Antarctic Science 1 (4): 345–350 (1989)

Geology and geochronology of McMurdo Volcanic Group rocks in the vicinity of Lake Morning, McMurdo Sound, Antarctica

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Abstract: Trachyandesite lava flows and trachytic dykes exposed at 'Gandalf Ridge' and near Lake Morning on the northern slopes of Mount Morning represent the oldest exposed volcanic rocks in the Erebus volcanic province of the McMurdo Volcanic Group. Conventional whole rock K-Ar age determinations show the rocks are mid-Miocene, ranging between 14.6 and 18.7 Ma. North–south trending faults, which parallel the Transantarctic Mountains, cut the dated dykes. The faults are probably part of a broad fault zone which bounds the uplifted Transantarctic Mountains and the down-dropped Ross Sea/Ross Ice Shelf embayment.

Received 29 July 1988, accepted 11 September 1989

Key words: Erebus volcanic province, K-Ar ages, late Cenozoic, undersaturated alkali volcanic rocks.

Introduction

Mount Morning is a large 2723 m high volcano situated to the south of the Koettlitz Glacier and east of the Royal Society Range, in southern Victoria Land (Fig. 1). The south side of the volcano is almost completely snow and ice covered, whereas on the northern slope, two extensive snow free areas extend from the summit to the Koettlitz Glacier.

Preliminary investigations of the northern slope of Mount Morning were prompted by a report, based on an aerial infrared survey, of an anomalously warm area (W.E. Burge & D.C. Parker, unpublished information 1969), suggestive of recent volcanic activity. A detailed ground search did not, however, confirm any geothermal activity or evidence of volcanism in the recent past. During the preliminary investigations, reconnaissance geologic mapping was undertaken and identified some volcanic rocks at 'Gandalf Ridge' (unofficial name), apparently much older than the bulk of Mount Morning. This paper gives a brief description

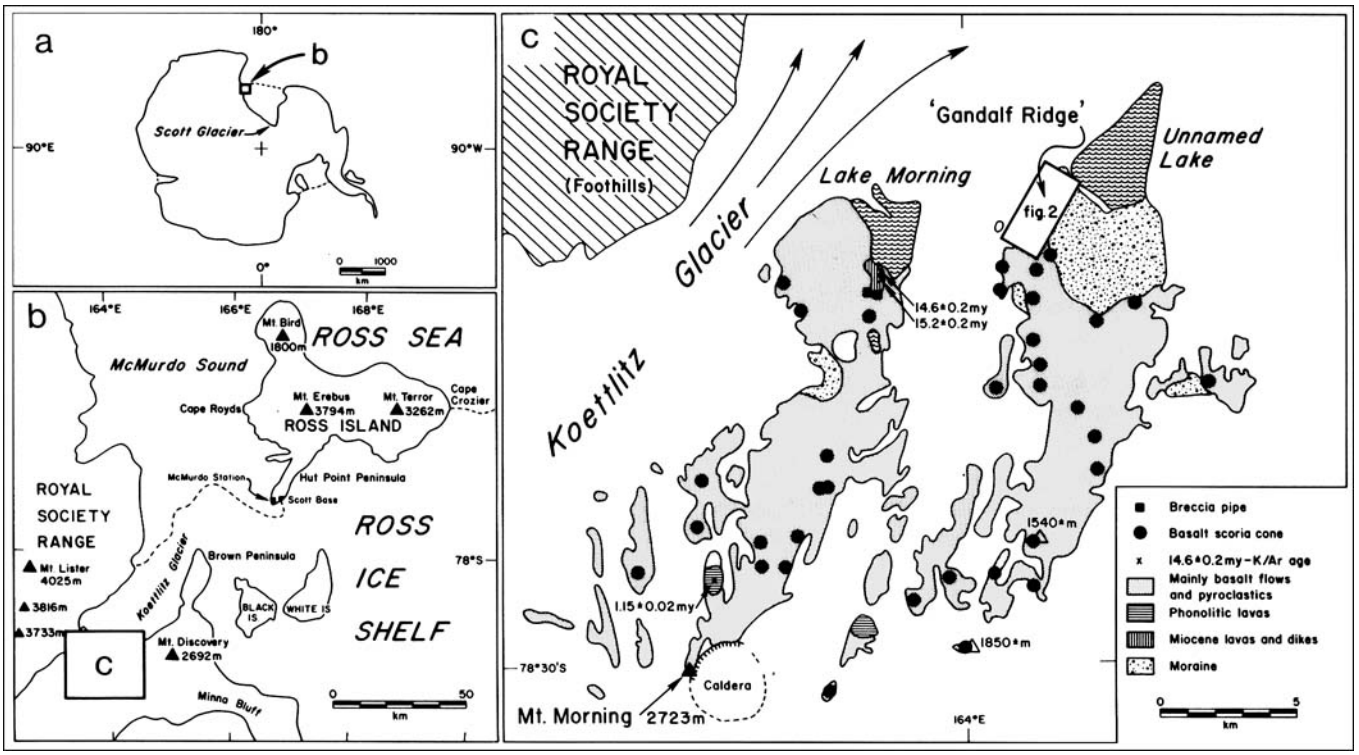

Fig. 1. Generalized reconnaissance geological sketch map of the northern slopes of Mount Morning. 'Gandalf Ridge' is an unofficial place name but was submitted to the US Board on Geographic Names for formal approval in July 1989.

of the geology of Mount Morning and describes in detail the rocks from 'Gandalf Ridge'.

Undersaturated alkali volcanic rocks of late Cenozoic age in the McMurdo Sound area constitute the Erebus volcanic province of the McMurdo Volcanic Group (Kyle & Cole 1974, Kyle, in press). The rocks of the Erebus volcanic province are mainly strongly undersaturated, ranging in composition from basanite (basanitoid) to phonolite. Two differentiation trends called the DVDP (for the Dry Valley Drilling Project) and Erebus lineages, have been recognized on the basis of geochemical and petrographic data (Kyle 1981, Kyle *et al.* in press).

Geology of Mount Morning

Mount Morning is a large shield volcano with a prominent summit caldera, about 4 km in diameter and with a youthful appearance. The volcano is mainly undissected so the internal composition is only poorly known. The low angle of slope suggests it is mainly basaltic; however, outcrops at the summit are mainly phonolitic (Wright-Grassham 1987). Basaltic scoria cones are numerous over most of the exposed northern slope (Fig. 1). The cones commonly have breached craters and are surrounded by aprons of thin lava flows. Phonolite domes are less numerous and occur mainly around the summit (Fig. 1). They are light in colour and irregular in form and may have developed by endogeneous growth. Lava flows of probable intermediate composition are rare.

A phonolite cone from near the summit has a K-Ar age of 1.15 ± 0.02 Ma (Armstrong 1978) and gives a minimum age for the formation of the main shield. Stuiver & Braziunas (1985) in their tabulation of K-Ar age determinations quoted ages ranging from 1.0 to 2.4 Ma for Mount Morning. Many of the basalt cones are extremely fresh and show no evidence of weathering or alteration. They could be less than 100 000 years old.

Field relationships at 'Gandalf Ridge'

'Gandalf Ridge' (Fig. 2) is a 2.5 km long ridge which trends NNE and is situated 5 km east of Lake Morning (Fig. 1). The ridge has a subdued smooth rounded appearance and rises a maximum of about 150 m above the surrounding area. It is bounded to the east by moraine, and to the north and west by ice. Younger basaltic scoria cones overlie the older volcanic rocks to the south.

Basement rocks

Granitic intrusive rocks enclosing sheets or screens of metasedimentary schists are exposed in a small valley located transversely across the southern end of 'Gandalf Ridge' and along the eastern flank of the ridge. The granite is a greyish white, medium-grained rock consisting predominantly of quartz, orthoclase, and biotite and is similar to intrusions around the head of the Koettlitz Glacier which have been termed the Crag Granite by D.N.B. Skinner (personal communication 1978) or the Anthill Limestone (Gunn & Warren 1962), both of which are part of the Skelton Group.

The occurrence of basement rocks at Mount Morning increases the known extent of lithologies similar to those in the Royal Society Range foothills. The Transantarctic Mountains Range is probably bounded to the east by a major fault or fault zone (Kyle & Cole 1974, Fitzgerald *et al.* 1986). Near Mount Discovery, the trend of the range shows a marked change which seems to coincide with the large volcanic centres of Mount Morning and Mount Discovery. The basement rocks at 'Gandalf Ridge' constrain the position of any major fault(s) and extends to the south the flexure point in the trend of the Transantarctic Mountains front.

Trachyandesite and dyke complex

A highly sheared and jointed trachyandesite unconformably overlies the basement and forms the majority of the exposed rock at 'Gandalf Ridge'. The trachyandesite appears to be a pile of thick flows which have been extremely broken up and altered. The pile is approximately 100 m thick and dips gently northward. The lavas show relict flow banding and contain vugs commonly filled with zeolite.

Quartz trachyte and oversaturated peralkaline trachyte dykes intrude the trachyandesite and are the cause of its highly sheared and brecciated nature. The dykes are best exposed at the northern end of the ridge where they generally trend E–W. The dykes are steeply dipping, vary in width from 0.2 m to 10 m, and are irregularly spaced. Most of the dykes are porphyritic with large phenocrysts of feldspar but some finer grained types also occur.

Lava flows

At the southern end of 'Gandalf Ridge', thin (up to 1 m thick) lava flows of trachyte are poorly exposed and covered by scree from the nearby young basanite cones. The flows are chemically similar to the dyke complex and are considered to be remnants of the volcano which once overlay the area.

Breccia

A breccia or diamictite disconformably overlies the trachyandesite and dyke complex. This unit is best exposed near the centre of 'Gandalf Ridge' close to its highest point. It forms a horizontal or near-horizontal tabular unit with a minimum thickness of 20 m, and caps part of the ridge. The

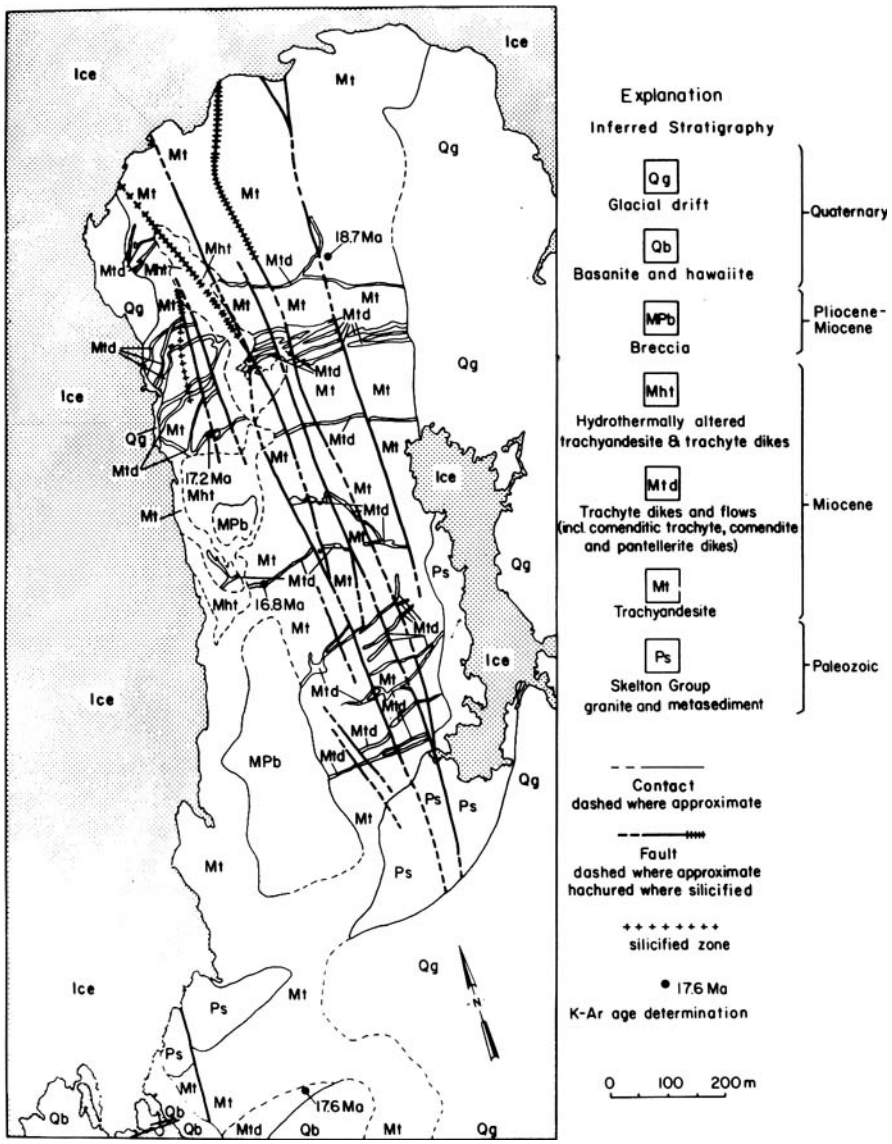

Fig. 2. Geological sketch map of 'Gandalf Ridge'.

clasts are highly angular to sub-rounded, occasionally exceed 5 m in size, and all are volcanic, mainly peralkaline trachyte or porphyritic trachyandesite. The matrix is exceedingly altered and weathered and supports the clasts. The breccia is believed to have originated as a mudflow.

Faulting

At 'Gandalf Ridge' N–S trending faults are roughly parallel to the ridge and cut basement rocks and the trachyandesite and dyke complex. The amount of displacement and relative movement along the faults could not be determined due to:

a. lack of correlation between dykes across the fault planes,
b. limited rock exposure due to ice cover, and
c. the extremely broken up and altered nature of the trachyandesite and dyke complex.

The faulting may be local, associated with Mount Morning volcanism, or of regional significance, being associated with the uplift of the nearby Transantarctic Mountains.

Hydrothermal zones

Zones of intense hydrothermal alteration and silicification occur throughout 'Gandalf Ridge'. These zones are commonly associated with the N–S trending faults which apparently provided paths for the migration of hydrothermal fluids. Some of the hydrothermal zones extend for almost the whole length of the ridge. The zones vary in width from a few cm to an area approximately 125 m wide and 200 m long, located near the centre of 'Gandalf Ridge'. Silicification is the most common hydrothermal alteration.

Lake Morning

The area south-west of Lake Morning is composed mainly of basaltic scoria cones and some intermediate differentiates. Compared to the upper slopes of Mount Morning the rocks are more dissected, possibly due to erosion by the Koettlitz Glacier. They are, however, considered to be equivalent in age and are likely to have formed the main shield-building phase of volcanism. Older quartz trachyte and peralkaline silicic flows and dykes are exposed near the south-western and western (Wright-Grassham 1987) shores of Lake Morning. These flows and dykes are very similar in appearance to those at 'Gandalf Ridge'. Two breccia pipes or possibly vent breccias intrude or overlie the quartz trachyte and over-saturated peralkaline flows. The pipes form resistant spines which, because of their ochre colour, makes them very distinctive against the reddish-black basaltic rubble. The largest pipe is about 100 m in diameter and rises about 150 m above the surface. Clasts within the pipes range from less than a few mm to over 4 m in diameter. The clasts vary from angular to rounded and appear to be composed mainly of trachyte.

K-Ar age determinations

Analytical methods

Six samples were dated by the conventional K-Ar dating method in the K-Ar laboratory at Ohio State University. Whole rock samples were used and ground –80 to +100 mesh and then washed with HCl, acetone and distilled water. Potassium concentrations were determined in duplicate, on a –100 mesh sample using the method of Cooper (1963), in which the alkalis are chemically separated, and then measured using a Zeiss PF-5 flame photometer. Duplicate analyses of the last 100 analyses in the laboratory have a pooled coefficient of variation of 0.5%. The Ar was extracted on the –80/+100 mesh fraction, using the extraction techniques described by Dalrymple & Lanphere (1969). Isotopic analyses of the Ar were made using a Nuclide Corporation model SGA 660 mass spectrometer operated in the static mode. Radiogenic ^{40}Ar concentrations were measured by isotope dilution using a manifold type (batch) ^{38}Ar tracer. Analytical precision of the Ar analyses is better than 1%.

Results

At 'Gandalf Ridge' the trachyandesite has an age of 18.7 ± 0.3 Ma (Table I). Using the Critical Value Test (CVT) of Dalrymple & Lanphere (1969) the peralkaline dykes, which intrude the trachyandesite and have ages of 17.2 ± 0.2 Ma and 16.8 ± 0.3 Ma (Table I), are significantly younger. A dyke sample (25799), collected by P. Kyle from 'Gandalf Ridge', was dated by Armstrong (1978) as 15.5 ± 0.5 Ma. Although Armstrong's date is statistically younger than those reported here, according to the CVT, the difference may be due to analytical biases of the two laboratories involved, rather than being geologically meaningful.

A comendite lava flow at the south end of 'Gandalf Ridge' gave an age of 17.56 ± 0.56 Ma, statistically in the same range as the dykes to the north.

At Lake Morning a quartz trachyte lava flow, 15.19 ± 0.20 Ma old, is cut by a comendite dike, dated at 14.63 ± 0.21 Ma. Although the dyke is younger, in agreement with the stratigraphy, the date is statistically similar to the lava flow using the CVT. West of Lake Morning, basanite to trachyte flows are dated between 13.0 and 14.1 Ma (Wright-Grassham 1987). The Lake Morning volcanic rocks are younger and less deeply eroded than those at 'Gandalf Ridge'.

Inception of volcanism

The dates reported here (Table I) are the oldest from the Erebus volcanic province of the McMurdo Volcanic Group and establish a new minimum age for the inception of volcanism. The dated samples indicate that there was an extensive period of volcanism at Mount Morning which commenced in the early Miocene (18.7 Ma ago) and lasted until 13.0 Ma ago.

Evidence for earlier episodes of volcanism are recorded in drill cores from McMurdo Sound. In the lower 25 m of the 227 m deep MSSTS-1 drill hole, volcanic sands exceed 30% of the sand fraction (Barrett *et al.* 1986). Microfossil data suggest an age of 28 to 30 Ma for the interval. Gamble *et al.* (1986) reported K-Ar dates of 13.7 and 24.3 Ma on basaltic clasts from a depth of 213 m. The discordance between the radiometric and palaeontological age determinations was blamed on partial argon loss from the basalt. In the upper 60 m of the MSSTS-1 core there is abundant volcanic debris. Microfossil data indicate that the debris appeared during the early Miocene (21 Ma ago).

In the CIROS-1 drill hole volcanic glass occurs throughout much of the 702 m depth (Barrett, 1987; A. George, personal communication 1987). An early Oligocene age (33–38 Ma) has been assigned to core from the bottom of the hole. The greatest influxes of volcanic debris occurred in the upper 300 m of CIROS-1. Core from 300 m depth correlates with the base of MSSTS-1 (Barrett 1987) and is probably about 30 Ma old.

Most of the exposed McMurdo Volcanic Group rocks in southern Victoria Land have been examined and dated in a reconnaissance manner (Kyle, in press). Therefore, it is unlikely that exposed rocks older than those at 'Gandalf Ridge' will be found. Although volcanogenic sediments range back to perhaps 40 Ma, the greatest influxes occurred less than 21 Ma ago. The evidence from 'Gandalf Ridge' and Lake Morning of widespread and continuous volcanism

Table I. K-Ar age determinations for rocks from Mount Morning area, Antarctica.

Sample	Locality and description	%K		Moles rad. Ar/g × 10^{-10}		% rad. ^{40}Ar	Age[1] × 10^6 yr
77M41	Trachyandesite at 'Gandalf Ridge'	1.94 1.93	1.94	0.631 0.633	0.632	67.3 73.2	18.73 ± 0.32
77M04	Comenditic trachyte dyke cutting trachyandesite at 'Gandalf Ridge'	4.49 4.42	4.45	1.344 1.328	1.336	36.9 36.5	17.23 ± 0.21
77M62	Comenditic trachyte dyke cutting trachyandesite at 'Gandalf Ridge'	4.18 4.20	4.19	1.229 1.224	1.227	53.3 68.6	16.79 ± 0.27
25799[2]	Trachyte dyke cutting trachyandesite at 'Gandalf Ridge'	4.21 4.23	4.22	1.178 1.147	1.162	24.0 23.0	15.5 ± 0.5
77M45	Comendite flow at south end of 'Gandalf Ridge'	4.30 4.29	4.30	1.296 1.333	1.314	30.2 32.6	17.56 ± 0.56
77M81	Quartz trachyte flow at Lake Morning	4.61 4.58	4.59	1.224 1.206	1.215	85.3 77.9	15.19 ± 0.20
77M84	Comendite dyke cutting quartz trachyte flows at Lake Morning	4.27 4.27	4.27	1.101 1.075	1.088	79.0 66.1	14.63 ± 0.21

[1] Constants used: $1/\lambda = 1.804 \times 10^9$ yr,
$\lambda_e/\lambda_\beta = 0.1171$,
$40_{K/K_{total}} = 1.167 \times 10^{-4}$ atom/atom
Error estimate reflects analytical precision only: calculated in a manner similar to that described by Cox & Dalrymple (1967).

[2] Sample analysed by Armstrong (1978); and recalculated using decay constants given above.

commencing about 19 Ma ago agrees well with the drill core data.

Stump *et al.* (1980) reported K-Ar age determinations, ranging from 19.21 ± 0.39 Ma to 15.45 ± 0.19 Ma on five volcanic samples from the head of Scott Glacier (Fig. 1). In northern Victoria Land, Mueller *et al.* (1988) have dated small stocks of peralkaline granite as between 18 and 25 Ma, and peralkaline trachyte dykes on the Malta Plateau range from 14 to 18 Ma.

Alkaline magmatism of the McMurdo Volcanic Group apparently commenced or became more widespread and extensive in the early Miocene, between 19 and 25 Ma ago. The similarity of ages for volcanic rocks from three areas, which are located on or adjacent to the Transantarctic Mountains and span a distance of 1500 km, may represent a regional tectonic event. The volcanism could coincide with increased extension in the Ross embayment and the early development of the Terror Rift in the Victoria Land Basin (Cooper *et al.* 1987).

Geological history of Mount Morning

The occurrence of peralkaline lava flows at 'Gandalf Ridge' and Lake Morning and the extensive dyke complex at 'Gandalf Ridge' suggest the area was once the site of a major peralkaline volcano. The dykes are interpreted to be part of a subvolcanic dyke complex which presumably acted as a feeder to overlying volcanic vents. Extensive erosion has occurred to expose the sequence and probably accounts for the subdued topography of 'Gandalf Ridge'. The present day extent of the lava flows is insufficient to allow a detailed reconstruction of the morphology of the volcanic complex. However, it is likely that erosion has removed at least several hundred metres of volcanic rocks.

The 'Gandalf Ridge' faults are approximately parallel to the front of the nearby Transantarctic Mountains, as are faults mapped by D.N.B. Skinner (personal communication 1978) along the foothills of the Royal Society Range. Together these faults may comprise part of a wide fault zone adjacent to the Transantarctic Mountains.

K-Ar dates on rocks cut by the 'Gandalf Ridge' faults, along with the fact that the faults do not cut the younger basanite to the south, suggest a Neogene age for the faults. We believe this to be some of the first documented evidence of Neogene faulting in terrestrial rocks in the Ross Sea area.

Conclusions

Trachyandesites, quartz and peralkaline trachytes from 'Gandalf Ridge' range from 14.6 to 18.7 Ma and are the

oldest rocks of the McMurdo Volcanic Group exposed in the Erebus volcanic province. Over the last decade most exposures of the McMurdo volcanic rocks in the McMurdo Sound area have been examined and dated (Armstrong 1978, Wright-Grassham 1987), but all are younger than those at 'Gandalf Ridge'. It is unlikely that extensive areas of McMurdo volcanic rocks older than 'Gandalf Ridge' will be found exposed on-shore. However, the presence of minor volcanic detritus in drill cores from McMurdo Sound ranging back to over 35–40 Ma ago shows that volcanism commenced considerably earlier. It is therefore likely that volcanic centres are buried beneath the East Antarctic Ice Sheet behind the Transantarctic Mountains or in sediments within the western Ross Sea.

Acknowledgements

K-Ar age determinations were made at Ohio State University under the supervision of John F. Sutter with the assistance of Dan Lux and Larry Snee. Field work would have been impossible without the support of the US Navy VXE-6 squadron, Holmes and Narver and the Division of Polar Programs. This work was supported by grants from the National Science Foundation, Division of Polar Programs.

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