Preliminary report on field investigations and argon-40/argon-39 geochronology of the Crary Mountains volcanoes, Marie Byrd Land, West Antarctica

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A field party of four geologists mapped and sampled volcanic outcrops in the Crary Mountains (76°45'S 117°00'W), Marie Byrd Land, during the 1992–1993 austral summer field season as part of the west antarctic volcano exploration (WAVE II) project. Our study objectives include the following:

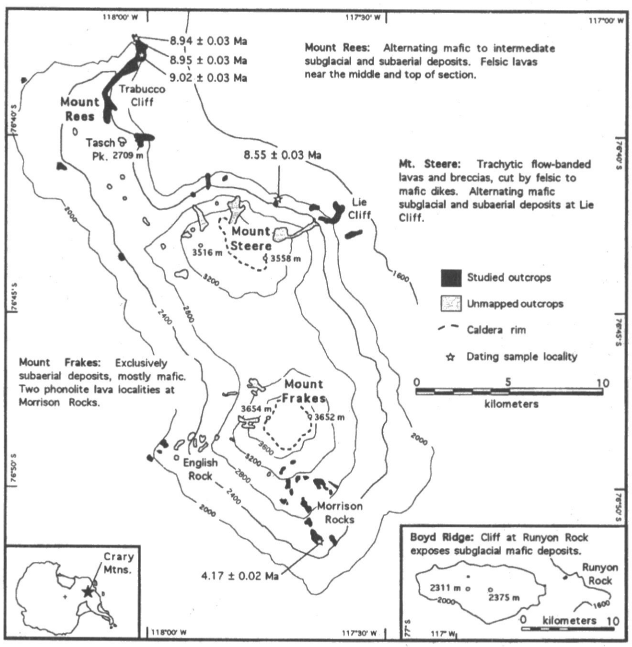
- to characterize the volcanic geology by field mapping, particularly to document and date radiometrically past magma-ice interactions;
- to build upon preliminary age and geochemical data from previous studies to develop a more thorough description of the volcanic evolution of the Crary Mountains; and
- to place the petrogenesis of the Crary Mountains in the broader context of Marie Byrd Land volcanism.

This article summarizes field observations and presents new argon-40/argon-39 ($^{40}Ar/^{39}Ar$) laser fusion dates from five samples.

The Crary Mountains consist of three main coalesced volcanoes, aligned from north-northwest to south-southeast: Mount Rees, Mount Steere, and Mount Frakes (figure). Southeast of these main volcanoes is Boyd Ridge, an east-west oriented, lower relief ridge with very limited rock exposures. The degree of dissection of the volcanoes increases to the north, with deep cirques cut into the east sides of both Mount Steere and Mount Rees. Previous geological investigations in the Crary Mountains are limited to 1 day of helicopter reconnaissance in 1968 (summarized by LeMasurier, Kawachi, and Rex 1990) and a brief visit by geologists during the Byrd geophysical traverse in 1960 (Doumani and Ehlers 1962). LeMasurier et al. (1990) reported four potassium-argon (K-Ar) radiometric dates: 9.6±1.0 million years for a Mount Steere trachyte; 8.35±0.3 million years for a Mount Steere basanite; 3.9±0.4 million years for a Mount Frakes phonolite; and 1.7±0.2 million years for basaltic parasitic cone at Mount Frakes. These preliminary studies described the Crary Mountains as late Miocene to early Pliocene shield volcanoes composed of bimodal alkaline lavas.

The late Miocene ages are similar to 8–9-million-year ages for lavas from Mount Murphy (75°20'S 111°W), where evidence of both syn- and posteruptive glacial activity has been described (LeMasurier, McIntosh, and Rex 1986; McIntosh, Smellie, and Panter 1991; our unpublished data). Basal stratigraphic sections at Mount Murphy contain numerous subglacial to periglacial volcaniclastic and lava deposits, tillites, and striated and polished surfaces. These syneruptive features have been inferred to indicate the presence of a continental ice sheet (LeMasurier et al. 1986) or an unstable, wet-based local ice cap (McIntosh et al. 1991) at Mount Murphy in the late Miocene. Glacially striated surfaces, located up to 900 meters (m) above present ice levels, have been interpreted as evidence for posteruptive overriding by the continental ice sheet (McIntosh et al. 1991). The late Miocene glaciovolcanic record at Mount Murphy provides a useful model for comparison to the Crary Mountains record.

During November and December 1992, we mapped outcrops on all four of the Crary Mountains volcanoes and collected a total of 195 samples for petrographic, geochemical, and $^{40}Ar/^{39}Ar$ dating analyses. Preliminary results from $^{40}Ar/^{39}Ar$ laser fusion dating analyses of anorthoclase feldspar crystals from five felsic lava samples are presented in the table and figure; preparations are underway to date an additional 90 samples using the same technique. Anorthoclase crystals were separated from crushed trachyte lava samples using standard magnetic and heavy liquid density techniques. Anorthoclase crystals were hand-picked from a large [2-centimeter (cm)] phenocryst in a phonolite sample. For our



Sketch map of three main volcanoes in Crary Mountains, with insets of the antarctic continent and Boyd Ridge. Base map in the Crary Mountains quadrangle (1973), scale 1:250,000 U.S. Geological Survey Reconnaissance Series, Antarctica, United States Geological Survey. Circles indicate elevation localities from U.S. Geological Survey base map. $^{40}Ar/^{39}Ar$ ages are described in text and table.

analyses, dating standards of Fish Canyon Tuff Sanidine (27.84 million years) were used to monitor the flux of fast neutrons during sample irradiation at the University of Michigan reactor. The irradiated feldspar crystals were fused by a carbon dioxide (CO_2) laser, and the argon-isotopic measurements were made in a Mass Analyzer Products model 215-50 mass spectrometer at the New Mexico Geochronology Research Laboratory at the New Mexico Institute for Mining and Technology. The $^{40}Ar/^{39}Ar$ technique, coupled with laser heating, a low blank extraction line, and a highly sensitive mass spectrometer, offers advantages over conventional K-Ar dating; for example, this technique has the ability not only to date very small samples [less than 1 milligram (mg)] but also to increase the level of precision tenfold.

$^{40}Ar/^{39}Ar$ laser dating results

Sample I.D.	Moles ^{39}Ar (rad)	$\%^{40}Ar$	Age	±	1 s.d.
TW92175-1	8.07E-12	98.3	9.00	±	0.05
TW92175-2	1.21E-11	96.9	8.97	±	0.04
TW92175-3	9.31E-12	96.9	8.83	±	0.04
TW92175-4	6.40E-12	96.9	8.95	±	0.06
TW92175-5	6.35E-12	96.5	8.95	±	0.07
TW92175-6	6.08E-12	97.3	8.99	±	0.07
TW92175-7	6.25E-12	96.8	8.93	±	0.06
TW92175-8	4.69E-12	97.1	8.90	±	0.08
TW92175-9	7.23E-12	97.3	9.02	±	0.06
		Mean ± SEM	8.95	±	0.03
TW92174-1	5.95E-12	98.9	9.04	±	0.07
TW92174-2	8.02E-12	98.6	8.85	±	0.05
TW92174-3	1.22E-11	99.0	8.96	±	0.03
TW92174-4	7.82E-12	98.7	8.94	±	0.05
TW92174-5	1.07E-11	98.8	8.91	±	0.04
TW92174-6	1.53E-11	98.9	8.86	±	0.03
TW92174-7	2.74E-11	98.9	8.97	±	0.03
TW92174-8	1.98E-11	98.8	9.03	±	0.03
		Mean ± SEM	8.94	±	0.03
TW92015-1	8.34E-12	98.4	9.11	±	0.06
TW92015-2	1.55E-11	98.7	9.06	±	0.03
TW92015-3	1.39E-11	98.9	9.06	±	0.03
TW92015-4	1.77E-11	98.7	8.99	±	0.03
TW92015-5	2.36E-11	99.0	8.97	±	0.02
TW92015-6	9.97E-12	98.2	8.97	±	0.03
TW92015-7	1.51E-11	98.5	9.02	±	0.03
TW92015-8	2.31E-11	98.1	8.97	±	0.02
		Mean ± SEM	9.02	±	0.03
TW92122-1	1.17E-11	84.1	4.16	±	0.04
TW92122-2	1.38E-11	89.8	4.20	±	0.02
TW92122-3	1.20E-11	90.5	4.11	±	0.03
TW92122-4	7.43E-12	87.8	4.14	±	0.04
TW92122-5	1.15E-11	87.0	4.22	±	0.04
TW92122-6	9.52E-12	92.2	4.15	±	0.03
TW92122-7	8.47E-12	89.3	4.11	±	0.04
TW92122-8	7.18E-12	87.2	4.27	±	0.05
		Mean ± SEM	4.17	±	0.02
TW92178-1	1.78E-11	98.6	8.55	±	0.03
TW92178-2	1.66E-11	98.9	8.53	±	0.03
TW92178-3	2.66E-11	98.0	8.62	±	0.02
TW92178-4	2.49E-11	98.4	8.59	±	0.02
TW92178-5	2.55E-11	97.8	8.58	±	0.02
TW92178-6	2.41E-11	97.0	8.49	±	0.02
TW92178-7	3.00E-11	98.6	8.52	±	0.02
TW92178-8	3.10E-11	95.8	8.52	±	0.02
		Mean ± SEM	8.55	±	0.03

Analytical uncertainties in individual ages are reported at one sigma level, without regard to uncertainty in J-value. Uncertainties in mean ages are based on the sums of standard error of the mean (SEM) and a 0.25 percent error associated with J-value.

Mount Rees (2,709 m) lies at the north end of the range and is the most dissected of the three main volcanoes. Well-exposed stratigraphic sections at Trabucco Cliff and the ridge east of Tasch Peak consist mostly of mafic to intermediate volcanic rocks with subordinate interlayered felsic lavas. The mafic to intermediate rock outcrops are characterized by two alternating lithofacies: unbrecciated lavas with oxidized bases and palagonitized glassy hyaloclastite breccias and pillow lavas. These alternating sequences are inferred to represent fluctuations between "dry" subaerial and "wet" subglacial eruption conditions. No tillites or glacially striated surfaces (both associated with wet- or warm-based glaciations) were observed within the subglacial volcanic sequences.

Anorthoclase feldspar separates from three subaerial felsic lavas in the middle and top of the Trabucco Cliff section were dated by the $^{40}Ar/^{39}Ar$ laser fusion technique. Eight multiple anorthoclase crystal subsamples from the middle of the stratigraphic section (TW92015) yielded a mean age of 9.02±0.03 million years. Analyses of two samples from the top of the stratigraphic section resulted in mean ages of 8.94±0.03 million years and 8.95±0.03 million years (based on eight anorthoclase subsample analyses of TW92174 and nine of TW92175). These age determinations record the rapid accumulation of the Trabucco Cliff section at 9.0 million years. We infer that there were repeated fluctuations in the extent of ice cover at this time because the coeval felsic lavas bracket numerous alternating subglacial and subaerial deposits.

Mount Steere is a trachytic volcano that has an intact caldera at 3,558 m above sea level (1,900 m above present ice level). The northeast flank is deeply dissected by cirques, which expose characteristic felsic flow-banded lavas and breccias, cut by numerous felsic to mafic dikes. Lie Cliff and the ridge exposures just north and south of the cliff section contain basal Mount Steere exposures, which are dominated by basanite deposits near the base and trachytic lavas near the top. The basanite outcrops at and near Lie Cliff resemble the glaciovolcanic sequences at Mount Rees, with alternating subglacial and subaerial volcanic deposits and no syneruptive tillites or striated surfaces. A glacial moraine composed of heterolithic igneous boulders is present on the north side of Mount Steere but is attributed to posteruptive, cold-based alpine glaciation localized at Mount Steere.

A trachyte lava outcrop on the north side of Mount Steere was dated by the $^{40}Ar/^{39}Ar$ laser fusion technique. Eight subsamples of multiple anorthoclase crystals yielded a mean age of 8.55±0.02 million years. On the basis of two K-Ar dates of 9.6±1.0 million years and 8.35±0.3 million years, LeMasurier et al. (1990) suggested that more dating is required to resolve the chronology at Mount Steere. The potential to improve the precision of the Mount Steere chronology is indicated by our preliminary $^{40}Ar/^{39}Ar$ age data.

Mount Frakes rises to an intact circular caldera at 3,654 m above sea level, (2,000 m above present local ice level). It is the least dissected of the three main volcanoes, with apparently noneroded flank slopes of 12–18°. Outcrops at Mount Frakes are concentrated at Morrison Rocks on the south side and English Rock on the west side. The lithologies of the more than 20 outcrops at Morrison Rocks appear to be bimodal, consisting of olivine-bearing basanite and subordinate porphyritic phonolite. A mean age of 4.17±0.02 million years for the Morrison Rocks phonolite was obtained from eight laser fusion analyses of populations of 2–3 anorthoclase crystals per analysis. This age is consistent with a K-Ar age of 3.9±0.4 million years reported by LeMasurier et al. (1990) for nepheline and anorthoclase from the same outcrop.

Only subaerially erupted rocks were observed in outcrop at Mount Frakes. The absence of glaciovolcanic sequences at Mount Frakes may simply be a result of the lack of dissection. Plutonic and volcanic boulders are present on the surface up to 3,200 m above sea level (1,600 m above present ice level); most appear to be volcanic xenoliths, although it is possible that some are glacial erratics deposited by the continental ice sheet. The absence of glacial tillites and cirques suggests that the cirque-cutting at Mount Steere and Mount Rees occurred between the eruption of Mount Steere (8.55 million years) and Mount Frakes (4.17 million years).

Boyd Ridge is a gently sloping east-west oriented ridge that is almost entirely ice-covered (figure, inset). We examined two outcrops located at the east end of the ridge: a small surface exposure of basaltic cinders and a more extensive cliff section at Runyon Rock. Runyon Rock includes approximately 150 m of clast-rich basaltic hyaloclastite, which is mostly massive and strongly palagonitized in places. The base of the section includes a debris flow dominated by felsic lava boulders. We observed no syn- or posteruptive glacial tillites or striated surfaces.

In summary, the Crary Mountains are late Miocene to Pliocene alkaline volcanoes. The first major pulse of volcanism was the formation of Mount Rees and Mount Steere between 9.02 and 8.55 million years. The stratigraphy at Mount Rees suggests that there was a fluctuation in composition among mafic basanite, intermediate hawaiite, and felsic trachyte. Mount Steere appears to have evolved from subordinate basanite in the basal succession to dominant trachyte for most of the volcano.

The second pulse of volcanism occurred at Mount Frakes at 4.17 million years and is characterized by phonolite lavas. A later stage of parasitic mafic volcanism at 1.7 million years was defined by LeMasurier et al. (1990). Future laser fusion analyses of other Mount Frakes mafic lavas will clarify whether all of the mafic volcanism was late Pliocene in age. No age or geochemical data have yet been obtained from the Boyd Ridge outcrops. Preparations are underway for petrographic, geochemical, and/or geochronological analyses of all of the Crary Mountains samples.

The syn- and posteruptive glacial records at the Crary Mountains contrast sharply with coeval records from Mount Murphy. We interpret alternations between "dry" and "wet" eruption conditions at the Crary Mountains as fluctuations in the extent of cold-based ice during the late Miocene. We are uncertain whether these fluctuations are related to changes in the level of the west antarctic ice sheet or simply reflect changes in the extent of ice or snow on the flanks of the erupting volcanoes. The lack of striated glacial unconformities and tillites precludes the presence of syneruptive warm-based glacial ice, as was inferred for Mount Murphy during this interval. The difference in basal ice conditions during the late Miocene can possibly be explained by geographic differences: Mount Murphy is a coastal volcano with lower elevation glaciovolcanic sequences (300–1,800 m above sea level); the Crary Mountains are inland volcanoes with higher elevation glaciovolcanic sequences (1,600–3,600 m above sea level). In addition, there is no evidence that the Crary Mountains have ever been overridden by warm-based ice. The last interval of significant glacial erosion was the cirque cutting of Mount Rees and Mount Steere, apparently between 8.55 and 4.17 million years.

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References

Doumani, G.A., and E.G. Ehlers. 1962. Petrography of rocks from mountains in Marie Byrd Land, West Antarctica. *Geological Society of American Bulletin*, 73(7), 877–882.

LeMasurier, W.E., Y. Kawachi, and D.C. Rex. 1990. Crary Mountains. In W.E. LeMasurier and J.W. Thomson (Eds.), *Volcanoes of the antarctic plate and southern oceans* (Antarctic Research Series, Vol. 48). Washington, D.C.: American Geophysical Union.

LeMasurier, W.E., W.C. McIntosh, and D.C. Rex. 1986. Miocene glacial history recorded at Mount Murphy volcano in eastern Marie Byrd Land. *Antarctic Journal of the U.S.*, 21(5), 52–54.

McIntosh, W.C., J.L. Smellie, and K.S. Panter. 1991. Glaciovolcanic interactions in eastern Marie Byrd Land, Antarctica. In *Abstracts—Sixth International Symposium on Antarctic Earth Sciences.* Saitama, Japan: National Institute of Polar Research.