Hamilton and Hayes—TYPE SECTION OF THE BEACON SANDSTONE OF ANTARCTICA—Geological Survey Professional Paper 456-A

Type Section of the Beacon Sandstone of Antarctica

GEOLOGICAL SURVEY PROFESSIONAL PAPER 456-A

Prepared on behalf of the National Science Foundation

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By WARREN HAMILTON *and* PHILIP T. HAYES

CONTRIBUTIONS TO THE GEOLOGY OF ANTARCTICA

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TYPE SECTION OF THE BEACON SANDSTONE OF ANTARCTICA

By Warren Hamilton and Philip T. Hayes

ABSTRACT

The Beacon Sandstone of Carboniferous(?), Permian, and early Mesozoic(?) age is widely distributed in East Antarctica. The formation was named by Ferrar in 1907 for exposures in Beacon Heights, near Taylor Glacier west of McMurdo Sound, but no type section has previously been described. This paper presents a composite section in the type area, assembled from a published description of the basal strata by Zeller and others (1961), a previously unpublished description of the middle part by the present authors, and a published description of the upper part by McKelvey and Webb (1959).

The Beacon Sandstone in its type area consists largely of light-colored medium- to coarse-grained sandstone, much of it crossbedded. Beds of fine-grained sandstone and siltstone are subordinate. Carbonaceous strata bearing constituents of the *Glossopteris* flora occur high in the formation. The middle part of the formation consists of cliff-forming sandstone, easily recognizable throughout the region, and is separated from the ledge-forming section beneath by a disconformity. Total thickness of the Beacon is about 4,000 feet. Intrusive into the Beacon are huge sills and inclined sheets of quartz diabase (the Ferrar Dolerites) of Mesozoic age, which have an aggregate thickness of about the same amount.

The three major units of the Beacon Sandstone in its type area are here referred to as the sandstone of New Mountain (the lower ledge-forming unit), the sandstone of Pyramid Mountain (the middle cliff-forming unit), and the sandstone of Finger Mountain (the upper ledge-forming fossiliferous unit). A thin sequence of diverse rocks, described by Zeller and others (1961), beneath the sandstone of New Mountain may not properly belong to the Beacon Sandstone.

Although several authors have proposed recently that the Beacon be elevated to group status, they have not established mappable formations within the Beacon; consequently, their proposals are premature. Because geologic fieldwork is likely to be of reconnaissance character and in widely separated areas for some time to come, it seems preferable for the present to maintain formation status for the Beacon Sandstone and to subdivide it into local formal members only when the utility of these is demonstrated by detailed work.

INTRODUCTION

The Beacon Sandstone of Carboniferous(?), Permian, and early Mesozoic(?) age forms a discontinuous cover upon much of East Antarctica, the large part of the continent lying mainly in east longitudes (fig. 1).

The sandstone carries a *Glossopteris* flora and shares many features with correlative rocks of the other "Gondwana" landmasses of Australia, India, South Africa (Karroo System), and South America.

The Beacon Sandstone was named by Ferrar (1907) for exposures on West Beacon Heights on the south side of upper Taylor Glacier (figs. 2 and 3), South Victoria Land. He estimated that about 2,500 feet of sandstone are present there but did not describe a type section. McKelvey and Webb (1959) presented a detailed section of the upper part of the formation in the type area, and Zeller and others (1961) described the basal part. These partial sections are here tied to the section studied by us in the middle part of the formation on West Beacon Heights to give, for the first time, a reasonably accurate type section of the Beacon Sandstone.

The Ross Sea coast of East Antarctica is bounded by a range of high mountains, which forms a dam against the vast inland ice plateau. Valley outlet glaciers, one of

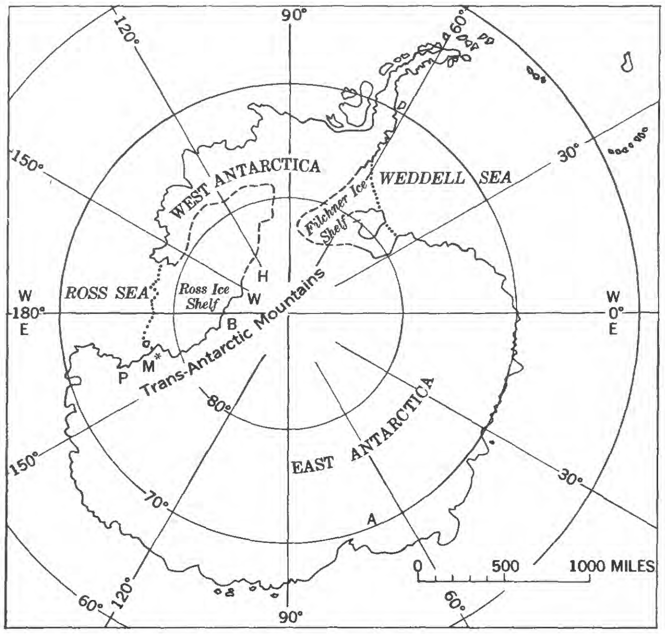

FIGURE 1.—Index map of Antarctica. Asterisk indicates location of Beacon Sandstone type locality. Localities mentioned in text are Priestley Glacier, P; Mount Gran, M; Beardmore Glacier, B; Mount Weaver, W; Horlick Mountains, H; and Amery locality, A.

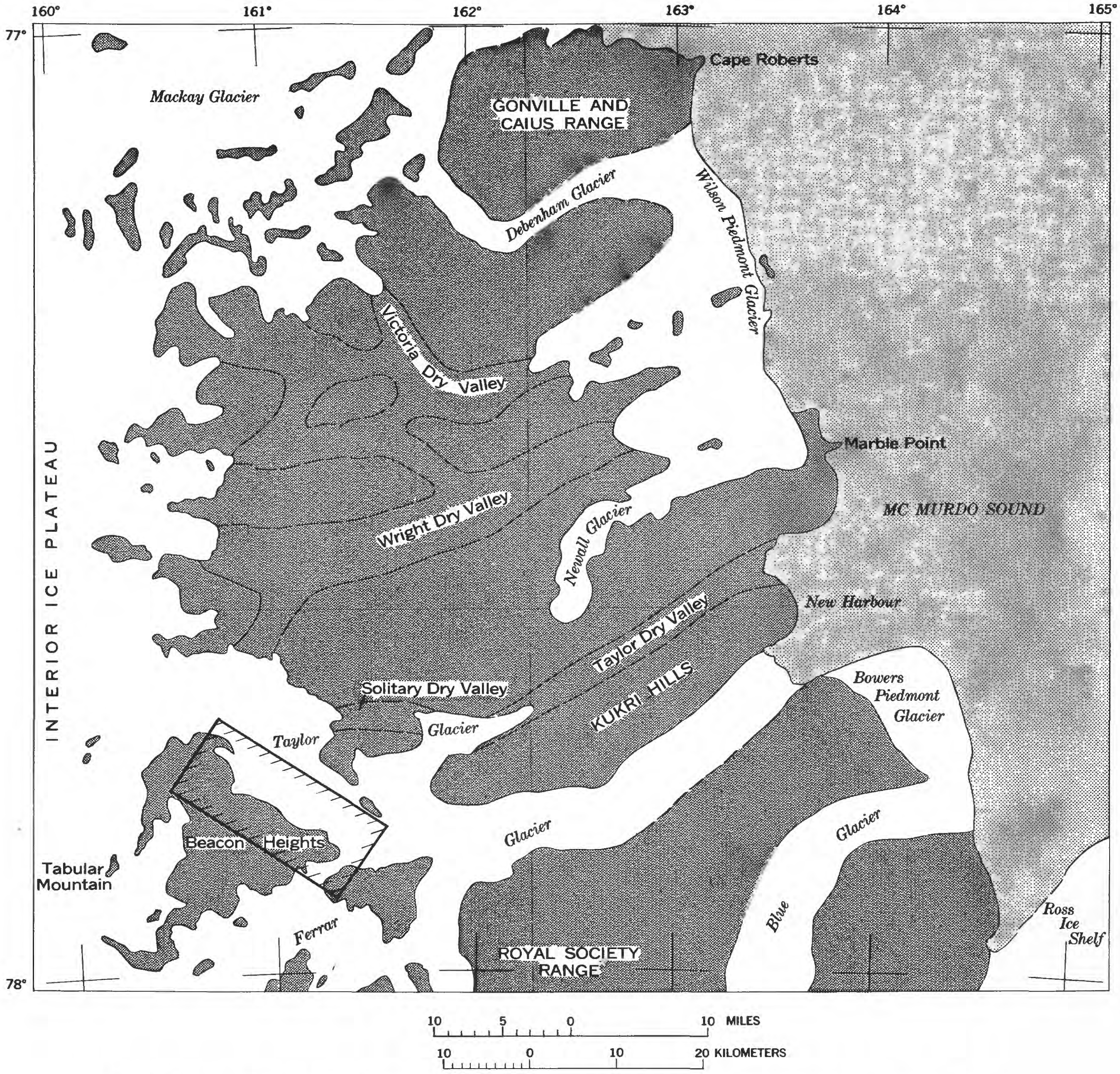

FIGURE 2.—Index map of mountains west of McMurdo Sound. Hatched line outlines area of geologic map (fig. 3).

which is Taylor Glacier, flow across these mountains from the plateau toward the sea through the major transverse valleys. Pre-Devonian granitic and metamorphic rocks form the coastal foothills and lower areas in the central part of the range. Above these basement rocks in the central part of the range, and forming nearly all the exposed rock of the western part of the range, is the almost undeformed Beacon Sandstone and the diabase sheets intruded into it.

Our fieldwork on the type section was done during November 1958, from a camp on Taylor Glacier, to which we were flown by a U.S. Navy ski-equipped airplane, as part of our study of the Taylor Glacier-Taylor Dry Valley region (Hamilton and Hayes, 1960).

We are much indebted to L. H. Daugherty, S. H. Mamay, J. J. Mulligan, and J. M. Schopf for permitting us to cite some of their unpublished data on the paleobotany of the Beacon Sandstone. To Schopf in particular must also go much of the credit for the discussion of paleobotany and age of the Beacon.

This work was carried out on behalf of the National Science Foundation.

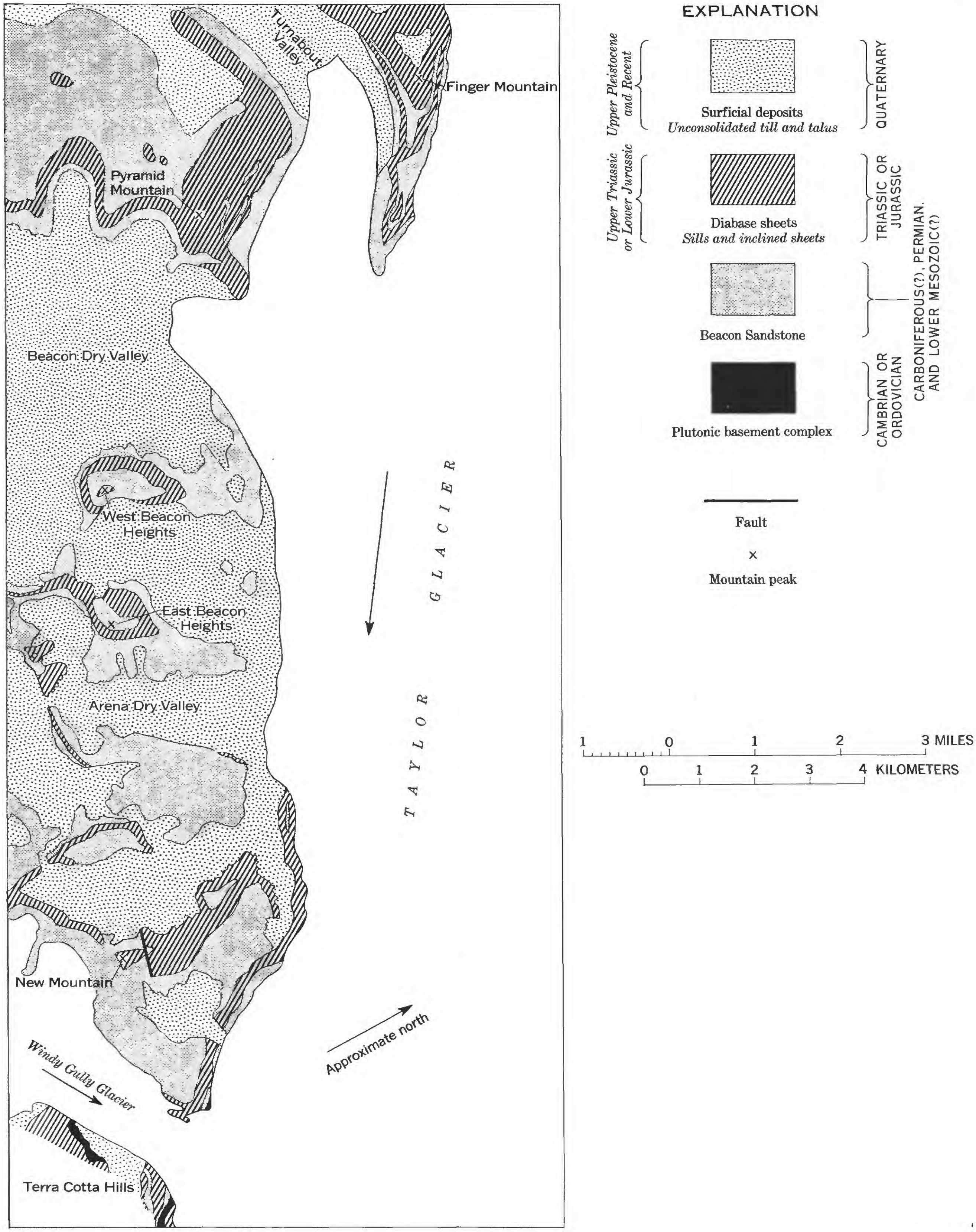

FIGURE 3.—Geologic map of Beacon Heights and vicinity. Map prepared by photogrammetric methods from vertical aerial photographs, supplemented by field observations and by ground and oblique aerial photographs. Dashed contacts modified from McKelvey and Webb (1959). Arrows show direction of ice flow.

TYPE SECTION

The Beacon Sandstone of the type area (fig. 3) is about 4,000 feet thick and dips 2°–4° westward. The few faults are short and of small displacement. Injected into the sandstone are huge sills and inclined sheets of quartz diabase with an aggregate thickness of about 4,000 feet, so that the total thickness of sandstone and diabase is about 8,000 feet. The local relief is but 4,000 feet, and it is necessary to define a composite type section from separate traverses.

The base of the Beacon Sandstone crops out at the southeast end of the mountain mass of the type area, and here Zeller and others (1961) described the lower part of the formation. We measured the middle part of the formation at West Beacon Heights, 7 miles to the northwest. McKelvey and Webb (1959) described the upper part of the sandstone 3 miles farther west.

All but the basal strata of the Beacon are divisible into three easily recognized units in the type area and the surrounding region. The lower unit, here referred to as the sandstone of New Mountain, is ledge-forming sandstone. The middle unit, the sandstone of Pyramid Mountain, is thick bedded and cliff forming. The upper unit, the sandstone of Finger Mountain, is ledge forming and includes much siltstone and carbonaceous strata. These units are defined more fully on page 10.

LOWER PART

The base and lower part of the Beacon Sandstone were examined by Zeller and others (1961) on the

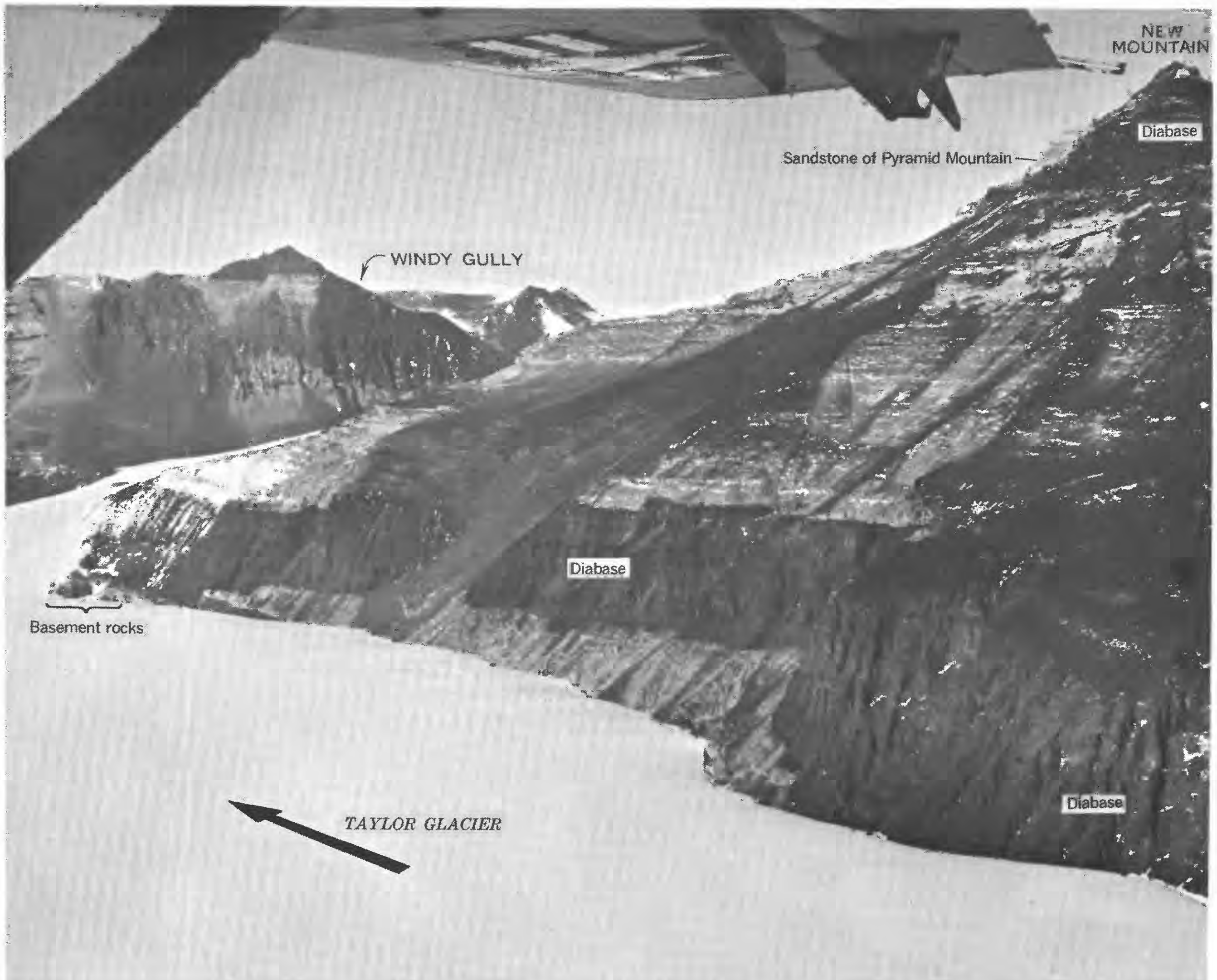

FIGURE 4.—New Mountain, seen from the north, showing the lower part of the Beacon Sandstone. Pre-Devonian basement rocks crop out at base of bluffs by Windy Gully. A thick diabase sill lies near the base of the Beacon, and another is at the top of New Mountain. The cliff-forming sandstone of Pyramid Mountain, the middle part of the Beacon, is visible to the left of the upper sill. The summit of New Mountain (alt about 7,800 ft) is 4,000 ft above Taylor Glacier.

lower northeast slope of New Mountain, a short distance northwest of Windy Gully (figs. 3 and 4), and in the Terra Cotta Hills on the southeast side of Windy Gully. The section they described is illustrated, diabase sills omitted, in figure 5.

The bedded rocks lie upon a surface with a local erosional relief of 100 feet cut into pre-Devonian plutonic rocks. A discontinuous basal conglomerate 0–5 feet thick grades upward into sandstone 5–100 feet thick that contains thin cobble beds; this basal section was designated the "Windy Gully Member" by Zeller and others (1961). Next above is the Terra Cotta Mountain Member of Zeller and others, which consists of 110 feet of interbedded green and purple shale and green, pink, white, and brown sandstone. This is succeeded, with what Zeller and others described only as a "decided break in sedimentation," by about 250 feet of white to buff sandstone, crossbedded in part, with pebbly beds. (At or near the top of this unit in this measured section is a diabase sill nearly a thousand feet thick). The next higher strata are 40 feet of thin-bedded buff and green sandstone, and above these is a thick sequence of beds

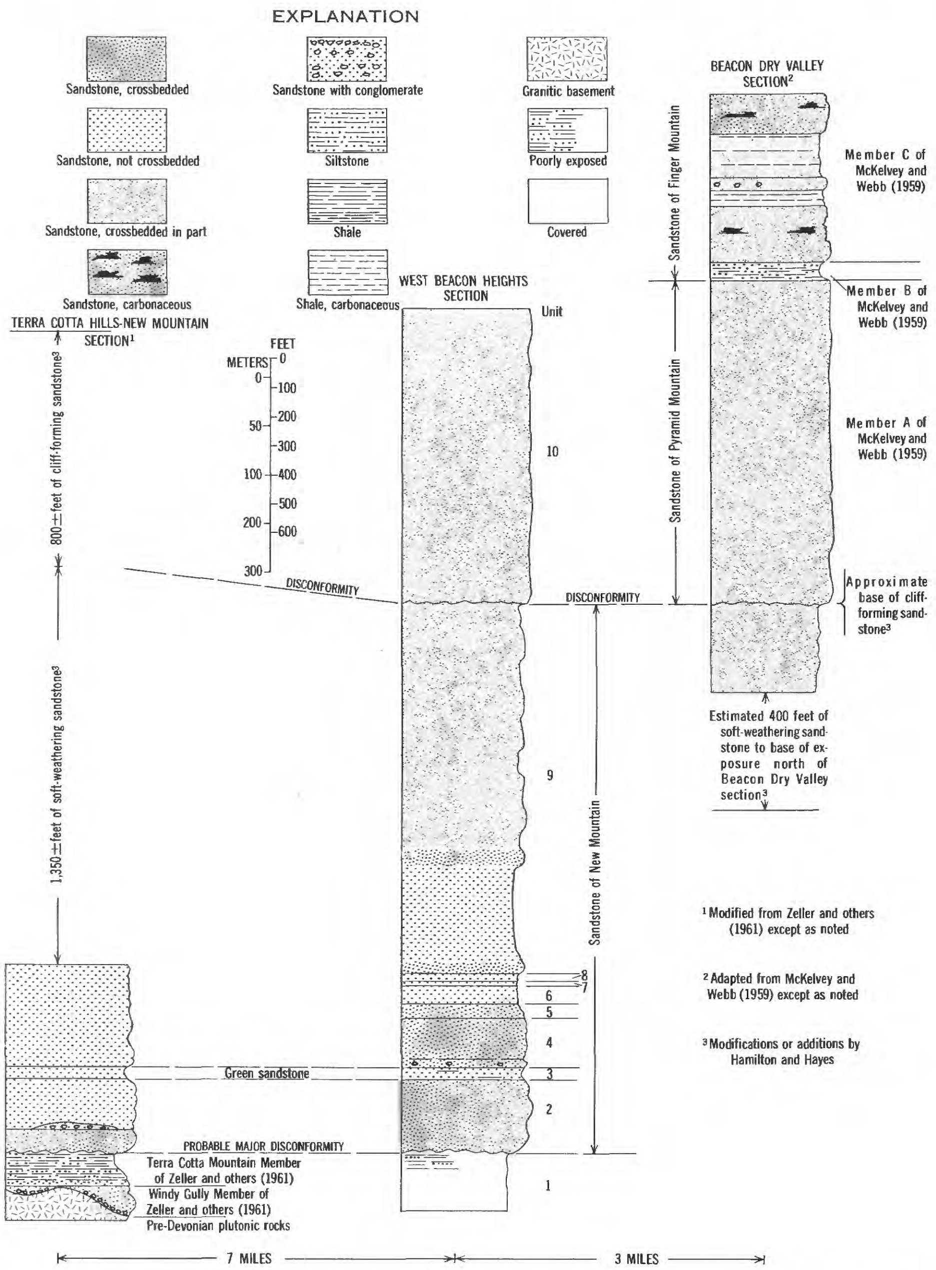

Figure 5.—Columnar sections of Beacon Sandstone at and near West Beacon Heights. These three sections form a composite type section.

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of alternately hard and soft thin-bedded to massive buff sandstone. Only the lower 350 feet of this upper part was measured. This upper unit was called "Member A1" by Zeller and others, who supposed it to correlate with the lower part of the section measured by McKelvey and Webb (1959). Because of the westerly regional dip, these rocks near Windy Gully actually lie far beneath the section studied by McKelvey and Webb.)

On vertical and oblique aerial photographs of New Mountain, alternate layers of hard and soft sandstone, weathering to form a rather smooth slope, can be seen to continue upward for a total thickness (including the 350 ft. measured by Zeller and others) of about 1,700 feet. The top of this slope-forming sandstone sequence is marked by an apparently disconformable contact with cliff-forming thick-bedded sandstone, about 800 feet thick, that continues to the base of the sill that caps New Mountain.

MIDDLE PART

The middle part of the type section of the Beacon Sandstone was studied by us on the lower north slope of West Beacon Heights (figs. 3, 5, and 6) above Taylor Glacier about 1½ miles east of the mouth of Beacon Dry Valley. We measured the lower 1,200 feet of the section (fig. 3) and determined the character of higher strata by binocular inspection from the top of the measured section and by examination of talus fragments. Thicknesses of the measured section were determined by aneroid altimeter, supplemented by height-of-eye measurements for thin units; thicknesses of the

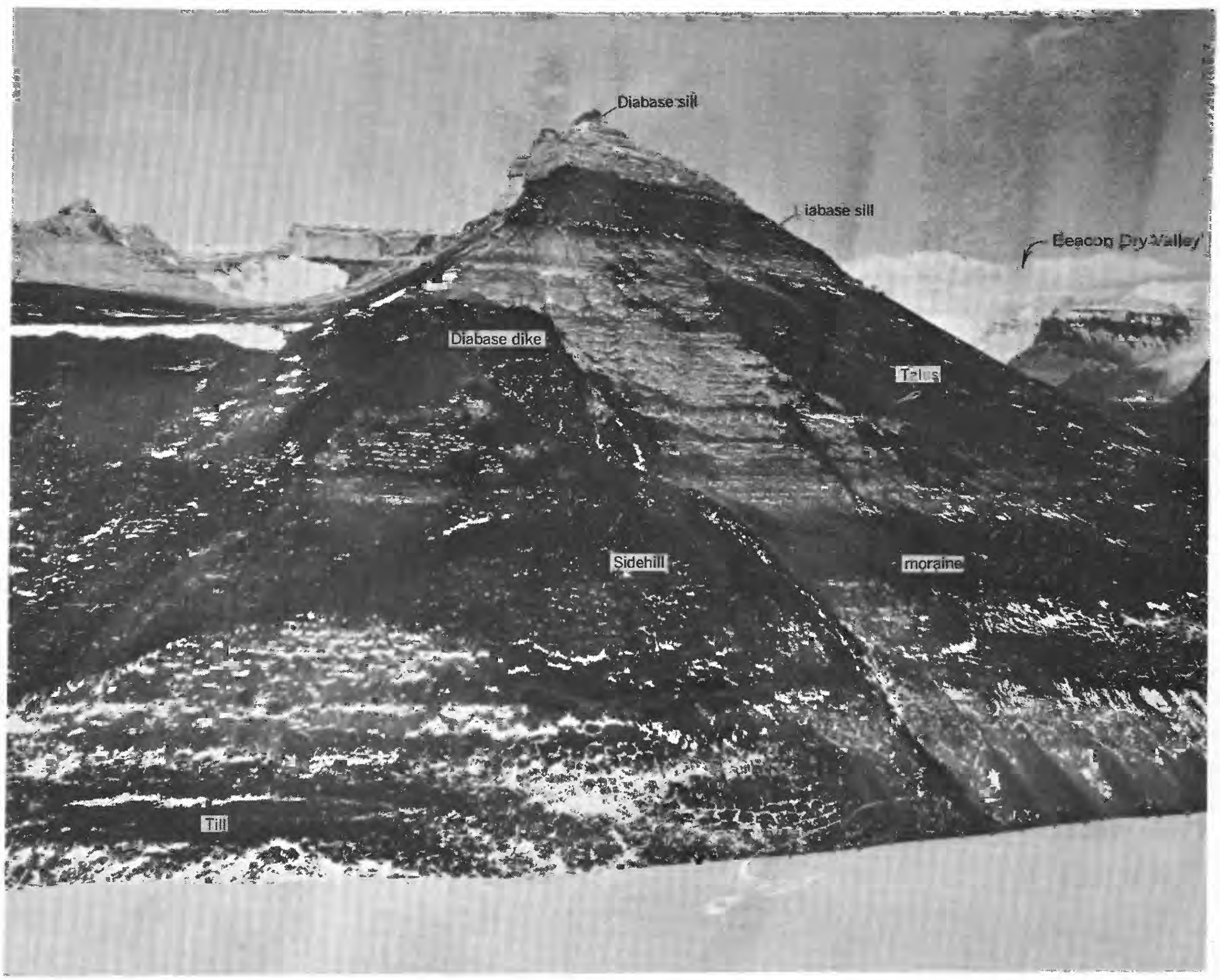

FIGURE 6.—West Beacon Heights seen from the northeast, showing the middle part of the Beacon Sandstone cut by diabase dikes and sills. The cliff-forming sandstone unit (sandstone of Pyramid Mountain) extends upward from the level of the hanging valley on the left. Frost polygons mark the talus and sidehill moraine near Taylor Glacier at the base of the mountain. The summit has an altitude of about 7,800 ft and stands 4,000 ft above Taylor Glacier.

overlying rocks, extending to the top of West Beacon Heights, were measured by rough triangulation from Taylor Glacier and confirmed photogrammetrically.

The following is the description of the middle part of the type section of the Beacon Sandstone as exposed on the north slope of West Beacon Heights:

Top of section: base of diabase sill that caps West Beacon Heights

	Thickness (feet)
10. Sandstone and quartzite, pale pink, buff, and white, medium- to coarse-grained; striped by irregular brown bands on weatherer outcrops; thick even beds form cliffs. (Diabase sill, 400 ft thick, injected into the middle of this unit is not included in the stratigraphic thickness)	1,000±
9. Sandstone, yellowish-gray, medium- to coarse-grained, quartzose, variably resistant; forms low ledges; some is evenly bedded, and some is in long sweeping crossbeds. Dark-brown concretions are abundant near top. Sparse thin intercalations of green sandstone and shale near base. Upper part of unit includes thick lenses of pink quartzite. Overlain by unit 10 with an apparently disconformable contact	1,250±
8. Sandstone, yellowish-gray, coarse-grained, slightly feldspathic, easily weathered; interbedded with platy beds of mottled light-olive-gray and greenish-yellow medium-grained micaceous sandstone, which constitutes about one-fourth of unit. Upper contact not exposed	25
7. Sandstone, pinkish-gray, medium- to coarse-grained, feldspathic; bedded in long thin lenses, not crossbedded; interbedded with platy mottled light-olive-gray to greenish-yellow fine- to medium-grained micaceous feldspathic sandstone. Both upper and lower contacts sharp and conformable	15
6. Sandstone, yellowish-gray, coarse-grained, slightly feldspathic, easily weathered; lenticular beds, discontinuously laminated, not crossbedded; a few beds of green argillite less than 2 in. thick	60
5. Sandstone, pinkish-gray, yellowish-gray, and white, medium- to very coarse grained, feldspathic; short lenticular beds, 2 in. to 1 ft thick, with steep internal crossbedding; interbedded with platy green micaceous sandstone and with several 2-in.-thick seams of green argillite in top 15 ft	50
4. Sandstone, yellowish-gray, coarse-grained, feldspathic, easily weathered; thin beds in lower part but thick beds in upper, variably crossbedded; lenses of conglomerate common near base, contains pebbles of quartz, fewer of pegmatitic feldspar, fine-grained crystalline rocks to 1 in. in diameter, sparse cobbles of sandstone to 3 in. in diameter, and several thin beds of platy green argillite. Basal contact of unit sharp and conformable; upper contact not exposed	170
3. Sandstone, yellowish-gray, thin-bedded; middle part medium grained and crossbedded in part; upper and lower parts fine grained and interbedded with numerous thin beds of pale-olive siltstone and micaceous sandstone	40
Top of section: base of diabase sill that caps West Beacon Heights—Continued	
2. Sandstone, very-light- to yellowish-gray, medium- to coarse-grained, very slightly feldspathic; in beds 2–15 ft thick, internally marked by long gentle crossbeds; outcrop ledges locally pitted by numerous circular cavities. Base not exposed	250
1. Covered by talus and moraine; indications of pink and grayish-green siltstone and easily weathered sandstone in upper part	200±
Base of section: bottom of hill, at edge of Taylor Glacier.	
Approximate total thickness of sedimentary sequence	3,000

UPPER PART

Most of the upper part of the Beacon Sandstone was measured by McKelvey and Webb (1959) on the west side of Beacon Dry Valley about 1 mile south of Pyramid Mountain (figs. 3, 5, and 7). They estimated the bottom of their measured section to be about 1,500 feet above the base of the formation. Their lowest unit, which they termed "member A," consists of more than 1,400 feet of white, buff, and light-gray sandstone, mostly crossbedded. Above this is "member B," 60 feet of red and green siltstone interbedded with white and green sandstone. Highest is their "member C," 565 feet thick, which consists largely of sandstone, carbonaceous in part, in the lower 190 feet; next above within the "member" is 55 feet of interbedded fine-grained sandstone and carbonaceous shale; next, 40 feet of massive sandstone containing thin beds of pebbles; then, 145 feet of interbedded sandstone and carbonaceous shale; and at the top 135 feet of crossbedded sandstone, carbonaceous in part. Still higher strata were not measured.

The carbonaceous strata of member C are displayed conspicuously on the north face of Finger Mountain (fig. 8).

McKelvey and Webb (1959) did not describe the outcrop characteristics of the rocks of their measured section nor did they indicate on any of their illustrations what members were pictured. The section measured by them presumably includes all the rocks illustrated in their figure 8. By comparing this figure with our own observations of that area from a distance and with our observations and photographs of Pyramid and Finger Mountains to the north of their measured section, we can supply this missing information with reasonable confidence and can correlate this section with the West Beacon Heights section.

Members B and C of McKelvey and Webb weather to long slopes formed of a series of ledges. The upper 1,100 feet or so of their Member A crops out in formid-

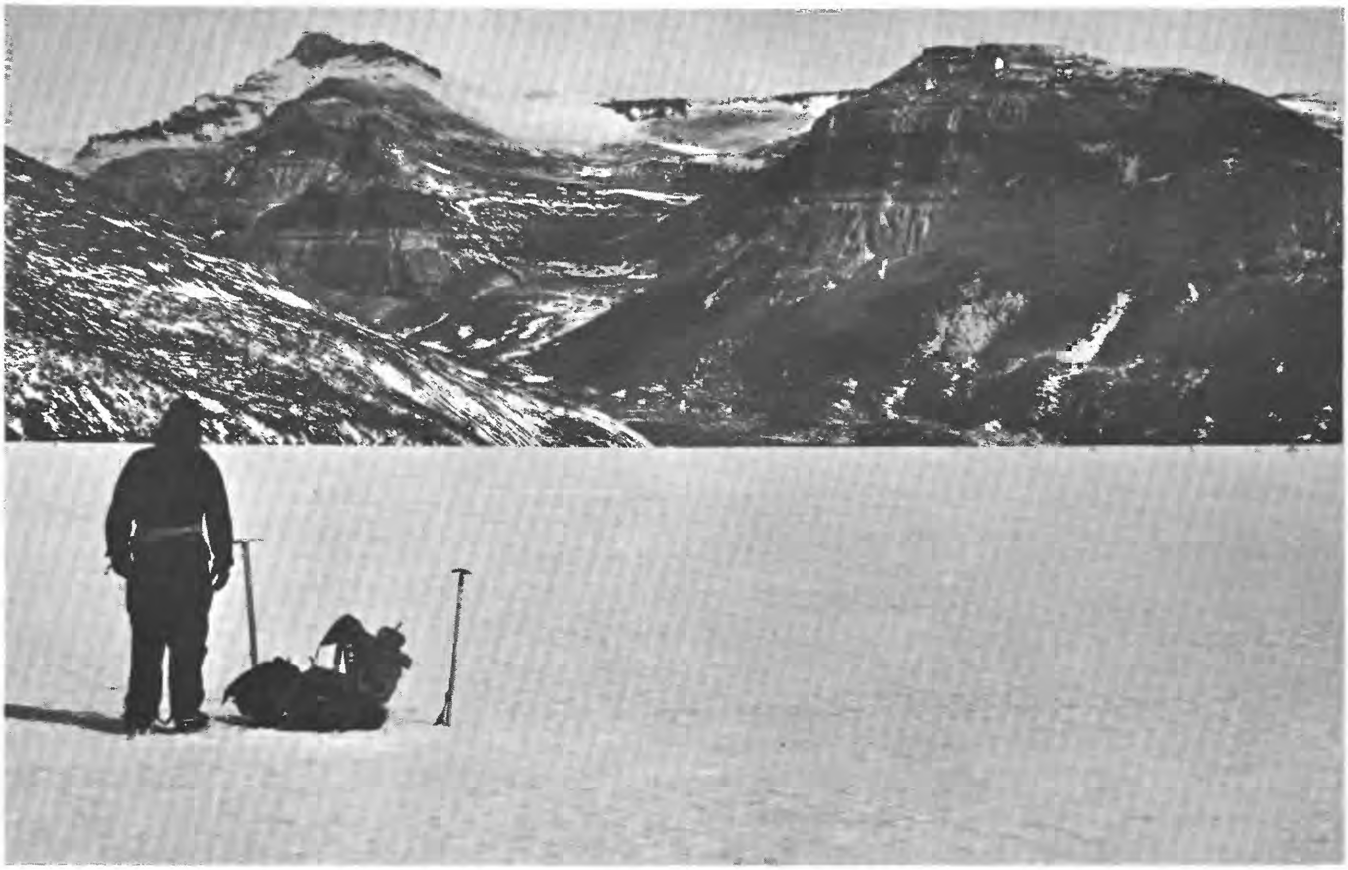

FIGURE 7.—West wall of Beacon Dry Valley seen from the northeast. The sandstone of New Mountain underlies talus slopes; the sandstone of Pyramid Mountain forms the conspicuous light-colored cliffs; and the sandstone of Finger Mountain forms highest slopes and capping ledges. Diabase sills form the thick dark layers. Pyramid Mountain is out of the picture to the right.

able cliffs, whereas the lower 300 feet that they measured of that member forms slopes composed of visible ledges or forms slopes that are in some places obscured by talus from the cliffs above. On the north face of Pyramid Mountain (fig. 9) and on the south face of Finger Mountain (fig. 10), about a thousand feet of this longer slope forming sandstone is exposed beneath the cliff-forming rock.

CORRELATIONS BETWEEN SECTIONS

The Terra Cotta Hills-New Mountain section of Zeller and others (1961), as extended upwards by us, is easily correlated with that of West Beacon Heights (fig. 5). In both sections, cliff-forming sandstone (our unit 10) is underlain by about 1,500 or 1,700 feet of ledge-making yellowish-gray standstone (our units 4 through 9); this is underlain by 40 feet of yellow and green sandstone (unit 3); this by another 250 feet or so of yellowish-gray sandstone (unit 2); and this by vari-colored siltstone and other fine-grained rocks (our unit 1; Terra Cotta Mountain Member of Zeller and others).

The Beacon Dry Valley section of McKelvey and Webb (1959) is also easily correlated with the West Beacon Heights section. The upper 1,100 feet or so of their member A corresponds to our unit 10 of cliff-forming sandstone, whereas the basal part of their member A is the upper part of our unit 9. Their members B and C are stratigraphically above our West Beacon Heights section. McKelvey and Webb stated that still higher strata of the Beacon occur nearby but did not specify the character or location of these rocks. After studying the U.S. Navy vertical and oblique aerial photographs, we conclude that such higher beds are unlikely to total more than a few hundred feet in thickness.

NOMENCLATURE

PAST NOMENCLATURE

Ferrar (1907) applied the name Beacon Sandstone to the entire sedimentary sequence in the Taylor Glacier area and attempted no subdivision. The name Beacon Sandstone has been long and widely used throughout East Antarctica, and only recently have modifications, all of which appear improper, been proposed. Harrington (1958) suggested that the rocks should be called Beacon Sandstone Group, but as he proposed no formational subdivision his suggestion is premature. Mc-

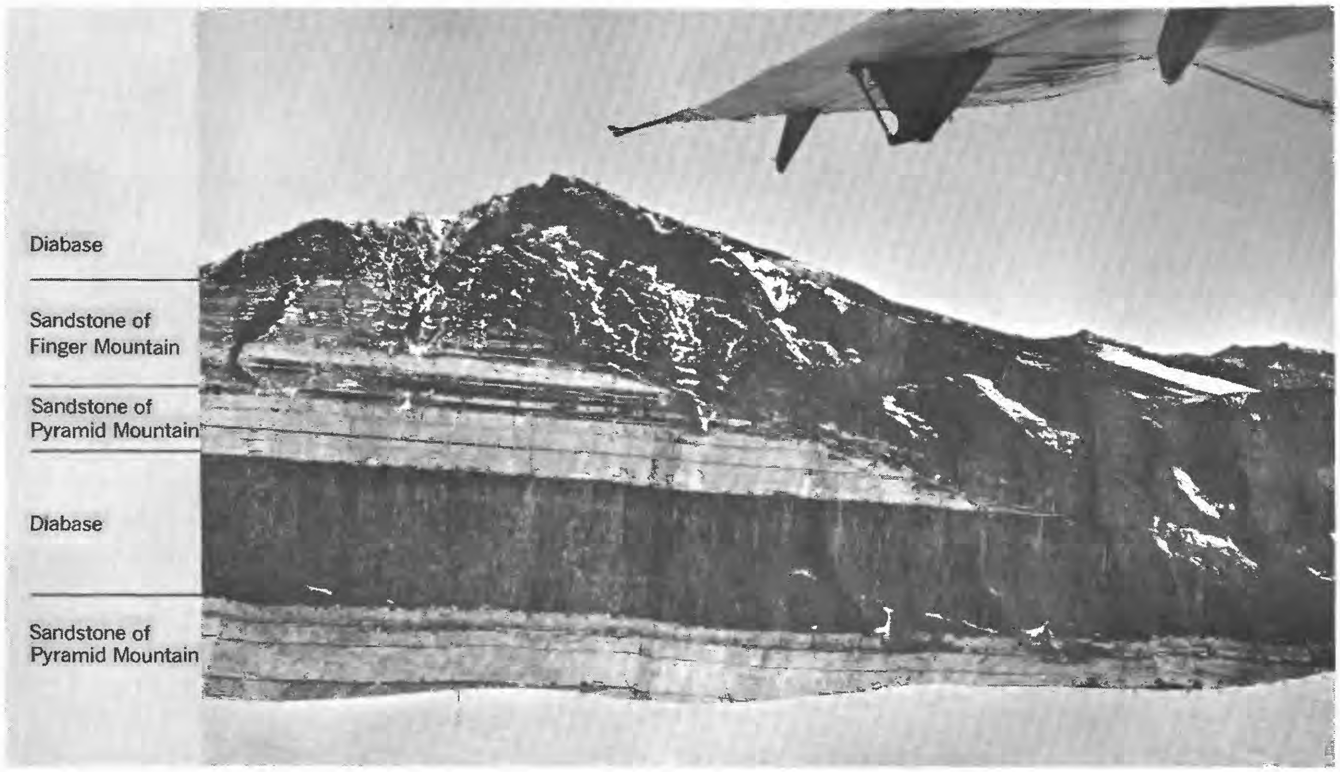

FIGURE 8.—West part of Finger Mountain. The sandstone and the thick lower sill of quartz diabase are cut obliquely by another sheet of diabase, which becomes a concordant sill at the top of the mountain. Dark bands in the sandstone of Finger Mountain are carbonaceous layers; this unit normally forms ledges and recessive outcrops. Altitude of the peak is about 7,100 ft, and the cliff is about 2,500 ft high.

Kelvey and Webb in 1959 referred to the sedimentary rocks as the Beacon Formation, but in a later paper (McKelvey and Webb, 1961) they subdivided the sequence into five informal lithofacies and used the term "Beacon Group"; as they designated no formations, this elevation to group designation is also premature.

Zeller and others (1961) suggested that " * * * the Beacon sandstone and associated sills be raised to group status and that formational names be used to identify smaller * * * units within the group." Despite this suggestion, Zeller and others referred to the Beacon interchangeably as "Beacon sandstone," "Beacon sandstone formation," and "Beacon group." They proposed formal member (not formational) names for part of the section but left most of the section unnamed. Stratigraphic terminology so misused is only confusing. Furthermore, as the diabase sheets cut across all parts of the sandstone from the base to the top (see fig. 8, for example) and were thus obviously intruded after deposition was complete, they cannot be included properly as a part of the Beacon sequence as was done by Zeller and others (1961).

Long (1961b, p 127, 128) referred to the Beacon as the "Beacon series," subdivided informally into "Upper Beacon" and "Lower Beacon." This usage also is improper.

PROPOSED NOMENCLATURE AND STRATIGRAPHIC SUMMARY

With the possible exception of basal strata in some parts of the region of the type section, the rocks named Beacon Sandstone by Ferrar (1907), and so called by many others since, comprise a remarkably homogeneous assemblage for which formational status seems more appropriate than group status at least until much more is known about the rocks. We recommend that the original name Beacon Sandstone be retained and that the type locality remain the vicinity of Beacon Heights as intended by Ferrar. We recommend further that the composite type section consist of the exposure of New Mountain, West Beacon Heights, and the west side of Beacon Dry Valley.

Three subdivisions of the Beacon Sandstone are widely recognizable in the region of the type locality. These units are indicated on some of the accompanying figures as the sandstone of New Mountain, sandstone of Pyramid Mountain, and sandstone of Finger Mountain in ascending order. The sandstone of Pyramid Mountain forms bold cliffs and the other two units generally form slopes of ledges. Beyond the vicinity of the type area of the formation (the area of fig. 3), we have observed these same three units along both sides of upper Ferrar Glacier, the Kukri Hills, and throughout the mountains between Taylor Glacier and Wright Dry Valley from Solitary Dry Valley westward to the interior ice plateau (fig. 2).

These three distinctive units can be identified from a distance and are easily mappable and are thus particularly suitable for reconnaissance mapping such as is likely to predominate in this region for some time to come. (The "lithofacies" for which McKelvey and Webb (1961) suggested formational status are based on slight compositional distinctions largely independent of gross outcrop or bedding characteristics of the rocks and are probably not mappable under general Antarctic field conditions.) As the recent literature on the Beacon is overburdened with new and supposedly formal, but generally invalid, names for stratigraphic units, we are here using only informal designations for the units but recommend their elevation to formal member rank as soon as they prove useful to other geologists working in the region.

The middle unit provides the primary basis for subdivision of the Beacon into three major parts and is accordingly described first below.

The cliff-forming sandstone, about 1,100 feet thick in the type section (unit 10 of our Beacon Heights section, fig. 5, and the greater part of member A of the Beacon Dry Valley section of McKelvey and Webb, 1959), is an easily recognizable unit throughout the moutnain mass from Windy Gully to the interior ice plateau. It overlies a ledge-forming sandstone unit and underlies a ledge-forming unit composed of siltstone, sandstone, and carbonaceous shale; hence it is recognizable from a distance of many miles. We have observed the same unit to be widespread north of upper and lower Taylor Glacier and also in the western Wright Dry Valley region (fig. 2) (for example, see McKelvey and Webb, 1959, fig. 4), where it constitutes the upper part of the orthoquartzite lithofacies of McKelvey and Webb (1961). We will call this cliff-forming sandstone the sandstone of Pyramid Mountain, the name coming from a peak (fig. 9), in the type area, on whose cliffs it is well exposed. If additional fieldwork shows that this unit should be formally recognized, its type section might well be that of the west wall of Beacon Dry Valley (fig. 7), 2 miles south of the crest of Pyramid Mountain. The unit consists of about 1,100 feet of buff, pink, and white cliff-forming medium- to coarse-grained sandstone and quartzite, in thick even beds, many of which are crossbedded. At Finger Mountain (fig. 10), this unit lies with obvious disconformity upon the rocks beneath.

That part of the Beacon above the sandstone of Pyramid Mountain is probably best designated as a

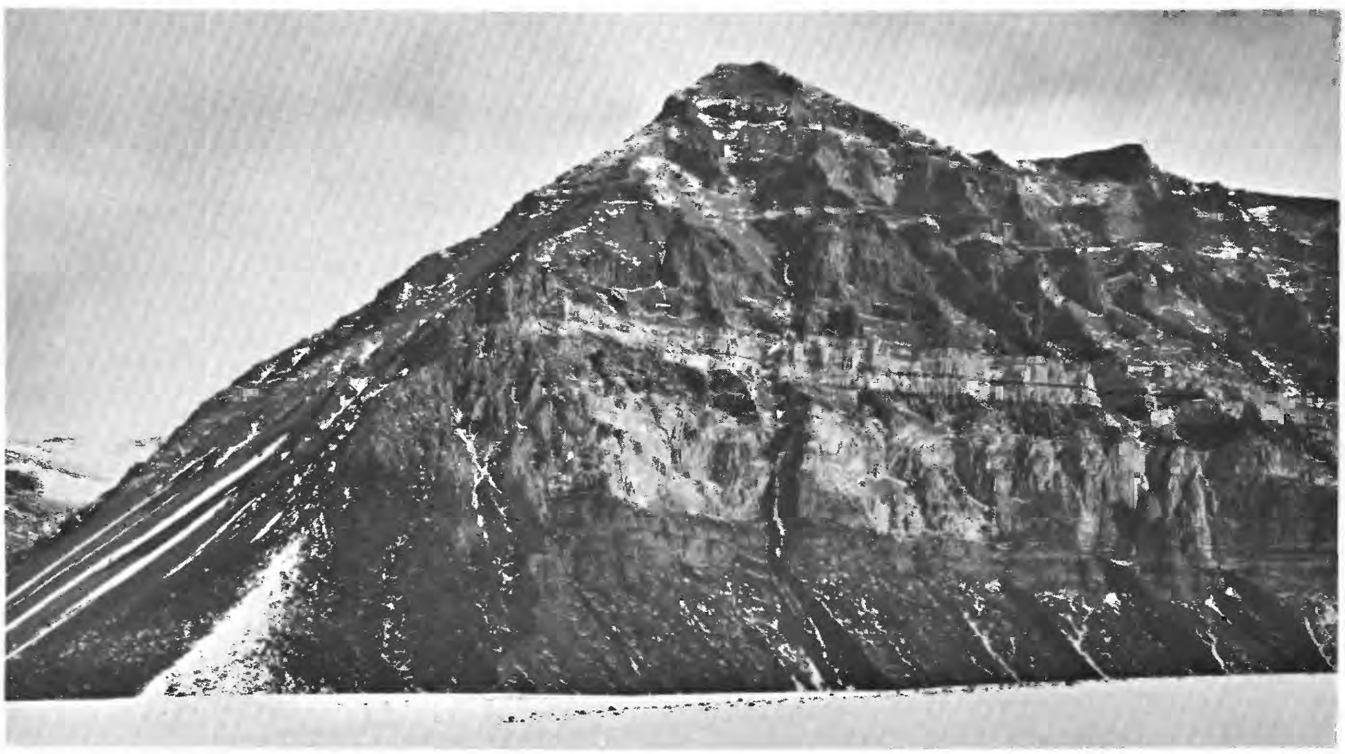

FIGURE 9.—Pyramid Mountain seen from the northeast. The upper part of the mountain is formed of three thick diabase sills, the lower of which turns into the inclined sheet which forms the lower cliffs to the left. The sandstone of Pyramid Mountain forms cliffs above the partly covered sandstone of New Mountain at the base. The summit is about 7,000 ft. above sea level and about 3,000 ft. above Taylor Glacier.

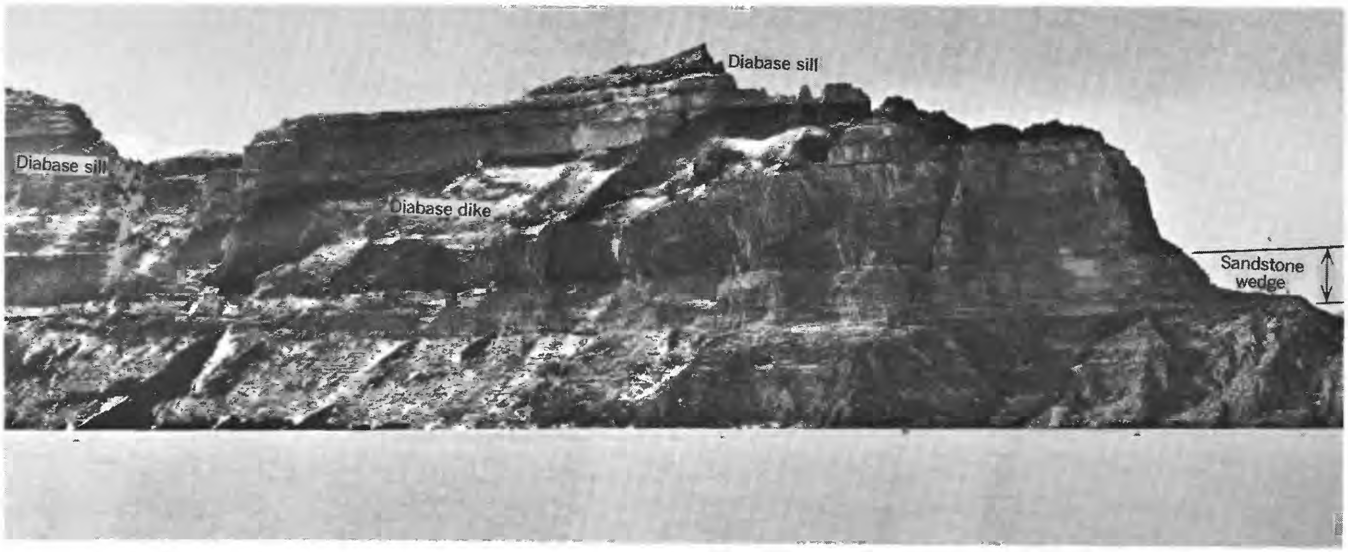

FIGURE 10.—East end of Finger Mountain showing south face. A westward-tapering wedge of sandstone, the basal part of the cliff-forming sandstone of Pyramid Mountain, lies disconformably upon the slope-forming sandstone of New Mountain. A thick sill of diabase at the left edge of the photograph becomes an inclined sheet dipping away from the observer in the rest of the picture. The pinnacle stands about 1,800 ft. above Taylor Glacier.

single unit, which we will call the sandstone of Finger Mountain after the well-known landmark (figs. 8 and 10) upon which it is well exposed. If this becomes a formally recognized unit as the result of additional work, its type section might be that west of Beacon Dry Valley 2½ miles south of Pyramid Mountain (the lower part of this section is at the top of the right-hand mountain face of fig. 7) as measured by McKelvey and Webb (1959) and included in their members B and C. The sandstone of Finger Mountain, which lies conformably upon the sandstone of Pyramid Mountain, consists of sandstone, shale, and siltstone, weathering to slopes and ledges. Its known total thickness is 630 feet in the study area, the top being absent. Carbonaceous shale and sandstone are conspicuously high in the known part of the unit (fig. 8), whereas the basal 60 feet of the member at the type section consists of variegated siltstone. This basal siltstone is lacking at Finger Mountain (fig. 8) but is considered by McKelvey and Webb (1961) to be widespread in the region. They refer to a "red-green siltstone facies," 70–300 feet thick, in the same stratigraphic position in Wright and Victoria Dry Valleys (fig. 2). However, even if continuous, this siltstone is too thin for practical mapping in the Antarctic and furthermore cannot be distinguished at a distance from the thin-bedded rocks above.

Beneath the sandstone of Pyramid Mountain is a section composed largely of yellowish-gray crossbedded coarse-grained sandstone, which weathers to slopes and ledges and which we will call the sandstone of New Mountain. The name is derived from the peak west of Windy Gully (fig. 4). If the results of further fieldwork show that this unit should be given formal status, its type section could be designated as the lower north slope of West Beacon Heights. The unit is about 1,850 feet thick and comprises our units 2 through 9. Interbedded with the sandstone and most abundant in the lower part of the unit, are platy, micaceous finer grained sandstone, green argillite and sandstone, and pebble conglomerate. The sandstone is composed primarily of quartz, but some feldspar, mostly potassic, is present, especially in the lower part of the unit. The unit corresponds to the "arkose facies" and to the lower part of the "orthoquartzite facies" of McKelvey and Webb (1961); these "facies" are designated very arbitrarily within a gradational interbedded sequence and are not mappable units.

The stratigraphy of the basal part of the Beacon Sandstone is variable in the type area and classification must await more detailed knowledge of this part of the section. The 110–210 feet of variegated sandstone, siltstone, and shale that lie between the basement and the sandstone of New Mountain in the Beacon type area were subdivided by Zeller and others (1961) into two members, "Windy Gully" below, "Terra Cotta Mountain" above. North of Solitary Dry Valley (fig. 2), we found the sandstone of New Mountain to lie directly upon the basement rocks, the variegated strata being absent. In Wright and Victoria Dry Valleys, McKelvey and Webb (1961) recognized a basal "subgraywacke facies" as thick as 300 feet lying upon the basement.

The apparently sporadic distribution of the basal sedimentary rocks, their general dissimilarity to rocks in most of the overlying Beacon, and the sharp and probably disconformable contact which separates these varied rocks from the sandstone of New Mountain, all suggest that they may not be properly assignable to the Beacon.

DIABASE SHEETS

FORM

Virtually coextensive with the Beacon Sandstone throughout East Antarctica are thick sheets of quartz diabase, for which Harrington (1958) proposed the name Ferrar Dolerites. The distribution and character of these sheets in the type area of the Beacon Sandstone are shown by some of the accompanying photographs and by figure 3.

The aggregate thickness of the sheets in the vicinity of Beacon Heights is on the order of 4,000 feet. Most of the individual sheets are thicker than 300 feet, and some are locally as thick as 1,500 feet. Although sills concordant to the bedding are most conspicuous, all the sills of the area of figure 3, except the one extending northwestward along Taylor Glacier from the junction of the Windy Gully glacier, branch, pinch out, or become markedly inclined to the bedding. The huge sheet capping Finger Mountain (fig. 8), for example, cuts obliquely upwards through 2,000 feet of sandstone and a concordant diabase sill, and, at the top of the mountain, itself becomes a concordant sill. The lower sill of Finger Mountain—the sill cut by the sheet just noted—is concordant with the Beacon for nearly 2 miles along the mountain, but near the east end it abruptly becomes a crosscutting inclined sheet (fig. 10).

A thick sill lies near the contact between sedimentary rocks and the basement complex (fig. 4) not only in the map area but in a broad region to the east and north. This sheet is much more consistently concordant to bedding than are any of the higher sheets. Another thick widespread sill lies within the basement granitic rocks and follows exfoliation joints, related to the pre-Beacon erosion surface, 500–1,500 feet below the base of the Beacon.

PETROLOGY

The diabase sheets are highly silicic, their chilled margins and bulk compositions containing between 52 and 56 percent SiO_2. The margins are texturally basalt which grades inward through diabase to gabbro, which forms the bulk of the sheets. Interstitial micropegmatite is present in the gabbro. Some of the sheets are markedly differentiated and contain layers of granophyre and gabbro-pegmatite near their upper surfaces; such a layer is shown by the light-colored streak one-sixth of the way down in the lower sill of figure 8. Augite is the dominant pyroxene; pigeonite, diallage, and hypersthene are variably present. The plagioclase is chiefly labradorite. The rocks are conspicuously low in opaque constitutents.

These rocks will be described in detail in another report.

METAMORPHISM OF THE BEACON SANDSTONE

The entire Beacon Sandstone of the type section has been slightly metamorphosed thermally by the diabase. This metamorphism is apparent in the field only in the hornfelsed or metasomatized rocks within a few feet of the sheets, for the rest of the Beacon does not appear to the unaided eye to be altered; however, metamorphism is obvious in thin section. Argillaceous fractions are reconstituted to fine-grained mica throughout the section we studied, and most of the quartz has been recrystallized marginally to form mosaics and, locally, interlocking grains. Much feldspar has been reconstituted to fine-grained mica.

AGE OF DIABASE

The diabase sheets postdate the deposition of at least most of the Beacon for they intrude rocks very high in most sections of the sandstone yet seen in the Antarctic. The petrologic consistency of the diabase suggests that it may have been intruded within a rather short time period, possibly synchronous over all or most of the extent of the Beacon. A whole-rock potassium-argon age determination on a gabbro from lat 68°52′ S., long, 154°10′ E., yielded a calculated age of 170 million years (Starik and others, 1959)—probably Early Jurassic, possibly very late Triassic.

Eleven potassium-argon determinations made on separated minerals and chilled rock from a diabase sill in Tasmania, intrusive into sandstone similar to the Beacon, indicated a probable age of about 165 million years (McDougall, 1961). Similar diabase sheets in similar sandstone in South America, southern Africa, and southeastern mainland Australia are broadly dated geologically as of Triassic or Jurassic age.

AGE OF THE BEACON SANDSTONE

Nearly all fossils yet found in the Beacon Sandstone have been plants of the *Glossopteris* flora, similar to those of the Gondwana sequences of South America, southern Africa, India, and Australia. No animal remains save probable molds of burrows have been recognized.

FOSSILS NEAR TYPE SECTION

The only diagnostic fossils yet reported from the Beacon Sandstone near its type section were collected by Ferrar (1907) from carbonaceous strata high in the sandstone of Finger Mountain on the west side of Tabular Mountain (fig. 2), about 9 miles southwest of West Beacon Heights. Although Arber (1907) and Seward (1914) found no recognizable fossils in this material, Edwards (1928) later broke up the material and discovered undoubted fronds of the large-leafed *Glossopteris indica*.

McKelvey and Webb (1959) noted unidentifiable plant remains from the same part of the section and "worm casts" from their member A. "Fucoids" were mentioned by Zeller and others (1961) as occurring low in the Beacon near Windy Gully but were not described. We noted small elliptical pellets, about 4 by 8 mm in size, which might have an organic origin but which are now only well-cemented packets of sandstone, high in the sandstone of New Mountain at the north base of Pyramid Mountain. We submitted samples of siltstone from low in the sandstone of New Mountain for spore and pollen analysis, but nothing organic was found in them.

We found straight to slightly curved intersecting cylindrical casts 70 feet above the base of the sandstone of New Mountain in the West Beacon Heights section (fig. 11). Prof. A. Seilacher (written communication, 1959) of Frankfurt, an expert in such casts, could suggest only that they were burrows made by a shallow-water animal of unknown type, and that similar casts are known from rocks ranging in age from Cambrian at least to Jurassic.

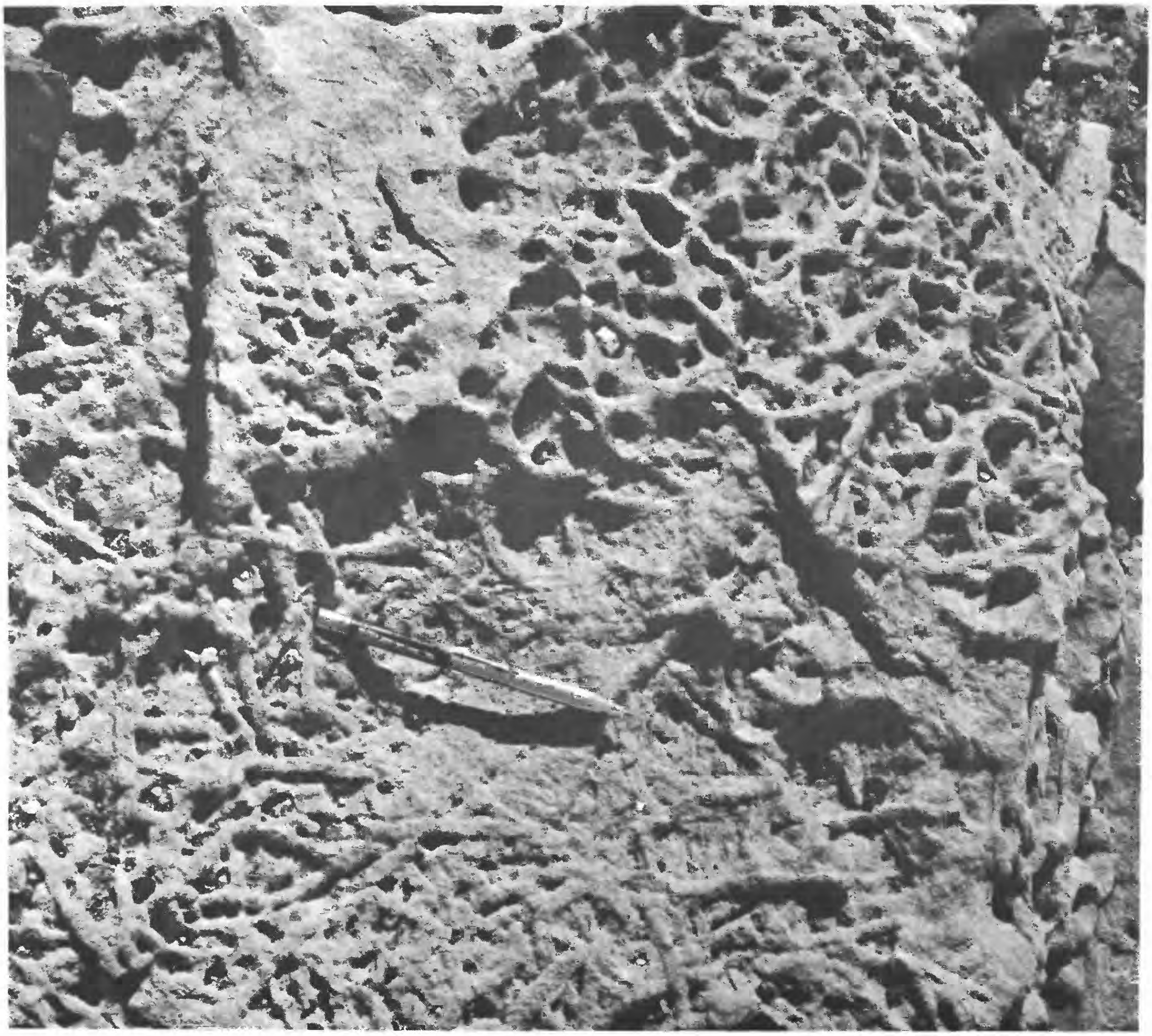

FIGURE 11.—Casts of probable burrows of shallow-water animals in sandstone of New Mountain, West Beacon Heights.

FOSSILS FROM THE BEACON SANDSTONE OF OTHER AREAS

Constituents of the *Glossopteris* flora have been found in carbonaceous rocks high in the Beacon Sandstone in the trans-Antarctic Mountains at Priestley Glacier, Mount Gran, Beardmore Glacier, Mount Weaver, and the Horlick Mountains (fig. 1).

The Priestley Glacier material yielded only a gymnosperm branch for which Seward (1914) proposed a new genus and species, *Antarcticoxylon priestleyi.* Although Walton (1923, 1925, 1956) questionably designated this same branch as *Rhexoxylon priestleyi* and inferred for it a Triassic age, both Krausel (1956) and Archangelsky and Brett (1961) consider Walton's assignment to be erroneous. Archangelsky and Brett believe *Antarcticoxylon* to be a valid genus, unrelated to *Rhexoxylon.* Seward (1914) also recognized several microspores, possibly from a conifer of pine or fir type (Abietineae), for which he coined the name *Pityosporites antarcticus.* Seward regarded the material as probably indicating an early Mesozoic age.

The Mount Gran specimens were collected by J. J. Mulligan (written communication, 1960) of the U.S. Bureau of Mines and examined by S. H. Mamay and J. M. Schopf (written communications, 1960, 1961), who recognized *Glossopteris indica* and an unidentified species of *Vertebraria.*

The Beardmore Glacier material (Seward, 1914) contains fronds of *Glossopteris indica*, scale leaves probably also from *Glossopteris*, and stems of uncertain type referred to *Vertebraria.* The age suggested by Seward is only bracketed between late Carboniferous and Early Jurassic.

The Mount Weaver specimens contain poorly preserved leaf fragments that were assigned by Darrah (1936) to the gymnosperms *Sagenopteris* (seed-fern foliage), *Taeniopteris* (an artificial genus of cycadlike foliage) and *Araucarites* (cones probably referable to the Araucariaceae, a coniferous family with extant species in the southwestern Pacific region). Darrah suggested a Jurassic age for these specimens. L. H. Daugherty (written communication, 1961) examined a large number of other specimens from Mount Weaver and found no evidence of either *Sagenopteris* or *Taeniopteris.* He recognized instead leaves of *Glossopteris*, a stem (*Vertebraria*), and a fruiting body probably also from *Glossopteris.* (The nomenclature of paleobotany is much complicated by the necessary independence of classification of different plant parts whose relation to each other is uncertain. Trunks, stems, foliage, fruiting bodies, and spores or pollen are commonly found separately, hence cannot be related to single plants, and are given unrelated taxonomic names until common identity is established. In the present example, *Vertebraria* stems probably bore *Glossopteris* foliage.) Barghoorn (1961) and J. M. Schopf (written communication, 1961) also doubt the validity of Darrah's identifications.

In the Horlick Mountains, Long (1961b) collected plant remains that were identified by J. M. Schopf (written communications, 1960, 1961) as including *Glossopteris indica*, a small seed referable to *Samaropsis*, plant microfossils, and silicified wood with wide growth rings.

Sandstone probably correlative with the Beacon but named the Amery Formation by Crohn (1959) occurs near the outer coast of East Antarctica, at about lat 70°30′ S., long 68°15′ E. (labeled Amery loc. fig. 1). Coal from this sandstone yielded pollen and microspores assigned to 14 different microfloral "species" (Crohn, 1959, p. 64). Although specific correlations between these "species" and macrofloral forms are not possible, gymnosperms are dominant and include gnetales(?), cycad, and pine types; ferns and allied plants are subordinate. Six probable "species" of the presumably gymnospermous pollen *Lueckisporites* were found, indicating a probable Late Permian age.

AGE OF ROCKS BENEATH THE BEACON SANDSTONE

In at least two places the Beacon Sandstone is underlain by little-deformed strata of Devonian age. Elsewhere the Beacon is underlain by crystalline rocks probably no younger than Ordovician.

In the central moraine of Mackay Glacier (fig. 2), Debenham (1921) found erratic boulders containing dermal plates and scales of fish. The boulders apparently had come from near the base of the sedimentary section that consists largely of the Beacon. Woodward (1921) considered these fossils to prove a Late Devonian age for the rocks containing them. No stratigraphic section has been published for this locality.

In the Horlick Mountains, Long (1961b) discovered a section about 1,300 feet thick conformably underlying rocks correlated with the Beacon. Near the base of this section he found abundant brachiopods that Boucot and Caster (1961) identified as belonging to a terebratuloid genus of Early Devonian age.

Elsewhere the Beacon rests upon plutonic rocks probably formed not later than Ordovician time (Hamilton, 1963).

AGE OF THE BEACON SANDSTONE

The Beacon Sandstone lies above rocks as young as Devonian at least near the Mackay Glacier and in the Horlick Mountains and is intruded by diabase sheets for which meager data suggest an Early Jurassic or possibly Late Triassic age. All thick sections of the Beacon yet studied in the trans-Antarctic mountains, in which lies the type section, contain plant fossils near the top of the formation but have not yet yielded fossils in the rest of the formation. This consistency suggests that the carbonaceous upper part of the formation is broadly correlative throughout the mountains.

Only land plants have yet been found in the Beacon. These belong to the widespread *Glossopteris* flora of the Gondwana lands. The common Gondwana species *Glossopteris indica* has been identified from three localities high in the Beacon, including one near the type section. This species is abundant in the upper Carboniferous and Permian of Australia, India, southern Africa, and South America (Barbosa, 1958; David and Browne, 1950; Du Toit and Haughton, 1953; and Krishnan, 1956) and probably continues into the Triassic at least in India (Krishnan, 1956). The species is thus primarily a late Carboniferous and Permian form but may have survived locally into Triassic time.

Although *Glossopteris indica* is not by itself closely definitive of age, the lack of diagnostic Carboniferous or Triassic (for example, *Thinnfeldia*) elements is presumptive evidence that the plants are of Permian age. The *Glossopteris-Vertebraria* assemblage characterizes Permian strata of the other Gondwana regions. Although similar forms occur in those regions in Carboniferous and Triassic strata, they are there associated with more abundant plants definitive of Carboniferous or Mesozoic ages.

As previously stated, Walton (1923, 1925, 1956) and Darrah (1936) assigned some Antarctic specimens to Mesczoic genera, but their identifications have been discredited by other workers.

FIGURE 12.—Outcrop of upper part of sandstone of New Mountain, at north base of Pyramid Mountain, showing diversely oriented crossbeds.

The age of the bulk of the Beacon beneath the carbonaceous horizons cannot yet be defined more closely than Carboniferous or Permian, and whether or not strata above the fossiliferous section include rocks of Mesozoic age is unproved.

CONDITIONS OF DEPOSITION

The Beacon Sandstone in its type area consists of water-laid clastic sediments. The prevalent crossbedding and the lack of aquatic fossils suggest a general fluvial origin for most of the formation. The carbonaceous beds in the upper part of the formation probably were deposited in swamps or lagoons.

CROSSBEDDING

Much of the medium- and coarse-grained sandstone of the Beacon is crossbedded, in beds 2–15 feet thick (fig. 12). Foreset layers dip from 1° to 30° but most commonly are inclined between 5° and 20° from the major bedding planes (fig. 13); cross layers form long swooping curves rather than short steep ones. Crossbedded layers of the sandstone of New Mountain tend to be lenticular and discontinuous, in contrast to the more even bedding of the sandstone of Pyramid Mountain.

Observations on direction of crossbedding have not yet been reported in the literature, so only our own few data on the sandstone of New Mountain are available. In the West Beacon Heights section, crosslaminae most commonly dip westward in the lower 300 feet of the unit (fig. 13), dip in all directions without obvious preferential orientation where seen 300 to 500 feet above the base of the sandstone of New Mountain, and are mostly inclined eastward at the 1,000-foot level. At the base of the north face of Pyramid Mountain, perhaps

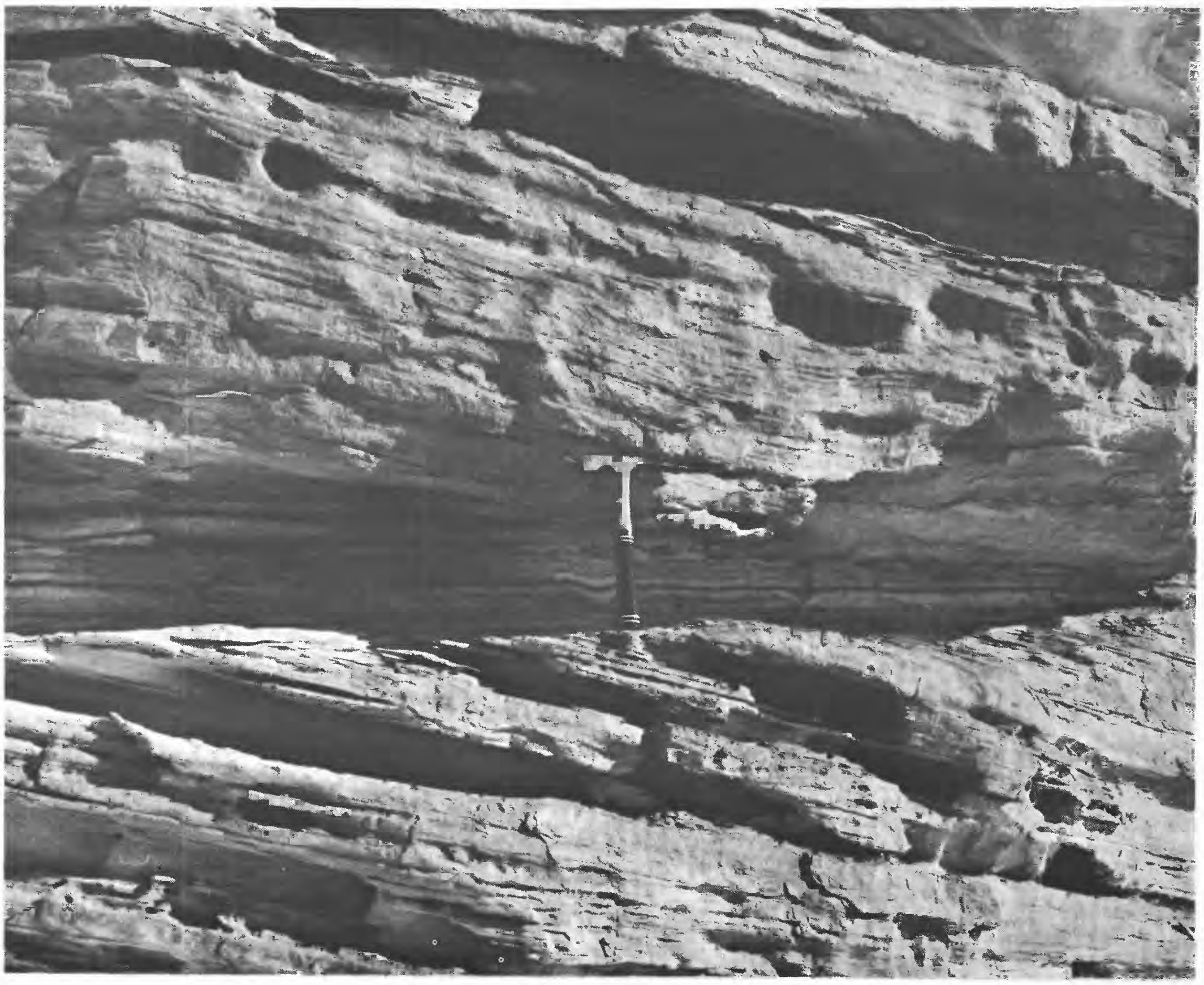

FIGURE 13.—Crossbedded strata of lower part of sandstone of New Mountain, on the north slope of West Beacon Heights. Crossbeds in this part of the section mostly dip westward (right).

1,400 feet above the bottom of the same unit, crosslayers are oriented diversely (fig. 12), but eastward dips appear dominant. These few observations suggest dominantly westward-flowing streams during deposition of the lower part of the sandstone of New Mountain, streams flowing in variable directions during deposition of the middle part, and generally eastward-flowing ones as the upper part was laid down. If the changes in the crossbed directions with stratigraphic position are real—and not the result of inadequate data—the changes may indicate shifts in the location of the source area of the sediments from which the unit was formed. The relatively feldspathic and micaceous lower part of the sandstone of New Mountain may have come from a source to the east, whereas the quartz-rich upper part may have come largely from the west. It is of course possible that much of the crossbedding represents only local directions which bear little relation to the direction of the original source of the sediments.

PALEOCLIMATE

The Beacon, wherever it has been studied in Antarctica, consists almost exclusively of water-laid clastic sediments, the bulk of them probably deposited in shallow water. Quartz-rich sandstone dominates the formation, but feldspar, mica, and clay are locally important components. Glacial sediments, widespread in the lower part of correlative strata of southern South America, central and southern Africa, India, and Australia, apparently are not present in the Beacon of the type area but Long (1961a) and Grindley (1962) have found tillite beneath the Beacon farther south.

All known fossils are of terrestrial plants. Fossil wood in the Beacon has well-defined annual rings, showing that the climate was markedly seasonal. According to J. M. Schopf (U.S. Geol. Survey, 1961, p. 52) the annual rings of *Glossopteris* wood from the Horlick Mountains are so large as to indicate a climate at least as warm as temperate. There are nowhere any red beds to suggest a savannah or other tropical or subtropical climate, however, nor any evaporites or eolian deposits to indicate an arid one. Reasoning from the relation between morphology of living plants and climate, the large thick leaves of *Glossopteris* might be interpreted to indicate a nonfrigid climate, although there are no living analogues of the genus for direct comparison. The wide distribution of the *Glossopteris* flora throughout the Gondwana regions shows that, with or without postulating continental drift, the flora had a broad climatic tolerance.

These various criteria indicate that the upper part of the Beacon was deposited in a temperate climate but are not definitive enough to show whether the climate was relatively cold or warm. A glacial climate prevailed shortly before the deposition of typical Beacon.

REFERENCES CITED

Arber, E. A. N., 1907, Report on the plant-remains from the Beacon Sandstone, *in* Ferrar, 1907: p. 48.

Archangelsky, S., and Brett, D. W., 1961, Studies on Triassic fossil plants from Argentina, I, *Rhexoxylon* from the Ischigualasto Formation: Royal Soc. London, Philos. Trans., ser. B, v. 244, p. 1–19.

Barbosa, O., 1958, On the age of the Lower Gondwana floras in Brazil and abroad: Internat. Geol. Cong., 20th, Mexico, 1956, Comision para la correlacion del sistema Karroo, p. 205–236.

Barghoorn, E. S., 1961, A brief review of fossil plants of Antarctica and their geologic implications, *in* Life Science in Antarctica: Natl. Acad. Sci.-Natl. Research Council Pub. 839, p. 5–9.

Boucot, A. J., and Caster, Kenneth, 1961, Relationships of a new Lower Devonian terebratuloid from Antarctica [abs.]: Geol Soc. America Spec. Paper 68, Abstracts for 1961, p. 139.

Crohn, P. W., 1959, A contribution to the geology and glaciology of the western part of Australian Antarctic Territory: Australian National Antarctic Research Expedition Repts., ser. A, v. 3, 103 p.

Darrah, W. C., 1936, Antarctic fossil plants: Science, v. 83, no. 2156, p. 390–391.

David, T. W. E., and Browne, W. R., 1950, The geology of the Commonwealth of Australia, v. 1: London, Arnold and Co., 747 p.

Debenham, Frank, 1921, The sandstone, etc., of the McMurdo Sound, Terra Nova Bay, and Beardmore Glacier regions: British Antarctic ("Terra Nova") Exped., 1910, Nat. History Rept., Geology, v. 1, p. 103–119.

Du Toit, A. L., 1937, Our wandering continents, an hypothesis of continental drifting: Edinburgh, Oliver and Boyd, 366 p.

Du Toit, A. L., and Haughton, S. H., 1953, The geology of South Africa: New York, Hafner, 611 p.

Edwards, W. N., 1928, The occurrence of *Glossopteris* in the Beacon Sandstone of the Ferrar Glacier, South Victoria Land: Geol. Mag., v. 65, p. 323–327.

Ferrar, H. T., 1907, Report on the field-geology of the region explored during the Discovery Antarctic Expedition, 1901–04: Natl. Antarctic Exped., Nat. History. v. 1, Geology, p. 1–100.

Grindley, G. W., 1962, Antarctic field work, 1961–62, Northern Party: Geol. Soc. New Zealand Newsletter, no. 12, p. 13–14.

Hamilton, Warren, 1963, Tectonics of Antarctica, *in* O. M. Childs, ed., Backbone of the Americas: Am. Assoc. Petroleum Geologists Mem. 2, p. 4–15.

Hamilton, Warren, and Hayes, P. T., 1960, Geology of Taylor Glacier-Taylor Dry Valley region, South Victoria Land, Antarctica, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B376–B378.

Harrington, H. J., 1958, Nomenclature of rock units in the Ross Sea region, Antarctica: Nature, v. 162, p. 290.

Krausel, Richard, 1956, Lianen aus den Karru-Schichten Sud-Afrikas; Ergebnisse der Forschungreise Richard Krausel's 1954 rach Sudund Sudwest Afrika: Senckenbergiana Lethaea, v. 37, p. 1–16.

Krishnan, M. S., 1956, Geology of India and Burma: Higginbothams, Madras, 555 p.

Long, W. E., 1961a, Permo-Carboniferous glaciation in Antarctica [abs.]: Geol. Soc. America Spec. Paper 68, Abstracts for 1961, p. 314.

——— 1961b, Preliminary report on the geology of the Central Range of the Horlick Mountains, Antarctica: Am. Geog. Soc., Repts. on Antarctic Geol. Observations, IGY Glaciological Rept. 4, p. 123–142.

McDougall, Ian, 1961, Determination of the age of a basic igneous intrusion by the potassium-argon method: Nature, no. 4782, p. 1184–1186.

McKelvey, B. C., and Webb, P. N., 1959, Geological investigations in South Victoria Land, Antarctica, Pt. 2, Geology of upper Taylor Glacier region: New Zealand Jour. Geology and Geophysics, v. 2, p. 718–728.

——— 1961, Geological reconnaissance in Victoria Land, Antarctica: Nature, v. 189, p. 545–547.

Seward, A. C., 1914, Antarctic fossil plants: British Antarctic ("Terra Nova") Exped., 1910, Nat. History Rept., Geology, v. 1, no. 1, p. 1–49.

Starik, I. E., Ravich, M. G., Krylov, A. Ya., and Silin, Yu. I., 1959, Ob absolyutnom vozraste porod Vostochno-Antarkticheskoi platformy: Doklady Akad. Nauk SSSR, v. 126, no. 1, p. 144–146.

U.S. Geological Survey, 1961, Synopsis of geologic and hydrologic results, *in* Geological Survey Research, 1961: U.S. Geol. Survey Prof. Paper 424–A, 194 p.

Walton, John, 1923, On *Rhexoxylon* Bancroft, a Triassic genus of plants exhibiting a liane-type of vascular organization: Royal Soc. London Philos. Trans., ser. B, v. 212, p. 79–109.

——— 1925, On some South African fossil woods: Ann. South African Mus., v. 22, p. 1–26.

——— 1956, *Rhexoxylon* and *Dadoxylon* from the Lower Shire region of Nyasaland and Portuguese East Africa, compared with previously described genera from Africa and other parts of the world: Colonial Geol. Mineral Resources, v. 6, no. 2, p. 159–168.

Woodward, A. S., 1921, Fish remains from the Upper Old Red Sandstone of Granite Harbour, Antarctica: British Antarctic ("Terra Nova") Exped., 1910, Nat. History Rept., Geology, v. 1, no. 2, p. 51–62.

Zeller, E. J., Angino, E. E., and Turner, M. D., 1961, Basal sedimentary section at Windy Gully, Taylor Glacier, Victoria Land, Antarctica: Geol. Soc. America Bull., v. 72, p. 781–786.

U.S. GOVERNMENT PRINTING OFFICE: 1963 O—678832