CONSIDERATIONS ON THE EMPLACEMENT OF THE JURASSIC DOLERITES OF TASMANIA

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(With 4 text figures.)

ABSTRACT

The emplacement of the Jurassic dolerites of Tasmania is considered in terms of the tectonic structure of Tasmania at the time of intrusion. At this time Tasmania consisted of a Permo-Triassic sedimentary cover draped in gentle downwarps over an uneven basement of folded Precambrian-Palaeozoic rocks, with uplifted highs in the west, north-east, and east.

Characteristics required for the recognition of dolerite feeders in Tasmania, particularly cones, are discussed and the structures are examined in the light of these. In form, the cones are generally asymmetrical structures. In many cases there is insufficient evidence present to determine whether they represent rootless conical sheets emplaced under a flotational mechanism, or whether they represent conical feeders. Possible modes of emplacement are considered. Some of the cones appear to be secondary structures developed in the sedimentary cover at about the base of the Triassic sequence, possibly from cupola-like structures on underlying sill sheets.

The intruding dolerite was controlled by, and also caused, extensive Jurassic faulting. The recognisable tectonic pattern is shown. The faulting in places suggests the development of horst-like and graben-like structures in the downwarps between the main pre-existing highs. Some of the major Tertiary faults of the State were originally lines of Jurassic movements, and there is a suggestion that the Tertiary Midlands, Cressy, Tamar, and possibly the Derwent and Oyster Bay trough structures were inherited, in part, from Jurassic structures. It is considered east-north-easterly and north-easterly tensional forces were important in producing the fault pattern and that it was controlled to a certain extent by the margins of the main pre-existing highs and structural trends in the basement. The greatest fracturing took place in the central trough of the main downwarp between the highs of western and eastern Tasmania. Dolerite magma probably rose here from feeder dykes and its emplacement was controlled by compensation surfaces, giving rise to transgressive sills, meeting in numerous large dykes, with considerable rafting of sedimentary blocks. Away from the main downwarp, sill sheets were more extensively developed and in the broad scheme their emplacement apparently followed compensation paths. Cone structures were emplaced, apparently mostly on the margins of the downwarps and on small intervening highs. On the upper flanks of the main highs, feeders were mainly plug and dyke-like plugs. Where basement highs exceeded heights of about 4,000 feet above the basement level in the downwarps, dolerite feeders were lacking.

At the time of the dolerite intrusions Tasmania was probably situated below the Antarctic Circle, just east of the Ross Sea, and comparisons are made with the similar Ferrar dolerites of Antarctica. Differences in the emplacement of the dolerite appear to be due to structural differences between the two regions at the time of emplacement. Only limited comparisons can be made between Jurassic trends associated with the dolerites of the two regions, but maxima in the trends of Tasmanian dykes were apparently similarly orientated to those of Antarctica.

INTRODUCTION

Tasmania is extensively intruded by tholeiitic dolerite (for map see Spry 1962) in the form of dykes, sills, plugs and cones (Carey 1958a; Spry 1962). The intrusion is Middle Jurassic (167 million years; McDougall 1961). The pattern of intrusion is complex, the dolerite spreading out through sub-horizontal Permo-Triassic strata from feeders rising through the folded Precambrian-Palaeozoic basement. Secondary feeders rise from the dolerite spreading out from the primary feeders. The intrusion was associated with extensive normal faulting. Little is known concerning the factors controlling the sites of intrusion and the emplacement of the dolerite, and no overall tectonic pattern has yet been recognised. This paper represents a preliminary attempt in this direction.

RECOGNITION OF PRIMARY FEEDERS

Primary feeders such as dykes, plugs, and possibly cones can be recognised where the Permo-Triassic cover has been stripped by erosion, exposing the folded basement. Elsewhere other methods are necessary to demonstrate downward extension of dolerite structures into the basement. Thus McNeil (1965) has suggested that the dolerite capping of St. Patrick's Head represents a plug rather than a sill remnant, on the grounds of the differentiation of the dolerite. Conversely, McDougall and Stott (1961) show from gravity measurements that the dyke at Red Hill is unlikely to continue in depth to the basement.

Carey (1958a) demonstrated a technique for locating possible feeders by means of isostrats. Dyke-like feeders are indicated by parallel closely spaced, successively falling isostrats; plugs and cones by concentric isostrats falling successively inwards. Isostrat patterns similar to those of cones, however, can result from alternative structures. Further, even if a conical structure is demonstrated it may not represent a feeder, but merely a basin-shaped sheet emplaced under the flotational mechanism outlined by Bradley (1965). Characteristics required for the recognition of cone-like feeders in Tasmania are set out below.

1. The dolerite is demonstrably *in situ*. Dolerite ranges in Tasmania are commonly skirted by talus deposits resulting from Cainozoic glacial, periglacial, and gravitational action and these, in cases, have been mapped as dolerite outcrops (see McNeil, 1965; Sutherland, 1965; Jennings, 1963, pp. 91-92).

2. The dolerite body is annular in plan with inwardly dipping sides and rises from a basal feeder channel. Annular outcrop may be obscured by the rugged dissection of the Tasmanian landscape and later Tertiary faulting; while the inward dip of the sides may be obscured by lack of exposure, or only become apparent by compensating for Tertiary epeirogenic tilting. In many cases the root zone will not be exposed and the presence of a feeder channel, or otherwise, cannot be confirmed by direct observation.

3. Isostrats and structure contours are concentric in plan and fall successively inwards towards the centre of the cone. Isostrats, unlike structure contours, are not greatly affected by the factors mentioned under 2. This is discussed in detail by Carey (1958a).

4. The roof rocks within the cone are uplifted dilationally with respect to the outside rocks.

5. The conical structure may be expressed physiographically as a basin where exhumed by erosion of the softer sedimentary core.

6. The intrusion of the cone may be accompanied by concomitant radial, peripheral and tangential faulting, particularly in the uplifted roof rocks. Strong updragging and shattering due to forcible intrusion of the cone may also occur.

7. Rocks within and around the apex of the cone may show greater baking effects than is normal with sedimentary-dolerite intrusive contacts. This is due to the concentrated heating here. Pyrite in the original sediments may be converted to pyrrhotite (Carey 1958a).

8. Differentiation zones of the dolerite will parallel the flare of the cone, passing from the upper zone along the inward margin, through the "pegmatitic" and central zones, to the lower zone along the outer margin. This has been demonstrated by Spry (1958), and Sutherland (1964). There will be a corresponding variation in density (Jaeger and Green, 1958). Granophyre may also occur within the upper margin of the cone (Anand Alwar, 1960; McDougall, 1964).

9. Gravity and magnetic surveys over the structure should show profiles compatible with a cone structure rising from a basal feeder channel.

CONE STRUCTURES IN TASMANIA

(Figures 1 and 2)

Several cone-like structures have been mapped in Tasmania to date and two further possible cases are proposed here. These structures are examined in the light of the characteristics listed above.

1. Great Lake Structure (Carey, 1958a; Jones, 1963; Haigh, 1963; McDougall, 1964). This structure shows characteristics 1, 2 (in part), 3, 5, 8 and 9. Only small patches of roof rocks remain. If these belong to the Permian System as suggested by McDougall (1964) then they also demonstrate characteristic 4. McKellar (1957) in the Weston Creek area notes a tendency towards an arrangement of faults radial from Great Lake. The faults are possibly Jurassic in origin (characteristic 6). There is thus considerable evidence for a conical structure at Great Lake. The large thickness of the dolerite here (Jones, 1963) suggests it is a centre of intrusion but this has not yet been proved conclusively.

2. Huon Structure (Carey, 1958a): This structure shows characteristic 1, 2 (in part), 3, 4, 5, 6 and 7. Further detailed mapping and geophysical surveying is being carried out here by the Geology Department, University of Tasmania. These investigations tend to confirm the presence of a cone-like feeder (D. E. Leaman and I Naqvi, pers. comm.).

3. Esperance structure (Carey 1958a): A small conical feeder was proposed here on the basis of characteristics 3 and 5. Further investigations are required to establish this.

4. Billop Structure (Carey 1958a): The proposal of a small intrusive cone at this locality is based on characteristics 2 and 3. Further detailed investigation is again required.

5. Golden Valley Structure (Carey, 1958a; Sutherland, 1965): Carey suggested the presence of a small conical feeder here on the basis of characteristics 2, 3 and 6. Further investigation by Sutherland indicated the need for more detailed examination of the structure in regard to characteristic 1.

6. Zeehan Structure (Spry, 1958; Blissett, 1962; Bradley, 1965): This shows characteristics 1, 2 (in part), 4 and 8. Characteristic 3 is not demonstrable as the Permo-Triassic cover has been mostly removed by erosion, but is in agreement with the stratigraphic level of the intrusion of the dolerite to the south-west at Firewood Siding. Spry notes that the Permian Tillite outcropping around the cone is more indurated than is normal but whether this indicates characteristic 7 is not certain. There is, as yet, insufficient evidence to determine whether the structure represents a conical feeder (Carey, 1958a), or a rootless conical sill sheet (Bradley, 1965).

7. Bloomfield Structure (Anand Alwar, 1960): This structure was mapped as a small cone sheet and shows characteristics 1, 2, 3, 5, 6 and 8. Characteristic 4 is not readily apparent as the rocks within and outside the cone consist of lithologically similar rocks of the Triassic System.

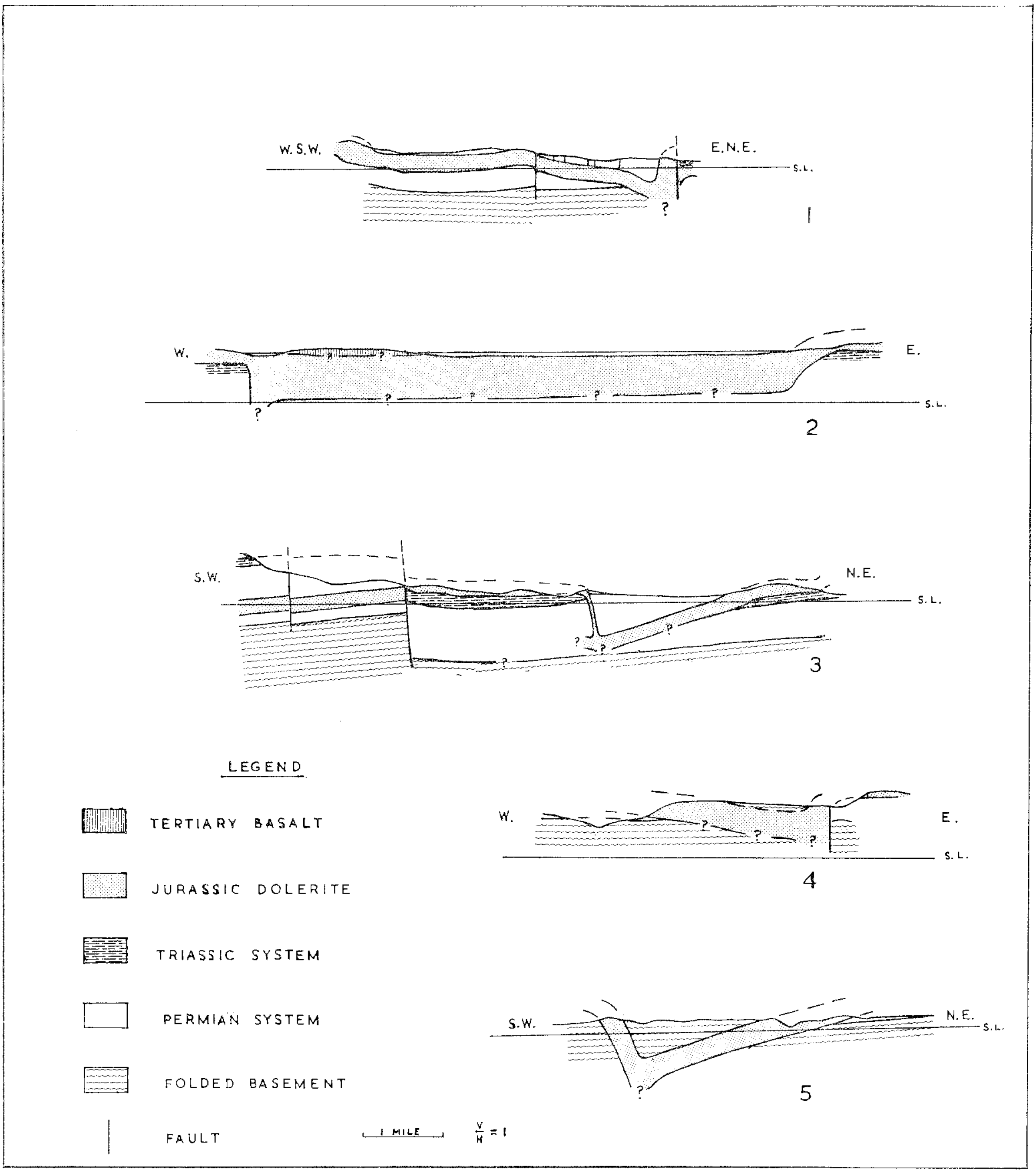


FIG. 1.—Sections through some Tasmanian cone-like structures. *1.* Collinsvale Structure (from the mapping of Sutherland 1964); *2.* Great Lake Structure (after Jones 1963); *3.* Mangalore Structure (from the mapping of McDougall 1959); *4.* Cheyne River Structure (from the mapping of Gulline, Longman, and Matthews 1963); *5.* Zeehan Structure (after Spry 1958).

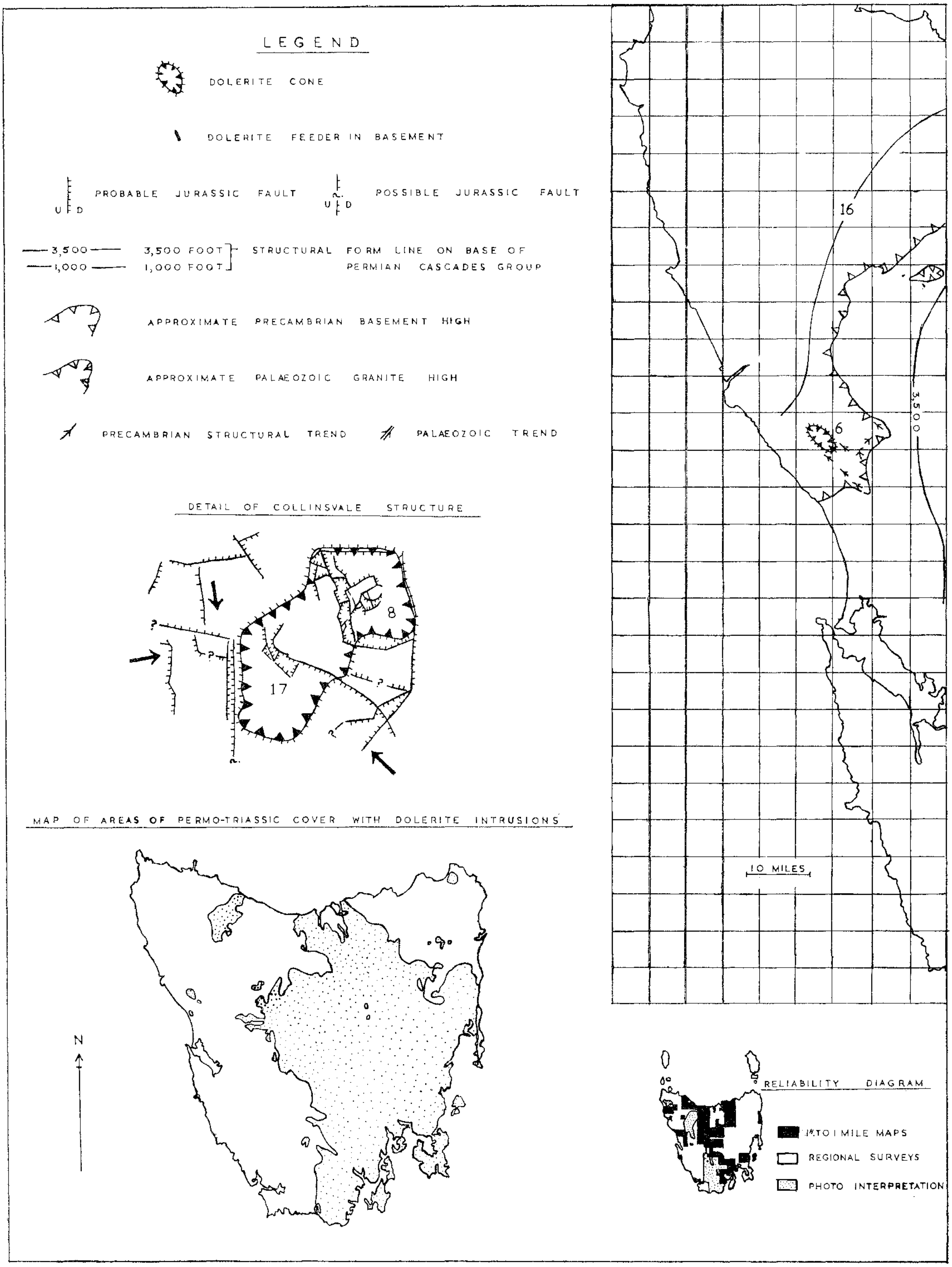
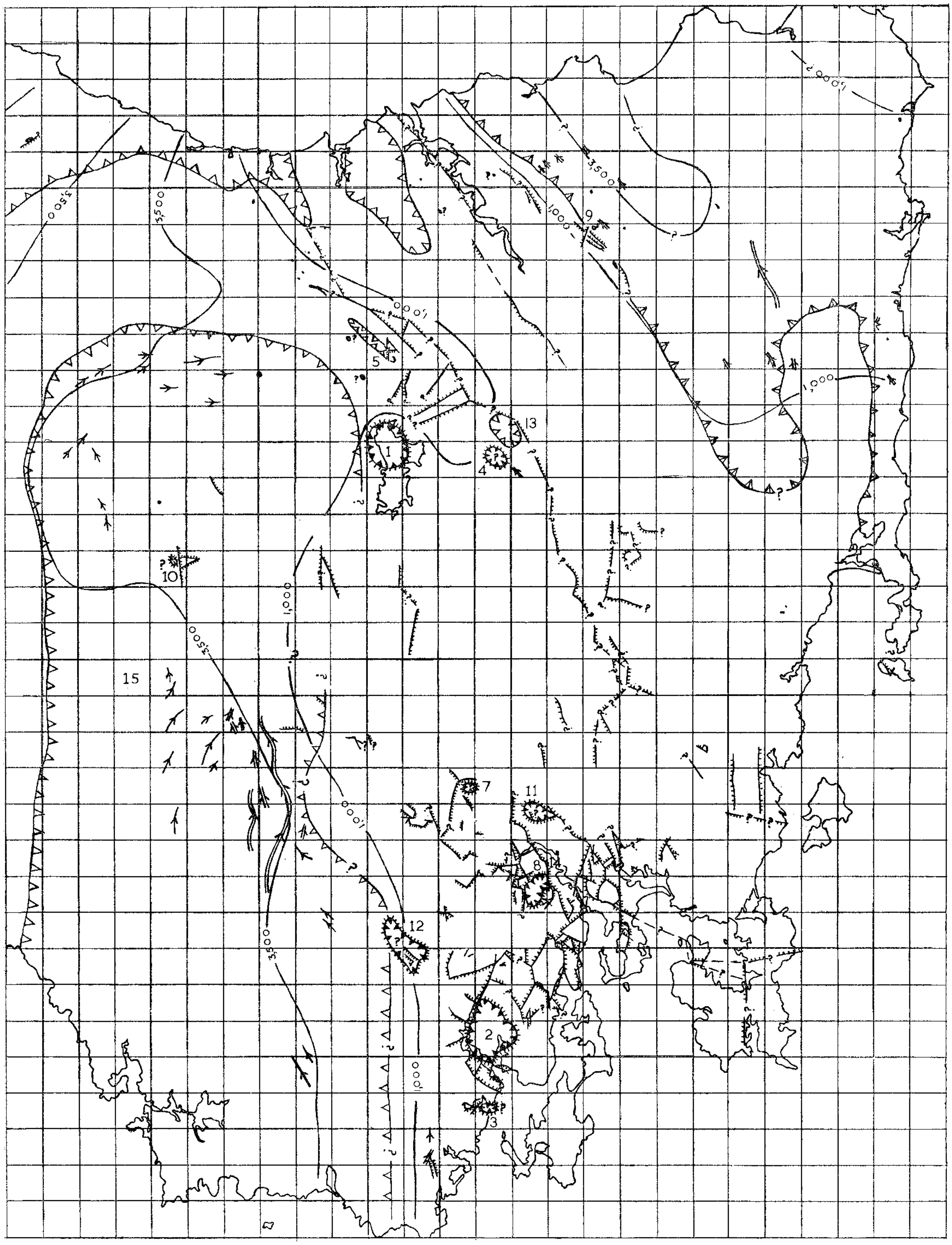


FIG. 2.—Map showing Jurassic tectonic features, including distribution of known dolerite feeders and cone structures, faulting, and structural highs. *1*. Great Lake Structure; *2*. Huon Structure; *3*. Esperance Structure; *4*. Billop Structure; *5*. Golden Valley Structure; *6*. Zeehan Structure; *7*. Bloomfield Structure; *8*. Collinsvale Structure; *9*. Patersonia Structure; *10*. Cheyne River Structure; *11*. Mangalore Structure; *12*. Little Denison River Structure; *13*. Tiers Fault Line; *14*. North-West Bay-Cascades-Dromedary Fault Line; *15*. Tyennan Geanticline; *16*. Rocky Cape Geanticline; *17*. Collinsvale Basin Structure at convergence of sill bodies (arrows).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8. Collinsvale Structure (Sutherland, 1964): This structure shows most of the characteristics of a conical feeder, namely 1, 2 (in part), 3, 4, 5, 6 and 8. Limited investigation also showed the structure to be compatible with characteristic 9. In regard to characteristic 2 the north-eastern outer margin of the cone S.E. of Abbottsfield is shown on other mapping (see Banks, 1965) as a vertical contact displaced slightly southwards by a Tertiary downthrow to the north-east. This implies a slight outward dip of the dolerite margin. Careful examination at this place by the writer, however, showed the margin to slope slightly inward and meet the Tertiary fault a few yards to the south of the contact on the downthrown side. It is perhaps also worthwhile to record a further example of characteristic 4, just to the south of the mapped area. Here Triassic sandstones and Permian Ferntree Mudstone are exposed underneath the dolerite by a branch of the Mountain River and are dilationally downthrown of the order of 1,000 feet with respect to the rocks within the cone.

9. Patersonia Structure (Longman, *et al.*, 1964): Regional mapping here has revealed a structure showing characteristics 1, 3 and 6 suggesting a possible cone-like feeder.

10. Cheyne River Structure (Gulline, 1965): A dolerite centre here shows characteristics 1, 2 (in part), 3, 4 and 6, and is suggestive of a cone-like feeder, although the root zone is not exposed.

11. Mangalore Structure: The structure has been mapped by Nye (1922), Lewis (1946), and McDougall (1959). The latter writer suggested the dolerite mass at Strathalie Hill was possibly an intrusive centre. It is suggested here the structure is possibly a cone-like feeder extending from Strathalie Hill to Wybra Hall (Figure 1).

The dolerite encloses a sedimentary block (characteristic 2, in part) and isostrats conform with characteristic 3. The inner margin of the southern wall of the structure was observed by the writer in a quarry north-west of Goat Hill. Here it is clearly seen sloping inward to the north at about 75 degrees. The outer margin of this wall extends outwards forming the sill body to the south and probably transgresses gently upwards through the Triassic strata. This is not immediately apparent as the dolerite on the southern side of the Jordan River is in places at a lower level than the dolerite of Goat Hill. This can be accounted for by the eight to ten degree tilt of the strata here, probably mostly due to tilting toward the Dromedary Fault plane during the Tertiary epeirogeny. McDougall considered the northern inner margin of the structure represented the top of the dolerite sheet sloping to the south underneath the sedimentary strata. The writer has observed dolerites of the upper differentiation zone at this contact, along the Broadmarsh Road one mile from Mangalore, confirming this interpretation (characteristic 8).

The sedimentary block enclosed by the dolerite is dilationally uplifted with respect to the rocks outside (characteristic 4) and is expressed physiographically as a basin (characteristic 5). This is most apparent near Wybra Hall. The northern dolerite-Triassic contact here was mapped by McDougall as a possible extension of the Tertiary Bagdad Fault, but he suggested it was probably an intrusive contact due to the presence of sandstones metamorphosed to quartzite. McDougall's map however, shows little apparent differential displacement at the western end of the structure. Check mapping by the writer proved the small area between the basalt plug and the dolerite margin about one mile north-west of Goat Hill, to be Ferntree Mudstone and not Triassic sandstone as shown by McDougall. The break in rock type is probably due to a fault, concomitant with the dolerite intrusion and down-throwing to the north-east. This was apparently the line of ascent of the Tertiary basalt plug, and its presence brings Ferntree Mudstone within the dolerite up against Triassic rocks on the outside. In association with the concomitant faulting there is strong updragging, shattering, and thermal metamorphism noted by McDougall along the intrusive contact at Strathalie Hill (characteristics 6 and 7).

A noticeable feature of the Mangalore structure is the much greater thickness of the dolerite to the west and north than to the south and east (see Figure 1). One possible explanation is that the sill-body, intruded low down in the Permian beds and brought to the surface on the upthrown side of the Dromedary Fault, originated from the southern part of the structure, tapping much of the dolerite magma from that part. Finally, although this structure shows many of the characteristics of a cone-like feeder, alternative structures are possible. A knowledge of the depth of the sedimentary block enclosed by the dolerite, such as might be gained from a geophysical survey, would help to indicate: (i) whether the dolerite is rising from a basement feeder; or (ii) whether the structure is merely a large sedimentary block rafted up above a low-level sill rising from the south-west.

12. Little Denison River Structure: The south-eastern end of this structure has been mapped by Ford (1955). Examination of this and the aerial photograph interpretation mapping to the north-west (Geological Map of Tasmania; Tasmanian Department of Mines, 1961) indicates characteristics 1, 2, 3, 4, 5 and 6, suggesting a possible cone-like feeder. Detailed mapping of the north-western section of the structure will be necessary to prove this.

Other Possibilities: Some other structures that have been mapped exhibit some of the characteristics associated with conical feeders and may prove to be so with further investigation. These include the structure south of Boyer (Woolley, 1959) and the structure east of Lindisfarne (Hastie, 1961). Banks (1958) suggested that the dolerite near Takone possibly represented a cone sheet. Recent mapping in this area, however, has shown the structure to be essentially a flat-lying concordant sill rising from a dyke-like body in the northern part (R. D. Gee, pers. comm.).

Large tracts of dolerite country in Tasmania are still incompletely known, particularly on the southern and eastern coasts. Further conical structures may be recognised with detailed mapping. Some of the plug-like bodies exposed in the folded basement may represent feeder channels of cones now completely denuded.

FORM OF THE CONE STRUCTURES

The cone-like structures of Tasmania are generally asymmetrical. Most are elongate in plan. They commonly have a north-westerly orientation, but some have a tendency to an east-west orientation (Figure 2). The Collinsvale structure at first sight is elongate north-easterly but its throat east of Glen Lusk has a north-westerly orientation. In sections one side of the cone is generally steeper than the other and is commonly almost vertical (Figure 1).

These structures present some difficulty in regard to interpretation of the mode of emplacement. As has been shown, in many instances, there is insufficient evidence to determine whether they represent rootless conical sheets, emplaced under the flotational mechanism of Bradley (1965), or whether they represent conical feeders as suggested by Carey (1958a). Indeed, examples of both posisbilities may be present. Where the intrusions are associated with concomitant radial and peripheral faulting, with strong fracturing of the roof rocks, and with strong thermal effects, &c. (e.g., Collinsvale, Huon and Bloomfield structures), they would seem to represent centres of intrusion. However the alternative case cannot be completely discounted as similar fracturing, &c., possibly may result from: (1) a building up of intrusive pressure associated with downward flow of dolerite, collecting where a compensation surface forms an angular pocket; and/or (2) cauldron subsidence as the emplacement of the dolerite magma continues by upstepping to higher levels. In this event it would be expected that the fracturing would be mostly confined to the roof rocks. This does not appear to be the case with the Bloomfield and Huon structures, at least.

If the Tasmanian structures mainly represent conical feeders, then most of them differ in form from the classical Hebridean cone sheets (Anderson, 1942) in several particulars. They differ in being unsymmetrical in section; in the limb angles (one limb generally being steeper and the other shallower compared with the classical case); in not forming concentric series; and in showing greater thicknesses of dolerite. Carey (1958b) has discussed how thicker, and more shallow-limbed, cone sheets than the classical types can arise where conical feeders intrude young sedimentary layers. This results from the tendency to flotational intrusion counteracting the conical shearing due to the hydrostatic head of the intruding magma. Some of the Tasmanian structures may be of this type (e.g., the Bloomfield structure, as discussed later) but the marked asymmetry shown by most of the conical structures requires further explanation.

Examination of these structures indicates that the steep limb of the cone is emplaced along a fault and that the shallower limb, as a rule, intruded on the upthrown side of the fault (e.g., Collinsvale, Cheyne River, and Mangalore structures). Emplacement of dolerite along a fault would greatly reduce the effect of conical shearing due to the hydrostatic head of intruding magma and emplacement by flotational intrusion would be the dominant intrusive process. Under these conditions conical structures could develop as the result of sideward emplacement of tongue-like wedges of dolerite from the magma rising along the feeder fault. Bradley (1965, fig. 5) illustrates the stress conditions at the apex of such a wedge and shows that there will be a tendency to tensional fracturing of the roof rocks in a plane inclined to that of the wedge. Thus, with a circular tongue-like wedge there will be a tendency to form a conical fracture around its margin. Bradley also notes (*loc. cit.*, p. 36) that in the early stages of intrusion, when such a wedge is fairly small in area, the magmatic pressure may be raised considerably by the load of the over-hanging roof. Such conditions would favour cone-like extension of the dolerite wedge, accompanied by peripheral and radial faulting of the intruded strata. As the wedge extended there would be a decrease in magmatic pressure. The course of the intrusion, then, would be influenced more by other controls, such as bedding planes and compensation surfaces, and there would be reduced breaking of roof rocks. The tendency to initial cone-like extension of tongue-like wedges will depend on the shape of the wedge in plan, and will decrease proportionally with the departure from a circular plan. Thus, there will be a range of possible structures from almost circular cone-like bodies, through increasingly elongated types, and finally to sill-like bodies. Even in instances where there is little or no tendency to conical fracturing by an intruding dolerite wedge, a conical structure may still ensue as the result of intrusion along a conical compensation surface.

Bradley (1965) remarks that the factors controlling the horizon at which initial sideways emplacement of a wedge takes place from a dolerite feeder are probably largely fortuitous. However, where the dolerite feeder dykes rise along a fault there is probably a tendency for a wedge to intrude initially on the upthrown side. This would result from an upstepping of compensation surfaces on downthrown sides of young faults (Bradley, 1965). This is illustrated in Figure 3 and would account for the asymmetrical profiles of many of the Tasmanian cone structures. The Mangalore structure (Figure 1) may represent the case where this tendency was only partly realized. Thus, there was emplacement of a sill wedge along a particularly favourable lower horizon on the downthrown side, in addition to the emplacement of the wedge on the upthrown side, Where rootless conical sheets, emplaced along compensation paths, meet young faults they may show similar asymmetrical upper profiles to those of conical feeders emplaced as detailed above. This again stresses the difficulty in determining the mode of emplacement of some of the cone-like structures where there is lack of evidence regarding the nature of the root zone.

The majority of the Tasmanian cones appear to rise from below the level of the folded basement beneath the Permo-Triassic cover. The Zeehan structure, thus, rises from some distance within the basement and alternative explanations for this by Carey (1958a; 1958b) and Bradley (1965) have already been dealt with. The structure at Bloomfield is an exception in that it appears to rise from about the base of the Triassic succession. This structure has been interpreted as a conical feeder (Anand Alwar, 1960) and, if so, then it is presumably a secondary rather than a primary feeder. A possible source is the sill intruded into the Ferntree Mudstone and rising up into the base of the Triassic System, eight miles to the south-west. Some of the conical sheets of the Karroo dolerites of South Africa have been considered to have developed from cupola-like structures on sill roofs (see Walker, 1958). The Bloomfield structure appears to be centered in a domal structure in the Permo-Triassic rocks, with radial and peripheral faulting and is accompanied by cauldron subsidence; all of which is compatible with such an origin. That such cupolas do occur on sill sheets in Tasmania is indicated by the structural interpretation of the Red Hill dyke body by McDougall and Stott (1961). It is interesting to note that the dolerite has differentiated to granophyre at both the Red Hill and Bloomfield structures. The possibility exists that a cone sheet structure was also originally developed on top of the Red Hill dyke, with perhaps another on the similar structure at Hickman Hill to the north. Evidence for this has been mostly destroyed by erosion. However, there is a dolerite sheet, to the east, capping Mt. Louis and sloping to the south-east, but on its western margin arching over and shelving downward towards both Red Hill and Hickman Hill.

The Bloomfield structure raises some interesting points regarding its mode of emplacement. As mentioned previously, it is considered unlikely to be a rootless conical sheet, emplaced along a conical compensation surface that would exist here complementary to the domal high. However, its emplacement as a shallow conical feeder, formed from magma rising from an underlying cupola-like reservoir, may have been largely guided by such a compensation surface. Alternatively, the cone may have resulted from the mechanism outlined by Carey (1958b) for conical intrusion in young sedimentary layers. The stratigraphic level of intrusion at Bloomfield, and also that of a possible similar structure at Red Hill, appears to be at about the base of the Triassic System and may be of significance. This horizon would consist of less consolidated sediments overlying slightly more consolidated and folded (warped) Permian beds. Under the intrusive mechanism of Carey (*loc. cit.*) it would bear the same relationship to a magma reservoir, but to a lesser degree, as would the unfolded Precambrian-Palaeozoic basement to its Permian cover. In the former case the magma reservoir was probably a sill-cupola, in the latter case subcrustal.

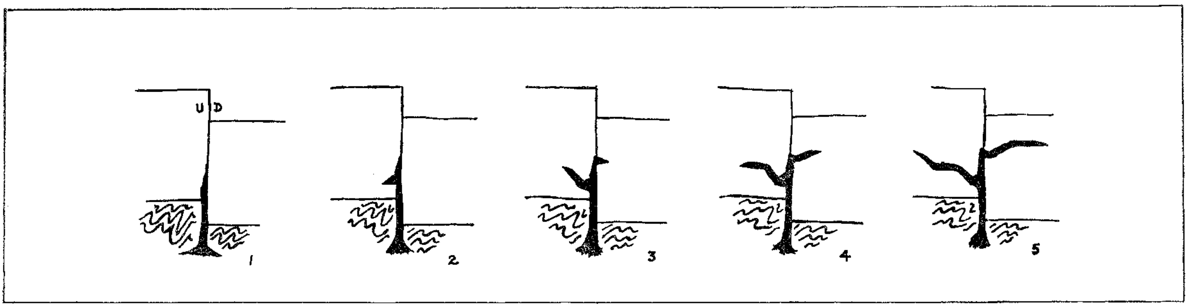

FIG. 3.—Diagrammatic representation of successive emplacement of dolerite (black) intruding along a fault, and giving the typical asymmetrical section as shown by some Tasmanian cone structures.

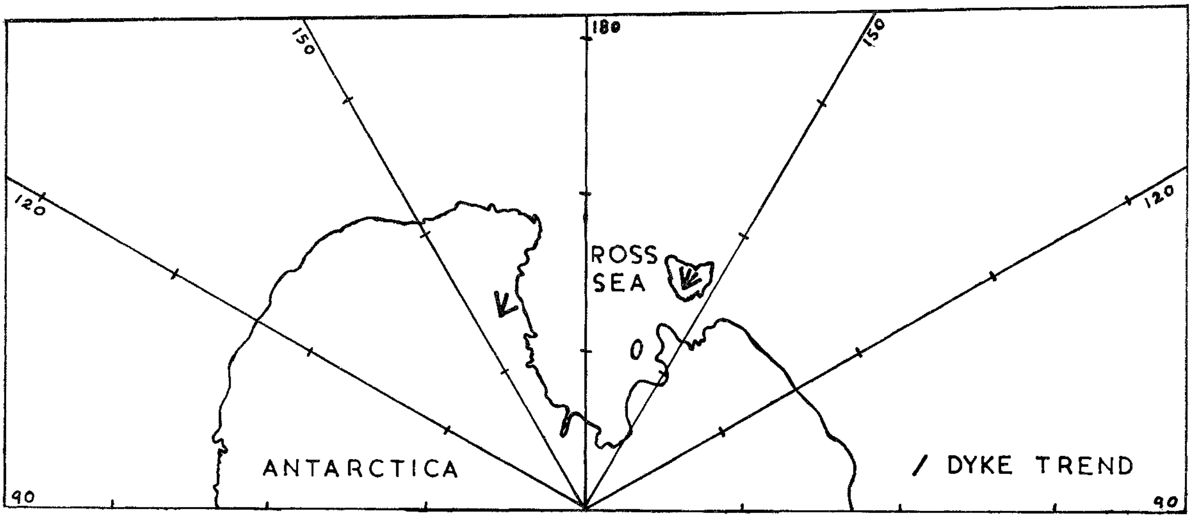

FIG. 4.—Trends of Jurassic dolerite dykes in Victoria Land, Antarctica (from Gunn and Warren 1962) compared with those of Tasmania (Banks 1958). Tasmania is restored to its probable location in the Jurassic.

TECTONICS OF THE DOLERITE INTRUSIONS

A knowledge of the structure of Tasmania prior to the intrusion of the dolerite is important in understanding the control of its emplacement. Banks (1962) has suggested epi-Permian uplifting in eastern, north-eastern and western Tasmania. The evidence he gives for this is further supported by the presence of Permian rocks in a conglomerate bed in the upper beds of the Triassic System (Nye, 1921). Banks (*loc cit.*) shows the Permian beds were folded into a major north-north-westerly synclinal structure that provided a basin of deposition for the Triassic freshwater succession. The main uplifted areas are outlined in Figure 2, in this paper, by the plot of the 1,000 foot and 3,500 foot structural form lines on the base of the Permian Cascades Group. Also plotted are the approximate margins of highs in the old Precambrian basement, relevant areas of the Palaeozoic highs, and the structural trends in these areas.

All recognisable cone structures, basement feeders and faulting associated with the dolerite intrusions are also plotted on Figure 2. The data has been compiled from the published detailed mapping of the State. This includes the Geology Department, University of Tasmania, 1 inch series; the Tasmanian Department of Mines 1 mile series, as well as maps in the Geological Survey Bulletins, Geological Survey Mineral Resources, and Technical Reports; mapping for the Hydro-Electric Commission in published papers in the Royal Society of Tasmania; and other incidental publications. Information was also used from unpublished maps of the Geology Department, University of Tasmania 1 inch series and from recent mapping by R. P. Mather, Hydro-Electric Commission, and R. D. Gee, Tasmanian Department of Mines. Early regional mapping published by the Tasmanian Department of Mines in the Geological Survey Bulletins, Geological Survey Mineral Resources and Underground Water Supply Papers was also used, but is generally insufficient to determine Jurassic structures. A reliability diagram is shown in Figure 2. Responsibility for the interpretations of Jurassic features from the above sources, and shown in Figure 2, rests with the writer.

It must be borne in mind that Figure 2 is not a complete representation of the Jurassic tectonic structure. This is due to the unfinished detailed mapping of the State, the lack of evidence as to the form of some of the dolerite bodies, the lack of evidence as to the precise age of many of the post-Permo-Triassic faults, the difficulty in recognising faults in lithologically similar strata, and the absence of exposures of the Permo-Triassic strata and dolerite structures due to denudation, mutual blanketing, or superficial deposits. Nevertheless, certain features concerning the emplacement of the dolerite are apparent.

Distribution of the Basement Feeders: One of the most striking features is the disparity in the concentration of the dolerite emplacement; by far the greatest density of dolerite and of exposed feeders being in the eastern two-thirds of the State. There is a lack of feeders in the areas enclosed by the 3,500 foot structural form line.

The cone-like structures are situated mostly along the margins of the main uplifted highs of pre-dolerite Tasmania or on smaller highs between these. In some cases these correspond to Precambrian basement highs. Thus the little Denison, Cheyne River, and Great Lake Structures are located along the eastern margin of the Tyennan Geanticline, the Zeehan structure along the eastern margin of the Rocky Cape Geanticline, and the Golden Valley and Billop structures on the flanks of narrow north-westerly trending Precambrian ridges. The Patersonia structure is sited on the margin of the north-eastern pre-dolerite high of Palaeozoics. Other cones are located on apparent highs in the Permo-Triassic strata. The Huon structure is centered in a domal structure (Banks, 1962). Whether this is controlled by an underlying local basement high, or whether it is due to the dolerite intrusion, has not yet been established. The Collinsvale structure appears to be sited on the flank of a north-west-northerly trending anticlinal structure following, and lying west of, the Cascades Fault line (see Banks, 1965). This structure may represent an underlying basement ridge or margin, as there is evidence, discussed later, that the Cascades Fault is pre-Collinsvale structure in origin, downthrowing to the north-east presumably with a corresponding drop in the basement.

The basement feeders on the flanks of the main pre-dolerite highs are dominantly plug or dyke-like plug structures. Examples are numerous and include plugs at Long Lake (MacLeod, Jack and Threader, 1961), Devil's Gullet (Ford, 1960; Jennings, 1963), Ringarooma (Nye, 1924a) and St. Patricks Head (McNeil, 1965). In contrast in the downwarps between the highs, long dyke-like structures (megadykes), transgressive sill-bodies and numerous rafted blocks of sediment are very characteristic. Numerous examples occur in the Midlands (Nye, 1921; 1922; 1924). The nature of the feeders in the basement for these structures is nowhere exposed, but it is difficult to visualise how they could arise unless fed by long feeder dykes.

Faulting Associated with the Dolerite Intrusions: The dolerite intrusions were controlled by, and also caused, extensive Jurassic faulting. Criteria for the recognition of Jurassic faulting in Tasmania have been discussed by Carey (1958a) and Banks (1958). The Jurassic fault pattern shown in Figure 2 is the result of the applications of these criteria to the available geological mapping of the State. The incompleteness of this pattern has already been stressed. In many cases it is not possible to determine whether the faults affect the basement or are merely breaks in the sedimentary cover resulting from intrusive dilational phenomena associated with the dolerite. Furthermore, the present relative movements shown on the faults are not necessarily the original sense of movement. This may result from later reverse movements associated with dilational phenomena of intruding dolerite or Tertiary epeirogenic movements (see Carey, 1958a). However, some tentative conclusions regarding the Jurassic faulting can be made.

Some, at least, of the major Tertiary faults of the State were originally lines of Jurassic movement. This has already been suggested for the Tiers Fault (Carey, 1958a). There is also evidence that the North-West Bay-Cascades-Dromedary Fault line is a pre-dolerite feature. The grounds are: (1) the fault line appears to be interrupted and displaced by the intrusive dolerite of the Ridgeway-Mt. Nelson's area; (2) the dolerite of the Red Hill-Hickman Hill-Picket Hill body appears to rise from the North-West Bay Fault, east of which it is either absent or at a considerably lower stratigraphic level (McDougall and Stott, 1961); (3) at Chigwell the outer margin of the Collinsvale cone-sheet structure is intrusive into the lower part of the Ferntree Mudstone on the western side of the fault, but on the eastern side is intrusive into beds of the Triassic System, suggesting a pre-intrusive downthrow to the north-east; and (4) at the north-western end of the Dromedary Fault, the Dromedary sill body is instrusive into Ferntree Mudstone on the western side of the fault, but on the opposite side the same sill body intrudes at least 650 feet above the base of the Triassic (McDougall, 1959), again suggesting a pre-intrusive downthrow to the north-east. Bradley (1965) has suggested that where dolerite bodies intrude across young faults they upstep on the downthrown side by an amount about seven times that of the throw of the fault. At Chigwell the eastern limb of the Collinsvale structure is near vertical and is intruded along the Cascades Fault, upstepping from low down in the Permian succession on the upthrown side to a considerable height in the Triassic succession on the downthrown side. Applying Bradley's dictum, this suggests a pre-dolerite throw of at least 350 feet. Similarly, a lesser throw is implied along this fault line at the north-western end of the Dromedary Fault, and is of the order of 100 feet.

The faulting in places suggests the development of horst-like and graben-like structures in the down warps between the main pre-existing highs. It also suggests that the Tertiary Midlands, and Cressy grabens are, in part, an inheritance from the Jurassic.

In the Tamar Valley Permo-Triassic strata show regional dips from both sides in towards the Tamar River, which appears to occupy the axis of a north-west-northerly downwarp (see mapping of Green, 1959; Marshall, 1965; and Longman, *et al.*, 1964). This downwarp does not continue much further south of the Tamar River where westerly regional dips continue to Poatina. There has been Tertiary tilting and faulting, but this structure does not seem to be completely explained by the known Tertiary faulting and may be partly a Jurassic structure. A long dolerite body is intruded on the west side of the Tamar River and dips steeply to the north-east. Just south of Blackwall the writer has observed steep downdragging in the Triassic(?) strata at the intrusive contact. Similar downdragging is also observed at Long Point where Green (1959) records a dip of 68° to the north-east. This suggests intrusion along a Jurassic fault line downthrowing to the north-east. If this interpretation is valid then it would appear that the Tertiary Tamar trough structure may also be partly inherited from Jurassic times.

The fault pattern in southern Tasmania is very complex. There appears to be a graben structure bounded to the west by the North West Bay-Cascades-Dromedary Fault and occupied by a complicated horst-like structure extending from Storm Bay to Grass Tree Hill. Whether the Tertiary Derwent graben was initially a Jurassic structure is not clear. Some of the Jurassic faulting parallels the trends of the main Tertiary faults, some of which, then, may represent movements along old Jurassic lines. Similarly there is also the possibility that the Tertiary Oyster Bay graben is, in part, Jurassic in origin.

There is some suggestion that the pattern of faulting was controlled to a certain extent by the margins of the main pre-existing basement highs and their associated structural trends. The complicated fracturing in the southern part of the State is possibly partly due to superposition of differing trends in the basement as can be seen to the west where the Palaeozoic trends oppose those of the Precambrian. In the northern part of the State these trends generally coincide and appear to be matched by the Jurassic trends.

The Jurassic tectonic pattern is as yet too incomplete to give a coherent picture of the stress environment but it is suggested north-east to east-north-easterly tension was important. Tensional stress in this direction is compatible with the elongation of many of the dolerite cone structures and the orientations of many of the megadykes. It is also noticeable that where the margins of the pre-dolerite highs and the trends in the basement rocks are co-incident with each other, and are normal to these tensional directions, as in northern Tasmania, there tends to be a corresponding parallelism in the Jurassic faulting and the pattern appears less complex than elsewhere.

EMPLACEMENT OF THE DOLERITE

The following synthesis of the emplacement of the Tasmanian dolerites is presented, arising from the foregoing discussion concerning the pre-dolerite structure, the nature and distribution of the dolerite cones and feeders, and the associated faulting.

Prior to the emplacement of the dolerite, and as a result of epi-Permian uplifts, Tasmania consisted of a cover of Permo-Triassic strata draped in downwarps between highs in the east, north-east, and west, and between lesser intervening highs. Normal faulting under Jurassic tensional forces, including north-east to east-north-easterly tension, developed in the downwarps between the uplifted highs, probably with development of graben and horst-like structures. Fairbridge (1949) has pointed out that it is in such downwarps that the basement fractures first under tension, rather than in the highs. Dolerite magma rose up along these feeder fractures. Where the margins and structural trends of the basement highs coincided and were normal to the main tensional forces there was a corresponding parallelism in the faulting. Where the margins and/or structural trends were opposed to each other and to the main tensional forces the faulting, and consequently dolerite intrusion, was more complex.

The greatest fracturing probably occurred in the central trough of the main downwarp between the western and eastern uplifted highs. Dolerite would ascend mainly through long feeder dykes. Compensation surfaces (Bradley, 1965) beneath this downwarp would occur as steepening arches with numerous vertical jumps across young faults. Thus, dolerite sills rising from feeders and following compensation paths would tend to be transgressive. Splitting of sills would also occur, due to alternative paths of intrusion being available as a result of divorces between compensation and bedding surfaces. Thus, rafted blocks would be a feature. Upstepping across faults would be common giving rise to numerous large dyke bodies (megadykes). All this seems to correspond well with the dolerite outcrop patterns in the Midlands and in parts of south-east Tasmania.

In the higher areas away from the downwarps there was reduced tensional fracturing. Old Precambrian-Palaeozoic structures probably played a greater part in guiding the ascent of the dolerite magma, as has been noted at Golden Valley (Sutherland, 1965) and near Takone (R. D. Gee, pers. comm.). In the broad view, compensation surfaces in the Permo-Triassic cover in these areas would tend to be correspondingly smoother and form flattening troughs, bottoming on the basement in areas of maximum uplift. Thus, in Tasmania the sill sheets tend to become correspondingly more extensive away from the central trough of the main downwarp between the western and eastern highs. Certain horizons proved more favourable than others for emplacement of sills. These were notably at about the level of the Grange-Malbina Formations in the Permian succession and above the Ross Sandstone in the Triassic sequence (see Fairbridge, 1949; Carey, 1958a). The extensive dolerite sill sheet that caps the Central Plateau, Upper Derwent and Upper Huon areas appears to generally conform in behaviour with the likely Jurassic regional compensation surfaces. Although showing exceptions due to the presence of dolerite feeder centres and locally imposed variations in the compensation surfaces, the dolerite shows a general downward transgression as it extends westward across the rising flank of the main pre-dolerite high in Western Tasmania. Thus, the dolerite descends from the Triassic succession into the Permian succession at about between the 2,000 and 2,500 foot structural form lines on the base of the Permian Cascades Group (Banks, 1962). It descends further and rests on basement rocks at about the 3,000 to 3,500 foot structural form lines.

Dolerite cones were emplaced apparently, mainly along the margins of the main downwarps, either on the lower flanks of the uplifted highs, or on lesser intervening ridges and highs. A complete explanation for this cannot be given at present due to uncertainties as to the mode of emplacement of many of these structures. If they mostly represent rootless emplacements of dolerite along conical compensation surfaces, then they express local domes and ridges in the pre-dolerite physiography (if in the Permo-Triassic cover), or depressions (if lying within the folded basement). Such physiographic features, in cases, probably were structurally controlled. Thus some of the asymmetrical cones with one of the limbs emplaced along a fault could represent a fault scarp with locally raised rims. However, it is considered that some, and possibly many, of the cones represent dolerite feeders. Assuming this, the apparent distribution of the cones can be accounted for as follows. The reduced fracturing in the highs compared to that in the downwarped areas resulted in greater resistance to dolerite intrusion. In these areas the dolerite would tend to intrude by conical fracturing where there was sufficient intrusive pressure to overcome resistance. This would be mainly in the thinner parts of the main highs, i.e., the marginal edges, and underneath the narrow and smaller intervening ridges and highs. The dolerite would exploit potentially favourable sites and weakness in these areas. Possible modes of intrusion of such feeders have been discussed previously. Some of the cones are emplaced in part along faults. Some are associated with structural highs (in cases with part emplacement along faults as well) and show concomitant radial and concentric fracturing. It has been pointed out that these highs would offer the greatest potential for relief of upward stresses by means of such fracturing (Sutherland, 1964). Again, if the structural highs were expressed physiographically, compensation surfaces would also favour cone-like emplacement. The respective roles of these and other factors in controlling cone emplacement is difficult to determine. Thus, the Huon cone is emplaced in a domal structure in the intruded sediments. This dome may represent control of the site of intrusion by a local pre-existing structural high, or itself have resulted from the intrusion of the dolerite. Even if the initial emplacement of the cone was not controlled by conical compensation surfaces that would exist here, it is probable that compensation influences came into play. The Scott Arch (Carey, 1958a) is probably an expression of this, with emplacement occurring along a compensation surface complementary to the peripheral low surrounding the domal high.

On the upper flanks of the main high areas dolerite feeders intruded as plugs and dyke-like plugs. Here the intrusive pressure of the dolerite was apparently insufficient to overcome the greater resistance to intrude as cone-like structures. Dolerite rising from these feeders, and from the plug, dyke, and cone feeders on the lower flanks of these highs, joined with the dolerite rising from the more intensively fractured downwarps. At Collinsvale there is some suggestion that the cone was intruded slightly later than dolerite rising from the surrounding areas. Dolerite sills rise toward the cone from the north-west, west, and south-east. These sills converging on this spot appear to have wedged up the strata before them into the Collinsvale basin structure (see Figure 2). On the north-east side of this basin structure small slivers of Permian rocks near Abbotsfield (see Banks, 1965), in association with the Jurassic Glen Lusk and Hull Faults (Sutherland, 1964) outline a small down faulted block. This block occurs where the strata would remain unlifted by the wedging action of the approaching sill bodies. The action of such wedging is illustrated by Bradley (1965, figure 4). These faults and the adjacent basin structure have controlled the Collinsvale intrusion and thus presumably antedate it. The Collinsvale structure is considered to have resulted from dolerite magma intruding up along the Cascades Fault at this spot, or from beneath the anticlinal ridge that flanks the Fault just to the west.

Secondary feeder cones probably developed on underlying sill bodies, as exemplified by the Bloomfield structure and possibly the Red Hill structure. These were apparently derived from laccolithic structures on the sills. Their emplacement may have been controlled by the nature of the Permo-Triassic boundary and/or by conical compensation surfaces that would exist complementary to the laccolithic doming.

Where the basement in the main highs exceeded heights of about 4,000 feet above its level in the downwarped areas, dolerite, apparently, was not intruded through the basement to any extent, and there is a lack of feeders in these areas. This, possibly, may be related to the lesser tendency to tensional fracturing in these areas, to insufficient intrusive pressure of dolerite to allow penetration, and to lowering of isogeotherms beneath the thicker parts of the basement highs.

COMPARISON WITH THE DOLERITES OF ANTARCTICA

Early Mesozoic palaeogeographic reconstructions show Tasmania as part of southern Pangaea or Gondwanaland continents at the time of the dolerite intrusions (Wegener, 1924; du Toit, 1937; King, 1958; Carey, 1958, &c.). The Tasmanian dolerites chemically closely match the Ferrar Dolerites of Antarctica (McDougall, 1962) and reconstruction of the southern land mass by Carey (1958) places Tasmania south of the Antarctic Circle, just east of the Ross Sea. This position accords with the dating of 167 million years for the Tasmanian dolerites (McDougall, 1961) in relation to datings of Ferrar dolerites which are 150-158 million years at latitudes south of Victoria Valley, 159-163 million years at the latitude of Victoria Valley, and 175 million years at the latitude of the north coast of Victoria Land (Webb and Warren, 1965). It is thus of interest to compare the emplacement of the Tasmanian dolerites with those of Antarctica.

The forms of the Antarctican intrusions have been described by Gunn and Warren (1962), Grindley (1963) and others. Sills were emplaced from dyke and plug feeders as in Tasmania, but were more extensive and the sill horizons more numerous. No cone structures have yet been described. The difference in mode of emplacement appears to be related to structural differences in the two areas at the time of dolerite intrusion. In Antarctica a cover of essentially horizontal beds of the Beacon Group (Devonian to Lower Jurassic) overlay a near-level peneplain (Kukri Peneplain) of folded basement rocks (Gunn and Warren, 1962). In Tasmania, on the other hand, the Permo-Triassic sedimentary cover overlay a more uneven basement, partly as a result of strong mid-Devonian folding (Tabberabberan Orogeny) and partly as a result of epi-Permian uplifts (probably associated with the Hunter-Bowen Orogeny). Neither of these events appear to have affected Eastern Antarctica. As a result Eastern Antarctica lacked the broad relief of Tasmania at the time of dolerite intrusion. Compensation surfaces would be much flatter and more continuous, resulting in the much greater extent of sill emplacement. The lack in contrast between downwarp fracturing on one hand, and reduced fracturing in highs on the other hand, would result in the lack of the Midlands type intrusion and the cone-like intrusions respectively. The development of secondary cone sheet structures at higher levels in Tasmania seems related to the presence of epi-Permian warping in the sedimentary cover. In areas where the basement relief became excessive in Tasmania, dolerite was not intruded. This may explain the scarcity of dolerite intrusions on the mainland of Eastern Australia, which was more strongly affected by the Hunter-Bowen Orogeny (Osborne 1950) than Tasmania.

Trends associated with Jurassic faulting and dolerite intrusion in Tasmania have been analysed by Banks (1958) but lack of information regarding those of Antarctica prevents a complete comparison. However trends of dykes in Victoria Land are reported by Gunn and Warren (1962). These are mostly north-east-northerly to easterly and in places, as in Tasmania, the emplacement of the dykes was guided by weaknesses in the basement rocks. The trends show some differences with the trends of maxima for dykes at 348-351°, 9°, 25°, and 38-41° in Tasmania given by Banks (*loc. cit.*). However, if Tasmania is restored to its probable position in Jurassic times, adjacent to the Ross Sea, then the Antarctican and Tasmanian dyke trends show closely similar orientations (Figure 4).

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