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NOTE ON THE ISOSTATIC BACKGROUND OF TASMANIAN PHYSIOGRAPHY.

By

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1. INTRODUCTORY.

The field observations accumulated for the evolving of the theory here propounded would fill a large volume, but it is more than an impossibility to get such a work published. Without this data my theory of the evolution of our major topographical features cannot be proved. However, some prevalent ideas appear to me to be so fundamentally in error that I am tempted to put on record the bare statement of the results of three years' field work. I trust that other observers will subject this theory to the closest scrutiny, and if this paper directs attention to several features hitherto overlooked it will prove useful.

Tasmanian physiography is so closely connected with the great occurrences of dolerite (diabase) that a correct understanding of the one is essential for the deciphering of the other. Every worker in geology in Tasmania has made some contribution towards the elucidation of the problem, and this paper merely carries our knowledge a little further. The statements here contained are not proved, and await further confirmation.

The deciphering of causal processes involves the reconstruction of the history of the landscape. In this paper I commence with notes on different rock series, stressing points which throw light on physiographical development, and then I summarise the conclusions forced on me by the field evidence. In regard to the Permo-Carboniferous-Trias-Jura rocks I accept, and my observations confirm, the statements and conclusions contained in *The Coal Resources of Tasmania.* In regard to the Devonian-Carboniferous and the Tertiary periods, the stratigraphical succession given here is based on recent field observations.

2. THE DEVONIAN-CARBONIFEROUS PERIOD.

The early Palæozoic sedimentations were brought to a definite termination by a major epoch of diastrophism occurring at the close of the Silurian or beginning of the Devonian period. Then great chains of folded mountains were formed over the present site of Tasmania, and within these granite batholiths consolidated (e.g., the granite mountains of the East Coast, and the Heemskirk Range and Granite Tor on the West). This epoch may be taken as the dawn of our present era, and divides Tasmanian stratigraphical geology in half—before it lies the ages of indecipherable physiographic conditions, and after it the historical records are voluminous and reasonably complete, merely requiring correct interpretation.

This diastrophism was followed, apparently, by a long epoch of quiescence, during which sub-aerial conditions existed over the whole of Tasmania, and which corresponds to the Devonian and Carboniferous periods elsewhere. By the end of the latter period the mountain ranges had been entirely denuded and the batholithic cores of granite exposed, in many places to a depth of 2,000 feet. Base-level peneplainal conditions existed in general, but with, certainly on the east and north, many isolated mountain peaks and, west of a line between the mouths of the Forth and the New Rivers, more elevated country.

3. THE PERMO-JURA SEDIMENTATION PERIOD.

This period, comprising rocks of Permo-Carboniferous, Triassic, and Jurassic ages, is in Tasmania one unbroken sequence, and I suggest the above name as a convenient one. It followed the last without an apparent break. At the time of the commencement of the Permo-Carboniferous glacial period the old land surface began to disappear below sea-level. Possibly the sinking commenced earlier, but only brought the rock platform to sea-level at this time. The cause of this sinking is discussed later. The following is an outline of the history of the period:—

A. Glacial Series.

This commenced just as the old rock platform reached sea-level. Where observable, deposits of this series rest on pre-Devonian rocks except at Cape Paul Lamanon, where Permo-Carboniferous limestones underlie them. Evidence points to intense ice-sheet conditions to the west, and at Wynyard and Weld River definite moraines can be found. These appear to have been dropped on a land surface. On the east and southern coasts glacial deposits appear to have originated from small valley glaciers and to have been deposited very often in shallow sea water (e.g., at Maria Island, Cape Paul Lamanon, round Hobart). The greatest observed thickness of these beds is about 2,000 feet at Wynyard, but this has no necessary connection with land movements.

B. Lower Marine Series.

Rocks referable to this series began to be deposited in the latter stages of the glacial age. Fossil evidence proves open shore line conditions and a depth not exceeding 100 fathoms. A maximum of 1,000 feet of lime- and mud-stones was deposited on a sea floor teeming the whole while with beach life, and throughout their deposition their surface was maintained at the same level, no species of the thousands entombed ceasing to flourish on the surface. Occasional bands of sandstone indicate local changes, probably referable to sea currents, and the succeeding beds of limestone show no material alteration of relative strand level.

C. Greta Series.

Then for a short time this sea floor was raised in certain localities just above sea-level, and shales, sandstones, and coal-measures were accumulated to a depth varying from 140 feet at Preolenna to 850 feet at Bruny. In other places the sea still covered the recently deposited sediments, but at a shallower depth, and marine shales were deposited (e.g., around Hobart). In the Mersey basin these were impregnated with spores or sporangia of cryptogams or algal organisms, and the Tasmanite (Mersey oil shale) beds resulted. These plants must have been growing on islands of Silurian rock which had not yet been submerged. In places Tasmanite is found directly covering Silurian strata without the interposition of marine sediments. This feature is referred to later. The rise necessary to produce these conditions would be under 600 feet, and a corresponding amount of sediments was deposited while the surface was maintained at sea-level. Perhaps the change of conditions was due to sinking of the ocean surface. In any case, the general sinking tendency was not interrupted.

D. Upper Marine Series.

Evidently the regular downward movement continued, and the Greta series was covered by these mud-stones, the nature of which indicates very shallow, close inshore, muddy conditions. Nearly 1,000 feet were accumulated (e.g., round Hobart), and throughout the time necessary for this deposition the surface remained at approximately the same elevation in reference to sea-level.

E. Tomago Series.

The Upper Marine Series was followed by conditions just above sea-level, during which shales and coal measures were formed. At Barn Bluff these attain a thickness of 740 feet.

F. Ross Series.

Similar geographic conditions persisted for a very long while, and are characterised by the Ross sandstones, rocks obviously formed from wind-driven sand. Lagoon and terrestrial conditions are occasionally indicated locally. These rocks accumulated—after 50 feet of grits—to a maximum of 700 feet without any indication of a change of geographical conditions.

G. Felspathic Sandstone Series.

Following the Ross series is a bed of great thickness, certainly over 800 feet as observed in many localities (e.g., Fingal, Dalmayne, etc.), and, from observations at Catamaran, perhaps originally 3,000 feet in thickness. The only material changes from the last series are the greater proportion of felspar among the sand grains and a slightly more swampy and enclosed topography. For the whole of the enormous length of time necessary for the accumulation of these beds, the surface kept at the same level relative to sea-level. Bands of shale, sandstone, and coal measures alternate, and all are impregnated with fossil remains of the same species of land plants. Probably such an accumulation requires a greater time than that necessary for the deposition of a similar depth of marine sediments.

H. Knocklofty Series.

In a few localities, especially west of Hobart and at Mt. Nicholas, the felspathic series are succeeded by further sandstones, indicating a return to open sand-dune conditions, and with, at Cascades and Tinderbox, remains of sea fishes. At the type locality a thickness of 1,350 feet is attained.

The sedimentation was closed abruptly and definitely by dolerite intrusions or accompanying earth movements. Nowhere has a complete succession of these sediments been observed, and therefore definite information as to maximum depth is not available. There is a certain variation in thickness from place to place, but later events have often been responsible, and there is much overlapping when a small section in one part of the country is compared with one at a distance. Probably between 5,000 and 8,000 feet of sediments were deposited. I incline toward the higher figure.

It is not possible at present to say from where these sediments came, but it must be remembered that the present limits of Tasmania are of recent evolution. Probably land to the westward or north-westward forming a southern extension of the Australian continental mass, and of which the ancient rocks of our West Coast are a remnant, supplied the sediment. There is also some evidence of land to the eastward.

4. ISOSTATICS OF THE SEDIMENTATION PERIOD.

At any time during the very lengthy period necessary for the accumulation of these deposits, the surface of the newest sediment was never more than 600 feet below sea-level, or 200 feet above. Probably the surface did not vary 200 feet. Several series of over 1,000 feet show no alteration of geographical condition or strand line at the surface, and there is no unconformity, discontinuity, or evidence of streams or other physiographical features. It cannot be assumed that the older surface of the globe was sinking regularly and an exact equivalent volume of sediment was deposited. Even if the sinking could be so regular, the supply of sediment is not likely to be so constant, and a very definite relation is indicated between sinking and deposition. In other words, examination of these beds forces the conclusion that the accumulation caused the sinking.

Interesting proof of the general sinking of the old land surface and of the fact that this persisted over at least the present area of Tasmania and was not by local segments is provided in several localities where hills remained at the commencement of the sedimentation period. These often now stand as islands embedded in the sedimentary series, and later members are deposited directly on the pre-Devonian rocks without the interposition of earlier members as the general sinking brought these older rocks down to the sedimentation level. Thus at Barn Bluff, in places, marine mudstones lie on Proterozoic schists, but here and there over the location of ancient hills the Tomago Series rests directly on them without any of the Marine Series intervening, and at Cradle Mountain both are absent and Ross sandstones directly succeed the original platform. Again, at Ida Bay, Upper Marine limestones unconformably succeed Silurian limestones; a little farther south Ross sandstones, and farther south still, felspathic sandstones rest directly on the Silurian rocks, and in each case the floor of the more recent sedimentary series appears at the same level over the limestones as it does elsewhere in the locality over the next inferior member of its own series. At Latrobe many included islands of Silurian quartzites are found in the shale beds, and these older rocks in no way interrupt the strata elsewhere. In places down the East Coast felspathic series rocks may be seen resting on the early Devonian granite batholiths, while elsewhere, in places where the granite did not rise so high (e.g., Maria Island), earlier series cover it.

The first question that must be solved before we can proceed further is how such a delicate adjustment extending over so many millions of years could have taken place. Field evidence first forced on me the explanation of the dolerite intrusions set out in para. 6 *post*. In seeking confirmation I came to the conclusion that these sediments were gradually forcing their rock floor into a magmatic reservoir. Without the opportunities afforded in large centres, I hesitated to advance such a theory until I read an article by Mr. W. B. Wright in the Geological Magazine of May, 1925, elaborating a theory that such a process could occur. It is interesting to find this confirmation on theoretical grounds of an empirical hypothesis evolved from field evidence.

The explanation of the perfect and instantaneous adjustment to the added sentiments then is that, throughout this period, there existed deep in the crust below Tasmania

a magma reservoir which allowed perfect adjustment to added weight on the old rock platform. The pressure of the accumulating sediments squeezed the magma outward—probably towards the west. This in turn caused a gentle rise in the land surface at some distance, and allowed the supply of sediment to be maintained.

The sedimentation period closed abruptly when the magma could no longer accommodate itself to the gradual increase of pressure. The isostatic conditions during this period were therefore those of perfect adjustment due probably to the existence of a magma reservoir. Further features regarding this magma will be discussed when the dolerite intrusions have been described.

5. DATE OF THE DOLERITE INTRUSIONS.

There is no doubt in my mind that this must be fixed in the Jurassic period, while typical flora of that age was flourishing and coal measures were being deposited. The intrusions terminate the sedimentation period most abruptly. No interval elapsed between the end of the depositions and the great diastrophic events, and no Cretaceous rocks have been identified. R. M. Johnston records the inclusion of a Jurassic plant in the dolerite of Mt. Faulkner (Johnston, 1922). At the New Town brick quarry and on the shore of South Cape Bay (see also Twelvetrees, 1915), I have seen boulders of what appears to be waterworn dolerite embedded in the coal measures. There is evidence in the Catamaran coal field and elsewhere that the dolerite penetrated unconsolidated mud, and it is by no means certain that sedimentation did not continue there and at La Pérouse in local patches for a short while after the intrusions. At present all we can say is that the dolerite intrusions closed this sedimentation period in Tasmania.

6. NATURE OF THE INTRUSIONS.

Round the dolerite has grown a literature worthy of its importance, and the main features are well enough known, but several must be stressed, as they have previously been misinterpreted or, to my way of thinking, wrongly explained. The following are the vital features for our present investigation:—

(i) The Absence of Any Violence in the Course of the Intrusions.

This is the most outstanding feature in connection with this rock. It is common to find dykes up to a quarter of a mile in width penetrating strata without any trace of disturbance. The Catamaran Dyke at South Cape Bay is 300 yards across, and intrudes coal measures. It has only affected these rocks to the extent of 10 feet alteration of level and one degree alteration of dip between the beds on one side and the beds on the other, and these differences may not have been caused by the dyke. Along Augusta Road and at East Risdon smaller dykes may be seen which do not alter the strata at all, and examples abound everywhere. Again sills up to 1,000 feet in thickness do not appear to have altered the strata above or below. At the summit of La Pérouse horizontal felspathic shales lie on the top of a sill 800 feet in depth, similar rocks exist below, and the strata are continued uninterrupted on the same horizontal level as the sill. On the Central Plateau horizontal and unaltered rocks (Ross sandstone at Arthur's Lakes, Marine mudstones at Chudleigh Lakes) lie on the top of perhaps 2,000 feet of sill, and unaltered horizontal limestones pass below it (e.g., at Waddamana). On the flanks of Mt. Wellington, Mt. Field, Adamson's Peak, Ben Lomond, and many other mountains many hundreds of feet of undisturbed sedimentary rock rest on hundreds of feet of laterally thrusted dolerite sills.

Metamorphism is always present at the intrusive contact, but in most cases I have not been able to find any trace of mechanical pressure, even when coal measures have been penetrated. Finest laminæ often continue right up to the igneous rock, which frequently meets them with a junction as sharp as a pencil line. Even coal seams are frequently penetrated without disturbance, and at Catamaran a sill of great thickness, certainly over 200 feet, underlies a coal seam by 6 feet for several hundred acres, and no trace of mechanical force can be traced in this seam. It is almost certain that this sill is intrusive.

(ii) The Dolerite Was Intrusive, At Least In Most Cases.

At times, metamorphism at the contact is obvious, although it seldom extends for a dozen feet, also there is usually a chilled margin zone in the igneous rock. But usually the only effect is an induration of the intruded rock for a few inches. However, in hundreds of occurrences examined I have never seen this absent, although, at times (e.g., at Catamaran and La Pérouse), it had to be searched for with a lens. A flow may have occurred on the top of the sedimentary series, but occurrences in lower members of the series must have been intrusions.

(iii) The Intrusions Take a Great Variety of Forms.

As has been pointed out (see *Coal Resources of Tasmania*), the dolerite is not found in any form which may be called typical, but a frequent form is that of a long dyke with a wall-like edge on one side, and on the other, one or more extensions in the form of sills, often extending for a considerable distance—these sills always having a very irregular outer edge. Mr. Nye's happy term—"asymmetric transgressive igneous mass of a general laccolithic type"—is very appropriate, but such forms may often be resolved into an irregular dyke with many offshoots, in the forms of sills, minor dykes, and latholith-like bulges. The absence of true latholiths is attributable to the mechanics of the intrusions described above. In general, it seems that the ascending dyke with its accompanying sill or sills is the typical form. So regularly do we find these features that we may almost enunciate the rule "no dyke without a sill."

It appears that the magma ascended vertically on a base of varying width, and as soon as an opportunity presented it intruded a horizontal wedge through the strata. Coal measures have been particularly attacked in this way, and the more massive members of the series are comparatively free. Often sills immediately underlie and overlie Ross sandstone beds.

(iv) The Present Dolerite Occurrences Were Originally At Very Different Levels.

In other words, the idea of a single sheet (sill or flow), as some earlier writers appear to have visualised, is not supported by field evidence. It is certain from the sedimentary rocks themselves that there was no great disturbance of these before the dolerite intrusions. To-day we find sills of dolerite intruding Cambrian or Silurian quartzites at Mt. Anne, directly overlying such rocks at Mt. Wedge, intruding Lower Marine limestones at Mt. Nelson, Ralph's Bay Neck, Cape Frederick Henry, etc., Upper Marine mudstones at Brown's River and Mt. Ironstone, Ross sandstones at Mt. Rumney, Grass Tree Hill, and Mt. Field West, felspathic series everywhere, and Knocklofty sandstones at Knocklofty, to give occasional examples only in each case. Successive intrusions throughout the whole of the sedimentation period are out of the question. Therefore, the original sills, etc., must at first have been at various levels, with a possible range of over 8,000 feet, whatever their present position may be. Where a sill is underlain and overlain by

Lower Marine mudstone, as at Mt. Nelson, and another intrudes Ross sandstone, as at the summit of Mt. Wellington, and a third intrudes Knocklofty sandstone, as at Knocklofty, the evidence points most strongly to three separate occurrences at different depths.

(v) Crystalline Structure As At Present Worked Out Affords Little Help in Deciphering Field Occurrences.

There is a great variation in the internal structure of the dolerite—from entirely microcrystalline to a completely crystallised rock with labradorite crystals 10 x 2 mm. Porphyritic structure is occasionally found, and a glassy base is common. In a few localities the dolerite passes into gabbro. It must be pointed out that the finest variety is basalt of accepted classifications. In Tasmania the term "basalt," has, by usage, become appropriated to the olivine variety of late Tertiary age, but this must not be allowed to obscure correct petrological classification.

There appears to be no absolute or constant relationship between stratigraphical situation and crystallographic structure. Small dykes and sills are usually of the finest-grained variety, and larger occurrences are usually of the normal holocrystalline type. A chilled margin zone is usually present. But none of these features appears constant. The occurrences at Mt. Anne (in Silurian strata), Mt. Nelson (in Lower Permo-Carboniferous strata), the Domain (in felspathic series), Pindar's Peak (on the very top of the sedimentary series) show exactly the same degree of crystallisation, in spite of their original difference of level. Again, on the route of the Launceston transmission line down the Central Plateau, a vertical depth of 2,000 feet of dolerite is observable. The whole of this depth shows no alteration, and is a uniformly fine-grained rock. Cradle Mountain shows the same feature to a depth of 1,000 feet, and on La Pérouse a sill 800 feet in thickness and 400 yards broad is extremely fine-grained, while a mile away at Pindar's Peak a laccolith-like extension at the same stratigraphic level shows very large crystals.

(vi) No Evidence of Vulcanism Now Exists, But It By No Means Follows That None Occurred.

It must be remembered that even if this magma ever flowed over the land surface, it has been subject to erosion since Jurassic times. Pliocene lavas in Tasmania have lost all trace of cones, vents, etc., and so we cannot point to the absence of these features in Jurassic rocks as proof that they never existed. On the other hand, as Mr. R. M. Johnston once said:—"It seemed to him incredible that a massive "sill 2,000-3,000 feet thick could be thrust for vast distances "between planes of stratified bedding of soft coal measures, "say within 800 feet of the surface, without causing innumer-"able fissures and fractures through which some portions of "the magma would be forced to the surface in the form of "lava, ashes, etc." (Johnston, 1898.) This—with some verbal modification—is my opinion. Against such deductive reasoning we have the negative evidence that no traces of lava flows or volcanos have been identified, and the opinion that crystallisation took place under great pressure. Both these objections will be answered in a later paragraph.

Much work remains to be done on the crystallography of the dolerite, and it is possible that a careful investigation of this branch would point to valuable conclusions, but it must be studied in the closest conjunction with field occurrences—a consideration which has been often neglected in the past.

7. PREVIOUS OPINIONS.

The wealth of field evidence available and the apparent conflict between this evidence in various localities makes it difficult to discover the true sequence of events. The history of philosophical thought on this subject may be summarised as follows:—Originally the dolerite mountain caps were considered to be volcanic, and earlier than the sedimentary series which were laid down on them. All the earlier geologists appear to have held this view, including Darwin (*Voyage of the Beagle*), and R. M. Johnston incorporated it in his Geology of Tasmania. (See Johnston, 1898.) Later, contact metamorphism was recognised. I am unaware whether Mr. T. Stephens first made the discovery, but he became the first champion of this idea, and many fiery debates on this subject were staged between him and Mr. Johnston before this society. Eventually Mr. Johnston accepted the evidence of intrusion. In 1898 Mr. Twelvetrees and Mr. Petterd (Twelvetrees, 1898) read a paper embodying the results of microscopic investigations, and they there advanced the conclusion that the dolerite intrusions must have cooled under great pressure. To permit of this, they postulated many thousands of feet of sedimentary rocks as an original covering for our present mountain tops, which mass of rock was subsequently eroded away, leaving bare the dolerite sills.

In 1915 Mr. Twelvetrees (Twelvetrees, 1915 (i)) elaborated his views. He recognised the existence of many true sills, the present position of which could only be accounted for by block faulting after a period of post-dolerite erosion. He also then set out the view that once dolerite was met with, it would continue downwards indefinitely.

In 1922 the Geological Survey thus set out their opinion:—"The diabase seems to have risen from below in a "somewhat similar fashion over almost the whole of northern, "eastern, southern, and central Tasmania, but the height to "which it rose varied greatly from point to point, there being "a range in elevation of the order of 5,000 feet. It was "this variation in the height reached by the diabase which "has caused the present existence of blocks of Permo-Car- "boniferous and Trias-Jura sediments at such varying "heights above sea-level, for it was only those blocks which "were raised to the highest levels which have suffered such "denudation as to have the sediments removed which lay on "the surface of the upwelling molten mass."

It was the impossibility of reconciling this statement with the field evidence in many places, especially in Southern Tasmania, that led me to undertake the investigations which have resulted in the conclusions here summarised.

8. ISOSTATICS OF THE DOLERITE INTRUSIONS.

In the first place, the magma referred to in para. 4, *supra*, must be assumed to have existed below the platform of ancient rocks upon which the sedimentary rocks were deposited. It is difficult to give reasons for the existence of this magma, but probably the fact that Tasmania is a wedge between the Pacific Coast trend line of the Australian continental mass, running S.W. and N.E., and the S.E. extension of the southern trend line of this mass, has something to do with it. Mountain systems, valleys, faults, etc., in Tasmania all give the impression of a pinching towards the south. A significant fact, also, which I have not seen commented on before is that, whereas on the continental masses vast areas are covered by similar rocks and most systems are of considerable extent, on small islands off the coasts of these continents there is often a very great vertical range of geological systems all of small extent. This applies to Tasmania—which within its 27,000 square miles has representatives of every age since the Proterozoic and of almost every petrological species known to science—and also to England, Japan, New Zealand, and other similarly situated islands. This leads us to the view that these appendages have been subject to every influence induced by isostatic causes. Certainly Tasmania appears to have been subjected to a rapid sequence of deposition and diastrophic epochs to an extent not equalled by any area of similar size on the continent of Australia. Whatever the reason for this may be, the pinching between the Tasman Sea and the Southern Ocean blocks of relative greater density appears to have had some effect. Perhaps these maintained a ge-anticline under Tasmania and with the release of pressure due to Devonian-Carboniferous erosion the enclosed rocks fused.

The magma began to exist from Permian times or slightly earlier. It cannot be connected with any result of the Devonian diastrophism which produced acidic magmas. The accumulation of sediments forced the rock platform deeper into this magma, or, in other words, the existence of the plutonic reservoir provided a weakness in the foundations which yielded to added weight. Up to the end of the Jurassic period the magma was able to accommodate itself to the displacement caused by the foundering segment. I reject as hopelessly speculative the theory that the Gondwana Land continent sank and simultaneously dolerite mountains were elevated in Tasmania. There is no clear evidence of the existence of Gondwana Land as a continental mass, or of its subsequent foundering, or of the date, mode, and effect of this happening. Too many intervals of time and connecting circumstances have to be assumed, and altogether it is too simple an explanation, and one for which there is not a scrap of evidence in Tasmania.

At the close of the Jurassic period either the magma completed its upward stoping process by reaching the surface or so near that its energy was exhausted or external pressure closed the paths by which it moved outwards in adjusting itself, and the added pressure squeezed portion of it towards the surface. The stage of these intrusions which we now see—that into the Permo-Jura sedimentary series—must have been accomplished at virtually the same time, and the effect where the lowest rocks of the platform were in contact with the magma for a long while has not yet been exposed to view. But, from whatever reason, these sedimentary rocks foundered in the basic magma.

As has been explained, there was an entire absence of violence. In many places whole segments of strata have disappeared, and it is clear they have not been pushed upward by the dolerite (e.g., at Mt. Royal Point, Brown's River, Ralph's Bay Canal, and many other localities). The inference is that they completely foundered in the viscous mass, and their place was taken by igneous rock. The mechanics of the intrusion appears to have been a stoping process, with, apparently, a certain horizontal splitting and often a sinking of separated wedges. There is an entire absence of evidence to show that this magma could or did raise our mountains to, approximately, their present position, and these features can be satisfactorily explained otherwise. Our only evidence shows that the dolerite intrusions or earth movements accompanying them raised the land above sea and coal swamp level. If the older rocks were of greater density than the dolerite they would have tended to founder in it, and if they were of a less density the magma would have escaped at the break. The top of the recent sediments was at sea-level, and all we can say is that the dolerite reached that point and probably boiled over the surface and piled up into considerable domes. This explains how a dyke half a mile broad, ten miles long, and of unknown depth, could be found in coal measures without any displacement of the sediments.

The objection to this conclusion forced upon observers by field evidence, is that provided by crystallographic structure, namely, as Twelvetrees and Petterd put it, "this rock "must have cooled under great pressure." This has been accepted in the past, and the field evidence constructed to fit it, and subsequently removed by a convenient erosion. Field evidence shows that intrusive masses which must have consolidated under 8,000-10,000 feet of strata have exactly the same structure as some which must have consolidated under only a few hundred feet at most. There is also evidence that little, if any, of the felspathic series has been removed from some localities (e.g., Catamaran). Further, all that Twelvetrees' and Petterd's investigations show is that the magma crystallised to a certain extent before it radiated so much heat that crystallisation ceased. Crystallisation under pressure is only one of several ways in which the described features could have been imparted. Compare the trachy-dolerite occurrences at Table Cape and Circular Head, which no one has ever contended cooled at a great depth, yet they show crystals larger than the average in the dolerite. I have not given the necessary attention to this branch of the subject to speak with certainty, but I suggest that the magma had commenced to crystallise before it reached the highest levels and that this crystallisation had proceeded sufficiently far to permit it being carried to a more or less complete conclusion in all except small occurrences by the energy imparted by the crystallisation. This would also explain the limited nature and occasional absence of metamorphism. But whatever the cause, we cannot stretch field evidence to fit a mineralogenetic theory.

Although it seems that the dolerite intrusions occurred as one event, there is some evidence of phases, and where normal dykes occur together with great irregular masses, the former appear to be the earlier, and the latter a result of a later continuation of the process. This certainly appears to have been the case at Catamaran and La Pérouse. Further, the fact that dykes are usually of fine-grained rock and the larger masses are coarse-grained points to the fact that the fine-grained occurrences were the first intrusions and the coarser types came somewhat later when crystallisation had proceeded a little farther. Of course, this only applies to cases in which a whole occurrence is fine-grained and not to small sill and dyke offshoots from a large mass.

9. OUTLINE OF THE SUBSEQUENT HISTORY OF OUR PHYSIOGRAPHY.

A. Development of a post-doleritic peneplain.

B. Era of Tertiary major block-faulting.

C. Tertiary volcanic period or periods.

D. Appearance of the present physiography.

E. Pleistocene Ice Age.

F. Some small local faulting (here or before E.).

These events will be touched upon *seriatim.*

10. THE TERTIARY PENEPLAINATION.

Tasmania, with the exception of a few square miles near Wynyard, does not appear to have been submerged again, and at whatever level the dolerite intrusions left the land there is ample evidence of the development of a peneplain prior to the movements which have given us the framework of our present topography.

(i) The remarkable concordance of mountain summits. Walch's Tasmanian Almanac gives the names of 39 mountains between 3,500-5,000 feet in altitude, and to these must be added the many considerable plateaux. The idea of an ancient peneplain is forced on any observer viewing the panorama from the summit of Mt. Wellington.

(ii) In many places there exists on the top of mountain and plateau tops a definite topography which cannot have arisen from any agencies at work to-day or since the elevation of the mountain. For example, on the Central Plateau there are considerable mountains (e.g., Brady's Look Out, Dry Bluff, Mt. Ironstone, Walls of Jerusalem, and several smaller hills rising over 500 feet—1,000 feet in the case of Brady's Look Out) from the general level of the plateau. In most cases they are obviously isolated by river action in the course of the erosion of a tract of land very different from the elevated plateau of to-day. To-day lakes lie round the foot of these mountains, and no agents capable of this erosion are at work. The same is to be seen on Ben Lomond, Mts. Field, Hartz Mts., Mt. Picton, Mt. Wellington, and most of our higher mountains that are not sharp peaks.

(iii) Tertiary sediments have been accumulated in the valley of the South Esk and its tributaries and southwards past Oatlands to Jericho. These consist very largely of early Palæozoic quartzites, ore vein rock, and other ancient types. Not a single occurrence of such rock occurs in the valley of many of the streams that flow over these deposits. The pebbles are thoroughly waterworn and are typical river drifts. On the other hand, except in obviously recent and surface accumulations, dolerite pebbles are noticeably absent, yet dolerite caps all the many ranges where these streams have their source and is largely found in their valleys. Rocks similar to these Tertiary pebbles are found *in situ* on the West Coast, but are separated from the beds under discussion by the Central Plateau. Similar beds, protected from erosion by a layer of basalt, can be seen on the top of the plateau at the north edge of St. Patrick's Plains, on the road to the Great Lake, and, I am told, elsewhere on the Central Plateau. They also occur in the valley of the Derwent at Bridgewater, New Norfolk, and farther north, and around Hamilton and Bothwell, and west of Southport, in the extreme south. These accumulations are definitely post-doleritic, and appear to indicate that the present outline of Tasmania did not prevail when they were deposited, but rivers running from the west distributed them where we now find them, and that these beds were more or less

continuous, with the very considerable tertiary sediments on the West Coast.

For these reasons it appears that after the dolerite intrusions the land surface of Tasmania was subjected to a long erosion interval stretching from the beginning of the Cretaceous to at least late in the Miocene period. During this time the surface was reduced to a peneplain, and all traces of Jurassic vulcanism, if any, removed. In many places the intrusive sills of dolerite were exposed and eroded into definite topographic features, and over much of the surface accumulations up to 600 feet in depth of terrestrial deposits were built up in much the same way as similar deposits were accumulated in the Murray and Darling Valleys in Australia, at the same time.

11. THE TERTIARY MAJOR BLOCK-FAULTING.

For several years past I have been struck with the difficulty of reconciling some of our physiographic features with the theory that the dolerite intrusions *caused* the present differences of level, and for the following reasons it has been forced upon me that some other explanation is necessary:—

(i) Many of our greater valleys do not possess the characteristics that water erosion would have imparted, and at the same time it seems far-fetched to assume in general that the sides could have been pushed up by dolerite intruding from below and narrow chasms left. There is nothing to indicate such a happening. Frequently the valley side meets its floor at a decided angle, and the natural curves of erosion are absent (e.g., round the north-eastern edge of the Central Plateau), and the river meanders over a flat floor covered with flood plain deposits, and is not very actively engaged in eroding its valley.

(ii) The theory of the intrusions causing the present topography postulates a core of dolerite pushing up some segments, while leaving others as a retaining wall. Field evidence shows this has not happened. Frequent overflow lava streams would be the rule, but none such has ever been identified, neither have retaining walls nor elevated blocks.

(iii) The present mountain ranges appear to be independent of the form of the dolerite intrusions. Although dolerite caps most of the higher mountains, except towards the West Coast, there are exceptions, as at La Pérouse, many of the hills east of the Derwent opposite Hobart, places on the Central Plateau, etc., while almost every dolerite-capped mountain has massive sedimentary beds on some flank. How can these exceptions be accounted for if the dolerite caused the elevation?

(iv) Although most of these mountains are dolerite capped, few, if any, consist entirely of dolerite. In most cases the cap does not extend a quarter of the way down the mountain side. If the cap caused the elevation, how can the raising of the remaining portion—often 3,000 feet (e.g., on Mt. Wellington and Mt. Field)—be accounted for? No dolerite, as a rule, supports what would be a considerable mountain even if the igneous rock were removed. Surely some cause subsequent to the dolerite intrusions must have elevated these masses.

(v) In almost every case where observations can be made dolerite sills are interstratified between the intruded sedimentary rocks. When these have been tilted the included sill has been tilted with them. I have never seen a horizontal or vertical occurrence of dolerite cutting a bed of inclined strata. If the strata are inclined the dolerite is inclined with it.

(vi) Everywhere cliffs and other features of a very juvenile drainage abound, and these often in the softest of rocks. In very few places can it be definitely said that river action has narrowed the watershed. Could such conditions have persisted if these mountains had been in existence since Jurassic times? Would not we have a reason to anticipate a most mature drainage system instead of a most youthful type?

The conclusion has therefore been forced upon me that the peneplaination was followed by an epoch of block-faulting on a major scale. This block-faulting was a gradual upward movement, and originated our present physiography. It occurred after the long erosion interval had exposed the dolerite sills in many places and it bodily lifted great tracts of country with their then topography into their present position.

The dolerite exercised a considerable physiographic control, by original resistance to the weather, by presenting in some cases a tough band in the strata to the disrupting forces, and in others a definite break, and thus modifying the local trend of the fault lines and also by subsequent resistance to erosion, especially through the Ice Age. Many

spurs and shoulders of our mountains (e.g., Snake Plains behind High Peak on Mt. Wellington, "The Shoulder" on Adamson's Peak, and best of all Table Mountain) are due to the resistance these dolerite sills offered to the breaking forces. But, although these influences were sometimes considerable, this is the extent of the dolerite control in the history of our landscape.

The fact that on one side of a dolerite hill we may find lower Marine limestones and on the other upper coal measures, is to be explained by the fact that the dolerite intruded one or other sedimentary zone and subsequently a fault-break occurred along one edge of the dolerite. This is exactly what can be clearly seen to have happened in every case I have examined. To hypothesise a vertical lift below one sedimentary bed and stationary conditions, or a vertical lift to a different degree below the other, is to explain one difficulty by creating a greater.

This theory of major block-faulting is strengthened by the general recognition of such faulting round the coasts, in some coal fields, and on the mainland of Australia. Further, relatively recent block-faulting is the obvious cause of such features as the Forth Gorge and the (so-called) Alum Cliffs on the Mersey. These features could hardly have persisted since Jurassic times. Also when the vast extent of erosion that has occurred since the dawn of the Pleistocene times (e.g., the Lake Dove, Lake Judd, and Lake Seal Cirques) is considered, it seems impossible that any of our mountains could have survived since Jurassic times when it is shown that little has been eroded from their summits.

12. AGE OF THE BLOCK-FAULTING.

The only thing that can be said under this head is that it was pre-glacial. As explained, it was later than the accumulations of Tertiary river sediments. These are dated, on very flimsy evidence, as Miocene. Taking into account the amount of erosion, previous to this faulting, and on the other hand the considerable volcanic period which elapsed prior to the Pleistocene glacial period, probably late Miocene or early Pliocene is the nearest date that can be fixed at present.

13. ISOSTATICS OF THE BLOCK-FAULTING EPOCH.

The Pliocene-Pleistocene periods throughout the world seem to have been times of earth stresses and adjustments.

These were felt in different parts of the world at different times, and it seems that the earlier the stress came on any part of the surface, the less severely was it felt. The causes of these stresses have been widely discussed, and appear to be due to adjustment of a plastic interior to varying pressures of surface segments, which variations are caused by necessary adjustments to a crystallising interior and by erosion removing weight from the land segments and adding it to the ocean segments. There is no need to repeat the accepted conclusions here, and I confine myself to the results apparent in Tasmania.

In Australia, during this time, pressure was being exerted from the Tasman Sea in a general north-westerly direction and from the Southern Ocean in a general northerly and north-easterly direction. Again, Tasmania lay between these two great compression lines. It seems that these stresses were first felt in Tasmania and passed as a ripple up the East Coast until they reached New Guinea and New Britain, where their effects are still being felt. The following facts are again observable:—

(i) The faulting was without violence. In many places adjacent blocks which have been displaced several thousands of feet are only crushed for a couple of feet from the centre of the fault (e.g., at the Waterworks).

(ii) It was gradual. Many rivers were able to adjust their valleys to the changing conditions (e.g., the Huon, to be discussed at length later).

(iii) The movement was vertical. There is no evidence of crumpling and only slight signs of local horizontal displacement (e.g., the bulging on the outcrop at Catamaran and the horizontal twist of the seam there, and the existence of an overthrust block of Marine mudstone just short of the National Park railway station). Elsewhere it appears that only vertical movements occurred.

The Huon River gives us most valuable evidence as to several of the features mentioned, and deserves special consideration. This river first becomes recognisable some miles south of Mt. Wedge, wandering through a broad plain not 1,000 feet above sea-level. It could find its way thence to the sea, via Lake Pedder and the Serpentine, without any rise, or via the Arthur Crossing with a rise of 200 feet or so. Instead, it cuts in a deep valley over 3,000 feet deep between Mt. Weld and Mt. Picton, and lower down between the Snowy Mountains and Mt. Hartz. The obvious explanation is that the Huon commenced to run when the western land was the highest and before the great mountain systems farther east came into existence. It thus provides additional proof of block-faulting as the cause of these mountains' existence. Also it proves that the eastern systems rose and not that the western sank, and that this rising was very gradual. If any of these features were not correct, we should expect the watershed to run Mts. Wedge, Anne, Picton, etc., and not to lie on the plains west of the mountains, with rivers cutting thence through the highest ranges in the vicinity. Further, but less impressive, examples may be found in other river valleys. Again, Mr. Nye has shown that there has been no appreciable movement in the Midlands valley since the basalt flows. He definitely proved that this valley is not a trough fault or rift valley (Nye, 1921). Taking these as our field observations, the explanation that commends itself to me at present is this:—A slight shortening of the earth's crust under Tasmania occurred at this time from isostatic causes; that is, pressures developing in adjacent segments were relieved by compressional movements under Tasmania. The pressure came from the south-east, against a resistant block or slighter pressure on the west, and was very deep-seated. This resulted in a succession of rather open folds, starting towards the west, at a depth certainly below any Permo-Carboniferous sediments and probably of abysmal character. In response to this folding, the surface rocks—those we now see—not being under pressure and being very friable, broke into blocks. Over the anticlines these blocks were elevated and over synclines they, in general, remained stationary.

It must be borne in mind that these blocks are really not raised to any remarkable height, 3,500 feet is about the average, and when this is compared to a rough diameter of five miles—to say nothing of over 40 miles in the case of the Central Plateau—the amount of elevation is not inconsistent with the above theory.

It appears that there have been a succession of these lines of elevation. How far west they extended it is difficult to say—this depending on the determination whether the whole of the old West Coast rocks were once covered with Permo-Jura sediments, as some small localities were. Should this prove to be the case, the western ranges may be the results of an earlier phase of the movements being described.

Mr. Clemes (Clemes, 1924) has pointed out the existence of three successively elevated plateaux at Lake St. Clair.

The oldest, including Cradle Mt., the Pelions, the Du Cane Range, and Mt. Olympus, is the most westerly, the highest, and the most thoroughly dissected. Then comes the Great Lake Plateau—barely dissected, and finally the most south-easterly—the Lake Echo Plateau, which is only elevated to half tbe height of the former. This sequence can be traced farther south. Mountains east of a line from Hobart to Launceston carry on a further succession of ridges and valleys, the ridges decreasing in height as you proceed eastward. Ben Lomond is the only exception. Successive steps in the elevation of the Central Plateau can be traced along the road from Hobart to the Great Lake, the first at Constitution Hill, the second between Apsley and Bothwell, and the third between Red Gate and the Steppes. The ridges are not straight or continuous, but are broken by many cross valleys. All this is what you would expect from a surface adjustment in response to a plutonic folding, and the arrangement of the elevated blocks corresponds with pressure from the south-east in a succession of ridges beginning in the west. Also the very persistent general westerly dip over so much of Tasmania, with the break on the east of each bed, is too significant to be altogether overlooked. The Bass Straits trough probably originated at this time also.

14. TERTIARY VOLCANIC PERIOD.

At some time there was a recurrence of volcanic activity. Probably there were at least two distinct phases, the earlier one being represented by the north-west and north-east basalt sheets, these being thoroughly weathered and dissected, and the later by smaller flows in the Midlands, Derwent Valley, Channel, and other localities in the south. The lava flows of this phase show far less weathering, and their flow down the river valleys may still be traced.

The date of this epoch is doubtful. It is certainly later than the Tertiary sedimentary deposits (e.g., at Wynyard and Launceston). These are classed as Miocene. And it is certainly earlier than the commencement of the glaciation. Pliocene is the tentative date, but from physiographic evidence it could not have long preceded the glacial epoch.

These lava flows are confined to the valleys, with occasional occurrences on mountain summits (e.g., on Mt. Wellington and the Central Plateau). This fact, together with the time of their occurrence, immediately suggests some relation between the volcanic activities and the block-faulting.

It seems reasonable to suppose that towards the close of the period of block-faulting the plutonic earth movements produced a second magma and later squeezed it to the surface. Perhaps it was an unconsolidated residual of the Jurassic magma differentiated to an ultrabasic facies, and squeezed upwards by these later movements. This magma has reached the surface over the base of the synclines, and in one or two localities over the apex of the anticlines—just the places to be expected in circumstances such as I have sketched. The Cygnet alkali rocks can be dated considerably earlier and before the block-faulting period, as they are affected by these movements.

15. THE PLEISTOCENE ICE AGE.

I have previously set out our knowledge of this period, and for the present it is sufficient to draw attention to one feature:—No observation has yet been recorded of isostatic recovery when the ice sheets disappeared. Hell's Gates, on the Davey River, and the terraces behind Strahan may be evidence, but the former may be due to a recent fault and the latter may be outwash aprons. There appears to have been no appreciable upward movement on the Central Plateau or the summits of other large mountain ranges. This is a point which warrants observations in the field.

16. LATER MINOR BLOCK-FAULTING.

There is some evidence of block-faulting of a more recent date than the major period. This has been responsible for such features as Bedlam Walls opposite Risdon, The Rocks, near New Norfolk, Cataract Gorge Launceston, the obvious fault running from Cape Bernier past Eaglehawk Neck, etc. Some recent interruption in drainage is evidenced by such swamps as Tiberius, Lake Dulverton, and Grimes Lagoon, and throughout the country the uneroded interruptions to normal erosion and the presence of cliffs along a fault line indicate a very recent period of faulting. But this was small in extent and has not affected our physiography beyond adding local features.

17. DEVELOPMENT OF OUR PRESENT TOPOGRAPHY.

To summarise, then, the physical outline of Tasmania is framed on blocks of country elevated to varying altitudes and consisting of relatively soft sediments with sills of very hard igneous rock intruded at various horizons. Previous to this elevation a definite topography had been eroded, the igneous rock modifying this considerably, and this topography was elevated or not according to its position. In the course of the elevation, again, the igneous rock modified the lines of break, and after elevation it largely controlled the rate of erosion. Subsequent to this elevation, the agents of erosion, chiefly frost, snow, and ice, on the highlands have moulded the details of the landscape, and some slight faulting has added a few features locally.

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