Jones Mountains, Antarctica: Evidence for Tertiary glaciation revisited

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Summary The Jones Mountains (lat. 73°30’ S, long. 94° W) were discovered in January, 1960. In November of the same year, a University of Minnesota party led by Cam Craddock initiated studies of the geology of this previously unknown small group of mountains. The rocks exposed in this east-west trending group consist of a Mesozoic basement complex of granites in fault contact with younger felsic rocks. Both of these are cut by basalt dikes, which in turn are cut by felsic dikes. This sequence of rocks is truncated by an erosion surface that is essentially horizontal. Overlying the unconformity is a sequence of Tertiary volcanoclastics about 500 m thick. The lower 10-20 m part of this sequence is made up of rocks unknown higher in the sequence. These rocks are of some importance as they contain erratic clasts in the form of pebbles, cobbles, and boulders, striated and faceted, of rock types unknown locally. A second lithology in these lower rocks is a tillite (diamictite) with a matrix of palagonite and exotic erratic clasts. The surface and the rocks immediately above it were the focus of additional studies in 1964 and 1968-69. The surface, now known to be exposed along the front of the mountains for about 33 km, is planed and polished and is marked by striations, grooves, and chattermarks. Ice-flow directions from these markings indicate of movement from south to north. The surface itself suggests a glacial erosion origin and the overlying rocks suggest the interaction of volcanic eruptions and ice. Field work supported by laboratory analysis confirms the conclusion that the sequence represents the result of subglacial eruptions. Recent $^{40}Ar/^{39}Ar$ incremental heating analysis of one basaltic sample provides a robust and precise age of 7.63 ± 0.11 Ma, interpreted as an accurate measurement of eruption age, thereby supporting previous interpretations based on K-Ar results of Jones Mountains volcanism at approximately 7 Ma. Other samples yielded low-precision, disturbed age spectra and isochrons indicating significant excess ^{40}Ar. When first reported in 1965, the Jones Mountains represented the first documented case for Tertiary glaciations in Antarctica. The Byrd Land Coast and other areas in Antarctica are known to contain similar sequences, and Tertiary glaciation is now generally accepted.

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Introduction and summary of field work

The Jones Mountains (lat. 73° S, long. 94° W.) were first sighted in January, 1960, by Cam Craddock and Edward Thiel while on an airborne geophysical traverse roughly along the 88th meridian from South Pole north. In December of the same year, Craddock led a team from the University of Minnesota into the mountains to initiate studies of this previously unknown group of small mountains. Accompanying the group was a surveyor from the U.S. Geological Survey. The group was put into the field directly from McMurdo Station via LC-130 aircraft. This may have been the first open field landing by an LC-130 in support of a field party in Antarctica.

The geologists had neither air photos nor maps to assist in their studies. Rough sketch maps of the area were made and the location and elevation information from the surveyor were incorporated as soon as they became available. The north-facing front of the bedrock exposures allowed reasonable elevation measurements, and at the end of the season an initial topographic map was completed (Figure 1). During this initial season in the Jones Mountains, the mode of transport was by man-hauling. In 1964, the area was revisited, this time with motor toboggans available. This visit was cut short by the onset of bad weather and the need to insure that the accompanying aircraft would be available for support of other field parties. Further studies during the 1967-68 season were supported by helicopters as well.

Bedrock and volcanoclastic geology

The bedrock geology of the Jones Mountains consists of an igneous basement sequence of mainly granitic rocks in fault contact with younger diverse volcanics. These units are cut by basalt dikes, which in turn are cut by felsic dikes. Sharply truncating this basement sequence is a major erosional unconformity that is overlain by a mainly basalt sequence of extrusive rocks (Craddock et al., 1964). The radioisotopic ages of the basement rocks have been discussed in some detail by Rutford et al. (1972). Suffice to say that the rocks exposed below the unconformity are believed to be of Mesozoic age (Figure 2).

Overlying the unconformity is a sequence of basaltic volcanoclastics about 500 m in thickness. Bastien (1963) has described these rocks in some detail. Of particular interest is the 10-20 m of rocks immediately above the unconformity. Two principal lithologies are present. Volcanic glass is abundant in a variety of forms including cooling rims on basaltic masses, massive units of volcanic tuff and in beds showing highly contorted bedding. Scattered throughout these rocks are boulders, striated and faceted in many cases, with lithologies that are not present in local outcrops. Angular blocks of the underlying basement rocks are also present.

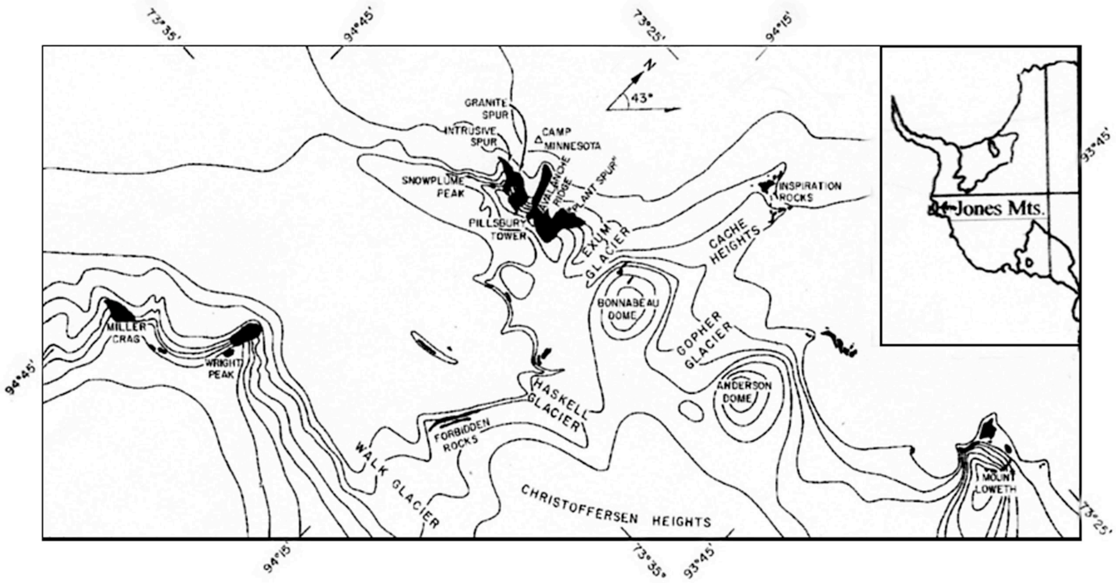

Figure 1. Map of the Jones Mountains. Solid black represents rock exposures. Contours at an estimated 100 meter interval

A second rock type on the unconformity surface is a tillite (diamictite). This unit varies in thickness and occurs all along the front from Mount Loweth to Intrusive Spur. Abundant rounded, faceted, and striated erratic pebbles, cobbles, and boulders are present in a matrix of palagonite and volcanic glass. No large clasts of the overlying volcanics are found in the tillite.

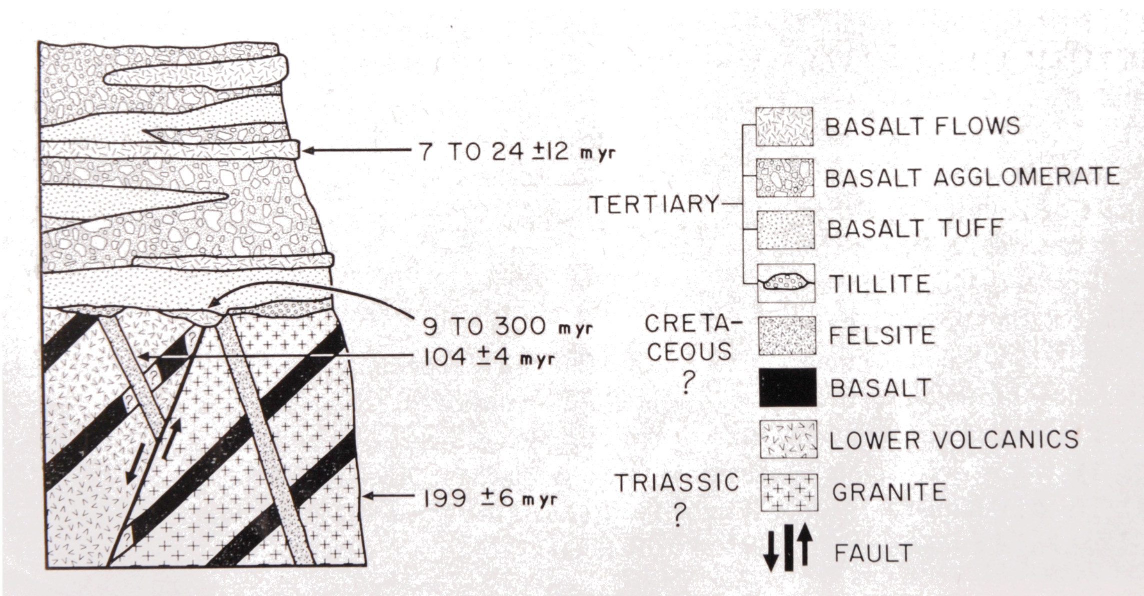

Figure 2. Geologic column, Jones Mountains

The upper and largest part of this volcanic pile consists of alkaline olivine basalts, primarily volcanoclastic varieties but with subordinate flows and hypabyssal bodies. Reported K/Ar ages from basalts above the basal 10-20 m of this volcanic sequence range from 7-24 Ma (Rutford et al., 1972). Recent $^{40}Ar/^{39}Ar$ incremental heating analyses performed at the New Mexico Geochronology Research Laboratory of four of the previously K-Ar dated samples yielded a precise weighted mean age for one sample of 7.63 ± 0.11 Ma (sample 69-C-9, Table 1, Figure 3). Based on the relatively flat spectrum, high radiogenic yields, and good agreement with the isochron age, the weighted mean age for this sample is interpreted as an accurate measurement of eruption age. Furthermore, this age determination is in general agreement with previously determined K-Ar ages, which are on average near 7 Ma for this sample. Results from the other three samples are not considered accurate, given their very low radiogenic yields, disturbed spectra, and poor agreement between the weighted mean and isochron ages (Table 1). The isochron data furthermore indicate significant excess ^{40}Ar, probably trapped by rapid quenching of the glass rich basaltic samples. In summary, the one new robust $^{40}Ar/^{39}Ar$ age provides strong evidence for eruption near 7.6 Ma, but the low quality results from other samples fail to provide evidence for the duration of volcanism at the Jones Mountains.

Table 1. Summary of $^{40}Ar/^{39}Ar$ results from Jones Mountains samples

		K-Ar age				Isochron Age								Weighted Mean Age				
Sample	Locality	Age (Ma)	±	2σ	max %40Ar*	n	MSWD	$^{40}Ar/^{36}Ar$	±	2σ	Age (Ma)	±	2σ	n	MSWD	Age (Ma)	± 2σ	Interpretation
69-C-9	"K" Peak	6.9	±	0.3	75.5	8	4.1	301.0	±	12.0	7.64	±	0.17	4	1.9	**7.63**	**± 0.11**	accurate eruption age
		6.1	±	0.2														
		7.5	±	0.4														
69-C-17	Snowplume Peak	10.0	±	1.2	12.0	11	2.4	314.0	±	2.0	4.9	±	1.0	4	3.4	11.77	± 1.95	accuracy doubtful
		8.5	±	2.8														
69-C-19	Pillsbury Tower	9.6	±	0.3	23.2	11	2.2	311.0	±	3.0	10.5	±	0.7	9	0.8	13.63	± 0.52	accuracy doubtful
		10.5	±	0.3														
69-C-20	Pillsbury Tower	6.8	±	0.3	20.0	11	5.7	324.0	±	5.0	6.5	±	1.2	5	1.9	15.74	± 1.18	accuracy doubtful
		9.6	±	0.2														

notes: K-Ar age is from Rutford et al. 91972/; max %40Ar* is the highest radiogenic yield seen in the age sprectrum;
MSWD is mean of standard weighted deviates, a measure of scatter about the isochron;
$^{40}Ar/^{36}Ar$ is the trapped component intercept of the isochron; Weighted mean age is caclulated from the flat central portion of the age spectrum;
all $^{40}Ar/^{39}Ar$ ages are calculated relative to Fish Canyon Tuff at 28.02 Ma (Renne at al., 1998).

K-Ar analyses of volcanic rocks in the lower 10-20 m, determined by two laboratories, yielded discordant and imprecise ages ranging from 22 ± 12 to 300 ± 5 Ma. It is believed that the differences are geologic not analytical. A discussion of the radioisotopic ages from the samples of the rocks in the lowest levels is provided by Rutford et al. (1968, 1972).

The unconformity

LeMasurier and Landis (1996) and LeMasuier and Rocchi (2005) provide details of the known extent of this West Antarctic erosion surface and its relation to tectonic and magmatic as well as the glacial and climatic history of Marie Byrd Land. Exposures have been described from four localities along a 1100 km coastal segment of Marie Byrd Land.

In the Jones Mountains the unconformity is exposed for 33 km along the front from Mount Loweth to Snowplume Peak. Below Pillsbury Tower, it is almost continuously exposed for about 6 km. The elevations on the unconformity range from 718m to 774 m ASL. Corrected altimeter readings indicate that there is less than 100 m relief on the 33 km of exposure, and probably 50 m is a better estimate. The mean slope of the unconformity surface is less than 1.5° to the north and less than 1.0° to the east. While some smaller features such as knobs or depressions have been described on the surface, it is best described as a gently undulating near-horizontal surface. Close examination of the surface of the unconformity shows striations, chattermarks, and grooves on the planed and polished surface. When the surface is excavated from under the overlying rocks, it is smooth to the touch and shows little if any signs of weathering.

Evidence for glaciation

The combination of the characteristics of the surface of the unconformity and the presence of what appears to be a tillite directly overlying it strongly suggests the interaction between glaciers and volcanics. In the 1960's any suggestion of a Tertiary age for the Antarctic ice Sheet was hindered by the absence of strong field and laboratory evidence. Another contributing factor to the consideration of a possible Tertiary beginning of glaciation was the fact that the majority of the work in the field at that time had been done by northern hemisphere glacial geologists who had been trained in the traditional four distinct Pleistocene glaciations model. Thus, strong evidence would be required to support the notion of Tertiary glaciation in Antarctica. Since the field evidence appeared to make a case for Tertiary glaciation, additional supporting evidence was sought.

The matrix of the tillite was examined first. The material was disaggregated without using mechanical means, and X-ray diffraction of the less than 44μ fraction showed the presence of quartz, feldspar, and a 14Å group of minerals. The clay size fraction of the 14Å group was further examined. Oriented mounts indicated quartz and feldspar in this size fraction suggesting that glacial flour was present. Further study confirmed the presence of montmorillonite and a final heating process established the presence of chlorite. A second analytical technique focused on the use of the electron microscope to examine the surface textures of the sand grains. The sand grains were extracted from the matrix by wetting and heating, no mechanical crushing was used. The techniques of Krinsley and his co-workers (Krinsley and

Takahashi, 1962; Krinsley and Newman, 1964,) were utilized to separate and prepare the quartz grains present in the separation from the matrix. The electron photomicrographs from the initial run of samples were examined by Krinsley, and following his suggestions a second set of photomicrographs was obtained.

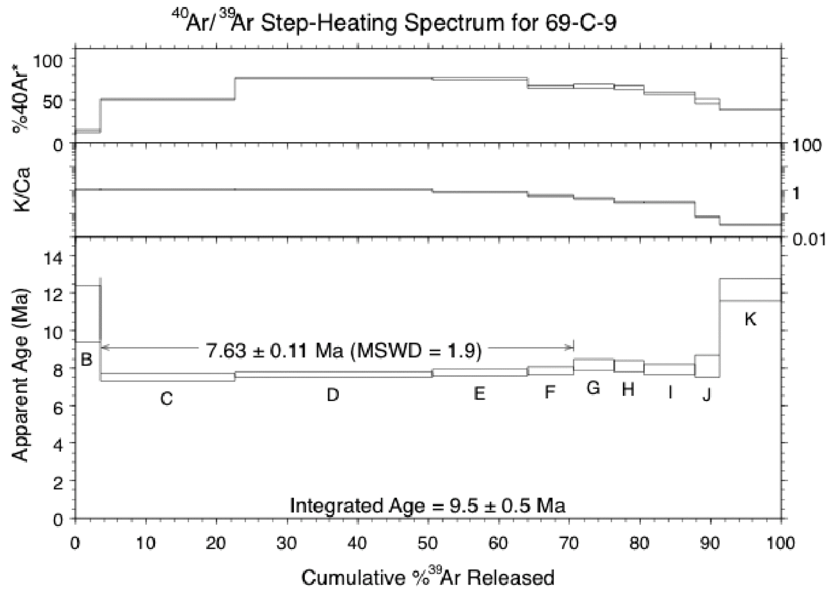

Figure 3. $^{40}Ar/^{39}Ar$ Step-Heating Spectrum for 69-C-9

Quartz grains that have been subjected to various processes of transportation have distinctive surface textures. Those that have been transported by glaciers have characteristic surface features that are (1) chonchoidal arc-shaped steps; (2) semi-parallel irregular steps; and (3) have extensive relief. Comparison of the microphotographs of the Jones Mountains quartz grains with the published examples by Krinsley show striking similarities. Dott (1961) suggests that the most diagnostic evidence of ancient tillites is an extensive grooved and polished surface overlain by the till-like material. The Jones Mountains outcrops meet these criteria.

Any suggestions for the processes that formed the surface of the unconformity must be able to convincingly explain (1) planed and polished surface; (2) the surface markings; (3) the striated and faceted clasts in the overlying tillite; (4) the erratics in the tillite; and (5) the surface texture of the sand grains. Rutford et al. (1968) considered a variety of possible mechanisms for the development of the unconformity surface. These fell into three basic categories; (1) tectonic sliding of the volcanic sequence over the basement rocks; (2) effects of the volcanic eruptions themselves; and (3) glacial action.

The first two mechanisms were rejected as the near-horizontal character of the surface precludes any major mass movement, either by sliding or by the effects of lahars or nuée ardentes. Both of these processes tend to be restricted to valleys, and they more commonly deposit debris along their course rather than eroding it. Neither of these two classes can account for the striated and faceted erratics.

The final mechanism is that of glacial action. The extent of the surface, the character of the markings, the presence of the striated and faceted pebbles in the tillite, and the textures quartz sand grains all point toward glacial processes as the most plausible mechanisms for the formation of the surface of the unconformity. Finally, the presence of what may be glacial flour in the matrix adds further support to glacial processes as the mechanisms of formation of the surface.

Nichols (1964), Flint (1961), and Schwarzbach (1963) each provide a list of criteria for the verification that a deposit is a tillite. A comparison of these criteria with evidence and data from the Jones Mountains points towards a glacial origin for the tillite and the surface.

The final question relates to the palagonite matrix of the tillite. Peacock (1926a) studied rocks on Iceland that were composed of palagonite and came to the conclusion they were a direct result of sub-glacial eruptions. There is a large literature dealing with the origin and the importance of palagonite in the deposits in Iceland with a wide range of views expressed. (See for example Van Bemmelen and Rutten, 1955). It was the composition of the matrix that led to the examination of the literature on the Palagonite Series in Iceland. The glassy matrix cannot be the result of the erosion of pre-existing volcanics as none are present. It certainly is almost certain that the Jones Mountains deposits represent the results of subglacial eruptions as the lithologies present are similar to those described from Iceland.

Conclusions

After consideration of all of the field and laboratory data, the Jones Mountains exposures represent a well documented case for Tertiary glaciation in Antarctica (Rutford, et al., 1965). The Jones Mountains are a part of a volcanic province that extends from the Antarctic Peninsula westward along the coast of Marie Byrd Land. Some speculation of the interaction between volcanoes and glaciers had been made for some of the exposures to the west of the Jones Mountains with no solid evidence to support that speculation at that time.

In the early 1960's, little was known about this volcanic province and its history. The Jones Mountains were, to the best of our knowledge, the first well-documented case for interaction between Tertiary volcanism and glaciation in Antarctica. In following years, the case for such glaciation has been confirmed from numerous areas within the volcanic province as well as in the McMurdo volcanic area. Most recently an outcrop recently exposed by deglaciation on King George Island suggests early Tertiary glaciation in that area (Birkenmajer, et al, 2005). The concept of a Tertiary onset of glaciation in Antarctica is now well documented and accepted.

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