Geologic and Geochronologic Studies of the Early Proterozoic Kanektok Metamorphic Complex of Southwestern Alaska

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Preface

History of the Manuscript

This Open-File Report makes available a valuable set of geochronological data that were produced more than 25 years ago. In the early 1980s, Donald L. Turner, Robert B. Forbes (since deceased), John N. Aleinikoff, Ian McDougall, and Carl E. Hedge wrote a report about their geochronologic studies of the Kanektok metamorphic complex, a terrane of high-grade metamorphic rocks in the Goodnews Bay quadrangle of southwest Alaska. The report was approved for publication in 1982, but unaccountably was never completed. The geochronological data from the manuscript has been in the "gray literature" for many years and we felt it important that the data and manuscript be made available for future studies as the data and report are the most extensive and detailed available on the metamorphic complex. We thank Don Turner and John Aleinikoff for permission to publish this manuscript and important data.

At the time of the writing of the original manuscript, Hoare and Coonrad (1979) informally named the metamorphic rocks the Kanektok metamorphic complex; the rocks were later assigned to the Kilbuck terrane (Jones and others, 1981), another informal designation. The rocks were originally mapped by Hoare and Coonrad (1959, 1961) who later revised their mapping (Hoare and Coonrad, 1978). On the basis of the high metamorphic grade and the belief that the rocks of the complex were overlain by Devonian to Ordovician limestone, Hoare and Coonrad (1959, 1961) proposed a Precambrian age for these rocks. During the field mapping leading to Hoare and Coonrad's 1978 map, D.L. Turner and R.B. Forbes began studies of the metamorphic complex. Turner and Forbes' mapping and extensive sampling of the rocks provide the basis for this report. Turner and Forbes confirmed the Precambrian age of the metamorphic rocks, but found that the geochronologic data was complex and difficult to interpret. Originally, conventional K-Ar methods were used, supplemented by a suite of samples analyzed using the Rb/Sr technique, and a few samples dated by the U/Pb technique. However, many of the K-Ar samples yielded discordant ages when multiple mineral phases were dated. A few samples were also dated using the then new $^{40}Ar/^{39}Ar$ technique, which yielded spectra indicating disturbance.

We have corrected a few typographical errors in the original manuscript and updated references that were in press at the time the manuscript was written. We have also re-checked the analytical data for the reported ages and made corrections from the original laboratory data where needed. We have also added a simplified geologic map derived from Wilson and others (2008) showing Turner's sample localities (fig. I-1). Also we have added, in brackets, the more formal Precambrian time subdivisions where appropriate.

New Results and Commentary

In the early 1990s, Paul Layer conducted additional $^{40}Ar/^{39}Ar$ analyses on a suite of samples to test the reliability of the conventional K-Ar analyses. An age spectrum on the oldest hornblende sample of Turner and others manuscript (sample DT 76-69a, table 1) confirmed the 1.78 Ga age (sample DT 76-69a, table I-1, fig. I-2); the spectrum was flat and did not indicate argon loss. However, multiple analyses of a hornblende that had yielded a younger age, 915±27 Ma, (sample DT 76-70, table I-1, fig. I-2) produced spectra indicating disturbance and indicated that the conventional K-Ar ages were not correct due to resetting.

Three biotite samples, collected from a reported pyroxene granulite have dates reported in the Turner and others manuscript and yielded ages of about 2.5 Ga, which are the oldest ages ever determined in Alaska. Other samples from the metamorphic complex yielded U/Pb zircon ages as old as 2.05 Ga; because of these zircon ages, Turner and his coworkers suggested that the biotite contains excess argon. Turner and others reported an $^{40}Ar/^{39}Ar$ analysis on one of the biotite samples (sample DT 75-72, table 2), which yielded what they reported as a "more-or-less normal" age spectra, which did not confirm the excess argon interpretation. However, Turner and others did report some interpretations from the literature of that period that suggested biotite may not be an appropriate mineral to analyze for excess argon. Unfortunately, no zircon was or has been dated from the granulite facies rocks.

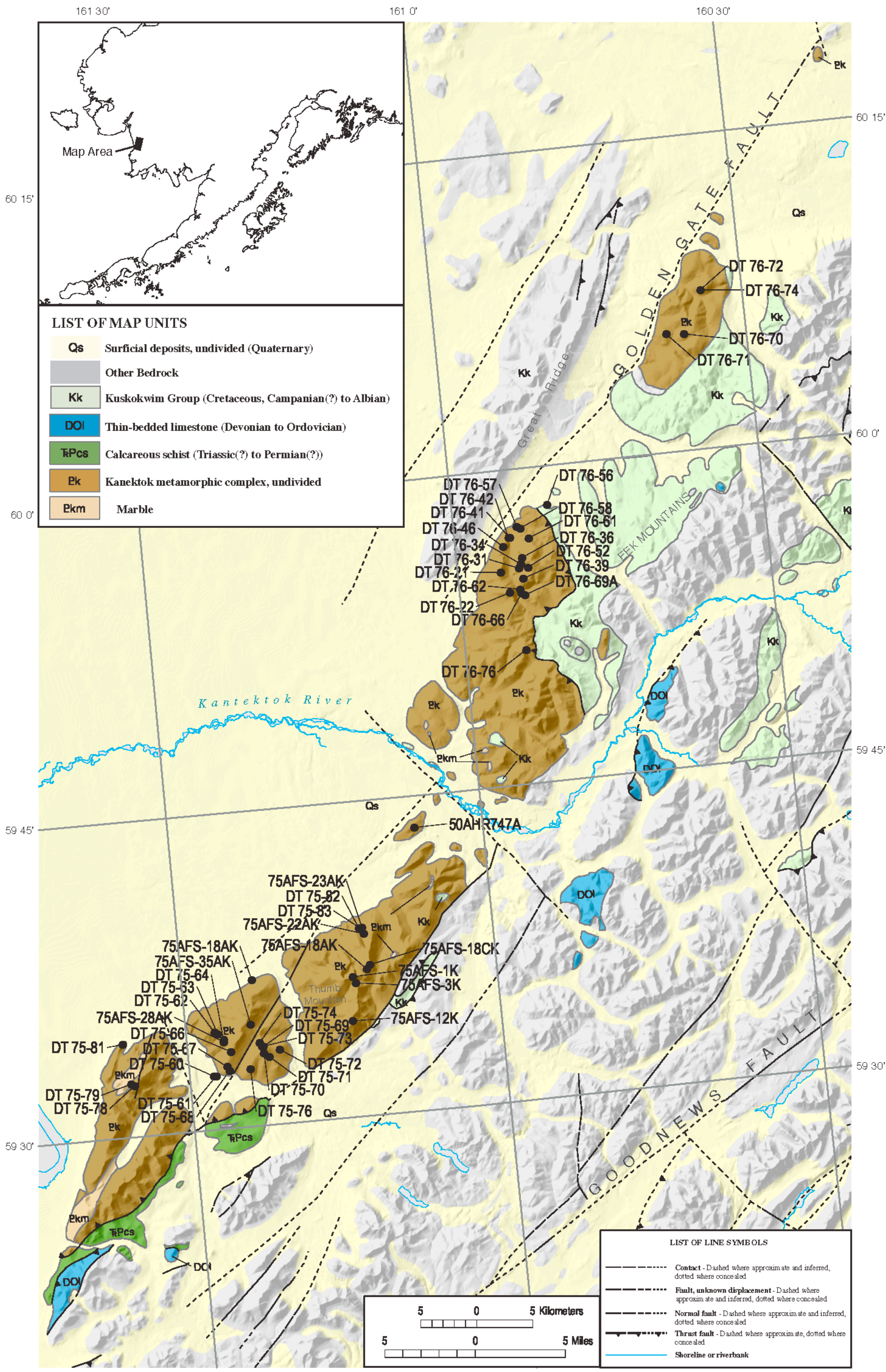

Figure I-1. Simplified geologic map showing collection localities for samples analyzed by Turner and others.

Table I-1. Analytical data for samples from the Kanektok metamorphic complex (analyses by Paul Layer).

DT76-69A Hornblende Temp. (Deg C)	Cumulative ^{39}Ar	$^{40}Ar/^{39}Ar$ measured	+/-	$^{37}Ar/^{39}Ar$ measured	+/-	$^{36}Ar/^{39}Ar$ measured	+/-	Weighted average of J from standards = 8.230e-03 +/- 1.642e-04 % Atm. ^{40}Ar	Ca/K	+/-	Cl/K	+/-	$^{40}Ar^*/^{39}Ar_K$	+/-	Age (Ma)	+/- (Ma)
600	0.0150	176.539	164.111	8.956	8.774	0.2346	0.7642	38.9	16.53	16.29	0.087	0.202	108.51	240.19	1151.3	1883.9
800	0.0306	143.053	130.597	8.092	7.873	0.0507	0.7223	10.0	14.93	14.60	0.191	0.252	129.34	244.85	1307.7	1761.0
900	0.0591	138.751	67.957	16.667	8.292	0.0245	0.3863	4.3	30.92	15.55	0.770	0.390	134.19	133.13	1342.3	939.3
925	0.1402	189.567	32.295	18.517	3.195	0.0176	0.1342	2.0	34.39	6.01	1.018	0.177	187.99	51.60	1686.8	300.8
950	0.3261	206.048	15.522	18.276	1.395	0.0139	0.0594	1.3	33.94	2.62	1.016	0.078	205.72	23.70	1787.2	130.7
975	0.3960	200.241	38.750	17.346	3.406	0.0034	0.1521	-0.1	32.19	6.39	0.960	0.190	202.80	60.36	1771.1	335.8
1000	0.4961	204.379	28.789	17.554	2.508	0.0134	0.1112	1.3	32.58	4.71	1.019	0.147	204.05	44.16	1778.0	244.7
1025	0.5527	197.456	47.818	17.248	4.239	0.0010	0.1906	-0.5	32.01	7.95	0.978	0.244	200.68	75.24	1759.3	421.3
1050	0.6390	209.805	32.621	18.106	2.853	0.0079	0.1222	0.5	33.62	5.36	1.024	0.163	211.29	49.40	1817.7	267.8
1075	0.6938	202.910	53.812	17.414	4.686	0.0081	0.2100	0.5	32.32	8.80	0.983	0.267	204.11	83.29	1778.3	461.5
1100	0.7335	213.738	76.884	18.212	6.638	0.0050	0.2842	0.1	33.82	12.47	1.030	0.378	216.16	115.84	1843.9	618.9
1150	0.7970	204.713	45.366	17.081	3.842	0.0067	0.1749	0.3	31.69	7.21	0.981	0.222	206.30	69.77	1790.4	384.0
1250	0.8986	207.943	28.482	17.300	2.404	0.0158	0.1080	1.6	32.10	4.51	1.003	0.140	206.87	43.16	1793.6	237.1
1400	0.9970	207.496	30.304	17.168	2.545	0.0311	0.1156	3.8	31.86	4.78	1.003	0.150	201.82	45.60	1765.6	254.5
1600	1.0000	122.653	596.217	6.381	34.249	0.3213	4.1543	77.0	11.76	63.37	0.411	2.226	28.29	1150.67	377.6	13857.5
Integrated		200.775	10.905	17.373	0.957	0.0180	0.0429	2.0	32.24	1.80	0.969	0.054	198.98	16.84	1749.7	97.4

Table I-1. Analytical data for samples from the Kanektok metamorphic complex (analyses by Paul Layer). (cont.)

DT76-70 Hornblende run #1								Weighted average of J from standards = 8.534e-03 +/- 7.746e-05								
Temp. (Deg C)	Cumulative ^{39}Ar	$^{40}Ar/^{39}Ar$ measured	+/-	$^{37}Ar/^{39}Ar$ measured	+/-	$^{36}Ar/^{39}Ar$ measured	+/-	% Atm. ^{40}Ar	Ca/K	+/-	Cl/K	+/-	$^{40}Ar^{*}/^{39}Ar_{K}$	+/-	Age (Ma)	+/- (Ma)
500	0.0533	155.583	5.126	0.682	2.041	0.0933	0.0272	17.7	1.25	3.75	0.029	0.007	128.09	9.04	1332.6	66.5
600	0.0653	48.726	7.133	-1.989	9.076	0.0326	0.1201	20.1	-3.64	16.61	0.001	0.029	38.86	35.89	516.7	414.9
675	0.0797	53.865	6.634	-6.854	7.682	-0.1475	0.1027	-80.0	-12.52	13.97	0.028	0.025	96.46	32.01	1083.6	270.3
750	0.2073	43.895	0.601	6.481	0.851	0.0062	0.0112	3.1	11.94	1.57	0.108	0.003	42.69	3.38	560.5	38.1
780	0.3695	49.128	0.535	7.096	0.676	-0.0005	0.0089	-1.4	13.08	1.25	0.120	0.003	50.00	2.70	641.1	29.1
810	0.4914	57.093	0.822	8.134	0.898	0.0021	0.0118	0.0	15.00	1.67	0.116	0.003	57.37	3.60	718.9	37.2
850	0.8315	80.209	0.422	8.130	0.322	0.0030	0.0042	0.4	15.00	0.60	0.099	0.001	80.32	1.33	941.8	12.1
900	0.8883	89.049	2.735	9.646	1.925	-0.0082	0.0252	-3.5	17.81	3.58	0.090	0.007	92.76	8.02	1052.0	68.9
950	0.9267	68.942	3.121	5.756	2.817	-0.0030	0.0371	-1.9	10.60	5.21	0.123	0.011	70.49	11.47	849.7	110.3
1000	0.9418	80.805	9.387	5.298	7.227	-0.0358	0.0954	-13.6	9.75	13.35	0.093	0.026	92.07	30.24	1046.0	260.7
1200	0.9915	77.530	9.353	7.899	8.036	0.0382	0.1095	13.8	14.57	14.90	0.109	0.028	67.14	33.51	817.2	328.0
1600	1.0000	122.774	25.281	1.704	12.768	0.2078	0.1742	49.9	3.13	23.48	0.092	0.045	61.54	51.57	761.6	520.5
Integrated		71.269	0.596	6.909	0.539	0.0078	0.0072	2.5	12.73	1.00	0.100	0.002	69.77	2.23	842.8	22.3

Table I-1. Analytical data for samples from the Kanektok metamorphic complex (analyses by Paul Layer) (cont.)

DT76-70 Hornblende run #2 Weighted average of J from standards = 8.405e-03 +/- 2.695e-05

Temp. (Deg C)	Cumulative ^{39}Ar	$^{40}Ar/^{39}Ar$ measured	+/-	$^{37}Ar/^{39}Ar$ measured	+/-	$^{36}Ar/^{39}Ar$ measured	+/-	% Atm. ^{40}Ar	Ca/K	+/-	Cl/K	+/-	$^{40}Ar^{*}/^{39}Ar_K$	+/-	Age (Ma)	+/- (Ma)
500	0.0183	203.463	11.929	-2.132	5.161	0.0987	0.0480	14.4	-3.91	9.44	0.007	0.012	173.87	17.39	1625.0	107.1
700	0.0502	99.513	3.286	3.007	2.904	0.1016	0.0270	29.9	5.53	5.35	0.023	0.007	69.83	8.27	833.1	79.1
800	0.0653	65.773	4.646	2.789	6.219	0.0416	0.0575	18.4	5.13	11.45	-0.001	0.014	53.77	17.43	672.8	182.1
850	0.0753	65.642	6.997	7.706	9.412	-0.0190	0.0866	-9.4	14.21	17.45	0.020	0.021	72.17	26.88	855.3	253.7
900	0.0917	60.680	3.951	6.660	5.746	0.0413	0.0530	19.3	12.27	10.64	0.046	0.013	49.15	16.05	623.8	172.2
950	0.1822	49.085	0.574	5.958	1.028	0.0135	0.0095	7.2	10.97	1.90	0.103	0.003	45.69	2.86	586.3	31.4
1000	0.5416	53.996	0.168	6.090	0.262	0.0018	0.0024	0.1	11.22	0.49	0.118	0.001	54.12	0.74	676.4	7.7
1050	0.8468	81.829	0.293	6.389	0.305	0.0004	0.0028	-0.4	11.77	0.56	0.097	0.001	82.50	0.88	950.3	7.9
1100	0.9060	86.122	1.536	5.058	1.568	0.0148	0.0145	4.6	9.31	2.90	0.090	0.004	82.37	4.54	949.2	40.7
1200	0.9507	94.819	2.242	9.503	2.090	0.0119	0.0192	2.9	17.55	3.88	0.093	0.005	92.57	6.12	1038.3	52.2
1600	1.0000	102.725	2.221	6.136	1.905	0.0196	0.0176	5.2	11.30	3.52	0.095	0.005	97.75	5.63	1081.9	46.9
Integrated		72.756	0.258	5.991	0.310	0.0105	0.0029	3.7	11.04	0.57	0.097	0.001	70.35	0.88	838.1	8.7

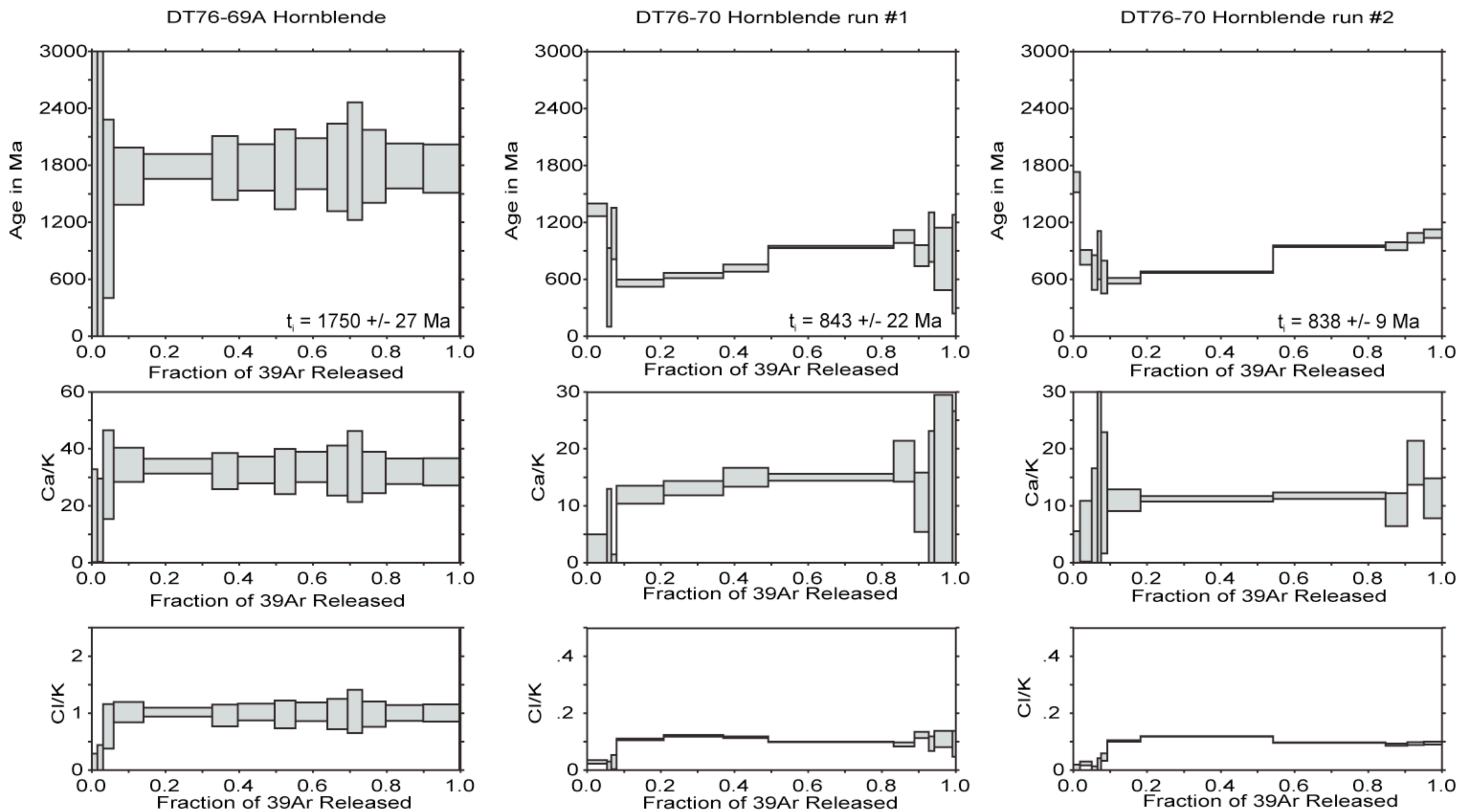

Figure I-2. $^{40}Ar/^{39}Ar$ age spectrums for samples DT 76-69A and DT 76-70 (2 analyses). Total fusion ages are 1,750±27 Ma, 843±22 Ma and 838±9 Ma, respectively. Sample analyses by Paul Layer, Univ. of Alaska, in early 1990s.

As discussed in Turner and others manuscript, the K-Ar ages range from about 130 Ma to 2.5 Ga. Within this dataset, many of the samples for which multiple minerals were dated yielded highly discordant ages. In examining the data, we noted a spatial pattern in the age distribution. Consistently, the youngest ages are on the west side of the terrane and the ages increase eastward. Within this spatial distribution pattern, the discordance between mineral phases also increases eastward; a number of the samples yielding youngest ages show concordant or only mildly discordant ages (for example, samples DT 76-57 and DT 75-67, table 1), whereas samples yielding older ages show extreme discordance (for example, sample DT 76-70, table 1). If the K-Ar ages are interpreted as cooling ages, then the K-Ar ages indicate late rapid cooling on the west and a more protracted and longer cooling on the east. Alternatively, if multiple thermal disturbances impacted the terrane through time, then these disturbances variably reset the K-Ar systems and disturbed the Rb/Sr systematics. Complicating any interpretation is that in a number of samples, biotite yielded K-Ar ages significantly older than co-existing hornblende, the reverse of what would be predicted from a simple cooling hypothesis. Turner and coworkers suggested possible excess argon in the biotite to explain the 2.5 Ga biotite ages. However, excess argon seems unlikely and the hornblende ages might be as much or more questionable than the biotite ages. Layer's analysis (fig. I-1) of one hornblende sample (DT 76-70, table I-1) indicated disturbance in the argon system in the mineral; this was in a sample that had yielded the predictable discordance of biotite younger than hornblende. In this case, the biotite yielded an age substantially younger than the hornblende age, 685±20 Ma versus 915±27 Ma.

A few of the biotite samples had anomalously low K_2O contents and as such the ages determined are quite likely suspect. John Obradovich (USGS, oral commun., 1982) indicated that if the biotite K_20 is less than 6 percent, then the K-Ar age is suspect; sample DT 76-34 has only 5.190 percent K_2O and the percent ^{40}Ar radiogenic is also low. Sample 75AFS-22AK has K_2O just above 6 percent and replicate splits produced discordant dates.

This is clearly a very complex package of rocks and many dating methods have been employed. Potassium-argon based methods were not adequate to clarify the later history of the terrane. The rubidium-strontium method used by Turner and others used on a suite of samples and used on a similar suite of samples reported by Moll-Stalcup and others (1996), was limited in resolving questions about the history of these rocks although Rb/Sr data from both suites, in conjunction with some K-Ar, $^{40}Ar/^{39}Ar$, and U/Pb data suggested that an event at about 1.8 Ga affected the terrane. Uranium-lead data on orthogneiss yielded most of the oldest ages for rocks of this complex (Turner and others, this manuscript; Box and others, 1990; 1993; Moll-Stalcup and others, 1996) and consistently indicated an age of about 2.05 Ga. Bradley and others (2007) reported a concordant 2.08 Ga (±10 m.y.) U/Pb zircon age from an orthogneiss from the Kilbuck terrane.

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Geologic and Geochronologic Studies of the Early Proterozoic Kanektok Metamorphic Complex of Southwestern Alaska

By Donald L. Turner[1], Robert B. Forbes[1], John N. Aleinikoff[2], Ian McDougall[3], and Carl E. Hedge[2]

Abstract

The Kanektok complex of southwestern Alaska appears to be a rootless terrane of early Proterozoic sedimentary, volcanic, and intrusive rocks which were metamorphosed to amphibolite and granulite facies and later underwent a pervasive late Mesozoic thermal event accompanied by granitic plutonism and greenschist facies metamorphism of overlying sediments. The terrane is structurally complex and exhibits characteristics generally attributed to mantled gneiss domes.

U-Th-Pb analyses of zircon and sphene from a core zone granitic orthogneiss indicate that the orthogneiss protolith crystallized about 2.05 b.y. ago and that the protolithic sedimentary, volcanic and granitic intrusive rocks of the core zone were metamorphosed to granulite and amphibolite facies about 1.77 b.y. ago. A Rb-Sr study of 13 whole-rock samples also suggests metamorphism of an early Proterozoic [Paleoproterozoic] protolith at 1.77 Ga, although the data are scattered and difficult to interpret.

Seventy-seven conventional $^{40}K/^{40}Ar$ mineral ages were determined for 58 rocks distributed throughout the outcrop area of the complex. Analysis of the K-Ar data indicate that nearly all of these ages have been totally or partially reset by a pervasive late Mesozoic thermal event accompanied by granitic plutonism and greenschist facies metamorphism. Several biotites gave apparent K-Ar ages over 2 Ga. These ages appear to be controlled by excess radiogenic ^{40}Ar produced by the degassing protolith during the 1.77 Ga metamorphism and incorporated by the biotites when they were at temperatures at which Ar could diffuse through the lattice.

Five amphibolites yielded apparent Precambrian $^{40}K/^{40}Ar$ hornblende ages. There is no evidence that these hornblende ages have been increased by excess argon. The oldest $^{40}K/^{40}Ar$ hornblende age of 1.77 Ga is identical to the sphene $^{207}Pb/^{206}Pb$ orthogneiss age and to the Rb-Sr "isochron" age for six of the 13 whole-rock samples.

The younger hornblende ages are interpreted as having been partially reset during the late Mesozoic thermal event.

$^{40}Ar/^{39}Ar$ incremental heating experiments suggest metamorphism occurred at least 1.2 b.y. ago but do not exhibit high temperature plateau ages significantly older than the $^{40}Ar/^{39}Ar$ total fusion ages of these samples. The age spectra are much more uniform than expected from a terrane with such a complex thermal history, perhaps caused by the small grain size of the samples which may possibly be less than the effective Ar diffusion radii of the analyzed hornblendes.

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The Kanektok complex comprises the Kilbuck tectonostratigraphic terrane of Jones and others (1981). The 1.77 Ga age of its high grade metamorphic rocks is significantly older than nearly all radiometric ages previously determined thus far for Alaskan rock units. The age and lithology of this terrane appear to be unique in Alaska. These characteristics should prove useful in tectonic reconstructions aimed at finding the source region for this terrane prior to its migration to its present position in southwestern Alaska.

Introduction

The search for documented Precambrian crystalline rocks in Alaska has proven to be unexpectedly long and complex. Spurr (1898) first assigned a Precambrian age to metamorphic rocks formerly known as the Birch Creek Schist in the Yukon-Tanana Upland. For many years thereafter, newly discovered metamorphic terranes in northern Alaska were arbitrarily correlated with the Birch Creek Schist and assigned a Precambrian age. Subsequently, however, the application of radiometric dating techniques has failed to document a Precambrian age for the metamorphic rocks of the Yukon-Tanana Upland. Aleinikoff and others (1981) have shown (by the U-Th-Pb zircon method) that a 350 m.y. old augen gneiss was derived from an early Proterozoic (about 2.3 b.y. old) parent rock. More recent studies (Aleinikoff and others, 1984) reveal that many metasedimentary rocks located throughout the Yukon-Tanana Upland, including wall rocks to the aforementioned augen gneiss, contain detrital zircons approximately 2.0 and 2.3 b.y. old.

Although many radiometric ages have been determined for various Alaskan metamorphic terranes, reliable Precambrian radiometric ages have been published for only three areas to date; a Rb-Sr whole-rock isochron age of 735 Ma determined for gneiss from the Kigluaik Mountains of the Seward Peninsula (Bunker and others, 1977); 587-756 Ma K-Ar mineral ages from a blueschist terrane in the southwestern Brooks Range (Turner and others, 1979, Mayfield and others, 1982); and a 730 Ma $^{207}Pb/^{206}Pb$ zircon age from a trondhjemite pluton cutting amphibolite of the Wales Group in southeastern Alaska (Churkin and Eberlein, 1977). In addition, Aleinikoff and others (1986) determined an approximately 2 Ga $^{207}Pb/^{206}Pb$ zircon age for a metarhyodacite in the eastern Alaska Range.

Precambrian sedimentary rocks have been delineated by paleontologic evidence at very few localities in northeastern Alaska. The Tindir Group of later Precambrian age (Subdivision Y = 800-1,600 Ma [early Neoproterozoic and Mesoproterozoic]), is exposed in two relatively small areas north of the Yukon River (Mertie, 1937; Brabb and Churkin, 1969); and Precambrian greenschist facies metasedimentary rocks unconformably underlie Olenellus-bearing sediments of the Neruokpuk Formation in the eastern Brooks Range (Dutro and others, 1972). The Precambrian localities discussed above are shown in figure 1.

The Kanektok metamorphic complex of southwestern Alaska was dated by several radiometric methods in order to determine the age of its protolith and the ages of subsequent metamorphic events.

Geology

Regional Geology and Tectonic Setting

Rocks of the Kanektok complex are exposed along a relatively narrow, northeast trending belt, which extends 160 km from the highlands east of Kuskokwim Bay across the northwest corner of the Goodnews quadrangle into the Bethel quadrangle (fig. 2). These rocks were first mapped and described by Hoare and Coonrad (1959, 1961) as a metamorphic complex composed of highly metamorphosed sedimentary and volcanic rocks, which probably included some recrystallized intrusive rocks. The complex was originally mapped as Precambrian because the rocks are more metamorphosed than nearby strata of Paleozoic age. As summarized in Hoare and Coonrad's earlier descriptions, the complex is dominated by pink and grey gneisses and light- to dark-grey schist, with subordinate marble, quartz-muscovite schist and amphibolite.

The complex is bordered on the southeast by a broad belt of isoclinally folded rocks ranging in age from Devonian to late Early Cretaceous (Albian) age. Folds in this belt verge northwestward, and are overturned or recumbent. The fold style suggests the existence of low-angle thrust faults.

North of the Kanektok River, the complex is bordered on the northwest by a narrow belt of sedimentary rocks of Late Cretaceous age, and by a wide, poorly exposed belt of andesitic volcanic rocks of Middle Jurassic age. The intensity and style of deformation in the volcanic rocks is unknown, due to lack of outcrop, but the sedimentary rocks of Late Cretaceous age are much less deformed than the Albian rocks on the southeast side of the complex.

Glacial deposits border the metamorphic complex south of the Kanektok River. Aeromagnetic data suggest that these glacial deposits are underlain by volcanic rocks. The magnetic anomaly pattern indicates that the volcanics dip southward toward the metamorphic complex, suggesting a possible fault contact.

In late Early Cretaceous (Albian) time, the northeastern part of the metamorphic complex was emergent and subject to erosion. A thick wedge of sedimentary rocks was deposited east and southeast of the complex. Conglomerate in this unit contains gneiss and schist clasts derived from the complex, whereas finer grained sediments contain abundant detrital muscovite. The north end of the metamorphic complex is chiefly concealed beneath a thin veneer of these sediments which thicken rapidly to the east and southeast.

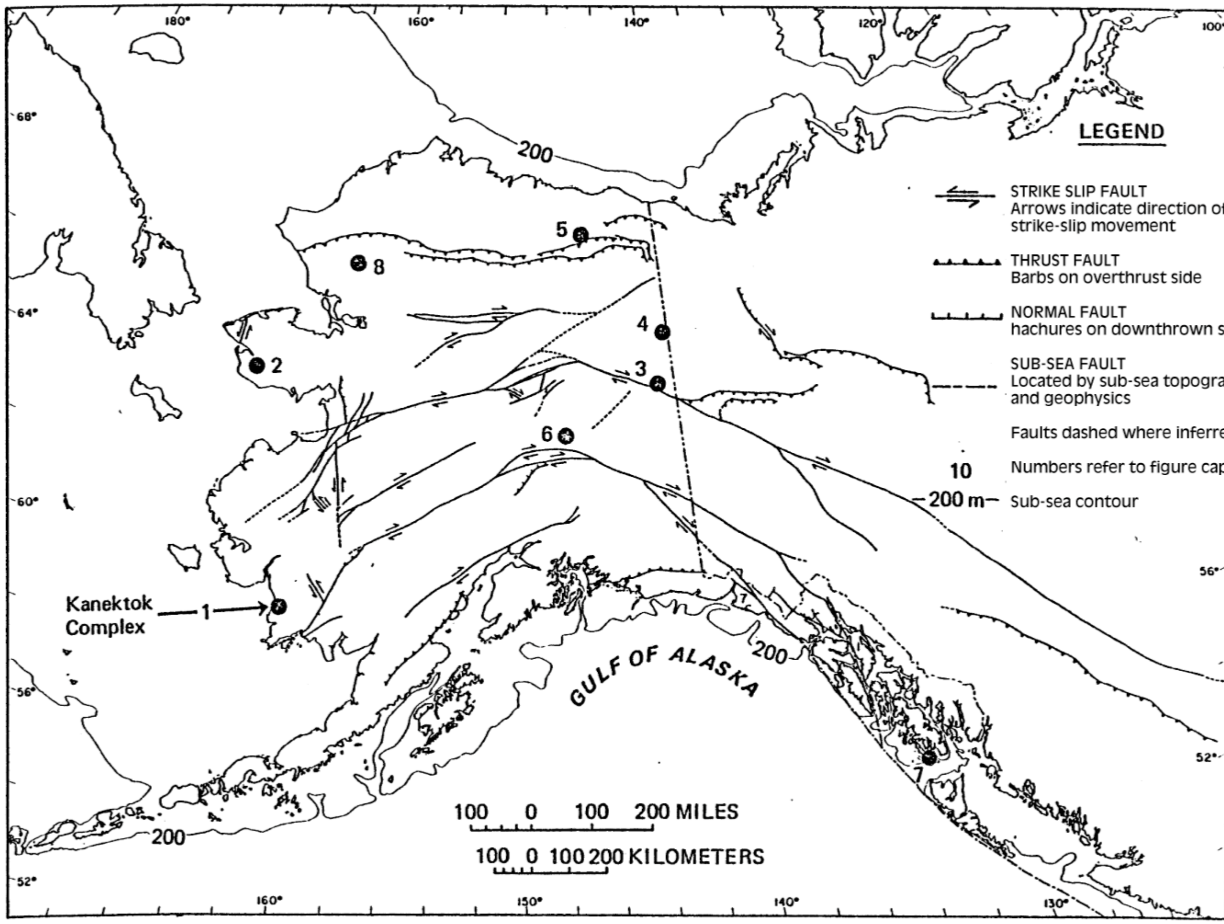

Figure 1. Tectonic map of Alaska and adjacent areas in Canada, showing 8 localities of Precambrian rocks discussed in this report:

1. Kanektok Complex.
2. The Kigluaik Mountains; site of the 735 Ma Rb-Sr whole rock isochron age reported by Bunker and others (1977).
3. Precambrian Tindir Group locality; Circle District.
4. Precambrian Tindir Group locality; Porcupine District.
5. Neruokpuk Formation; *Olenellus* locality.
6. Metarhyodacite in eastern Alaska Range yielding an approximately 2 b.y. $^{207}Pb/^{206}Pb$ zircon age (Aleinikoff and others, 1986).
7. Prince of Wales Island, where a trondhjemite pluton dated at 730 Ma intrudes amphibolite of the Wales Group (Churkin and Eberlein, 1977).
8. Precambrian blueschist terrane in southwestern Brooks Range (Turner and others, 1979; Mayfield and others, 1982).

Structure

In 1975, Forbes and Turner completed three mapping and sampling traverses across the southwestern part of the Kanektok complex. Turner completed additional mapping and sampling in the northeastern part of the complex in 1976. The best geologic section was obtained from the Thumb Mountain traverse (fig. 3); however, all of the sections are complicated by faulting, and we are unsure as to whether the composite structure section of figure 4 represents a complete section across the complex. For example, the northwest end of the Thumb Mountain and Snow Gulch traverses terminate in coarse-grained dioritic gneisses, whereas the rocks encountered in the northwesternmost traverse include greenschists, marbles and calc-phyllites (fig. 3). However, a reasonable structural picture emerges from a model which assumes that the greenschist facies rocks on the northwest end of this traverse represent the northwest flank of the complex, with similar rocks at the southeast end of the Thumb Mountain traverse as the southeast flank of the complex. The resultant composite section is shown in figure 4.

The Kanektok terrane appears to be an antiformal crystalline complex cored by granitic gneisses with intercalated metabasites and metasediments, flanked by an outer zone or envelope of greenschist facies rocks. Rocks in the outer zone dip away from the complex, and the core zone granitic gneisses appear to be deformed into sub-isoclinal upright folds with limbs which descend toward the margins of the complex. Mineral foliation tends to parallel compositional layering, and the mineral lineation, foliation and layering strike consistently to the northeast (fig. 3).

Petrology

The central zone of the complex is dominated by layered biotite- hornblende gneisses with intercalated pyroxene granulites, garnet amphibolites, garnet-mica schists, orthogneisses and rare marbles and quartzites. The biotite-hornblende gneisses range in composition from diorite to granodiorite. The orthogneisses are granitic to monzonitic, coarse grained, and characterized by pink orthoclase.

The pyroxene granulites represent lower granulite facies metamorphic rocks with the assemblage garnet-augite-biotite and anti-perthitic plagioclase. K-feldspar bearing variants are also present. Pyroxene granulites thus far located are restricted to the Snow Gulch traverse, on both sides of the Snow Gulch Fault (fig. 3). Layered biotite-hornblende gneisses, which dominate the central segment of the Thumb Mountain traverse, typically have granodioritic or quartz dioritic whole rock compositions. Biotite (± muscovite) orthogneiss masses, with compositions ranging from granite to quartz monzonite and monzonite (fig. 3), are in part discordant to the layering and foliation in adjacent rock units. These units typically contain pink K-feldspar, and a fabric dominated by flaser or augen structure.

Pelitic schists and marbles are rare in the core of the complex. However, a kyanite-bearing garnet-mica schist was collected from one station on the southeastern segment of the Thumb Mountain traverse, and an impure marble with incipient diopside was recovered from a nearby outcrop. The kyanite and diopside "in" reactions are in agreement with the first appearance of garnet amphibolites in the same part of the section. Intercalated marble units are thin and discontinuous, and often contain white mica, phlogopite, quartz, plagioclase and epidote as minor phases.

The northwest and southeast margins of the complex are bounded by greenschist facies rocks which appear to grade into the amphibolite facies rocks of the core zone.

The greenschist facies rocks include greenschists, epidote-quartz-biotite schists, micaceous quartzites, calc-phyllites, marbles, feldspathic quartzites, and metaconglomerates.

On the northwest flank of the complex, the marginal facies rocks disappear under valley floor alluvial deposits. On the southeast margin near Keno Creek the greenschist facies rocks appear to be in fault contact with Cretaceous sediments.

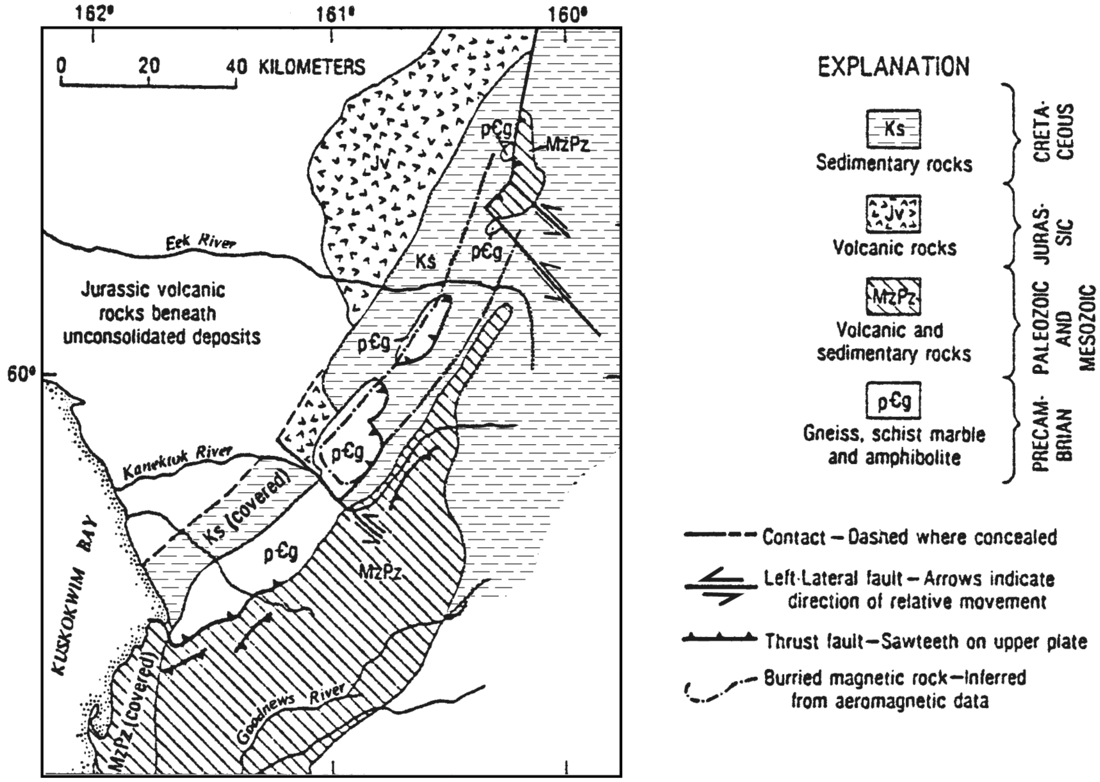

Figure 2. Geologic map of the Kanektok complex and associated rocks (from Hoare and Coonrad, 1979).

Suggested Structural Model

The structural and petrologic characteristics of the Kanektok complex appear to be similar to those described elsewhere for "mantled gneiss domes", including a core zone of older metamorphic rocks overlain by an envelope of younger greenschist or epidote-amphibolite facies (supracrustal) metasediments. According to more recent models, such domes may be formed by upfaulted piston or trapdoor-like basement blocks of older crust, accompanied by the emplacement of synkinematic and post-kinematic granitic rocks.[1] The accompanying thermal perturbation is responsible for recrystallizing the overlying supracrustal sediments under the pressue/temperature conditions of the greenschist and/or epidote-amphibolite facies. Removal of supracrustal rocks by subsequent erosion during the final stage of uplift of the complex exposes the older and higher grade metamorphic core, surrounded by an envelope of greenschist facies rocks.

[1] Many gneiss domes are now thought to be extensional core complexes.

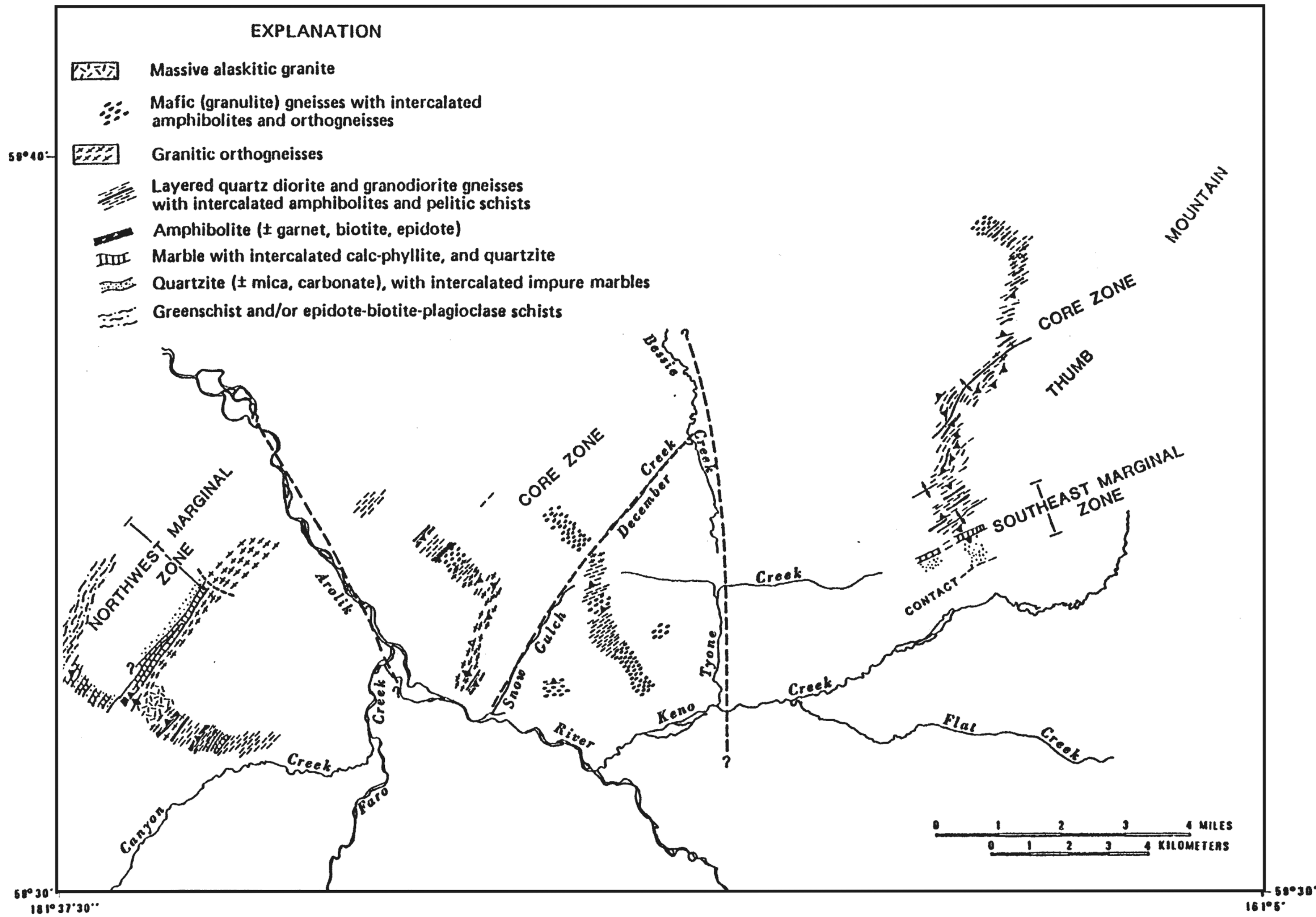

Figure 3. Geologic traverse map of the southwestern part of the Kanektok complex based on field work by Forbes and Turner in 1975.

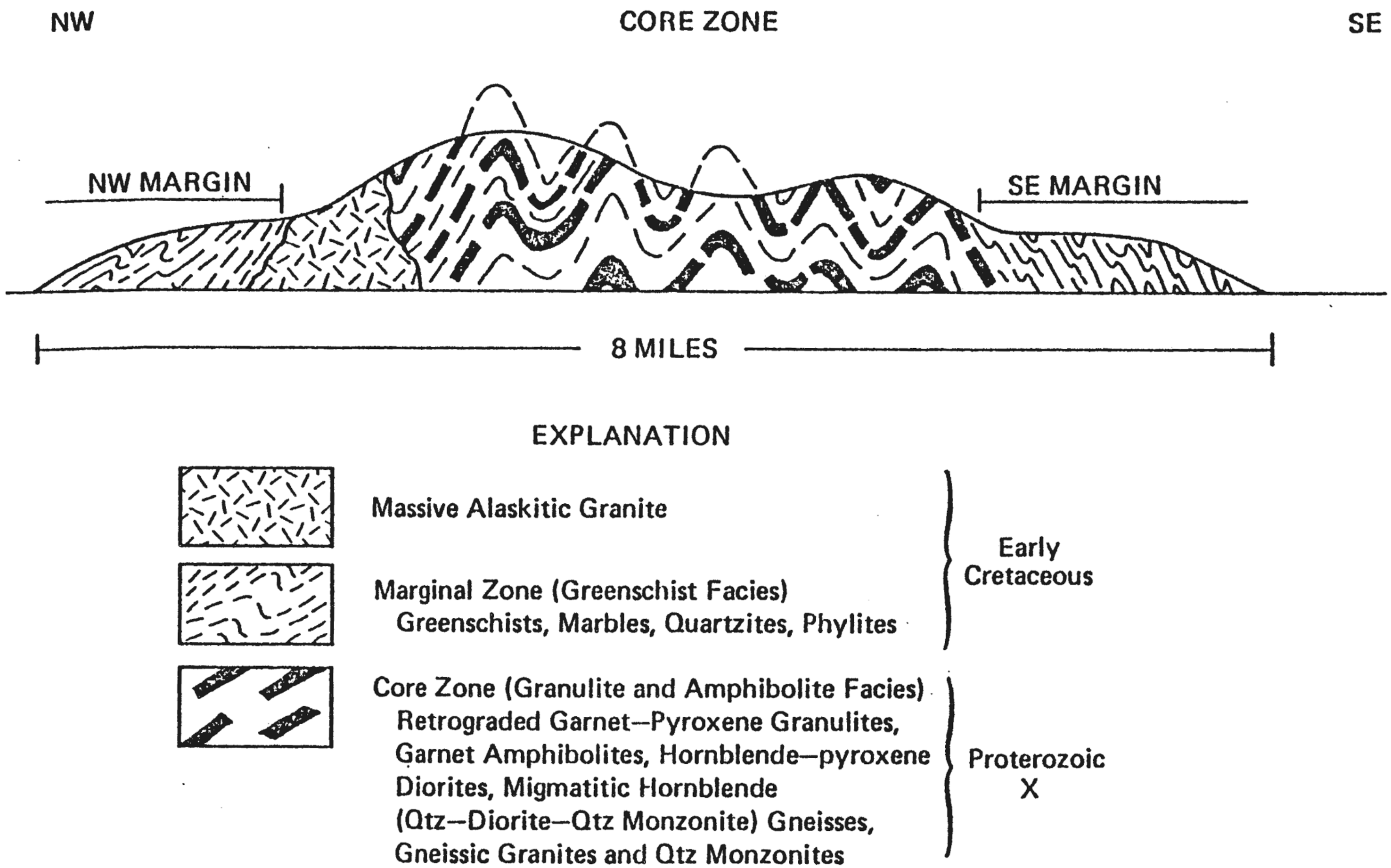

Figure 4. Diagrammatic structure section across Kanektok complex.

Although mapping of the Kanektok complex provides a reasonable fit for the proposed model, the stratigraphy of the layered metamorphic rocks has been disrupted by both high angle vertical and low angle thrust faulting. Block faulting and imbrication within the complex have resulted in a complex outcrop pattern within the core zone.

Hoare and Coonrad (1979) have reported field mapping, gravity and aeromagnetic data indicating that the Kanektok complex is rootless and thrust over underlying Paleozoic and Mesozoic sedimentary and volcanic rocks, as shown in figure 2. The apparent 2-sided symmetry and descending antiformal structural style of the complex does not fit the asymmetrical structural style and zonation pattern that one expects to encounter in "rootless" crystalline thrust plates. However, the evidence presented by Hoare and Coonrad (1979) for an allochthonous origin of the complex is convincing, and it is difficult to offer a satisfactory explanation for an apparent allochthonous origin versus structural and petrologic characteristics that are generally attributed to mantled gneiss domes. Jones and others (1981) accepted the evidence of Hoare and Coonrad (1979) that the complex is rootless, re-named it the Kilbuck terrane, and designated it as one of the 50 tectonostratigraphic terranes which they have defined in Alaska.[2]

Geochronology

$^{40}K/^{40}Ar$ Studies

Thus far, 77 $^{40}K/^{40}Ar$ total fusion mineral ages have been determined for 58 rocks distributed throughout the major outcrop areas of the Kanektok complex. Mineral separations and K-Ar analyses were done by D.L. Turner at the Geochronology Laboratory of the Geophysical Institute, University of Alaska, Fairbanks. Analytical data are given in table 1.

Figure 5 is a histogram of these ages which range from 120 to 2,500 Ma. Seventy-three percent are grouped in the 120-225 Ma range and most of these are in the 120-150 Ma range (latest Jurassic to earliest Cretaceous). Ages in the 120-150 Ma range from both biotite and hornblende are present in all rock types throughout the entire length of the complex. These younger ages are interpreted as having been reset by a pervasive late Mesozoic thermal event accompanied by plutonism. An unfoliated alaskitic granite body intrudes greenschists in the southwestern part of the complex (figs. 3 and 4). The granite contains no biotite or hornblende and therefore could not be dated by K-Ar methods. Greenschists near the granite contact, however, gave an actinolite age of 137 Ma and a biotite age of 130 Ma. An amphibolite 2 miles north of the contact gave a hornblende age of 146 Ma. No older apparent ages were found within 4 miles of the contact. The widespread distribution of 120-150 Ma ages and the occurrence of small scale igneous intrusive bodies throughout the complex (table 1) indicate that the entire complex was affected by the late Mesozoic thermal event. The numerous biotite, muscovite and hornblende K-Ar ages older than 100-150 Ma and younger than 1.77 Ga (fig. 5) are believed to represent Precambrian rocks that have undergone varying degrees of partial argon loss during the late Mesozoic thermal event.

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[2] At present, few workers believe 50 tectonically independent terranes exist in Alaska as the definitions of many of these terranes have been revised or abandoned.

Table 1. Analytical data for K-Ar analyses of samples from Kanektok complex.
[Sample collectors: AHR, J.M. Hoare; AFS, R.B. Forbes; DT, D.L. Turner, x = number of analyses for K_2O]

Sample No.	Lab No.	Latitude ° N	Longitude ° W	Rock Type	Mineral	x	K_2O (wt.%)	$^{40}Ar_{rad}$ (mol/g) x 10^{-11}	$^{40}Ar_{rad}$/ $^{40}Ar_{total}$	Age (Ma)	±1 (m.y.)
50AHR747A	72003	59.7250	161.1083	quartz diorite	biotite	1	7.840	561.70	0.937	439.5	12.9
50AHR747A	72003	59.7250	161.1083	quartz diorite	biotite	2	7.840	561.70	0.937	439.5	13.0
50AHR747A	72151	59.7250	161.1083	quartz diorite	hornblende	4	1.417	128.40	0.964	539.9	15.9
50AHR747A	72147	59.7250	161.1083	quartz diorite	hornblende	2	1.417	129.60	0.820	544.3	16.0
50AHR747A	72147	59.7250	161.1083	quartz diorite	hornblende	4	1.417	129.60	0.820	544.3	16.1
75AFS-12K	76120	59.5767	161.2350	garnet amphibolite	muscovite	4	10.051	205.20	0.883	136.5	3.9
75AFS-12K	76127	59.5767	161.2350	garnet amphibolite	hornblende	4	0.801	19.69	0.777	163.1	4.8
75AFS-18AK	76123	59.6167	161.3883	biotite muscovite granodiorite gneiss	muscovite	2	10.595	214.70	0.842	135.5	3.9
75AFS-18AK	76128	59.6167	161.2050	biotite muscovite granodiorite gneiss	biotite	2	8.916	191.90	0.970	143.6	4.2
75AFS-18CK	76122	59.6200	161.2000	biotite-bearing amphibolite	hornblende	4	1.090	21.76	0.846	133.6	3.9
75AFS-1K	76131	59.6117	161.2283	biotite-muscovite gneiss	biotite	2	9.220	236.10	0.969	169.6	4.9
75AFS-22AK	76121	59.6450	161.2050	biotite-hornblende diorite gneiss	biotite	2	6.480	166.60	0.961	170.3	4.9
75AFS-22AK	76172	59.6450	161.2050	biotite-hornblende diorite gneiss	biotite	2	6.480	194.80	0.956	197.6	19.3
75AFS-22AK	76172	59.6450	161.2050	biotite-hornblende diorite gneiss	biotite	2	6.480	194.80	0.956	197.6	5.8
75AFS-22AK	76119	59.6450	161.2050	biotite-hornblende diorite gneiss	hornblende	4	1.160	43.88	0.946	245.3	7.2

Table 1. Analytical data for K-Ar analyses of samples from Kanektok complex (cont.).

Sample No.	Lab No.	Latitude ° N	Longitude ° W	Rock Type	Mineral	x	K_2O (wt.%)	$^{40}Ar_{rad}$ (mol/g) x 10^{-11}	$^{40}Ar_{rad}$/ $^{40}Ar_{total}$	Age (Ma)	±1 (m.y.)
75AFS-23AK	77107	59.6500	161.2067	biotite-hornblende diorite gneiss	biotite	2	8.426	255.80	0.941	199.4	5.8
75AFS-28AK	77103	59.5700	161.4417	biotite-hornblende biotite gneiss	hornblende	2	1.344	38.02	0.963	186.5	5.5
75AFS-35AK	77164	59.5817	161.3967	biotite-hornblende granodiorite	biotite	2	8.702	180.70	0.891	138.8	4.1
75AFS-35AK	77071	59.5817	161.3967	biotite-hornblende granodiorite	hornblende	4	0.785	28.41	0.876	235.3	6.9
75AFS-3K	76126	59.6067	161.2250	epidote amphibolite	biotite (impure)	3	7.391	162.20	0.956	146.3	4.3
75AFS-3K	76124	59.6067	161.2250	epidote amphibolite	hornblende	4	1.110	28.56	0.894	170.4	4.9
DT 75-60	76057	59.5433	161.4617	garnet amphibolite	hornblende	2	0.805	20.61	0.879	169.6	5.0
DT 75-61	76081	59.5433	161.4583	retrograded pyroxene granulite	biotite	2	9.101	5778.00	0.998	2231.1	67
DT 75-61	76159	59.5433	161.4583	retrograded pyroxene granulite	biotite	2	9.101	6147.00	0.994	2311.1	70
DT 75-61	76159	59.5433	161.4583	retrograded pyroxene granulite	biotite	2	9.101	6147.00	0.994	2311.1	70
DT 75-62	76052	59.5783	161.4550	garnet amphibolite	hornblende	4	0.630	24.09	0.822	247.8	7.2
DT 75-63	76082	59.5767	161.4500	biotite-granodiorite gneiss	biotite	2	8.946	177.80	0.961	133.0	3.9
DT 75-64	76063	59.5717	161.4417	biotite-hornblende-granodiorite gneiss	biotite	2	8.567	167.20	0.933	130.7	3.8
DT 75-64	76070	59.5717	161.4417	biotite-hornblende-granodiorite gneiss	hornblende	2	0.770	16.33	0.714	141.6	4.1

Table 1. Analytical data for K-Ar analyses of samples from Kanektok complex (cont.).

Sample No.	Lab No.	Latitude ° N	Longitude ° W	Rock Type	Mineral	x	K_2O (wt.%)	$^{40}Ar_{rad}$ (mol/g) x 10^{-11}	$^{40}Ar_{rad}$/ $^{40}Ar_{total}$	Age (Ma)	±1 (m.y.)
DT 75-66	76069	59.5617	161.4317	biotite-hornblende granodiorite gneiss	biotite	2	8.295	159.40	0.816	128.8	3.8
DT 75-66	76053	59.5617	161.4317	biotite-hornblende granodiorite gneiss	hornblende	2	0.770	16.20	0.770	140.5	4.1
DT 75-67	76084	59.5500	161.4400	biotite-muscovite granodiorite gneiss	hornblende	2	9.114	174.00	0.927	128.0	3.7
DT 75-67	76075	59.5500	161.4400	biotite-muscovite granodiorite gneiss	muscovite	3	10.363	210.40	0.779	135.8	4.0
DT 75-68	76054	59.5467	161.4367	biotite, garnet amphibolite	hornblende	4	0.868	18.74	0.878	144.1	4.2
DT 75-69	76059	59.5633	161.3800	garnet amphibolite	hornblende	4	0.798	61.08	0.908	465.9	13.7
DT 75-70	76083	59.5583	161.3800	biotite quartz monzonite gneiss	biotite	2	9.221	761.00	0.980	497.8	14.7
DT 75-71	76060	59.5550	161.3717	pyroxene granulite	biotite	3	9.123	4501.00	0.995	1920.5	58
DT 75-71	76060	59.5550	161.3717	pyroxene granulite	biotite	3	9.123	5468.00	0.997	2158.1	65
DT 75-71	76168	59.5550	161.3717	pyroxene granulite	biotite	4	9.123	6663.50	0.993	2414.2	271
DT 75-71	76168	59.5550	161.3717	pyroxene granulite	biotite	3	9.123	6663.50	0.993	2414.2	73
DT 75-71	76085	59.5550	161.3717	pyroxene granulite	biotite	3	9.123	7265.00	0.998	2530.5	76
DT 75-72	76061	59.5600	161.3550	pyroxene granulite	biotite	2	8.645	6397.00	0.996	2431.5	73
DT 75-72	76061	59.5600	161.3550	pyroxene granulite	biotite	2	8.645	6407.00	0.975	2433.6	73
DT 75-72	76061	59.5600	161.3550	pyroxene granulite	biotite	2	8.645	6441.00	0.996	2440.7	74
DT 75-72	76163	59.5600	161.3550	pyroxene granulite	biotite	5	8.645	6976.00	0.995	2548.5	75
DT 75-72	76163	59.5600	161.3550	pyroxene granulite	biotite	2	8.645	6976.00	0.995	2548.5	77
DT 75-72	76086	59.5600	161.3550	pyroxene granulite	biotite	2	8.645	7053.00	0.996	2563.5	77

Table 1. Analytical data for K-Ar analyses of samples from Kanektok complex (cont.).

Sample No.	Lab No.	Latitude ° N	Longitude ° W	Rock Type	Mineral	x	K_2O (wt.%)	$^{40}Ar_{rad}$ (mol/g) x 10^{-11}	$^{40}Ar_{rad}$/ $^{40}Ar_{total}$	Age (Ma)	±1 (m.y.)
DT 75-73	76078	59.5633	161.3817	biotite-muscovite gneiss	muscovite	2	10.095	232.30	0.836	153.1	4.5
DT 75-73	76089	59.5633	161.3817	biotite-muscovite gneiss	biotite	2	9.227	275.10	0.974	196.0	5.7
DT 75-74	76044	59.5667	161.3850	garnet amphibolite	hornblende	4	0.980	37.35	0.887	247.0	7.2
DT 75-76	76055	59.5467	161.4033	garnet amphibolite	hornblende	3	1.020	205.60	0.978	1036.2	31
DT 75-76	76160	59.5467	161.4033	garnet amphibolite	hornblende	2	1.020	212.70	0.976	1063.3	32
DT 75-76	76160	59.5467	161.4033	garnet amphibolite	hornblende	3	1.020	212.70	0.976	1063.3	32
DT 75-78	76080	59.5417	161.5883	greenschist	actinolite	8	0.344	7.05	0.708	137.0	4.0
DT 75-79	76079	59.5433	161.5933	biotite-epidote schist	biotite	2	8.877	172.70	0.956	130.3	3.8
DT 75-81	76072	59.5750	161.6017	biotite-bearing greenschist	actinolite	4	0.500	10.99	0.706	146.6	4.3
DT 75-82	77108	59.6500	161.2117	biotite-hornblende-diorite gneiss	biotite	4	8.578	278.60	0.958	212.6	6.2
DT 75-82	77162	59.6500	161.2117	biotite-hornblende-diorite gneiss	biotite	2	8.578	283.00	0.970	215.7	6.3
DT 75-82	77162	59.6500	161.2117	biotite-hornblende-diorite gneiss	biotite	4	8.578	283.00	0.970	215.7	6.3
DT 75-82	77091	59.6500	161.2117	biotite-hornblende-diorite gneiss	hornblende	4	1.214	40.33	0.933	217.1	6.4
DT 76-21	77109	59.9200	160.9317	hornblende diorite	hornblende	2	0.585	10.65	0.807	122.2	3.6
DT 76-22	77076	59.9033	160.9200	garnet amphibolite	hornblende	4	0.824	16.07	0.810	130.6	3.8
DT 76-31	77089	59.9217	160.9017	biotite-muscovite gneiss	muscovite	4	9.313	181.60	0.905	130.6	3.8

Table 1. Analytical data for K-Ar analyses of samples from Kanektok complex (cont.).

Sample No.	Lab No.	Latitude ° N	Longitude ° W	Rock Type	Mineral	x	K_2O (wt.%)	$^{40}Ar_{rad}$ (mol/g) x 10^{-11}	$^{40}Ar_{rad}$/ $^{40}Ar_{total}$	Age (Ma)	±1 (m.y.)
DT 76-31	77157	59.9217	160.9017	biotite-muscovite gneiss	biotite (impure)	4	8.686	259.90	0.941	196.7	5.8
DT 76-34	77095	59.9250	160.8983	biotite gneiss	biotite	2	5.190	109.40	0.703	140.8	4.1
DT 76-36		59.9300	160.8950	biotite-muscovite-quartz schist	muscovite	4	9.793	230.50	0.858	156.5	4.6
DT 76-36	77158	59.9300	160.8950	biotite-muscovite-quartz schist	biotite (impure)	4	7.398	471.00	0.926	395.5	12.0
DT 76-39	77096	59.9133	160.8967	granodiorite gneiss	biotite	2	8.639	394.70	0.959	292.3	8.6
DT 76-41	77097	59.9467	160.9117	biotite-hornblende-epidote schist	hornblende	2	0.730	14.12	0.889	129.6	3.8
DT 76-41	77149	59.9467	160.9117	biotite-hornblende-epidote schist	biotite	4	7.893	188.50	0.924	158.7	4.7
DT 76-42	77152	59.9467	160.9133	biotite-muscovite granodiorite gneiss	biotite	4	8.431	172.10	0.943	136.5	4.0
DT 76-46	77155	59.9400	160.9233	biotite-hornblende-muscovite schist	hornblende	3	0.606	17.67	0.848	191.9	5.6
DT 76-46	77078	59.9400	160.9233	biotite-hornblende-muscovite schist	biotite	2	8.495	291.20	0.911	223.6	6.6
DT 76-52		59.9217	160.8867	quartz-muscovite gneiss	muscovite	4	9.522	185.60	0.923	130.5	3.9
DT 76-56	77084	59.9700	160.8467	biotite-muscovite-hornblende schist	muscovite	3	9.839	278.90	0.914	186.9	5.5
DT 76-56	77156	59.9700	160.8467	biotite-muscovite-hornblende schist	biotite	4	8.281	462.30	0.938	351.2	10.3
DT 76-57	77101	59.9550	160.8983	quartz-muscovite-biotite gneiss	muscovite	4	10.549	200.90	0.880	127.7	3.9

Table 1. Analytical data for K-Ar analyses of samples from Kanektok complex (cont.).

Sample No.	Lab No.	Latitude ° N	Longitude ° W	Rock Type	Mineral	x	K_2O (wt.%)	$^{40}Ar_{rad}$ (mol/g) x 10^{-11}	$^{40}Ar_{rad}$/ $^{40}Ar_{total}$	Age (Ma)	±1 (m.y.)
DT 76-57	77099	59.9550	160.8983	biotite-muscovite gneiss	biotite	2	9.134	179.90	0.876	131.9	3.9
DT 76-58	77100	59.9533	160.8933	hornblende diorite	hornblende	4	0.612	11.74	0.799	128.6	3.8
DT 76-61	77106	59.9450	160.8817	porphyroblastic amphibolite	hornblende	2	0.393	12.05	0.911	201.3	5.9
DT 76-62	77079	59.9050	160.9033	amphibolite	hornblende	2	0.340	35.41	0.937	608.3	18.0
DT 76-66	77105	59.9017	160.9017	?	biotite	2	8.815	335.10	0.961	246.4	7.2
DT 76-69A	77083	59.9000	160.8967	garnet amphibolite	hornblende	2	0.280	121.30	0.972	1770.3	53
DT 76-70	77165	60.0933	160.6000	biotite amphibolite	biotite	2	7.836	939.00	0.964	684.4	20.0
DT 76-70	77072	60.0933	160.6000	biotite amphibolite	hornblende	2	0.715	122.70	0.893	915.1	27.0
DT 76-71	77161	60.0950	160.6283	biotite-hornblende gneiss	hornblende	4	0.595	24.53	0.900	265.8	7.8
DT 76-72	77093	60.1267	160.5667	biotite-hornblende-epidote-plagioclase rock	biotite	4	8.234	177.10	0.487	143.5	4.2
DT 76-72	77094	60.1267	160.5667	biotite-hornblende-epidote-plagioclase rock	hornblende	2	0.595	13.71	0.899	153.3	4.5
DT 76-74	77092	60.1267	160.5667	biotite-hornblende-epidote rock	biotite	4	8.798	214.70	0.900	162.0	4.7
DT 76-74	77081	60.1267	160.5667	biotite-hornblende-epidote rock	hornblende	4	0.608	31.53	0.935	328.4	9.7
DT 76-76	77086	59.8567	160.9033	garnet amphibolite	hornblende	4	0.463	50.83	0.941	636.0	19.0

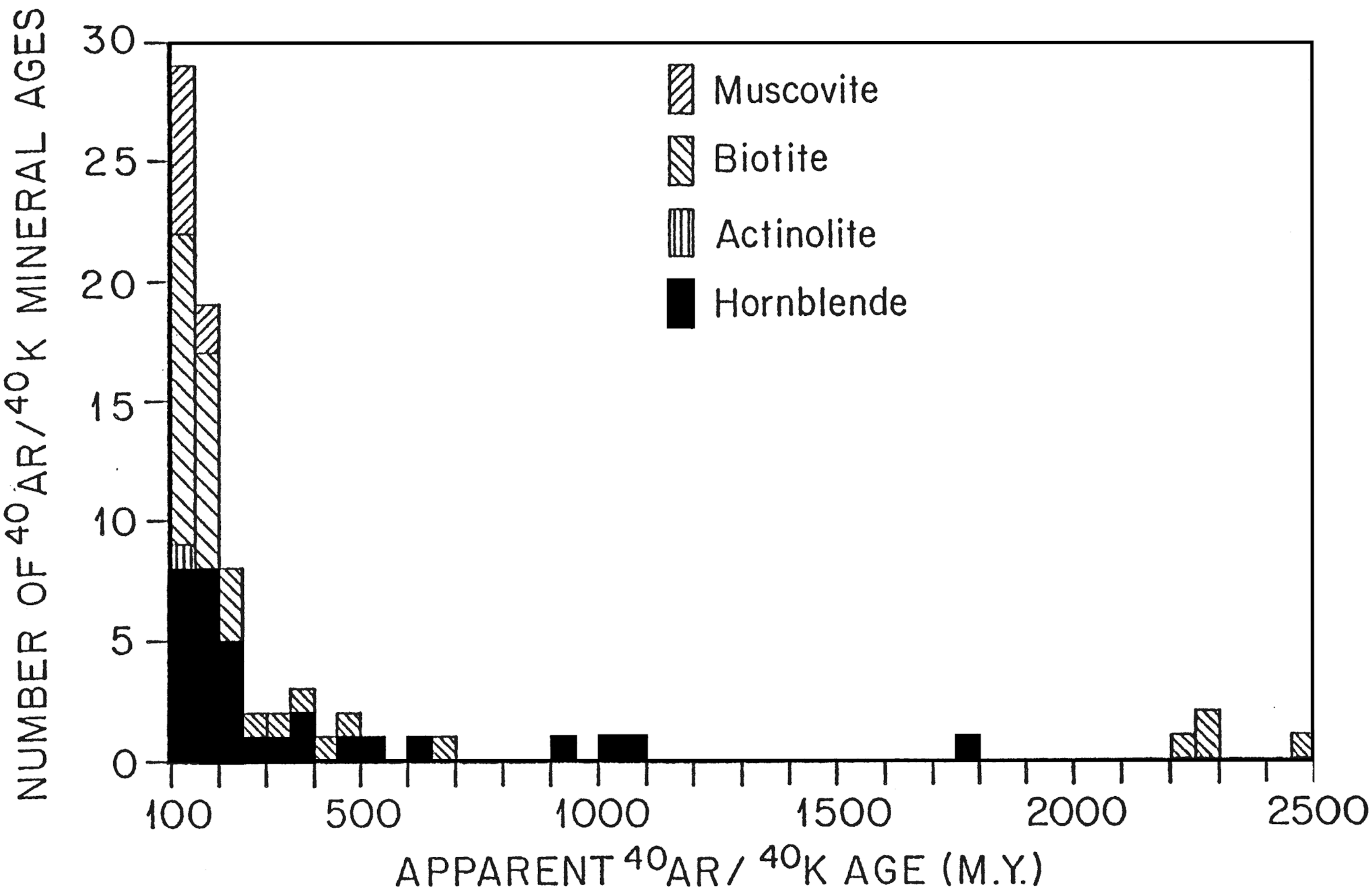

Figure 5. Histogram of 77 apparent $^{40}Ar/^{40}K$ mineral ages from all major outcrop areas of the Kanektok complex.

Evidence for Excess ^{40}Ar

Five pyroxene granulites have apparent Precambrian biotite ages (685, 2,203, 2,255, 2,271 and 2,474 m.y). Argon analyses for four of the five biotite samples were each repeated 2 to 5 times. Each of these four biotite samples shows an extremely variable content of radiogenic ^{40}Ar/g. (6.2%, 9.9%, 22.7% and 46.3% spreads, table 1). Two samples of biotite from gneiss sample DT 75-61 gave a mean age of 2,271 Ma with a 6.2% spread in radiogenic ^{40}Ar/g (table 1). A garnet amphibolite interlayered with the gneiss at the same locality, however, gave a hornblende age of only 170 Ma. These results strongly suggest the incorporation of variable amounts of excess ^{40}Ar which is distributed in a non-homogeneous way throughout the biotites in each of these rocks.

The hypothesis that these biotites contain excess argon is supported by the fact that only one of the dated hornblendes gives an age greater than 1,100 Ma, and its age (1770 Ma) is significantly younger than the 2,200-2,500 Ma apparent ages of most of the above biotites. Because hornblendes are known to be more resistant than biotites to thermal overprinting, one would normally expect hornblende K-Ar ages to be older than biotite ages in a complex metamorphic terrane such as this. There are no biotite ages in the 700-2,200 Ma interval, but there are four hornblende ages in this interval (fig. 5).

Studies of 3,700 m.y. old gneisses from Greenland by Pankhurst and others (1973) have found clear evidence of excess radiogenic ^{40}Ar in metamorphic biotites. Most of their biotite $^{40}Ar/^{39}Ar$ ages exceeded hornblende ages from the same rock suites, and one of these biotites yielded an impossibly old age of 4,940 Ma. Russian workers have found similar results in Precambrian biotites from gneisses of the Baltic Shield (Lobach-Zhuchenko and others, 1972). They found 4,800-5,200 Ma K-Ar biotite ages from one area, while Rb-Sr whole-rock and U-Pb zircon studies on biotite-bearing gneisses and granites gave 2,600-2,700 Ma ages. These rocks were shown to have undergone metamorphic overprinting about 1,800 m.y. ago.

Five Kanektok complex amphibolites have apparent Precambrian hornblende ages (637, 915, 1,049, 1,089 and 1,770 Ma). Four of these hornblendes were analyzed for argon in duplicate. All duplicates show reproducible radiogenic ^{40}Ar content within analytical uncertainty (table 1). These hornblendes do not appear to be subject to the excess argon problem found in the biotites.

The hornblende ages strongly suggest that the amphibolite facies core zone of the complex is Precambrian, probably at least 1 b.y. old and possibly as much as 1.77 b.y. old, as confirmed by the U-Pb and Rb-Sr results to be discussed later. Most K-Ar mineral ages from the terrane, however have been overprinted by a pervasive late Mesozoic thermal event, accompanied by plutonism, which appears to have totally reset most of the K-Ar ages and may have partially reset the remainder (fig. 5).

$^{40}Ar/^{39}Ar$ Studies

A six-step $^{40}Ar/^{39}Ar$ incremental heating study of a biotite sample (DT 75-72) yielding a conventional $^{40}K/^{40}Ar$ age of approximately 2.5 Ga was done by D.L. Turner at the Isotope Geology Laboratory of the U.S. Geological Survey, Menlo Park, California. Analytical data are given in table 2; analytical methods are described by Lanphere and Dalrymple (1971).[3] The heating spectrum appears to be more-or-less "normal", with a

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[3] Many advances in the application of ^{40}Ar-^{39}Ar dating have been made since this manuscript was prepared; see for example, Faure, Gunter and Mensing, T.K., 2005, Isotopes, principles and applications (3rd ed.): Hoboken, New Jersey, John Wiley and Sons, Inc., 896 p.

fairly good plateau at about 2.52 Ga (fig. 6). The lower age of the first step suggests a partial loss of radiogenic ^{40}Ar during a later thermal event. There is no obvious evidence of excess ^{40}Ar, such as anomalously old ages from the lower temperature gas releases. This result night appear to be consistent with the interpretation that the dated rock was recrystallized at least 2.5 billion years ago. However, recent studies of biotite release spectra from metamorphic rocks (Lanphere and Dalrymple, 1971; Pankhurst and others, 1973; Hanson and others, 1971; Tetley, 1978) raise serious questions regarding the suitability of biotites for this type of analysis. It appears that many, if not all, biotite $^{40}Ar/^{39}Ar$ incremental heating plateaus are experimental artifacts resulting from chemical and/or physical changes occurring in the biotite structure during heating in a vacuum. It now seems clear that the $^{40}Ar/^{39}Ar$ technique is unable to resolve excess from in-situ radiogenic ^{40}Ar in biotites from regionally recrystallized metamorphic rocks, and that a $^{40}Ar/^{39}Ar$ incremental heating plateau for biotite cannot be regarded as indicating a geologically meaningful age.

In view of the evidence discussed above and the U-Pb and Rb-Sr results to be discussed later, it is clear that the apparent Precambrian biotite ages from the Kanektok metamorphic complex have been artificially increased by excess radiogenic ^{40}Ar formed by degassing of basement rocks during metamorphism. These biotite ages should therefore be considered unreliable.

Three additional samples were selected for $^{40}Ar/^{39}Ar$ incremental heating studies in an attempt to obtain meaningful high-temperature plateau ages that might help in the interpretation of the complex history of the terrane. It was hoped that the early-to-middle Proterozoic [Paleoproterozoic] metamorphic event indicated by the U-Pb and Rb-Sr studies to be discussed later and by the oldest conventional $^{40}K/^{40}Ar$ hornblende age might be reflected in the high-temperature gas releases from one or more mineral samples whose conventional $^{40}K/^{40}Ar$ ages were intermediate between 1.77 Ga and the late Mesozoic thermal event. Accordingly, the following core zone samples were analyzed:

- DT 75-70 biotite from a quartz monzonite gneiss yielded a $^{40}Ar/^{39}Ar$ total fusion age of 487 Ma.
- DT 75-69 hornblende from a garnet amphibolite yielded a $^{40}Ar/^{39}Ar$ total fusion age of 478 Ma.
- DT 75-76 hornblende from a garnet amphibolite yielded a $^{40}Ar/^{39}Ar$ total fusion age of 1,124 Ma.

Analytical work was done by D.L. Turner and Ian McDougall at The Research School of Earth Sciences, Australian National University, Canberra. Analytical data for $^{40}Ar/^{39}Ar$ analyses are given in table 2. Analytical techniques are described in Harrison and McDougall (1980).

The $^{40}Ar/^{39}Ar$ age spectrum for DT 75-70 biotite is shown in figure 7. The spectrum rises from an initial age of 152±87 Ma to a plateau age of 496±1.5 Ma, defined by nine of the thirteen gas release steps. The plateau age does not differ greatly from the $^{40}Ar/^{39}Ar$ total fusion age of 487±4.3 Ma. The lower ages of the first three steps suggest partial loss of radiogenic ^{40}Ar during a later thermal event. The spectrum is consistent with the hypothesis that this event is the late Mesozoic intrusive episode which has reset most of the conventional ages (fig. 5). The plateau age of 496 Ma probably represents a minimum age of metamorphic recrystallization for the biotite. However, in view of the problems discussed previously, age spectra from this mineral must be interpreted with caution.

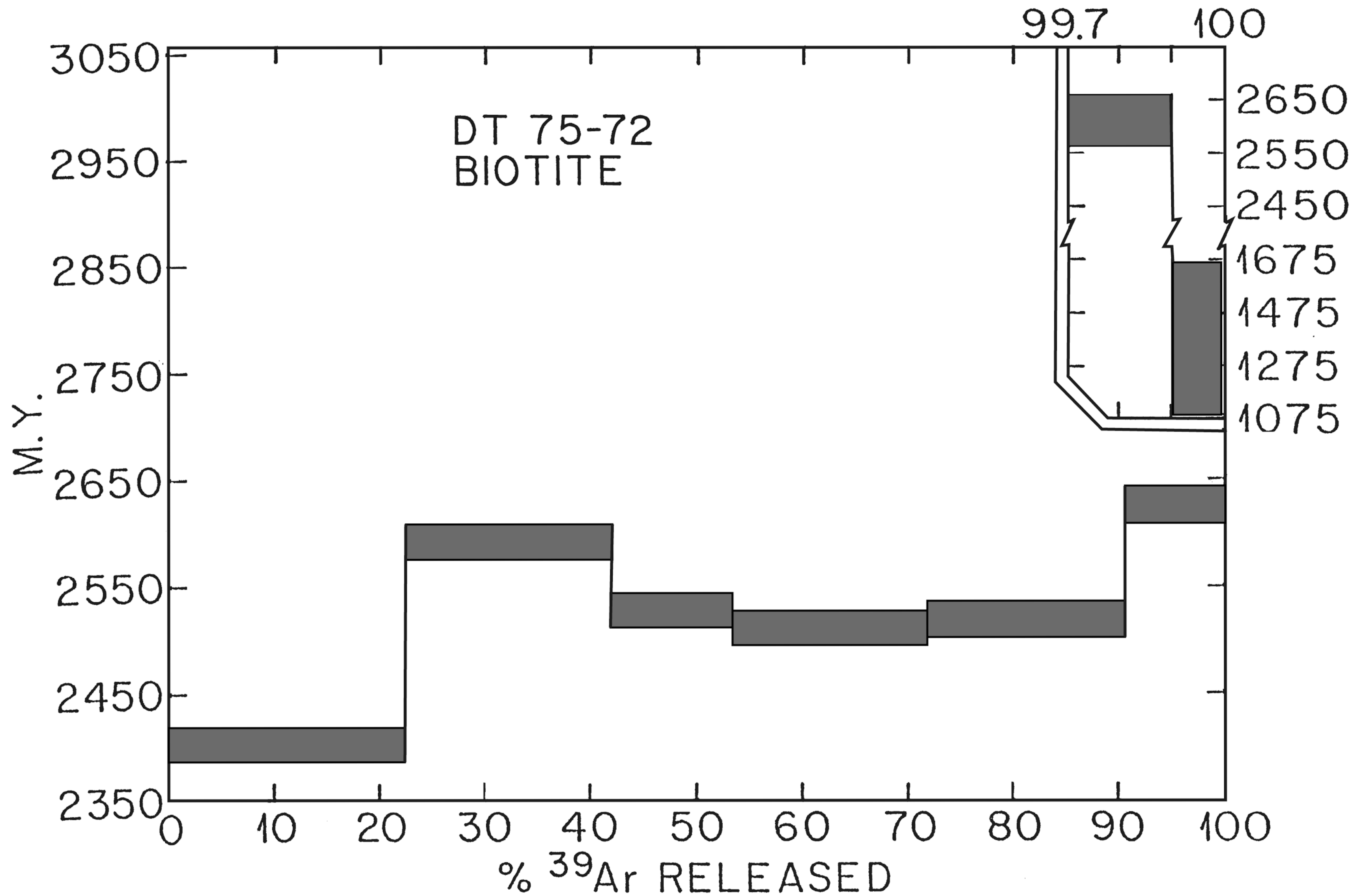

Figure 6. $^{40}Ar/^{39}Ar$ incremental heating release spectrum for DT 75-72 biotite ($^{40}Ar/^{40}K$ total fusion age 2.5 b.y.).

Table 2. Analytical data for $^{40}Ar/^{39}Ar$ age spectra.

[[1] Uncorrected for line blank; [2] Corrected for decay 37Ar; [3] Obtained by manometric measurement of gas calibrated using 38Ar tracer; [4] Uncertainties quoted at the level of standard deviation; [5] FM – flux monitor GA1550 biotite; K/Ca = 38.5; [6] TF – total fusion run with air leak in extraction line; [7] FM – flux monitor 77-600 hornblende; K/Ca = 0.037]

Sample No.	Step Temperature (°C)	$^{40}Ar/^{39}Ar$ [1]	$^{37}Ar/^{39}Ar$ [2]	$^{36}Ar/^{39}Ar$ [1] ($x10^{-1}$)	^{39}Ar [3] ($x10^{-14}$ mol)	Cumulative ^{39}Ar (%)	$^{40}Ar^{*}/^{40}Ar_{total}$ (%)	$^{40}Ar/^{39}Ar$	Age (Ma)	Standard error [4] (m.y.)
DT 75-70 Biotite Latitude 59.5583° N.; Longitude 161.3800° W.										
	FM[5]	14.22	0.0177	0.0858	459.6		82.0	11.66		(0.15%)
	TF[6]	87.15	0.00514	0.7519	59.34		74.5	64.91	486.6	4.3
	525	1707.01		57.15	4.862	0.446	1.08	18.39	151.7	87.0
	600	508.1	0.021	15.55	32.18	3.40	9.55	48.50	375.5	12.3
	655	236.0	0.00480	5.881	143.4	16.6	26.3	62.15	459.7	6.12
	760	80.84	0.00207	0.5274	268.1	41.2	80.7	65.22	488.7	4.33
	800	67.28	0.00398	0.0304	304.0	69.0	98.6	66.36	496.1	4.36
	830	69.91		0.0536	15.03	70.4	97.7	58.29	508.7	4.48
	870	63.31	0.013	0.0378	77.03	77.5	98.4	68.17	507.9	4.45
	910	68.60	0.014	0.0533	44.42	81.6	97.7	67.00	500.3	4.40
	945	67.20	0.020	0.0511	49.34	86.1	97.7	65.67	491.6	4.33
	990	56.51	0.013	0.0471	79.62	93.4	97.8	65.08	487.7	4.29
	1060	67.05	0.00834	0.0690	35.83	96.8	96.9	64.99	487.1	4.29
	1145	71.43	0.0430	0.1481	32.89	99.8	93.8	67.03	500.5	4.40
	1250	85.46	0.377	0.5029	2.24	100.0	82.6	70.63	523.8	7.01

Table 2. Analytical data for $^{40}Ar/^{39}Ar$ age spectra (cont.).

Sample No.	Step Temperature (°C)	$^{40}Ar/^{39}Ar$[1]	$^{37}Ar/^{39}Ar$[2]	$^{36}Ar/^{39}Ar$[1] ($x10^{-1}$)	^{39}Ar[3] ($x10^{-14}$ mol)	Cumulative ^{39}Ar (%)	$^{40}Ar^*/^{40}Ar_{total}$ (%)	$^{40}Ar/^{39}Ar$	Age (Ma)	Standard error[4] (m.y.)
DT 75-72 Biotite Latitude 59.5600° N.; Longitude 161.3550° W.										
	500	342.9	0.01134	0.06397	0.2082	22.5	99.4	342.0	2401	16.3
	500	394.0	0.04039	0.04991	0.1787	41.8	99.6	394.0	2589	16.9
	700	375.9	0.01911	0.04111	0.1078	53.4	99.7	375.9	2524	16.7
	775	372.3	0.01584	0.03817	0.1697	71.7	99.7	372.3	2511	16.6
	850	373.7	0.01455	0.03458	0.1749	90.6	99.7	373.7	2516	16.5
	950	404.5	0.05391	0.03949	0.08452	99.7	99.7	404.5	2625	18.6
	1025	399.6	1.248	1.629	0.001675	99.9	89.3	399.9	2609	49.9
	Fusion	766.2	3.763×10^{-8}	2.119	0.0004836	100.0	18.3	140.1	1371	294

Table 2. Analytical data for $^{40}Ar/^{39}Ar$ age spectra (cont.).

Sample No.	Step Temperature (°C)	$^{40}Ar/^{39}Ar$ [1]	$^{37}Ar/^{39}Ar$ [2]	$^{36}Ar/^{39}Ar$ [1] ($x10^{-1}$)	^{39}Ar [3] ($x10^{-14}$ mol)	Cumulative ^{39}Ar (%)	$^{40}Ar^*/^{40}Ar_{total}$ (%)	$^{40}Ar/^{39}Ar$	Age (Ma)	Standard error[4] (m.y.)
DT 75-69 Hornblende Latitude 59.5633° N.; Longitude 161.3800° W.										
	FM[7]	56.84	13.85	0.1790	87.46		92.8	53.31		(0.12%)
	TF	64.54	5.282	0.0867	125.1		96.7	62.67	47.80	4.23
	690	56.52	1.440	0.5656	19.90	2.25	70.6	39.94	318.9	3.29
	790	36.32	0.9625	0.4439	23.25	4.89	64.1	23.28	192.7	10.8
	860	46.13	1.797	0.5788	15.05	6.60	63.2	29.20	238.5	2.48
	910	62.07	3.853	0.5490	11.46	7.89	74.4	46.29	364.8	3.81
	930	70.47	4.865	0.4925	8.254	8.82	79.9	56.53	436.4	4.11
	970	69.76	5.503	0.1163	38.91	13.2	95.7	67.06	507.2	4.47
	1010	70.89	5.574	0.08452	74.55	21.6	97.1	69.15	520.9	4.57
	1030	71.53	5.559	0.07595	47.55	27.0	97.5	70.01	526.5	4.60
	1040	70.36	5.558	0.07332	50.34	32.7	97.6	68.94	519.6	4.55
	1070	67.84	5.601	0.06405	102.2	44.2	97.9	66.70	504.8	4.43
	1080	65.45	5.558	0.05653	86.78	54.0	98.2	64.52	490.4	4.31
	1100	62.55	5.554	0.05433	84.40	63.5	98.2	61.66	471.3	4.17
	1110	60.04	5.517	0.04936	104.5	75.3	98.4	59.29	455.2	4.05
	1400	61.61	5.561	0.07475	219.3	100.0	97.2	60.12	460.8	4.09

Table 2. Analytical data for $^{40}Ar/^{39}Ar$ age spectra (cont.).

Sample No.	Step Temperature (°C)	$^{40}Ar/^{39}Ar$[1]	$^{37}Ar/^{39}Ar$[2]	$^{36}Ar/^{39}Ar$[1] ($x10^{-1}$)	^{39}Ar[3] ($x10^{-14}$ mol)	Cumulative ^{39}Ar (%)	$^{40}Ar^{*}/^{40}Ar_{total}$ (%)	$^{40}Ar/^{39}Ar$	Age (Ma)	Standard error[4] (m.y.)
DT 75-76 Hornblende Latitude 59.5467° N.; Longitude 161.4033° W.										
	FM[7]	59.72	13.86	0.2519	94.26		89.6	54.05		(0.11%)
	TF	184.0	4.209	0.1252	64.49		98.2	181.18	1123	8.4
	500	1130	6.281	20.63	0.4339	0.086	46.1	523.6	2260	94.8
	550	503.7	3.934	7.792	0.3747	0.160	54.3	274.5	1624	44.0
	630	502.6	3.395	8.403	0.4703	0.253	50.7	262.6	1466	31.3
	680	1129	2.536	31.43	1.000	0.451	17.7	194.7	1186	41.0
	780	2869	3.052	93.58	1.122	0.673	3.64	104.6	731.0	221
	810	253.9	3.813	2.838	0.9085	0.851	67.1	172.2	1083	180
	860	215.2	4.622	1.261	3.108	1.46	82.9	178.9	1114	9.1
	910	194.1	4.304	0.1658	39.78	9.33	97.7	190.1	1165	8.6
	930	193.1	4.230	0.1275	45.59	18.3	98.2	190.3	1156	8.7
	940	193.0	4.202	0.1140	24.22	23.1	98.4	190.6	1167	8.6
	970	190.5	4.199	0.0823	56.99	34.4	98.9	189.0	1160	8.6
	980	187.9	4.170	0.0808	45.34	43.4	98.9	186.4	1148	8.5
	1020	183.6	4.141	0.0760	42.40	51.7	99.0	182.2	1129	8.4
	1070	176.9	4.131	0.0526	140.2	79.5	99.3	176.2	1101	8.3
	1115	171.3	4.222	0.0639	95.43	98.5	99.1	170.3	1073	8.1
	1150	176.0	4.793	0.1260	6.83	999.0	98.1	173.3	1088	8.4
	1400	248.9	7.289	1.591	0.635	100.0	81.36	203.6	1225	28.0

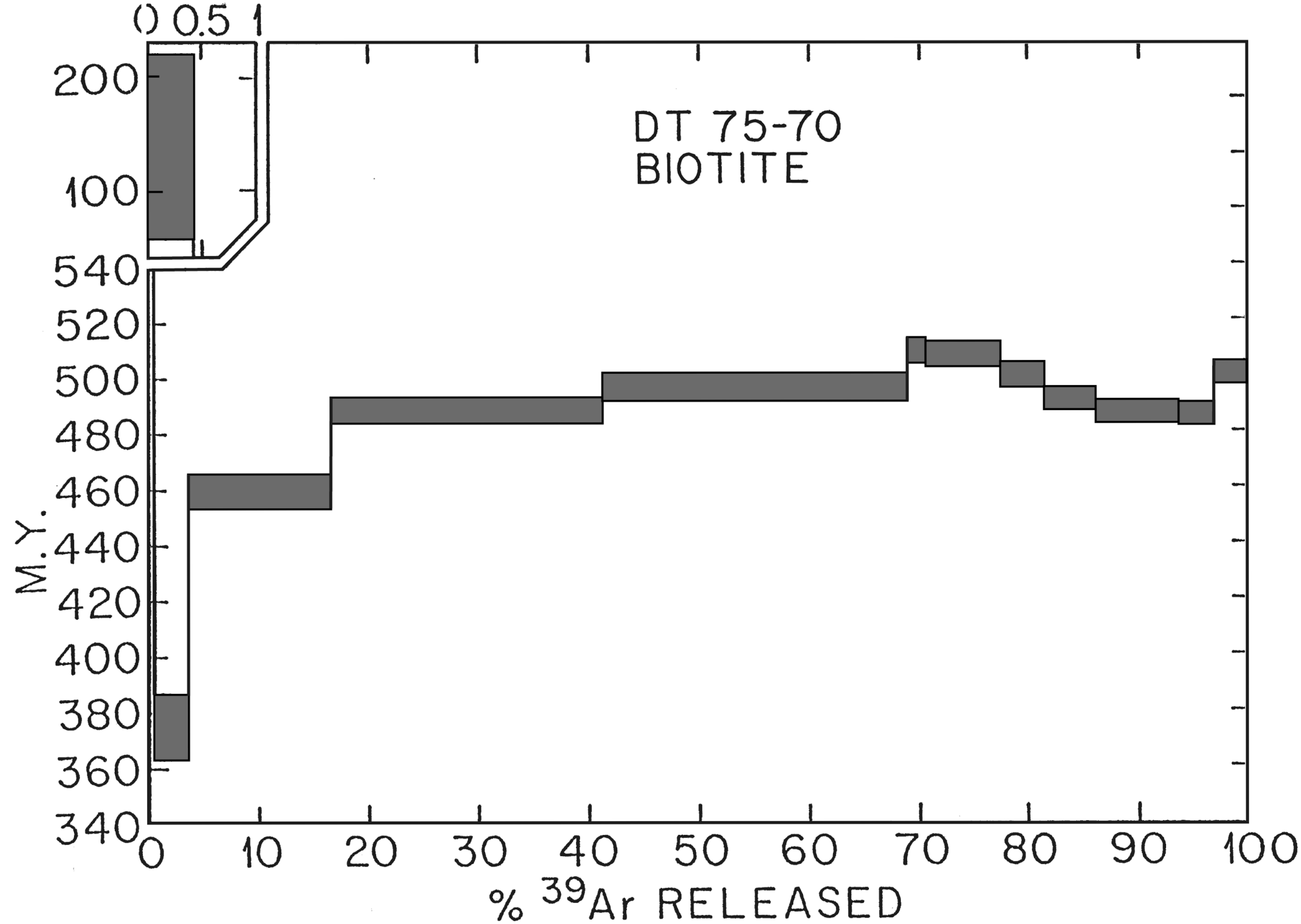

Figure 7. $^{40}Ar/^{39}Ar$ age spectrum for DT 75-70 biotite ($^{40}Ar/^{39}Ar$ total fusion age 487 Ma). [Conventional K-Ar age was 497.8±14.7 Ma]

Figure 8 shows the $^{40}Ar/^{39}Ar$ age spectrum for DT 75-69 hornblende, which gave a $^{40}Ar/^{39}Ar$ total fusion age of 478±4.2 Ma. Beginning with an initial age of 319 Ma for the first 2.25% of ^{39}Ar released, the age decreases to about 200 Ma and then increases steadily to a plateau age of 511±4.2 Ma, a value similar to the 476 m.y. plateau age for the biotite discussed above. The plateau age is defined by steps 6-11 representing 45% of the total ^{39}Ar released. Steps 12-14, however, yield significantly younger ages (471, 455, and 461 Ma respectively). The low temperature part of the spectrum (steps 1-5) clearly indicates a partial loss of radiogenic ^{40}Ar from the sample during a later thermal event. The step 2 age of about 200 Ma is interpreted as representing a maximum age for this later thermal event, and is consistent with the hypothesis that the event in question represents the late Mesozoic thermal event discussed previously. At present, we have no satisfactory explanation for the anomalously young ages for steps 12-14, representing 46% of the total ^{39}Ar released, a pattern which is also present in the spectrum of DT 75-76 hornblende (fig. 9). Anomalously young ages are also present in the higher temperature heating steps of some of the Greenland hornblendes studied by Pankhurst and others (1973) but they do not discuss possible explanations for this phenomenon.

The old apparent ages of the first three steps comprising 0.25% of the total ^{39}Ar released (2.26, 1.62 and 1.47 Ga, respectively) from DT 75-76 hornblende (fig. 9) may possibly be due to recoil of ^{39}Ar out of the rims of grains during irradiation and therefore may have no geological significance. After these steps, the age spectrum drops abruptly to 731±222 Ma (step 5, 0.22% ^{39}Ar), then rises abruptly to a 5-step plateau at about 1.16 Ga comprising 41.9% of the total ^{39}Ar released. The next four steps comprising 56.5% of the ^{39}Ar released are significantly younger (1.13, 1.10, 1.07 and 1.09 Ga). The final step gives an age of 1.22 Ma, but contains only 0.125% of the total ^{39}Ar released. The plateau age of 1.16 Ga for this hornblende probably represents a valid minimum age for the metamorphic recrystallization of the sample but the reason for the anomalous age decrease in the latter part of the spectrum is unclear. The $^{40}Ar/^{39}Ar$ total fusion age for this sample is 1.12±0.008 Ga, a value slightly less than the plateau age.

In summary, the three $^{40}Ar/^{39}Ar$ incremental heating experiments have failed to recover high-temperature plateau ages significantly older than the $^{40}Ar/^{39}Ar$ total fusion ages of these samples. This result is surprising and was not anticipated in view of the extremely large spread in conventional $^{40}Ar/^{40}K$ ages from this terrane.

The incremental heating experiments did not reveal any evidence for excess radiogenic ^{40}Ar. In general, the four age spectra are much more uniform (flat) than was expected for samples from a terrane with such an obviously complex thermal history as revealed by the $^{40}Ar/^{40}K$ age histogram (fig. 5).

In view of the above results, we suspect that the rather fine grain size of all the samples (150-250 mesh, or 0.104-0.061 mm) may have tended to homogenize the $^{40}Ar^{*}/^{39}Ar_k$ ratios of gas releases in these experiments. Harrison and McDougall (1980) have estimated an effective diffusion radius for spherical grains of igneous hornblendes at 0.08±0.02 mm. If, indeed, the samples have been crushed to a size range below their effective diffusion radii, obliteration of heterogeneous Ar isotope distributions would be expected in the step heating experiments because grain cores and rims would be outgassing simultaneously. The analyzed samples were selected from mineral separates which were initially prepared for conventional K-Ar dating, in which this grain size presents no problems. We plan to prepare new hornblende separates with the coarsest possible grain size for follow-up $^{40}Ar/^{39}Ar$ step heating experiments designed to evaluate the effect of grain size on this type of analysis, and to determine whether or not significantly higher temperature plateau ages can be recovered from these samples.

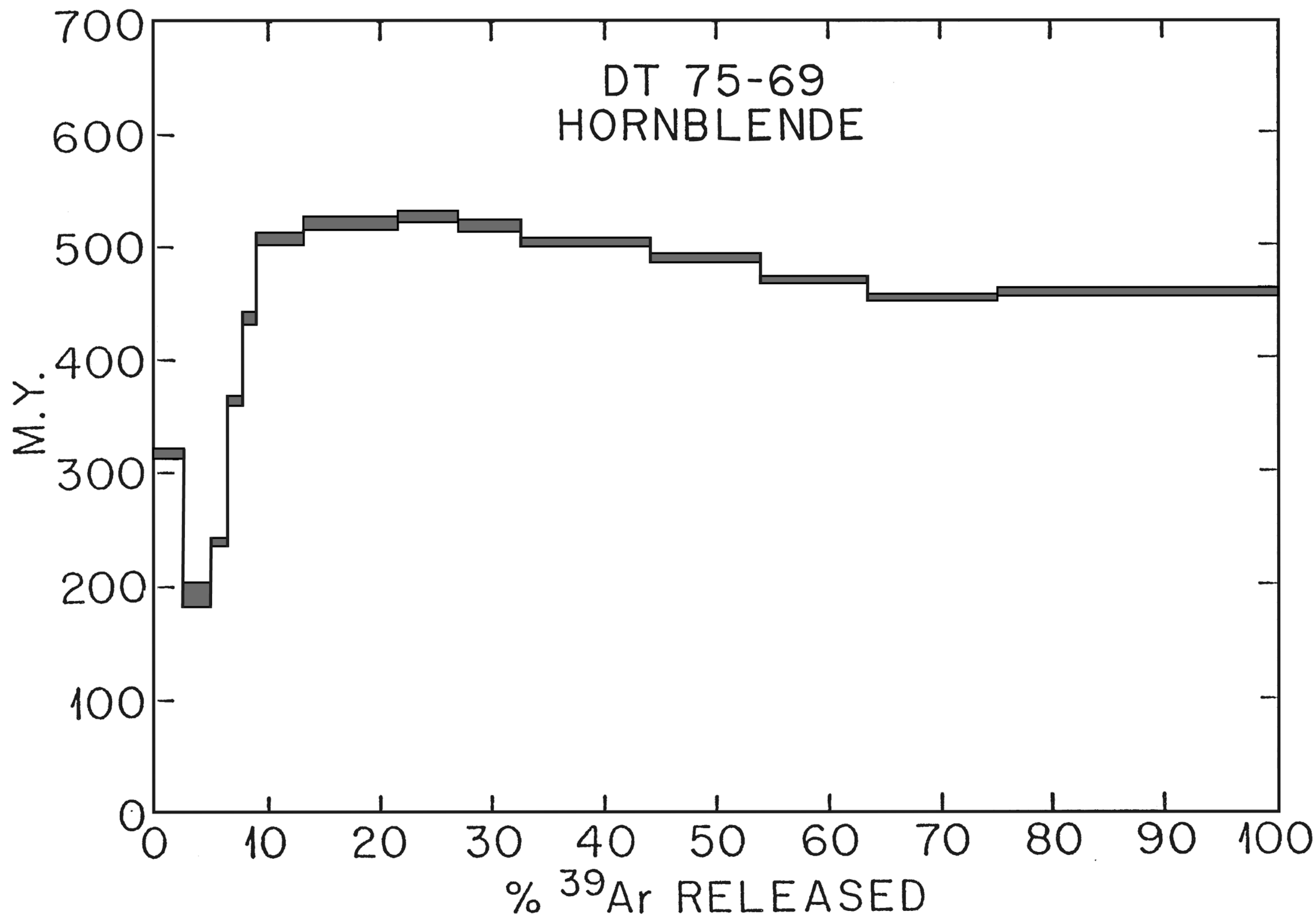

Figure 8. $^{40}Ar/^{39}Ar$ age spectrum for DT 75-69 hornblende ($^{40}Ar/^{39}Ar$ total fusion age 478 Ma). Steps 1-5 indicate partial loss of radiogenic ^{40}Ar from a sample at least 511 m.y. old (plateau age) during a later thermal event. Step 2 age of about 200 Ma is interpreted as representing a maximum age for this event. The reason for the anomalous age decrease at the latter part of the spectrum is unclear.

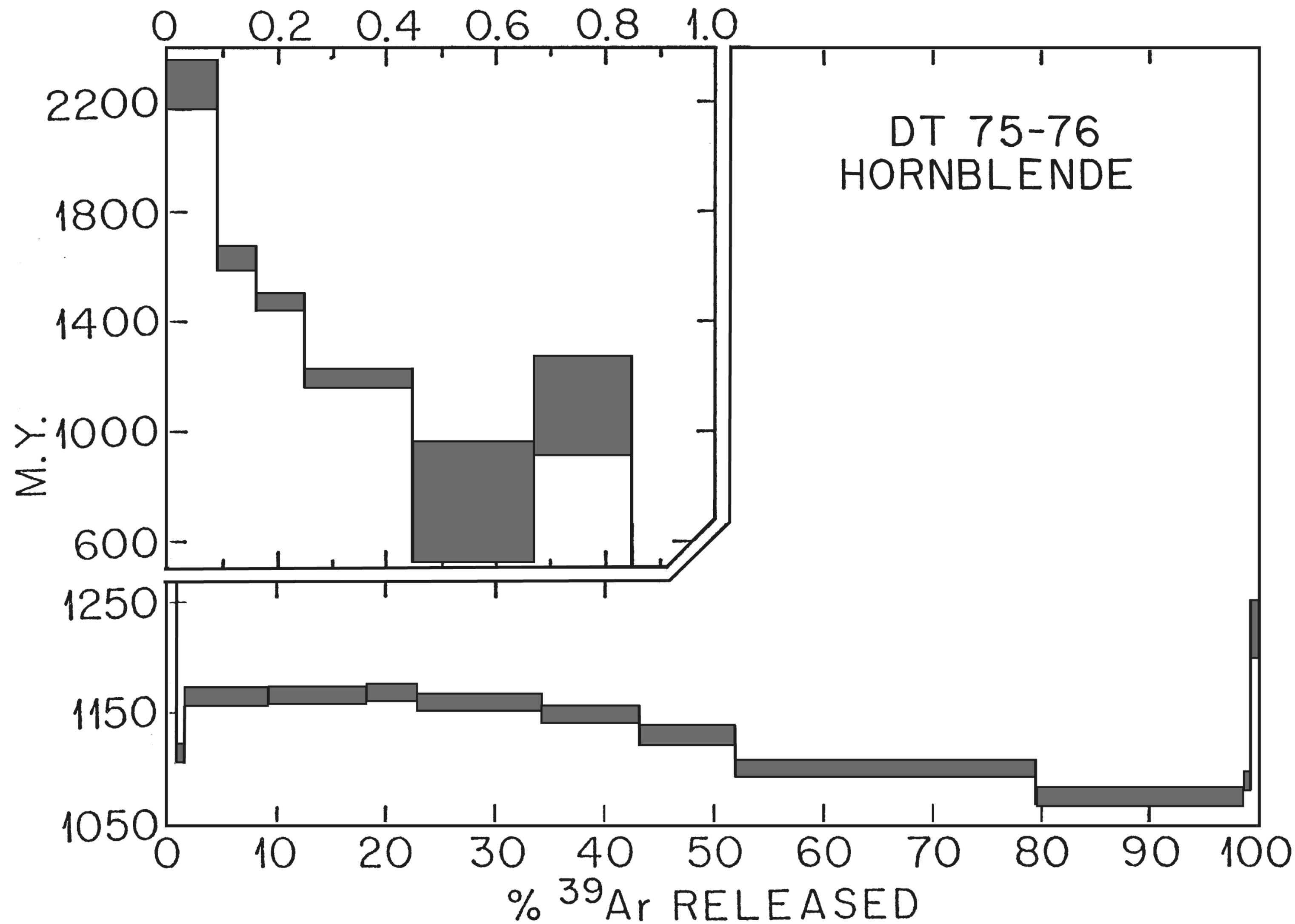

Figure 9. $^{40}Ar/^{39}Ar$ age spectrum for DT 75-76 hornblende ($^{40}Ar/^{39}Ar$ total fusion age 1124 Ma). High apparent ages in the first three steps (2.26, 1.62, and 1.47 b.y.) may be due to recoil of ^{39}Ar out of the rims of grains during irradiation. The plateau age of 1.16 b.y. probably represents a valid minimum age for the metamorphic recrystallization of the hornblende, but the reason for the anomalous age decrease at the latter part of the spectrum is unclear.

Rb-Sr Study

A suite of thirteen 20-kg samples was collected along a 2.5 mile traverse in the Thumb Mountain core zone region of the Kanektok complex for Rb-Sr whole-rock isochron analysis (fig. 3). Analytical work was done by Turner and Hedge at the Denver laboratory of the Branch of Isotope Geology, U.S. Geological Survey. Sample lithologies include garnet amphibolite, biotite amphibolite, hornblende biotite granodiorite gneiss, biotite granodiorite gneiss, biotite quartz monzonite gneiss, biotite granite gneiss, plagioclase-biotite-epidote rock and plagioclase-biotite- muscovite-epidote rock. Results are shown in figure 10 and table 3.

The suite is characterized by low rubidium and relatively high strontium values and the data scatter widely on the $^{87}Sr/^{86}Sr$ versus $^{87}Rb/^{86}Sr$ diagram (fig. 10). We offer the following speculations regarding the interpretation of these data:

- 1. The six samples that lie on the line determining the lower boundary of the cone of data on the diagram appear to define an isochron age of 1.78 Ga. This age agrees with the oldest K-Ar hornblende age and also with the $^{207}Pb/^{206}Pb$ age of sphene from an orthogneiss body, to be discussed later. This is believed to represent the age of the amphibolite facies metamorphism of the Kanektok terrane.
- 2. Three of the remaining seven samples lie along a line defined by the initial $^{87}Sr/^{86}Sr$ ratio and the composite composition point for all thirteen samples. The apparent age of this group is about 2.3 Ga. This value is not grossly different from the U-Pb age of zircon from the orthogneiss and probably approximates the age of the Kanektok protolith.
- 3. Three additional samples plot far above the composite sample line, in the low-Rb, high- $^{87}Sr/^{86}Sr$ area of the diagram. Two of these samples (97, 100) are amphibolites that would have had low Rb prior to metamorphism and can be interpreted as having incorporated considerable amounts of ^{87}Sr during the 1.77 Ga metamorphism. This interpretation seems reasonable in view of the fact that these amphibolites are interlayered with biotite-bearing felsic gneisses whose protoliths would be a likely source for the ^{87}Sr during metamorphism. The third sample (88), a biotite granite gneiss, is the most difficult to explain. Such a rock would be expected to be high in both Rb and ^{87}Sr. Its position on the diagram, however, strongly suggests that it has lost a considerable quantity of Rb, an observation which has no obvious explanation.

Table 3. Analytical data for Rb-Sr analyses of whole-rock samples from Kanektok complex core near Thumb Mountain.

Sample No.	Rock Type	Latitude ° N	Longitude ° W	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
DT 75-85	Garnet amphibolite	59.6483	161.2050	20.829	155.88	0.386897	0.711365
DT 75-86	Quartz monzonite gneiss	59.6483	161.2050	91.187	555.76	0.475359	0.717395
DT 75-88	Biotite granite gneiss	59.6450	161.1917	23.230	137.17	0.153951	0.717476
DT 75-91	Biotite granodiorite gneiss	59.6450	161.1933	92.27	889.33	0.300363	0.709336
DT 75-94	Plagioclase-biotite-muscovite-epidote rock	59.6383	161.1950	54.371	435.78	0.361275	0.711981
DT 75-98	Garnet amphibolite	59.6267	161.2033	21.525	261.77	0.238006	0.707776
DT 75-100	Garnet epidote amphibolite	59.6250	161.2033	7.254	262.27	0.080063	0.708632
DT 75-83-1	Hornblende biotite granodiorite gneiss	59.6500	161.2083	38.627	847.33	0.131922	0.705760
DT 75-97	Garnet amphibolite	59.6283	161.2033	8.4709	209.92	0.116853	0.712313
DT 75-82	Hornblende biotite granodiorite gneiss	59.6500	161.2100	38.873	858.63	0.1310013	0.7047931
DT 75-83-2	Biotite amphibolite	59.6500	161.2083	21.0418	390.90	0.155775	0.705722
DT 75-87	Biotite granodiorite gneiss	59.6450	161.1917	45.708	638.65	0.207171	0.708520
DT 75-92	Plagioclase-biotite epidote rock	59.6433	161.1933	66.309	726.90	0.264042	0.708012

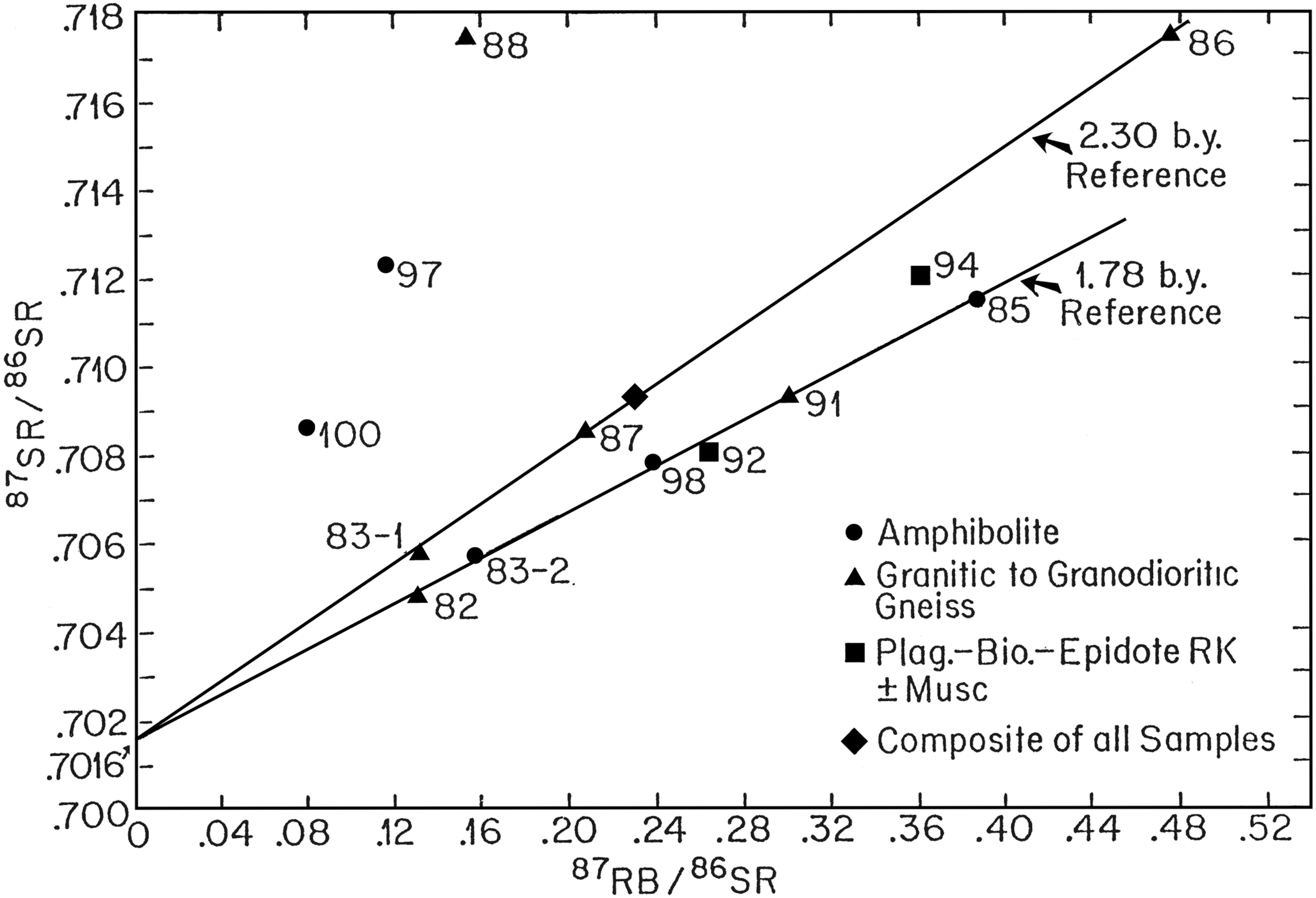

Figure 10. Rb-Sr diagram for 13 whole-rock samples of Kanektok core zone amphibolite facies rocks collected along a 2.5 mile traverse in the Thumb Mountain area (fig. 3).

U-Th-Pb Results

Zircon and sphene were separated from an orthogneiss (sample DT 75-86) from the Thumb Mountain core zone area of the Kanektok complex (fig. 3). The gneiss is granitic in composition and is composed primarily of quartz, pink orthoclase and biotite. The zircons are generally euhedral and clear, with length to width ratios of about 3:1. Although some grains are cracked and broken, most appear to have remained idiomorphic.

Standard isotope dilution techniques for U and Pb (modified from Krogh, 1973), were performed by Aleinikoff on three size fraction splits of the zircons (table 4). $^{207}Pb/^{206}Pb$ ages in all three splits are identical (2.05 Ga) and the Pb/U ages vary only slightly (from 1,610 to 1,834 Ma). The uranium concentrations, which range from 375 to 414 ppm, are fairly low and thus the crystals are not metamict. The low uranium concentrations have caused little damage to the crystal lattices, and therefore, the structures have remained essentially impermeable to leaching fluids until very recent time. A concordia plot (fig. 11) with a best-fit line calculation (Ludwig, 1980) indicates that the orthogneiss protolith crystallized about 2.05±0.03 Ga. Although the rock was subsequently metamorphosed to amphibolite grade, this event is not recorded in the zircon data. Modern lead loss due to dilatancy (Goldich and Mudrey, 1972) has moved the data points down a discordia towards the present.

A sphene fraction from the same sample of orthogneiss was analyzed for U, Th, and Pb isotopes in order to determine the age of metamorphism of the Kanektok complex (table 4). Sphene ages are known to be more susceptible to resetting by thermal metamorphism than are zircon ages, but are more resistant than biotite and hornblende K-Ar ages (Hanson and others, 1971). Thus, we interpret the U-Pb data from the sphene as indicating that the amphibolite-grade metamorphism occurred about 1.77 b.y. ago ($^{207}Pb/^{206}Pb$ age). The high Pb/Th age cannot be explained on geologic grounds, but may have been caused by loss of some Th during dissolution of the sample in the laboratory.

Summary and Conclusions

The Kanektok complex of southwestern Alaska appears to be a rootless terrane of early Proterozoic sedimentary, volcanic, and intrusive rocks which were metamorphosed to amphibolite and granulite fades and later underwent a pervasive late Mesozoic thermal event accompanied by granitic plutonism and greenschist facies metamorphism of overlying sediments. Although the terrane exhibits characteristics generally attributed to mantled gneiss domes, field mapping and geophysical studies by Hoare and Coonrad (1979) suggest that the complex is rootless and thrust over much younger rocks.

Table 4. U, Th, and Pb isotopic data for zircon and sphene from quartz monzonite orthogneiss near Thumb Mountain.
[Sample locality latitude 59° 38.9’ N, longitude 161° 12.3’ W. * Atomic percent is blank corrected.
$^{235}U/^{238}U = 1/137.88$, $\lambda_{235} = 0.98485 \times 10^{-9}$/yr, $\lambda_{238} = 0.155125 \times 10^{-9}$/yr, $\lambda_{232} = 0.049475 \times 10^{-9}$/yr (Steiger and Jager, 1977)]

	Concentration (ppm)			**Atomic percent***				**Ages (Ma)**			
Sample No.	**U**	**Th**	**Pb**	**^{204}Pb**	**^{206}Pb**	**^{207}Pb**	**^{208}Pb**	**$^{206}Pb/^{238}U$**	**$^{207}Pb/^{235}U$**	**$^{207}Pb/^{235}Pb$**	**$^{208}Pb/^{232}Th$**
DT 75-86											
Zircon (+150)	374.6		116.7	0.015	78.61	10.12	11.26	1610	1808	2046	
Zircon (-150 +200)	402.6		129.0	0.006	78.59	10.00	11.40	1653	1834	2046	
Zircon (-325)	414.2		132.3	0.002	78.17	9.90	11.91	1642	1827	2046	
Sphene	8.4	18.6	16.6	1.075	30.43	17.97	50.52	1751	1761	1774	2408

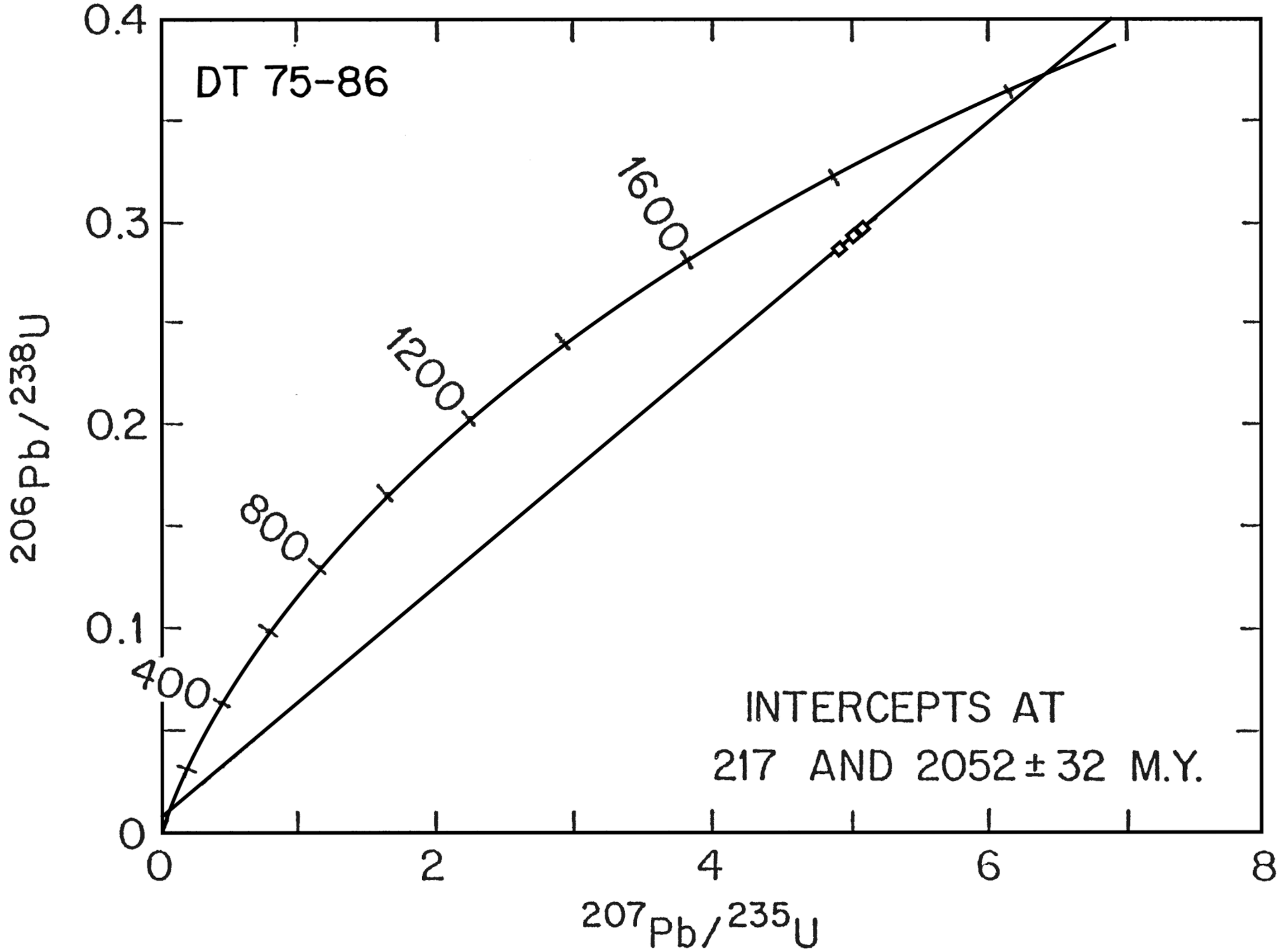

Figure 11. Concordia plot of 3 size fraction splits of zircons from core zone orthogneiss sample DT 75-86 from the Thumb Mountain area (fig. 3).

The granitic gneisses of the Kanektok complex are assigned an intrusive age of 2.05±0.03 Ga. They were metamorphosed about 1.77 b.y. ago, and have not suffered severe deformation since then. The early Proterozoic age for the protolith of the orthogneisses is similar to recently determined ages from the Yukon-Tanana Upland (Aleinikoff and others, 1981).[4] Although slightly older ages (2.1 to 2.3 Ga) are present in the Upland, those ages are mostly derived from detrital zircons in metasediments and plutonic zircons with inheritance. Only one metarhyodacite (2.1 Ga) has been directly dated (Aleinikoff and others, 1986).

A Rb-Sr study of 13 whole-rock samples also suggests metamorphism of an early Proterozoic [Paleoproterozoic] protolith at 1.77 Ga, although the data are widely scattered and difficult to interpret. It is clear from the Rb-Sr data that Sr isotopes were not homogenized over the scale of sampling (2.5 miles) during the 1.77 Ga metamorphism.

Analysis of K-Ar mineral ages from 58 rocks indicate that nearly all of these ages have been totally or partially reset by a pervasive late Mesozoic thermal event. Several biotites gave apparent K-Ar ages over 2 Ga. These ages appear to be controlled by excess radiogenic ^{40}Ar produced by the degassing protolith during the 1.77 Ga metamorphism and incorporated by the biotites when they were at temperatures at which Ar could diffuse through the lattice.

Five amphibolites yielded apparent Precambrian ^{40}K/^{40}Ar ages. There is no evidence that these hornblende ages have been increased by excess argon. The oldest conventional ^{40}K/^{40}Ar hornblende age of 1.77 Ga is identical to the sphene ^{207}Pb/^{206}Pb orthogneiss age and to the Rb-Sr "isochron" age for six of the 13 whole-rock samples. The younger hornblende ages are interpreted as having been partially reset during the late Mesozoic thermal event. This event is believed to coincide with granitic plutonism and with the greenschist facies metamorphism of the marginal metasediments flanking the core zone of the complex.

^{40}Ar/^{39}Ar incremental heating experiments suggest metamorphism occurred at least 1.2 b.y. ago but do not exhibit high temperature plateau ages significantly older than the ^{40}Ar/^{39}Ar total fusion ages of these samples. The age spectra are much more uniform than expected from a terrane with such a complex thermal history. We suspect that this may be an experimental artifact perhaps caused by the fine grain size of the samples which may possibly be less than the effective Ar diffusion radii of the analyzed hornblendes.

The Kanektok complex comprises the Kilbuck tectonostratigraphic terrane of Jones and others (1981). The 1.77 Ga age of its high grade metamorphic rocks is significantly older than nearly all radiometric ages determined thus far for present Alaskan rock units. The age and lithology of this terrane appear to be unique in Alaska. These characteristics should prove useful in tectonic reconstructions aimed at finding the source region for this terrane prior to its migration to its present position in southwestern Alaska.

[4] The orthogneiss from the Yukon-Tanana Upland that the Turner and others manuscript mentions, citing Aleinikoff and others (1981) is now recognized as a metamorphosed 350 Ma pluton containing inherited zircons (Wilson and others, 1985; Aleinikoff and others, 1986).

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