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Th, U AND Pb ANALYTICAL DATA AND CHIME DATING OF MONAZITES FROM METAMORPHIC ROCKS OF THE RAYNER, LÜTZOW-HOLM, YAMATO-BELGICA AND SØR RONDANE COMPLEXES, EAST ANTARCTICA

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Abstract: This is a data-set paper, listing a total of 1091 electron microprobe ThO_2, UO_2 and PbO analyses and CHIME ages of monazites from 12 granulite-facies paragneiss samples from Mt. Vechernyaya (west-coastal Rayner Complex, 2 samples), Syowa Station (Lützow-Holm Complex, 2 samples), the Yamato Mountains (Yamato-Belgica Complex, 2 samples) and the Sør Rondane Mountains (Sør Rondane Complex, 6 samles), East Antarctica. Most monazite grains are chronologically unzoned. They occur in garnet as well as in other main constituent minerals and at grain-boundaries. The CHIME ages are within a narrow range: 533±9 Ma (MA88021504B) and 532±9 Ma (MA88021515-2) at Mt. Vechernyaya, 533±10 Ma (MA80020603B) and 537±9 Ma (MA80020702) at Syowa Station, 534±7 Ma (Y80A119) and 531±8 Ma (Y80A121d) in the Yamato Mountains, and 534±10 Ma (MA88011002-1), 529±14 Ma (MA88012216), 543±18 Ma (MA88020202-1), 542±6 Ma (84021904B), 539±16 Ma (84022004) and 541±15 Ma (85020401C) in the Sør Rondane Moutains. Distinct stepwise age zoning is observed in some grains from samples from the Yamato Mountains (Y80121d) and Sør Rondane Mountains (MA88020202-1, 84021904B and 84022004). The zoned grains, like the unzoned ones, occur in garnet as well as in other main constituent minerals and at grain-boundaries. The rims of the zoned monazite grains give CHIME ages of 530–550 Ma, almost the same as those of unzoned grains, but the CHIME ages of the cores range from *ca.* 620 to *ca.* 750 Ma. The intergrain variation in the core age within a single sample suggests that the older cores are of detrital origin; the paragneiss protolith, at least in the Yamato-Belgica and Sør Rondane Complexes, is considered to have been deposited after the ~620 Ma thermal event in the provenance. This demonstrates that these paragneisses, if not all, are not of the polymetamorphosed late Proterozoic complexes as so far believed. The post-~620 Ma sediments, along with the protolith in the west-coastal Rayner and Lützow-Holm Complexes, are likely to have undergone high-grade metamorphism in the Cambrian (530–550 Ma). The Cambrian orogenic belt is more widespread in East Antarctica than has been thought.

key words: CHIME monazite age, granulite facies, Cambrian, East Antarctica

1. Introduction

High-grade metamorphic rocks together with plutonic rocks make up the Rayner, Lützow-Holm, Yamato-Belgica and Sør Rondane Complexes in East Antarctica (Fig. 1). The metamorphic rocks are essentially of granulite- to upper amphibolite-facies, and show evidence of a retrogressive overprint, possibly related to the emplacement of plutonic rocks. The timing of the granulite- to upper amphibolite-facies regional metamorphism has been studied through the K-Ar, Rb-Sr, Sm-Nd and U-Pb methods (*e.g.* NICOLAYSEN *et al.*, 1961; PICCIOTTO and COPPEZ, 1964; PICCIOTTO *et al.*, 1964; MAEGOYA *et al.*, 1968; PASTEELS and MICHOT, 1970; YANAI and UEDA, 1974; GREW, 1978; KOJIMA *et al.*, 1982; SHIBATA *et al.*, 1985, 1986; BLACK *et al.*, 1987; TAKAHASHI *et al.*, 1990; GREW *et al.*, 1992; SHIRAISHI and KAGAMI, 1992). Although most age data, especially K-Ar and Rb-Sr mineral ages, are concentrated at *ca.* 500 Ma, several Rb-Sr and Sm-Nd whole-rock data and U-Pb zircon data give late Proterozoic ages (*ca.* 1000 Ma). By referring to these ages, some researchers have considered that the granulite- to upper amphibolite-facies regional metamorphism took place at the late Proterozoic and the retrogressive overprinting at the Cambrian (*e.g.* HIROI *et al.*, 1983; YOSHIDA *et al.*, 1983; SHIBATA *et al.*, 1986; BLACK *et al.*, 1987; GREW *et al.*, 1992; SHIRAISHI and KAGAMI, 1992).

Recent geochronological studies, however, have revealed the existence of Cambrian granulite- to upper amphibolite-faces metamorphic rocks in the Rayner, Lützow-Holm, Yamato-Belgica and Sør Rondane Complexes on the basis of ion microprobe zircon ages of 520–600 Ma (SHIRAISHI *et al.*, 1992, 1994, 1996) and CHIME monazite ages of *ca.* 535 Ma (ASAMI *et al.*, 1996). To determine the regional extent of the Cambrian high-grade metamorphic rocks and the sedimentation age of the gneiss protolith, we undertook CHIME dating of monazites from paragneisses from Mt. Vechernyaya (Rayner Complex), Syowa Station (Lützow-Holm Complex), the Yamato Mountains (Yamato-Belgica Complex) and the Sør Rondane Mountains (Sør Rondane Complex).

2. Description of Analyzed Samples

A total of 12 paragneiss samples from the four metamorphic complexes were selected for the CHIME monazite dating (Figs. 1 and 2). Sample numbers, rock types and

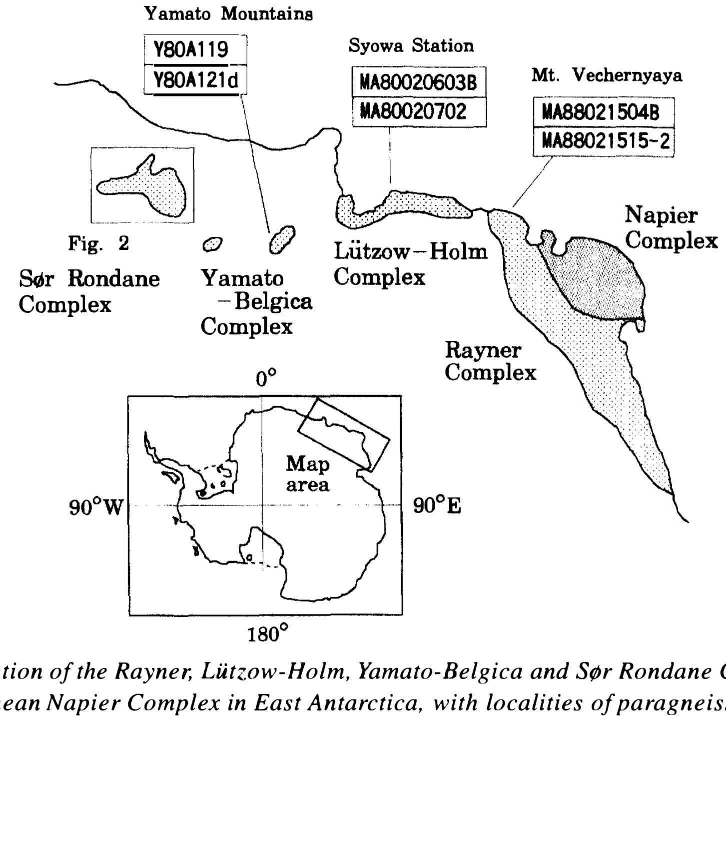

Fig. 1. Distribution of the Rayner, Lützow-Holm, Yamato-Belgica and Sør Rondane Complexes, and the Archean Napier Complex in East Antarctica, with localities of paragneiss samples.

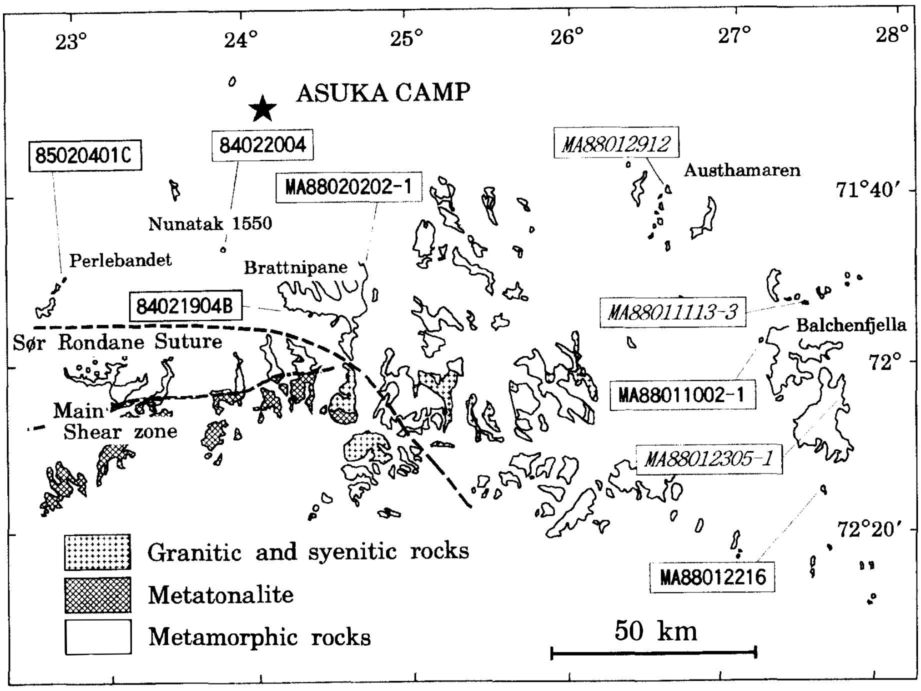

Fig. 2. Geologic map of the Sør Rondane Complex, with localities of paragneiss samples. The CHIME monazite ages for samples shown in italic were reported in ASAMI *et al. (1996).*

localities of these samples are listed in Table 1, and mineral assemblages of the samples are summarized in Table 2.

Mt. Vechernyaya (67°39'S, 46°09'E) in the Thala Hills is situated about 15 km east of Molodezhnaya Station along the west coast of the Rayner Complex. Rocks at Mt. Vechernyaya were described by GREW (1978, 1981) as the eastward continuation of the Proterozoic granulite-facies metamorphic rocks exposed around Molodezhnaya Station. The Rayner samples were collected from orthopyroxene gneiss layers that are comformably associated with two-pyroxene-hornblende gneiss and sillimanite-garnet-biotite gneiss layers. These gneisses are members of the unit of migmatitic pyroxene, hornblende, garnet-biotite and garnet-pyroxene gneisses in the map of GREW (1978). However, no distinct migmatitic feature is observed on the samples studied.

The Lützow-Holm and Yamato-Belgica Complexes were considered to form the Late Proterozoic paired metamorphic belts (HIROI *et al.*, 1991): the former is characterized by medium-pressure type progressive metamorphism with a south-westward increase in metamorphic grade from amphibolite- to granulite-facies, and the latter by low-pressure type granulite-facies metamorphism accompanied by widespread igneous activity. The timing of metamorphism for both the complexes, however, has been reinterpreted to be the Cambrian (SHIRAISHI *et al.*, 1994).

Syowa Station on East Ongul Island (69°00'S, 39°35'E) is located in the granulite-facies terrane of the Lützow-Holm Complex. The Lützow-Holm samples were collected at different positions within a single layer of garnet gneiss on the island, which was mapped by YANAI *et al.* (1974). The garnet gneiss is conformably associated with pyroxene gneiss including two-pyroxene-biotite quartzo-feldspathic gneiss and with metabasite such as orthopyroxene-garnet amphibolite. The Yamato-Belgica samples are from Mas-

Table 1. Sample numbers, rock types and localities of the analyzed samples.

	Sample No.	Rock type	Locality
			<Rayner Complex>
(1)	MA88021504B	Opx-Grt-Bt gneiss	Mt. Vechernyaya, Thala Hills
(2)	MA88021515-2	Opx-Grt-Bt gneiss	Mt. Vechernyaya, Thala Hills
			<Lützow-Holm Complex>
(3)	MA80020603B	Grt-Bt gneiss	Syowa Station, East Ongul Island
(4)	MA80020702	Grt-Bt gneiss	Syowa Station, East Ongul Island
			<Yamato-Belgica Complex>
(5)	Y80A119	Grt-Bt gneiss	Massif A, Yamato Mountains
(6)	Y80A121d	Spl-Opx-Bt gneiss	Massif A, Yamato Mountains
			<Sør Rondane Complex>
(7)	MA88011002-1	Grt-Bt gneiss	Balchenfjella, eastern Sør Rondane Mountains
(8)	MA88012216	Grt-Bt gneiss	Eremitten, eastern Sør Rondane Mountains
(9)	MA88020202-1	Grt-Bt gneiss	Brattnipane, central Sør Rondane Mountains
(10)	84021904B	Sil-Grt-Bt gneiss	Brattnipane, central Sør Rondane Mountains
(11)	84022004	Grt-Bt gneiss	Nunatak 1550, western Sør Rondane Mountains
(12)	85020401C	Grt-Bt gneiss	Perlebandet, western Sør Rondane Mountains

MA80- and MA88-prefixed samples were collected by M. Asami during JARE-21 and -29, respectively, Y80-ones by M. Asami and K. Shiraishi during JARE-21, and 84- and 85- ones by K. Shiraishi during JARE-25 and -26, respectively. Mineral abbreviations: Bt-biotite, Grt-garnet, Opx-orthopyroxene, Sil-sillimanite, Spl-spinel.

Table 2. Mineral assemblages of the analyzed samples.

Sample	Spl	Sil	Grt	Opx	Bt	Kfs	Pl	Qtz	Ap	Mnz	Rt	Zrn	Gr	Ore	Secondary
Mt. Vechernyaya															
MA88021504B			+	+	+		+	+	-	-	-	-		-	
MA88021515-2				+	+	+	+	+	-	-		-		-	
Syowa Station															
MA80020603B			+		+	+	+	+	-	-	-	-		-	
MA80020702			+		+	+	+	+	-	-/G	-	-		-	
Yamato Mts.															
Y80A119			+		+	+	+	+	-	-		-	-	-Ilm	
Y80A121d	$(+)_P$			+	+		+		-	-		-	-	-	
Sør Rondane Mts.															
MA88011002-1			+		+	+	+	+	-	-		-		-	
MA88012216			+		+	+	+	+	-	-		-		-	
MA88020202-1			+		+		+	+	-	-	-	-		-	Bt,Ms
84021904B	$(+)_{SGP}$	+	+		+	+	+	+	-	-/G	-	-		-Ilm	Ky,Bt,Ms
84022004			+		+	+	+	+	-	-		-		-	
85020401C			+		+	+	+	+	-	-/G		-		-	Bt,Ms

Mineral abbreviations: Ap-apatite, Bt-biotite, Gr-graphite, Grt-garnet, Ilm-ilmenite, Kfs-K-feldspar, Ky-kyanite, Mnz-monazite, Ms-muscovite, Opx-orthopyroxene, Pl-plagioclase, Qtz-quartz, Rt-rutile, Sil-sillimanite, Spl-spinel, Zrn-zircon. +,-: present as main constituents and accessories, respectively. $(+)_{SGP}$: enclosed in sillimanite, garnet and plagioclase, respectively. /G: occurs in garnet as well as in the matrix.

sif A of the Yamato Mountains (71°43'S, 35°50'E). In Massif A, metamorphic rocks occur as isolated masses intruded in places by syenitic rocks and as xenolithic blocks enclosed in the syenitic rocks, and include two-pyroxene-bearing gneiss and amphibolite (ASAMI and SHIRAISHI, 1983). The samples are parts of xenolithic blocks in the syenitic rocks. A more detailed description of Sample Y80A119 was given in ASAMI and SHIRAISHI (1985).

The Sør Rondane Mountains are underlain largely by granulite-facies metamorphic rocks, including garnet-biotite-sillimanite-orthoclase gneiss and two-pyroxene-garnet-hornblende-biotite gneiss, northeast of the Sør Rondane Suture, and by lower-grade metamorphic rocks and metatonalite southwest of the suture (ASAMI *et al.*, 1992; OSANAI *et al.*, 1992). In this paper rocks of the two regions are provisionally grouped as the Sør Rondane Complex. Small plutonic bodies intruded sporadically throughout this complex. The granulite-facies metamorphic rocks underwent an amphibolite-facies retrogressive recrystallization including the formation of kyanite and andalusite in pelitic gneisses (ASAMI *et al.*, 1992). The granulite-facies metamorphism and amphibolite-facies overprinting have been regarded as late Proterozoic (*ca.* 1000 Ma) and early Paleozoic (*ca.* 500 Ma) thermal events, respectively (GREW *et al.*, 1992; SHIRAISHI and KAGAMI, 1992). Recent CHIME geochronology, however, revealed that the granulite-facies mineral assemblages of pelitic gneisses in the eastern part of this complex formed in the Cambrian (ASAMI *et al.*, 1996).

The Sør Rondane samples were all collected from the granulite-facies terrane (Fig. 2). They are, in most cases, associated with orthopyroxene-bearing metamorphic rocks. Among the study samples, the kyanite-bearing one (84021904B) was described in detail by ASAMI and SHIRAISHI (1987).

3. Experiments

We analyzed monazites in polished thin sections prepared for conventional electron microprobe analyses. The main advantage of this way of analysis is that we know the petrographic positions of individual monazite grains, which may be helpful in age interpretation. All analyses were carried out using a JEOL JXA-733 microprobe equipped with three wavelength-dispersive type spectrometers. Instrument operating conditions were 15 kV accelerating voltage, 0.3 μA beam current and 5 μm beam diameter. The ThM_α, UM_β, PbM_α and YL_α lines were measured with the PET crystal; no other elements were analyzed. X-ray intensities were integrated over a 200-s period. The background was measured at two optimum positions on both sides of each line peak position. Marginal portions of monazite grains in contact with K-rich phases were not analyzed to avoid the potential spectral interference of KK_α on UM_β. Standards are euxenite provided by SMELLIE *et al.* (1978) for Th and U, a synthesized glass (10.18% PbO, 47.15% SiO_2, 14.21% Al_2O_3, 8.99% MgO and 19.58% CaO, analyst: K. SUZUKI) for Pb and a synthesized YPO_4 for Y.

The superimposition of YL_γ upon PbM_α was corrected through the procedure described by ÅMLI and GRIFFIN (1975):

Net PbM_α (sample)

$$= PbM_\alpha \text{ (sample)} - YL_\alpha \text{ (sample)} \times \frac{PbM_\alpha \text{ position } YL_\gamma}{YL_\alpha} \text{ (Pb-free Y standard).}$$

The net X-ray intensity data were converted into concentrations by the method described by BENCE and ALBEE (1969) using a composition of Th-rich natural monazite as a reference (10.29% ThO_2, 0.08% UO_2 and 0.523% PbO; 0.90% SiO_2, 0.95% Y_2O_3, 11.18% La_2O_3, 27.42% Ce_2O_3, 2.68% Pr_2O_3, 12.02 % Nd_2O_3, 2.12% Sm_2O_3, 0.70% Gd_2O_3, 0.16 Tb_2O_3, 0.21% Dy_2O_3, 1.29% CaO, and 28.64% P_2O_5). The small difference in the matrix elements barely affect the ThO_2, UO_2 and PbO determinations; the maximum error in this calculation, about 0.5% of the concentration, is less than the uncertainty in the X-ray counting.

4. Results and Discussion

Microprobe analyses of ThO_2, UO_2 and PbO together with the apparent age and ThO_2^* value (sum of the measured ThO_2 and ThO_2 equivalent of the measured UO_2) are listed in the Appendix. The detection limit of PbO at the 2σ confidence level is 0.01 wt%, and the relative error in the PbO determination is 5–10% for 0.1 wt% of the concentration. The CHIME ages were calculated through the method described by SUZUKI and ADACHI (1991a, b, 1994), SUZUKI *et al.* (1991, 1992, 1994) and ADACHI and SUZUKI (1992). The results are summarized in Table 3.

Most monazite grains in the paragneiss samples are chronologically unzoned. They are 0.05 to 0.3 mm in size and anhedral, but some grains show a trace of euhedral crystal form. Within individual samples, most grains are dispersed in the matrix (within quartz, K-feldspar, plagioclase, biotite or sillimanite grains, or at their grain boundaries), and several grains are enclosed in garnet grains. The unzoned grains give a narrow range of CHIME ages, 529–543 Ma (Table 3).

Detailed analyses of monazite grains have revealed that some of them have cores much older than *ca.* 540 Ma (Table 3). This is particularly common in Sample 84021904B that shows a high-grade mineral assemblage of spinel-garnet-biotite-sillimanite-orthoclase-plagioclase-quartz (see Table 2). The chronologically zoned monazite grains, like the unzoned *ca.* 540 Ma ones, are dispersed in some garnet grains as well as in the matrix (Fig. 3). They exhibit anhedral form, and are indistinguishable from the unzoned grains on the basis of the mode of occurrence and morphological characteristics.

Figure 4a shows the PbO *vs.* ThO_2* plot of analytical data for M09 grain enclosed in a garnet grain (Fig. 3a) in Sample 84021904B. Data points for the core (solid squares) and rim (solid circles) are separately arrayed, and define different isochrons of 753±37 Ma and 550±10 Ma. Figure 4b shows the PbO *vs.* ThO_2* plot of analytical data for M18 monazite grains enclosed in another garnet grain (Fig. 3b) in the same sample. Within this grain, the UO_2 is heterogeneously distributed with respect to the shape, showing various concentrations from 0.33 to 1.05 wt% in the core and from 0.61 to 1.10 wt% in the rim. The ThO_2 distribution, on the other hand, is stepwise, low in the core (<5 wt%) and high in the rim (7 to 14.7 wt% for most analyzed spots). This compositional discon-

Table 3. CHIME ages of chronologically unzoned and zoned monazites from the paragneiss samples.

Sample	Number of analyses	Age (Ma)
Mt. Vechernyaya		
(1) MA88021504B	81 spots on 4 grains	533 ± 9
(2) MA88021515-2	24 spots on 3 grains	532 ± 9
Syowa Station		
(3) MA80020603B	30 spots on 4 grains	533 ± 10
(4) MA80020702	83 spots on 5 grains	537 ± 9
Yamato Mountains		
(5) Y80A119	47 spots on 5 grains	534 ± 7
(6) Y80A121d	27 spots on 3 grains	531 ± 8
	M01-07 grain	619* (c)
Sør Rondane Mountains		
(7) MA88011002-1	65 spots on 11grains	534 ± 10
(8) MA88012216	114 spots on 4 grains	529 ± 14
(9) MA88020202-1	16 spots on 1 grain	543 ± 18
	M01-01 grain	623* (c)
(10) 84021904B	146 spots on 14 grains	542 ± 6
	18 spots on M09 grain	753 ± 37 (c)
	8 spots on M09 grain	550 ± 10 (r)
	9 spots on M18 grain	697 ± 47 (c)
	16 spots on M18 grain	547 ± 17 (r)
	15 spots on M12 grain	622 ± 11 (c)
	26 spots on M12 grain	549 ± 8 (r)
	M03, M13, M15, M19, M20, M21, M22 & M25 grains	622 – 639** (c)
	M25 grain	~760* (c_i)
(11) 84022004	85 spots on 9 grains	539 ± 16
	M08 grain	~670* (c)
(12) 85020401C	73 spots on 5 grains	541 ± 15

For zoned monazites, core and rim ages are marked with (c) and (r), respectively.
c_i - inner core. * Apparent ages; ** isochron and apparent ages (refer to the text for details).

tinuity suggests overgrowth of the rim under different chemical environments. The CHIME ages are 697±47 Ma for the core (solid squares) and 547±17 Ma for the overgrown rim (solid circles). Figure 4c shows the PbO *vs.* ThO_2* plot of analytical data for M12 monazite grain in the matrix of Sample 84021904B. This grains anhedral spherical in shape, although it is not given in Fig. 4c. The ThO_2 concentration, as in M18 grain, is low in the core (<5 wt% for most spots) and high in the rim (>10 wt% for most spots). The 15 data points for the core (solid squares) define an isochron of 622±11 Ma, and the 26 data points for the rim (solid circles) yield an isochron of 549±8Ma.

The core ages for other zoned monazite grains in this sample are 624 Ma (average of 9 apparent ages) for M03 grain, 639±66 Ma for M13 grain, 623±41 Ma for M15 grain, 627 Ma (average of 6 apparent ages) for M19 grain, 623 Ma (average of 6 apparent ages) for M20 grains, 633 Ma (average of 4 apparent ages) for M21 grain, 635 Ma (average of 4 apparent age) for M22 grain and 623±26 Ma with *ca.* 760 Ma at the inner core for M25

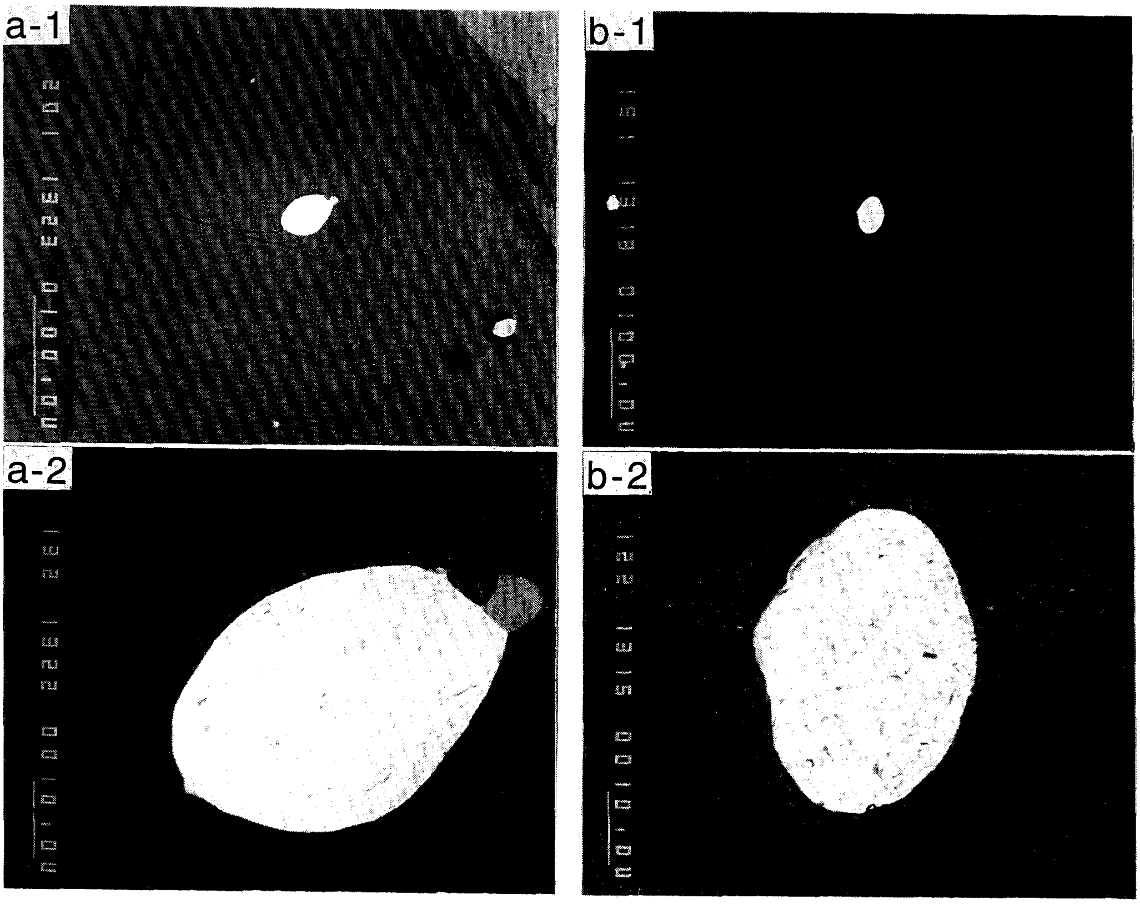

Fig. 3. Back scattered electron images of monazite grains enclosed in garnet porphyroblasts from Sample 84021904B, Sør Rondane Mountains. a-1: M09 monazite grain (center), a-2: ditto (enlargement). b-1: M18 monazite grain (center), b-2: ditto (enlargement). The grains in a and b correspond those in Fig. 4a and b, respectively. Scale bars (lower left) indicate 100 μm.

grain. These ages, except for the inner-core age of M25, are restricted to 620–640 Ma. As a result, all the core ages of this sample can be grouped into (1) 750–760 Ma, (2) 697 Ma and (3) 620–640 Ma.

The age and zoning pattern for the cores is different from grain to grain even in a single paragneiss sample, although every rim gives unequivocal ages of 530–550 Ma. Consequently, we consider that the older cores, at least those giving the isochron ages, are of detrital origin, retaining pre-metamorphic information. Inheritance of monazite grains in metamorphic rocks is not uncommon. PARRISH (1990) reported the persistence of detrital monazite in the upper-most amphibolite to lower granulite facies paragneiss near Passmore, British Columbia, Canada, and SMITH *et al.* (1992) showed the inheritance of monazite from the Neogene Shengus gneiss in the Himalaya of Pakistan. Further, SUZUKI and ADACHI (1994) and SUZUKI *et al.* (1994) identified many detrital grains of monazite as old as 1700 Ma from the Permian Hida gneiss of the upper amphibolite grade and the Cretaceous Ryoke gneiss of the upper amphibolite grade in southwest Japan. These examples reinforce the view that detrital monazite grains can persist in

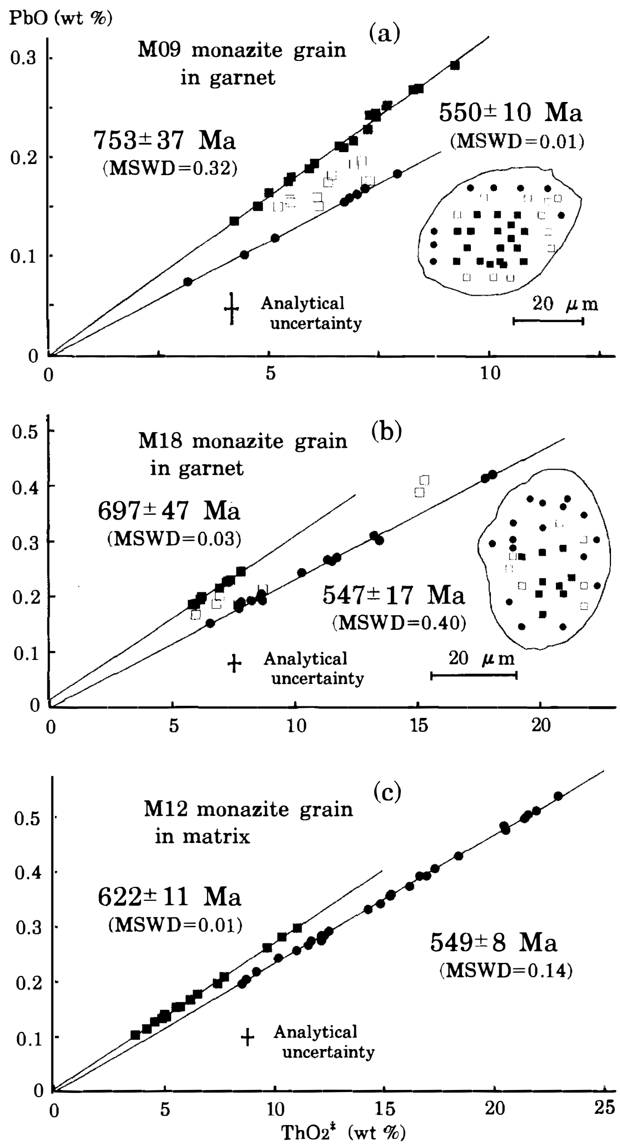

Fig. 4. PbO vs. ThO_2 plots of analytical data for chronologically zoned monazite grains M09 (a) and M18 (b) in garnet and M12 in matrix of Sample 84021904B from the Sør Rondane Mountains. Solid square shows data points for the core, solid circle shows those for the rim, and open square shows those for the transition part between the core and rim. Error bars in the figure represent maximum analytical uncertainty at 2σ, and the error given to the age is of 2σ.*

high-grade metamorphism.

If the older cores are of detrital origin, the youngest core age of monazite grains constrains the lower limit of sedimentation for the paragneiss protolith. It is 623 Ma (apparent age on M01-01) for Sample MA88020202-1, 622±11 Ma (M12 grain) for Sample 84021904B and *ca.* 670 Ma (apparent ages of M08) for Sample 84022004 in the Sør Rondane Mountains and 619 Ma (apparent age on M01-07) for Sample Y80A121d in the Yamato Mountains. The paragneiss protolith, at least in the Sør Rondane and Yamato Mountains, therefore, is considered to have deposited after the ~620 Ma thermal event in the provenance. This demonstrates that these paragneisses, if not all, are not of the polymetamorphosed late Proterozoic (*ca.* 1000 Ma) complexes as has been thought (*e.g.* HIROI *et al.*, 1983, 1991; YOSHIDA *et al.*, 1983; SHIBATA *et al.*, 1986; GREW *et al.*, 1992; SHIRAISHI and KAGAMI, 1992). It is likely that the post-~620 Ma sediments in the Sør Rondane and Yamato-Belgica Complexes, together with the protolith in the west-coastal Rayner and Lützow-Holm Complexes, underwent granulite- to upper amphibolite-facies metamorphism in the Cambrian, which is represented by the ubiquitous 530–550 Ma age for rims of zoned monazite grains and unzoned monazite grains.

Recent iron microprove (SHRIMP) dating indicated U-Pb zircon-rim ages of 520–600 Ma, representing the time of main regional, high-grade metamorphism in the west-coastal Rayner, Lützow-Holm and Yamato-Belgica Complexes (SHIRAISHI *et al.*, 1992, 1994, 1996). It is noteworthy that the CHIME monazite ages of 530–550 Ma in this study, along with those of ~535 Ma in ASAMI *et al.* (1996), are in good agreement with the SHRIMP ages. The inherited zircon U-Pb ages of 780–800 Ma were also reported by SHIRAISHI *et al.* (1996) from Mt. Vechernyaya as consistent ages with 770 Ma igneous activity in the Nye Mountains, Rayner Complex (BLACK *et al.*, 1987; SHERATON *et al.*, 1987). The 753 Ma CHIME monazite-core age obtained for the Sør Rondane sample (84021904B) is close to the above inherited zircon U-Pb ages.

5. Conclusions

The present CHIME dating of monazites revealed that at least some of the metamorphic rocks in the Rayner, Lützow-Holm, Yamato-Belgica and Sør Rondane Complexes are not part of a polymetamorphosed late Proterozoic complex, but were developed through the granulite- to upper amphibolite-facies metamorphism in the Cambrian (530–550 Ma). The paragneisses, at least in the Sør Rondane and Yamato-Belgica Complexes, are likely to have formed from the post-~620 Ma sediments. The Cambrian metamorphic belt is more widespread in East Antarctica than reported by SHIRAISHI *et al.* (1992, 1994, 1996) and ASAMI *et al.* (1996).

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Appendix. Microprobe analyses of ThO_2, UO_2 and PbO of monazites in metamorphic rocks from the Rayner, Lützow-Holm, Yamato-Belgica and Sør Rondane Complexes, East Antarctica.

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
** Rayner Complex: Mt. Vechernyaya					
MA88021504B: Opx-Grt-Bt gneiss					
M01-01	17.1	0.094	0.392	528	17.4
M01-02	17.6	0.096	0.401	525	18.0
M01-03	17.5	0.091	0.392	518	17.8
M01-04	17.1	0.091	0.391	527	17.4
M01-05	17.0	0.089	0.390	530	17.3
M01-06	16.8	0.091	0.381	524	17.1
M01-07	17.0	0.089	0.382	520	17.2
M01-08	16.5	0.090	0.377	526	16.8
M01-09	17.2	0.094	0.387	519	17.5
M01-10	15.8	0.124	0.351	510	16.2
M01-11	15.7	0.091	0.370	544	16.0
M01-12	15.3	0.085	0.349	526	15.6
M01-13	15.9	0.082	0.360	525	16.1
M01-14	14.8	0.121	0.337	521	15.2
M01-15	16.9	0.098	0.381	520	17.2
M01-16	16.8	0.071	0.390	536	17.1
M01-17	16.3	0.085	0.370	525	16.6
M01-18	15.7	0.091	0.347	510	16.0
M01-19	17.3	0.103	0.391	521	17.6
M01-20	17.3	0.087	0.388	520	17.6
M01-21	17.8	0.147	0.410	526	18.3
M02-01	20.7	0.194	0.477	526	21.3
M02-02	21.9	0.147	0.506	531	22.4
M02-03	21.7	0.174	0.489	517	22.2
M02-04	22.8	0.165	0.525	528	23.4
M02-05	22.6	0.158	0.518	525	23.2
M02-06	21.8	0.195	0.502	525	22.4
M03-01	20.6	0.097	0.476	534	20.9
M03-02	18.4	0.145	0.428	531	18.9
M03-03	13.9	0.148	0.320	523	14.4
M03-04	20.3	0.094	0.471	536	20.7
M03-05	20.3	0.094	0.467	532	20.6
M03-06	18.7	0.118	0.431	531	19.0
M03-07	15.6	0.159	0.356	519	16.1
M03-08	19.9	0.114	0.453	524	20.3
M03-09	20.6	0.121	0.482	538	21.0
M03-10	20.2	0.111	0.458	523	20.6
M03-11	20.0	0.115	0.449	518	20.4
M03-12	19.5	0.087	0.442	524	19.8
M03-13	19.3	0.092	0.437	524	19.6
M03-14	18.6	0.099	0.418	518	18.9
M03-15	15.6	0.122	0.357	523	16.0
M04-01	17.3	0.108	0.398	529	17.7
M04-02	17.1	0.105	0.393	531	17.4
M04-03	17.3	0.097	0.402	536	17.6
M04-04	24.6	0.172	0.565	527	25.2
M04-05	21.6	0.159	0.498	528	22.2
M04-06	17.6	0.106	0.402	525	18.0
M04-07	17.6	0.112	0.398	519	18.0
M04-08	17.1	0.096	0.397	534	17.4
M04-09	23.1	0.155	0.518	516	23.6
M04-10	23.3	0.149	0.535	528	23.8
M04-11	18.4	0.094	0.420	528	18.7
M04-12	19.0	0.107	0.430	522	19.4
M04-13	22.9	0.171	0.521	521	23.5
M04-14	18.1	0.109	0.409	520	18.5
M04-15	12.8	0.128	0.292	521	13.2
M04-16	16.9	0.124	0.390	530	17.3
M04-17	16.7	0.088	0.383	529	17.0
M04-18	16.7	0.062	0.374	520	16.9
M04-19	16.4	0.116	0.380	531	16.8
M04-20	16.6	0.108	0.375	520	17.0
M04-21	16.8	0.107	0.384	526	17.1
M04-22	17.1	0.107	0.389	523	17.5
M04-23	25.9	0.185	0.598	530	26.5
M04-24	21.4	0.124	0.486	524	21.8
M04-25	18.8	0.095	0.422	518	19.2
M04-26	16.6	0.104	0.381	529	16.9
M04-27	16.6	0.090	0.375	522	16.9
M04-28	23.4	0.185	0.540	529	24.0
M04-29	18.2	0.138	0.420	528	18.7
M04-30	17.8	0.091	0.410	533	18.1
M04-31	22.0	0.142	0.511	533	22.5
M04-32	23.2	0.160	0.536	530	23.7
M04-33	23.6	0.191	0.543	527	24.2
M04-34	23.3	0.194	0.534	524	23.9
M04-35	16.9	0.065	0.387	530	17.1
M04-36	16.8	0.083	0.384	530	17.0
M04-37	17.9	0.135	0.415	530	18.4
M04-38	16.1	0.079	0.364	522	16.4
M04-39	16.8	0.101	0.383	525	17.1

Note

ThO_2*: sum of the measured ThO_2 and ThO_2 equivalent of the measured UO_2.

Age: apparent age calculated through equation 1 of SUZUKI and ADACHI (1991a,b, 1994), SUZUKI *et al.* (1992, 1994) and ADACHI and SUZUKI (1992).

zc: core of zoned grain, r: rim and g: included in garnet.

Analyzed position is shown for some grains in μm: for example, M09-01g4028 means 40 μm from right and 28 μm from top.

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
MA88021515-2: Opx-Bt charnockitic gneiss					
M01-01	11.3	0.121	0.245	496	11.7
M01-02	11.2	0.147	0.244	495	11.7
M01-03	11.5	0.167	0.257	502	12.0
M01-04	11.4	0.130	0.251	505	11.8
M01-05	12.0	0.141	0.264	503	12.4
M01-06	11.8	0.149	0.256	492	12.3
M01-07	12.2	0.156	0.266	497	12.7
M01-08	11.8	0.152	0.260	502	12.3
M01-09	11.7	0.159	0.251	489	12.2
M01-10	12.0	0.164	0.270	511	12.5
M01-11	11.8	0.155	0.263	506	12.3
M01-12	12.0	0.147	0.266	505	12.5
M02-01	7.81	0.182	0.181	506	8.41
M02-02	9.00	0.116	0.195	489	9.38
M02-03	6.02	0.190	0.138	488	6.65
M02-04	5.45	0.187	0.128	497	6.07
M02-05	5.69	0.261	0.138	494	6.56
M02-06	8.24	0.156	0.185	496	8.75
M03-01	8.10	0.172	0.185	502	8.67
M03-02	8.19	0.151	0.183	496	8.69
M03-03	8.44	0.154	0.193	508	8.95
M03-04	5.95	0.166	0.138	498	6.50
M03-05	4.85	0.188	0.118	506	5.47
M03-06	4.88	0.185	0.114	489	5.49
** Lützow-Holm Complex: Syowa Station					
MA80020603B: Grt-Bt gneiss					
M01-01	4.84	0.226	0.125	527	5.59
M01-02	5.72	0.198	0.140	515	6.38
M01-03	5.05	0.207	0.130	531	5.73
M01-04	5.57	0.180	0.138	525	6.17
M01-05	5.06	0.204	0.133	545	5.74
M02-01	6.07	0.161	0.147	521	6.60
M02-02	6.17	0.203	0.153	524	6.84
M02-03	6.11	0.169	0.153	540	6.67
M02-04	6.29	0.247	0.159	526	7.11
M02-05	6.66	0.239	0.171	539	7.45
M02-06	6.36	0.301	0.164	523	7.36
M02-07	6.15	0.211	0.153	525	6.85
M03-01	5.20	0.299	0.139	527	6.19
M03-02	5.02	0.315	0.135	524	6.07
M03-03	5.35	0.324	0.145	531	6.42
M03-04	5.35	0.324	0.149	546	6.42
M03-05	10.8	0.200	0.262	535	11.5
M03-06	6.14	0.314	0.160	523	7.18
M03-07	7.60	0.171	0.185	532	8.16
M03-08	5.95	0.288	0.159	541	6.90
M03-09	13.5	0.197	0.321	534	14.1
M03-10	8.31	0.259	0.206	528	9.17
M03-11	15.2	0.215	0.360	532	15.9
M03-12	5.08	0.315	0.135	518	6.12
M03-13	11.7	0.244	0.279	523	12.5
M04-01	6.35	0.168	0.158	536	6.91
M04-02	6.47	0.186	0.159	528	7.09
M04-03	6.18	0.248	0.159	533	7.00
M04-04	6.10	0.187	0.154	539	6.72
M04-05	6.01	0.215	0.149	522	6.72
MA80020702: Grt-Bt gneiss					
M01-01	4.66	0.201	0.121	534	5.33
M01-02	4.61	0.188	0.118	531	5.24
M01-03	4.93	0.216	0.128	534	5.65
M01-04	4.62	0.208	0.116	513	5.31
M01-05	4.97	0.196	0.125	524	5.62
M01-06	5.05	0.204	0.126	519	5.72
M01-07	4.58	0.194	0.116	521	5.22
M01-08	4.63	0.183	0.120	537	5.24
M01-09	5.55	0.253	0.142	523	6.39
M01-10	5.05	0.191	0.128	527	5.69
M01-11	5.09	0.217	0.129	523	5.81
M01-12	4.29	0.169	0.109	527	4.85
M01-13	4.55	0.200	0.116	523	5.21
M01-14r	4.67	0.183	0.0951	425	5.27
M02-01r	6.05	0.210	0.136	476	6.74
M02-02r	5.72	0.222	0.128	467	6.46
M02-03	5.05	0.267	0.137	543	5.93
M02-04	3.82	0.299	0.108	529	4.81
M02-05	6.00	0.221	0.154	537	6.73
M02-06	4.36	0.291	0.116	514	5.32
M02-07	4.02	0.300	0.116	545	5.02
M02-08	8.05	0.403	0.212	529	9.39
M02-09	7.96	0.376	0.210	535	9.20
M02-10	5.52	0.311	0.149	532	6.56
M02-11	3.96	0.312	0.112	527	4.99
M02-12	5.95	0.251	0.151	522	6.78
M02-13	5.03	0.235	0.129	522	5.81
M02-14	4.28	0.303	0.113	503	5.28
M02-15	4.49	0.287	0.121	521	5.45
M02-16	6.68	0.363	0.179	534	7.89
M02-17	6.50	0.294	0.171	537	7.48
M02-18	5.57	0.282	0.142	514	6.50
M02-19	4.85	0.212	0.128	542	5.55
M02-20	4.45	0.212	0.117	533	5.15
M02-21	4.97	0.220	0.124	512	5.69
M02-22	6.86	0.262	0.171	521	7.72
M02-23	6.86	0.274	0.174	525	7.77
M02-24	7.01	0.269	0.178	529	7.90
M02-25	7.35	0.230	0.180	520	8.11
M02-26	7.43	0.212	0.187	538	8.14
M02-27	6.05	0.212	0.150	520	6.75
M02-28	7.29	0.230	0.180	524	8.05
M03-01	4.76	0.204	0.124	535	5.43
M03-02	4.28	0.224	0.113	530	5.02

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M03-03	5.51	0.267	0.144	528	6.40
M03-04	4.39	0.216	0.112	517	5.10
M03-05	4.08	0.236	0.108	521	4.86
M03-06	6.29	0.434	0.176	535	7.73
M03-07	6.30	0.453	0.177	534	7.80
M03-08	6.29	0.449	0.177	533	7.78
M03-09	6.19	0.435	0.168	518	7.63
M03-10	4.29	0.208	0.114	538	4.98
M03-11	4.48	0.218	0.116	521	5.21
M03-12	4.26	0.206	0.110	522	4.94
M03-13	4.66	0.313	0.129	530	5.70
M03-14	6.86	0.441	0.190	535	8.32
M03-15	5.88	0.358	0.158	524	7.06
M03-16	4.55	0.226	0.120	533	5.29
M03-17	4.44	0.227	0.117	527	5.19
M03-18	4.72	0.230	0.121	520	5.48
M03-19r	5.51	0.214	0.116	441	6.21
M03-20r	4.85	0.247	0.100	417	5.66
M03-21r	6.12	0.245	0.130	443	6.93
M03-22r	5.91	0.339	0.127	426	7.03
M03-23r	4.86	0.329	0.115	455	5.94
M03-24r	5.60	0.416	0.158	531	6.98
M03-25r	5.55	0.428	0.153	517	6.97
M03-26r	5.74	0.428	0.145	477	7.15
M03-27r	5.86	0.430	0.157	507	7.28
M03-28r	4.34	0.257	0.113	511	5.19
M03-29r	5.04	0.364	0.138	521	6.24
M03-30r	4.70	0.301	0.113	468	5.70
M04-01	5.87	0.326	0.161	543	6.95
M04-02	6.11	0.331	0.161	526	7.21
M04-03	5.78	0.359	0.156	526	6.96
M04-04	6.01	0.312	0.161	535	7.05
M04-05	5.90	0.336	0.157	526	7.01
M04-06	5.54	0.333	0.150	529	6.65
M04-07	5.49	0.357	0.150	527	6.67
M05-01	6.72	0.158	0.161	522	7.25
M05-02	7.15	0.133	0.173	535	7.59
M05-03	7.36	0.188	0.179	526	7.98
M05-04	7.66	0.207	0.193	542	8.35
M05-05	7.30	0.269	0.184	528	8.20
M05-06	6.45	0.270	0.164	524	7.34
M05-07	6.84	0.280	0.177	535	7.77
M05-08	5.94	0.495	0.171	531	7.58
M05-09	6.36	0.277	0.163	527	7.27
M05-10	7.36	0.161	0.178	531	7.89
M05-11	3.13	0.174	0.0824	523	3.70
M05-12	6.97	0.101	0.169	542	7.31
M05-13	6.51	0.298	0.170	532	7.49
M05-14	6.81	0.275	0.170	518	7.72
M05-15	6.83	0.343	0.175	517	7.96
M05-16	6.87	0.275	0.178	537	7.78
M05-17	6.60	0.267	0.170	532	7.49

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M05-18	7.69	0.112	0.179	523	8.06
M05-19	4.81	0.198	0.123	527	5.47
** Yamato-Belgica Complex: Yamato Mountains					
Y80A119: Grt-Bt gneiss					
M01-01	4.96	1.61	0.237	540	10.3
M01-02	4.85	1.66	0.232	528	10.3
M01-03	4.72	1.70	0.235	533	10.4
M01-04	4.63	1.76	0.239	535	10.5
M01-05	4.70	1.72	0.237	535	10.4
M01-06	4.71	1.68	0.237	541	10.3
M01-07	4.83	1.67	0.238	539	10.4
M01-08	4.85	1.65	0.234	534	10.3
M01-09	4.86	1.61	0.233	537	10.2
M01-10	4.64	1.52	0.212	516	9.67
M02-01	6.77	0.810	0.213	529	9.45
M02-02	7.23	0.651	0.209	524	9.38
M02-03	7.58	0.578	0.217	536	9.50
M02-04	7.45	0.547	0.214	541	9.27
M02-05	7.09	0.566	0.208	545	8.97
M02-06	7.01	0.599	0.202	528	8.99
M02-07	7.94	0.565	0.220	526	9.81
M02-08	7.76	0.573	0.219	533	9.66
M02-09	6.55	0.732	0.207	541	8.98
M02-10	6.58	0.702	0.203	536	8.90
M02-11	6.87	0.740	0.211	533	9.32
M02-12	5.71	1.10	0.215	540	9.35
M02-13	5.96	1.30	0.232	531	10.3
M02-14	5.19	1.53	0.236	541	10.3
M02-15	4.70	1.66	0.231	531	10.2
M03-01	2.93	0.459	0.102	537	4.45
M03-02	3.07	0.418	0.100	528	4.46
M03-03	3.50	0.563	0.124	541	5.36
M03-04	3.59	0.576	0.125	536	5.50
M03-05	3.90	0.658	0.140	541	6.08
M03-06	4.39	0.768	0.158	535	6.93
M03-07	4.06	0.628	0.137	523	6.14
M03-08	3.21	0.494	0.111	539	4.84
M03-09	4.81	0.931	0.178	529	7.89
M03-10	4.09	0.743	0.148	531	6.55
M03-11	3.28	0.502	0.110	522	4.94
M03-12	3.10	0.491	0.109	539	4.72
M03-13	4.87	0.801	0.171	535	7.52
M03-14	3.89	0.676	0.142	544	6.13
M03-15	2.92	0.433	0.0996	537	4.35
M03-16	2.86	0.498	0.103	537	4.51
M03-17	5.69	0.787	0.187	530	8.29
M04-01	5.52	0.798	0.188	541	8.16
M04-02	5.24	0.745	0.180	547	7.71
M04-03	4.75	0.728	0.162	531	7.17
M05-01	2.63	0.344	0.0852	531	3.77
M05-02	4.23	0.522	0.135	533	5.96

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
Y80A121d: Spl-Opx-Bt gneiss					
M01-01	7.51	0.272	0.190	531	8.41
M01-02	7.86	0.535	0.216	527	9.63
M01-03	7.46	0.399	0.202	539	8.78
M01-04	8.31	0.352	0.216	535	9.48
M01-05	6.87	0.346	0.183	535	8.01
M01-06	5.22	0.271	0.139	532	6.12
M01-07zc	9.97	0.467	0.304	619	11.5
M01-08	8.22	0.328	0.210	531	9.31
M01-09zc	11.6	0.540	0.350	613	13.4
M01-10zc	10.3	0.399	0.305	612	11.7
M01-11zc	7.99	0.370	0.240	609	9.22
M01-12	7.22	0.268	0.183	531	8.11
M01-13	5.79	0.433	0.162	527	7.22
M01-14	4.17	0.338	0.121	538	5.29
M01-15	7.44	0.285	0.189	529	8.38
M02-01	5.13	0.262	0.136	531	6.00
M02-02r	6.83	0.334	0.173	512	7.94
M02-03r	6.44	0.351	0.157	485	7.60
M02-04	6.24	0.351	0.169	537	7.40
M02-05	4.63	0.191	0.120	536	5.27
M02-06	6.37	0.189	0.157	526	7.00
M02-07	5.99	0.193	0.151	534	6.63
M02-08	6.94	0.165	0.167	525	7.48
M02-09	6.92	0.290	0.179	532	7.88
M02-10	6.61	0.446	0.183	531	8.09
M02-11	4.92	0.163	0.124	533	5.46
M02-12	6.34	0.293	0.168	539	7.31
M02-13	5.21	0.194	0.132	531	5.85
M02-14	6.88	0.211	0.171	529	7.58
M02-15	6.52	0.239	0.166	534	7.31
M03-01	4.79	0.168	0.120	525	5.35
M03-02	5.80	0.239	0.149	530	6.59
M03-03	4.25	0.171	0.110	535	4.81
** Sør Rondane Complex: Sør Rondane Mountains					
MA88011002-1: Grt-Bt gneiss					
M01-01	4.72	0.231	0.123	525	5.48
M01-02	5.12	0.251	0.139	546	5.95
M01-03	4.48	0.307	0.124	530	5.49
M01-04	4.82	0.247	0.131	545	5.64
M01-05	4.64	0.265	0.125	534	5.52
M01-06	4.51	0.282	0.122	525	5.44
M02-01	6.87	0.226	0.171	529	7.62
M02-02	6.04	0.253	0.153	522	6.88
M02-03	6.59	0.216	0.166	535	7.30
M03-01	6.41	0.231	0.166	543	7.17
M03-02	6.09	0.215	0.151	523	6.80
M03-03	6.24	0.208	0.156	529	6.93
M04-01	5.36	0.231	0.138	529	6.13
M04-02	5.97	0.215	0.150	528	6.68
M04-03	5.09	0.220	0.132	533	5.82
M04-04	5.35	0.203	0.136	531	6.03
M04-05	4.88	0.249	0.128	526	5.70
M04-06	5.25	0.192	0.132	525	5.88
M04-07	5.59	0.206	0.143	535	6.27
M05-01	5.20	0.248	0.135	525	6.02
M05-02	5.43	0.239	0.140	527	6.22
M05-03	5.60	0.233	0.143	527	6.37
M05-04	5.69	0.225	0.145	529	6.43
M05-05	5.16	0.283	0.138	531	6.10
M05-06	5.24	0.274	0.141	539	6.15
M05-07	5.27	0.245	0.134	517	6.08
M06-01	5.92	0.274	0.155	532	6.83
M06-02	6.06	0.263	0.154	523	6.93
M06-03	6.13	0.226	0.156	534	6.88
M06-04	5.95	0.321	0.158	529	7.01
M06-05	6.15	0.214	0.154	528	6.86
M07-01	5.64	0.265	0.149	537	6.52
M07-02	6.63	0.349	0.177	534	7.78
M07-03	7.12	0.382	0.189	530	8.39
M07-04	6.44	0.329	0.168	524	7.53
M07-05	6.32	0.239	0.162	536	7.12
M07-06	6.33	0.263	0.161	525	7.20
M07-07	6.01	0.273	0.155	527	6.91
M07-08	5.86	0.307	0.158	541	6.87
M07-09	5.56	0.613	0.170	526	7.59
M08-01	6.97	0.357	0.186	536	8.15
M08-02	6.01	0.270	0.157	534	6.90
M08-03	7.56	0.395	0.202	534	8.87
M08-04	6.18	0.232	0.160	541	6.95
M08-05	5.93	0.261	0.155	535	6.79
M08-06	5.98	0.258	0.153	525	6.83
M08-07	5.97	0.238	0.153	532	6.76
M08-08	5.83	0.261	0.153	538	6.69
M08-09	5.94	0.254	0.153	530	6.78
M08-10	5.88	0.259	0.152	531	6.74
M09-01	6.52	0.249	0.165	527	7.35
M09-02	6.53	0.265	0.166	527	7.40
M09-03	6.27	0.280	0.166	541	7.20
M10-01	5.99	0.568	0.180	538	7.87
M10-02	5.67	0.240	0.144	522	6.46
M10-03	5.98	0.267	0.154	527	6.86
M10-04	6.79	0.318	0.177	530	7.84
M10-05	7.07	0.360	0.188	533	8.26
M10-06	8.01	0.410	0.211	529	9.36
M10-07	8.65	0.459	0.231	532	10.2
M11-01	4.51	0.291	0.123	529	5.48
M11-02	5.00	0.252	0.133	534	5.83
M11-03	4.33	0.204	0.114	535	5.01
M11-04	4.75	0.243	0.126	534	5.55
M11-05	4.95	0.260	0.129	521	5.81

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
MA88012216: Grt-Bt gneiss					
M01-01	5.85	0.254	0.154	540	6.69
M01-02	5.88	0.242	0.156	548	6.68
M01-03	7.18	0.166	0.176	535	7.73
M01-04	6.38	0.231	0.159	521	7.15
M01-05	5.60	0.199	0.140	524	6.26
M01-06	6.89	0.237	0.171	524	7.67
M01-07	7.18	0.173	0.177	537	7.75
M01-08	6.96	0.164	0.170	532	7.50
M01-09	7.08	0.135	0.169	528	7.52
M01-10	7.11	0.178	0.173	528	7.70
M01-11	6.78	0.236	0.171	531	7.56
M01-12	6.80	0.156	0.166	532	7.32
M01-13	5.77	0.238	0.148	532	6.56
M01-14	5.85	0.258	0.154	540	6.70
M01-15	6.09	0.264	0.156	528	6.96
M01-16	6.68	0.184	0.162	521	7.28
M01-17	7.20	0.161	0.179	542	7.73
M01-18	5.92	0.210	0.150	533	6.62
M01-19	7.05	0.183	0.170	522	7.65
M01-20	6.64	0.162	0.161	526	7.17
M01-21	5.87	0.503	0.174	542	7.53
M01-22	5.77	0.352	0.159	537	6.94
M01-23	6.36	0.231	0.164	539	7.13
M01-24	6.80	0.161	0.168	537	7.33
M01-25	5.91	0.158	0.147	535	6.43
M01-26	5.82	0.314	0.154	528	6.86
M01-27	6.07	0.270	0.155	524	6.96
M01-28	6.42	0.863	0.211	533	9.27
M01-29	6.50	0.160	0.158	527	7.03
M01-30	6.70	0.140	0.161	527	7.16
M01-31	6.46	0.198	0.159	526	7.12
M01-32	6.39	0.247	0.159	517	7.21
M01-33	5.66	0.510	0.167	532	7.35
M01-34	5.68	0.250	0.147	529	6.51
M01-35	6.54	0.694	0.200	530	8.84
M01-36	7.27	0.115	0.175	537	7.65
M01-37	7.11	0.102	0.168	531	7.45
M01-38	6.47	0.142	0.161	543	6.94
M01-39	6.44	0.133	0.154	526	6.88
M01-40	6.29	0.880	0.206	527	9.20
M01-41	6.25	0.638	0.191	536	8.36
M01-42	6.11	0.274	0.158	530	7.01
M01-43	5.90	0.299	0.160	546	6.90
M01-44	5.91	0.307	0.157	533	6.93
M01-45	6.83	0.169	0.168	534	7.40
M01-46	6.28	0.173	0.156	534	6.85
M01-47	6.69	0.125	0.162	536	7.10
M01-48	6.51	0.131	0.158	534	6.94
M01-49	6.81	0.496	0.195	542	8.46
M01-50	7.05	0.106	0.168	534	7.40
M01-51	7.03	0.119	0.171	541	7.42
M01-52	6.77	0.203	0.170	537	7.44
M01-53	7.21	0.193	0.180	537	7.85
M01-54	5.73	0.328	0.154	532	6.82
M01-55	7.71	0.098	0.181	529	8.04
M01-56	6.69	0.141	0.162	532	7.16
M01-57	7.02	0.155	0.166	517	7.54
M01-58	6.69	0.214	0.165	525	7.40
M01-59	6.86	0.185	0.171	536	7.47
M01-60	6.71	0.227	0.168	527	7.47
M01-61	6.25	0.238	0.161	535	7.04
M01-62	6.18	0.213	0.154	526	6.89
M01-63	6.30	0.219	0.158	527	7.02
M02-01	6.97	0.137	0.169	535	7.43
M02-01	6.64	0.154	0.161	527	7.15
M02-03	6.98	0.152	0.171	536	7.49
M02-04	7.38	0.130	0.177	532	7.81
M02-05	7.58	0.161	0.183	531	8.12
M02-06	6.71	0.167	0.167	539	7.26
M02-07	6.21	0.199	0.153	522	6.87
M02-08	6.02	0.200	0.151	531	6.68
M02-09	6.00	0.195	0.151	534	6.65
M02-10	6.28	0.235	0.159	530	7.05
M02-11	6.31	0.197	0.156	527	6.96
M02-12	6.16	0.235	0.158	534	6.94
M02-13	6.18	0.244	0.155	520	6.99
M02-14	6.21	0.244	0.158	530	7.01
M02-15	6.06	0.235	0.158	542	6.84
M02-16	6.38	0.153	0.153	521	6.88
M02-17	5.95	0.200	0.148	527	6.62
M02-18	6.37	0.144	0.154	530	6.85
M02-19	6.16	0.211	0.158	541	6.86
M03-01	5.28	0.442	0.151	527	6.74
M03-02	5.88	0.317	0.156	529	6.93
M03-03	6.96	0.713	0.213	536	9.32
M03-04	7.33	0.115	0.172	524	7.71
M03-05	7.54	0.131	0.179	528	7.97
M04-01	7.36	0.113	0.175	530	7.74
M04-02	6.72	0.184	0.161	517	7.33
M04-03	6.85	0.139	0.163	524	7.31
M04-04	7.12	0.124	0.172	536	7.53
M04-05	7.31	0.111	0.174	532	7.68
M04-06	7.43	0.112	0.174	524	7.80
M04-07	7.39	0.109	0.173	523	7.75
M04-08	7.23	0.115	0.173	534	7.62
M04-09	7.08	0.103	0.167	529	7.42
M04-10	6.87	0.175	0.166	525	7.45
M04-11	7.15	0.148	0.172	530	7.64
M04-12	7.53	0.124	0.178	527	7.94
M04-13	7.36	0.112	0.172	523	7.73
M04-14	7.46	0.108	0.177	530	7.82
M04-15	7.83	0.115	0.185	530	8.21
M04-16	7.34	0.108	0.171	520	7.70

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M04-17	7.90	0.110	0.187	532	8.26
M04-18	7.20	0.128	0.172	530	7.62
M04-19	7.52	0.130	0.176	519	7.95
M04-20	8.06	0.126	0.190	527	8.48
M04-21	7.51	0.106	0.177	528	7.87
M04-22	7.39	0.102	0.173	524	7.73
M04-23	7.15	0.119	0.168	523	7.55
M04-24	6.85	0.154	0.166	530	7.36
M04-25	7.15	0.115	0.169	527	7.54
M04-26	7.40	0.118	0.175	527	7.80
M04-27	6.57	0.187	0.161	525	7.19
MA88020202-1: Grt-Bt gneiss					
M01-01zc	9.68	0.944	0.341	623	12.8
M01-02zc	9.52	0.966	0.321	591	12.7
M01-03zc	8.46	1.09	0.287	557	12.1
M01-04	4.67	1.08	0.191	543	8.24
M01-05	6.82	1.12	0.242	540	10.5
M01-06	4.61	1.52	0.223	542	9.65
M01-07	5.85	1.05	0.212	533	9.33
M01-08	6.64	1.07	0.233	536	10.2
M01-09	4.62	1.54	0.222	537	9.71
M01-10	5.69	1.04	0.209	537	9.14
M01-11	5.31	1.48	0.231	531	10.2
M01-12	4.57	1.24	0.199	539	8.66
M01-13	6.12	1.45	0.253	543	10.9
M01-14	4.63	1.13	0.191	535	8.36
M01-05	6.70	1.15	0.241	538	10.5
M01-16	4.35	1.14	0.186	535	8.14
M01-17	8.48	1.08	0.277	540	12.1
M01-18	6.08	1.47	0.251	537	11.0
M01-19	4.73	1.09	0.192	541	8.34
84021904B: Sil-Grt-Bt gneiss					
M01-01	6.54	1.25	0.255	561	10.7
M01-02	8.33	0.970	0.277	562	11.6
M01-03	7.41	1.67	0.311	563	13.0
M01-04	5.59	1.36	0.239	557	10.1
M01-05	5.52	1.34	0.232	546	9.95
M01-06	5.06	1.28	0.224	564	9.31
M02-01	6.07	1.08	0.234	566	9.68
M02-02	6.36	1.07	0.238	563	9.93
M02-03	4.70	0.901	0.181	552	7.69
M02-04	4.99	0.948	0.192	554	8.13
M02-05	4.02	0.859	0.156	534	6.87
M02-06	6.15	1.05	0.225	548	9.64
M03-01zc	6.48	2.72	0.414	624	15.6
M03-02zc	6.22	2.58	0.393	622	14.8
M03-03zc	6.37	2.73	0.410	621	15.5
M03-04zc	6.13	2.65	0.400	626	15.0
M03-05zc	6.02	2.56	0.384	619	14.5
M03-06zc	6.01	2.53	0.388	629	14.5
M03-07zc	6.05	2.56	0.390	626	14.6
M03-08zc	6.15	2.68	0.405	628	15.1
M03-09zc	6.14	2.59	0.392	622	14.8
M04-01	3.10	1.11	0.157	541	6.79
M04-02	3.09	1.10	0.160	558	6.73
M04-03	3.46	1.23	0.177	551	7.53
M04-04	3.69	1.27	0.191	566	7.92
M04-05	4.10	1.32	0.201	557	8.48
M05-01	5.96	1.10	0.226	553	9.60
M05-02	6.13	1.11	0.228	545	9.80
M05-03	6.04	1.18	0.235	554	9.96
M05-04	5.30	0.979	0.202	556	8.55
M05-05	5.23	0.965	0.196	544	8.43
M05-06	5.56	1.08	0.209	536	9.13
M05-07	5.18	0.942	0.199	562	8.31
M06-01	6.52	1.41	0.268	561	11.2
M06-02	7.16	1.51	0.292	562	12.2
M06-03	4.43	0.965	0.174	536	7.63
M07-01	3.97	0.734	0.157	573	6.41
M07-02	4.24	0.725	0.155	549	6.64
M07-03	2.87	0.666	0.120	553	5.08
M08-01 1512	6.60	0.775	0.219	559	9.18
M08-02 2712	7.88	0.880	0.255	554	10.8
M08-03 4212	6.44	0.982	0.229	553	9.70
M08-04 4912	10.1	1.000	0.310	544	13.4
M08-05 3707	6.68	0.839	0.215	534	9.46
M08-06 6620	5.79	1.04	0.211	537	9.23
M08-07 5420	6.59	1.19	0.249	555	10.5
M08-08 4320	6.57	1.12	0.242	551	10.3
M08-09 2420	9.92	1.31	0.339	557	14.3
M08-10 1420	6.73	0.764	0.217	551	9.27
M08-11 0730	6.35	0.730	0.207	555	8.77
M08-12 1630	6.54	0.774	0.221	568	9.11
M08-13 2930	13.4	1.16	0.400	545	17.2
M08-14 4530	13.5	1.34	0.415	544	17.9
M08-15 2242	6.71	0.771	0.216	546	9.26
M08-16 0442	6.24	0.691	0.204	559	8.54
M08-17 1915	5.63	0.699	0.183	540	7.95
M08-18 3115	6.26	0.820	0.210	548	8.98
M08-19 4015	5.69	0.852	0.198	546	8.51
M08-20 4915	7.45	0.935	0.243	541	10.5
M08-21 5415	7.92	0.888	0.254	548	10.9
M08-22 5412	6.77	0.741	0.211	537	9.22
M08-23 4708	6.29	0.754	0.204	545	8.79
M08-24 3408	5.57	0.731	0.184	539	8.00
M08-25 2708	5.35	0.672	0.176	545	7.58
M08-26 1025	5.39	0.554	0.168	545	7.23
M08-27 2025	5.88	0.751	0.197	553	8.37
M08-28 2925	8.13	1.06	0.265	534	11.6
M08-29 3825	10.5	1.38	0.352	546	15.1
M08-30 4825	10.6	1.05	0.329	547	14.1
M08-31 6025	6.42	1.17	0.242	553	10.3

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M08-32 4633	7.47	0.797	0.228	529	10.1
M08-33 4033	12.4	1.21	0.386	553	16.4
M08-34 3233	12.5	1.19	0.385	551	16.4
M08-35 2433	7.77	0.852	0.240	533	10.6
M08-36 1333	5.76	0.730	0.193	552	8.19
M08-37 0533	5.50	0.631	0.175	542	7.59
M08-38 0738	4.97	0.532	0.155	542	6.73
M08-39 1338	5.48	0.667	0.181	551	7.69
M08-40 2338	5.67	0.727	0.186	541	8.08
M08-41 3038	5.83	0.743	0.198	560	8.30
M08-42 3438	6.33	0.807	0.214	559	9.01
M08-43 1446	4.66	0.539	0.149	543	6.45
M09-01g4028	4.05	0.629	0.151	575	6.14
M09-02g3028	7.27	0.296	0.269	758	8.27
M09-03g2528	5.26	1.17	0.293	743	9.22
M09-04g1528	6.99	0.419	0.270	750	8.40
M09-05g2633	3.93	0.993	0.229	737	7.27
M09-06g2233	3.67	0.874	0.212	748	6.61
M09-07g2013	3.93	0.382	0.151	681	5.21
M09-08g3313	4.31	0.348	0.158	676	5.47
M09-09g4213	4.86	0.737	0.177	569	7.31
M09-10g2821	4.66	0.378	0.189	744	5.93
M09-11g2825	5.80	0.338	0.217	730	6.94
M09-12g1537	3.70	0.723	0.160	612	6.11
M09-13g2337	3.79	0.767	0.175	645	6.36
M09-14g2837	3.53	0.868	0.182	663	6.44
M09-15g3232	4.37	0.696	0.210	730	6.72
M09-16g2532	6.42	0.378	0.253	768	7.69
M09-17g1932	5.42	0.603	0.245	768	7.45
M09-18g1232	5.99	0.391	0.243	775	7.31
M09-19g0532	4.59	0.644	0.155	542	6.73
M09-20g0527	2.85	0.489	0.102	536	4.47
M09-21g0523	1.91	0.383	0.0737	545	3.18
M09-22g1223	2.86	0.405	0.136	753	4.22
M09-23g1623	3.59	0.347	0.151	741	4.76
M09-24g2423	4.90	0.340	0.194	751	6.05
M09-25g3223	6.21	0.373	0.241	754	7.47
M09-26g3923	4.64	0.744	0.197	648	7.12
M09-27g4318	4.25	1.11	0.184	545	7.92
M09-28g3718	4.25	0.806	0.193	651	6.95
M09-29g3018	4.15	0.405	0.181	765	5.52
M09-30g2418	3.93	0.450	0.176	755	5.45
M09-31g1818	2.97	0.603	0.165	771	5.01
M09-32g1218	3.22	0.680	0.155	660	5.50
M09-33g1610	2.74	0.723	0.119	543	5.13
M09-34g2310	3.85	0.903	0.159	546	6.84
M09-35g3110	3.87	0.947	0.163	545	7.01
M09-36g3910	3.94	0.981	0.169	551	7.20
M09-37g3914	3.88	1.00	0.177	577	7.21
M10-01	2.21	0.207	0.0693	561	2.90
M10-02	3.17	0.360	0.108	582	4.37
M10-03	3.18	0.352	0.102	551	4.35

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M11-01	6.25	0.438	0.185	564	7.71
M11-02	5.87	0.378	0.164	541	7.12
M11-03	6.03	0.348	0.166	543	7.18
M11-04	6.22	0.372	0.172	542	7.45
M12-01 1028	14.8	1.10	0.427	544	18.4
M12-02 1033	17.0	1.32	0.497	545	21.4
M12-03 1541	7.55	1.05	0.255	542	11.0
M12-04 2032	17.7	1.26	0.511	547	21.9
M12-05 3040	2.09	0.650	0.114	628	4.26
M12-06 6421	9.31	0.681	0.266	540	11.6
M12-07 5511	17.5	1.22	0.504	549	21.5
M12-08 4613	6.16	0.784	0.204	546	8.76
M12-09 2816	7.87	0.704	0.242	556	10.2
M12-10 1824	11.2	0.936	0.331	544	14.3
M12-11 4233	2.03	0.511	0.102	637	3.74
M12-12 5530	2.58	0.958	0.154	625	5.78
M12-13 3028	6.52	0.957	0.260	627	9.71
M12-14 0530	12.3	0.904	0.355	545	15.3
M12-15 1430	18.8	1.24	0.538	551	22.9
M12-16 2330	16.6	1.19	0.476	544	20.6
M12-17 3530	2.37	0.804	0.138	650	5.06
M12-18 4830	2.26	0.711	0.127	642	4.63
M12-19 6330	6.39	0.849	0.218	556	9.21
M12-20 6921	13.3	0.886	0.372	540	16.2
M12-21 6021	16.9	1.09	0.484	554	20.5
M12-22 5021	7.30	1.13	0.295	626	11.1
M12-23 4221	2.67	0.745	0.136	620	5.16
M12-24 2321	6.47	0.635	0.196	538	8.57
M12-25 1321	11.9	0.880	0.341	538	14.9
M12-26 3313	9.81	0.749	0.283	541	12.3
M12-27 4113	9.27	0.732	0.274	549	11.7
M12-28 5113	13.8	0.943	0.391	540	17.0
M12-29 5713	14.2	0.941	0.404	547	17.3
M12-30 6113	12.6	0.836	0.358	548	15.3
M12-31 4309	9.73	0.736	0.283	546	12.2
M12-32 3709	9.51	0.804	0.274	529	12.2
M12-33 5440	3.54	0.901	0.176	628	6.55
M12-34 4640	2.44	0.755	0.133	631	4.96
M12-35 3840	2.59	0.892	0.153	641	5.57
M12-36 1940	8.93	1.08	0.291	546	12.5
M12-37 1040	13.0	1.09	0.391	550	16.7
M12-38 1745	4.46	0.994	0.208	628	7.78
M12-39 2345	4.48	0.899	0.196	614	7.48
M12-40 4445	2.86	1.01	0.166	622	6.24
M12-41 5344	6.90	1.04	0.279	618	10.4
M13-01zc	7.65	1.21	0.316	633	11.7
M13-02zc	6.10	1.08	0.264	636	9.72
M13-03zc	6.12	1.14	0.266	627	9.93
M13-04zc	6.36	1.18	0.275	626	10.3
M13-05zc	6.15	1.16	0.269	608	10.4
M13-06	5.91	1.08	0.226	559	9.49
M13-07	6.94	1.39	0.269	546	11.6

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M14-01	5.33	0.481	0.160	543	6.93
M14-02	5.12	0.683	0.175	557	7.38
M14-03	5.09	0.760	0.183	563	7.62
M14-04	5.10	0.541	0.157	536	6.89
M14-05	5.01	0.471	0.152	544	6.57
M14-06	4.36	0.449	0.133	534	5.85
M14-07	4.59	0.719	0.157	530	6.97
M14-08	4.49	0.479	0.138	533	6.08
M14-09	4.41	0.457	0.140	554	5.93
M14-10	4.33	0.429	0.139	566	5.75
M15-01	7.93	0.873	0.255	552	10.8
M15-02	8.92	0.920	0.280	548	12.0
M15-03	8.77	0.911	0.279	555	11.8
M15-04zc	10.9	0.994	0.380	626	14.2
M15-05zc	12.9	1.08	0.444	628	16.5
M15-06zc	12.9	1.19	0.474	657	16.9
M15-07zc	4.47	0.849	0.216	690	7.32
M15-08zc	4.48	0.796	0.204	668	7.15
M15-09zc	14.6	1.11	0.502	643	18.3
M15-10zc	10.2	0.977	0.348	608	13.4
M16-01	7.64	0.840	0.245	551	10.4
M16-02	7.63	0.820	0.251	568	10.4
M16-03	7.93	0.854	0.254	553	10.8
M16-04	7.62	0.811	0.243	553	10.3
M16-05	8.16	0.877	0.253	537	11.1
M16-06	6.91	0.751	0.223	557	9.40
M17-01	7.54	0.728	0.236	556	9.96
M17-02	7.25	0.721	0.232	564	9.65
M17-03	7.87	0.775	0.246	552	10.4
M18-01g1510	10.3	0.881	0.311	551	13.3
M18-02g1516	7.19	0.930	0.244	556	10.3
M18-03g1522	4.27	1.05	0.246	735	7.82
M18-04g1529	3.99	0.976	0.229	735	7.28
M18-05g1537	5.06	0.338	0.200	752	6.20
M18-06g0734	7.70	1.10	0.267	553	11.4
M18-07g0726	11.7	1.10	0.411	628	15.3
M18-08g0821	14.7	1.02	0.421	548	18.1
M18-09g0823	11.7	1.03	0.388	602	15.1
M18-10g0815	10.9	0.782	0.302	526	13.5
M18-11g0819	14.4	1.02	0.415	548	17.8
M18-12g2519	5.51	0.953	0.215	582	8.68
M18-13g2523	5.56	0.801	0.194	554	8.22
M18-14g2530	3.93	0.856	0.187	644	6.79
M18-15g2535	3.64	0.691	0.167	658	5.95
M18-16g2228	4.02	0.998	0.231	731	7.38
M18-17g1915	4.53	0.953	0.186	566	7.69
M18-18g1930	4.51	0.386	0.186	750	5.81
M18-19g1030	4.44	0.745	0.202	683	6.94
M18-20g1040	5.15	0.908	0.190	546	8.17
M18-21g2040	4.53	0.990	0.191	573	7.81
M18-22g1023	4.14	0.829	0.215	726	6.93
M18-23g2011	5.50	0.926	0.199	545	8.56
M18-24g1209	8.81	0.881	0.271	542	11.7
M18-25g2109	5.36	0.985	0.206	561	8.63
M18-26g2619	4.82	0.878	0.179	545	7.73
M18-27g2632	4.06	0.752	0.152	546	6.55
M18-28g0320	9.49	0.614	0.264	538	11.5
M18-29g1432	4.85	0.326	0.187	734	5.95
M18-30g2032	4.39	0.520	0.195	740	6.14
M18-31g2021	4.09	0.930	0.227	734	7.22
M18-32g2513	5.67	0.902	0.194	527	8.66
M19-01zc	6.35	1.17	0.271	619	10.3
M19-02zc	6.42	1.14	0.270	619	10.2
M19-03zc	6.56	1.16	0.283	635	10.4
M19-04zc	7.74	1.21	0.316	628	11.8
M19-05zc	7.00	1.16	0.285	615	10.9
M19-06zc	7.25	1.18	0.308	646	11.2
M20-01	6.35	1.10	0.238	559	10.0
M20-02	6.61	1.19	0.250	556	10.6
M20-03zc	6.66	1.31	0.298	633	11.0
M20-04	6.33	1.16	0.239	550	10.2
M20-05zc	6.45	1.37	0.277	589	11.0
M20-06	6.21	1.01	0.228	560	9.57
M20-07zc	5.99	1.46	0.271	585	10.9
M20-08zc	5.72	1.61	0.276	585	11.1
M20-09zc	5.72	1.64	0.294	616	11.2
M20-10zc	5.69	1.77	0.309	623	11.6
M20-11zc	5.80	1.81	0.318	629	11.8
M20-12zc	6.44	1.37	0.288	613	11.0
M20-13zc	6.59	1.28	0.290	625	10.9
M21-01	6.37	0.817	0.216	558	9.08
M21-02	5.11	0.749	0.182	563	7.59
M21-03	5.37	0.754	0.186	555	7.88
M21-04	5.93	0.782	0.205	565	8.52
M21-05zc	6.43	0.819	0.247	632	9.16
M21-06zc	7.92	0.900	0.292	627	10.9
M21-07zc	3.45	0.400	0.133	649	4.78
M21-08zc	5.61	0.760	0.217	624	8.14
M22-01zc	6.73	0.540	0.228	627	8.53
M22-02zc	6.29	0.504	0.215	631	7.97
M22-03zc	7.53	0.748	0.274	640	10.0
M22-04zc	7.78	0.642	0.271	640	9.92
M23-01g2011	4.36	0.459	0.141	560	5.88
M23-02g2019	4.50	0.508	0.147	558	6.18
M23-03g2026	4.85	0.510	0.155	556	6.55
M23-04g2034	4.89	0.520	0.153	542	6.61
M23-05g2043	4.68	0.509	0.155	571	6.37
M23-06g2052	4.77	0.717	0.172	566	7.15
M23-07g2749	5.04	0.626	0.162	536	7.11
M23-08g2740	4.74	0.509	0.151	553	6.42
M23-09g2728	4.82	0.499	0.150	543	6.47
M23-10g2719	4.02	0.436	0.125	538	5.46
M23-11g2512	4.49	0.456	0.145	569	6.00
M23-12g1223	6.16	0.743	0.205	557	8.63

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M23-13g1230	4.63	0.496	0.146	546	6.27
M23-14g1237	4.53	0.498	0.149	564	6.18
M23-15g1614	4.95	0.504	0.151	534	6.62
M23-16g1622	5.03	0.509	0.156	546	6.71
M23-17g1647	5.83	0.838	0.204	556	8.61
M23-18g2647	5.11	0.589	0.160	531	7.06
M23-19g2637	5.11	0.496	0.155	540	6.75
M23-20g2625	5.13	0.490	0.155	540	6.75
M23-21g2615	4.57	0.435	0.138	537	6.02
M23-22g2205	5.24	0.430	0.152	535	6.67
M23-23g1805	5.36	0.441	0.159	546	6.83
M23-24g0911	4.74	0.478	0.144	536	6.32
M23-25g0619	8.15	0.849	0.253	541	11.0
M23-26g0427	5.06	0.590	0.162	542	7.02
M23-27g0441	5.74	0.962	0.206	542	8.93
M23-28g0940	5.64	0.946	0.203	544	8.78
M23-29g0948	2.68	0.362	0.0906	548	3.88
M23-30g1554	4.91	0.631	0.161	539	7.00
M23-31g1544	5.09	0.502	0.156	541	6.75
M23-32g1530	6.20	0.673	0.192	535	8.43
M23-33g3629	4.25	0.456	0.131	534	5.76
M23-34g3242	3.91	0.353	0.117	540	5.08
M23-35g3234	4.36	0.369	0.132	555	5.58
M23-36g3222	4.22	0.344	0.120	526	5.36
M24-01	3.68	0.690	0.141	555	5.97
M24-02	3.87	0.713	0.150	566	6.24
M24-03	4.00	0.752	0.157	566	6.50
M24-04	3.96	0.748	0.145	529	6.44
M24-05	3.17	0.440	0.108	550	4.62
M24-06	3.55	0.649	0.132	542	5.70
M24-07	3.36	0.628	0.123	533	5.44
M24-08	3.27	0.581	0.119	539	5.19
M24-09	3.63	0.602	0.131	546	5.63
M24-10	3.24	0.830	0.139	545	5.99
M24-11	3.78	0.642	0.141	561	5.91
M25-01	3.46	0.924	0.154	555	6.53
M25-02	4.95	0.853	0.184	555	7.78
M25-03	4.36	0.800	0.167	557	7.02
M25-04zc	6.68	0.907	0.256	617	9.71
M25-05zc	7.41	0.919	0.270	606	10.5
M25-06zc	3.88	0.335	0.164	767	5.01
M25-07zc	6.53	0.288	0.242	755	7.50
M25-08zc	8.06	0.821	0.295	640	10.8
M25-09zc	5.65	0.788	0.200	569	8.26
M25-10zc	13.0	0.766	0.358	541	15.5
M26-01	6.62	2.09	0.311	539	13.5
M26-02	6.76	2.02	0.313	545	13.5
M26-03	7.11	1.75	0.297	540	12.9
M26-04	7.62	1.13	0.261	538	11.4
M26-05	6.75	1.03	0.234	540	10.2
M26-06	7.47	1.13	0.261	545	11.2
M26-07	7.63	1.12	0.265	547	11.4

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M26-08	7.00	0.939	0.231	536	10.1
M26-09	7.25	1.10	0.251	540	10.9
M26-10	6.97	1.02	0.237	537	10.3
M26-11	7.47	0.923	0.242	540	10.5
M26-12	8.11	1.26	0.290	552	12.3
M26-13	7.08	1.94	0.313	543	13.5
M26-14	7.26	2.09	0.328	542	14.2
M26-15	7.18	1.93	0.309	535	13.6
M26-16	8.15	0.912	0.259	543	11.2
M26-17	6.59	1.02	0.224	529	9.96
M26-18	6.60	1.35	0.254	540	11.1
M26-19	7.79	1.52	0.301	550	12.8
M26-20	8.31	1.20	0.275	525	12.3
M26-21	8.99	1.04	0.281	532	12.4
M27-01	9.99	0.929	0.304	546	13.1
M27-02	12.4	0.981	0.359	537	15.7
M27-03	12.2	1.11	0.372	549	15.9
M27-04	12.4	1.01	0.361	539	15.7
M27-05	9.38	0.907	0.287	544	12.4
M27-06	4.88	0.871	0.181	547	7.77
M27-07	10.4	0.950	0.313	543	13.5
M27-08	12.8	0.991	0.372	544	16.0
M28-01	15.5	0.925	0.429	541	18.6
M28-02	8.66	0.687	0.253	542	10.9
M28-03	8.81	0.629	0.246	530	10.9
M28-04	10.9	0.769	0.306	533	13.5
M28-05	7.99	0.419	0.216	540	9.38
M28-06	5.72	0.431	0.167	547	7.15
M28-07	13.0	0.836	0.361	538	15.7
M28-08	5.58	0.584	0.170	530	7.52
M28-09	8.22	0.690	0.243	542	10.5
M28-10	10.3	0.938	0.308	542	13.4
84022004: Grt-Bt gneiss					
M01-01	5.43	0.245	0.144	543	6.24
M01-02	6.86	0.277	0.179	541	7.78
M01-03	6.76	0.308	0.180	544	7.78
M01-04	5.24	0.342	0.147	542	6.37
M01-05	5.51	0.343	0.148	521	6.64
M01-06	6.14	0.326	0.168	546	7.22
M01-07	5.03	0.236	0.134	543	5.82
M01-08	6.13	0.243	0.160	543	6.94
M01-09	6.49	0.247	0.164	527	7.31
M01-10	6.61	0.307	0.181	557	7.63
M01-11	6.31	0.299	0.172	552	7.30
M01-12	6.75	0.321	0.183	550	7.81
M01-13	5.73	0.273	0.153	541	6.63
M01-14	4.67	0.222	0.125	542	5.40
M01-15	4.79	0.236	0.128	537	5.57
M01-16	5.53	0.232	0.144	537	6.30
M01-17zc	12.5	0.585	0.369	601	14.4
M01-18	8.43	0.402	0.224	538	9.76

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M02-01	6.33	0.153	0.160	549	6.83
M02-02	6.71	0.182	0.173	555	7.32
M02-03	6.04	0.149	0.157	564	6.53
M02-04	5.16	0.179	0.132	540	5.75
M02-05	5.61	0.285	0.152	544	6.56
M02-06	5.75	0.164	0.150	559	6.29
M02-07	6.01	0.183	0.151	536	6.62
M02-08	6.27	0.175	0.159	546	6.85
M02-09	4.73	0.148	0.122	547	5.22
M02-10	5.76	0.170	0.148	549	6.33
M02-11	5.77	0.176	0.145	534	6.36
M02-12	6.41	0.139	0.161	551	6.87
M02-13	6.13	0.152	0.154	546	6.64
M02-14	4.57	0.170	0.119	543	5.14
M02-15	6.32	0.138	0.151	524	6.77
M02-16	6.12	0.161	0.154	544	6.65
M02-17	6.12	0.199	0.153	530	6.77
M02-18	6.27	0.164	0.161	553	6.81
M02-19	6.59	0.180	0.169	553	7.19
M03-01zc	9.39	0.236	0.250	577	10.2
M03-02	9.35	0.282	0.237	541	10.3
M03-03zc	12.1	0.390	0.333	585	13.4
M03-04zc	13.3	0.438	0.381	606	14.7
M03-05zc	15.7	0.477	0.444	601	17.3
M03-06	6.69	0.219	0.170	539	7.42
M03-07zc	13.3	0.423	0.383	609	14.7
M03-08zc	13.4	0.436	0.384	605	14.9
M04-01	5.84	0.203	0.148	532	6.51
M04-02	5.63	0.160	0.140	532	6.16
M04-03	5.84	0.185	0.154	558	6.46
M04-04	5.40	0.121	0.137	555	5.80
M04-05	5.42	0.190	0.137	530	6.05
M04-06	6.33	0.223	0.163	543	7.06
M04-07	6.37	0.241	0.165	541	7.17
M04-08	5.86	0.145	0.148	548	6.34
M04-09	5.77	0.131	0.144	545	6.21
M04-10	5.86	0.146	0.143	528	6.34
M05-01	5.97	0.224	0.157	549	6.72
M05-02	5.33	0.253	0.147	559	6.17
M05-03	5.39	0.266	0.141	528	6.27
M05-04	5.81	0.248	0.154	545	6.63
M05-05zc	6.66	0.244	0.203	637	7.47
M05-06	4.69	0.157	0.123	553	5.21
M05-07zc	5.87	0.236	0.180	634	6.66
M05-08zc	5.89	0.219	0.181	641	6.62
M05-09zc	6.39	0.224	0.177	582	7.13
M05-10	5.51	0.244	0.149	552	6.32
M05-11	5.47	0.210	0.146	556	6.17
M05-12	6.07	0.217	0.160	554	6.79
M05-13	4.75	0.201	0.127	552	5.41
M05-14	5.33	0.190	0.140	550	5.96
M05-15	5.94	0.236	0.158	553	6.72

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M05-16zc	5.84	0.206	0.179	643	6.53
M05-17	5.23	0.231	0.138	541	5.99
M06-01	4.79	0.239	0.128	538	5.58
M06-02	4.52	0.215	0.122	545	5.23
M06-03	5.41	0.258	0.144	540	6.27
M06-04	6.13	0.280	0.168	560	7.05
M06-05	6.27	0.256	0.170	561	7.12
M06-06	5.79	0.255	0.150	531	6.64
M06-07	5.03	0.221	0.131	534	5.76
M06-08	5.64	0.299	0.153	543	6.63
M06-09	5.97	0.290	0.163	552	6.93
M06-10	4.52	0.232	0.123	547	5.29
M07-01	5.71	0.233	0.149	538	6.48
M07-02	5.66	0.238	0.146	531	6.45
M07-03	5.89	0.203	0.158	563	6.56
M07-04	5.64	0.219	0.145	534	6.37
M07-05	5.36	0.236	0.141	538	6.14
M07-06	5.70	0.251	0.152	546	6.53
M07-07	6.27	0.254	0.166	548	7.12
M07-08	5.57	0.227	0.145	539	6.33
M07-09	5.45	0.199	0.145	559	6.10
M07-10	5.58	0.229	0.149	551	6.34
M08-01	5.23	0.196	0.140	560	5.88
M08-02zc	7.02	0.155	0.212	659	7.54
M08-03zc	6.85	0.165	0.207	655	7.41
M08-04zc	6.75	0.149	0.206	666	7.25
M08-05zc	6.72	0.156	0.207	668	7.24
M08-06zc	5.58	0.126	0.151	592	6.00
M08-07zc	6.48	0.145	0.193	649	6.97
M08-08zc	6.79	0.161	0.192	616	7.32
M08-09zc	4.84	0.172	0.141	609	5.41
M08-10	5.07	0.123	0.131	562	5.48
M08-11	5.17	0.093	0.129	553	5.48
M08-12	5.33	0.112	0.133	547	5.70
M08-13	5.53	0.114	0.135	538	5.90
M08-14	5.45	0.104	0.135	546	5.80
M08-15	5.32	0.233	0.140	539	6.09
M09-01zc	8.56	0.450	0.271	631	10.1
M09-02	7.14	0.367	0.197	552	8.36
M09-03	8.24	0.441	0.225	545	9.70
M09-04	7.00	0.444	0.197	546	8.47
M09-05	7.73	0.348	0.209	552	8.88
M10-01	7.50	0.401	0.201	536	8.83
M10-02	6.34	0.348	0.173	541	7.49
M10-03	7.44	0.358	0.202	549	8.63
M11-01zc	9.28	0.244	0.259	602	10.1
M11-02	4.97	0.229	0.137	561	5.73
M11-03zc	9.19	0.242	0.255	597	10.00
M11-04	6.30	0.215	0.161	539	7.01
M11-05	8.49	0.260	0.214	538	9.35
M11-06	6.35	0.214	0.163	543	7.06
M12-01zc	7.20	0.235	0.195	573	7.98

Appendix (continued).

Grain #	ThO_2 (wt%)	UO_2 (wt%)	PbO (wt%)	Age (Ma)	ThO_2* (wt%)
M12-02	4.78	0.178	0.122	532	5.36
M12-03	6.61	0.292	0.180	558	7.58
M12-04	3.64	0.182	0.102	563	4.25
M12-05	3.02	0.188	0.0850	548	3.64
M12-06zc	10.8	0.295	0.306	611	11.7
M12-07zc	9.44	0.298	0.272	612	10.4
M12-08	5.26	0.195	0.135	536	5.91
M12-09	4.75	0.192	0.125	546	5.39
M12-10	5.75	0.196	0.150	551	6.40
M13-01	5.24	0.215	0.134	531	5.95
M13-02	5.23	0.193	0.140	559	5.87
M13-03	5.02	0.201	0.131	541	5.69
M13-04	5.63	0.196	0.146	546	6.28
M13-05	5.91	0.242	0.156	546	6.72
M13-06	4.91	0.218	0.132	552	5.63
M13-07	4.96	0.198	0.134	561	5.61
M13-08	4.76	0.195	0.124	539	5.41
M13-09	4.92	0.194	0.131	554	5.56
M13-10	5.48	0.200	0.149	570	6.14
M14	4.45	0.269	0.123	540	5.34
M15-01	5.59	0.163	0.144	553	6.12
M15-02	4.59	0.221	0.125	551	5.32
M15-03	4.33	0.240	0.122	557	5.12
M15-04	6.42	0.214	0.164	541	7.13
M15-05	5.69	0.190	0.147	546	6.31
85020401C: Grt-Bt gneiss					
M01-01	5.35	0.629	0.178	563	7.44
M01-02	5.20	0.598	0.162	530	7.18
M01-03	5.46	0.649	0.182	561	7.61
M01-04	5.46	0.780	0.185	540	8.05
M01-05	5.45	0.670	0.177	542	7.67
M01-06	5.34	0.625	0.173	549	7.41
M01-07	5.32	0.707	0.175	535	7.67
M01-08	5.75	0.759	0.194	551	8.26
M01-09	5.25	0.656	0.171	540	7.43
M01-10	5.69	0.861	0.199	548	8.54
M01-11	4.83	0.835	0.173	535	7.59
M01-12	5.17	0.660	0.169	540	7.36
M01-13	5.59	0.683	0.177	530	7.85
M01-14	5.25	0.623	0.167	537	7.32
M01-15	4.98	0.555	0.162	557	6.82
M01-16	5.61	0.751	0.187	542	8.10
M01-17	5.61	0.833	0.191	536	8.37
M01-18	5.61	0.618	0.173	531	7.66
M01-19	5.11	0.538	0.159	540	6.89
M01-20	4.89	0.545	0.153	536	6.70
M02-01	6.12	1.46	0.250	536	11.0
M02-02	6.05	1.44	0.250	543	10.8
M02-03	5.93	1.44	0.253	555	10.7
M02-04	6.00	1.44	0.240	522	10.8
M02-05	6.16	1.43	0.253	545	10.9
M02-06	5.57	1.15	0.210	527	9.37
M02-07	5.43	1.02	0.199	533	8.79
M02-08	5.51	0.859	0.192	539	8.36
M02-09	5.71	0.957	0.205	542	8.89
M02-10	6.43	1.46	0.262	545	11.3
M02-11	6.33	1.47	0.262	549	11.2
M02-12	5.84	1.38	0.244	551	10.4
M02-13	5.44	1.33	0.231	550	9.84
M02-14	5.46	1.33	0.219	521	9.87
M02-15	5.47	1.29	0.222	535	9.75
M02-16	5.58	1.18	0.220	544	9.49
M02-17	5.77	1.24	0.232	551	9.88
M02-18	5.71	1.38	0.241	549	10.3
M02-19	5.64	1.34	0.235	548	10.1
M02-20	5.45	1.32	0.225	538	9.84
M03-01	8.24	0.587	0.232	535	10.2
M03-02	8.09	0.598	0.225	525	10.1
M03-03	8.22	0.580	0.229	531	10.1
M03-04	8.22	0.591	0.234	539	10.2
M03-05	8.07	0.613	0.229	532	10.1
M03-06	8.05	0.587	0.229	539	9.99
M03-07	7.83	0.566	0.218	529	9.70
M03-08	7.72	0.578	0.226	549	9.64
M03-09	7.81	0.578	0.220	530	9.73
M03-10	7.62	0.572	0.221	546	9.51
M03-11	7.77	0.569	0.222	540	9.65
M03-12	7.87	0.559	0.227	548	9.73
M03-13	7.52	0.543	0.211	531	9.32
M03-14	6.47	0.492	0.184	534	8.10
M03-15	6.54	0.517	0.188	536	8.25
M03-16	7.52	0.560	0.216	542	9.38
M03-17	6.71	0.516	0.196	545	8.42
M04-01	7.35	0.992	0.238	526	10.6
M04-02	6.93	1.08	0.245	547	10.5
M04-03	6.32	1.27	0.243	541	10.5
M04-04	5.42	0.746	0.183	543	7.89
M04-05	4.53	0.544	0.144	535	6.34
M04-06	6.70	1.30	0.254	543	11.0
M04-07	5.82	0.480	0.171	542	7.41
M04-08	7.25	1.02	0.247	546	10.6
M04-09	7.20	1.02	0.243	540	10.6
M05-01	7.96	0.779	0.248	552	10.5
M05-02	5.68	0.564	0.178	554	7.55
M05-03	7.45	0.724	0.227	541	9.85
M05-04	7.03	0.736	0.217	537	9.47
M05-05	5.70	0.560	0.179	554	7.56
M05-06	7.18	1.02	0.248	551	10.6
M05-07	7.54	0.700	0.230	548	9.86