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LITERATURE REVIEW (Anta 502)

The volcanoes of Marie Byrd Land and their importance in understanding the tectonics of West Antarctica as *well* as *the reconstruction of the West Antarctic ice sheet (WAfS) in the last interglacial.*

Marie Byrd Land (MBL, longitude 100-150° W) is one of the least accessible and least frequently visited regions in Antarctica (Fig. 1, 2). It was discovered from the air and claimed for the United States by Richard E. Byrd in 1929, and named for his wife. Much of this region was then explored during the second Byrd expedition (1934-35) by two tractor parties, one sled party led by Paul Siple and four exploratory flights.
The US Antarctic Service Expedition explored the region in 1939-41, as well as the Executive Committee Range Traverse in 1959, with oversnow tracked vehicles from Byrd Station.
More recently, US scientists mapped, sampled and collected GPS data, as well as drilled snow and ice cores on the summit of some of the volcanoes.

Marie Byrd Land contains the largest volcanic region of Antarctica and one of the largest in the world, covering a lenght of almost 960 Km along the Pacific coast. The West Antarctic Ice Sheet (WAIS) covers most of the region, with a thickness exceeding 4.000 m in some areas. Protruding up through the vast expanse of ice are 18 large central volcanoes, including Mount Sidley (4.181 m, the highest volcano in Antarctica, Fig. 3) and more than 30 small satellitic volcanic centers.

The volcanism is caused by rifting along the massive West Antarctic rift system (WARS), which stretches for 3.200 Km from the base of the Antarctic Peninsula to the vicinity of Ross Island, with a width of 600-800 Km. In size, the West Antarctic rift is fully comparable to the East African Rift, from the Red Sea to Mozambique (2). The Transantactic Mountains forms, for a large part of his lenght, the rift shoulder of the WARS. The geochemistry of the volcanic rocks indicates impingement of a mantle plume beneath the nearly stationary Antarctic continental lithosphere as the likely cause of both uplift and volcanism, which dates back to 35 Ma (3).

Extensive hyaloclastites have been reported to be present on the volcanoes of West Antarctica. These have been interpreted as products of volcanic eruptions beneath or adjacent to a thicker continental ice sheet present during each eruptive episode. The volume of hyaloclastite rocks is problably the largest of any other subaerial volcanic region in the world. The ages of the hyaloclastites range from Oligocene (27-28 my) to early Quaternary (less than 0.2 my).

Witch et a/. (3) indicate that the hyaloclastite records shows that the WAIS reached present proportions by late Miocene (ca 9 Ma). They also report a thickening of the WAIS, inferred from Mt. Takahe (about 150 km from the coast) of about 350 m above the present glacier surface level during late Pleistocene time about 29 ka. At times it advanced across the Ross Sea and the Weddell Sea continental shelves. The ice sheet continued to advance and retreat across the continental shelf during the Plio-Pleistocene. Several data indicates that about 400.000 years ago the ice sheet was lost entirely, possibly causing loss of some ice from East Antarctica.

At least four large Marie Byrd Land subaerial stratovolcanoes (Mt. Berlin, Mt. Takahe, Mt. Siple and Mt. Waesche) have been active in the Late Quaternary (*1).* Two volcanoes are probably active (Mt. Berlin and Mt. Siple); images of Mt. Siple taken from satellite NOAA 10 on October 4, 1988, show an apparent volcanic plume extending 160-170 Km to the north-northeast. An aerial inspection on December 30, 1988 found no evidence of fresh ash, new craters or disruption of the snow cover (W.E. LeMasurier and J.W.Thomson, *Volcanoes of the Antarctic Plate and Southern* Oceans, p. 187).
Four to six fumaroles have been observed on the west side of Mt. Berlin's caldera rim, producing the characteristic Antarctic fumarolic ice towers. No eruption has ever been directly observed in any of the volcanoes in Marie Byrd Land.

Investigations of the petrology and petrogenic evolution of these volcanoes can provide insight into the tectonics of West Antarctica. Furthermore, examination of the eruptive and depositional environment of volcanic deposits of different ages allows the past thickness of the West Antarctic Sheet to be reconstructed. The analysis of ice cores drilled in blue ice areas on the summit of some of the largest volcanoes and the dating of the englacial tephra layers within the ice sheet, would permit to deduce how the West Antarctic ice sheet responded to the previous interglacial (between 140.000 and 125.000 years ago). Establishing how the West Antarctic ice sheet responded to the interglacial period is important as we need to assess the stability of WAIS to project future climate change in response to recent anthropogenic activities. Several West Antarctic englacial tephra sites exist : Mt. Waesche, Mt. Moulton, Mt. Berlin and Mt. Takahe (7).

«Geologic history of West Antarctica- wrote Le Masurier in 1982- *has evidently involved a complex interplay of volcanic, tectonic and glacial phenomena, all of which must be viewed together in order to understand any one of the three».*

Characteristics of the MBL volcanoes :

The 18 large central volcanoes occur as single cones, as closely coalescent doublets, and as linear chains of single and coalescent volcanoes. Each is characterized by two or more of the following features : large size (10 to 50 Km base diameter) ; caldera 1-10 km in diameter; predominantly felsic compositions. Ten are more than 3.000 m in summit elevation, with Mt. Sidley – 4.181 m - being the highest volcano in Antarctica. All 18 appear to be shield volcanoes, composed mainly of flow rock, with constructional slopes of 10°-15°. The WAIS and the polar climate have had significant effect on the nature of rock exposures in this region. The surface of the ice sheet is near sea level on the coast but raises inland to an elevation of about 2.000 m. Therefore, the bases of the volcanic sections are exposed mainly near the coast, and only the upper portions of the inland volcanoes are exposed. Most volcanoes, even those of Miocene age, are morphologically well preserved and the rocks exceptionally fresh, because the ice is not an effective agent of erosion and the rates of weathering are slow. The MBL volcanoes presents a vertical succession of rocks : a pre-Cenozoic basement overlaid by hyaloclastites, with lava flows (basalts, basanites, tephrites, hawaiites), Strombolian bombs and cinders. Collectively, these have been termed basal successions. Transition from basal succession to shield volcano may be topographically abrupt and represent a long time interval.

In recent years, researchers with the West Antarctic Volcano Exploration (WAVE, funded by the NSF) carried out seven seasons of field work in Marie Byrd Land, mapping and sampling the virtually inexplored volcanoes (4). In the 1998-99 field season, mapping, sampling and collection of GPS elevation data were carried out at Mount Takahe. During the 1999-2000 Antarctic field season, US scientists retrieved a 600 m horizontal ice core from the Mount Moulton blue ice field. The summit of Mt. Moulton contains a 600 m-thick horizontal section of ice with intercalated tephra layers from nearby Mt. Berlin (Fig. 3). Dating of the tephra layers provides an unprecedented chronology of climate change in WAIS between 14.500 and 492.000 years ago. Initial analyses suggest that the Moulton site may offer an unparalleled repository of ancient West Antarctic snow and trapped air that can be used to investigate West Antarctic climate over the last 500.000 years (5, 6, 7,8).

The initial goal of the US scientists was to confirm the continuous nature of the Moulton ice core by comparing the gas records with the continuous Vostok gas record spanning the last 423.000 years (9).
In the 2003-2004 field season the US researchers (representing three separate US institutions: Penn State University, New Mexico Tech. and University of Colorado) returned to the summit of Mt. Moulton and spent 3 1/2 weeks to drill over 203 m of firn and 73 m of blue ice. They had an Eclipse drill provided by Ice Core and Drilling Services-SSEC University of Wisconsin, Madison (with funds from the NSF).

LIST of the Major Central Volcanoes of the Marie Byrd Land Volcanic Province (from: *Volcanoes of the Antarctic Plate and Southern Oceans,* Wesley E. LeMasurier and Janet W.Thomson, American Geophysical Union, Antarctic Research Series Volume 48, May 1990)

Volcano	Elevation, m.	K-Ar Indicated Age range
1) Mount Takahe 76° 15' S, 112° W	3.460	Pleistoc-Holocene ?
2) Mount Berlin 76° S, 136° W	3.478	Pliocene-Holocene ?
3) Toney Mount. 75° 45' S, 116° W	3.595	Pleistocene
4) Mount Waesche 77° 10' S, 127° W	3.292	Pliocene-Holocene ?
5) Mount Siple 73° 30'S, 127 W	3.110	Pliocene-Holocene ?
6) Mount Frakes 76° 48' S,117° W	3.654	Plioc-Pieistocene
7) Mount Sidley 77° S, 126° W	4.181	Pliocene

8) Mount Moulton 77° 00' s ,135° 00' W	3.078	Pliocene
9) Mount Kauffman 75° 35' s ,132° 30' W	2.364	Miocene-Pliocene
10) Mount Bursey 76° 00' s ,132° 30' W	2.787	Miocene-Pliocene
11) Mount Hartigan 76° 50's ,126° W	2.811	Late Miocene
12) Mount Hampton 76° 25'S, 126 W	3.323	Middle- Late Miocene
13) Mount Steere 76° 44's ,117° 45° W	3.558	Late Miocene
14) Mount Cumming 76° 40's ,126° W	2.612	Late Miocene
15) Mount Kosciusko 75° 43's ,132° 13' W	2.909	Late Miocene
16) Mount Andrus 75° 50' s ,132° 20' W	2.978	Mid-Miocene-Holocene?

17) Mount Murphy 75° 20' s , 110° 45' W	2.703	Late Miocene
18) Mount Flint 75° 40's , 129° W	2.695	Early Miocene- Middle Miocene

Mount Takahe

Mount Takahe was named by members of the 1957-1958 Marie Byrd Land Traverse party, who were the first to visit the mountain. The *takahe* is a native flightless bird – almost extinct – native of New Zealand. Its name was given as a nickname to the U.S. Navy LC-47 aircraft that resupplied the traverse party.

Mt. Takahe (75° 48' S, 115° 50' W) is an isolated, dormant volcano almost perfectly cone-shaped, located 3.460 m above the sea level, and 2.100 above the ice level. The slopes rise from a base 35 Km wide at the surface of the surrounding ice sheet, to a circular caldera of 8 Km in diameter on the summit.

The base of Mt. Takahe is composed of lava flows on two localities and of hydroclastic deposits at three others. The hydroclastic deposits consist of a complex assemblage of pillow lavas, pillow breccias and hyaloclastites. The K-Ar indicated age range is Pleistocene-Holocene. Mt. Takahe is one of the youngest volcanoes in the region, with much of its bulk constructed within the past 400.000 years. There is evidence of subglacial eruptions around its base which occurred when the WAIS was as much as 300 m. thicker (10). *LeMasurier* and *Kyle* et al. suggested that some tephra layers in ice cores from Byrd station (80° S, 120° W) and from the first Dome C station (77° S, 120° E) were derived from eruptions of Mount Takahe, on the basis of petrografic and chemical characteristiscs of the ash layers and on consideration of atmospheric circulation patterns. This could indicate that Mt. Takahe erupted within the last 30.000 years (2).

Mt. Berlin

Mt. Berlin -the highest volcano in the western part of Marie Byrd Land, 3.478 m - is named for Leonard M. Berlin, leader of the US Antarctic Service Expedition party (USAS), that visited the mountain in 1940. It is the most impressive volcano of the Flood and Ames Ranges and one of the two or three volcanoes in MBL that are probably active. It consists of two coalescent volcanoes – Berlin Crater and Merrem Peak – each with a summit caldera of 2 Km in diameter. Berlin Crater is believed to be the youger of the two because of the presence of 4-6 steaming fumaroles on the west side of the caldera: it lies 300 m above and 3 1/2 Km east-south-east of the Merrem Caldera. The base of the volcano is completely surrounded by the WAIS, with an exposure above ice level of about 2.100 m on the north side and 1.500 m on the south side (Brandemberger Bluff, 300-400 m high, entirely made of well stratified trachytic hyaloclastite tuffs : this deposit is apparently older than either of the two peaks and may represents eruption beneath the ice sheet at a time when the seaward ice sheet was not dammed behind the massif). The main period of shield building seems to have been within the last 600.000 years. Lavas around the summits of both volcanic peaks are less than 100.000 years old, indicating that Mt. Berlin is one of the two youngest volcanoes in MBL with Mt. Takahe.

Mt. Moulton (Flood Range)

The Mt. Moulton massif is a 30 Km long segment of the east-west oriented Flood Range volcanic chain. It is formed by two coalescent volcanic cones (« East » and « West »), each with snow covered calderas 3 Km in diameter. They are 8 Km apart, with an elevation of 3.078 m above sea level. East and West volcanoes are of different petrologic character : one is phonolitic (West) and the other is pantelleritic (East). The K-Ar age of Mt. Moulton is 4,7 and 4,9 million years, older than Mt. Berlin which lies 20 Km to the west.

Like Mt. Berlin, the base of Mt. Moulton is completely surrounded by the WAIS, with an exposure above ice level of 1.700 m. The ice of the West Antarctic Ice Sheet is quite younger than the ice found in the caldera of the volcano : dating of tephra layers included in the ice cores extracted from the summit yelds an age of almost half million years. These cores are being used to reconstruct the paleoclimatic record stretching back for 492.1 years (comparable to the ice cores extracted - for ex - at Vostok). Ref. 5-6-7-8-9. Mount Moulton is named for Richard S. Moulton, chief dog driver with the 1939-1941 U.S. Antarctic Service Expedition, which visited the west end of the Flood Range in December 1940.

Toney Mountain

Toney mountain – an elongated volcanic massif over 50 Km long - is named for George R. Toney, scientific leader at Byrd station in 1957. The mountain was first visited in December 1957 by a traverse party from Byrd station and again in 1959-60 by the Byrst Station Traverse. Toney Mt. Is a young volcano, with rocks dated to less than a million years old on the upper part of the cone.

Mount Waesche (Executive Committee Range)

Named for Vice Admiral Russell R. Waesche, U.S. Coast Guard, who was a member of the executive committee of the US Antarctic Service Expedition (1939-1941), Mt. Waesche is a closely coalescent doublet in which the higher volcano appears to have developed on the caldera rim of an older volcano – the Chang Peak volcano. K-Ar dates obtained from the two volcanoes suggest that Chank Peak lavas were erupted at approximately 1.6 Ma and that Mt. Waesche shield volcano formed around 1 Ma. There are lavas younger than 100.000 years on the upper slopes, and the volcano may have been active within the past 30.000 years depositing ash layers found in ice cores from Byrd station. The WAIS is quite thick in this region : the summit of Mt. Waesche extends only about 1.200 m from the ice (height : 3.292 above sea level) and Chang Peak only 700 m above ice level (height: 2.920 m).
Mt. Waesche lies 25 Km southwest of Mt. Sidley, the highest volcano in Antarctica and highest point of the Executive Committee Range.

Mount Sidley (Executive Committee Range)

Mount Sidley is the highest mountain in Marie Byrd Land and the highest volcano in Antarctica, standing 387 m higher than Mount Erebus. Its height is 4.181 m above sea level, and 2.200 m above the ice. Mount Sidley was discovered on November 18, 1934, during an airplane flight by Rear Admiral Richard Byrd. It was named by him for Mabelle E. Sidley, daughter of William Horlick who was a contributor to the second Byrd expedition (1933-35).

The main Mount Sidley caldera is 5 Km in diameter and the summit peak stands 1.200 m above the caldera floor. The major part of Mt. Sidley was constructed 4,7 million years ago. An explosive eruption blew out most of the south side of the caldera, forming a basin (the Weiss Amphitheater) which is open to the south, with extensive hydrovolcanic deposits from the subglacial eruption extending outward for several miles. The 1.200 wall on the north side of the caldera (composed of lava flows) provides the best view of the interior of any Marie Byrd Land volcanoes.

Mount Siple

Mount Siple is an enormous shield volcano which forms the bulk of Siple Island on the coast of Antarctica. It is an almost perfect cone, rising directly from the water's edge to a height of 3.110 m, with a circular summit caldera of 5 Km in diameter. In volume, Mt. Siple is comparable to Mt. Erebus : 1.800 Km3. This volcano is not concealed by the WAIS – which only has a thickness of 200 m along the coast. Mt. Siple was formed within the last 2 million years, and some satellite cones are younger than 100.000 years.

Images of Mt. Siple taken from satellite NOAA 10 on October 4, 1988, show an apparent volcanic plume extending 160-170 Km to the north-northeast. An aerial inspection on December 30, 1988 found no evidence of fresh ash, new craters or disruption of the snow cover (2).

Mt. Siple was named after Paul A. Siple, member of the 1928-1930 and 1933-1935 Byrd Expeditions, as well as of the 1939-1941 U.S. Antarctic Service Expedition. Siple was the scientific leader at the South Pole station during the IPY 1957-58.

Mount Hampton (Executive Committee Range)

Mt. Hampton – named after Ruth Hampton, Department of the Interior and member of the Executive Committee of the Antarctic Service Expedition (1940) – is a closely coalescent doublet in which Whitney Peak caldera appears to be cut on its southeast flank by Mount Hampton shield volcano. Both calderas are 5 Km wide : on the rim of Mt. Hampton caldera are several conical snow and ice towers, which are believed to be remnants of fumarolic ice towers like those of Mt. Erebus and Mt. Berlin. Mt . Hampton is one of the oldest volcanoes in Marie Byrd Land : its age is 11, 4 million years, but the remnants of the fumarolic towers may be evidence of geologically recent activity (Holocene). The cone of Mt. Hampton is almost completely concealed by the WAIS except for 900 m on the summit.

Mt. Cumming (2.612 m), which lies some kilometers south of Mt. Hampton, is an isolated single caldera almot entirely buried by the WAIS : only the upper 400 m of its summit lies above the ice level.

Mt. Frakes and Mt. Steere

(Crary Mountains, Eastern Marie Byrd Land)

The Crary Mountains are an isolated massif in eastern MBL, consisting in four major shield volcanoes : Mt. Frakes (3.654 m), Mt. Steere (3.558 m), Mount Rees (2.709 m) and Boyd Ridge (2.375 m). The two major volcanoes – Mt. Frakes and Mt. Steere – rise as distinctly separated cones above a relatively flat plateau-like surface that stretches along a main northwest-southeast axis for roughly 60 Km. Mt. Frakes, the highest point in the Crary Mountains, is 4 million years and has been constructed on the southeast flank of the older Mt. Steere (8 million years old). On the summit of Mt. Frakes and Mt. Steere are 2.5 Km wide calderas. Just north of the northeast flank of Mt. Steere is a deep subglacial basin whose floor lies 1.900 m below sea level : it is filled by ice as deep as 3.400 m.

The Crary Mountains are named for Albert P. Crary, deputy chief scientist for the US-IGY Antarctic Program in 1957-58. The mountains were first visited during the 1959-1960 Byrd Station Traverse by means of oversnow tracked vehicles.

Mount Murphy (Eastern Marie Byrd Land)

Mount Murphy has been deeply dissected by erosion since it was formed about 8 million years ago. Distant views suggest that its form was originally a flat cone, with slopes of approximately 6.5°-8°. Being located on the Antarctic cast, Mount Murphy was eroded much more than the volcanoes located at inland locations.

Inland, the WAIS surrounds and protects the bases of the volcanoes, while on the coast the ice sheet extends only to about 800 m above sea level on the southern side of the volcano and 200 m on the seaward northern side. Mt. Murphy was named for Robert Cushman Murphy, a naturalist who studied wildlife of South Georgia during the 1912-1913 summer.

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