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Preliminary CHIME dating of granites from the Nkambe area, northwestern Cameroon, Africa

Samuel TETSOPGANG, Kazuhiro SUZUKI and Mamoru ADACHI

Department of Earth and Planetary Sciences, Graduate School of Science, Nagoya University, Nagoya 464-8602, Japan

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ABSTRACT

The chemical Th-U-total Pb isochron method (CHIME) has been adopted for dating the syntectonic foliated and post-tectonic unfoliated granites in northwestern Cameroon. The CHIME ages are 532±35 Ma for allanite and 523±45 Ma for zircon from Sample I_{10} of foliated biotite granite, 530±9 Ma for monazite from Sample N_9 of foliated two-mica granite, and 510±25 Ma for monazite from Sample I4 of unfoliated two-mica granite. Several monazite grains from Sample N_9 and I_4 yield 436±13 and 420±16 Ma CHIME ages, respectively. The 532-510 Ma ages are interpreted as the time of granite emplacement and the 436-420 Ma ages as the time of hydrothermal alteration. The CHIME ages coupled with the concordant relation between the foliated granites and migmatitic gneiss suggest a ca. 530 Ma metamorphic-plutonic episode in northwestern Camaroon rather than a thermal overprint by granite intrusion.

INTRODUCTION

The Pan-African orogeny was recorded in a wide area of Africa (Kröner, 1977), but the timing and nature of individual mobile zones have remained unclear. The main point of argument is whether the numerous Cambrian (ca. 530 Ma) ages record a single cycle with integral sedimentary-metamorphic-plutonic episodes or a simple thermal imprint an older rocks through granite intrusion. Tingey (1991) regarded the 500 Ma event in East Gondwana as a thermal event free from deformation. Recent geochronogical studies, however, have disclosed a widespread occurence of Cambrian granulite-facies paragneisses in East Antarctica (521-553 Ma, Shiraishi et al., 1994; 529±14 - 541±15 Ma, Asami et al., 1996, 1997), South India (527±10 Ma, Bindu et al., 1998) and Madagascar (527±15 - 534±10 Ma, Ito et al., 1997). Since the paragneisses contain 622-797 Ma detrital monazites (Asami et al., 1997; Ito et al., 1997) and 640-800 Ma detrital zircons (Shiraishi et al., 1994, Bindu et al.,1996), they do not represent reworked older basements, but formed newly from post-620 Ma sediments by the single metamorphism linked to the collision of East Gondwana (Shiraishi et al., 1994; Asami et al., 1997; Ito et al., 1997). West Gondwana, on the other hand, has been considered to have formed by the collision of the Western Africa craton, Congo craton and a Proterozoic mobile zone during the Pan-African-Brasilliano orogeny (Castaing et al., 1993; Trompette, 1994). The timing of the metamorphism and plutonism during the Pan-African-Brasilliano orogeny is important for proper understanding of the amalgamation history of the Gondwana supercontinent. Cameroon, located to the north of the Congo craton (Fig. 1: e.g. Kennedy, 1964; Rocci, 1965; Clifford, 1970), occupies a key position for studying of the Pan-African-Brasiliano orogeny.

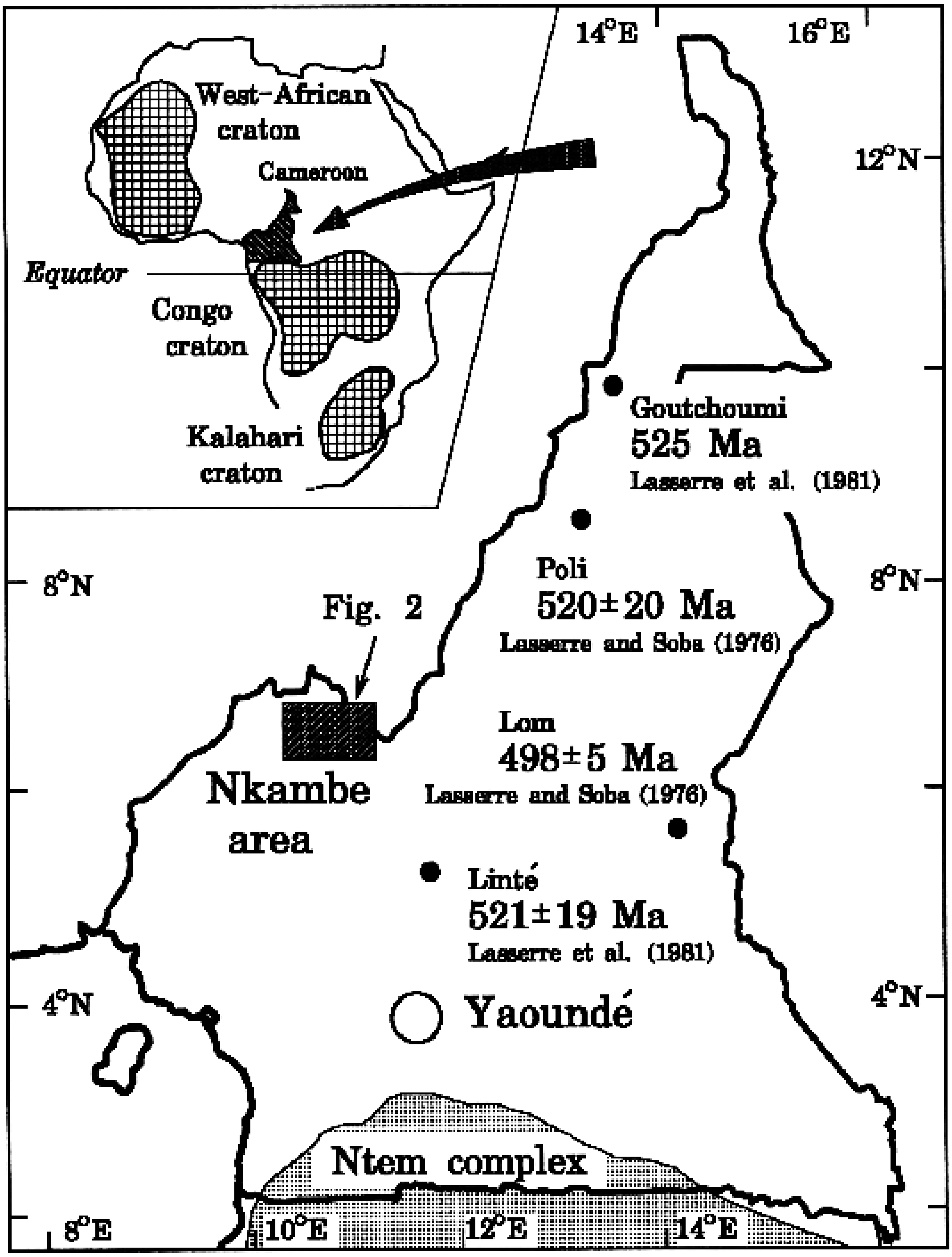

Fig. 1. Map showing the location of the Nkambe area in northwestern Cameroon. The location of the Ntem Complex of the Congo craton and radiometric ages reported by Lasserre and Soba (1976) and Lasserre et al. (1981) are also shown. Inset map shows the distribution of craton in Africa (after Kennedy, 1964).

Lasserre (1966) separated the basement rocks in Cameroon into the Ntem Complex in the southern end of Cameroon and the Central-Africa mobile zone in the rest of the territory. The Ntem Complex constitutes the northern part of the Congo craton, and consists predominantly of charnockitic gneiss and granites. Studies on the Ebolowa Granite have yielded 2.5 and 3.2 Ga Pb-a zircon ages (Cahen and Snelling, 1966), a 2566±100 Ma K-Ar hornblende age (Lasserre, 1969) and a 3010±50 Ma Rb-Sr whole-rock isochron age (Lasserre and Bessoles, 1976). Other granitoids have Rb-Sr biotite ages of 1800-2350 Ma (Cahen and Snelling, 1966; Lasserre, 1969).

The Central-Africa mobile zone is composed of a mixture of schist, gneiss, migmatite and granite. Granitic rocks in the mobile zone have been classified into two groups, "uncircumscribed" granites with a marked foliation and/or mylonitic texture and "circumscribed" granites with no foliation (Bessoles and Trompette, 1980). Hereafter, we designate the uncircumscribed and circumscribed granite as the foliated and unfoliated granites, respectively. The foliated granite was emplaced possibly during the Pan-African orogeny and the unfoliated one on an later anorogenic stage. Rb-Sr age data have been reported for granitoids from Groutchoumi (ca. 525 Ma, Lasserre et al., 1981), Poli (520±20 Ma, Lasserre and Soba, 1976), Linté (521±19 Ma, Lasserre et al., 1981), and Lom (498±5 Ma, Lasserre and Soba, 1976). We, however, are not confident whether these ages date the intrusion time of the foliated granite or the overprint time by the intrusion of the unfoliated granite.

The Nkambe area in northwestern Cameroon (Fig. 1) is underlain by predominantly granitic rocks. These granitoids, like those in other area of the Central-African mobile zone, can be classified into the foliated and unfoliated types. CHIME dating by the authors is currently in progress, to know the emplacement ages of the granitoids. This paper reports CHIME age data for representative samples of the foliated and unfoliated granites from the Nkambe area.

GEOLOGICAL OUTLINE AND SAMPLE DESCRIPTION

The Nkambe area ranges in latitude from 6°25' to 6°53' N and in longitude from 10°22' to 11°00'E (Fig. 1). The area consists mainly of plateaus with deep river valleys flowing in to the Donga River in the northeast, and high volcanic mountains in the southeast. The geology of the Nkambe area is shown in Fig. 2. The basement rocks include magmatitic gneiss, anatectic granite, amphibolite and granite, which are overlain in part by Cenozoic basalt, andesite and alkali rhyolite (Peronne, 1969). The migmatitic gneiss trends NNE-SSW direction.

Granitic rocks in the Nkambe area consist of the foliated and unfoliated granites. Although these types are not distinguished in the map, the former type includes biotite granite, anatectic granite and small phacoliths in the migmatitic gneiss domains in Fig. 2. Since the foliated granites grade into the migmatitic gneiss at the margins and are deformed along with the migmatitic gneiss, they can be regarded as syntectonic intrusives. The unfoliated granites intrude into the migmatitic gneiss as small stocks of about 500-1000 m in diameter.

Two samples (Sample I_{10} and N_9) of the foliated granite and one sample (Sample I_4) of the unfoliated granite were used for the present CHIME dating. The sample

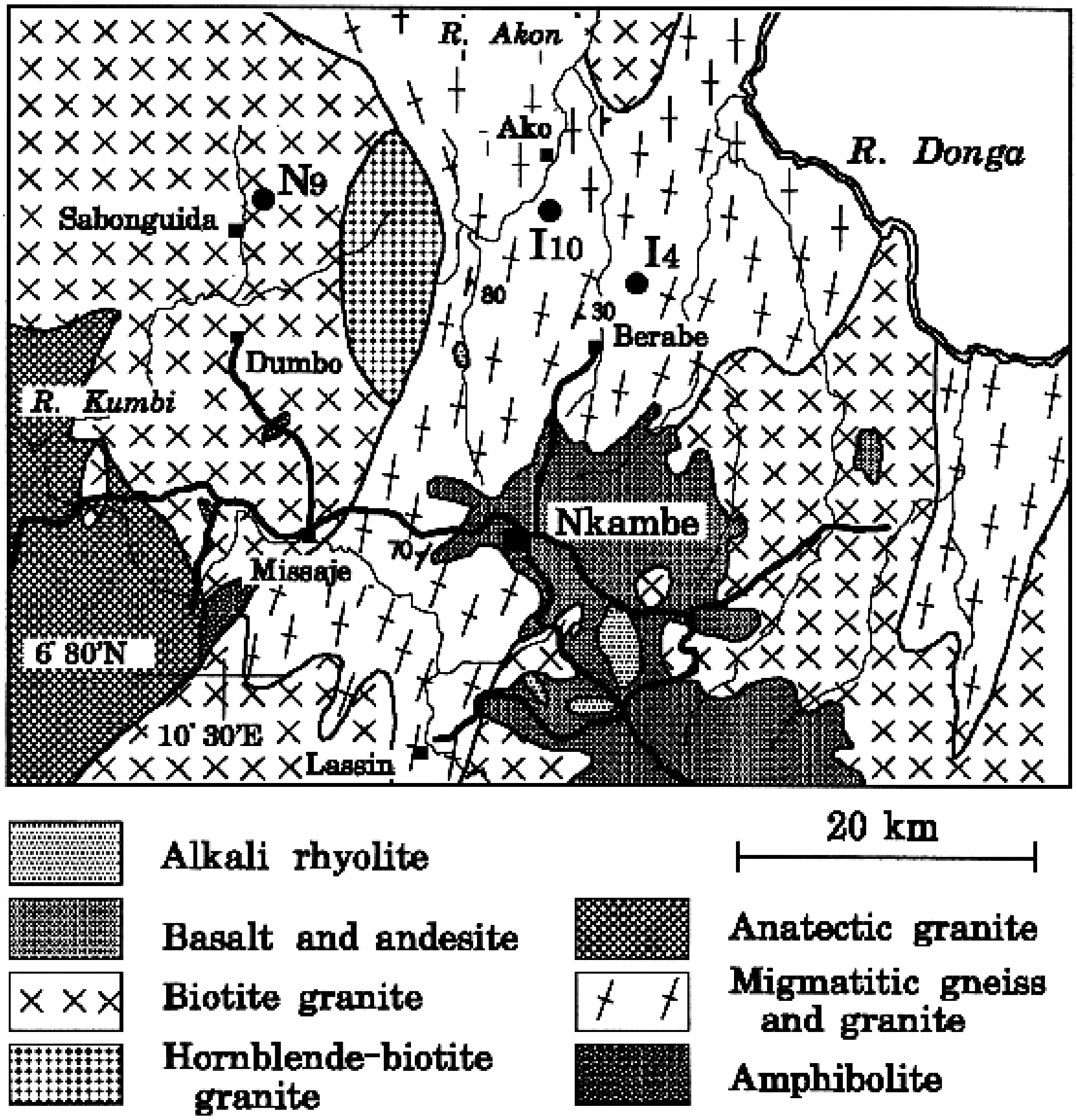

Fig. 2. Geological map of the Nkambe area (simplified and modified from Peronne, 1969). Sample localities are indicated by solid circles.

localities are shown in Fig. 2.

Sample I_{10} was collected from a phacolith in the migmatitic gneiss domain. It is of biotite granite containing quartz, microcline, plagioclase, biotite and muscovite. The modal proportions of quartz, mcrocline and plagioclase are 41.2, 49.4 and 9.4%, respectively. Quartz porphyroclasts exhibit a strong wavy extinction, and are granulated along their grain boundaries. Feldspar porphyroclasts are extensively deformed. Granulated particles are flattened, and form a fine-grained matrix. Biotite and muscovite flakes are commonly kinked. Accessory minerals include zircon, allanite and magnetite. Zircon occurs as euhedral prisms of 0.1 to 0.3 mm in length. No visible cores or overgrowth rims can be observed, but some grains show concentric growth zoning. Allanite occurs as inclusions in deformed quartz porphyroclasts as well as in deformed biotite flakes.

Sample N_9, a medium-grained porphyritic two-mica granite, was collected from the central part of the concordant biotite granite domain in Fig. 2. It is foliated and consists mainly of quartz, microcline-microperthite, plagioclase, biotite and muscovite. Myrmekites of quartz and feldspar are common. The modal proportions of quartz, microcline and plagioclase are 31.2, 39.6 and 29.2%, respectively. Quartz grains are granulated along their boundaries. Feldspar grains remain resistant to granulation, and are responsible for the porphyritic texture. Biotite flakes are not deformed, and in some place are replaced by chlorite. Accessory minerals include apatite, zircon, monazite and magnetite. Zircon occurs as transparent euhedral prismatic crystals of 0.1-0.2 mm in length, and is found in quartz and microcline, and along grain boundaries. Subhedral to anhedral grains of monazite, up to 0.2 mm across, occur on the boundaries of quartz and feldspar grains, and are also found within the foliated matrix. Most monazite grains are inclusion-free, although several anhedral monazite grains contain minute black inclusions.

Sample I_4 is undeformed fine-grained two-mica adamellite with magnetite grains 2-5 mm across. It consists mainly of quartz, sodic oligoclase, microcline, biotite and muscovite. The modal proportions of quartz, microcline and plagioclase are 31.2, 32.9 and 35.9%, respectively. Biotite is almost entirely altered to chlorite. Some muscovite is intergrown with biotite. Magnetite grains are surrounded by pink-colored altered patches 5-10 mm across. Under the microscope, the magnetite grains are fringed with secondary muscovite, and feldspars in the altered patches are replaced partly by an aggregate of muscovite. Accessory minerals include monazite, zircon and apatite. Monazite grains are more abundant than zircon, and range from 0.1 to 0.4 mm across. Monazite grains in the fresh part of the sample are clear, but those in the altered patches are studded with minute black inclusions and are altered at the margin to apatite and an unidentified REE-, Fe- and Ca-bearing brown to opaque mineral.

CHIME DATING

Monazite, allanite and zircon were analyzed on a JEOL JCXA-733 electron microprobe equipped with four wavelength-dispersive type spectrometers. The details of sample preparation and analysis have been described elsewhere (Suzuki and Adachi, 1991a, b; Suzuki et al., 1999). The detection limit if ThO_2, UO_2 and PbO at a 2σ confidence level are 0.015, 0.02 and 0.006%, respectively. The relative errors in the PbO determination are 30, 10, 5 and 3% at -0.02, -0.1, -0.2 and 0.4 wt. % levels, respectively. The relative errors in the ThO_2 and UO_2 determinations are 20, 10, 5, 3 and 1% at <0.1, -0.3, -4 and >8 wt.%, respectively. The ThO_2, UO_2 and PbO analytical results are listed in Table 1. CHIME ages were calculated as described by Suzuki and Adachi (1991a, b, 1994, 1998) and Suzuki et al. (1991, 1994, 1999).

Sample I_{10}: biotite granite

A total of 39 spots on 7 allanite grains and 9 spots on 2 zircon grains were analyzed. The ThO_2 concentration in allanite ranges from 1.32 to 12.3%, UO_2 from 0.039 to 1.61%, and PbO from 0.036 to 0.224%. Thirty-one of the 39 analyses form a linear array on the PbO-ThO_2^* diagram (Fig. 3A), with the rest of the analyses plotted below the array.

Table 1. Electron microprobe analyses (wt.%) of ThO_2, UO_2 and PbO of allanite (A), zircon (Z) and monazite (M) frm foliated (Samples I_{10} and N_9) and unfoiated (Sample I4) granites in northwestern Cameroon. Age: apparent age in Ma, RO_2*: (ThO_2*) measured ThO_2 plus ThO_2 equivalent of the measured UO_2 for allanite and monazite and (UO_2*) measured UO_2 plus UO_2 equivalent of the measured ThO_2 for zircon.

Spot No.	ThO_2	UO_2	PbO	Age	RO_2*
Sample I_{10} (foliated granite)					
A01-01 *	3.85	0.062	0.103	594	4.06
A01-02 *	3.13	0.049	0.0782	557	3.30
A01-03 *	5.00	0.072	0.127	569	5.23
A01-04	6.85	0.122	0.128	414	7.25
A01-05	12.3	0.171	0.105	193	12.9
A01-06 *	3.61	0.049	0.0847	528	3.77
A01-07 *	3.87	0.109	0.101	558	4.23
A01-08 *	3.40	0.059	0.0934	608	3.60
A01-09 *	7.74	0.126	0.168	484	8.16
A01-10	10.5	0.153	0.108	233	11.0
A01-11	7.35	0.111	0.130	396	7.72
A01-12	3.40	0.089	0.0369	237	3.69
A02-01	2.59	0.671	0.0505	250	4.77
A02-02 *	4.26	1.61	0.224	549	9.60
A02-03 *	4.00	0.306	0.112	525	5.01
A02-04 *	3.44	0.605	0.145	623	5.45
A03-01 *	2.92	0.154	0.0777	533	3.42
A03-02 *	3.46	0.448	0.112	530	4.95
A03-03	2.47	0.906	0.0486	213	5.40
A03-04 *	1.83	0.103	0.0602	648	2.18
A03-05 *	3.64	0.424	0.123	572	5.04
A03-06 *	3.94	0.737	0.1273	470	6.37
A03-07	3.39	1.04	0.120	415	6.81
A04-01 *	1.32	0.039	0.0361	584	1.45
A04-02 *	3.97	1.27	0.202	577	8.20
A04-03 *	4.87	0.107	0.125	563	5.22
A05-01 *	3.09	0.057	0.0837	599	3.28
A05-02 *	3.17	0.065	0.0801	556	3.38
A05-03 *	3.70	0.073	0.0980	583	3.94
A05-04 *	3.61	0.069	0.0950	580	3.84
A05-05 *	3.71	0.057	0.0869	523	3.90
A05-06 *	3.30	0.062	0.0757	507	3.51
A06-01 *	5.10	0.104	0.124	533	5.45
A06-02 *	4.20	0.075	0.106	558	4.45
A07-01 *	2.81	0.060	0.0655	512	3.01
A07-02 *	3.25	0.074	0.0840	565	3.49
A07-03 *	2.77	0.061	0.0673	532	2.97
A07-04 *	3.47	0.063	0.0833	531	3.68
A07-05 *	3.34	0.052	0.0762	509	3.52
A07-06	4.01	0.083	0.0777	427	4.28
Z01-01 *	0.230	0.261	0.0244	528	0.330
Z01-02 *	0.238	0.254	0.0243	533	0.326
Z01-03 *	0.260	0.279	0.0279	557	0.357
Z01-04 *	0.187	0.255	0.0232	533	0.312
Z01-05 *	0.111	0.170	0.0163	572	0.203
Z01-06 *	0.270	0.279	0.0214	428	0.362
Z02-01 *	0.061	0.185	0.0166	582	0.203
Z02-02 *	0.087	0.121	0.0113	548	0.147
Z02-03 *	0.099	0.208	0.0173	521	0.238

* marks data points shown with solid circles in Figs. 3, 4 and 5, and / marks data points shown with open circles

Spot No.	ThO_2	UO_2	PbO	Age	RO_2*
Sample N_9 (foliated granite)					
M01-01 /	7.82	0.335	0.173	457	8.93
M01-02 *	14.5	0.588	0.363	519	16.5
M01-03	11.2	0.441	0.266	494	12.7
M01-04	8.39	0.369	0.198	485	9.61
M01-05 *	16.2	0.548	0.397	516	18.1
M01-06 *	16.5	0.549	0.408	524	18.3
M01-07 *	15.1	0.479	0.367	516	16.7
M01-08	11.3	0.386	0.266	498	12.6
M01-09	9.73	0.374	0.232	496	11.0
M01-10 *	7.48	0.327	0.184	504	8.56
M01-11	8.64	0.299	0.199	487	9.62
M01-12	12.2	0.387	0.281	489	13.5
M01-13 /	7.95	0.403	0.182	462	9.28
M01-14 *	21.0	0.605	0.518	529	23.0
M01-15 /	16.8	0.334	0.315	415	17.9
M01-16 /	5.03	0.277	0.111	440	5.94
M02-01	9.55	0.374	0.220	480	10.8
M02-02 *	7.20	0.333	0.179	507	8.30
M02-03	7.99	0.364	0.191	488	9.19
M02-04	8.14	0.390	0.197	490	9.43
M02-05	6.40	0.326	0.156	490	7.48
M02-06 *	5.90	0.323	0.151	510	6.97
M02-07	9.53	0.460	0.229	487	11.0
M02-08 /	7.57	0.393	0.172	455	8.87
M02-09 *	8.39	0.411	0.213	513	9.75
M02-10 *	9.11	0.403	0.227	510	10.4
M02-11 /	7.70	0.384	0.170	447	8.96
M02-12 *	5.95	0.320	0.150	504	7.01
M02-13	8.66	0.359	0.203	485	9.85
M02-14	7.73	0.436	0.191	491	9.17
M02-15 *	7.95	0.417	0.208	523	9.33
M02-16	7.33	0.377	0.179	489	8.58
M02-17	6.21	0.333	0.151	486	7.31
M02-18	7.03	0.331	0.168	488	8.12
M02-19 /	11.4	0.349	0.242	454	12.5
M02-20 *	5.85	0.374	0.153	506	7.09
M03-01 /	8.15	0.455	0.187	457	9.65
M03-02	8.01	0.409	0.186	467	9.36
M03-03 /	8.70	0.371	0.190	450	9.92
M03-04 /	18.9	0.611	0.393	443	20.9
M03-05	7.62	0.408	0.184	482	8.97
M03-06 /	7.59	0.377	0.160	428	8.83
M03-07 /	9.63	0.409	0.203	435	11.0
M03-08 /	7.77	0.456	0.178	453	9.27
M03-09 /	7.90	0.446	0.170	426	9.37
M03-10 /	7.25	0.419	0.151	412	8.63
M04-01 /	7.29	0.468	0.165	441	8.83
M04-02 /	6.76	0.434	0.153	438	8.19
M04-03 /	6.69	0.433	0.149	432	8.12
M04-04 /	7.10	0.465	0.159	433	8.63
M04-05 /	7.40	0.324	0.162	450	8.46
M04-06 /	10.2	0.438	0.218	441	11.6
M04-07 /	7.82	0.344	0.170	447	8.95
M05-01 /	8.34	0.506	0.189	444	10.0
M05-02	7.89	0.473	0.200	497	9.45
M05-03 *	7.62	0.472	0.201	513	9.18
M05-04	8.27	0.501	0.210	497	9.92
M05-05	7.79	0.477	0.199	499	9.36

Table 1. (continued)

Spot No.	ThO_2	UO_2	PbO	Age	RO_2*
M05-06 *	5.13	0.324	0.137	517	6.20
M05-07	7.85	0.453	0.194	487	9.34
M05-08 *	8.27	0.455	0.213	513	9.78
M05-09 *	6.58	0.400	0.171	507	7.91
M05-10 *	5.14	0.338	0.138	518	6.26
M05-11 *	8.23	0.444	0.207	502	9.70
M05-12	8.21	0.449	0.205	497	9.70
M05-13 *	5.59	0.356	0.144	500	6.76
M05-14	8.01	0.428	0.194	485	9.42
M05-15	6.53	0.415	0.158	472	7.89
M05-16	6.50	0.282	0.146	461	7.43
M05-17 /	6.53	0.267	0.143	454	7.41
M05-18	6.52	0.340	0.156	479	7.64
M05-19 /	9.04	0.321	0.193	449	10.1
M05-20 /	5.43	0.270	0.122	454	6.32
M06-01 /	9.63	0.298	0.201	445	10.6
M06-02 /	11.3	0.341	0.242	459	12.4
M06-03 /	11.6	0.369	0.237	436	12.8
M06-04 /	9.98	0.242	0.203	444	10.8
M06-05 /	11.2	0.335	0.234	449	12.3
M07-01 /	9.73	0.295	0.200	439	10.7
M07-02 /	10.2	0.329	0.215	451	11.2
M07-03	9.92	0.322	0.216	463	11.0
M07-04	8.34	0.267	0.187	477	9.22
M07-05	9.76	0.319	0.214	466	10.8
M08-01 /	10.3	0.203	0.211	451	11.0
M08-02	9.80	0.207	0.210	470	10.5
M08-03 /	10.5	0.231	0.214	445	11.3
M08-04 /	11.5	0.316	0.243	454	12.6
M08-05 /	10.5	0.200	0.215	453	11.1
M09-01	8.18	0.187	0.176	471	8.79
M09-02 /	9.21	0.203	0.192	456	9.88
M09-03	8.66	0.160	0.134	343	9.18
M09-04 /	8.92	0.207	0.180	440	9.60
M09-05 /	8.24	0.191	0.172	456	8.87
M10-01 *	6.26	0.342	0.158	502	7.39
M10-02 *	6.26	0.344	0.161	512	7.40
M10-03 *	5.69	0.322	0.149	517	6.76
M10-04 *	6.86	0.282	0.178	536	7.79
M10-05 /	7.70	0.320	0.164	440	8.75
M10-06 *	6.89	0.317	0.175	518	7.94
M10-07 *	6.19	0.333	0.157	506	7.29
M10-08 *	5.84	0.359	0.159	532	7.03
M10-09 *	8.69	0.347	0.209	500	9.83
M10-10 *	7.00	0.326	0.178	517	8.08
M10-11 *	6.44	0.306	0.159	502	7.45
M10-12 *	8.72	0.393	0.221	517	10.0
M10-13 *	4.33	0.239	0.114	524	5.12
M10-14 /	6.82	0.318	0.153	457	7.87
M10-15	5.94	0.357	0.142	469	7.12
M10-16 *	5.38	0.327	0.145	528	6.46
M10-17 *	6.95	0.292	0.170	504	7.91
M10-18 /	7.40	0.366	0.167	456	8.60
M10-19 *	5.45	0.293	0.141	516	6.42
M10-20 *	6.74	0.320	0.173	522	7.80
M10-21 *	9.35	0.388	0.229	507	10.6
M10-22 *	10.3	0.405	0.265	533	11.7
M10-23	7.53	0.339	0.170	461	8.65
M10-24 *	6.87	0.309	0.172	512	7.89
M10-25 *	5.68	0.318	0.145	505	6.73
M10-26 /	5.10	0.305	0.117	451	6.11
M10-27 /	6.13	0.239	0.131	444	6.92
M10-28 /	6.44	0.284	0.144	458	7.37
M10-29	6.87	0.266	0.168	508	7.76
M10-30	8.87	0.412	0.201	463	10.2
M10-31	9.94	0.525	0.232	468	11.7
M10-32 *	6.90	0.279	0.168	504	7.83
M10-33 *	10.3	0.404	0.248	502	11.6
M10-34 *	7.61	0.328	0.194	523	8.70
M10-35 *	6.71	0.342	0.169	507	7.84
M10-36 *	6.71	0.285	0.165	506	7.65
M10-37 *	7.73	0.358	0.201	529	8.92
M10-38 *	6.62	0.300	0.163	502	7.61
M10-39	7.20	0.323	0.173	491	8.27
M10-40 *	6.40	0.240	0.155	505	7.19
M10-41 *	7.37	0.330	0.188	522	8.47
M10-42 *	8.23	0.378	0.211	521	9.49
M10-43 *	5.66	0.256	0.147	531	6.51
M10-44 *	8.29	0.357	0.212	526	9.47
M10-45 *	7.69	0.320	0.192	516	8.75
M10-46 *	5.99	0.344	0.153	504	7.13
M10-47 *	10.2	0.391	0.258	526	11.5
M10-48 *	6.02	0.335	0.150	495	7.13
M10-49 *	9.09	0.373	0.225	513	10.3
M10-50 *	4.01	0.239	0.103	503	4.80
M10-51	9.14	0.366	0.218	496	10.3
M10-52 *	7.38	0.337	0.185	511	8.49
M10-53 *	6.40	0.382	0.167	511	7.66
M10-54 *	7.46	0.383	0.196	528	8.73
M10-55 *	10.7	0.458	0.282	544	12.2
M10-56 *	7.06	0.277	0.178	525	7.98
M10-57 *	7.31	0.309	0.187	528	8.33
M10-58 *	6.94	0.319	0.185	544	7.99
M10-59 *	6.91	0.249	0.178	540	7.74
M10-60 *	6.68	0.309	0.181	551	7.70
M10-61 *	7.71	0.368	0.208	545	8.93
M10-62 *	6.54	0.322	0.174	537	7.61
M10-63 *	7.17	0.343	0.197	555	8.31
M11-01 *	6.05	0.329	0.156	515	7.14
M11-02	5.81	0.346	0.147	498	6.96
M11-03 *	5.82	0.378	0.160	532	7.08
M11-04 *	6.01	0.273	0.157	532	6.92
M11-05 *	6.60	0.341	0.173	527	7.72
M11-06 *	5.87	0.359	0.160	531	7.05
M11-07 *	5.07	0.323	0.134	514	6.13
M11-08 *	7.41	0.355	0.199	543	8.58
M11-09	6.84	0.352	0.170	498	8.00
M11-10 /	6.08	0.372	0.133	429	7.30
M11-11 *	6.67	0.338	0.170	512	7.78
M11-12	7.02	0.341	0.169	488	8.14
M11-13 /	5.13	0.299	0.117	451	6.11
M11-14 *	6.00	0.350	0.159	523	7.16
M11-15 /	7.49	0.347	0.169	459	8.64
M12-01 *	6.68	0.394	0.178	524	7.99
M12-02 /	10.0	0.411	0.202	418	11.4
M12-03 *	9.88	0.478	0.260	532	11.5
M12-04 *	8.31	0.297	0.205	518	9.29
M12-05 *	5.16	0.275	0.133	515	6.07
M12-06 *	7.99	0.351	0.199	511	9.15
M12-07 *	9.31	0.432	0.243	530	10.7
M12-08 *	9.48	0.425	0.246	531	10.9
M12-09 *	8.33	0.346	0.213	528	9.48
M12-10 *	8.19	0.369	0.206	513	9.42
M12-11 *	7.76	0.371	0.205	536	8.98
M12-12 *	8.33	0.356	0.214	530	9.50
M12-13 *	8.38	0.361	0.211	519	9.57

Table 1. (continued)

Spot No.	ThO_2	UO_2	PbO	Age	RO_2*
M12-14	7.91	0.335	0.198	515	9.02
M12-15	9.64	0.436	0.258	545	11.1
M12-16	7.34	0.399	0.175	475	8.66
M12-17 *	7.95	0.408	0.206	521	9.30
M12-18 *	8.18	0.416	0.209	513	9.55
M12-19 *	7.86	0.406	0.198	507	9.20
M12-20	7.41	0.399	0.181	488	8.73
M12-21	6.69	0.391	0.166	489	7.99
M12-22	7.56	0.412	0.189	498	8.92
M13-01 *	7.42	0.366	0.189	515	8.63
M13-02	6.00	0.308	0.147	493	7.02
M13-03 *	6.02	0.307	0.153	510	7.04
M13-04 *	4.70	0.305	0.123	507	5.71
M13-05 *	8.74	0.360	0.224	530	9.94
M13-06 *	7.17	0.348	0.188	529	8.32
M13-07 *	16.5	0.499	0.407	528	18.1
M13-08 *	6.23	0.304	0.168	547	7.23
M13-09 *	4.85	0.219	0.128	541	5.58
M13-10 *	15.4	0.510	0.390	535	17.1
M14-01 *	4.59	0.321	0.132	550	5.65
M14-02 *	6.98	0.462	0.191	526	8.51
M14-03 *	6.55	0.508	0.195	556	8.23
M14-04 *	6.76	0.507	0.201	559	8.45
M14-05 *	6.80	0.559	0.199	540	8.65
M14-06 *	4.50	0.352	0.123	509	5.66
M14-07 *	4.49	0.360	0.122	507	5.68
M14-08 *	6.22	0.396	0.173	539	7.53
M14-09 *	7.57	0.470	0.206	530	9.13
M14-10 /	4.62	0.341	0.110	452	5.74
Sample I_4 (unfoliated granite)					
M01-01	5.12	0.142	0.119	498	5.59
M01-02 *	4.57	0.436	0.137	535	6.01
M01-03 *	4.45	0.126	0.109	528	4.87
M01-04 *	5.18	0.295	0.140	532	6.16
M01-05 *	4.51	0.123	0.111	531	4.92
M01-06 *	4.13	0.212	0.107	518	4.83
M01-07	4.37	0.113	0.0992	491	4.75
M01-08 /	4.10	0.070	0.0816	444	4.33
M01-09 *	4.40	0.125	0.116	563	4.81
M01-10 *	3.82	0.412	0.115	523	5.18
M01-11 *	3.15	0.286	0.0964	552	4.10
M01-12	5.60	0.319	0.139	491	6.65
M01-13 /	2.82	0.039	0.0549	439	2.94
M01-14 *	5.47	0.149	0.142	559	5.96
M01-15 *	4.02	0.085	0.101	550	4.30
M01-16 *	3.24	0.269	0.0898	511	4.13
M01-17 *	3.25	0.339	0.102	549	4.37
M01-18 *	3.42	0.278	0.104	562	4.34
M01-19 *	3.75	0.305	0.109	535	4.76
M01-20 /	3.76	0.184	0.0826	445	4.36
M01-21 *	4.96	0.138	0.119	518	5.42
M01-22 *	3.28	0.273	0.0982	551	4.18
M02-01	3.81	0.241	0.0963	491	4.61
M02-02 *	3.21	0.474	0.102	502	4.77
M02-03 *	4.52	0.291	0.123	526	5.48
M02-04 /	4.63	0.204	0.0981	435	5.30
M02-05 *	3.83	0.305	0.111	536	4.84
M02-06 *	3.25	0.210	0.0867	516	3.95
M02-07 *	3.47	0.225	0.0942	525	4.22
M02-08 /	3.63	0.197	0.0817	450	4.27
M02-09	3.57	0.339	0.0920	462	4.69
M02-10 /	5.50	0.218	0.118	447	6.22
M02-11 *	4.54	0.284	0.123	528	5.49
M02-12 *	4.43	0.365	0.132	550	5.64
M02-13 *	5.20	0.172	0.129	524	5.77
M02-14	4.62	0.388	0.122	486	5.90
M02-15 *	4.57	0.386	0.132	530	5.85
M02-16 *	4.01	0.149	0.115	600	4.51
M02-17 *	4.71	0.300	0.125	516	5.70
M02-18 *	4.69	0.289	0.125	520	5.65
M02-19 *	3.31	0.201	0.0923	545	3.98
M02-20 *	4.11	0.292	0.110	507	5.08
M03-01 /	3.94	0.238	0.0906	451	4.72
M03-02 /	2.74	0.021	0.0535	448	2.81
M03-03 /	4.95	0.079	0.101	455	5.21
M03-04 /	3.52	0.026	0.0644	420	3.61
M03-05 /	3.80	0.048	0.0686	408	3.96
M03-06 /	3.15	0.038	0.0639	459	3.28
M03-07 /	2.92	0.037	0.0584	452	3.04
M03-08	4.21	0.043	0.0669	362	4.35
M03-09 *	4.77	0.139	0.131	586	5.23
M03-10	5.06	0.073	0.0849	378	5.29
M03-11	5.05	0.075	0.0847	377	5.30
M03-12	4.64	0.098	0.102	481	4.96
M03-13	1.54	0.015	0.0244	362	1.59
M03-14 /	4.78	0.087	0.0964	447	5.07
M03-15	4.48	0.070	0.0768	385	4.70
M03-16	3.49	0.030	0.0540	355	3.59
M03-17 /	6.33	0.113	0.121	425	6.70
M03-18 /	5.46	0.181	0.113	441	6.05
M03-19 *	5.17	0.187	0.126	510	5.79
M03-20	4.96	0.155	0.110	474	5.47
M03-21	5.33	0.046	0.0915	393	5.48
M03-22 /	5.26	0.062	0.0965	416	5.46
M03-23 /	4.78	0.091	0.0960	445	5.08
M03-24 /	4.31	0.112	0.0876	440	4.68
M03-25	4.81	0.066	0.0844	396	5.02
M04-01	4.91	0.085	0.105	476	5.19
M04-02 *	3.70	0.146	0.0925	519	4.19
M04-03 *	4.74	0.201	0.119	516	5.40
M04-04	4.77	0.218	0.111	474	5.49
M04-15 *	4.97	0.202	0.130	543	5.64
M04-06	4.92	0.202	0.115	484	5.59
M04-07 *	5.04	0.216	0.134	546	5.75
M04-08 *	4.81	0.213	0.125	533	5.52
M04-09 *	4.61	0.209	0.112	495	5.30
M04-10	5.91	0.103	0.123	464	6.25
M04-11 *	5.62	0.098	0.130	513	5.95
M04-12 *	4.99	0.219	0.128	526	5.72
M04-13 *	4.88	0.225	0.121	504	5.63
M04-14 *	4.84	0.212	0.119	506	5.54
M04-15 *	4.85	0.197	0.119	508	5.50
M04-16 *	4.89	0.195	0.122	516	5.53
M04-17 /	4.53	0.185	0.0974	446	5.14
M04-18 /	5.90	0.158	0.114	419	6.42
M04-19 /	7.24	0.192	0.152	453	7.87
M04-20 /	5.72	0.150	0.110	416	6.22
M04-21	5.11	0.131	0.0902	384	5.54
M04-22	4.02	0.092	0.0860	469	4.32
M04-23 /	7.45	0.196	0.148	429	8.10
M04-24 /	7.65	0.217	0.151	424	8.36
M04-25 /	5.61	0.150	0.117	453	6.10
M04-26 /	4.98	0.159	0.103	440	5.51
M04-27 /	5.46	0.161	0.109	427	5.99

Table 1. (continued)

Spot No.	ThO_2	UO_2	PbO	Age	RO_2*
M04-28 *	3.98	0.122	0.0939	504	4.38
M04-29 /	6.90	0.189	0.132	415	7.52
M04-30 /	6.52	0.159	0.127	425	7.04
M04-31 /	5.56	0.164	0.118	454	6.10
M04-31 /	6.00	0.167	0.125	450	6.55
M04-32 /	7.71	0.220	0.147	411	8.43
M04-34 /	7.89	0.224	0.151	413	8.63
M04-35 /	7.74	0.205	0.156	437	8.41
M04-36 /	4.78	0.083	0.0919	428	5.05
M04-37 /	9.38	0.228	0.177	411	10.13
M04-38	4.45	0.087	0.0930	462	4.74
M05-01 /	4.33	0.180	0.0856	410	4.92
M05-02 /	4.45	0.121	0.0879	427	4.85
M05-03 /	4.28	0.159	0.0936	458	4.80
M05-04 /	4.73	0.109	0.0915	423	5.09
M05-05 /	4.19	0.123	0.0818	420	4.59
M05-06 /	4.54	0.344	0.108	448	5.67
M05-07 /	4.19	0.111	0.0840	434	4.55
M05-08 /	4.52	0.181	0.0997	458	5.12
M05-09 /	4.64	0.268	0.103	439	5.52
M05-10 /	4.22	0.335	0.0971	429	5.32
M05-11 /	4.31	0.287	0.0985	441	5.26
M05-12	4.62	0.167	0.101	461	5.17
M05-13	4.38	0.243	0.103	467	5.18
M05-14 *	4.47	0.175	0.113	524	5.05
M06-01 /	4.30	0.113	0.0894	450	4.67
M06-02 /	4.06	0.137	0.0826	431	4.51
M06-03 /	5.18	0.141	0.105	439	5.64
M06-04 /	4.30	0.127	0.0868	433	4.72
M06-05	5.56	0.165	0.123	472	6.11
M06-06	4.45	0.094	0.0942	465	4.76
M06-07 /	4.88	0.138	0.0982	433	5.33
M06-08	4.54	0.108	0.0777	374	4.89
M06-09	4.45	0.125	0.0987	477	4.86
M06-10	4.42	0.121	0.101	491	4.82
M06-11 /	5.98	0.153	0.124	451	6.48
M07-02 /	5.84	0.158	0.109	402	6.36
M07-03 /	5.28	0.157	0.0993	404	5.79
M07-04 /	5.02	0.177	0.106	443	5.61
M07-05	5.27	0.143	0.122	498	5.75
M07-06 /	5.22	0.143	0.109	452	5.69
M07-07	5.98	0.155	0.131	476	6.49
M07-08 /	7.12	0.067	0.142	455	7.34
M07-09 /	4.59	0.273	0.0991	425	5.49
M07-10	4.85	0.080	0.0845	389	5.12
M07-11	5.04	0.136	0.112	480	5.49
M07-12	5.15	0.162	0.112	463	5.68
M07-13	5.39	0.180	0.100	395	5.98
M07-14	5.04	0.146	0.108	461	5.52
M07-15	5.15	0.127	0.117	494	5.57
M08-01 *	5.78	0.403	0.159	526	7.11
M08-02 *	5.73	0.382	0.160	537	7.00
M08-03 *	5.54	0.365	0.152	527	6.75
M08-04 *	5.65	0.398	0.149	501	6.97
M08-05 *	5.13	0.463	0.152	534	6.66
M08-06 *	5.10	0.455	0.151	536	6.61
M08-07 *	5.08	0.458	0.154	546	6.60
M08-08 *	5.03	0.456	0.149	536	6.54
M08-09 *	4.28	0.262	0.116	531	5.15
M08-10 *	4.18	0.263	0.110	511	5.05
M08-11 *	4.04	0.259	0.111	530	4.90
M09-01 *	5.66	0.215	0.141	520	6.38
M09-02 *	4.20	0.127	0.0995	506	4.62
M09-03 *	4.55	0.136	0.109	512	5.00
M09-04 *	4.96	0.345	0.132	510	6.10
M09-05 *	5.04	0.289	0.132	516	6.00
M10-01 *	4.86	0.144	0.118	522	5.33
M10-02	4.34	0.080	0.0900	460	4.60
M10-03	5.13	0.241	0.118	470	5.92
M10-04 /	4.47	0.116	0.0834	405	4.85
M10-05	3.98	0.398	0.107	475	5.30
M10-06 /	4.35	0.317	0.104	455	5.39
M11-02 /	4.32	0.084	0.0816	418	4.59
M11-03	4.09	0.228	0.0955	464	4.84
M11-04 *	4.15	0.202	0.108	528	4.82
M11-05 /	4.28	0.233	0.0957	447	5.04
M11-06 *	4.31	0.262	0.115	522	5.18
M11-07 *	3.69	0.138	0.0906	513	4.15
M11-08	4.12	0.064	0.0641	349	4.33
M11-09	4.11	0.156	0.0939	478	4.62
M11-10 /	4.29	0.077	0.0794	412	4.54
M11-11 *	4.22	0.144	0.102	510	4.70
M11-12	4.59	0.158	0.105	481	5.11
M11-13	3.94	0.096	0.0889	491	4.26
M11-14	3.88	0.127	0.0844	462	4.29
M11-15 /	4.04	0.096	0.0765	414	4.36
M12-01 /	5.88	0.208	0.126	451	6.56
M12-02 /	5.10	0.091	0.105	457	5.40
M12-03 /	4.18	0.311	0.0993	449	5.20
M12-04	4.70	0.570	0.138	491	6.59
M12-05	5.75	0.602	0.116	355	7.72
M12-06 /	4.45	0.143	0.0934	447	4.92
M12-07 /	4.89	0.143	0.101	443	5.36
M12-08	4.64	0.111	0.101	475	5.00
M12-09	4.59	0.620	0.138	488	6.63
M12-10	5.57	0.687	0.162	487	7.84
M13-01 *	5.50	0.125	0.128	507	5.92
M13-02 *	5.90	0.131	0.138	511	6.33
M13-03 *	5.87	0.143	0.138	513	6.34
M13-04 *	5.40	0.124	0.132	535	5.81
M13-05 *	4.74	0.121	0.113	515	5.14
M13-06 *	4.24	0.116	0.101	511	4.63
M13-07 *	5.44	0.130	0.126	506	5.87
M13-08 *	5.59	0.133	0.137	532	6.03
M13-09 *	5.39	0.174	0.134	528	5.97
M13-10 *	5.30	0.189	0.133	527	5.93
M13-11 *	5.31	0.175	0.127	507	5.89
M13-12 *	6.74	0.169	0.167	538	7.31
M13-13 *	6.96	0.168	0.166	518	7.52
M13-14 /	6.16	0.143	0.127	451	6.63
M13-15 /	5.19	0.136	0.104	436	5.64
M13-16 /	5.47	0.151	0.115	454	5.97
M13-17 *	7.44	0.223	0.187	538	8.18
M13-18 *	8.03	0.207	0.194	522	8.72
M13-19 *	5.52	0.131	0.131	516	5.95
M13-20 *	6.42	0.144	0.152	519	6.90
M13-21 *	4.33	0.100	0.108	543	4.66
M13-22 *	5.13	0.115	0.123	524	5.51
M13-23 *	5.51	0.138	0.136	533	5.97
M13-24 *	5.32	0.124	0.130	533	5.73
M13-25 *	4.82	0.117	0.114	515	5.21
M13-26 *	4.99	0.131	0.124	538	5.43

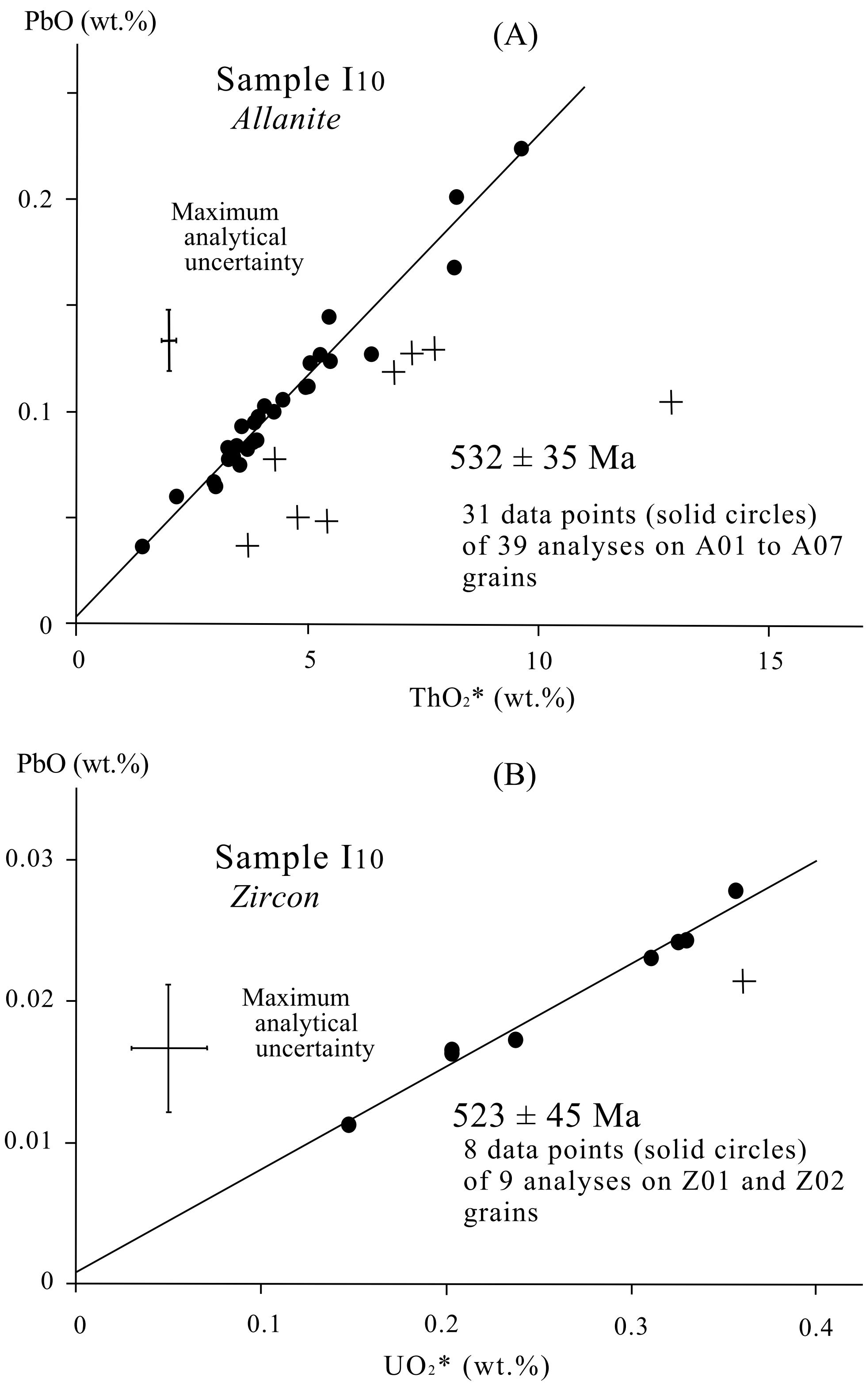

Fig. 3. A) PbO vs. ThO_2* plot of allanite grains from Sample I_{10}. B) PbO vs. UO_2* plot of zircon grains from Sample I_{10}. ThO_2* = the sum of the measured ThO_2 and ThO_2 equivalent of the measured UO_2; UO_2* = the sum of the measured UO_2 and UO_2 equivalent of the measured ThO_2. Error bars in the figures represent 2σ maximum analytical uncertainty, and all errors are quoted at 2σ.

A linear regression through the 31 data points defines an isochron of 532±35 Ma age with an intercept of 0.0038±0.0071.

Zircon contains 0.061-0.270% ThO_2, 0.121-0.279% UO_2 and 0.011-0.0280% PbO. All data points, excepting one analysis on a clouded portion, were fitted to a linear regression, corresponding to an isochron of 523±45 Ma with an intercept of 0.0008±0.0019 (Fig. 3B). The CHIME allanite and zircon ages agree within the limit of analytical uncertainty.

Sample N9: medium-grained porphyritic two-mica granite

A total of 213 spots on 14 monazite grains were analyzed. The ThO_2, UO_2 and PbO concentrations in monazite are 4.01-21.0, 0.160-0.611 and 0.103-0.518%, respectively. Grains M03, M04, M06,, M07, M08 and M09 rarely give apparent ages older than 460 Ma. The rest of the grains analyzed yielded apparent ages greater than 480 Ma. Data points for the older domains (>480 Ma, solid circles) and those for younger domains (<460 Ma, open circles) form separate arrays on the PbO-ThO_2^* diagram (Fig. 4); 115 data points define an isochron of 530±9 Ma with an intercept of -0.0032±0.0034, and 51 data points yield a 436±13 Ma isochron with an intercept of 0.0039±0.0056.

Sample I4: two-mica adamellite

A total of 216 spots on 13 monazite grains were analyzed. Six grains (M01, M02, M04, M08, M09 and M13) were from the fresh part of the sample; the other grains

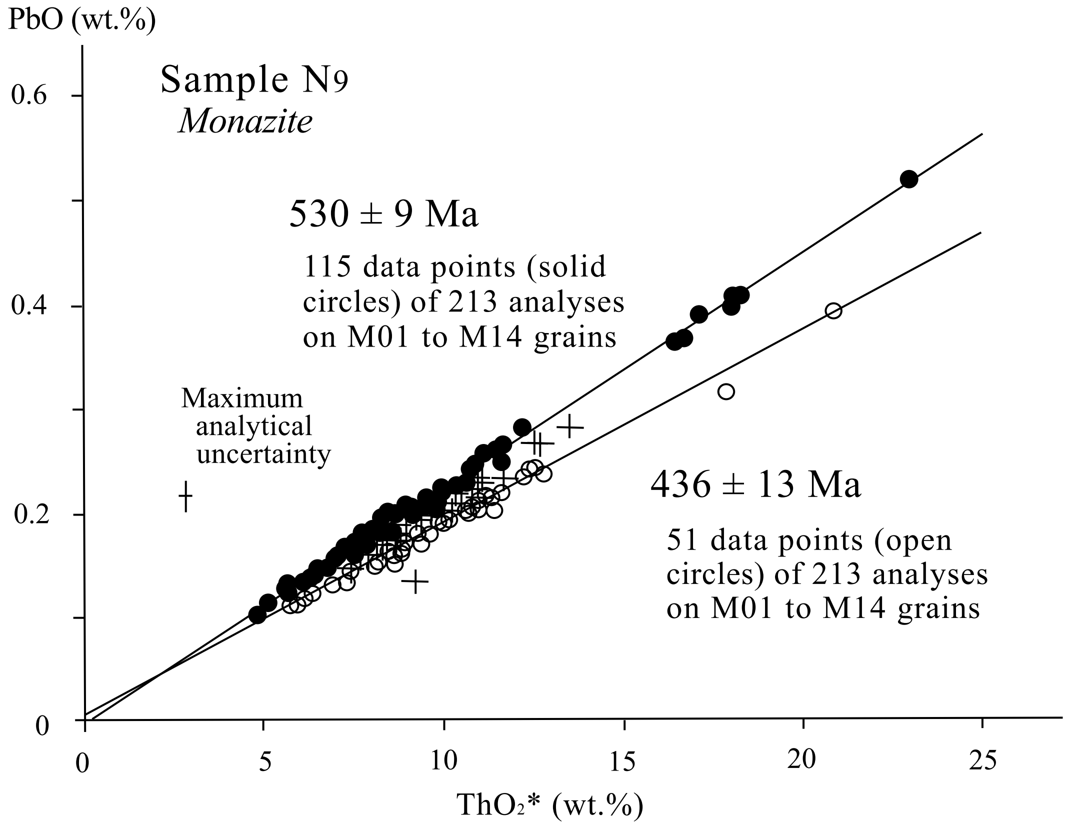

Fig. 4. PbO vs. ThO_2^* plot of monazite grains from Sample N9. Explanation for errors is the same as for Fig. 3.

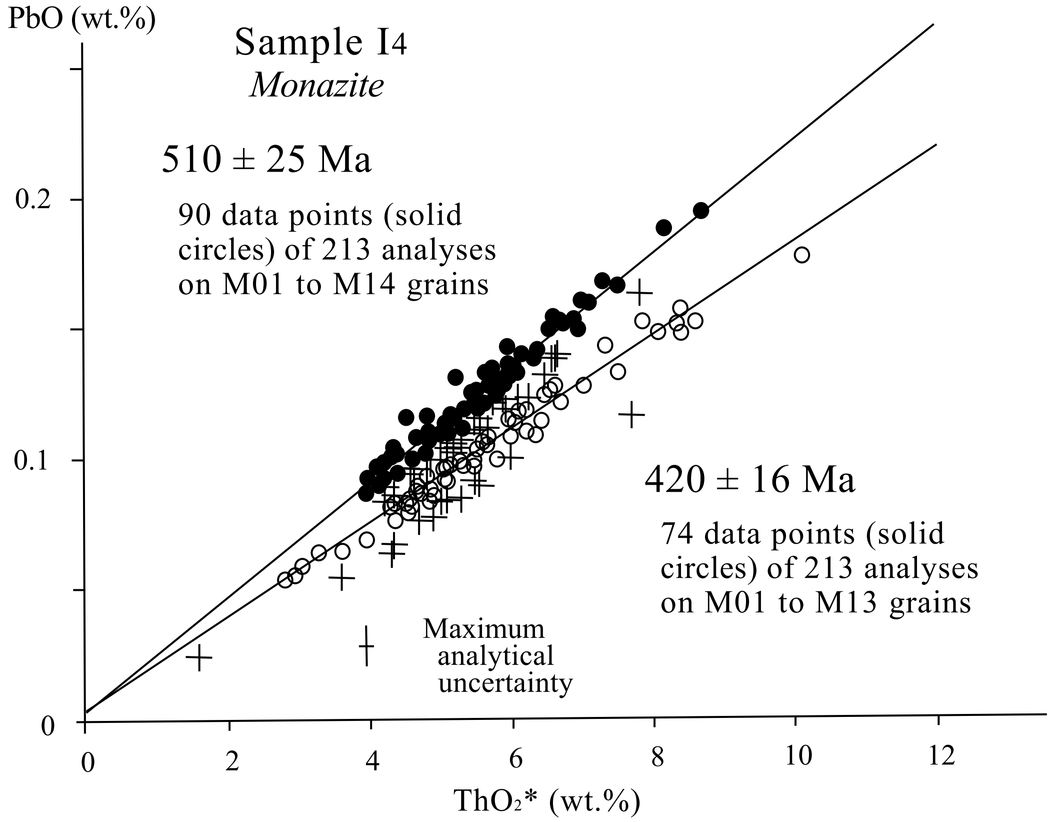

Fig. 5. PbO vs. ThO_2* plot of monazite grains from Sample I_4. Explanation for errors is the same as for Fig. 3.

(M03, M05, M06, M07, M10, M11, ane M12) were in or close to the altered patches. Monazite grains contain 1.54-9.38% ThO_2, 0.021-0.687% UO_2 and 0.0244-0.194% PbO, and no significant difference in the ThO_2 and UO_2 concentrations can be seen between grains from the fresh parts and the altered patches. Apparent ages differ significantly, however, between the two groups: monazites from the fresh parts are older than 500 Ma for most analyses; whereas monazites from the altered patches are usually younger than 450 Ma. Ninety data define an isochron of 510±25 Ma (intercept value = 0.0038±0.0060), and 74 data define an isochron of 420±16 Ma (intercept value = 0.0042±0.0040) (Fig. 5). Since the altered patches formed through hydrothermal events, permeation of fluids possibly caused the partial recrystallization of monazite at 420±16 Ma.

DISCUSSION

The CHIME ages are 532±35 Ma (allanite) and 523±45 Ma (zircon) for Sample I_{10}, 530±9 Ma and 436±13 Ma (monazite) for Sample N_9 and 510±25 Ma and 420±16 Ma (monazite) for Sample I_4. These dates, except the young two ages, just overlap within 2σ. We interpret the 532-510 Ma CHIME ages as dating the emplacement of granites in the Nkambe area. The younger 436±13 and 420±16 Ma ages are regarded as the time of late hydrothermal and/or thermal imprints. The foliated granites are essentially synchronous with the regional metamorphism that produces the migmatitic gneiss, amphibolite and anatectic granite in the Nkambe area. As stated before, similar ca. 530 Ma granitoids are reported from Goutchoumi (525 Ma, Lasserre et al., 1981), Poli (520±20 Ma, Lasserre and Soba, 1976), Linte (521±19 Ma, Lasserre et al., 1981) and Lom (498±5 Ma, Lasserre and Soba, 1976) areas within the Central-Africa mobile zone of Cameroon (Fig. 1). An extensive metamorphic-plutonic event occurred in the Central African mobile zone at middle Cambrian time (530 Ma) rather thab a thermal overprint.

Outside Cameroon, ca. 530 Ma ages were reported from granites in southeastern Nigeria (538±8 Ma for the Nassarawa Eggon Granite and 547±38 Ma for the Mkar-Gboko Granite, Umeji and Caen-Vachette, 1984). The 530 Ma episode in Cameroon and southeastern Nigeria was a metamorphic-plutonic episode caused possibly by collision of West Gondwana (Casting et al., 1993; Trompette, 1994). Although it has not been proven if the 530 Ma metamorphic belt in Cameroon is continuous to those in Madagascar, southern In dia and East Antarctica, the metamorphism and plutonism are contemporaneous in both West Africa and East Africa.

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