THE THOLEIITIC BASALT STRATIGRAPHY OF THE MOUNT BUMSTEAD AREA, ANTARCTICA

Senior Thesis

Presented in Partial Fulfillment of the Requirements
for the Degree Bachelor of Science

by

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Approved by

Advisor
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The north central face of Mount Bumstead, Antarctica.
(Elevation 8,000 feet - Average relief 326 meters)

ACKNOWLEDGMENTS

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The writer wishes to thank Dr. David H. Elliot for his advice, helpful discussions and unending patience, without which this manuscript would not be possible. Also, the writer would like to thank Mr. Edmund Stump for his assistance in the field, and Mr. Helmut E. Ehrenspeck, who critically reviewed parts of the manuscript.

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INTRODUCTION

In the Transantarctic Mountains igneous, metamorphic, and sedimentary rocks of late Precambrian/Cambrian age were uplifted during the Ordovician Ross Orogeny and subsequently eroded. On this surface was deposited approximately 3,000 meters of mainly terrigenous sedimentary rocks called the Beacon Supergroup. The Beacon rocks range in age from Devonian to Triassic (Barrett, 1970). The sedimentary rocks have been intruded by thick diabasic sills with co-magnetic extrusive tholeiitic flood basalts capping the stratigraphic sequence in the Transantarctic Mountains.

The igneous rocks which intrude and cap the Beacon strata in this area were named the Ferrar Dolerite(s) (Group) by Harrington (1958). Grindley (1963) observed and formally named the extrusive tholeiitic basalts in the Ferrar Group the Kirkpatrick Basalts. The intrusive and extrusive rocks have been dated radiometrically by Potasium/Argon methods by McDougall (1963), Wade (1965), and Elliot (1970), and yielded ages between 183 m. y. and 161 m. y., and indicate a Jurassic age of emplacement. In addition, "Paleontological evidence of a Jurassic age is given by conchostracons assignable to Cyzicus (Lioestheria)species, in sedimentary interbeds..." (Elliot & Tasch, 1967). Plant material and microfloras collected from sedimentary interbeds between basalt flows also indicate an early Jurassic age.

The primary purpose of this study is to describe and interpret the tholeiitic basalt stratigraphy of the Mount Bumstead area, a nunatak located in the Grosvenor Mountains (E. long. 175 25'00", S. lat. 85 30'40"),

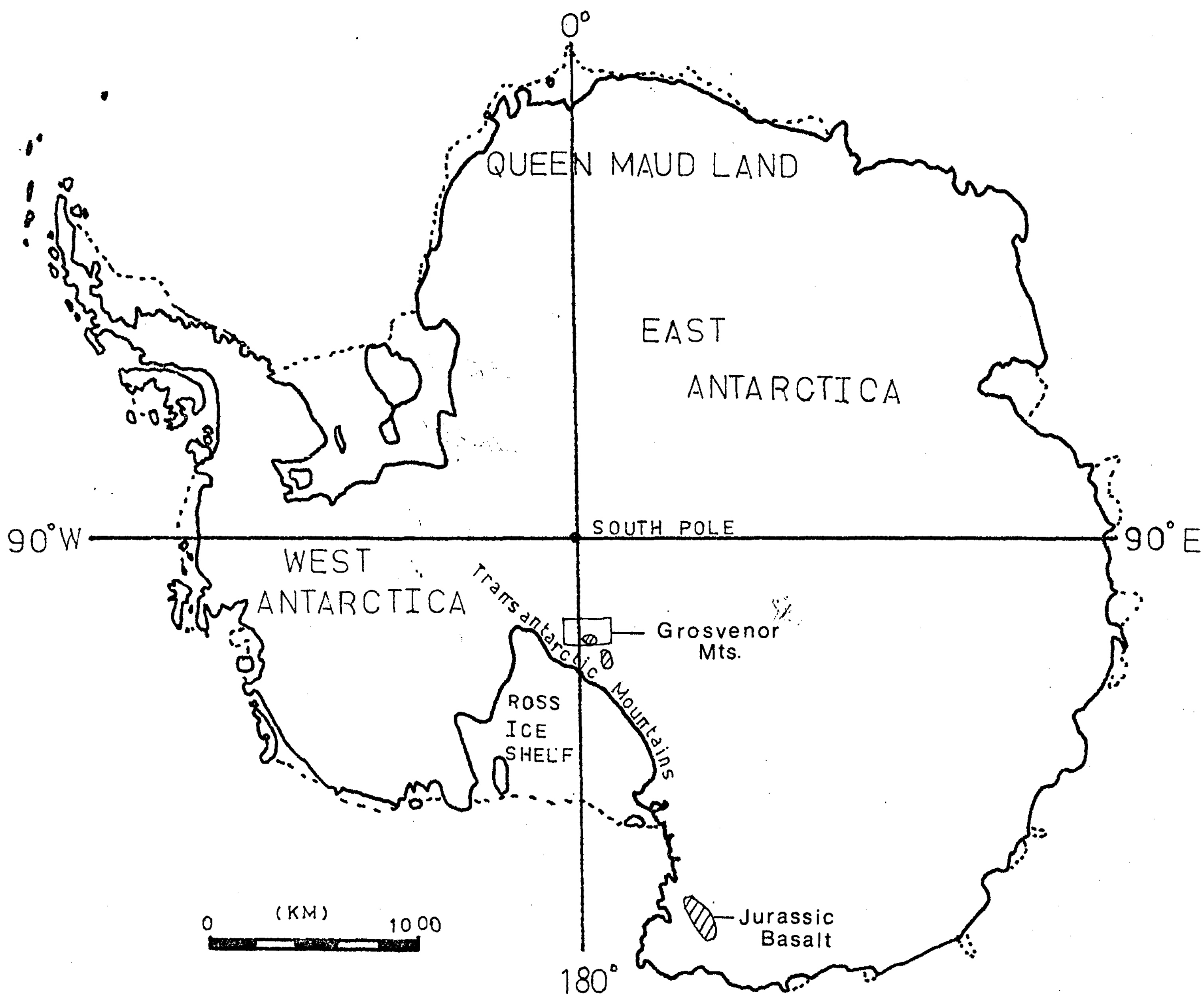


Figure 1. Geographical map of antarctica and major areas of exposed Tholeiitic Basalt of Jurassic age.

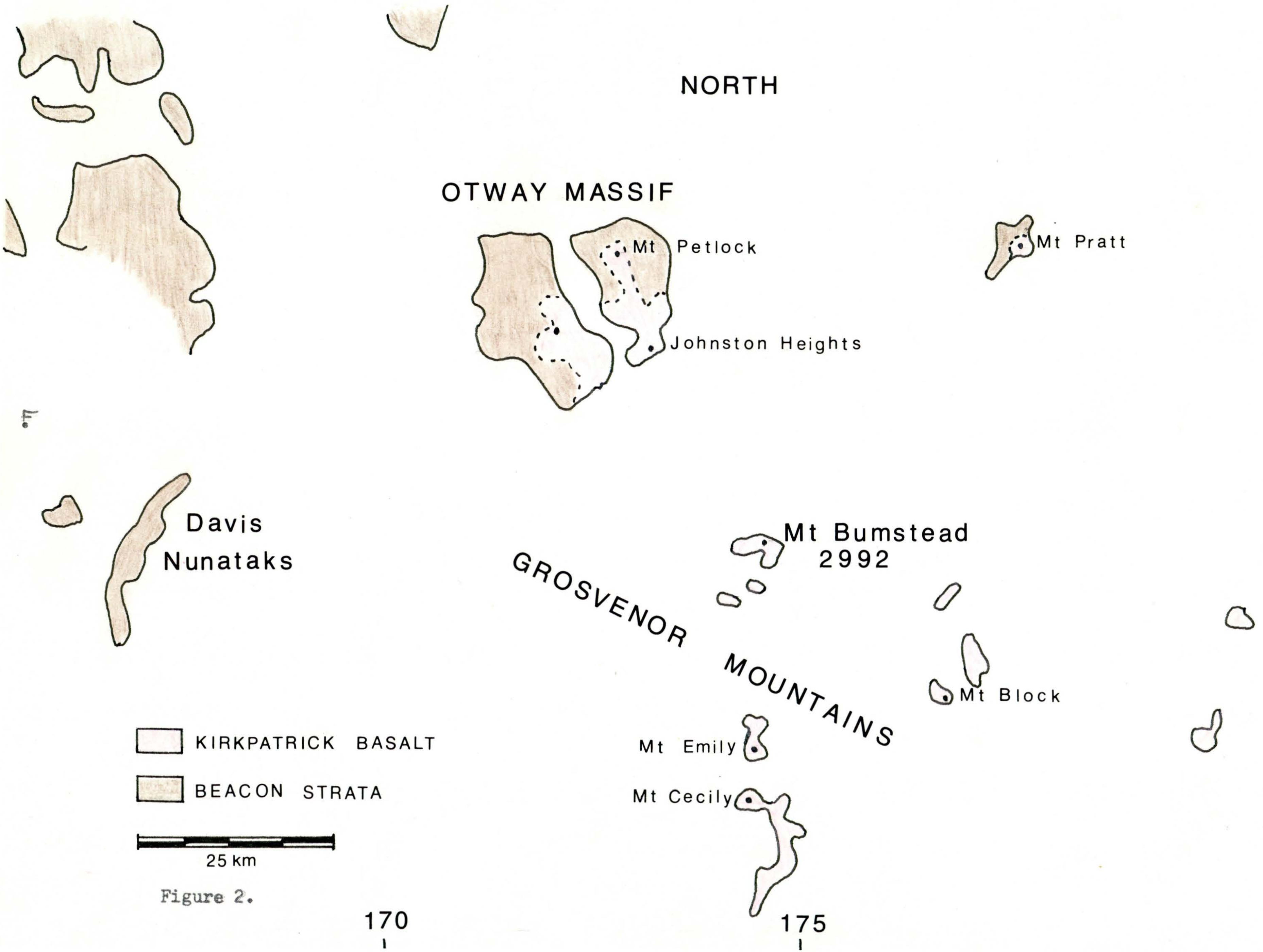

NORTH
OTWAY MASSIF
Mt Petlock
Johnston Heights
Mt Pratt
Davis Nunataks
Mt Bumstead 2992
GROSVENOR MOUNTAINS
Mt Block
Mt Emily
Mt Cecily
KIRKPATRICK BASALT
BEACON STRATA
25 km
170
175

Figure 2.

south central Transantarctic Mountains, Antarctica (fig. 2.).

PREVIOUS WORK

The area of study was first traversed during a reconnaisance by the New Zealand Southern Field Party of 1961-1962 (McGregor, 1965). The Kirkpatrick Basalt of the Mount Bumstead area was first described by McGregor (1965) to expand more fully the Kirkpatrick sequence as observed in the Marshall Mountains. As a result, McGregor (1965) suggested that some of the basalts may have originated from what is considered a remnant volcanic vent of Jurassic age located approximately 40 kilometers northward on the Otway Massif (Fig. 6.).

Elliot (1969) published a detailed petrographic study of the Kirkpatrick sequence which included rocks collected from a measured section of the northwest face of Mount Bumstead. His study showed that the basalts are typical tholeiites in their mineralogy, and that distinctive flows can be correlated are rare. The area was not visited again until 1970-1971 when the writer collected data for this report.

PRE-BASALT LAND SURFACE

The Kirkpatrick Basalt overlies a unit of paraconglomerate, agglomerate, tuff, and tuffaceous sedimentary rock called the Prebble Formation of late Triassic age (Barrett and Elliot, 1972). In the Grosvenor Mountains the Kirkpatrick/Prebble contact is below ice level. However, the contact has been observed by Elliot (1969) at several localities north of Mount Bumstead - the nearest being located on the southwest side of the Otway Massif, 40 kilometers to the north/northwest. "...Where the contact is exposed, it is likely that there was at least moderate topographic relief at the time of extrusion" (Elliot, 1969, pg. 313). Evidence cited for the existence of relief is the presence and character of pyroclastic and mudflow deposits of considerable and variable thickness found on the Otway Massif. Mudflow units accumulate in thickness only when confined topographically. A difference in relief of 72 meters, observed over a distance of 1.5 kilometers in a thick black basalt flow with an horizontal upper surface in the Marshall Mountains, also suggests a pre-basalt land surface of moderate relief (Elliot, 1969).

FLOW FEATURES

Extrusive basalts of the Mount Bumstead area exhibit few flow features. However, flow features have been observed locally by the writer. The features primarily consist of spiracles, stretched amygdales, and stretched vesicles. Because the stretched amygdales and vesicles are of localized occurence, they should be considered less reliable than the spiracles, although some idea of the direction of flow can be obtained. The localized concentration of flow features may be caused by slight changes in topography that

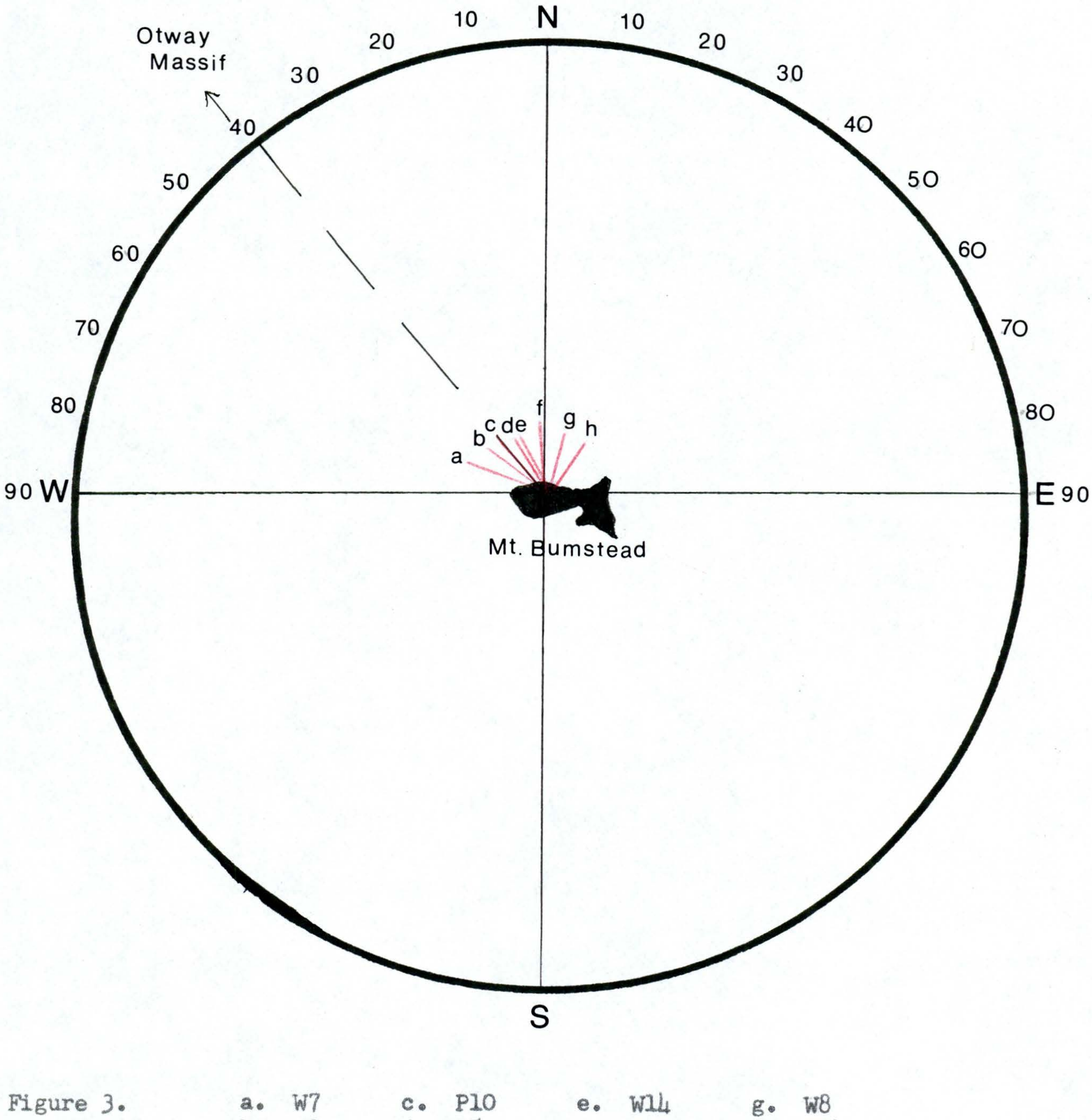


Figure 3. a. W7 c. P10 e. W14 g. W8
b. W3 d. P5 f. spiracle h. P14

Localized flow directions measured from stretched amygdales, stretched vesicles, and vesicle trains of spiracles from amygdaloidal basalt, Mount Bumstead. The directions of flow indicate a possible basalt origin in the vicinity of Otway massif where a central volcanic vent of Jurassic age is located.

TABLE #1

Flow Directions and Oriented Samples

Spiracle	N 10 W	Flow # 3.
P. 14.	N 30 E	Flow # 8.
P. 10.	N 55 W	Flow # 4.
P. 5.	N 30 W	Flow # 2.
W. 3.	N 50 W	Flow # 2.
W. 7.	N 70 W	Flow # 3.
W. 8.	N 10 E	Flow # 4.
W. 14.	N 25 W	Flow # 8.

yield some difference in flow direction. A spiracle which occurs at the base of flow #3, section P, is dendritic in appearance, rising from the bottom contact and branching upwards. Waters (1960) suggests that dendritic spiracles develop when a flow encounters wet sediments, water, or vegetation. In the Mount Bumstead area such spiracles are associated with sedimentary interbeds or interbeds of weathered material. Waters (1960) used spiracles as a means of measuring direction of flow. Vesicle trains form this spiracle trend N10 W and may be the only reliable indicator of local flow direction measured.

Eight field samples specifically oriented to obtain source directions indicate flow vectors that generally trend northwest/southeast (Fig. 3.). Since only a few basalt outcrops occur southward, accompanied by the existence of the South Polar Ice Cap, these vectors may indicate a basalt origin from the north in the vicinity of the Otway Massif. A remnant central volcanic vent of Jurassic age has been observed at Otway Massif and investigated by Elliot (1969). However, due to the vent's small size in proportion to the amount of extrusive basalt in the area, it seems highly unlikely that the lavas have originated from this vent (Elliot, pers. comm.). However, the flow indicators do suggest that this may well be the general area of origin.

The writer did not observe evidence of flow ramping or angular jointing patterns that indicate flow directions. Also, examination of thin sections for evidence of micro-flow features such as oriented feldspar laths was unsuccessful. Hence, the rarity of flow features in this area supports the idea that the flows have formed huge lava ponds.

Figure 4. A spiracle with vesicle trains (extending diagonally left) rising from the bottom contact and branching upwards. Waters (1960) used spiracles as a means of measuring direction of flow.

Figure 5. Interbed B, and dendritic spiracle, section P. Waters (1960) suggests that dendritic spiracles develop when a flow encounters wet sediments, water, or vegetation.

LAVA PONDING

The succession of basalt flows of the Mount Bumstead areaprobably indicates the extrusion of large quantities of lava that spread rapidly over wide areas forming lava ponds. Evidence which lends support to this hypothesis could be: (1) moderate topographic relief of the pre-basalt land surface, (2) the great thickness of some flows, greater than expected for a presumably very fluid lava flow, (3) consistent and regular vesicular and amygdaloidal zones, and (4) the rarity of flow features previously noted. The slow cooling of such lava ponds would account for the diabasic character of the thicker flows. Repeated injection of new magma into a solidifying lava pond might account for the vertical textural variation within some flows such as

Figure 6. A remnant central volcanic vent of Jurassic age, Otway Massif.

alternations of glassy black basalt and diabasic basalt, flow # 3, Mount Bumstead (Elliot, 1969).

These lavas may be the result of extrusion of large volumes of low viscosity basalt which moved rapidly across the land, enabling individual lavas to extend over wide areas. Lefebvre (1969, pg. 23) suggests that flood basalts "are not the consolidated equivalents of moving lava flows, but instead represent crystallization of large ponds of lava". This would account for the scarcity of physical evidence of flow movement in these basalts. The origin of platy jointing observed in the Bumstead area could be attributed to the differential internal movement within a lava pond (Fuller, 1950; Macdonald, 1963), or the result of vesicle collapses (Waters, 1941)(See section on jointing patterns). However, no real evidence of the origin of platy jointing could be determined.

The rate of extrusion through time is thought to have been slow but constant, as shown by the development of soils or interbeds displaying weathering profiles during periods of volcanic quiescence. The average rate of extrusion of flood basalts of this type has been suggested to be 1 flow per 500,000 years (Brown, 1969). Moreover, unlike the Columbia River basalts which display persistent basining along with persistent extrusion, basining toward the south in the Grosvenor Mountains cannot be proven due to the lack of structural detail imposed by the South Polar ice cap, even though the ponded basalts dip gently (less than 5°) in that direction.

Inferences can be made concerning the type of vents contributing material to the lava pond, although no definite conclusions can be reached due mainly to the existence of the South Polar ice cap or to post-Jurassic erosion. Fissures are cited as the principal type of vent for flood basalts, but it is entirely possible that low angle shield cones existed which are now obscured or partially obscured as exemplified by the Jurassic vent on the Otway Massif. It has been observed in Iceland that fissures and shield cone eruptions occur side by side in the fracture zone (Rutten, 1964). If this assumption can be applied in the Grosvenor Mountain area, then it is possible to infer the origin of the huge lava pond. Perhaps no high volcanic cones were built up because of the low viscosity of the magma. Or, perhaps the lava ponds result from contemperaneous extrusions from a row of vents (Bingham, 1969).

INTERBEDDED MATERIAL

Interbeds occur at three separate horizons (Fig. 12.) above the lowermost flow (interbed A.), above flow # 2. (interbed B.), and beneath the uppermost flow (interbed C.). The lower and uppermost interbeds also mark the vertical boundaries of the Bumstead Tholeiite member. The interstratified material extends laterally between concordant basalt flows and ranges from less than 1 m to 3 m in thickness. The interbeds consist primarily of layers of compacted air fall tuff, with grains ranging generally less than 4 mm in diameter. The tuff interbeds form horizontal contact interfaces that are even to very uneven, and indicate local relief of several meters.

Where the contact is uneven, such as interbed A., the interbedded tuff occurs in the low lying areas along

Figure 7. Interbed A, section P. The sediment appears light green in color as the result of secondary alteration to chlorite. A hand specimen exhibited thin cross-bedded laminations suggesting reworking by flowing water.

Figure 8. The step-like topography of Mount Bumstead.

the contact, and appears as lenticular bodies. A hand specimen collected from section P. (p. 3.) exhibits thin cross-bedded laminations 0.5 to 3 mm, thus suggesting reworking by flowing water. Small sand-sized grains of basaltic rock fragments and amygdale minerals occur in some laminae. The separate cross-bedded laminae of sand-size grains suggest energy fluctuations and the existence of currents. The sediment appears light green in color which may be due to secondary alteration to chlorite. Thin section V.5., and a thin section obtained from D. H. Elliot, section W., exhibit lateral iron concentrations that extend across glass shards. This suggests the possible occurence of the normal leaching of iron. However, more probable than the normal leaching of iron may be the chloritic alteration of the devitrification of glass shards. This may be due to thermal heating - perhaps from a new flow overriding the sediment. Since the indurated sedimentary interbed is composed of a mixture of pyroclastic volcanic ash and sedimentary detritus (sand-sized basaltic fragments) the interbedded material should be labled a tuffite (Dictionary of Geologic Terms, 1962).

Interbed B.,which lies directly above flow # 2, consists of weathered material, but without any observable profile. Horizontally, the contact interface is slightly uneven. The interbed averages 0.5 meters in thickness and is buff brown in color opposed to the typical green color displayed by the other interbeds in the area. The material is easily weathered and consists in part of angular basaltic inclusions which tend to become larger in size from the surface to the base of the interbed. The upper portion of the interbed exhibits peculiar inclusions which appear like rootlets or rootcasts. These inclusions were noted and described by Dr. James Schopf, paleobotanist of the U. S. Geological Survey. The thin section described (P. 5. 1.) yields the following:

> "The rock appears to consist of silicified pond bottom mud (or moist material) from which all traces of bedding have been obliterated. The rock is shot full of irregular, linear streaks with silicious centers and limonitic margins which may represent voids left by decay of fibrous roots and rootlets. No traces of carbonaceous matter remain, so identification of roots is inferential. No examples of stems or coarser plant material appears in the hand specimen.
>
> The limonitic inclusions show shrinkage cracks, possibly a result of hysteresis. The specimen also shows a few minute calcitic veinlets."
>
> (Schopf, pers. comm.)

Elliot (1969) has observed tuff interbeds in many sections from the Queen Alexandra Range to the north that contain plant remains on their upper surfaces. One such locality on the Otway Massif, exhibits a weathering profile which is "interpreted as a paleosoil" (Elliot & Everett, in preparation). Based on the megascopic characters and microscopic examination of interbed B., the writer suggests the weathered material may also be considered a paleosoil.

The uppermost interbed (interbed C.) appears in thin lenses of massive tuff less than 0.5 meters thick. Light gray in color, the interbed contains angular basaltic fragments, some chloritized, along with angular amygdale minerals. The amygdales and basaltic inclusions range up to 1 cm. in size. In contrast to interbeds A. & B., interbed C. is highly indurated and resistant to weathering. Due to scree cover accumulated from the above thick flow, detailed investigation of the contact interface proved difficult.

Correlation of interbeds from Mount Bumstead to the adjacent nunataks is possible, but projection to Mount Emily and Mount Cecily is rather tenuous and is based on the presence of the thick flow capping Mount Bumstead which overlies interbed C.. In addition, correlation of interbed C. is possible at Mauger nunatak in which the interbed contains brackish/freshwater fossils (conchostracans) of Jurassic age (Elliot, 1969; Tasch, 1970).

CONTACT ZONES AND THEIR RELATIONSHIP TO ADJACENT FLOWS

Investigation of flow contacts is essential for obtaining an understanding of the local geologic history of the Mount Bumstead area. One of the main purposes in measuring the three stratigraphic sections was to observe in greater detail the horizontal variation of the contacts and their relationship to the adjacent flows.

The contact is the surface separating two distinct flows or flow units (Dictionary of Geologic Terms, 1962).

The surface of separation appears as a zone of high secondary alteration and devitrification which facilitates weathering in the field. The contact zone is the area which generally extends vertically for not more than 2 or 3 m and includes the extreme upper part of the underlying flow and lowermost parts of the overlying lava flow. The zones of alteration are the result mainly of heating by the overriding of new lava (a zone of baking), of surface weathering during prolonged volcanic quiescence, or a combination of both.

Concentrations of glass occur near the flow surface, a result of more rapid cooling, and have been devitrified to chlorite and possibly to hydrated iron oxides. Also, feldspar is being broken down to various clay minerals, and densely compacted amygdale zones occuring in the upper and lower extremities of flows have been filled with zeolite and greatly aide to a contact zone of low resistivity to weathering. Since the contact zone is less resistant to weathering than other parts of the flow, a small lateral indentation or "cleft" results which makes the contact easibly observable in the field.

The horizontal extent of the contact zones are varied and range from even to uneven. Even contact zones are zones in which there is little or no local relief, in which the degree of alteration is horizontally uniform. The zones are usually developed between two concordant flows extruded probably during periods of more rapid extrusion. Furthermore, little evidence of erosion or the development of weathering profiles is observed. On the other hand, uneven contact zones display moderate local relief between 1 m and 5 meters. The zones are likely to be the result of long periods of volcanic quiescence during which the flow surface may have become subjected to periods of erosion and weathering. Moreover, uneven zones may develop upon undulating surfaces of pahoehoe lava toes or other types of viscous flowage such as occurs in flow # 4, sections P. and W.

Distinguishing between actual flow contacts and pahoehoe toes may sometimes prove difficult. Locally, however, there is a consistent "cleft" developed which aids in this delineation. "Clefts" also develop at the contacts of each pahoehoe toe, but are characteristically thinner, usually no more than a few centimeters in thickness, and are locally very uneven, following the general shape of each pahoehoe toe. In addition, the delineation is also marked by the concentric arrangement of amygdale bands which also follow the general shape of each toe. On the other hand, "clefts" which develop at actual flow contacts are greater in thickness due to a much higher degree of alteration. The "clefts" comprise several tens of centimeters, and are horizontally much more even.

Contact zones involving interbeds of weathered material (interbed B.) or of reworked material (interbed A.), display the "cleft" only on the upper surface and not at the base of the interbed. Thus, the contact between the upper surface of the flow and the base of the interbed is gradational. In areas where interbeds are very thin, less than 0.25 m in thickness, the "cleft" may incorporate the whole interbed. In some localized areas, spiracles tens of centimeters in length extend upwards from the base of the flow. Most are formed by water vapor derived from the underlying wet interbedded material that streamed upward into the lava. Vesicle trains may develop from which orientations may be taken to indicate the direction of the overriding flow (see section on flow features).

ZEOLITE INTERPRETATION

Amygdale Zones and Occurrences

Amygdales, small mineralized gas cavities, occur in zones near the lower and upper contacts of each flow unit. The lower zone contains rounded to sub-rounded amygdales from less than 1 cm. to less than 2.5 cm. in diameter. In some instances the amygdales are stretched or elongated sufficiently to indicate localized flow directions (Fig. 4.). The zone of highest amygdale concentration occurs directly above the lower contact, is variable in thickness, and extends upward as much as 2 meters into the flow. Amygdales within the lower flow occur at random and are sparsely packed. Selvages also occur within the lower zone as somewhat larger mineralized gas cavities. Their distribution is random, and their appearance is irregular. The upper zone of amygdales, on the other hand, generally ranges from 5 m to 10 m in thickness and extends to the upper contact of the unit. The amygdales first appear at random and are sparsely packed, grading upwards into dense to very densely packed zones at or near the contact. Streaks and distinct bands of amygdales are quite common near the contact in localized areas. The bands appear horizontal and range in thickness from 3 cm. to 5 cm. and may be the result of several small overlapping surges of one flow. In some areas where banding occurs, the amygdales appear irregular and the immediately surrounding rock is oxidized. Geodes (amygdales larger than 15 cm. in diameter) of highly irregular outline also occur in local areas and range up to 1 meter in diameter. One laterally persistent geode layer or band is a distinctive key horizon in the entire area and occurs at the top of flow # 3.

Amygdale Minerals and Occurrences

The amygdales contain principally zeolites with abundant chalcedony, quartz, and calcite. Minor amounts of chlorite and apophyllite, with scolecite, analcite, and mordenite are present with the principal zeolites (Elliot, 1969; Grindley, 1963). Geodes are filled with quartz, and selvages are composed mainly of zeolites, chalcedony, and quartz. The concentric arrangement of minerals in the amygdales is quite consistent . Chlorite usually forms a thin rim enclosing chalcedony. This, in turn, encloses zeolite(s) and/or quartz, with calcite crystals in the innermost part of some amygdales (Fig.). A higher abundance of quartz bearing amygdales occur in the upper zone of a given flow.

Zeolite Interpretation and Zeolite Zoning

X-ray diffraction analyses of several amygdales from different field specimens have positively identified heulandite (Ca, Na_2, K_2) Al_2, Si_7, O_{18} $6H_2O$) and stilbite (Ca, Na_2, K_2) Al_2, Si_7, O_{18} $7H_2O$) as the principal zeolites in the amygdales (Fig.). The two zeolites are generally found in association with chabazite, calcite, analcite, and natrolite (only calcite has been positively identified in the x-ray analysis;perhaps a more lengthy x-ray analysis would show that the other minerals also occur)(Walker, 1960a and Deer, Howie, & Zussman, 1963).

Zeolites which typically occur in amygdales, chiefly in mafic volcanic rocks, indicate environments of late-stage hydrothermal alteration (Deer, Howie, and Zussman, 1963). Cornu (1908) states that "in a series of zeolites crystallizing with falling temperature, the zeolites will appear in the order of increasing hydration". In acidic hydrothermal environments, virtually all the cations in basalts are removed, leaving only silica and other minor constituents. Neutral hydrothermal waters tend to form ferrugenous clays whereas alkaline waters yield little chemical change, but tend to develop new minerals such as zeolites, chlorite, and calcite (Williams, Turner, and Gilbert, 1954). Walker (1960) sees the importance in the occurrence of zeolites in that zeolites occur in distinct assemblages or zones and reflect the temperature distribution in the lava pile during zeolitization. In this scheme, the chabazite - thomsonite assemblage characterizes the upper part of the flow succession and is underlain by the natrolite-analcite assemblage. This assemblage is in turn underlain by the heulandite-stilbite assemblage in which zeolitization has been most intense (Fig. 9.) (Deer, Howie, and Zussman, 1963).

Hence, according to the zeolite zones established by Walker (1960) and the results of the x-ray analyses

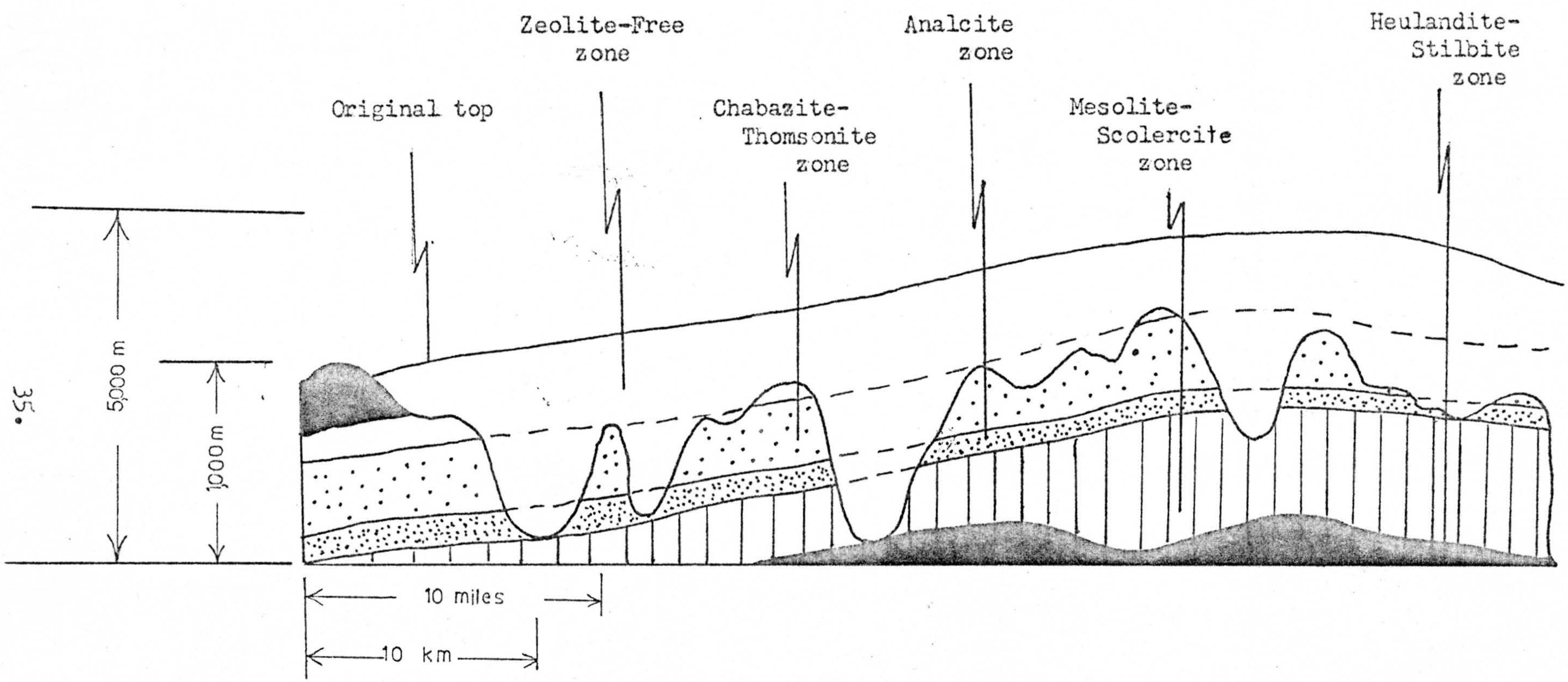


Figure 9. Diagramatic section across the Tertiary lavas of eastern Iceland showing the zonal distribution of amygdale minerals (after Walker, 1960).

of the writer, at least 1000 to possibly 1500 meters of basalt has been removed by post-Jurassic erosion, because "the amygdale minerals present are characteristic of the lowest zeolite zone" (Elliot, 1969).

THE BUMSTEAD BASALT MEMBER

Article 13 of the Code of Stratigraphic Nomenclature (1970) describes the procedure in establishing formal rock-stratigraphic units as following:

(i) statement of intention to designate a formal unit;
(ii) selection of name;
(iii) definition of unit in type area with specific location of type section;
(iv) distinguishing characteristics;
(v) definition of boundaries and contact relationships;
(vi) dimensions and shape; and, as far as possible,

(vii) geologic age and correlation.

A member is part of a formation. At Mount Bumstead the writer believes it is advantageous to recognize a specially developed part of the Kirkpatrick Basalt formation as a member. Since the member is designated solely by lithology, its usage is technically "informal"; however, some informal units are stratigraphically significant and may be recognized "formally" (article 13; 7; & 4f).

The new member formally designated is the Bumstead Tholeiite Member of the Kirkpatrick Basalt. The formal name is binomial, consisting of a geographic name combined with a descriptive lithologic term (article 10 & 13). The type section is located on the north central face of Mount Bumstead (E. long. 174 25'00", S. lat. 85 30'40"). The member consists of seven individual flows ranging in thickness from 9 m to 75 m, all typical tholeiites in their mineralogy, and amygdaloidal near the contacts. The Bumstead Basalt member lies between air-fall tuff interbeds at the lower and upper boundaries (interbeds A and C respectfully) and includes a lenticular interbed of weathered material that contains roots or a rootlet horizon (see section on Interbeds). A glassy, black, fine-grained basalt flow extends diagnostically across the width of the area and can be recognized easily for correlation. In addition, several geode horizons, especially one horizon that can be used as a good marker bed, are located near the upper contact of flow # 3 (the diagnostic fine-grained black flow just mentioned) (Fig. 12.). Since a member is a geographically restricted rock unit that terminates on all sides within the formation, it has the shape and dimensions of a lentil (article 7). Basalt from this member has a whole rock potassium/argon age of 161 million years which indicates that it is Jurassic in age. A detailed description of the lithology and contact relationships are included in another section

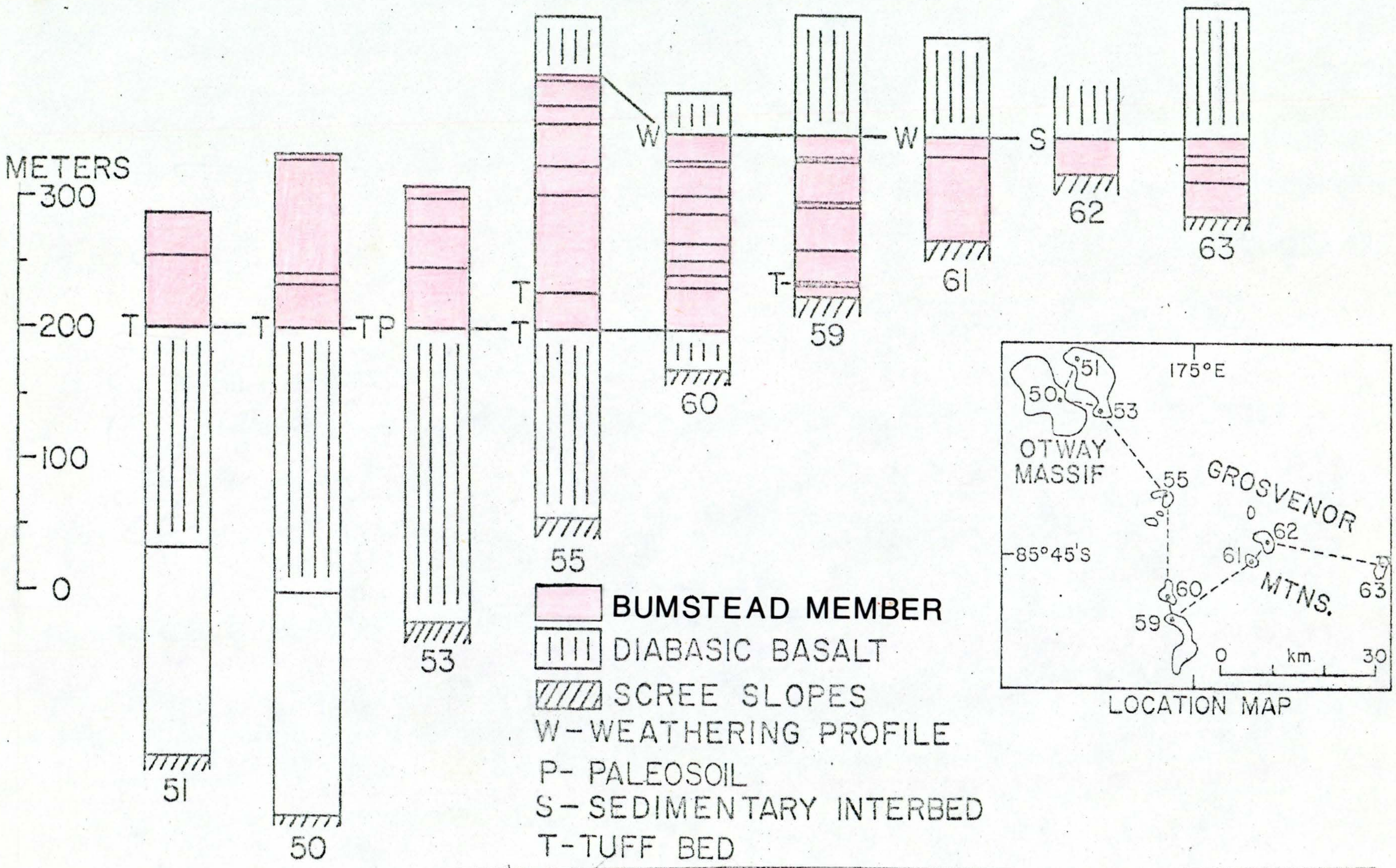
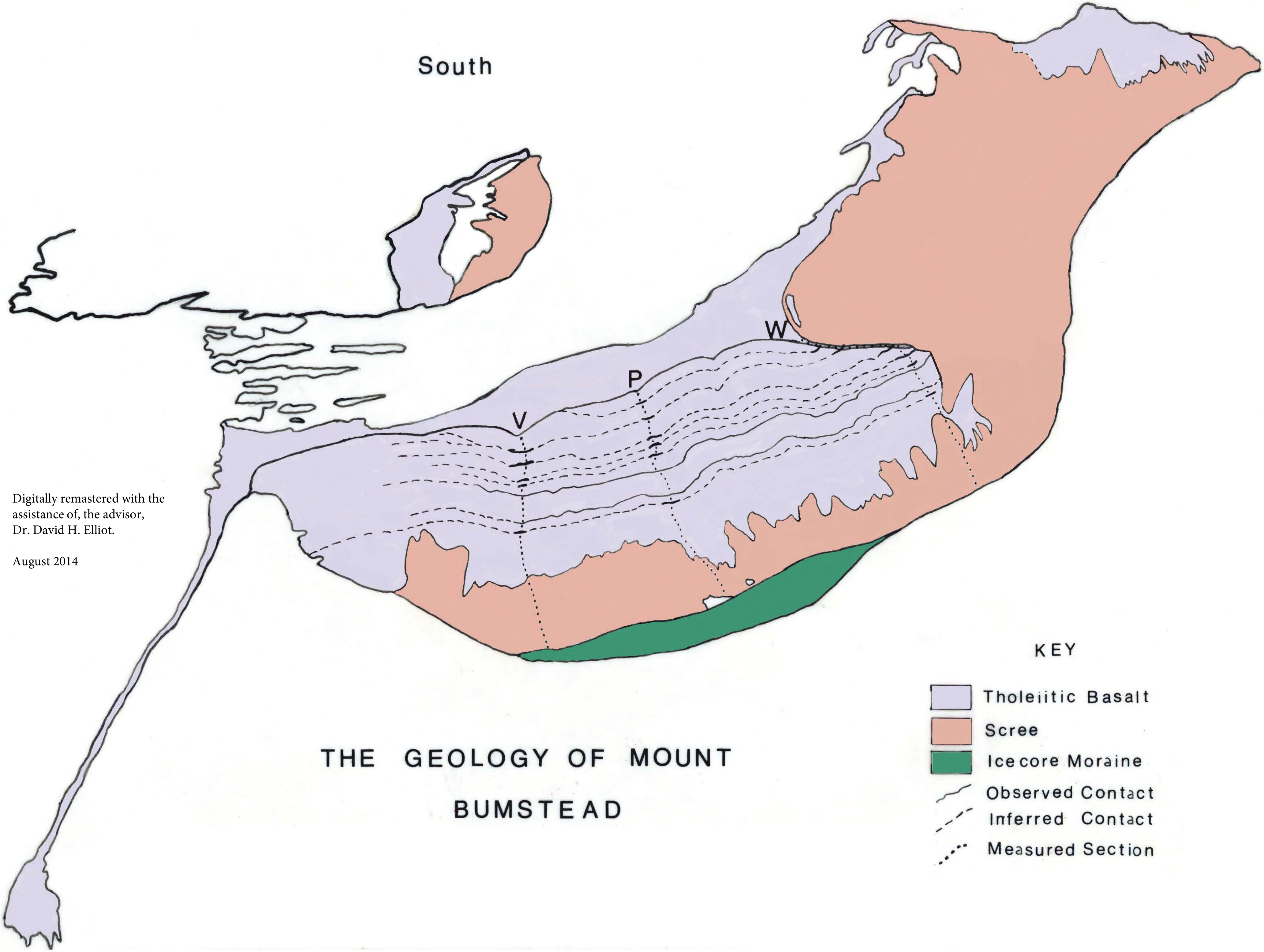


Figure 10. Stratigraphic correlation of the Bumstead Tholeiite Member, as defined in this report, of the Kirkpatrick Basalt, Otway Massif and Grosvenor Mountains (after Elliot, 1969).

50 Mt Spohn
51 Mt Petlock
53 Johnston Heights
55 Mt Bumstead
59 Mt Cecily
60 Mt Emily
61 Mt Block
62 Mauger Ntk
63 Larkman Ntk



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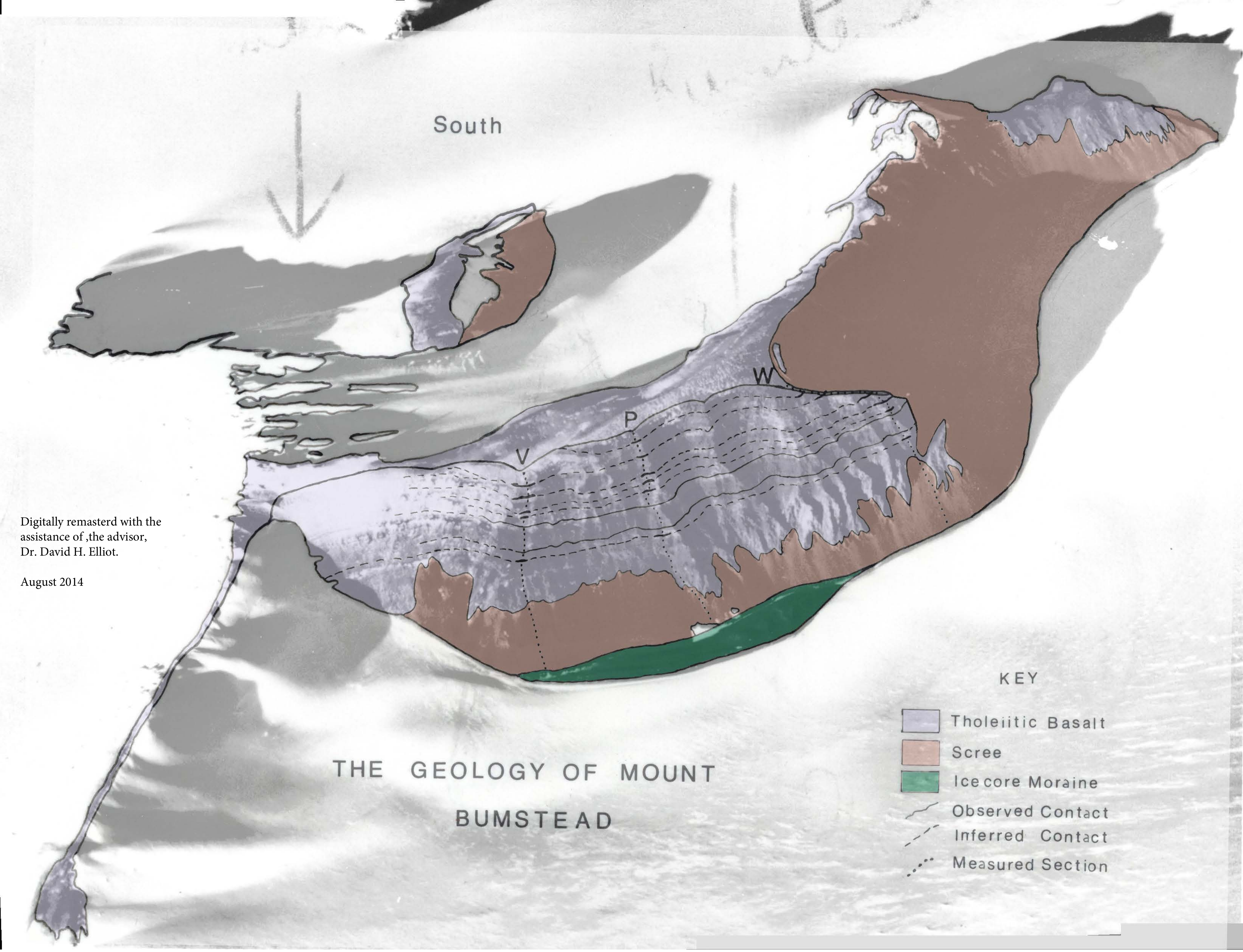
August 2014


South
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THE GEOLOGY OF MOUNT
BUMSTEAD
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Dr. David H. Elliot.
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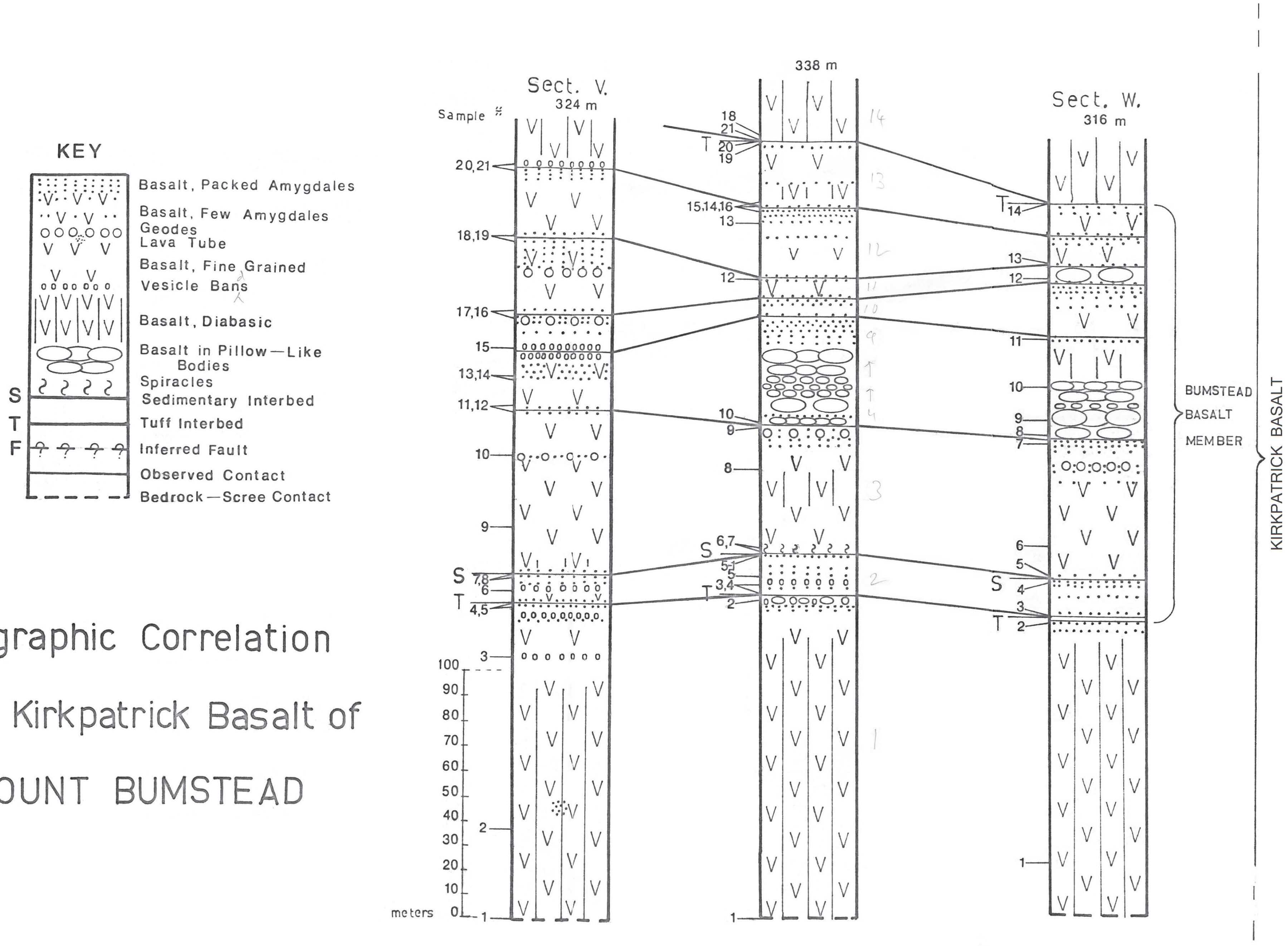

Stratigraphic Correlation of the Kirkpatrick Basalt of MOUNT BUMSTEAD of this paper (Elliot, 1969; Code of Stratigraphic Nomenclature, 1970).

PILLOW-LIKE BODIES

(PAHOEHOE TOES)

Pahoehoe lava flows are relatively common in the Mount Bumstead area. They are observed, however, only in cross-section as filled tubes (or toes), crudely circulate in structure, with concentric bonds of more or less vesicular and/or amygdaloidal lava in which the amygdales are commonly elongated tangentially. The pahoehoe flows consist of a zone or layers of toes that probably represent a single flow. The toes range from approximately 1.5 m to 8.5 m in thickness, with the average flow thickness ranging from 10 m to 25 m.

G. A. Macdonald (1967) has observed the pahoehoe toes in formation in the Hawaiian Islands and has noted the following:

> "The edge of a large slow-moving pahoehoe flow commonly does not advance as a unit, but rather by the protusion of one small tongue after another. These pahoehoe "toes" are commonly 0.1m to 1 m across and advance only 1 - 2 m before they become immobile. The crust of the flow front cracks and allows the emergence of a bulb of red-hot liquid lava, which quickly becomes covered with a dark skin that slowly stretches, drawing out the network of threads of the typical filamented surface. Many toes advance in much the same way as the small, rapidly moving pahoehoe flows mentioned above. Others extend themselves by a process of inflation; the stretching skin remains unbroken; or, if broken, is quickly resealed by lava squeezed from within. Soon, however, the skin becomes too viscous to continue its expansion, and the toe becomes immobile. Other toes move out on either side of it, and still others fill in the spaces between the earlier ones. Commonly, the end of a toe cracks open, to allow the emergence of another toe, and so on."

(Macdonald, 1967, pg. 12)

In the Mount Bumstead area vesicles and amygdales are abundant in the pahoehoe flows and are characteristically spherical or spheroidal and slightly to moderately distorted. Macdonald (1967) states as to their origin that "the gas bubbles were apparently still expanding when the liquid stopped flowing and consequently retained their spherical shape, only slightly distorted by flowage or upward movement of the bubbles" (Macdonald, 1967, pg. 14)(Flow # 4, sections P. and W., along with flow # 6, section W., exemplifies typical pahoehoe flows) (Fig. 12).

JOINTING PATTERNS

Jointing patterns probably indicate rates of cooling within a lava flow, and are due to shrinkage upon cooling. In the Mount Bumstead area the jointing patterns occur either in columnar or platy jointing patterns.

Columnar joints appear crudely developed which suggests a rapid rate of cooling in most flows. In addition, the crudely developed patterns tend to occur only in the more thick flows, usually flows over 10 m in thickness. Columnar jointing is rare in thin flows where rapid cooling tends to produce irregular, very crude columnar jointing patterns, if developed at all (Macdonald, 1962, pg. 252-261). The crude columnar patterns are primary and develop progressively as the flow cools. Secondary patterns develop from primary patterns and become broken down into smaller and smaller blocks.

Platy jointing patterns are easily observed in the field and occur consistently near the base of the flows in which they are located. The platy patterns develop parallel to flow planes and may be so closely spaced that they give the rock a sheeted or shalely appearance. At the base of flow # 1, section V., parallel joints occur on the average of 6 cm. thinning to 3 cm. in the same flow at section W.. These patterns may appear "to result from a tendency for movement to continue after the lava becomes too viscous to flow, producing a slight shearing along the flow planes" (Macdonald, 1967, pg. 43).

The consistent occurrence of platy jointing patterns near the base of lava flows may aid in predicting the nearness of contact zones that may be covered by scree. On these grounds, there may be a contact zone a very short distance below the scree contact on flow #1., perhaps not more than 10 m.

GENERAL STRUCTURAL TRENDS

Rocks at Mount Bumstead are virtually flat lying, dipping southward at less than 5 degrees. Other than the regional dip, there is no significant structure affecting the Mount Bumstead area.

APPENDIX __ GEOGRAPHY - ACCESSIBILITY - FIELD WORK - METHODS

Mount Bumstead is located in the Grosvenor Mountains in the south central Transantarctic Mountains. These nunataks protrude through the South Polar Ice Cap to an average elevation of approximately 3,000m above sea level. Mount Bumstead has an average relief of approximately 326 m and consists entirely of tholeiitic flood basalts that dip southward less than 5 degrees. The area trends generally east/west, incompassing an area of approximately 3 square miles with a volume of nearly 3/5 cu. miles of basalt (6.5 x 1/5 x 1/2 statute miles).

Mount Bumstead is 115 kilometers from the McGregor Glacier base camp in the Queen Maud Range. Field support was provided by UHID Helicopters of the United States Navies Task Force 43.

Field work at Mount Bumstead began on December 7th, continued on December 12th, and concluded on December 15th, 1970. The area was initially examined from aerial photographs and air reconnaisance prior to actual field observations. The basalts were sampled and described from three sections measured on the north central face of Mount Bumstead. Each section was measured with a Jacob Staff, and samples were collected from the lower contact zones, middle, and upper contact zones of each lava flow and also from all interbeds. Oriented samples were collected where there was evidence of flow features.

The samples were shipped to the Mendenhall Laboratory at the Ohio State University, Columbus, Ohio, for data analysis. Typical basalt samples and a sample from a sedimentary interbed have been described and analyzed petrographically on a Leitz polarizing microscope (data included in this report, see appendix___). Zeolite mineralization was determined, analyzed, and interpreted with the aid of a General Electric x-ray diffractometer, model XRD6, using a copper target x-ray tube with a nickel filter.

HISTORY OF EXPLORATION IN THE CENTRAL TRANSANTARCTIC MOUNTAINS

Knowledge of the Transantarctic Mountains (the Queen Maud Range and vicinity) was first gathered from exploratory parties aiming to reach the South Pole. The Beardmore Glacier was first ascended by Ernest Shackleton and his party during the 1907-1909 British Antarctic Expedition. Shackleton (1909) observed " a gently dipping sedimentary sequence of at least 450 meters thick, dominated by massive sandstone in the lower part and coal seams in the upper part" (Barrett, 1969). In 1911-12, Robert F. Scott, leader of the British National Antarctic Expedition, discovered Glossopteris leaf impressions at Buckley Island on his ill-fated sled journey from the South Pole. This "established for the first time the presence in Antarctica of Permo-Triassic strata similar in age and lithology to those of other Gondwana continents" (Barrett, 1969). Concurrently, Amundsen ascended the Axel Heiberg Glacier in 1911 and collected rock specimens on his return journey from the South Pole.

The area was not visited again until 1929 when Richard E. Byrd, first to fly to the South Pole, crossed the Queen Maud Range in the vicinity of Liv Glacier (Wade & others, 1965). In the same year

L. M. Gould (1931), the first geologist to visit the area, mapped portions between the Liv Glacier and the Leverett Glacier (Wade & others, 1965). In 1934 Q. A. Blackburn (1937) led a survey partly up the Thorne Glacier (now called the Robert Scott Glacier) to Mount Weaver to examine the earth's most southern points of land; however, only preliminary data of this investigation have been published. And, in 1940, Siple and Wade observed and photographed areas between the Beardmore Glacier and Liv Glacier during a flight along the northern portions of the Transantarctic Mountains (Siple, 1945).

In the late 1950's, a "new phase" of Antacrtic exploration began with unprecented international co-operation aiming at the intensive collection of scientific data from various parts of Antarctica: this was the International Geophysical Year of 1957-

1958, or IGY. From 1960 through 1965, several New Zealand field parties were active in the central Transantarctic Mountains under the leadership of Grindley and Herbert (Oliver, 1964).

The discovery of a labyrinthodont jaw fragment by Barrett "established the existence of tetrapods in Antarctica and initiated an intensive search for a fauna comparable with those from other parts of Gondwanaland" (Barrett & others, 1968; Elliot & others, 1970, pg. 265). Fossil bones and bone fragments of a labyrinthodont were discovered at Coalsack Bluff in 1969 by D. H. Elliot of the Institute of Polar Studies, The Ohio State University. The following year, J. W. Collinson, of the same institute, found the first whole vertebrate skeleton, a Thrinaxodon, in Antarctica in the McGregor Glacier area. The discovery of the vertebrate fossils in the Transantarctic Mountains, closely comparable to the South African species, definitely "lends further support to the concept of Gondwanaland and continental drift" (Kitching & others, 1972).

STRATIGRAPHIC SECTIONS

This appendix contains the field description of each of the three sections measured at Mount Bumstead. The strata are described with the hand samples, numbered in ascending order. The first column contains the flow thickness (in meters) above the base of the flow. The second column contains the rock sample number; and the third column contains a brief description of the samples collected along with other relative comments.

Each stratigraphic unit is identified by a letter signifying the section location and a digit identifying the rock sample collected. Thus each sample is individually identified by two characters: V. 14. signifies the northeast section, sample number 14.

Rock properties are described in the following order: lithology, color of unweathered surface, weathered color ("weathers" has been abbreviated to "w/"), grain size (cryptocrystalline has been abbreviated to crypto.), and then other relevant comments. The nature of the contact between units is briefly described; however, a more detailed description is found in the section "Contacts and contact relationships", page 25 .

Mount Bumstead

Stratigraphic section V.

December 7, 1970

Northeast section

Meters	Sample	Scree....
	V.1.	Basalt, grey to greenish grey (w/ red brown), crystalline, some concentrated iron oxidation.
		vertical jointing
31.5		platy jointing, exfoliation
37.7	V.2.	Basalt, yellowish grey (w/ dark red brown), crystalline, highly oxidized.
46.5		possible lava tube or down dropping?
66		exfoliation of smooth "w" iron crusts....
100		platy jointing patterns, dut to

Meters	Samples	
		vesicle bands or differential movement of lava pond?
103.6	V.3.	Basalt, grey to dark brown (w/dark brown to red brown), crystalline... glassy, traces of very small amygdales.
		amygdale zone
123		bands of vesicles and amygdales... 1.5 in. separated 2 in. of basalt.
	V.4	Basalt, amygdaloidal, light bluish brown (w/ pitted brown tan), crypto., stretched amygds. filled mostly with heulandite altered to a blue/ green mineraloid chlorite? up to 1 cm in diameter.
	V.5.	Tuffite Interbed, blue-green to light green (w/ lightgreen), pyroclastic ash, cross-bedded, thinly laminated. Basalt and amygdale fragments (sand size) laminated. Approx. 30 cm thick.
127.1		CONTACT......very irregular

<u>Flow # 2</u>

Meters	Samples	
2.6		End of baked contact zone....end of amygdale zone.
6	V.6.	Basalt, amygdaloidal, grey (w/ very dark red brown, pitted), crystalline, traces of chlorite alteration, amygd. filled with chalcedony and subrounded, up to 1 cm in diameter.
12	V.7.	Basalt, amygdaloidal, buff brown (w/ light reddish brown), crypto., elliptical amygds., filled with chalcedony and heulandite, up to 2 cm in diameter.
	V.8.	Interbed, light green (w/ brown), sedimentary, pyroclastic tuff. Thinly laminated, brecciated.

CONTACT....very irregular

<u>Flow # 3</u>

Meters	Samples	
4.5		End of platy jointing...rocks become massive and crystalline.
19	V.9.	Basalt, dark grey (w/ light red brown), crystalline, some iron oxidation.
20		platy jointing patterns...
53.5	V.10.	Basalt, black (w/ red brown),

Meters	Samples	
		crypt., glassy, highly fractured... large geode horizon...quartz fillings.
55.5	V.11.	Basalt, highly amygdaloidal, green to brown (w/ brown pitted to dark brown), crypto., basalt. Amygds. contain chalcedony, heulandite, stilbite, and calcite, 1 cm in diameter, and altered to chlorite?
60		CONTACT....slightly irregular, maybe erosional?
		<u>Flow # 4</u>
4.5	V.12.	Basalt, black to brown/black (w/ dark red brown), crypto., glassy, small rounded concentrations of iron which weathers out resulting in a pit-like appearance.
13.5	V.13.	Basalt, amygdaloidal, brown (w/ red brown, pitted); crypto., amygds. rounded and densely compacted, filled with crystals of heulandite, chalcedony, and stilbite, some chlorite alteration?

Meters	Samples	
14.5		new zone of amygdales.
26.2		CONTACT...."cleft", regular to slightly irregular zone.

Flow # 5

Meters	Samples	
	V.15.	Basalt, highly amygdaloidal, light red brown (w/ pitted brown to yellowish brown, pitted), crypto., highly stretched amygds. of chalcedony and heulandite, up to 0.25 cm in diameter.
7		new zone of amygdales.
15	V.17.	Basalt, amygdaloidal, light brown (w/ pitted brown), crypto., amygds., filled with chalcedony and quartz, elliptical, up to 1 cm in diameter, outside perimeter is chloritized? geodes.
		CONTACT....poorly defined "cleft"; very irregular, erosional?

Flow # 6

Meters	Samples	
	V.18.	Basalt, amygdaloidal, pinkish-brown (w/ very pitted dark red brown), crypto., sparse random amygds. filled with chalcedony and chloritized...subrounded, 0.25 cm in diameter.
16		Geode horizon and beginning of a new zone of amygdales.
31		CONTACT....highly weathered, baked contact zone.

Flow # 7

1	V.19.	Basalt, black to greenish grey (w/ very dark red brown), cryto., some chloritic alteration?
3o	V.20.	Interbed, light greenish brown (w/ brown to dark brown), pyroclastic ash (tuff), brecciated...angular amygdale and basalt fragments randomly distributed, 0.75 cm in diameter, some fragments are altered to chlorite?
	V.21.	Basalt, vesicular, brown to light brown (w/ very dark brown)(pitted),

crypto.,contains numerous small, oxidized vesicles up to o.1 cm in diameter.

CONTACT....this contact is almost devoid of amygdales.

Flow # 8

Not sure if intrusive or extrusive.

21 Top of Mount Bumstead...End of section V.

Stratigraphic Section P.

December 12, 1970

(Middle Section)

Meters	Samples	
		Scree.....
	P.1.	Basalt, dark grey (w/ dark red brown), crystalline. Slight iron oxidation throughout.
87		traces of amygdales, scattered.

113 color and texture change from brown/crystalline to black/ cryptocrystalline...probably due to change in chemical composition

125 back to brown amygdaloidal basalt.

130 P.2. Basalt, highly amygdaloidal, red to red brown (w/ yellow brown, pitted), crypto., rounded, tightly compacted amygds. filled with heulandite. Oriented Sample (N55 E).

Interbed, green to light green (w/ dark green), pyroclastic ash sedimentary cross-bedding, thinly laminated with laminated sand size basalt and amygd. fragments, (tuffite).

CONTACT....irregular and highly baked.

Flow # 2

0.5 End of contact and amygdale zone.

3 Platy jointing pattern.

7.5 New zone of amygdales.

Meters	Samples	
	P.4.	Basalt, amygdaloidal, red brown (w/ brown to light red brown, pitted), crypto., subrounded amygds. filled with chalcedony altered to chlorite to 1 cm in diameter. Some are altered to the green mineraloid chlorite.
	P.5.	Basalt, amygdaloidal, dark grey (w/ pitted, light brown), crypto., highly stretched amygdales of quartz, stilbite, heulandite, and chalcedony. Stretched to 2 cm.
	P.5.1.	Interbed, buff brown (w/ brown to red brown), weathered material? very fine grained, inclusions of roots or root-like casts filled with iron. Possible paleosol? 0.5 m thickness.

Spiracle protruding into overlying flow with train of vesicles. Oriented Sample (N10 W).

CONTACT....weathered surface?

Flow # 3

Meters	Samples	
19.5		End of platy jointing patterns and base of massive fine grained glassy basalt.
33	P.8.	Basalt, black (w/ dark brown), crypto., glassy, a trace of iron oxidation.
48		New zone of amygdales.
50		Geode horizon, very diagnostic.
56	P.9.	Basalt, amygdaloidal, buff brown (w/ brown to pitted greenish brown), crypto., subrounded, randomly distributed amygds. filled with amethyst quartz, chalcedony, and heulandite, to 0.5 cm in diameter.
56.6		CONTACT....very irregular.

<u>Flow # 4</u>

	P.10.	Basalt, amygdaloidal, geey to brown (w/ tan brown), crypto., stretched amygdales filled with chalcedony, and quartz crystals to 2 cm.

Meters	Samples	
		Beginning of vertical sequence of Pahoehoe Lava Toes.
1.5		CONTACT....
1.5		CONTACT....
4.5		Bands of amygdales...typical concentric bands.
7.5		CONTACT....Poorly defined.
4.5		New zone of amygdales.
7.7		CONTACT....irregular and poorly defined.
3.5		CONTACT....End of zone of Pahoehoe toes.
8.5		CONTACT....normal contact zone.
		<u>Flow # 5</u>
0.5		End of contact zone and zone of amygdales.
9		CONTACT....

Meters	Samples	
		<u>Flow #6</u>
10	P.12.	Basalt, amygdaloidal, dark red brown (w/ very dark red brown, pitted), crystalline; amygds., subrounded, filled with stilbite, quartz, and heulandite to 0.75 cm. in diameter. Some are completely altered to chlorite?
		CONTACT....regular.
		<u>Flow # 7</u>
16		New zone of amygdales. Very large amygdales, 2 cm to 6 cm in diameter.
	P.13.	Basalt, amygdaloidal, light grey (w/ brown to red brown, pitted), crystalline, amygds., all are small, rounded, almost all have been completely altered to chlorite?
28	P.15.	Basalt, highly amygdaloidal, brown (w/ red brown, pitted), crypto., subrounded, densely compacted amygds. filled with heulandite. Other perimeter altered to light green chlorite?
		CONTACT....slightly irregular.
		<u>Flow # 8</u>

Meters	Samples	
	P.14.	Basalt, amygdaloidal, orange brown (w/ green to red brown, pitted), crypto.; large amygds. of chlorite, quartz, heulandite, and chalcedony. Oriented sample (N10 E).
6	P.16.	Basalt, dark grey (w/ dark brown), crystalline, some iron oxidation, and some chloritic alteration.
12		New zone of amygdales.
27	P.17.	Basalt, vesicular, yellow brown (w/ dark yellow brown, pitted), crypto., vesicles appear as areas of iron concentrations due to oxidation.
	P.18.	Basalt, amygdaloidal, orange brown (w/ brown, pitted), crypto., large amygds. filled with amethyst and smokey quartz, chalcedony, and heulandite, up to 3.5 cm in diameter. Oriented sample (N55 E).
	P.19.	Interbed, brown, (w/ dark brown), massive pyroclastic ash (tuff),

Meters	Samples	
		large whole rock basalt incorporated, weathered contact?
		CONTACT....poorly exposed and/or not well developed, the arubt contact zone consists of amygds. below the contact but not typically extending into the new flow.
		<u>Flow # 9</u>
	P.20.	Basalt, light grey (w/ red brown), stringers of chalcedony. Some concentrated iron oxidation.
25		Top of Mount Bumstead....End of Section P.

Stratigraphic Section W.

December 15, 1970

Northwest Section

Meters	Samples	
		Scree.....
25	W.1.	Basalt, grey (w/ red to brown), crystalline. Some iron oxidation throughout. Platy jointing patterns....may

Meters	Samples	
		indicate nearness of lower contact?
117		New zone of amygdales.
120	W.2.	Basalt, pink to red (w/ yellowish brown), crypto.
		Interbed, (tuff) sedimentary, upper 8 in. laminated, 2 m thickness; "cleft" developed at upper surface of interbed but not at the lower surface.
		CONTACT....
		Scree....
	W.3.	Basalt, amygdaloidal, very dark grey (w/ yellowish brown, pitted), crypto. highly stretched amygdales of chalcedony, heulandite, with chloritic alteration? (2 cm long) <u>Oriented sample (N75 W)</u>.
7.5		New zone of amygdales...bands 0.5 in. vertical with 3 in. separation between bands.
15	W.4.	Basalt, amygdaloidal brown (w/ light brown, pitted), crypto., subrounded amygds. filled mainly with heulandite up to 1.5 cm in diameter.

Meters	Samples	
	W.5.	Interbed, light grey (w/grey to red brown), pyroclastic ash (tuff), with rootlets and/or root casts filled with iron or silica? Weathered material? Paleosol? 0.5 m thickness.
		CONTACT....regular.
		<u>Flow # 3</u>
6		End of platy jointing pattern.
15	W.6.	Basalt, black (w/ grey), crypto., glassy, diagnostic.
40		New amygdale zone.
45		Key geode horizon...1 m to 3 m in diameter, filled with quartz and chalcedony.
57	W.7.	Basalt, amygdaloidal, purplish to brown (w/ red brown to brown, pitted), crypto., amygds. ave. 2 cm in diameter, subrounded to stretched, consists of heulandite and chalcedony.
		CONTACT....irregular.
		<u>Flow #4</u>
		Beginning of vertical sequence of Pahoehoe Lava Toes.

Meters	Samples	
	W.8.	Basalt, amygdaloidal, light brown to grey (w/ dark red brown, pitted), crypto., subrounded to rounded, amygds. filled with chalcedony and altered to chlorite. Oriented sample (N55 W).
3		New zone of amygeales.
6		CONTACT....irregular toes exemplify "cleft".
4.5		New zone of amygdales.
	W.9.	Basalt, amygdaloidal, dark brown (w/ dark brown, pitted), crypto., subrounded to stretched amygds. filled with heulandite.
7		CONTACT.....
1.5		CONTACT.....
2		New zone of amygdales.
5		CONTACT.....
4		End of zone of Pahoehoe lava toes.
	W.10.	Basalt, dark grey (w/ very dark red brown), crypto., some iron oxidation throughout.

Meters	Samples	
		Beginning of platy jointing pattern.
12		End of platy jointing pattern.
18.5	W.11.	Basalt, amygdaloidal, brown (w/ red brown, pitted), crypto., amygds. filled with stilbite and heulandite. <u>Oriented sample (N50 W)</u>.
		CONTACT....
		<u>Flow # 5</u>
12		New amygdale zone.
21		CONTACT....
		<u>Flow # 6</u>
2	W.12.	Basalt, amygdaloidal, light grey (w/ light grey, pitted), crystalline, amygds. subrounded, most completely altered to chlorite?
		Zone of Pahoehoe lava toes.
		CONTACT....very irregular.
		<u>Flow # 7</u>
	W.13.	Basalt, amygdaloidal, brown (w/ brown, pitted), crypto., amygds. stretched and highly zealitized, chlorite alteration around amygd. perimeter. Average amygd. diameter

Meters	Samples	
		is 0.25 to 0.50 cm. <u>Oriented sample</u> <u>(N75 E)</u>.
10		New zone of amygdales.
		CONTACT....
		<u>Flow</u> <u># 8</u>
		Spiracle (no orientation).
10.5		New zone of amygdales.
13.5	W.14.	Basalt, amygdaloidal, dark grey (w/ purplish grey), crypto., amygds. subrounded to highly stretched, ave. diameted is 0.50 cm and stretched to 3 cm filled with heulandite, stilbite, and chalcedony.
		Traces if an interbed, but poorly exposed due to scree accumulation.
		CONTACT....very irregular. The existence of an interbed and an irregular contact suggests that an overlying basalt is extrusive rather than intrusive.
		<u>FLOW</u> <u># 9</u>
27		Top of Mount Bumstead. End of Section W.

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