

ART. XXX.—*Diastrophic and other Considerations in Classification and Correlation, and the Existence of Minor Diastrophic Districts in the Notocene.*

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I. DIASTROPHIC CONSIDERATIONS IN CORRELATION, AND THE EXISTENCE OF MINOR DIASTROPHIC DISTRICTS IN NEW ZEALAND DURING LATE CRETACEOUS AND EARLY TERTIARY TIMES.

CORRELATION by lithology implicitly involves diastrophic considerations, but the first explicit use of these in the classification and correlation of the younger rocks of New Zealand occurred in a paper by Marshall, Speight, and Cotton (1911). The thesis put forward by these writers after an examination of several critical localities was that no unconformity exists within these younger rocks, which were deposited in a single cycle of depression and re-elevation. In different localities the basal beds of the series vary in age from Cretaceous to Miocene, owing to overlap during depression on a surface of high relief; but the middle member, the limestone, was deposited at the period of maximum depression, apparently "early Oligocene," and is therefore contemporaneous throughout the country.* In support of this principle of correlation a paper by T. C. Chamberlin (1909), entitled "Diastrophism the Ultimate Basis of Correlation," was cited in a footnote. The authors mentioned their intention to state fully the palaeontological side of the question in future papers, thereby admitting to some extent that the palaeontological evidence was not adequately known, but would be expected to fall into line with the diastrophic considerations.

Diastrophism is defined by Chamberlin and Salisbury (1909) as including all crustal movements, whether slow or rapid, gentle or violent, slight or extensive. In claiming that these movements form the ultimate basis of correlation, Chamberlin (1909) gives reasons for accepting the periodicity of the great world-warping deformations, while admitting the adjustment of minor stresses at other times, producing intercurrent departures from the strict tenor of the great systematic movements. The base-levelling

* The contradiction implied in this statement is presumably only a slip on the part of the authors. The highest basal beds should not be later than Oligocene on their theory. Marshall now classes the limestone as Miocene.

of the land which follows the great deformations means a contemporaneous filling of the sea-basins by transferred matter, and hence a slowly advancing sea-edge, which is thus brought into active function as a base-levelling agent. "The water-movement is essentially contemporaneous the world over, and is thus a basis for correlation. The base-levelling process involves a homologous series of deposits" It is further pointed out that diastrophism lies back of both stratigraphy and palaeontology, and furnishes the conditions on which they depend. The relationship is not reciprocal in any radical sense. The life does not in any appreciable way affect diastrophism, nor does deposition control diastrophism except by exercising a localizing influence. "Diastrophism therefore seems to be the ultimate basis of correlation. The criteria of this correlation include at once its own specific criteria, the criteria of stratigraphy as dependent on diastrophism, and the criteria of palaeontology as modified by the direct and indirect effects of diastrophism."

Chamberlin recognizes four stages produced by diastrophism—" (1) the stages of climacteric base-levelling and sea-transgression; (2) the stages of retreat which are the first stages of diastrophic movement after the quiescent period; (3) the stages of climacteric diastrophism and of greatest sea-retreat; and (4) the stages of early quiescence, progressive degradation, and sea-advance." For stratigraphical purposes it appears useful to introduce a grouping of them, and to recognize in a diastrophic cycle two main periods—one of climacteric deformational activity, and one of relative inactivity, including the stages of sea-retreat which are the first stages of a new deformation, and the stage of early quiescence. During the period of climacteric activity the land is greatly extended and its surface diversified, and inequalities of climate and such extremes as aridity and glaciation are liable to occur. The deposits of such a period include clastic deposits in land basins and on low slopes, wind deposits such as loess, glacial deposits, and clastic deposits on the sea-margins. The terrestrial deposits of this period are largely destroyed during the subsequent base-levelling, while the marine deposits lying on the outside of the continental slopes are seldom likely to be raised above sea-level. The deposits of the period of relative deformational inactivity are dominantly marine, and furnish the main deposits of the stratigraphical record. The cycle of marine sedimentation as opposed to the diastrophic cycle includes a series of deposits formed during a period of gradual sea-advance followed by gradual sea-retreat, the land surface which supplies the sediments being at first diversified and later base-levelled, so that the sediments of the later stages of sea-retreat are marked by the increased erosion of the deep soil-mantles accumulated in the base-level period. The succession of sediments given by Marshall as characteristic of the younger rocks of New Zealand is an excellent example of such a sedimentary cycle. The first deposits are gravels and sands, marking the early base-levelling process. Then follow greensands, the formation of the glauconite in which is believed to be conditioned by a scanty supply of sediment to the sea-floor, indicating that base-levelling was well advanced or the coast distant. These are followed by limestones, during the formation of which there was a nearly complete absence of sediment, corresponding to very distant or low-lying (peneplained) coasts. Greensands succeed, and then follow mudstones arising from the erosion of the thick soil-mantles accumulated on the peneplains, and finally sands and gravels, indicating that the surface of the peneplains has been destroyed by erosion due to sea-retreat. Marshall and his colleagues, it should be noticed, did not recognize the physiographic implications of their theory, and supposed that depression

was so rapid as to produce marked overlap without allowing for the lowering by erosion of the land surface during deposition which the deposits themselves indicate.

Willis (1910) in discussing the periodicity of diastrophism finds it necessary to make certain qualifications. "The general law should be supplemented by one which recognizes unlike dynamic histories of different oceanic regions. It may be stated thus: The phenomena of diastrophism are grouped according to several distinct dynamic regions. Each region has experienced an individual history of diastrophism, in which the law of periodicity is expressed in cycles of movement and quiescence peculiar to the regions. The cycles of one region have been, however, to some extent parallel, though not conterminous, with the cycles of other regions, and thus major cycles of world-wide conditions are constituted by coincidences of regional conditions."

There is a considerable difference between these points of view so far as the world-wide application of diastrophic criteria are concerned. According to Chamberlin's view, the great deformations are world-warping, and it is the effect of these movements and of subsequent sedimentation through base-levelling on the level of the sea the whole world over which is emphasized as important for correlation. According to Willis's view, the existence of independent dynamic districts means that emergence of land in one district may at any particular time more or less compensate for the filling of the sea-basins by sedimentation in another. The rise and fall of the sea-level, so far as this is effected by displacement simply and not by gravitational attraction, will be the sum of the displacements produced by different great deformations, which are not necessarily in the same phase; and the sedimentary cycles of the different districts may be in different stages, and differently effected by the world-wide changes in sea-level. It is only when the great deformations are approximately in the same phase that the deposits can be homologous the whole world over. This latter view seems better adapted to explain the stratigraphical diversity of different parts of the world, the greater duration of sedimentary cycles in one part than another, and the frequent impossibility of bringing important groups of sediments into fully developed cycles of sedimentation.

When it comes to the discussion of actual problems of correlation the specific criteria of diastrophism may at times appear to conflict with the criteria of palaeontology, and in such a case Ulrich (1911) contends that the palaeontological evidence is the more trustworthy. This, indeed, seems axiomatic. The physical conditions controlling the deposition of beds of a given lithological character may be reproduced by diastrophism; the life accompanying the recurring conditions may be similar, but can never be exactly the same, owing to the fact of organic evolution. The criteria of palaeontology as at present developed are more delicate, and permit a more certain discrimination of apparently similar but really different effects than do the criteria of diastrophism. The latter are affected by the intercurrent departures within the cycles, departures which are only revealed by the criteria of stratigraphy and palaeontology.

In New Zealand about the early Cretaceous* there was a great diastrophic deformation, with wrinkling of the earlier Hokonui and so-called Maitai rocks and the formation of an extended land surface. Base-levelling and

* The ammonite beds of Kawhia lie on the dividing-line between Jurassic and Cretaceous; the belemnite beds and plant beds of Waikato Heads are later, and generally ascribed to the Wealden. The deposition of these beds apparently preceded the close at least of the great post-Hokonui deformation.

sea-advance followed, and it was not until a comparatively late Tertiary period that a new cycle of major diastrophism commenced with the Kaikoura orogenic movements.* Between these maxima of diastrophism were laid down those sediments, ranging from Middle Cretaceous (Utatur) to late Tertiary (Wanganui), which were called by Marshall and his colleagues the younger rock-series of New Zealand, and named by Marshall the Oamaru system.† Previous classifications had not brought out the close diastrophic relationship of this group of rocks, and in this respect the paper in question marked a great advance.

Cotton (1916) has recently attacked the study of the younger rocks from a physiographical and structural point of view, and his conclusions as to the surface on which the beds were laid down are diametrically opposed to those reached in 1911. After the folding of the middle and lower Mesozoic rocks, he concludes that the surface was reduced practically to a peneplain before the deposition of the covering strata in several districts. The evidence for this is very clear in the case of the Ngaparan rocks of North Otago and South Canterbury, and the still younger rocks of the Aorere Valley and the Goulard Downs. Cotton (1913) originally suggested a similar state of affairs for the Middle Cretaceous covering rocks of the Clarence Valley, but it is not to be expected on theoretical grounds that at this date peneplanation was complete, nor does the very thick series of conglomerates, sandstones, and mudstones of this age support the suggestion. The presence of thick beds of greensand in the Senonian of North Canterbury, however, makes it likely that by this date the land surface had lost its former great diversity. Speight (1915) from an analysis of the nature of the sediments in Canterbury has come to a similar conclusion. If this view is correct, and if the great differences in the age of the basal covering beds in different districts are admitted, a view for which the palaeontological evidence is overwhelming, it follows, as I pointed out in 1914, that the earth and sea movements which permitted the deposition of these beds were not purely regional sea-advance, so far as the New Zealand area is concerned, as is assumed in the simple diastrophic theory, but movements irregular in their effects. Depression below sea-level occurred at an earlier date in some regions than in others. In north-east Marlborough it occurred in the Middle Cretaceous, in North Canterbury in the Upper Cretaceous, at Kaitangata between Senonian and Ngaparan, in South Canterbury and north-east Otago in the Ngaparan, in the Lower Awatere district in the Upper Oamaruan, at Maharahara in the Wanganui, and so on. A still stronger line of evidence than the period of commencement of depression below sea-level is afforded by a consideration of the periods at which deposition ceased owing to sea-retreat. Even if the different age of the sea-advance in the different districts was due in some measure to differential relief, the irregularities in the surface would have been obliterated by sedimentation, and deposition should have ceased, under uniform regional conditions, approximately contemporaneously in all areas, whatever the date of its commencement. Nevertheless, the youngest marine deposits of the Clarence Valley are Oamaruan (stage uncertain), those of North Otago are Awamoan, those of North Canterbury (the Motunau beds) are probably

* Cf. Cotton, 1916. The Kaikoura movements did not commence everywhere at the same time, and probably the Awatere and Clarence areas were the first to be affected.

† Marshall has not yet included the Middle Cretaceous rocks of the Clarence and Awatere Valleys in his Oamaru system, but it is difficult to see how otherwise he could deal with them.

Waitotaran, those of Wanganui are Castlecliffian. Regional sea-advance and sea-retreat may have been operative all the time, but differential movements of the land surface were certainly also operative in an important measure, and the total effect of the movements of land and sea resulted in the formation of sedimentary series in different districts, each of which resembles a full cycle of sedimentation but does not coincide in point of phase with the series of other districts.

We are thus led to the discrimination of minor diastrophic districts in New Zealand during the general relative inactivity between the great post-Hokonui and Kaikoura deformations. Two such districts were indicated by me (1916, No. 2) in contrasting the Amuri and Ototara limestones, and there are many others. It is the presence of these districts that has given rise to the problems of classification and correlation which have so much impeded geological inquiry in New Zealand, and it will be by a clearer recognition of them that the problems will be elucidated.

Marshall (1916, No. 1) has supplemented his original diastrophic argument for the correlation of all the younger limestones of New Zealand by an argument based on palaeontological grounds. His conclusion as to the equivalence in age of the Ototara and Amuri limestones is directly opposed to the conclusions drawn by me (1916, No. 2), and one or the other must be wrong. As a matter of fact, Marshall has reasoned incorrectly. The Ototara limestone contains *Amphistegina*, and so also do the polyzoal limestones of Whangarei (Horahora and Waro). "The frequent occurrence of *Amphistegina* thus points decisively to a Miocene age for this rock, and this organism may be used to correlate all those limestones in which it occurs, for it appears to be the same species in all of them." In passing, it may be pointed out that the premises do not justify the conclusion. The genus *Amphistegina*, on Marshall's own showing, ranges from Upper Eocene to Recent, and the species in question may, like other species of Foraminifera have a range nearly as large as that of the genus. Having thus correlated the Ototara and Whangarei limestones, Marshall then states that it is the general opinion of geologists that the Whangarei limestone is a lower horizon than the hydraulic limestone in the North of Auckland, or at least that the two limestones belong to the same series. The Amuri limestone, he continues, has always been correlated with the hydraulic limestone, and is therefore of approximately the same age as the Ototara limestone. No palaeontological evidence has been presented for the correlation of the Amuri and the Whangarei hydraulic limestones, and, until it has, the correlation of the Amuri limestone with the Ototara limestone by the intermediary of the Whangarei hydraulic and polyzoal limestones cannot be given any weight.

Marshall supports his arguments by stating that "the Otaio limestone, which is always regarded as an outcrop of the Amuri limestone, and which is a very fine-grained type of rock with an abundance of *Globigerina*, also contains this *Amphistegina*, which is apparently the same species as in other parts of the country." The only reason advanced for regarding the Otaio limestone as an outcrop of the Amuri limestone is its lithological nature. It is not directly underlain, as is the Amuri limestone, by Cretaceous rocks. It lies within the diastrophic district of north-east Otago and South Canterbury, where the sequence commences with Ngaparan coal-beds, and within which no Cretaceous rocks have ever been found. The typical Amuri limestone is always underlain by rocks containing Cretaceous fossils, and has never been found resting

on rocks with Tertiary fossils. It is not known south of the Trelissick Basin.

A further argument advanced by Marshall in support of his correlation is the statement that Thomson and Speight have discovered a (Miocene) molluscan fauna in the beds beneath the Amuri limestone in the Trelissick Basin. In this case Professor Marshall seems to have misunderstood a verbal statement. There is a molluscan fauna beneath the Amuri limestone of the Trelissick Basin, the genera represented being *Ostrea* and *Inoceramus*. The fauna intended to be indicated by Marshall is of an Oamaruan type, and lies near the top of the Amuri limestone. There is no reason, however, to regard it as Ototaran rather than Waiarekan.

The substantial palaeontological arguments advanced by Marshall thus have no reference to the typical Amuri limestone of Marlborough and North Canterbury, and apply to rocks of other districts which are correlated on lithological grounds alone with the Amuri limestone. The evidence advanced by myself (1916, No. 2) is drawn from the district within which the typical Amuri limestone occurs, and is the only evidence at present available on which an opinion may be based.

Marshall (1916, No. 2) has himself brought forward new evidence which militates directly his position. From his description of the fossils of the beds at Wangaloa it is clear that this fauna occupies a position intermediate between the Senonian and the Oamaruan.* If the Amuri limestone follows the Senonian conformably, as Marshall believes, and correlates with the Ototaran, then between it and the Senonian beds there should be developed beds which are the equivalent of the Waiarekan, the Ngaparan, and the Wangaloa beds. The section observed by me in the Waipara River between the limestone gorge and the Doctor's Gorge is as follows:—

| | | | |
|-----------------|---------------------------|--|--------------|
| | Oamaruan Weka Pass stone. | | |
| Amuri limestone | { | Hard white short-fractured limestone including a few marly bands | Feet. 100 |
| | | Grey marly limestone | 60 |
| | | Grey marly limestone passing gradually down into a dark blue-grey mudstone with plant remains, glauconitic at the base | 150 |
| | | A few well-marked hard bands of greensand with Saurian teeth | 6 |
| | | Black glauconitic mudstone with yellow efflorescence | 80 |
| | | Concretionary greensands | 150 |
| Senonian | { | Purple mudstones (Saurian beds) with yellow efflorescence | 100 |
| | | Sulphur sands passing down into white sands | 200 |
| | | Poecilitic sandstone) | 15 |
| | | <i>Ostrea</i> bed) | |
| | | Sandstones and fine conglomerates with coal | 40 |

* This discovery is one of the highest importance, and greatly simplifies our problems of classification. It fills the palaeontological gap caused by the unfossiliferous nature of the Amuri limestone, and thus removes one of our greatest stumbling-blocks. Professor Marshall is to be heartily congratulated on his discovery.

The total thickness between the highest bed with Senonian fossils and the base of the Amuri limestone is less than 150 ft. of mudstone. This bed is hardly thick enough to represent the Waiarekan alone, much less that stage in addition to the Wangaloa beds and any immediate beds which may exist. The truth seems to be that the Wangaloa beds are represented in this section by some part (probably the lower part) of the Amuri limestone, and that the latter rock belongs to a much lower horizon than the Ototara limestone. The only alternative to this view is disconformity at the base of the mudstone into which the Amuri limestone passes down.

In the districts within which they are typically developed the Amuri and Ototara limestones each represent the period of maximum depression or sea-advance. These periods are, I contend, not the same, owing to the masking of any general regional sea advance or advances that may have occurred by the provincial warpings of distinct diastrophic districts.

The existence of other districts of this nature is proved, as pointed out above, by a consideration of the periods at which deposition commenced and ceased. In further support of my thesis I now propose to give palaeontological evidence which supports a difference in age between the Ototara and Takaka limestones.

In the Takaka and Aorere Valleys, including the Gouland Downs and Tata Island, there is a limestone which rests almost directly on the older mass of the Aorere series, being separated only by a thin bed of rolled quartz pebbles, bound together in many places by a calcareous cement. The limestone is followed by more or less calcareous mudstones upwards of 100 ft. in thickness. Higher beds are not known. From the limestone the following brachiopods have been identified: *Rhizothyris rhizoida* (Hutton), *Neothyris novara* (von Ihering), and a new species of *Neothyris* peculiar to this district. From the clays in the Brown River, Aorere Valley, I collected *Pachymagas abnormis* n. sp. (see Appendix I). The known ranges of these species are as follows: *Rhizothyris rhizoida* occurs in all Oamaruan stages from the Waiarekan to the Awamoan, but the specimens from the Waiarekan are dwarfed, and are perhaps to be distinguished specifically. The species is found most abundantly in the Hutchinsonian. *Neothyris novara* occurs outside Nelson Province only in the Weka Pass district, where it is confined to the uppermost Mount Brown limestone, which I regard on the evidence of its other brachiopod fauna and its stratigraphical relations as Awamoan. *Pachymagas abnormis* occurs in the main or middle Mount Brown limestone of the Weka Pass, which I regard as Hutchinsonian on the evidence of its other brachiopod fauna, in the Awamoan blue clays of All Day Bay, and in mudstones in the Gisborne district.

These facts suggest that the age of the limestone is Upper Oamaruan rather than Ototaran. Excluding the new species distinctive to the district, all three brachiopods are known elsewhere from the Awamoan; one is confined, so far as present knowledge goes, to this horizon; a second ranges down only to the Hutchinsonian; and the third, while rarely found as far down as the Ototaran in its typical form, is most abundant in the Hutchinsonian. Further knowledge of the range of these species may invalidate these conclusions,* and, in any case, they must be considered in connection with the evidence obtainable from other groups of fossils, but until this other evidence has been similarly analysed the Takaka limestone must be regarded as younger than the Ototaran. In this district sea-advance did not commence until after the period of maximum depression at Oamaru.

* My statements as to the range of these brachiopods are based on the determination of well over ten thousand specimens from all parts of New Zealand.

The histories of the individual diastrophic districts thus indicated within the New Zealand area are not in all cases parallel. In some there has been a conformable series of sediments deposited; in others there have been earth-movements of different ages, producing unconformities in the series. There is no single unconformity that has been proved to be common to all districts. Hence any classification that shall be applicable to the whole country cannot be made to depend on the presence or absence of unconformities.

II. SUPPLEMENTARY STATEMENT OF PRINCIPLES INVOLVED IN CLASSIFICATION.

It appears at first sight unfortunate that two new sets of local names applicable to the divisions of the Tertiary in New Zealand should be proposed in the same volume of the *Transactions* (Thomson, 1916, No. 1; Marshall, 1916, No. 2). As the principles given for selecting them are, however, fundamentally distinct, the adoption of either of them will doubtless be determined ultimately by the acceptance given to those principles, and I do not desire to insist unduly on the claims of priority which attach to my own proposals. It seems desirable, however, to state more fully the principles which are at issue, as until there is agreement concerning these it is hopeless to expect that any system of nomenclature will meet with acceptance. The analysis shows that there is no necessary conflict between the two proposals, but that Marshall's procedure is somewhat premature and his nomenclature not satisfactory.

A distinction must be drawn in the first place between classification and correlation. Marshall's principle of classification is also made the main principle of correlation. The principles of correlation are numerous and intricate, especially as applied to Tertiary rocks, and they must be used as they are found applicable, and, if necessary, independently of any principles used in classification. The latter are much more simple.

The first point of my paper was that correlation with the divisions of the European classification is a matter of considerable difficulty in New Zealand, and one that has not been at all adequately discussed except for a very few groups of organisms, and then only for fossils from a very limited number of districts. The conclusions reached are contradictory, and none is entitled to outweigh the others. Consequently we begin at the wrong end when we call our rocks Eocene, Miocene, or Pliocene. There is no finality in such a procedure. Marshall's Miocene is not the same as Hector's or Hutton's, and yet all these authors were in practical agreement as to the relative position within the New Zealand succession of the rocks they so termed. The order of superposition of our Tertiary rocks is not in doubt in practically any district where there is a series developed. Let us, then, frame a classification with local names which are non-committal as far as European correlation is concerned. So far Marshall appears to be in agreement: "It would obviously be better to use New Zealand local names for the horizons of the Tertiary rocks of this country."

Geological classification is no longer governed by considerations of conformity or unconformity, but by the succession of faunas. This was first established as an empirical conclusion, and later received a logical basis through diastrophic considerations. Diastrophism is now recognized to be cyclic, and to be a prime cause of the changes of fauna. The interpretation of diastrophic history, however, depends again on palaeontological and stratigraphical studies, and, of the three kinds of criteria available, those of palaeontology are found to be the least open to misinterpretation.

Hitherto the only subdivisions recognized by Marshall within his Oamaru system have been the unit rocks of the series—conglomerates, sandstones,

greensands, limestone, greensands, mudstones, sands and gravels; and he has even attempted to correlate beds in different parts of New Zealand by their height above the limestones there developed. He has now proposed a classification of the post-Cretaceous members of his system on the basis of faunas, characterized by their percentage of Recent species. With this method of characterizing faunas I shall deal below. Meanwhile it is satisfactory to note that in adopting the principle of successive faunas, employed by Hutton, he has returned to sound lines. Concerning his Waitaki series, which appears to be the equivalent of the Oamaruan, he states, "The dominant fact emerges that the species are so similar throughout that the beds obviously belong all to one series." If this conclusion is maintained, as I believe it will be, it of course justifies the use of a series name to include them. It is based, however, on small collections from few localities for each stage, except in the case of the Awamoan, and takes into cognizance only the molluscan fauna. In my opinion it is premature to attempt to revise the earlier groupings of the Tertiary rocks into series by their faunas without a much more exhaustive statement of what those faunas are.

My own proposal was for a series of unit or stage names for the smaller well-marked rock divisions, which have been recognized in all earlier classifications, leaving their grouping into series or systems until our palaeontological knowledge is more complete. Such a system of stage names will still have a permanent value after the grouping is possible, unless the divisions prove too large for zonal purposes. It is, of course, also based on the succession of faunas, as Marshall himself has helped to show by his statement of the increase of the percentage of Recent species in successively younger beds of his series; but it neglects intentionally the grouping of the units into series by major faunistic considerations, because this is considered premature. It may be a minor diastrophic accident that the succession at Oamaru commences with the Ngaparan. The fauna of the preceding stage may also be such that it should be grouped in the same faunistic series as the Oamaruan stages.

The two sets of local names for divisions of our Tertiary rocks are not, therefore, necessarily in conflict. One is a set of names for stages, the other a set of names for faunistic series. Both are based on the principle of a succession of faunas independent of considerations of conformity and unconformity. It remains to be considered whether the principles by which the divisions are selected and the names chosen are sound.

The only principle of division adopted by Marshall is that of the percentage of Recent molluscan species in the different beds. In passing, it may be observed that the percentages of Recent species adopted by Lyell included also the Brachiopoda, which are unimportant in the European Tertiary, but assume a much greater importance in New Zealand. To use the percentage of Recent species as a sole principle of division seems to me premature. The lists of fossils published during recent years do not cover one-tenth part of the determinations made by Mr. Suter for the Geological Survey on old and new collections, and for no single bed that I know of has collecting been so thorough that a further visit has not added to the list of species. We do not know accurately the percentage of Recent species for any division of the New Zealand Tertiary. Even if we did, the results could not be used with confidence in the correlation of one bed with another without a further analysis. The percentages may be different for the species which lived above and below the 100-fathom line; they may be different again for the faunules which inhabited sandy, muddy, glauconitic, or calcareous bottoms. Further, it would be

an assumption to consider that the successive Tertiary faunas are entirely direct descendants the one of the other, and that the curve obtained by plotting the percentages of Recent species against even divisions of time is necessarily a straight line. If we suppose a large immigration of foreign species at any one stage, and suppose further that the immigrants subsequently became extinct or evolved into new forms in a greater proportion than the endemic forms derived from the previous stage, then it is not beyond the bounds of possibility that the later stage would show a lower percentage of Recent species than the earlier one, although the actual number of the Recent forms could not, of course, be smaller unless they had temporarily emigrated elsewhere. A numerical example worked out in Appendix II to this paper will make this possibility more clear. Although such a reversal of the increase of the percentage of Recent species in successively younger stages is very unlikely in the New Zealand area, still the possible effect of immigration or emigration in making the curve irregular must always be looked for. Until the course of the curve is much better known it seems premature to base divisions of the time scale upon arbitrarily chosen percentages of Recent species.

It is, of course, true that the original classification of the European Tertiary by Lyell was nominally based upon the principle of the percentage of Recent species. There were special circumstances in this case which caused the departure from the more ordinary methods, such as gave rise to the divisions of the Jurassic or Cretaceous in England. Lyell was faced with the problem of devising a classification for widely separate sets of beds, the order of age of which could not be fixed by superposition. In New Zealand we have not this difficulty. Lyell had in his mind, however, and definitely mentioned, certain actual beds which would serve as types for his different divisions—viz, the deposits of the London and Paris Basins for the Eocene, the faluns of Touraine for the Miocene, the Subapennine beds of Italy for the Older Pliocene, and still younger beds in Sicily for the Newer Pliocene. The percentages of Recent species which characterized his different divisions were not chosen or stated arbitrarily, but were directly derived from the known faunas of these "type" beds. When an increase in the knowledge of the fossils of these beds necessitated a change in the value of the percentages, this change was accepted without question by him, even although, as he stated, it rendered the derivations of his names somewhat inaccurate.

Stratigraphical classification resembles biological classification to this extent: that the ultimate court of appeal must be not the idea set up by the systematist in founding his species or division, but the actual and immutable thing or *type* that lies behind it. A classification by percentages of Recent species is based upon an idea liable to modification. A classification by beds is based on things which for human purposes are immutable. Behind any division of geological time based on a succession of faunas there must be the actual beds which contain those faunas, and from which the nature of the faunas can be ascertained. There is no past fauna of which our knowledge is complete, and it is not necessary to wait for a complete knowledge before using the faunas for classification, provided the rocks containing them can be defined. This definition Marshall has neglected to carry out, except so far as the names he suggests imply certain beds.

If the principle of the type in stratigraphical classification is admitted it may be desirable to import into stratigraphy the procedure used in zoological classification—viz the right of a subsequent author to fix a type when the original author has left it vague. It would hardly be fair at

present to go so far until the principle has been recognized, nor is it necessary. For all practical purposes Marshall's Wanganui series is equivalent to Wanganuian, and his Waitaki series to Oamaruan, the types of which are defined. The Wangaloa series is discussed more fully below.

As regards nomenclature, I have given in my former paper an account of the principles which seem to be necessary for attaining finality in this respect. The earliest-used name for a geological division should be retained if possible. In any case, a name once used should not be later taken up in a different sense. The rocks intended to be covered under a given name should be fully developed in the district from which the name is chosen, although it is not necessary that all the rocks developed in the district should be embraced by the name. The last two of these principles are violated by Marshall's use of the term "Oamaru system." This name was previously used in a different sense by Hutton, and is therefore preoccupied. In any case, it is made by Marshall to include large and important series of rocks which are not developed near Oamaru at all. His use of the term is therefore open to very grave objections, and must be rejected. The names suggested by him for his series are not open to such serious objection, but two of them nevertheless violate the principle of priority without any compensating advantage. The "Waitaki series" is a new name not before used in any different sense, but the same beds originally were given the name of "Oamaru series" by Hector in 1864, and if the unity of the series is established this name should be revived. Marshall would no doubt have used it if it had not coincided with the name he had given to the whole system. "Wangaloa series" is a new name, but the same beds have been termed the "Kaitangata series" by Park (1912). "Wanganui series" is presumably equivalent to Hutton's "Wanganui system" and Park's "Wanganuian."

III. AN AGE NAME FOR THE "COVERING STRATA" OR "YOUNGER ROCK-SERIES" OF NEW ZEALAND.

As stated above, there is a succession of beds in different parts of New Zealand which, apart from the controversial question of their conformity or unconformity, have a certain diastrophic unity in that they were laid down between two epochs of major diastrophism. It is desirable for many purposes in New Zealand geology to have a name which will embrace them all, a name which will replace the earlier name of "marginal rocks" used by Park and myself, and the physiographic and structural term of "covering strata," when an age significance is intended. Marshall's name of "Oamaru system" is undesirable for the reason stated above, and for similar reasons it is impossible to find any local name that is suitable. This is owing to the development of minor diastrophic districts within New Zealand. In the Clarence Valley the rocks in question commence with the Middle Cretaceous and end with some stage of the Oamaruan. In the Waipara district they commence with the Upper Cretaceous and end with the Motunau beds, probably Waitotaran. At Oamaru they are entirely comprehended within the Oamaruan, and at Maharahara within the Wanganuian, and so on. There is no district where the complete sequence is developed. Hence no local name is suitable.

The systems of the stratigraphical record as established in the Old World are now known to correspond approximately to major diastrophic cycles. Had these divisions been first worked out in New Zealand there is no doubt that the break roughly corresponding to that between the Mesozoic and Tertiary in Europe would have been placed between the Hokonui and the younger rocks, and that corresponding roughly to the break

between Tertiary and the Quaternary would have been placed between the Wanganuian and the raised-beach deposits.

So far as New Zealand is concerned, the rocks deposited between the post-Hokonui and Kaikoura deformations are the younger rocks. Let us recognize this fact by giving them the descriptive name of *Notocene*.* To avoid all ambiguity, the Notocene embraces all the beds lying with marked unconformity above the Hokonui or so-called Maitai series, including the Middle Cretaceous beds of the Clarence Valley and the Castlecliffian of Wanganui, and all the intermediate beds, but excludes the raised beaches and other superficial deposits which lie unconformably on the Castlecliffian. Should still older or younger beds than those mentioned, deposited in the periods between the Hokonui and Kaikoura deformations, be subsequently discovered, they should also be included in the Notocene. The use of the term implies no necessary assumption that the beds embraced by it are all conformable or separable into unconformable groups, any more than the use of the term "Tertiary" implies that the Eocene and Miocene are necessarily conformable or unconformable. It also is not intended to imply that the post-Hokonui deformations ceased or the Kaikoura deformations commenced in all parts of New Zealand at the same time. Considered as a period of time, the Notocene is continuous, whether or not the present New Zealand area was wholly a land surface during any part of it, and no marine rocks corresponding to that part of it are accessible.

IV. NEW ADJECTIVAL NAMES APPLICABLE TO THE DIVISIONS OF THE NOTOCENE

The use of local adjectival stage names for the younger or Tertiary divisions of the Notocene was advocated because of the doubt attaching to direct correlation of these divisions with those of the European Tertiary. Although it appears from the exhaustive analysis of the available collections by Wood (1917) that direct correlations with foreign beds are possible for the older or Cretaceous divisions, a little consideration will show the advisability of local names for these also. Thus the beds below the Amuri limestone in the Amuri Bluff, and Waipara districts are placed in the Senonian, but it is exceedingly unlikely in view of the different diastrophic history of Pacific and Atlantic lands that these beds correlate exactly and completely with the European Senonian. Again, the Cretaceous beds of the Clarence Valley are correlated with the Upper Utatur of India, and by this bridge with the Middle Cretaceous of England. To term these beds in New Zealand "Utatur" would be highly inconvenient. Local names may therefore be applied with advantage. Until further study of these lower beds has been made, unit or stage names for the smaller divisions of the lower Notocene are unnecessary, and only names for larger divisions comparable to groups of stages such as Oamaruan and Wanganuian are at present advisable.

The Cretaceous beds of north-east Marlborough below the flint-beds are best developed in the Middle Clarence Valley, and may be termed *Clarentian*. They include coal-beds and marine rocks. The younger Cretaceous beds underlying the Amuri limestone between Kaikoura and Oxford are most fully developed at Amuri Bluff, and there is no previous name which applies to them exactly. Thus Haast's "Amuri Bluff beds" included the Amuri limestone, Hector's "Amuri series" was restricted to the beds below the Black Grit, and Hutton's "Waipara system" included the Amuri limestone. Hutton's name of "Ngarara group" meets the case

* Greek *voros*, south, *kaivos*, recent (as in Eocene, &c).

more nearly; but this name was descriptive and not derived from a locality, being founded on *ngarara*, Maori for a reptile.

As the term "Amuri" is indissolubly connected with the Amuri limestone, which must be excluded from the group for which a name is sought, it cannot be used, and a new name becomes necessary. The most appropriate appears to be *Piripauan*, derived from Piripaua, the Maori name for Amuri Bluff. The disadvantage of this introduction of an entirely new name is compensated by the greater definiteness attaching to it. The Piripauan includes the sequence of beds at Amuri Bluff below the *Teredo* limestone, excluding the latter rock. It also excludes the "marlstone," or "cannon-ball sandstone," probably of Lower Cretaceous age, on which the Upper Cretaceous beds rest unconformably. The Piripauan in North Canterbury includes both coal-beds and marine rocks.

As thus defined both Clarentian and Piripauan are group names, embracing each a considerable thickness of rocks, but as Wood's researches show that each has a faunistic unity they may be also considered as names of series. The period of the Notocene between these two divisions is not at present known to be represented by fossiliferous rocks in the New Zealand area.

Marshall's Wangaloa series is apparently based collectively on the beds of Wangaloa, Brighton, and Hampden, which he correlates with one another. The reasons given for this correlation are not entirely satisfactory, and are practically only that in each of these three localities species with Cretaceous affinities are found. These species are different in each of the three localities, and two of them at least, *Trigonia neozelanica* Suter and *Trigonia* n. sp., are not really proved to have any Cretaceous affinities. The genus *Trigonia* is divided by ornament into several sections, each of which has a restricted stratigraphical range, and *Trigonia neozelanica* is distinctly of a post-Cretaceous type. If the new species mentioned is similar, this will leave only *Avellana tertiaria* Marshall of the Hampden fossils as a Cretaceous survival. This species is not shown to have any near relative in the New Zealand Cretaceous.

Previous collections at Hampden have not disclosed any notable differences from the faunas of the Oamaruan. Hutton (1887), indeed, found no difficulty in placing the Hampden beds in the Pareora system—*i.e.*, Awamoan; but McKay (1884) on stratigraphical grounds considered them the correlatives of those overlying the coal-beds in the district inland of Oamaru—*i.e.*, of the Waiarekan; and Park (1905) came to a similar conclusion. The latter view seems the most reasonable in the present state of our knowledge, as we know now that Hutton's Pareora fauna was composed of a mixture of Awamoan and Waiarekan fossils, and that he placed other Waiarekan beds in the Pareora system. Marshall apparently considers the Waiarekan as Miocene; but although there is some direct evidence in favour of the Miocene age of the Ototaran, contradicted in this case by other evidence, there is none yet adduced, beyond the imperfectly known percentage of Recent species, to prove that the Waiarekan is Miocene. It hardly seems necessary to point out that if the present New Zealand fauna is the direct descendant of the Oamaruan fauna without important immigrations, as Marshall seems to hold, the percentages of Recent species in the Oamaruan is likely to be much greater than in its correlatives in Europe, where successive recessions and transgressions of the sea in the Tertiary caused bodily migrations of the faunas, and the cold of the late Pliocene and the Glacial Epoch forced the greater number of the species surviving the early Pliocene into more southern

seas. The percentage of Recent species in the Waiarekan is not inconsistent with an older age than Miocene for this stage, and there seems no reason why a Cretaceous survival should not occur. The presence of *Avellana tertiaria* does not by itself prevent the correlation of the Hampden beds with the Waiarekan. Obviously, then, it would be unsafe at present to base a new stage or group name on the Wangaloa series of Marshall if the Hampden beds are correctly placed in this series.

The beds at Wangaloa, however, are in a different category. They are given a more distinctively Cretaceous aspect than the Hampden beds by the presence of *Pugnellus australis* Marshall, a form nearly allied to *Conchothyra parasitica* Hutton of the Piripauan. Marshall's list of fossils contains twenty-nine new species not hitherto found in the Tertiary, and only twenty-one found in the Oamaruan or higher beds. Although little has been yet published as to the range of the species within the Oamaruan, a large number of species from this division of the Notocene has already been described, and from the very considerable collections examined by Mr. Suter a large number of additional new species have been detected and are now being described. The presence of so many new species at Wangaloa (58 per cent of the entire collection), coupled with the Cretaceous relationships of some of them, is sufficient ground for considering that this fauna is intermediate between the Oamaruan and the Piripauan. A new adjectival name is therefore desirable, and in choosing it two earlier local names must be taken into consideration—viz, the Kaitangata series (Park, 1912) and the Wangaloa series (Marshall, 1916). On grounds of priority Park's name should be chosen as the basis, a course that has the further advantage that the rocks intended to be included in it are clearly defined, which is not the case with the Wangaloa series. The *Kaitangatan*, then, includes the Kaitangata upper and lower coal-measures as described by Park (1911) and the intermediate marine horizon, but excludes the Oamaruan coal series and overlying Oamaruan marine rocks which rest unconformably, according to Park, on the Kaitangata coal-measures proper. The *Kaitangatan*, like the Piripauan and the Clarentian, includes both coal-beds and marine rocks, and is a group name, which may be subsequently resolved into stages, for the name of one of which "Wangaloa" may still serve as a basis.

The classification of the Notocene rocks proposed by me is thus as follows:—

| Group Names | Stage Names. |
|------------------------------------|---|
| Wanganuian | { Castlecliffian. { Waitotaran (Other stages possible) |
| Oamaruan | { Awamoan. { Hutchinsonian { Ototaran { Waiarekan { Ngaparan (coal-beds) (Other stages possible) |
| (Other groups or stages possible) | Paparoan (coal-beds) |
| Kaitangatan | |
| (Other groups or stages possible) | |
| Piripauan | |
| (Other groups or stages necessary) | |
| Clarentian. | |

The only possible overlapping of the above names is that the Upper or Lower Kaitangatan coal-measures may correlate with the Paparoan. One is, however, a stage name and the other a group name, and both may still be retained. It is worthy of notice that each of the groups of rocks named above embraces coal-beds in some part of the country.

V. A NEW NAME FOR THE SO-CALLED QUATERNARY ROCKS OF NEW ZEALAND.

As we have no evidence that the highest Notocene stage, the Castlecliffian, corresponds exactly to the youngest Pliocene rocks of the Old World, it is undesirable to use such a name as "Quaternary" for the superficial rocks such as raised-beach deposits, glacier deposits, alluvial gravels, and loess, of which all we know is that they are post-Castlecliffian, or even only that they are subsequent to the main Kaikoura deformation affecting the area in which they occur. It is still more undesirable to attempt to distinguish between Pleistocene and Recent deposits in New Zealand, where the fossil Mammalia on which these distinctions have been based are not found. New names that do not beg the question of correlation are desirable. It is quite possible that in time the criteria of correlation will be sufficiently developed to permit the recognition of distinct stages to which local names may be given within the period intended to be covered; but as there is nowhere, and from the nature of the case hardly can be, in any one locality an accessible complete succession of rocks covering the period to be embraced, no local name is suitable for the totality of rocks to be included, and a descriptive term is preferable. For this *Notopleistocene** may be suggested. The Notopleistocene period may be defined as commencing where the Notocene, which has already been defined, leaves off, and continuing to the present day.

In general there will be no difficulty in the application of the term, and there are important series of rocks, notably in Taranaki, to which it may usefully be applied. In some cases there may be a difficulty. If the Kaikoura orogenic movements commenced very much earlier in one area than another (and we do not know that they have yet ceased everywhere), it is possible that superficial deposits were accumulating unconformably on Notocene rocks in the former area while ordinary marine Notocene rocks were being deposited in the latter. These superficial deposits would, by the definitions given above, have to be classed as Notocene in age. Thus in the Waipara district there is a series of terrestrial gravels which overlie the Motunau beds unconformably, but nevertheless share to some extent in the general tilt which the marine Notocene rocks of that district have experienced, having in the Kowhai River a dip of 12° to the south-east. These gravels, in addition to the greywackes of which they are mainly composed, contain boulders not only of the Motunau and Mount Brown beds, but also of the Amuri limestone and underlying greensands. The marine Notocene rocks forming the cover to the greywackes must have been tilted, and in places completely removed by denudation, exposing the underlying greywackes, before the gravels were deposited. In other words, the latter are subsequent to the main Kaikoura deformation of the area. They have, however, shared in a later tilting, which is presumably a continuation of the Kaikoura movements, and they are much older than the terrace-gravels of the present Kowhai River. It is an open question whether their age is Notocene or Notopleistocene. McKay has described similar

* Greek *voros*, south; and Pleistocene.

gravels in South Canterbury, which presumably rest unconformably on the Awamoan rocks, and there are other terrestrial rocks in other districts which have been regarded as "Pliocene."

VI. APPENDIX I.—Description of *Pachymagas abnormis* n. sp.

Shell small, suborbicular with a slightly straightened front, nearly as broad as long; valves depressed, the dorsal with a well-marked anterior median sinus, the ventral with a broad median fold and flattened sides; anterior commissure with a broad, fairly deep sinuation. Hinge-line broad, nearly straight. Beak short, sharply keeled, the ridges meeting in an apex; foramen hypothyrid, moderately large, reaching nearly to the hinge-line, deltidial plates strong, united only at their bases. Surface smooth with numerous fine and a few strong growth-lines.

Hinge pattern pachymagoid with a minute pyramidal cardinal process occupying only about one-quarter the length of the hinge-trough.

Dimensions of holotype: Length, 20.5 mm, breadth, 20 mm.; thickness, 9.5 mm.

Type locality: Sand interbedded with main Mount Brown limestone, cuesta overlooking the Weka Pass, Canterbury.

VII. APPENDIX II—A Hypothetical Case illustrating the Effect of Immigration on the Percentage of Recent Species.

Suppose A to be a stage in which a certain area was isolated, and contained a provincial fauna of 400 species of Mollusca, of which 20 per cent. (80 species) subsequently survived to become Recent. Suppose B to be a later stage in which isolation came to an end and immigration occurred, the climate being different from that of A. Suppose C to be a still later stage in which isolation was restored and the climate reverted to the conditions of A.

Owing to the change of climate and the competition produced by immigration there would be at the beginning of B a severe mortality and probably a considerable evolution in the endemic fauna of A. Suppose of the original 400 species in A, 200 (including necessarily the 80 Recent species) survived into B, 100 became extinct, while 100 evolved into new forms, of which 10 subsequently survived to become Recent species: the endemic element of B would then consist of 300 species, of which 90 were Recent. Suppose the number of the immigrants to be 300, of which, owing to the later change in climate in C, only 20 survived to become Recent species: the total fauna of B would be then 600 species, with 110, or 18 per cent., of Recent species.

A reversal of the percentage of Recent species is thus shown to be within the bounds of possibility.* That it has actually occurred in our area is not very probable. The above figures have been carefully manipulated to create the reversal. If 30 of the immigrants in B survived to become Recent species the percentages in A and B would be the same. On the other hand, if some of the Recent species in A temporarily emigrated from the area during B, returning in C, as would be the case if the north-south extension of the coast were considerable, a reversal might easily occur. In any case, the figures show that migration is a factor complicating the application of the principle of percentage of Recent species in classification.

* Professor Benson has kindly pointed out that the Sarmatian fauna, with no Recent species, overlies the normal second Mediterranean stage (early Miocene).

Migration in brachiopods is conditional on continuous areas of sea-bottom above the 1,000-fathom line. The deep seas are barriers as effective as land barriers. With molluscs, however, this is not the case. The free-swimming larvae can cross the deep oceans in the surface currents, and distribution is controlled by the direction of the currents. A land connection with Australia or the Antarctic is not, therefore, essential for immigration of molluscs, but only such a change in the distribution of land and sea as would cause new currents to strike these shores.

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