213.5 ± 1.4 Ma (Webb *et al.*, 2006), 218.7 ± 4.4 and 214.1 ± 4.3 Ma (Xu *et al.*, 2006); biotite ages are c. 218 Ma (Chen *et al.*, 1992), 213.4 ± 1.2 Ma (Webb

et al., 2006) and 216.3 ± 0.5 Ma (this study); and K-feldspar high-temperature step ages are as old as 214 Ma (this study) and 214 Ma (Li *et al.*, 2003). A single Rb-Sr K-white mica age from an eclogite is 216 ± 6 Ma (Zhao *et al.*, 2006b). There are no marked differences in the $^{40}\text{Ar}/^{39}\text{Ar}$ ages from north Sulu (Weihai) to south Sulu (Donghai). Cooling following the 222–220 Ma plutonism is defined by the c. 219–214 Ma hornblende, mica and feldspar ages, indicating a rate of $50\text{--}200\text{ }^{\circ}\text{C Myr}^{-1}$. Such rapid cooling implies tectonic unroofing.

Continued amphibolite facies metamorphism or resetting? 205–170 Ma

There are numerous other ages in the 210–170 Ma range (Fig. 7), just as in Dabie (Hacker & Wang, 1995). These ages may reflect protracted cooling or partial resetting of older ages by Jurassic and/or Cretaceous tectonism; we favour the latter in light of the widespread Mesozoic magmatism. A Sm-Nd age of

Continued cooling or resetting

Fig. 7. Ages related to continued cooling or resetting (see caption of Fig. 4).

207.8 ± 7.7 Ma (Li *et al.*, 1993) is considerably younger than all known UHP ages and younger than post-UHP plutons and therefore must be partially reset. Less certain are the meaning of zircon U-Pb ages from gneisses of 210.5 ± 2.4 Ma (Leech *et al.*, 2006) and 202.4 ± 2.7 Ma (Hacker *et al.*, 2006); $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende ages of 206.3 ± 1.0 Ma (Faure *et al.*, 2003), 205.9 ± 1 Ma (Chen *et al.*, 1992); K-white mica ages of *c.* 209 Ma (Chen *et al.*, 1992), 200 ± 10 and 201–189 Ma (this study), 206.6 ± 1.2 Ma (Faure *et al.*, 2003); biotite ages of *c.* 204 Ma (Chen *et al.*, 1992), 206.6 ± 1.0 Ma (Webb *et al.*, 2006), 209.7 ± 1, 207.0 ± 1.8 Ma (this study), 203.5 ± 1.8, 203.6 ± 2.1 Ma (Li *et al.*, 2003) and 199.1 ± 2.1 Ma (Faure *et al.*, 2003); and K-feldspar ages of 200 → 182 Ma (Chen *et al.*, 1992), 207 → 188 Ma (this study), and 206.1 ± 1.3 → 180 Ma (Webb *et al.*, 2006).

Jurassic magmatism: 166–149 Ma

From 166 to 149 Ma, the northern and central Sulu areas were the site of renewed magmatism (Fig. 8), as

indicated by zircon ages of plutons and dykes of 166 ± 4, 154 ± 5 Ma (Zhang *et al.*, 2003), 160.4 ± 2.3 Ma (Hacker *et al.*, 2006), 159.9 ± 3.0 Ma (Hu *et al.*, 2004), 158 ± 3 Ma (Chu, 2005) and 149.1 ± 1.8 Ma (Leech *et al.*, 2006). Elemental and isotopic compositions suggest that these plutons were derived from melting of Mesozoic and Proterozoic crust, similar to magmatic rocks of this age range throughout eastern Asia (Wu *et al.*, 2005). Subsequent cooling at rates of *c.* 15 °C Myr⁻¹ is indicated by a hornblende $^{40}\text{Ar}/^{39}\text{Ar}$ age of 146.1 ± 0.4 Ma (this study), K-white mica $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 155.8 ± 3.4, 135.6 ± 0.5 Ma (Webb *et al.*, 2006) and 136.9 ± 1.9 Ma (Liu *et al.*, 2005), $^{40}\text{Ar}/^{39}\text{Ar}$ biotite ages of 157.8 ± 4.6 Ma (this study) and 150.7 ± 0.8 Ma (this study), a biotite K-Ar age of 155 Ma (Ishiwatari *et al.* (1992) in Ishizaka *et al.*, 1994) and K-feldspar high-temperature step ages of 142 and 135 Ma (this study, Webb *et al.*, 2006). There is only one K-feldspar sample that gave low-temperature step ages in this age range, suggesting that temperature stayed above ~300 °C.

Jurassic magmatism

Fig. 8. Ages related to Jurassic magmatism (see caption of Fig. 4).

Cretaceous magmatism

Fig. 9. Ages related to Cretaceous magmatism (see caption of Fig. 4).

Cretaceous magmatism: 129–118 Ma

Between 129 and 118 Ma, the entire Sulu area was invaded by Cretaceous magma (Fig. 9): U-Pb zircon ages from plutons and Au-related veins range from 129 to 118 Ma (Guo *et al.*, 2004; Yang *et al.*, 2005b; Huang *et al.*, 2006), and K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ whole rock and biotite ages on dykes are 126–111 Ma (Guo *et al.*, 2004; Yang *et al.*, 2005b). There is no spatial variation in the ages of these rocks. These plutons and dykes have elemental and isotopic compositions consistent with metasomatized mantle and Proterozoic lower crustal sources, as expected for an extensional setting (Guo *et al.*, 2004; Yang *et al.*, 2005b; Huang

et al., 2006). Similar magmatism was widespread along the eastern margin of Asia (Ratschbacher *et al.*, 2000).

Cooling during and following the Cretaceous magmatism and deformation is recorded by hornblende $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 124–120 Ma (Chen *et al.*, 1992; Faure *et al.*, 2003; Lin *et al.*, 2005; Yang *et al.*, 2005b; Huang *et al.*, 2006), K-white mica $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 121 ± 3 Ma (Zhang *et al.*, 2003) and 128.2 ± 0.7 Ma (Webb *et al.*, 2006), biotite $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 125–106 Ma (this study, Lin *et al.*, 2005; Webb *et al.*, 2006) and K-feldspar low-temperature step ages indicating cooling from 119 through 88 Ma (this study, Chen *et al.*, 1992; Lin *et al.*, 2005). Minor differences

Fig. 10. History of tectonics events as indicated by geochronology. Top: Individual types of ages stacked chronologically, with normalized vertical spacing. Bottom: Age v. distance from south-west to north-east. Slow cooling following UHP metamorphism – 10 Myr for biotite and 25 Myr for K-feldspar indicate deep burial. Rapid cooling to K-feldspar closure following Cretaceous magmatism indicates magmatism at shallow levels; in contrast, lack of K-feldspar closure after Jurassic magmatism suggests deeper intrusion levels. Vertical distributions of data are normalized for each of the three 'events' so that bulk cooling rates are meaningful. K-Ar ages shown with 2% uncertainty. Ages most diagnostic of a particular event are represented by thicker lines. Arrows indicate $^{40}\text{Ar}/^{39}\text{Ar}$ spectra with a range of ages, with the arrow pointing from the high-temperature to the low-temperature step ages.

between zircon, hornblende and mica ages imply cooling rates in excess of $50\text{ }^{\circ}\text{C Myr}^{-1}$, indicating relative shallow levels of plutonism. The 129–118 Ma range of plutonism in Sulu is slightly younger than the 135–125 Ma plutonism in Dabie (Ratschbacher *et al.*, 2000; Xu *et al.*, 2007), but the range of cooling ages is similar.

Summary

The geochronology data set for Sulu is quite good in terms of areal coverage and number of analyses (Fig. 10). We face a significant hurdle, however: the Cretaceous and Jurassic magmatic events caused radiogenic-daughter isotope loss that varies in space and in magnitude, making it difficult to understand the Triassic – much less the Precambrian – tectonic history of Sulu. To overcome this hurdle, a precise U–Pb age for every igneous body would help understand how and where the crust was modified by post-UHP magmatism. More areally comprehensive data from individual minerals and decay schemes (e.g. Rb–Sr of biotite) combined with multi-mineral data from single outcrops could then potentially clear away some of the ambiguity in the current data set and allow us to see more clearly back into the past.

CONCLUSIONS

New $^{40}\text{Ar}/^{39}\text{Ar}$ ages from hornblende, muscovite, biotite and K-feldspar are presented from the Sulu area. These data, in conjunction with existing geochronology lead to the following conclusions.

1 The record of tectonothermal events in the Qinling microcontinent spans 2.0–1.4 Ga. A subsequent magmatic event at 750 Ma – clearly visible SE of the YQW fault – caused partial resetting of biotite and K-feldspar in the Qinling microcontinent and cooling to $<200\text{ }^{\circ}\text{C}$ by 660 Ma. Heating of the Qinling microcontinent was minimal during the Triassic UHP and Mesozoic magmatic events, as suggested by $^{40}\text{Ar}/^{39}\text{Ar}$ K-feldspar step ages of 305 Ma; Triassic heating of equivalent rocks in Dabie was more profound.

2 Zircon, Sm–Nd, and Lu–Hf data pin the UHP event to c. 245 to c. 222 Ma (blue–grey band in Fig. 10), suggesting that older or equivalent $^{40}\text{Ar}/^{39}\text{Ar}$ ages are affected by excess ^{40}Ar .

3 Zircon ages from plagioclase-bearing plutons mandate that the UHP metamorphism had finished by 222 Ma and that the Sulu terrane had reached crustal depths, implying plate-tectonic exhumation rates of $25\text{--}5\text{ km Myr}^{-1}$, as noted by numerous authors. Hornblende, mica and K-feldspar $^{40}\text{Ar}/^{39}\text{Ar}$ ages in the 219–210 Ma range (orange–grey band in Fig. 10) imply that the post-UHP amphibolite facies overprint was relatively short (perhaps 3–12 Myr, depending on location and choice of data), and indicate a crustal

cooling rate of $50\text{--}200\text{ }^{\circ}\text{C Myr}^{-1}$, requiring tectonic unroofing.

4 As in Dabie, numerous ages in the 210–170 Ma range (orange–pink bands in Fig. 10) may reflect protracted cooling or partial resetting by Jurassic or Cretaceous magmatism.

5 Following Jurassic, 166–149 Ma, plutonism, temperatures cooled at rates of c. $15\text{ }^{\circ}\text{C Myr}^{-1}$, but remained above $300\text{ }^{\circ}\text{C}$, suggesting relatively deep crustal levels.

6 Following Cretaceous, 129–118 Ma, plutonism, temperatures cooled at rates of c. $50\text{ }^{\circ}\text{C Myr}^{-1}$ down to $<200\text{ }^{\circ}\text{C}$, suggesting relatively shallow crustal depths.

ACKNOWLEDGEMENTS

This study is dedicated to H. W. Green in recognition of his pioneering work on rheology, microstructure, mineralogy and microscopy. And – although he might not want to take credit for his demon spawn – Harry was instrumental in shaping the career of the senior author by teaching inspiring microscopy and microstructure courses almost 30 years ago. Samples used in this study were collected during JSPS projects awarded to S. Banno, T. Hirajima and S. Wallis. This study was supported by NSF grants EAR-9796119, EAR-9725667, EAR-0003568 and EAR-0510453. Reviews by A. Schmidt and an anonymous reviewer are gratefully acknowledged.

REFERENCES

- Ames, L., Zhou, G. & Xiong, B., 1996. Geochronology and geochemistry of ultrahigh-pressure metamorphism with implications for collision of the Sino–Korean and Yangtze cratons, central China. *Tectonics*, **15**, 472–489.
- Banno, S., Enami, M., Hirajima, T., Ishiwatari, A. & Wang, Q., 2000. Decompression P–T path of coesite eclogite to granulite from Weihai, eastern China. *Lithos*, **52**, 97–108.
- Calvert, A.T., Gans, P.B. & Amato, J.M., 1999. Diapiric ascent and cooling of a sillimanite gneiss dome revealed by $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology: the Kigluaik Mountains, Seward Peninsula, Alaska. In: *Exhumation Processes: Normal Faulting, Ductile Flow, and Erosion, Special Publication 154*, (eds Ring, U., Brandon, M.T., Lister, G. & Willett, S.), pp. 205–232. Geological Society, London.
- Chen, W., Harrison, T.M., Heizler, M.T., Liu, R., Ma, B. & Li, J., 1992. The cooling history of melange zone in north Jiangsu–south Shandong region: evidence from multiple diffusion domain $^{40}\text{Ar}/^{39}\text{Ar}$ thermal geochronology. *Acta Petrologica Sinica*, **8**, 1–17.
- Chen, J.-F., Xie, Z., Li, H.M. *et al.*, 2003. U–Pb zircon ages for a collision-related K-rich complex at Shidao in the Sulu ultrahigh pressure terrane, China. *Geochronological Journal*, **37**, 36–46.
- Chu, W., 2005. *Geochronological and Petrological Studies of Haiyangsuo Region Sulu UHP Terrane, Eastern China*. Masters Thesis, Stanford University, Stanford, California, 82 p.
- Cong, B., 1996. *Ultrahigh-Pressure Metamorphic Rocks in the Dabieshan–Sulu Region of China*. Science Press, Beijing, 224 p.
- Connolly, J.A.D., 2005. Computation of phase equilibria by linear programming: a tool for geodynamic modeling and its application to subduction zone decarbonation. *Earth and Planetary Science Letters*, **236**, 524–541.

- Enami, M., Suzuki, K., Zhai, M. & Zheng, X., 1993. The chemical Th-U-total Pb isochron ages of Jiaodong and Jiaonan metamorphic rocks in the Shandong Peninsula, eastern China. *Island Arc*, **2**, 104–113.
- Faure, M., Lin, W. & Le Breton, N., 2001. Where is the North China–South China block boundary in eastern China? *Geology*, **29**, 119–122.
- Faure, M., Lin, W., Monié, P. *et al.*, 2003. Exhumation tectonics of the ultrahigh-pressure metamorphic rocks in the Qinling orogen in east China: new petrological-structural-radiometric insights from the Shandong Peninsula. *Tectonics*, **22**, 3–1–3–22, doi: 10.1029/2002TC001450.
- Giorgis, D., Cosca, M. & Li, S., 2000. Distribution and significance of extraneous argon in UHP eclogite (Sulu terrane, China): insight from in situ $^{40}\text{Ar}/^{39}\text{Ar}$ UV-laser ablation analysis. *Earth and Planetary Science Letters*, **181**, 605–615.
- Guo, F., Fan, W., Wang, Y. & Zhang, M., 2004. Origin of early Cretaceous calc-alkaline lamprophyres from the Sulu orogen in eastern China: implications for enrichment processes beneath continental collisional belt. *Lithos*, **78**, 291–305.
- Hacker, B.R., 2006. Pressures and temperatures of ultrahigh-pressure metamorphism: implications for UHP tectonics and H_2O in subducting slabs. *International Geology Review*, **48**, 1053–1066.
- Hacker, B.R. & Wang, Q.C., 1995. Ar/Ar geochronology of ultrahigh-pressure metamorphism in central China. *Tectonics*, **14**, 994–1006.
- Hacker, B.R., Ratschbacher, L., Webb, L.E. *et al.*, 2000. Exhumation of ultrahigh-pressure continental crust in east-central China: Late Triassic–Early Jurassic tectonic unroofing. *Journal of Geophysical Research*, **105**, 13339–13364.
- Hacker, B.R., Ratschbacher, L. & Liou, J.G., 2004. Subduction, collision, and exhumation in the Qinling–Dabie Orogen. In: *Aspects of the Tectonic Evolution of China, Special Publication 226*, (eds Malpas, J.G., Fletcher, C.J.N., Ali, J.R. & Aitchison, J.C.), pp. 157–175, Geological Society, London.
- Hacker, B.R., Wallis, S.R., Ratschbacher, L., Grove, M. & Gehrels, G., 2006. High-temperature geochronology constraints on the tectonic history and architecture of the ultrahigh-pressure Dabie–Sulu orogen. *Tectonics*, **25**, TC5006; doi: 10.1029/2001JB001129/2005TC001937.
- Hu, F., Fang, H., Yang, J. *et al.*, 2004. Mineralizing age of the Rushan lode gold deposit in the Jiaodong Peninsula: SHRIMP U–Pb dating on hydrothermal zircon. *Chinese Science Bulletin*, **49**, 1629–1636.
- Huang, J., Zheng, Y.F., Zhao, Z.F., Wu, Y.B., J.B., Z. & Liu, X., 2006. Melting of subducted continent: element and isotopic evidence for a genetic relationship between Neoproterozoic and Mesozoic granitoids in the Sulu orogen. *Chemical Geology*, **229**, 227–256.
- Ishizaka, K., Hirajima, T. & Zheng, X.S., 1994. Rb–Sr dating for the Jiaodong gneiss of the Su–Lu ultrahigh pressure province, eastern China. *The Island Arc*, **3**, 232–241.
- Kato, T., Enami, M. & Zhai, M., 1997. Ultrahigh-pressure (UHP) marble and eclogite in the Su–Lu UHP terrane, eastern China. *Journal of Metamorphic Geology*, **15**, 169–182.
- Leech, M.L., Webb, L.E. & Yang, T.N., 2006. Diachronous histories for the Dabie–Sulu orogen from high-temperature geochronology. *Geological Society of America Special Paper*, **403**, 1–22.
- Li, S., Xiao, Y., Liou, D. *et al.*, 1993. Collision of the North China and Yangtze blocks and formation of coesite-bearing eclogites: timing and processes. *Chemical Geology*, **109**, 89–111.
- Li, S., Wang, S., Chen, Y. *et al.*, 1994. Excess argon in phengite from eclogite: evidence from the dating of eclogite minerals by the Sm–Nd, Rb–Sr and $^{40}\text{Ar}/^{39}\text{Ar}$ methods. *Chemical Geology*, **112**, 343–350.
- Li, J., Yang, T., Chen, W. & Zhang, S.-H., 2003. $^{40}\text{Ar}/^{39}\text{Ar}$ dating of deformation events and reconstruction of exhumation of ultrahigh-pressure metamorphic rocks in Donghai, east China. *Acta Geologica Sinica*, **77**, 155–167.
- Lin, L.-H., Wang, P.-L., Lo, C.-H., Tsai, C.-H. & Jahn, B.-M., 2005. ^{40}Ar – ^{39}Ar thermochronological constraints on the exhumation of ultrahigh-pressure metamorphic rocks in the Sulu Terrane of eastern China. *International Geology Review*, **47**, 872–886.
- Liu, Y.C. & Li, S.G., 2008. Detachment within subducted continental crust and multi-slice successive exhumation of ultrahigh-pressure metamorphic rocks: evidence from the Dabie–Sulu orogenic belt. *Chinese Science Bulletin*, **53**, 3105–3119.
- Liu, F., Xu, Z., Liou, J.G. & Song, B., 2004a. SHRIMP U–Pb ages of ultrahigh-pressure and retrograde gneisses, south-western Sulu terrane, eastern China. *Journal of Metamorphic Geology*, **22**, 315–326.
- Liu, F., Xu, Z. & Xue, H., 2004b. Tracing the protolith, UHP metamorphism, and exhumation ages of orthogneiss from the SW Sulu terrane (eastern China): SHRIMP U–Pb dating of mineral inclusion-bearing zircons. *Lithos*, **78**, 411–429.
- Liu, F., Liou, J.G. & Xu, Z., 2005. U–Pb SHRIMP ages recorded in the coesite-bearing zircon domains of paragneisses in the southwestern Sulu terrane, eastern China: New interpretation. *American Mineralogist*, **90**, 790–800.
- Liu, D., Jian, P., Kroner, A. & Xu, S., 2006a. Dating of prograde metamorphic events deciphered from episodic zircon growth in rocks of the Dabie–Sulu UHP complex, China. *Earth and Planetary Science Letters*, **250**, 650–666.
- Liu, F.L., Gerdes, A., Liou, J.G., Xue, H.M. & Liang, F.H., 2006b. SHRIMP U–Pb zircon dating from Sulu–Dabie dolomitic marble, eastern China: constraints on prograde, ultrahigh-pressure and retrograde metamorphic ages. *Journal of Metamorphic Geology*, **24**, 569–589.
- Ludwig, K.R., 1998. On the treatment of concordant uranium–lead ages. *Geochimica et Cosmochimica Acta*, **62**, 665–676.
- Nakamura, D. & Hirajima, T., 2000. Granulite-facies overprinting of ultrahigh-pressure metamorphic rocks, northeastern Sulu region, eastern China. *Journal of Petrology*, **41**, 563–582.
- Ratschbacher, L., Hacker, B.R., Webb, L.E. *et al.*, 2000. Exhumation of ultrahigh-pressure continental crust in east central China: Cretaceous and Cenozoic unroofing and the Tan–Lu fault. *Journal of Geophysical Research*, **105**, 13303–13338.
- Regional Geological Survey of Jiangsu, 1984. *Regional Geology of Jiangsu Province and Shanghai Municipality*. Geological Publishing House, Beijing, 857 p.
- Regional Geological Survey of Shandong, 1991. *Regional Geology of Shandong Province*. Geological Publishing House, Beijing, 595 p.
- Renne, P.R., Swisher, C.C., Deino, A.L., Karner, D.B., Owens, T.L. & DePaolo, D.J., 1998. Intercalibration of standards, absolute ages and uncertainties in $^{40}\text{Ar}/^{39}\text{Ar}$ dating. *Chemical Geology*, **145**, 117–152.
- Rolfo, F., Compagnoni, R., Wu, W. & Xu, S., 2004. A coherent lithostratigraphic unit in the coesite–eclogite complex of Dabie Shan, China: geologic and petrologic evidence. *Lithos*, **73**, 71–94.
- Schmidt, A., Weyer, S., Mezger, K. *et al.*, 2008. Rapid eclogitization of the Dabie–Sulu UHP terrane; constraints from Lu–Hf garnet geochronology. *Earth and Planetary Science Letters*, **273**, 203–213.
- Tang, J., Zheng, Y.-F., Wu, Y.-B., Gong, B., Zha, X. & Liu, X., 2008. Zircon U–Pb age and geochemical constraints on the tectonic affinity of the Jiaodong terrane in the Sulu orogen, China. *Precambrian Research*, **161**, 389–418.
- Wallis, S.R., Ishiwatari, A., Hirajima, T. *et al.*, 1997. Occurrence and field relationships of ultrahigh-pressure metagranitoid and coesite eclogite in the Su–Lu terrane, eastern China. *Journal of the Geological Society of London*, **154**, 45–54.
- Wallis, S., Tsuboi, M., Suzuki, K., Laili, J. & Tanaka, T., 2005. Role of partial melting in the evolution of the Sulu UHP terrane. *Geology*, **33**, 129–132.

- Webb, L.E., Leech, M.L. & Yang, T.N., 2006. $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology of the Sulu terrane: Late Triassic exhumation of high- and ultrahigh-pressure rocks and implications for Mesozoic tectonics in east Asia. *Geological Society of America Special Paper*, **403**, 77–92.
- Wu, Y.-B., Zheng, Y.-F. & Zhou, J.-B., 2004. Neoproterozoic granulite in northwest Sulu and its bearing on the North China-South China Blocks boundary in east China. *Geophysical Research Letters*, **31**, 1–4, doi:10.1029/2004GL019785.
- Wu, F.-Y., Yang, J.-H., Wilde, S.A. & Zhang, X.-O., 2005. Geochronology, petrogenesis and tectonic implications of Jurassic granites in the Liaodong Peninsula, NE China. *Chemical Geology*, **221**, 127–156.
- Wu, Y.-B., Zheng, Y.-F., Zhao, Z.-F., Gong, B., Liu, X. & Wu, F.-Y., 2006. U-Pb, Hf and O isotope evidence for two episodes of fluid-assisted zircon growth in marble-hosted eclogites from the Dabie orogen. *Geochimica et Cosmochimica Acta*, **70**, 3743–3761.
- Xu, Z.Q., Zeng, L., Liu, F.L., Zhang, Z., McWilliams, M.O. & Liou, J.G., 2006. Polyphase subduction and exhumation of the Sulu high-pressure-ultrahigh-pressure metamorphic terrane. *Geological Society of America Special Paper*, **403**, 93–113.
- Xu, H., Ma, C. & Ye, K., 2007. Early cretaceous granulites and their implications for the collapse of the Dabie orogen, eastern China: SHRIMP zircon U-Pb dating and geochemistry. *Chemical Geology*, **240**, 238–259.
- Yang, J.S., Wooden, J.L., Wu, C.L. *et al.*, 2003. SHRIMP U-Pb dating of coesite-bearing zircon from the ultrahigh-pressure metamorphic rocks, Sulu terrane, east China. *Journal of Metamorphic Geology*, **21**, 551–560.
- Yang, J.-H., Chung, S.-L., Wilde, S.A. *et al.*, 2005a. Petrogenesis of post-orogenic syenites in the Sulu Orogenic Belt, East China: geochronological, geochemical and Nd-Sr isotopic evidence. *Chemical Geology*, **214**, 99–125.
- Yang, J.-H., Wu, F.-Y., Chung, S.-L. *et al.*, 2005b. Petrogenesis of Early Cretaceous intrusions in the Sulu ultrahigh-pressure orogenic belt, east China and their relationship to lithospheric thinning. *Chemical Geology*, **222**, 200–231.
- Zhai, M., Cong, B., Guo, J., Liu, W., Li, Y. & Wang, Q., 2000. Sm-Nd geochronology and petrography of garnet pyroxene granulites in the northern Sulu region of China and their geotectonic implication. *Lithos*, **52**, 23–33.
- Zhang, R., Liou, J.G. & Ernst, W.G., 1995. Ultrahigh-pressure pressure metamorphism and decompressional P-T paths of eclogites and country rocks from Weihai, eastern China. *The Island Arc*, **4**, 293–309.
- Zhang, X.O., Cawood, P.A., Wilde, S.A. *et al.*, 2003. Geology and timing of mineralization at the Cangshang gold deposit, north-western Jiaodong Peninsula, China. *Mineralium Deposita*, **38**, 141–153.
- Zhang, R.Y., Liou, J.G., Tsujimori, T. & Maruyama, S., 2006. Non-ultrahigh-pressure unit bordering the Sulu ultrahigh-pressure terrane, eastern China: transformation of Proterozoic granulite and gabbro to garnet granulite. *Geological Society of America Special Paper*, **403**, 169–206.
- Zhao, R., Liou, J.G., Zhang, R.Y. & Li, T., 2006a. SHRIMP U-Pb zircon dating of the Rongcheng eclogite and associated peridotite: new constraints for ultrahigh-pressure metamorphism of mantle-derived mafic-ultramafic bodies from the Sulu terrane. *Geological Society of America Special Paper*, **403**, 115–125.
- Zhao, Z.F., Zheng, Y.F., Gao, T.S. *et al.*, 2006b. Isotopic constraints on age and duration of fluid-assisted high-pressure eclogite-facies recrystallization during exhumation of deeply subducted continental crust in the Sulu orogen. *Journal of Metamorphic Geology*, **24**, 687–702.
- Zhao, R., Zhang, R.Y., Liou, J.G., Booth, A.L., Pope, E.C. & Chamberlain, C.P., 2007. Petrochemistry, oxygen isotopes and U-Pb SHRIMP geochronology of mafic-ultramafic bodies from the Sulu UHP terrane, China. *Journal of Metamorphic Geology*, **25**, 207–224.
- Zhou, D., Cheng, L. & Liu, M., 1995. The discovery of sole-nopora in the Wulian group in the Jiaonian area, Shandong, and its significance. *Regional Geology of China*, **14**, 379–384.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. $^{40}\text{Ar}/^{39}\text{Ar}$ data.

Appendix S1. Descriptions of samples measured.

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

Received 19 March 2009; revision accepted 11 July 2009.

Table 1. Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ data

Sample Name	Mineral	Sample Mass (mg)	J	TFA (Ma)	WPMA (Ma)	$\pm 2\sigma$	% ^{39}Ar	IA (Ma)	$\pm 2\sigma$	$^{40}\text{Ar}/^{36}\text{Ar}$	MSWD	Preferred Age (Ma)	$\pm 2\sigma$	$\pm 2\sigma$ total	Lab
92CD3	hbl	15.1	0.00353090	148	146.1	0.4	36	141.2	3.6	1506 ± 770	3.5	141.2	3.6	3.8	SU
92HFS01	bt	2.4	0.00346229	904	n/a	n/a	n/a	n/a	n/a	n/a	n/a	904	n/a	n/a	SU
92HFS01	kfs	0.5	0.00345681	380	~275 Ma	n/a	n/a	n/a	n/a	n/a	n/a	~275	n/a	n/a	SU
92HH1	bt	2.2	0.00345080	782	n/a	n/a	n/a	n/a	n/a	n/a	n/a	782	n/a	n/a	SU
92HXS05#1	bt	1.7	0.00348220	1463	1685	14	36	n/a	n/a	n/a	n/a	1685	14	19	SU
92HXS05#2	bt	0.3	0.01578694	1472	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1700	100	100	UCSB
92KB1	bt	0.4	0.01581700	901	n/a	n/a	n/a	736	36	856 ± 347	2.9	736	36	36	UCSB
92LJ06	bt	1.7	0.00344419	2319	n/a	n/a	n/a	1620	220	62223 ± 14000	0.63	1620	220	220	SU
92NZ13	kfs	1.9	0.00343563	294	n/a	n/a	n/a	n/a	n/a	n/a	n/a	305→206	n/a	n/a	SU
92WQ-G	bt	0.5	0.01580409	100	111	7	n/a	n/a	n/a	n/a	n/a	100	~10	~10	UCSB
92XS04	kfs	0.8	0.00349418	649	662.6	0.9	94	n/a	n/a	n/a	n/a	662.6	0.9	5.1	SU
94BC13	kfs	3.0	0.00354865	235	n/a	n/a	n/a	n/a	n/a	n/a	n/a	214→127	n/a	n/a	SU
94BC13	bt	0.2	0.01577202	209	209.7	1	80	207.9	2.9	449 ± 422	0.45	209.7	1.1	1.9	UCSB
94DYJ19	bt	3.3	0.00354168	209	216.3	0.5	34	215.8	1.7	528 ± 670	0.01	215.8	1.7	2.4	SU
94HYS13	bt	0.1	0.01580064	70	67.6	2.4	30	80	22	244 ± 119	0.68	67.6	2.4	2.5	UCSB
94MJY01	hbl	7.4	0.00347430	1750	1802	10	91	n/a	n/a	n/a	n/a	1802	10	17	SU
94MY08a	bt	2.4	0.00352480	194	207.0	1.8	84	n/a	n/a	n/a	n/a	207.0	1.8	2.4	SU
94WHB5	kfs	1.1	0.00349905	145	n/a	n/a	n/a	107.8	3.4	461 ± 16	1.5	107.8	3.4	3.5	SU
94WHB5	bt	0.6	0.00350457	147	157.8	4.6	35	160	10	284 ± 43	3.4	157.8	4.6	4.8	SU
94YK46	kfs	0.9	0.00348885	133	n/a	n/a	n/a	n/a	n/a	n/a	n/a	196→110	n/a	n/a	SU
94YK46	ms	0.4	0.01580827	193	n/a	n/a	n/a	n/a	n/a	n/a	n/a	201→189	n/a	n/a	UCSB
95CLSW	kfs	2.9	0.00341801	116	n/a	n/a	n/a	n/a	n/a	n/a	n/a	122→88	n/a	n/a	SU
95HZ14a	bt	0.4	0.00339946	110	115.7	4.4	42	96	95	353 ± 350	0.16	115.7	4.4	4.5	SU
95HZ14a	ms	1.1	0.00339352	201	200	10	96	197.4	8	1388 ± 1300	3.1	197.4	8	8.1	SU
95HZ14a	kfs	2.9	0.00340552	186	n/a	n/a	n/a	n/a	n/a	n/a	n/a	207→188	n/a	n/a	SU
95LYG07	ms	3.1	0.00337741	222	221.5	1	45	225.4	1.1	169	53	221.5	1.0	2.0	SU
95LYG07	bt	0.1	0.01582294	113	n/a	n/a	n/a	n/a	n/a	n/a	n/a	113	~10	~10	UCSB
95YTST01f	ms	0.1	0.01582075	175	174.9	0.7	40	173.5	9.4	10004	2382	195→150	n/a	n/a	UCSB
95YZB1	kfs	3.2	0.00342889	90	n/a	n/a	n/a	n/a	n/a	n/a	n/a	135→110	n/a	n/a	SU
95ZY10	ms	0.1	0.01579711	283	283.1	1.9	61	279.6	1.4	421 ± 35	1.2	279.6	1.4	2.6	UCSB
99DPC2	bt	2.3	0.00341088	121	124.7	1	n/a	n/a	n/a	n/a	n/a	124.7	1.1	1.5	SU
99JP7	kfs	3.5	0.00338764	191	188.3	0.3	n/a	n/a	n/a	n/a	n/a	190→177	n/a	n/a	SU
99SMC06	bt	2.4	0.00351480	146	150.7	0.8	99	146.3	6.5	1312 ± 1500	1	150.7	0.8	1.4	SU

J = irradiation parameter; TFA = total fusion age; % ^{39}Ar = fraction ^{39}Ar used in computing WPMA and IA age;

WPMA = weighted mean plateau age (italic = weighted mean age); $^{40}\text{Ar}/^{36}\text{Ar}$ = isochron intercept; MSWD = mean square of weighted deviates

h→l (for example, 207→188) indicates spectrum with a range of step ages from a high-temperature step age (h) to a low-temperature step age (l)

Appendix 1 Description of Samples Measured

- 92HH1** (N37°02.73' E120° 40.12'), **92HXS05** (N37° 21.07' E120°10.30'), and **92KB1** (N37°10.17' E120°46.90'). Monazite-bearing sillimanite-K-feldspar-garnet-biotite schists from SW of Yantai Th/Pb ages from these rocks range from 2068 Ma to 347 Ma [*Enami et al.*, 1993; *Hacker et al.*, 2006].
- 92HFS01** (N 37°B14' 27" E120°45'39"). Biotite K-feldspar orthogneiss with well-recovered microstructure.
- 94BC13** (no GPS location). K-feldspar biotite hornblende sphene gneiss with amphibolite-facies fabric.
- 94DYJ19** (37°06' 46" E120°22'08"). Biotite hornblende quartzofeldspathic schist with amphibolite-facies fabric.
- 94MY08A** (N36°53.70' E122°30.22). 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 Fig. 5E in *Wallis et al.*, 1999]. A first, folded foliation is truncated by a second foliation, implying a complex tectonic history; zircon U-Pb dating indicates a metamorphic age of 227.8 ± 2.2 Ma [*Hacker et al.*, 2006].
- 94WHB05** (N37°31.08' E122°09.45'). Strongly deformed, compositionally layered biotite-K-feldspar augen gneiss in the northern part of the UHP domain with a U-Pb zircon age of ~ 224 Ma [*Hacker et al.*, 2006].
- 94YK46** (N36°15.07' E120°40.67'). Phengite-K-feldspar granitic gneiss from the northern part of the UHP domain showing weak compositional layering; zircon grains gave a U-Pb age of 216.3 ± 2.4 Ma [*Hacker et al.*, 2006].
- 95HZ14A** (N34°29.80' E118°48.12'). Mica-K-feldspar deformed granite from the southern part of the UHP domain where there is little evidence for either partial melting or late-stage igneous intrusion. A metamorphic zircon age of ~ 226 Ma was reported [*Hacker et al.*, 2006].
- 95YZB01** (N37°06.05' E121°18.43'). Strongly deformed granitic orthogneiss located immediately northwest of the YQW fault. It lacks the clear compositional layering of the previous two samples. It has a zircon crystallization age of 160.4 ± 2.3 Ma [*Hacker et al.*, 2006].
- 99DPC2** (N35°52.75' E119°27.18'). Granitic orthogneiss with well-defined compositional layering from the southern part of the UHP domain. At least two phases of folding are preserved. Local cm-scale garnet clusters and aegirine are found in the gneiss. Zircon U-Pb ages imply an initial metamorphic event around 219 Ma followed by Pb loss [*Hacker et al.*, 2006].
- 99JP7** (N34°31.90' E119°07.70'). Quartzofeldspathic schist likely derived from a granite near Lianyangang. Field observations suggest this schist overlies the main gneiss region, probably along an unconformable contact. A U-Pb zircon discordia indicates partial Jura–Triassic Pb loss of a Proterozoic protolith [*Hacker et al.*, 2006].
- 99SMC6** (N37°10.97' E122°02.53'). Biotite-K-feldspar gneiss with compositional layering showing two stages of deformation from 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. A rather young U-Pb zircon age of 202.4 ± 2.7 Ma is attributed to Pb loss [*Hacker et al.*, 2006].

- 92CD3** (37°01'09"N, 121°29'30"E). Amphibolite layer within felsic gneiss locally associated with 10 cm-scale quartz-rich layers with plagioclase porphyroclasts. Weak feldspar lineation at 290° and asymmetry of porphyroclasts suggests top-west sense of shear.
- 92LJ06** (37°05'00"N, 120°38'58"E). Deformed granitic gneiss with local mm to cm-grain size weakly to undeformed veins cross-cutting the foliation. Local internal boudin necks filled by granitic pegmatite implying localized melting. Gneissosity shows local tight folds. Late-stage hematite-filled fractures.
- 92NZ13** (37°10'02"N, 120°38'22"E). Red deformed granite associated with orthogneiss containing 1 m-scale mafic lenses. Tight folds locally present with southward vergence. Plagioclase shows ductile deformation with associated mineral lineation trending 110° and shear bands indicating a dominant top-west sense of shear.
- 92WQ-G** (37°20'56"N, 122°14'16"E). Strongly foliated biotite granite with minor muscovite and epidote. Local mm layers with a strong concentration of biotite. Garnet-bearing mafic schist present nearby.
- 92XS04** (37°09'51"N, 122°30'25"E). Deformed biotite K-feldspar granite associated with orthogneiss. Locally cm-scale discontinuous layers of K-feldspar present. Overall asymmetry suggests top-east sense of shear.
- 94HYS13** (36°44'10"N, 121°38'10"E). Biotite amphibole K-feldspar orthogneiss. The K-feldspar is porphyroclastic. Green amphibole is also pre-deformational. This orthogneiss contains meter-scale garnet-bearing mafic lenses. Deformation in the orthogneiss overprints an earlier fabric in the mafic lenses.
- 94MJY01** (37°21'09"N, 121°00'23"E). Epidote amphibole schist with irregular-shaped garnet. No pyroxene. Titanite is locally common. The amphibole defines a foliation. Only limited effects of static recrystallization. This mafic unit occurs as a 2m lens within felsic gneiss.
- 95CLSW** (35°04'13"N, 118°53'03"E). Strongly deformed granite with approximately horizontal well-developed linear fabric oriented approximately NW–SE. Main constituent minerals are quartz, K-feldspar, plagioclase, biotite with less titanite and garnet. Garnet is fine grained and occurs as elongate aggregates. Quartz and plagioclase strongly affected by static recrystallization. K-feldspar and biotite preserve deformation microstructures. Cut by undeformed mafic dykes.
- 95LYG07** (34°44'05"N, 119°25'24"E). Muscovite biotite schist with plagioclase porphyroclasts. Outcrop reveals a biotite foliation oblique to a dominant foliation defined largely by the alignment of white mica. Locally 10 cm scale interlayers of mafic material.
- 95YTST01f** (34°41'55"N, 119°26'09"E). Garnet chlorite muscovite schist layer associated with deformed granite. Garnet grains have irregular outlines. No biotite present. Plagioclase occurs as porphyroclasts. \
- 95ZY10** (35°02'34"N, 118°51'06"E). Foliated phengite eclogite from a sequence of interbedded mica-rich and more-mafic layers at dm scale probably reflecting an original sedimentary sequence. Garnet, pyroxene and phengite are sub- to euhedral. Rutile is common.

Supplemental Data part 2. 40/39 data

Data from Stanford University

T°C	40Ar*/39Ar	±1 s	39Ar/40Ar	±1 s	36Ar/40Ar	±1 s	f39Ar	age (Ma)	±1 s
92DC3									
		hornblende							
700	402.79	5.20	0.0018	0.000013	0.000884	0.000009	0.0005	1565.5	40.5
800	47.62	1.17	0.0168	0.000110	0.000677	0.000043	0.0007	273.0	18.7
900	28.06	0.73	0.0239	0.000117	0.001115	0.000043	0.0012	165.8	12.4
1000	24.60	0.06	0.0386	0.000024	0.000174	0.000005	0.0153	146.1	1.0
1050	23.97	0.02	0.0410	0.000014	0.000055	0.000001	0.0693	142.6	0.3
1070	25.17	0.01	0.0391	0.000012	0.000050	0.000001	0.1005	149.4	0.2
1080	23.89	0.01	0.0415	0.000012	0.000028	0.000000	0.0970	142.1	0.2
1090	23.95	0.03	0.0413	0.000017	0.000034	0.000001	0.0277	142.4	0.6
1100	23.59	0.38	0.0411	0.000138	0.000103	0.000016	0.0023	140.4	6.5
1110	23.23	0.31	0.0407	0.000120	0.000184	0.000018	0.0028	138.3	5.3
1130	23.70	0.20	0.0408	0.000061	0.000116	0.000011	0.0044	141.0	3.4
1150	24.55	0.06	0.0401	0.000022	0.000054	0.000003	0.0153	145.9	1.0
1170	24.53	0.03	0.0402	0.000017	0.000047	0.000001	0.0314	145.7	0.5
1190	25.48	0.53	0.0351	0.000129	0.000356	0.000029	0.0016	151.1	9.1
1210	20.54	2.92	0.0323	0.000640	0.001138	0.000142	0.0003	122.8	50.7
1260	-10.44	10.17	0.0088	0.000406	0.003696	0.000223	0.0001	-65.8	195.8
1310	-28.58	20.06	0.0033	0.000173	0.003700	0.000118	0.0001	-186.1	412.9
92HFS01									
		biotite							
600	80.79	3.15	0.0107	0.000185	0.000470	0.000097	0.0005	441.3	45.7
700	104.16	0.80	0.0093	0.000039	0.000119	0.000021	0.0022	551.1	11.0
800	303.63	0.56	0.0033	0.000006	0.000035	0.000002	0.0090	1287.5	5.1
850	215.26	0.28	0.0046	0.000006	0.000018	0.000001	0.0278	997.5	3.0
900	137.46	0.25	0.0072	0.000013	0.000024	0.000001	0.0444	696.9	3.2
950	181.22	0.35	0.0055	0.000010	0.000014	0.000001	0.0332	872.1	4.0
1000	291.46	1.69	0.0034	0.000020	0.000009	0.000001	0.0212	1250.2	15.7
1050	200.69	0.35	0.0050	0.000008	0.000014	0.000001	0.0296	944.9	3.8
1100	144.68	0.36	0.0069	0.000017	0.000019	0.000001	0.0416	727.0	4.5
1150	163.89	0.31	0.0061	0.000011	0.000020	0.000001	0.0367	804.7	3.7
1200	215.13	0.34	0.0046	0.000007	0.000017	0.000001	0.0278	997.1	3.7
1300	325.74	1.35	0.0030	0.000012	0.000022	0.000004	0.0052	1353.3	11.9
1400	15.03	19.99	0.0129	0.001325	0.002726	0.000766	0.0001	90.7	352.9
92HFS01									
		K-feldspar							
550	537.81	9.29	0.0017	0.000023	0.000206	0.000010	0.0003	1886.1	60.6
600	141.26	3.40	0.0066	0.000086	0.000227	0.000025	0.0004	712.8	42.5
650	124.57	2.32	0.0076	0.000071	0.000185	0.000020	0.0005	641.8	30.2
700	72.87	1.47	0.0129	0.000094	0.000192	0.000026	0.0007	402.5	21.8
750	57.77	1.05	0.0164	0.000089	0.000184	0.000023	0.0009	326.1	16.3
800	53.96	0.95	0.0172	0.000106	0.000252	0.000024	0.0010	306.4	15.0
850	53.65	0.80	0.0176	0.000087	0.000186	0.000020	0.0012	304.7	12.5
900	46.55	0.60	0.0208	0.000092	0.000110	0.000014	0.0016	267.2	9.5
950	52.35	0.39	0.0186	0.000048	0.000093	0.000010	0.0025	297.9	6.2
1000	49.19	0.21	0.0199	0.000030	0.000066	0.000006	0.0046	281.3	3.3
1050	46.01	0.23	0.0213	0.000034	0.000061	0.000007	0.0040	264.4	3.7
1100	47.08	0.24	0.0209	0.000032	0.000047	0.000006	0.0040	270.1	3.8
1150	55.91	0.24	0.0175	0.000028	0.000064	0.000006	0.0042	316.5	3.8
1200	82.30	0.21	0.0119	0.000016	0.000074	0.000004	0.0058	448.6	3.1
1300	74.71	0.07	0.0132	0.000008	0.000037	0.000002	0.0206	411.6	1.0
92HH1									
		biotite							
600	72.95	5.30	0.0095	0.000244	0.001027	0.000145	0.0003	402.9	78.7
700	65.84	0.91	0.0134	0.000076	0.000392	0.000037	0.0019	367.3	13.8
800	164.34	0.26	0.0060	0.000009	0.000064	0.000002	0.0164	806.5	3.1
850	156.88	0.59	0.0063	0.000024	0.000020	0.000001	0.0378	776.7	7.1
860	166.07	1.68	0.0057	0.000039	0.000205	0.000022	0.0014	813.3	19.9
870	172.62	0.30	0.0058	0.000010	0.000007	0.000001	0.0275	839.0	3.5
880	165.65	1.32	0.0055	0.000029	0.000320	0.000016	0.0017	811.7	15.6
890	166.81	0.74	0.0060	0.000026	0.000013	0.000003	0.0113	816.3	8.7
900	163.84	0.33	0.0061	0.000010	0.000017	0.000004	0.0090	804.5	3.9
910	160.08	0.42	0.0062	0.000013	0.000025	0.000005	0.0066	789.6	5.0
920	157.91	0.50	0.0063	0.000016	0.000025	0.000006	0.0055	780.9	6.1
930	156.91	0.49	0.0063	0.000015	0.000027	0.000007	0.0050	776.9	5.9
940	154.71	0.57	0.0064	0.000018	0.000025	0.000007	0.0047	768.0	6.9
950	152.69	0.56	0.0065	0.000018	0.000024	0.000008	0.0044	759.8	6.9
970	149.58	0.60	0.0066	0.000020	0.000030	0.000009	0.0042	747.1	7.3
990	144.44	0.45	0.0069	0.000016	0.000018	0.000006	0.0058	726.0	5.6

1010	137.71	0.32	0.0072	0.000012	0.000021	0.000005	0.0076	697.9	5.0
1030	134.78	0.38	0.0074	0.000019	0.000015	0.000003	0.0119	685.6	4.8
1050	131.88	1.42	0.0066	0.000041	0.000433	0.000024	0.0015	673.3	18.2
1070	140.69	1.24	0.0064	0.000034	0.000356	0.000020	0.0018	710.4	15.5
1090	146.10	1.30	0.0062	0.000035	0.000339	0.000019	0.0018	732.8	16.1
1110	146.75	1.29	0.0061	0.000034	0.000337	0.000019	0.0018	735.5	16.0
1130	148.78	1.51	0.0060	0.000037	0.000384	0.000022	0.0015	743.9	18.6
1150	148.30	1.79	0.0059	0.000042	0.000447	0.000026	0.0013	741.9	22.1
1170	159.52	0.36	0.0063	0.000013	0.000010	0.000003	0.0126	787.3	4.4
1190	178.78	0.44	0.0056	0.000012	0.000019	0.000004	0.0088	862.8	5.1
1210	175.89	0.85	0.0056	0.000021	0.000022	0.000010	0.0033	851.6	9.9
1230	183.69	1.65	0.0053	0.000035	0.000060	0.000019	0.0016	881.5	18.8
1280	170.81	1.81	0.0057	0.000042	0.000068	0.000024	0.0014	831.9	21.2
1350	183.47	2.51	0.0054	0.000053	0.000052	0.000030	0.0011	880.7	28.6
1400	24.00	30.58	0.0108	0.001598	0.002510	0.000934	0.0001	142.7	524.5

92HXS05		biotite							
600	54.55	0.90	0.0099	0.000052	0.001552	0.000023	0.0021	309.4	14.1
700	73.20	0.30	0.0117	0.000028	0.000491	0.000009	0.0074	404.1	4.4
800	226.86	0.97	0.0042	0.000017	0.000121	0.000002	0.0156	1038.4	10.1
850	327.02	1.07	0.0030	0.000009	0.000064	0.000004	0.0272	1357.0	9.3
900	369.65	1.32	0.0027	0.000009	0.000048	0.000002	0.0388	1477.3	10.8
950	356.01	1.42	0.0028	0.000011	0.000042	0.000001	0.0294	1439.7	11.8
1000	371.24	1.16	0.0027	0.000008	0.000043	0.000001	0.0265	1481.6	9.5
1050	442.15	1.33	0.0022	0.000007	0.000039	0.000001	0.0247	1665.0	9.8
1100	443.07	1.41	0.0022	0.000007	0.000038	0.000001	0.0256	1667.2	10.4
1150	428.02	8.87	0.0023	0.000047	0.000055	0.000001	0.0152	1629.9	66.7
1200	422.33	5.96	0.0023	0.000032	0.000063	0.000001	0.0120	1615.6	45.2
1300	430.08	11.94	0.0022	0.000059	0.000144	0.000004	0.0043	1635.1	89.6
1400	87.97	49.66	0.0016	0.000092	0.002918	0.000074	0.0001	475.7	708.2

92LJ06		biotite							
600	17.04	0.29	0.0500	0.000123	0.000499	0.000049	0.0050	102.5	5.1
700	17.05	0.30	0.0500	0.000118	0.000498	0.000051	0.0050	102.5	5.3
800	822.57	2.77	0.0012	0.000004	0.000023	0.000001	0.0044	2418.6	13.5
810	847.96	2.97	0.0012	0.000004	0.000014	0.000001	0.0044	2459.2	14.1
820	835.79	2.90	0.0012	0.000004	0.000011	0.000001	0.0054	2439.9	13.9
830	838.23	3.23	0.0012	0.000005	0.000009	0.000002	0.0035	2443.8	15.5
840	822.94	2.78	0.0012	0.000004	0.000009	0.000001	0.0065	2419.2	13.5
850	817.36	2.12	0.0012	0.000003	0.000008	0.000001	0.0075	2410.1	10.4
860	806.44	2.68	0.0012	0.000004	0.000008	0.000001	0.0110	2392.3	13.2
870	797.95	2.37	0.0013	0.000004	0.000007	0.000001	0.0126	2378.3	11.8
880	794.33	2.47	0.0013	0.000004	0.000008	0.000001	0.0120	2372.3	12.3
890	775.72	2.38	0.0013	0.000004	0.000009	0.000001	0.0121	2341.1	12.0
900	779.86	3.71	0.0013	0.000006	0.000010	0.000001	0.0097	2348.1	18.7
910	770.94	2.48	0.0013	0.000004	0.000009	0.000001	0.0104	2333.0	12.6
920	764.90	2.51	0.0013	0.000004	0.000009	0.000001	0.0104	2322.7	12.9
930	764.32	2.58	0.0013	0.000004	0.000010	0.000001	0.0098	2321.7	13.2
940	757.96	3.47	0.0013	0.000006	0.000012	0.000001	0.0087	2310.8	17.9
950	737.53	2.38	0.0014	0.000004	0.000013	0.000001	0.0081	2275.3	12.5
970	737.11	2.45	0.0014	0.000004	0.000013	0.000001	0.0091	2274.6	12.9
990	755.83	2.55	0.0013	0.000004	0.000011	0.000001	0.0096	2307.1	13.2
1010	793.68	3.74	0.0013	0.000006	0.000011	0.000001	0.0093	2371.2	18.6
1030	859.88	3.50	0.0012	0.000005	0.000010	0.000001	0.0105	2478.0	16.4
1050	893.69	3.39	0.0011	0.000004	0.000009	0.000001	0.0111	2530.2	15.5
1070	915.71	4.24	0.0011	0.000005	0.000009	0.000001	0.0127	2563.4	19.0
1090	884.84	3.53	0.0011	0.000004	0.000008	0.000000	0.0166	2516.7	16.3
1110	853.38	3.59	0.0012	0.000005	0.000009	0.000000	0.0199	2467.8	17.0
1130	808.36	2.73	0.0012	0.000004	0.000006	0.000000	0.0202	2395.4	13.4
1150	759.48	2.82	0.0013	0.000005	0.000007	0.000001	0.0165	2313.4	14.5
1170	736.46	2.78	0.0014	0.000005	0.000006	0.000001	0.0159	2273.5	14.7
1190	700.01	2.30	0.0014	0.000005	0.000007	0.000001	0.0156	2208.3	12.6
1210	672.18	2.60	0.0015	0.000006	0.000006	0.000001	0.0111	2157.0	14.6
1230	474.32	2.03	0.0021	0.000009	0.000017	0.000003	0.0052	1742.4	14.3
1280	372.59	1.63	0.0027	0.000011	0.000027	0.000005	0.0034	1485.3	13.2

92NZ13		K-feldspar							
550	193.52	0.39	0.0047	0.000007	0.000330	0.000003	0.0059	918.5	4.3
600	34.91	0.46	0.0253	0.000107	0.000399	0.000029	0.0025	204.0	7.7
650	57.57	0.27	0.0160	0.000036	0.000259	0.000011	0.0047	325.1	4.1

700	40.42	0.17	0.0233	0.000037	0.000193	0.000011	0.0063	234.2	2.8
750	39.73	0.15	0.0245	0.000043	0.000095	0.000009	0.0072	230.5	2.5
800	39.75	0.14	0.0244	0.000038	0.000105	0.000008	0.0083	230.6	2.2
850	39.95	0.11	0.0246	0.000030	0.000059	0.000006	0.0094	231.6	1.8
900	40.32	0.10	0.0243	0.000025	0.000068	0.000006	0.0111	233.7	1.7
950	43.50	0.08	0.0227	0.000017	0.000049	0.000005	0.0142	250.9	1.3
1000	46.91	0.07	0.0210	0.000015	0.000048	0.000003	0.0175	269.1	1.0
1050	48.18	0.06	0.0205	0.000012	0.000044	0.000003	0.0201	275.9	1.0
1100	48.50	0.05	0.0202	0.000010	0.000064	0.000003	0.0280	277.6	0.8
1150	49.33	0.04	0.0198	0.000009	0.000085	0.000002	0.0484	282.0	0.6
1200	53.73	0.04	0.0182	0.000010	0.000073	0.000001	0.0769	305.1	0.6
92XS04 K-feldspar									
550	34.84	3.59	0.0120	0.000237	0.001964	0.000114	0.0003	203.6	59.5
600	66.61	0.60	0.0124	0.000044	0.000585	0.000019	0.0021	371.2	9.0
650	98.08	0.65	0.0095	0.000033	0.000227	0.000013	0.0018	523.2	9.1
700	119.99	0.62	0.0080	0.000030	0.000140	0.000008	0.0024	621.8	8.2
750	125.03	0.35	0.0078	0.000014	0.000098	0.000005	0.0039	643.8	4.5
800	127.54	0.26	0.0077	0.000012	0.000075	0.000003	0.0065	654.7	3.3
850	127.03	0.16	0.0077	0.000007	0.000083	0.000002	0.0108	652.5	2.0
900	127.17	0.08	0.0076	0.000004	0.000099	0.000001	0.0245	653.1	1.0
950	127.01	0.09	0.0078	0.000006	0.000042	0.000001	0.0625	652.4	1.2
1000	127.15	0.08	0.0078	0.000004	0.000034	0.000001	0.0369	653.0	1.0
1050	126.32	0.10	0.0078	0.000005	0.000054	0.000001	0.0209	649.4	1.3
1100	126.96	0.09	0.0077	0.000005	0.000061	0.000001	0.0267	652.1	1.2
1150	127.29	0.09	0.0078	0.000005	0.000024	0.000000	0.0683	653.6	1.1
1200	125.90	0.31	0.0079	0.000013	0.000021	0.000004	0.0051	647.6	4.0
94BC13 K-feldspar									
500	1251.96	6.36	0.0008	0.000004	0.000091	0.000002	0.0014	3056.6	22.4
550	249.81	1.30	0.0039	0.000016	0.000056	0.000008	0.0013	1145.1	13.2
600	161.21	0.45	0.0061	0.000014	0.000065	0.000004	0.0040	816.2	5.5
650	63.45	0.18	0.0154	0.000028	0.000069	0.000006	0.0064	366.4	2.7
700	38.20	0.11	0.0256	0.000042	0.000074	0.000007	0.0091	229.3	1.8
750	27.42	0.07	0.0356	0.000025	0.000077	0.000007	0.0125	167.5	1.2
800	24.35	0.05	0.0403	0.000027	0.000062	0.000006	0.0158	149.5	0.9
850	24.19	0.04	0.0405	0.000027	0.000066	0.000005	0.0189	148.6	0.8
900	21.06	0.05	0.0465	0.000032	0.000070	0.000006	0.0165	130.1	0.8
950	20.60	0.05	0.0475	0.000029	0.000071	0.000007	0.0154	127.3	0.9
1000	20.57	0.05	0.0478	0.000032	0.000057	0.000007	0.0155	127.1	0.9
1050	22.15	0.05	0.0443	0.000036	0.000064	0.000006	0.0170	136.5	0.9
1100	26.05	0.04	0.0377	0.000022	0.000058	0.000004	0.0216	159.5	0.7
1150	31.23	0.03	0.0314	0.000016	0.000062	0.000003	0.0309	189.6	0.6
1200	35.47	0.02	0.0277	0.000012	0.000054	0.000001	0.0779	213.9	0.4
94DYJ19 biotite									
600	15.07	0.99	0.0330	0.000265	0.002062	0.000098	0.0013	90.9	17.5
700	20.90	0.28	0.0357	0.000087	0.001044	0.000030	0.0044	124.9	4.9
800	36.04	0.06	0.0255	0.000014	0.000335	0.000004	0.0224	210.3	1.0
850	35.82	0.03	0.0274	0.000010	0.000082	0.000002	0.0459	209.1	0.5
900	35.99	0.03	0.0272	0.000012	0.000084	0.000002	0.0406	210.0	0.5
950	36.12	0.04	0.0275	0.000013	0.000034	0.000003	0.0304	210.7	0.7
1000	36.33	0.05	0.0272	0.000016	0.000043	0.000004	0.0254	211.9	0.8
1050	36.54	0.03	0.0272	0.000010	0.000030	0.000002	0.0455	213.0	0.5
1100	36.19	0.02	0.0276	0.000009	0.000011	0.000001	0.0912	211.1	0.3
1150	35.99	0.02	0.0277	0.000009	0.000012	0.000001	0.0914	210.0	0.3
1200	35.98	0.03	0.0277	0.000011	0.000010	0.000002	0.0533	209.9	0.5
1300	36.08	0.11	0.0276	0.000027	0.000020	0.000006	0.0108	210.5	1.9
1400	29.96	7.71	0.0246	0.001415	0.001080	0.000380	0.0002	176.5	129.8
94MJY01 hornblende									
700	122.18	1.48	0.0036	0.000012	0.001897	0.000009	0.0011	631.4	19.3
800	143.43	2.17	0.0059	0.000044	0.000514	0.000023	0.0006	721.8	26.9
900	194.51	1.65	0.0044	0.000020	0.000471	0.000011	0.0009	922.1	18.4
1000	405.52	0.98	0.0024	0.000005	0.000050	0.000002	0.0031	1572.6	7.6
1050	503.30	0.62	0.0020	0.000002	0.000011	0.000000	0.0221	1809.4	4.2
1070	494.63	0.51	0.0020	0.000002	0.000006	0.000000	0.0094	1789.6	3.5
1080	467.54	2.59	0.0021	0.000009	0.000021	0.000002	0.0012	1726.4	18.5
1090	470.01	3.52	0.0021	0.000012	0.000023	0.000003	0.0009	1732.2	25.0
1100	485.69	2.78	0.0021	0.000009	0.000014	0.000002	0.0012	1769.0	19.4

1110	490.86	2.75	0.0020	0.000009	0.000021	0.000002	0.0013	1780.9	19.0
1130	502.31	0.40	0.0020	0.000001	0.000007	0.000000	0.0140	1807.2	2.7
1150	504.32	0.42	0.0020	0.000002	0.000008	0.000000	0.0139	1811.7	2.9
1170	514.11	2.88	0.0019	0.000009	0.000030	0.000002	0.0013	1833.8	19.4
1190	439.07	8.33	0.0022	0.000033	0.000115	0.000010	0.0003	1657.4	61.7
1210	405.07	14.78	0.0023	0.000067	0.000230	0.000026	0.0002	1571.4	114.8
1260	235.05	15.55	0.0033	0.000148	0.000786	0.000066	0.0001	1066.6	159.8
1310	49.18	15.15	0.0048	0.000278	0.002579	0.000165	0.0001	281.2	240.7

94MY08a		biotite							
600	13.04	0.32	0.0421	0.000250	0.001527	0.000041	0.0053	79.0	5.8
700	23.52	0.19	0.0332	0.000127	0.000738	0.000017	0.0103	139.9	3.3
800	32.68	0.33	0.0281	0.000256	0.000273	0.000005	0.0321	191.7	5.5
825	34.37	0.23	0.0276	0.000162	0.000173	0.000008	0.0174	201.1	3.8
850	34.69	0.27	0.0276	0.000201	0.000139	0.000006	0.0269	202.8	4.5
875	35.01	0.40	0.0275	0.000298	0.000129	0.000006	0.0232	204.6	6.6
900	34.51	0.33	0.0277	0.000245	0.000149	0.000009	0.0167	201.8	5.5
925	34.32	0.51	0.0275	0.000368	0.000193	0.000014	0.0110	200.8	8.5
950	33.35	0.51	0.0279	0.000366	0.000240	0.000019	0.0083	195.4	8.5
975	32.48	0.31	0.0283	0.000164	0.000278	0.000022	0.0071	190.5	5.2
1000	33.14	0.29	0.0278	0.000082	0.000270	0.000025	0.0063	194.2	4.8
1025	33.78	0.37	0.0273	0.000208	0.000265	0.000022	0.0069	197.8	6.2
1050	33.92	0.46	0.0278	0.000333	0.000197	0.000015	0.0107	198.5	7.7
1075	34.89	0.32	0.0274	0.000226	0.000152	0.000011	0.0151	203.9	5.4
1100	34.00	0.10	0.0284	0.000069	0.000120	0.000006	0.0286	199.0	1.7
1125	34.55	0.10	0.0281	0.000063	0.000099	0.000006	0.0299	202.0	1.7
1150	34.97	0.11	0.0280	0.000066	0.000074	0.000006	0.0264	204.4	5.0
1175	35.04	0.14	0.0278	0.000061	0.000092	0.000010	0.0175	204.8	2.2
1200	31.73	0.38	0.0292	0.000122	0.000250	0.000034	0.0051	186.4	6.3
1250	22.87	0.92	0.0324	0.000242	0.000879	0.000095	0.0021	136.2	15.8
1300	-53.61	14.37	0.0671	0.010768	0.015561	0.002998	0.0002	-366.6	326.9
1400	-63.84	6.70	0.2426	0.072579	0.055794	0.017333	0.0003	-445.8	159.2

94WHB5		K-feldspar							
550	120.92	8.59	0.0026	0.000047	0.001563	0.000029	0.0003	625.9	112.7
600	41.34	3.32	0.0090	0.000145	0.001428	0.000077	0.0004	239.2	54.0
650	29.84	1.94	0.0107	0.000109	0.001544	0.000056	0.0006	175.8	32.6
700	20.93	1.29	0.0144	0.000115	0.001587	0.000053	0.0008	125.1	22.4
750	18.02	0.79	0.0195	0.000116	0.001476	0.000044	0.0012	108.2	13.8
800	18.02	0.61	0.0253	0.000127	0.001238	0.000046	0.0015	108.2	10.7
850	18.60	0.45	0.0235	0.000083	0.001278	0.000032	0.0021	111.6	7.9
900	19.24	0.39	0.0187	0.000046	0.001457	0.000021	0.0025	115.3	6.7
950	16.40	0.32	0.0211	0.000058	0.001488	0.000019	0.0032	98.7	5.6
1000	18.57	0.23	0.0310	0.000072	0.000965	0.000021	0.0044	111.4	3.9
1050	17.38	0.21	0.0425	0.000090	0.000593	0.000027	0.0046	104.5	3.7
1100	18.45	0.21	0.0358	0.000084	0.000770	0.000023	0.0048	110.7	3.7
1150	23.86	0.20	0.0257	0.000051	0.000878	0.000016	0.0058	141.9	3.5
1200	42.47	0.21	0.0145	0.000022	0.000873	0.000009	0.0068	245.4	3.4

94WHB5		biotite							
600	9.39	0.84	0.0472	0.000390	0.001885	0.000131	0.0014	57.2	15.2
700	15.89	0.45	0.0469	0.000196	0.000862	0.000070	0.0029	95.8	8.0
800	24.23	0.38	0.0371	0.000485	0.000339	0.000017	0.0100	144.0	6.5
850	26.41	0.16	0.0360	0.000068	0.000165	0.000018	0.0092	156.5	2.7
900	27.22	0.19	0.0354	0.000098	0.000123	0.000020	0.0079	161.0	3.2
1000	23.96	0.34	0.0257	0.000101	0.001300	0.000027	0.0055	142.5	5.9
1050	24.57	0.19	0.0296	0.000100	0.000926	0.000015	0.0111	146.0	3.3
1100	25.78	0.16	0.0295	0.000061	0.000813	0.000014	0.0132	152.8	2.7
1150	26.31	0.27	0.0262	0.000058	0.001053	0.000022	0.0083	155.9	4.6
1200	24.62	0.72	0.0186	0.000152	0.001838	0.000037	0.0033	146.3	12.4
1300	21.26	2.05	0.0097	0.000087	0.002684	0.000056	0.0012	127.0	35.5

94YK46		K-feldspar							
550	76.60	1.29	0.0116	0.000081	0.000386	0.000041	0.0009	420.9	19.0
600	22.59	0.60	0.0413	0.000260	0.000224	0.000079	0.0016	134.6	10.4
650	19.48	0.41	0.0492	0.000191	0.000141	0.000064	0.0022	116.7	7.2
700	18.69	0.29	0.0516	0.000170	0.000118	0.000046	0.0032	112.1	5.1
750	18.22	0.21	0.0542	0.000129	0.000045	0.000036	0.0044	109.4	3.7
800	17.95	0.18	0.0545	0.000083	0.000076	0.000028	0.0053	107.8	3.1
850	18.55	0.17	0.0529	0.000108	0.000062	0.000026	0.0056	111.3	2.9

900	21.08	0.74	0.0517	0.000312	-0.000306	0.000077	0.0012	126.0	12.8
950	19.46	0.10	0.0514	0.000077	-0.000003	0.000004	0.0096	116.6	1.7
1000	19.45	0.15	0.0515	0.000082	-0.000008	0.000009	0.0066	116.5	2.6
1050	19.62	0.16	0.0514	0.000093	-0.000032	0.000019	0.0060	117.5	2.8
1100	20.02	0.16	0.0502	0.000105	-0.000015	0.000017	0.0065	119.8	2.7
1150	23.45	0.16	0.0420	0.000084	0.000050	0.000022	0.0066	139.6	2.8
1200	32.91	0.12	0.0294	0.000038	0.000105	0.000010	0.0098	192.9	2.0

95HZ14a		biotite							
600	17.09	0.28	0.0500	0.000146	0.000492	0.000045	0.0050	102.8	4.9
700	17.11	0.28	0.0500	0.000175	0.000490	0.000045	0.0050	102.9	4.9
800	17.57	0.11	0.0327	0.000037	0.001440	0.000011	0.0140	105.6	1.8
850	18.39	0.16	0.0312	0.000047	0.001445	0.000016	0.0103	110.3	2.8
900	17.53	0.25	0.0311	0.000064	0.001537	0.000026	0.0068	105.3	4.4
950	19.34	0.34	0.0301	0.000082	0.001417	0.000033	0.0049	115.8	5.8
1000	20.53	0.26	0.0304	0.000071	0.001270	0.000026	0.0062	122.8	4.6
1050	18.44	0.25	0.0310	0.000071	0.001452	0.000025	0.0066	110.7	4.3
1050	18.48	0.25	0.0309	0.000065	0.001451	0.000025	0.0066	110.9	4.3
1100	20.32	0.45	0.0291	0.000127	0.001380	0.000041	0.0036	121.5	7.9
1150	19.72	1.94	0.0308	0.000428	0.001328	0.000189	0.0008	118.1	33.7
1200	17.66	2.64	0.0374	0.000778	0.001149	0.000304	0.0006	106.1	46.2
1300	18.48	7.34	0.0324	0.001853	0.001356	0.000720	0.0002	110.9	128.2
1400	-17.16	18.29	0.0610	0.016453	0.006926	0.003861	0.0001	-109.5	360.8

95HZ14a	K-feldspar								
550	62.04	0.55	0.0041	0.000008	0.000312	0.000003	0.0049	348.0	8.4
600	22.85	0.23	0.0224	0.000041	0.000205	0.000014	0.0040	136.1	4.0
650	29.35	0.14	0.0213	0.000033	0.000158	0.000007	0.0081	173.0	2.3
700	31.43	0.09	0.0240	0.000031	0.000103	0.000005	0.0135	184.7	1.5
750	31.02	0.05	0.0266	0.000012	0.000073	0.000004	0.0210	182.4	0.8
800	30.98	0.04	0.0294	0.000017	0.000037	0.000003	0.0303	182.2	0.6
850	30.79	0.02	0.0296	0.000014	0.000038	0.000002	0.0499	181.1	0.4
900	31.64	0.03	0.0308	0.000014	0.000011	0.000002	0.0352	185.9	0.5
950	30.73	0.05	0.0308	0.000018	0.000022	0.000004	0.0206	180.8	0.8
					0.000017				

1050	32.46	0.08	0.0307	0.000026	0.000002	0.000010	0.0120	190.5	1.4
1100	31.15	0.03	0.0300	0.000014	0.000027	0.000003	0.0332	183.1	0.6
1150	30.96	0.03	0.0288	0.000012	0.000046	0.000003	0.0326	182.1	0.6
1200	31.65	0.02	0.0275	0.000010	0.000054	0.000002	0.0584	185.9	0.4

95LYG07 **K-white mica**

700	17.07	0.26	0.0500	0.000133	0.000495	0.000043	0.0050	102.7	4.6
800	17.08	0.28	0.0500	0.000138	0.000494	0.000045	0.0050	102.7	4.8
820	38.46	0.53	0.0250	0.000097	0.000124	0.000042	0.0026	223.6	8.7
840	37.55	0.49	0.0252	0.000085	0.000178	0.000040	0.0028	218.5	8.1
880	38.53	0.19	0.0248	0.000049	0.000151	0.000014	0.0079	223.9	3.1
900	38.79	0.11	0.0251	0.000033	0.000088	0.000008	0.0142	225.3	1.8
933	39.10	0.06	0.0253	0.000035	0.000037	0.000002	0.0866	227.0	1.0
966	38.85	0.10	0.0256	0.000066	0.000022	0.000001	0.1851	225.7	1.7
1000	38.65	0.05	0.0256	0.000029	0.000032	0.000002	0.0827	224.6	0.8
1050	38.42	0.07	0.0258	0.000047	0.000032	0.000002	0.0748	223.3	1.2
1100	38.25	0.08	0.0257	0.000046	0.000061	0.000004	0.0337	222.4	1.4
1150	38.32	0.11	0.0254	0.000032	0.000094	0.000008	0.0155	222.8	1.8
1200	38.77	0.26	0.0249	0.000107	0.000115	0.000016	0.0081	225.3	4.2
1250	36.10	0.54	0.0251	0.000211	0.000323	0.000035	0.0038	210.6	9.0
1300	37.71	0.28	0.0251	0.000057	0.000178	0.000022	0.0062	219.5	4.6
1400	37.03	0.43	0.0247	0.000096	0.000290	0.000032	0.0043	215.7	7.0

95YZB1 **K-feldspar**

550	17.32	0.27	0.0120	0.000024	0.000871	0.000008	0.0059	104.1	4.7
600	12.92	0.34	0.0546	0.000257	0.000323	0.000047	0.0025	78.2	6.0
650	11.16	0.16	0.0427	0.000065	0.000575	0.000020	0.0058	67.8	2.8
700	12.04	0.07	0.0446	0.000040	0.000509	0.000010	0.0120	73.0	1.3
750	14.79	0.04	0.0507	0.000031	0.000275	0.000007	0.0202	89.3	0.8
800	14.85	0.03	0.0511	0.000023	0.000265	0.000005	0.0282	89.6	0.6
850	15.66	0.03	0.0521	0.000021	0.000202	0.000004	0.0297	94.4	0.5
900	15.42	0.03	0.0504	0.000026	0.000244	0.000004	0.0277	93.0	0.5
950	12.95	0.03	0.0469	0.000026	0.000431	0.000004	0.0272	78.4	0.5
1000	14.94	0.04	0.0497	0.000029	0.000283	0.000006	0.0227	90.2	0.7
1050	16.44	0.04	0.0517	0.000029	0.000166	0.000006	0.0229	98.9	0.7
1100	16.13	0.04	0.0496	0.000032	0.000219	0.000006	0.0256	97.1	0.7
1150	15.92	0.04	0.0464	0.000030	0.000288	0.000006	0.0271	95.9	0.7
1200	15.14	0.03	0.0383	0.000015	0.000462	0.000003	0.0534	91.3	0.5

99DPC2 **biotite**

600	0.69	0.17	0.0361	0.000044	0.002177	0.000019	0.0049	4.3	3.2
700	14.81	0.06	0.0507	0.000032	0.000555	0.000009	0.0128	89.4	1.1
800	20.10	0.02	0.0458	0.000016	0.000179	0.000003	0.0388	120.3	0.4
850	20.61	0.02	0.0460	0.000017	0.000117	0.000003	0.0370	123.2	0.4
900	20.74	0.03	0.0462	0.000021	0.000093	0.000003	0.0300	124.0	0.5
950	20.69	0.03	0.0455	0.000020	0.000132	0.000004	0.0249	123.7	0.6
1000	20.82	0.03	0.0447	0.000018	0.000155	0.000003	0.0333	124.4	0.5
1050	20.82	0.02	0.0463	0.000016	0.000080	0.000002	0.0531	124.5	0.3
1100	20.80	0.01	0.0471	0.000013	0.000044	0.000001	0.0810	124.3	0.2
1150	20.74	0.02	0.0474	0.000015	0.000037	0.000002	0.0542	124.0	0.3
1200	21.12	0.13	0.0457	0.000061	0.000080	0.000009	0.0065	126.2	2.3
1300	18.94	0.78	0.0369	0.000215	0.000672	0.000056	0.0011	113.5	13.6

99JP7 **K-feldspar**

550	100.60	1.31	0.0047	0.000021	0.001782	0.000012	0.0017	534.8	18.1
600	31.73	0.42	0.0263	0.000105	0.000558	0.000033	0.0022	186.4	7.0
650	30.28	0.23	0.0279	0.000060	0.000528	0.000020	0.0038	178.3	4.0
700	30.69	0.13	0.0286	0.000041	0.000410	0.000011	0.0070	180.5	2.2
750	31.19	0.07	0.0304	0.000022	0.000175	0.000006	0.0124	183.3	1.2
800	32.39	0.05	0.0302	0.000024	0.000076	0.000004	0.0200	190.0	0.8
850	32.49	0.03	0.0303	0.000011	0.000048	0.000002	0.0311	190.6	0.4
900	32.44	0.02	0.0303	0.000011	0.000056	0.000002	0.0417	190.3	0.4
950	32.50	0.02	0.0304	0.000013	0.000041	0.000001	0.0506	190.7	0.3
1000	32.50	0.02	0.0304	0.000012	0.000043	0.000001	0.0581	190.7	0.3
1050	32.51	0.02	0.0305	0.000012	0.000031	0.000002	0.0618	190.7	0.4
1100	32.17	0.02	0.0308	0.000012	0.000033	0.000002	0.0631	188.8	0.3
1150	32.35	0.02	0.0307	0.000015	0.000026	0.000001	0.1322	189.8	0.3
1200	32.81	0.02	0.0302	0.000012	0.000032	0.000001	0.0998	192.4	0.3

biotite

600	5.08	3.01	0.0219	0.000413	0.003008	0.000209	0.0005	31.2	54.9
700	13.40	0.67	0.0537	0.000337	0.000949	0.000120	0.0025	81.1	12.0
800	24.20	0.12	0.0395	0.000053	0.000150	0.000016	0.0149	143.8	2.1
850	24.76	0.08	0.0398	0.000070	0.000049	0.000009	0.0274	147.0	1.4
900	24.62	0.07	0.0403	0.000096	0.000024	0.000006	0.0390	146.2	1.3
950	24.57	0.08	0.0403	0.000073	0.000033	0.000008	0.0296	146.0	1.3
1000	24.82	0.10	0.0398	0.000102	0.000044	0.000011	0.0227	147.4	1.8
1050	24.97	0.06	0.0398	0.000041	0.000025	0.000008	0.0326	148.2	1.1
1100	24.61	0.05	0.0403	0.000052	0.000027	0.000005	0.0503	146.2	0.9
1150	24.76	0.06	0.0400	0.000053	0.000031	0.000006	0.0437	147.0	0.9
1200	24.83	0.14	0.0399	0.000091	0.000034	0.000017	0.0153	147.4	2.4
1300	21.24	3.32	0.0388	0.001011	0.000594	0.000418	0.0007	126.9	57.4

Data from UC Santa Barbara

T	40(mol)	40Ar/39Ar	38Ar/39Ar	37Ar/39Ar	36Ar/39Ar	K/Ca	f39Ar	40Ar*	age (Ma)	±1 s
92HXS05		biotite								
600	8.80E-14	37.9558	7.70E-04	0.1006	0.003	4.9	0.04232	0.977	831.2	2.1
650	1.80E-13	64.7173	<0	0.1015	0.0026	4.8	0.09262	0.988	1259	2.2
670	1.80E-13	68.6133	<0	0.0449	0.0024	11	0.14004	0.99	1314.2	2.5
700	3.10E-13	73.6785	<0	0.3578	0.0023	1.4	0.21533	0.991	1382.8	1.7
700	1.70E-13	71.8508	<0	0.0593	0.0011	8.3	0.25869	0.996	1363.5	2.5
710	1.70E-13	73.172	<0	0.0849	0.0008	5.8	0.30084	0.997	1382.1	2.7
720	1.70E-13	74.7312	<0	0.0856	0.0009	5.7	0.34134	0.997	1402.4	2.6
750	2.60E-13	77.5105	<0	0.0508	0.0008	9.6	0.40226	0.997	1438.7	2.2
760	1.90E-13	78.3069	<0	0.0892	0.0009	5.5	0.44684	0.997	1448.6	2.5
770	1.40E-13	76.9367	8.90E-04	0.0587	0.0008	8.3	0.48099	0.997	1431.4	2.9
800	1.80E-13	75.8955	<0	0.0555	0.0008	8.8	0.52499	0.997	1417.9	2.5
820	1.50E-13	76.0612	<0	0.0167	0.0006	29	0.56074	0.998	1420.6	2.9
850	1.70E-13	76.8519	4.00E-04	<0	0.0005	<0.001	0.60072	0.998	1431.5	2.7
870	1.50E-13	80.2588	1.50E-04	0.0036	0.0007	138	0.63565	0.997	1473.9	2.8
900	2.20E-13	89.0101	<0	<0	0.0007	<0.001	0.67968	0.998	1580.9	2.5
920	1.80E-13	94.8598	8.10E-04	<0	0.0007	<0.001	0.71402	0.998	1649	3
950	2.10E-13	101.1805	1.10E-03	0.0513	0.0005	9.5	0.75236	0.999	1720.3	2.8
970	1.90E-13	102.0011	1.70E-03	0.0241	0.0008	20	0.78555	0.998	1728.2	3.5
1000	2.50E-13	101.4874	<0	0.0040	0.0006	124	0.83095	0.998	1723.3	2.5
1025	2.60E-13	96.9159	1.10E-03	<0	0.0006	<0.001	0.87883	0.998	1672.6	2.7
1050	2.50E-13	92.4713	6.60E-05	0.0195	0.0005	25	0.92872	0.998	1622	2.6
1100	2.70E-13	88.1415	7.40E-04	0.0432	0.0008	11	0.98395	0.997	1570.2	2.3
1150	7.40E-14	84.1603	4.00E-04	0.0817	0.0003	6	1	0.999	1523.8	5.2

92KB1		biotite								
500	1.40E-13	37.7555	2.80E-02	0.0925	0.033	5.3	0.04846	0.742	661.1	2.6
550	2.80E-13	39.3487	1.30E-02	0.0648	0.0153	7.6	0.14211	0.885	791.7	1.6
600	2.80E-13	38.9649	2.60E-02	0.1003	0.0065	4.9	0.23917	0.95	831.5	1.4
600	1.10E-13	41.3761	1.10E-02	0.0673	0.0043	7.3	0.27531	0.969	886.1	3
610	8.90E-14	44.0593	2.90E-04	0.0890	0.0037	5.5	0.3024	0.975	935.7	3.9
620	7.80E-14	46.6531	1.20E-03	0.0584	0.0033	8.4	0.32483	0.979	980.9	4.4
630	7.00E-14	48.5254	<0	0.0776	0.0034	6.3	0.34406	0.98	1011.5	5.3
650	7.80E-14	49.2799	<0	0.0449	0.0038	11	0.36531	0.977	1021.4	4.7
670	8.00E-14	48.6346	<0	0.0401	0.0044	12	0.38736	0.973	1008	4.3
690	7.80E-14	46.2834	<0	0.0194	0.0064	25	0.4099	0.959	959.3	4.5
710	8.30E-14	41.8699	<0	0.0425	0.0078	12	0.43634	0.945	876.8	4.1
730	1.10E-13	38.6668	<0	0.0607	0.0077	8.1	0.47279	0.941	820	2.9
750	1.40E-13	36.6379	2.00E-04	0.0409	0.006	12	0.52215	0.952	792.3	2.5
770	1.50E-13	35.5647	<0	0.0299	0.0042	16	0.58032	0.965	782.4	2
800	2.40E-13	34.3573	<0	0.0190	0.0033	26	0.67212	0.972	764.9	1.5
830	2.90E-13	38.4296	<0	0.1112	0.003	4.4	0.77338	0.977	841.1	1.4
830	1.80E-13	45.0441	<0	0.0133	0.0023	37	0.82674	0.985	959.1	2.2
850	1.70E-13	48.1665	<0	0.0325	0.0019	15	0.87438	0.988	1012.5	2.7
880	1.50E-13	51.7086	<0	0.0630	0.0018	7.8	0.91232	0.989	1069.6	3
900	1.00E-13	58.9021	<0	0.0690	0.0019	7.1	0.93583	0.99	1179.2	4.3
920	7.40E-14	63.5968	5.30E-04	0.0812	0.0016	6	0.95129	0.992	1248.9	6.9
950	7.10E-14	61.2696	6.70E-04	0.0824	0.0018	5.9	0.96679	0.991	1214.7	6.4
970	6.20E-14	62.9701	<0	0.0732	0.002	6.7	0.98004	0.991	1238.3	7.1
1000	3.90E-14	71.5469	<0	0.1335	0.0009	3.7	0.9873	0.996	1362	12
1020	1.90E-14	77.6407	<0	0.4305	0.001	1.1	0.99051	0.996	1441.5	29.7
1050	2.20E-14	82.5694	<0	<0	0.0023	<0.001	0.994	0.992	1498.8	25.9
1070	5.80E-15	68.5974	<0	<0	0.0033	<0.001	0.99513	0.986	1312	78.4
1100	6.90E-15	69.7175	1.20E-03	0.7122	0	0.69	0.99644	1	1342.8	68.3
					0.0027					

1150	7.90E-15	75.9282	<0	0.4428	0.0041	1.1	1	0.984	1407.4	61.3
92WQ-G		biotite								
500	6.40E-14	7.4377	2.20E-03	0.0740	0.0169	6.6	0.07218	0.327	68	1.2
550	1.10E-13	6.6784	2.20E-03	0.0592	0.0117	8.3	0.21516	0.483	89.7	0.7
580	8.20E-14	6.447	3.80E-03	0.0522	0.0092	9.4	0.32239	0.579	103.4	0.8
600	5.40E-14	6.2635	4.30E-03	0.0493	0.0084	9.9	0.39491	0.602	104.3	1
650	6.70E-14	5.8145	5.60E-03	0.0371	0.0073	13	0.49166	0.629	101.3	0.9
700	4.50E-14	5.7806	7.60E-03	0.0454	0.0077	11	0.55698	0.606	97.1	1.2
750	3.20E-14	7.8712	8.80E-03	0.0720	0.0125	6.8	0.59094	0.532	115.5	2
800	3.90E-14	6.9198	2.00E-03	0.0420	0.0084	12	0.63814	0.641	122.2	1.6
850	4.40E-14	6.6228	<0	0.0524	0.0079	9.4	0.69357	0.646	118	1.3
900	6.50E-14	6.1724	<0	0.0419	0.0071	12	0.78303	0.662	112.8	0.9
950	7.70E-14	5.8257	<0	0.0343	0.0069	14	0.89456	0.65	104.9	0.8
1000	5.10E-14	5.0573	<0	0.0314	0.007	16	0.98007	0.591	83.3	0.9
1050	1.00E-14	5.3526	<0	0.0781	0.0047	6.3	0.99585	0.741	109.7	4.3
1100	2.00E-15	5.7295	<0	1.1000	0.0058	0.45	0.9988	0.699	110.7	21.7
1150	6.60E-16	6.5984	<0	0.4160	0.013	1.2	0.99964	0.417	76.8	72.5
1200	4.30E-16	10.2825	4.10E-02	2.0449	0.0207	0.24	1	0.405	114.5	182.6
94BC13		biotite								
650	1.4E-14	9.0209	0.00001500	0.0415	0.0	12	0.05868	0.839	203.4	2.6
730	4E-14	8.0705	<0	<0	0.0	<0.001	0.2471	0.973	210.7	0.8
770	2.9E-14	7.938	<0	<0	0.0	<0.001	0.38777	0.986	209.9	1.1
790	1.4E-14	8.0282	<0	<0	0.0	<0.001	0.45432	0.97	208.9	2.8
800	6.3E-15	7.8638	<0	<0	0.0	<0.001	0.48517	0.97	205	4.3
810	4.1E-15	7.8248	<0	<0	0.0	<0.001	0.50536	0.95	200	7
820	3.1E-15	7.8527	0.00250000	<0	0.0	<0.001	0.52034	0.977	206.1	8.9
830	2.6E-15	7.7176	<0	<0	0.0	<0.001	0.53315	0.979	203.1	11.2
880	5.6E-15	7.9273	<0	<0	0.0	<0.001	0.5605	0.98	208.4	5.1
920	8.1E-15	7.8157	<0	<0	0.0	<0.001	0.60041	0.991	208	3.4
990	1.8E-14	7.8133	<0	<0	0.0	<0.001	0.68707	0.991	207.8	1.7
1080	4.3E-14	7.893	<0	<0	0.0	<0.001	0.89449	0.99	209.6	0.8
1150	2.2E-14	8.1122	<0	<0	0.0	<0.001	1	0.977	212.5	1.3
94HYS13		biotite								
500	3.20E-14	4.4924	<0	0.0161	0.0086	30	0.10889	0.434	54.8	1.1
540	4.20E-14	4.8234	<0	0.0074	0.008	66	0.24453	0.508	68.6	0.9
580	4.30E-14	5.131	<0	<0	0.0083	<0.001	0.37257	0.523	75	1
620	4.20E-14	5.2917	<0	<0	0.0086	153	0.49462	0.52	76.8	1
660	3.80E-14	5.2991	<0	<0	0.0087	<0.001	0.60483	0.517	76.5	1.1
700	2.60E-14	5.2757	<0	<0	0.0086	<0.001	0.67961	0.516	76	1.6
740	7.80E-15	5.4012	<0	<0	0.0095	<0.001	0.70193	0.48	72.4	5.1
770	4.60E-15	5.6458	<0	<0	0.0117	51	0.71457	0.387	61.3	10.1
800	7.00E-15	5.374	<0	<0	0.0105	<0.001	0.73476	0.423	63.7	5.9
830	7.10E-15	5.1657	<0	<0	0.01	<0.001	0.75599	0.426	61.6	5.4
860	6.60E-15	5.0955	<0	<0	0.0098	<0.001	0.77601	0.432	61.6	5.4
890	7.40E-15	5.099	<0	<0	0.0095	<0.001	0.79833	0.45	64.2	5.2
920	8.90E-15	5.0184	<0	<0	0.0085	<0.001	0.82578	0.5	70.1	4.2
950	1.10E-14	4.9443	<0	<0	0.0083	<0.001	0.86114	0.504	69.7	3.2
980	1.90E-14	4.9871	<0	<0	0.0087	<0.001	0.92055	0.483	67.4	2.2
1010	1.80E-14	4.9978	<0	<0	0.0086	<0.001	0.97763	0.491	68.6	2
1050	4.70E-15	5.4042	<0	<0	0.0086	<0.001	0.99094	0.532	80.2	8.5
1090	1.10E-15	5.5023	1.00E-04	0.3080	0.0085	1.6	0.994	0.544	83.3	35.7
1130	7.00E-16	5.5525	4.20E-04	0.5622	0.008	0.87	0.99595	0.573	88.4	58.1
1180	1.40E-15	5.4344	4.50E-03	0.3274	0.0067	1.5	0.99985	0.633	95.5	29.5
1250	3.00E-16	29.877	0.00E+00	13.9870	0.133	0.035	1	-0.316	-291.1	809.8
94YK46		K-white mica								
550	7.90E-15	9.5293	1.60E-03	0.1851	0.0095	2.6	0.00553	0.707	182.5	9.6
600	1.30E-14	7.8083	3.20E-03	0.0978	0.0032	5	0.01671	0.88	186	4.9
650	2.30E-14	7.3837	<0	0.0028	0.0013	173	0.03796	0.946	189	2.5
690	3.40E-14	7.3438	<0	0.0195	0.0012	25	0.06878	0.95	188.7	1.6
720	4.10E-14	7.4154	<0	0.0088	0.0015	56	0.10598	0.942	188.9	1.6
740	4.80E-14	7.3478	<0	0.0103	0.0011	47	0.15	0.955	189.7	1.2
750	4.70E-14	7.149	<0	0.0185	0.0005	27	0.19447	0.98	189.4	1.2
760	4.70E-14	7.0946	<0	0.0161	0.0005	30	0.23906	0.981	188.3	1.3
765	4.20E-14	7.1206	<0	0.0187	0.0004	26	0.27871	0.985	189.7	1.3
770	4.00E-14	7.158	<0	0.0051	0.0005	96	0.31594	0.98	189.7	1.5
775	3.80E-14	7.1793	<0	0.0144	0.0004	34	0.3518	0.982	190.6	1.5

780	3.80E-14	7.1723	<0	0.0090	0.0004	54	0.3874	0.984	190.7	1.6
785	3.80E-14	7.2102	<0	0.0096	0.0004	51	0.42319	0.982	191.5	1.6
790	3.80E-14	7.2152	<0	<0	0.0004	<0.001	0.45849	0.983	191.6	1.5
800	4.60E-14	7.2399	<0	0.0040	0.0004	122	0.50148	0.983	192.3	1.3
810	5.20E-14	7.2514	<0	0.0131	0.0004	37	0.5495	0.985	192.9	1.1
820	5.60E-14	7.2575	<0	0.0065	0.0005	76	0.6015	0.98	192.2	1
840	7.70E-14	7.3101	<0	0.0112	0.0006	44	0.67246	0.976	192.7	0.8
860	9.00E-14	7.3565	<0	<0	0.0006	<0.001	0.75493	0.976	194	0.7
880	9.20E-14	7.4629	<0	0.0090	0.0006	54	0.83746	0.975	196.4	0.8
900	8.20E-14	7.5103	<0	0.0085	0.0006	57	0.91075	0.978	198.1	0.8
920	5.90E-14	7.5298	<0	0.0018	0.0005	269	0.96361	0.979	198.8	1
940	3.20E-14	7.5337	<0	<0	0.0004	<0.001	0.99212	0.984	200	1.8
960	7.80E-15	7.5101	1.60E-04	0.0021	0.0002	233	0.99907	0.993	201.1	7.6
990	7.90E-16	7.7728	6.70E-03	0.8724	0.0001	0.56	0.99975	0.996	208.2	79
1060	8.60E-16	33.6617	2.20E-02	1.2395	0.0427	0.4	0.99992	0.625	517.7	293.8
1160	9.30E-16	82.19	8.30E-02	5.1628	0.0721	0.095	1	0.741	1215.8	547.8

95LYG1 biotite										
500	8.4E-14	6.7295	<0	0.0404	0.0111	12	0.10812	0.514	96.2	0.8
550	1.1E-13	7.8014	<0	0.0258	0.0132	19	0.23088	0.499	107.9	0.8
600	1E-13	8.3802	<0	0.0155	0.0141	32	0.33401	0.504	116.6	0.9
650	1.2E-13	8.5164	<0	0.0211	0.0141	23	0.45966	0.511	120.1	0.8
700	1.4E-13	8.5303	<0	0.0165	0.0144	30	0.59676	0.501	118.1	0.7
750	4.6E-14	8.4176	<0	0.0068	0.0132	72	0.64409	0.537	124.5	1.8
800	3.4E-14	8.2785	<0	0.0045	0.0137	108	0.67917	0.511	117	2.5
850	5.3E-14	8.4101	<0	0.0175	0.0146	28	0.73419	0.487	113.2	1.7
900	6.4E-14	8.3189	<0	0.0166	0.0144	30	0.80068	0.49	112.7	1.4
950	1.2E-13	8.2426	<0	0.0182	0.0145	27	0.92552	0.479	109.3	0.8
1000	6.4E-14	8.2948	<0	0.0409	0.014	12	0.99267	0.502	115.2	1.3
1050	5.9E-15	8.6279	<0	0.1676	0.014	2.9	0.99855	0.521	124	12.7
1100	1.2E-15	8.9245	<0	0.3684	0.01	1.3	0.99967	0.669	162.9	73.2
1150	3.9E-16	10.2552	0.026	0.5513	0.0122	0.89	1	0.648	180.1	225.4

95YTST01f K-white mica										
550	5.40E-15	5.9704	<0	0.0569	0.0023	8.6	0.00592	0.885	144.8	9.3
600	1.30E-14	5.9103	<0	0.0274	0.001	18	0.02033	0.952	153.8	3.7
650	2.60E-14	5.782	<0	0.0243	0.0003	20	0.04966	0.985	155.6	1.8
700	4.80E-14	5.9412	<0	0.0004	0.0002	1301	0.10275	0.991	160.7	1
750	6.40E-14	6.0935	<0	0.0066	0.0001	74	0.17126	0.994	165.1	0.9
800	7.00E-14	6.2666	<0	0.0052	0.0001	93	0.24377	0.994	169.6	0.8
850	8.60E-14	6.4809	<0	0.0017	0.0001	282	0.33048	0.995	175.3	0.7
900	1.10E-13	6.4601	<0	0.0078	0.0001	63	0.43928	0.997	175	0.6
950	1.00E-13	6.4383	<0	0.0071	0.0001	69	0.54202	0.997	174.5	0.6
1000	9.60E-14	6.4645	<0	0.0135	0.0001	36	0.63898	0.996	175	0.6
1050	9.50E-14	6.5099	<0	0.0041	0.0001	121	0.73416	0.996	176.1	0.6
1100	8.10E-14	6.5839	<0	0.0117	0.0001	42	0.81495	0.997	178.2	0.8
1150	9.20E-14	6.8412	<0	0.0191	0.0001	26	0.90269	0.997	184.8	0.7
1200	1.10E-13	7.2713	<0	0.0020	0.0001	240	1	0.996	195.7	0.7

95ZY10 K-white mica										
600	1.40E-14	12.9246	5.10E-03	<0	0.0049	<0.001	0.01042	0.888	300.5	7.2
640	2.10E-14	12.5386	1.30E-03	<0	0.0043	<0.001	0.0267	0.899	295.6	4.5
680	3.80E-14	12.7223	<0	0.0185	0.0059	26	0.05595	0.862	288.3	2.4
720	7.20E-14	11.8246	<0	0.0123	0.003	40	0.1163	0.926	287.9	1.2
760	2.00E-13	11.3188	<0	0.0002	0.0016	3017	0.29008	0.959	285.6	0.6
780	9.30E-14	10.8378	<0	<0	0.0005	<0.001	0.37477	0.986	281.3	0.9
790	9.30E-14	10.8706	<0	<0	0.0005	<0.001	0.45974	0.986	282.2	0.9
800	8.00E-14	10.8427	<0	<0	0.0005	<0.001	0.53331	0.986	281.5	1.1
810	6.00E-14	10.8892	<0	<0	0.0006	<0.001	0.58772	0.984	282.1	1.3
820	4.60E-14	10.9352	<0	<0	0.0008	<0.001	0.62909	0.978	281.6	1.8
840	4.40E-14	10.9951	<0	<0	0.0008	<0.001	0.66886	0.978	283	1.7
860	6.10E-14	10.9599	<0	<0	0.0008	<0.001	0.72445	0.978	282.3	1.3
890	1.00E-13	10.7927	<0	<0	0.0007	<0.001	0.81818	0.981	278.9	0.9
920	6.90E-14	10.8007	<0	<0	0.0007	<0.001	0.88128	0.982	279.4	1.2
950	4.20E-14	10.7375	<0	<0	0.0005	<0.001	0.91987	0.985	278.8	1.6
980	2.40E-14	10.8215	<0	<0	0.0005	<0.001	0.94164	0.985	280.8	3.3
1000	1.50E-14	10.8933	<0	<0	0.0006	<0.001	0.95532	0.984	282.2	5.3
1020	1.10E-14	10.9484	<0	<0	0.0011	<0.001	0.96545	0.971	279.9	7.7
1040	8.20E-15	11.1173	<0	<0	0.0016	<0.001	0.97278	0.957	280.3	10.1
1060	7.10E-15	11.4734	<0	<0	0.0025	<0.001	0.97892	0.937	282.9	11.9

1080	5.50E-15	11.4703	3.70E-04	<0	0.0023	<0.001	0.98369	0.94	283.8	15.4
1100	4.60E-15	11.5945	<0	<0	0.003	<0.001	0.98758	0.923	281.7	17.7
1120	3.80E-15	11.6702	<0	<0	0.0041	<0.001	0.99081	0.896	275.8	23
1140	2.30E-15	12.3606	<0	<0	0.0077	<0.001	0.99267	0.816	266.8	38.8
1160	3.50E-15	11.8455	<0	<0	0.0043	<0.001	0.99561	0.894	279	25.4
1200	2.80E-15	13.118	<0	<0	0.0051	<0.001	0.9977	0.885	303.6	30.6
1250	3.30E-15	14.1904	<0	<0	0.01	<0.001	1	0.791	294.6	31.2