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ART. I.[1]—*Records of Unconformities from Late Cretaceous to Early Miocene in New Zealand.*

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INTRODUCTION.

VARIOUS geologists, notably Hutton, have striven, mainly on palaeontological grounds, to show that unconformity exists between the Cretaceous and Tertiary rocks of New Zealand. On the other hand, Hector and the various workers associated with him as members of the staff of the Geological Survey stoutly supported what is commonly known as the Cretaceo-tertiary theory, and consistently denied the existence of any stratigraphical break in the horizon postulated by Hutton. Being willing, however, to admit unconformities between Cretaceo-tertiary and supposed Eocene strata, and again between the latter and Miocene rocks, in the course of field-work they frequently recorded breaks as present in one or other of these positions. Park, though at one time a supporter, in 1900 (34,* p. 350) definitely dissociated himself from the Cretaceo-tertiary hypothesis, and since then, except in minor details, has been in essential agreement with Hutton. In 1911 Marshall, Speight, and Cotton, in a joint paper (47), expressed their opinion that the Cretaceous and Tertiary rocks of New Zealand form a single series, unbroken by any marked unconformity. Their views must therefore be regarded as an extension of the old Cretaceo-tertiary hypothesis, the main point of difference being that the two unconformities supposed by Hector and his colleagues to exist in the Lower and Middle Tertiary sequence were eliminated.

Since the Cretaceous and Tertiary rocks of New Zealand contain practically all the workable coal, the interpretation of their stratigraphical relations becomes one of great importance. As an example, the problem

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* This and other numbers similarly enclosed in parentheses refer to the bibliography at the end of this paper.

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of discovering hidden coalfields may be mentioned. The geologist's estimates of the probability of buried coal and of its depth in a district where only younger Tertiary rocks are exposed at the surface will be strongly influenced by his preconceived views of what to the layman appear to be purely scientific and therefore economically immaterial questions Progress in stratigraphical geology has till recently been greatly impeded by the lack of detailed surveys and of reliable determinations of fossils Advance in these matters is now being made, but for some years to come the imperfect data available will afford scope for rival hypotheses such as those that were so keenly debated in past years.

The object of the present paper is to review the stratigraphical evidence that has been advanced for unconformities in the succession of rocks embraced by Hector's Cretaceo-tertiary, Eocene, and Miocene formations, or, alternately, by Hutton's Waipara, Oamaru, and Pareora systems A perusal of the paper by Marshall, Speight, and Cotton already mentioned will give the reader a good idea of the confusion introduced into New Zealand literature by the uncoordinated efforts of independent observers, each of whom was endeavouring to add to the sum of human knowledge On this occasion the writer, taking a somewhat different standpoint from that of Marshall and his colleagues, hopes to be able to clear a portion of the field. In order to do so the various localities where stratigraphical breaks have been suspected will be separately discussed. Most attention will be given to an unconformity that seems to be invariably present at the base of the strata included in Hutton's Oamaru System The palaeontological evidence for this may here be summarized by the statement that it is nowhere inconsistent with this view, and, as a rule, strongly supports it.

The following classification of the Cretaceous and Tertiary formations roughly represents the writer's views :—

Age.	Extent.
Pliocene	Ormond beds, Petane Series, upper part of Wanganui System, &c.
Local unconformities ..	(Gisborne district, Reefton district)
Upper Miocene	Waitemata Series; Pareora System of Hutton; Eocene and Miocene of Hector and McKay
Probable local unconformities	(Reefton district, North Canterbury, &c.)
Middle and Lower Miocene ..	Papakura Series, &c., Oamaru System of Hutton; Cretaceo-tertiary System of Hector, in part.
Unconformity	(Not fully proved in all districts)
Eocene	Bituminous-coal measures on west coast of South Island, Cretaceo-tertiary System, in part.
Unconformity (?).	
Cretaceous (with possibly some early Tertiary strata) .	Waipara System of Hutton, Cretaceo-tertiary System, in part

Local unconformities such as those shown in the above table between Middle and Upper Miocene, and again between Miocene and Pliocene, almost certainly do not belong only to the horizons mentioned It is highly probable that detailed field-work will demonstrate that from the Middle Miocene to the Pleistocene differential movements in some part

or another of New Zealand were almost constantly in progress, and consequently that a series of local stratigraphical breaks exists, no two of which are exactly synchronous

Owing to the close relationship between Hutton's Oamaru and Pareora systems, and to the fact that in many localities no trace of unconformity can be found between them, they may well be included in one series or system, as is done in various Geological Survey bulletins.

The localities to be discussed so far as conveniently possible will be taken in order from north to south, and will be arranged under the headings of—(I) North Auckland; (II) Waitemata, Drury, and Waikato Districts; (III) Gisborne–East Cape District; (IV) Hawke's Bay; (V) East Wellington; (VI) Marlborough and South-east Nelson; (VII) North Canterbury; (VIII) West Coast of South Island; and (IX) Otago.

I. NORTH AUCKLAND.

1. *Whangaroa District*.—In 1877 McKay (4, p. 57) states that on the east side of Whangaroa Harbour Secondary rocks are overlain unconformably by green and brown sandstones. The latter rocks may be definitely identified with the upper part of Bell and Clarke's Kaeo Series (42, p 46 *et seq.*), which contains Tertiary fossils; and, since McKay records *Inoceramus* in the Secondary rocks, it is probable that he refers to a contact between the lower and upper portions of the Kaeo Series. In 1892 McKay (16, pp 68–71) somewhat fully discusses the relations of the green and brown sandstones to underlying "hydraulic limestone," and doubtfully decides in favour of conformity.

In 1909 Bell and Clarke, as the result of detailed field-work, state that the lower part of the Kaeo Series contains Mesozoic fossils (42, pp. 16, 49, 58). They sought for a stratigraphical break, but finding evidence of this at one point only (p. 49), in the form of a conglomerate, remain doubtful as to whether there really is a physical unconformity in the Kaeo Series or not. They add, however, that "it is quite probable that more extended observation will justify the division on stratigraphical grounds of the Kaeo rocks into two distinct series of Late Mesozoic and Early Tertiary age respectively—a division which is certainly warranted by the palaeontological evidence" (p 49) A similar statement appears on a later page of the Whangaroa Bulletin, and is quoted by Park in a paper published in 1911 (48, p 549).

2. *Kawakawa District*.—Cox reported in 1877 (5, pp. 135–38) on the Kawakawa Colliery, but nothing very definite can be gathered from his remarks or from the accompanying bore-logs, though the latter, if trustworthy, indicate unusual variation in the beds overlying the coal. In 1884 McKay (11, pp. 122–34) gives a fuller account of the geology of the district. His statement that the clays found in diamond-drill bores above a hard crystalline limestone are equivalent to the Amuri limestone is open to adverse criticism (39, p. 410). Both the upper and the lower surfaces of the limestone encountered in the bores are irregular—in the former case probably owing to Quaternary erosion; in the latter case, according to McKay, through replacement of the greensand overlying the coal by limestone, or *vice versa*. In 1894 Hector (17, pp. ix *et seq.*) and McKay (17, pp. 60–61) discuss the Kawakawa Coalfield, the former giving several plans and sections. The latter, as drawn, induce suspicion of an unconformity between the hard limestone ("Whangarei limestone") and the coal-

measures. This view has been advanced by Cox (8, pp. 17–18), but the available evidence is inconclusive, and for the present one must regard the supposed discordance as doubtful.

3. *Hikurangi, Kamo, and Whangarei Districts.*—Cox, reporting on the Whangarei district in 1877 (5, pp. 95–106) and 1881 (8, pp. 15 *et seq.*), finds the geology of the coal-measures and associated beds difficult to explain. He places unconformities both above and below the Whangarei limestone (8, pp. 17–18). In 1884 McKay (11, pp. 110–22) refers all the sedimentary strata associated with or overlying the coal-measures to the Cretaceo-tertiary formation, and recognizes no unconformities. In 1894 the same geologist states that at Hikurangi the apparently unconformable relation of the Whangarei limestone to the beds above and below "has to be accounted for by dislocation and faulting of the beds along certain lines" (17, p. 61), which, however, he does not definitely indicate. He further mentions that the fossils from the beds immediately overlying the coal at Hikurangi are found also in corresponding beds at Kamo and Kawakawa, and occur in the coalfields of Canterbury and the west coast of the South Island. The fossils referred to are presumably those mentioned by Cox in his reports—namely, *Cardium brunneri* and "*Ostrea carbonacea.*" A brief examination of the Whangarei and Kawakawa districts made by the writer a few months ago has not afforded any fresh evidence bearing on the question of conformity or unconformity in the so-called Cretaceo-tertiary sequence. Flows of volcanic rock and deep surface clays offer impediments to the collection of geological data. Faulting, too, seems to be prevalent. Thus, with our present knowledge, no decided conclusion regarding the unconformities suggested by Cox can be reached. A suspicion that there is an unconformity below the Whangarei limestone seems justified.

4. *Waipu.*—Hector, in 1877 (4, p vi of Progress Report), states that at Morrison's Caves, behind Waipu, limestone rests unconformably on greensand.

5. *Pahi and Paparoa.*—In 1881 and 1882 Cox reports that near Pahi the Whangarei limestone of Eocene age rests unconformably upon the chalk-marls of Cretaceo-tertiary age, and is also unconformably overlain by Miocene greensand (8, pp 18–19, 33–34*; 9, p. 23). His section (9, p. 19) intended to illustrate these unconformities is to some extent unsatisfactory, for although it clearly shows the Miocene rocks resting on the upturned edges of the hydraulic limestone, yet it brings the Whangarei limestone into a position of which faulting is the most probable explanation, thus leaving the question of unconformity between it and the hydraulic limestone entirely open In 1887 Park confirms the presence of an unconformity between the Miocene greensand and the underlying rocks, which he considers to be of Jurassic age, and illustrates his views by sections (13, pp 222, 224; see also remarks on Komiti Point, *postea*). In an earlier report, however, he describes the Pahi rocks without mentioning any unconformity (12, pp 168–69), and gives the generic names of a large number of fossils collected from a steeply dipping greensand which both he and Cox state underlies the hydraulic limestone. The list certainly has a Miocene facies, and unless it can be proved that the apparently inferior position of the greensand is due to faulting or to overfolding the age of the hydraulic limestone becomes very doubtful The Pahi section

* Presumably the word "unconformably" ought to be inserted in the bottom line of page 33 of Cox's report

has been discussed by Hutton, who, reasoning from the available evidence, decides that the hydraulic limestone is of Upper Oamaru age (30, pp. 380, 381, 382), a view that the writer is by no means inclined to endorse.

6. *Komiti (Kumete) Point.*—As early as 1877 Hector notes an unconformity at Komiti Point between Miocene and Cretaceo-tertiary strata (4, p. v of Progress Report). In 1881 Cox records that here, and at other localities in the Arapaoa Arm of the Kaipara Harbour, strata containing a varied Tertiary fauna, and referable to the Waitemata Series, rest unconformably upon chalky clay or hydraulic limestone supposed to belong to the Cretaceo-tertiary Series (8, pp. 17, 33, 37). The next year he renews the statement, and illustrates it by a section (9, pp. 23, 24). In 1886 Park after a brief visit to Komiti Point states that the junction of the Komiti beds and the chalky marls is obscured, but omits to give any definite opinion concerning the unconformity reported by Cox (12, pp. 165–66). In 1887, however, after making a close examination of Komiti Peninsula, he describes a sharp discordance, which he shows in section, between the Komiti beds and blue shaly clays (13, p. 221). The lower beds, for no very convincing reasons, he regards as Jurassic (p. 229), and therefore not part of the Cretaceo-tertiary sequence. He also comes to the conclusion that there is only a limited amount of unconformity between the Komiti beds and the hydraulic limestone, and that the obtainable evidence strongly favours a stratigraphical break between the latter rock and the underlying shaly clays (pp. 228, 229).

The sections and descriptions given by Cox and Park may be accepted as proof of an unconformity between the Komiti beds of Miocene age and probable Cretaceous strata. Recently (September, 1915) an unconformable junction—doubtless that seen by Cox and Park—has been observed in the south-eastern part of Komiti Peninsula by Mr J. A Bartrum and the writer, but owing to adverse weather-conditions was not closely examined. The angular discordance was clear, but apparently not very great. How far there is justification for extending this unconformity to neighbouring areas where less clear sections are observable is open to discussion. Two points of view have been presented, by Park (48, p. 546) and by Marshall (49, p 319)

7. *Kaipara Flats, Wellsford, &c* — According to Cox, the Cretaceo-tertiary chalk-marl of the Kaipara Flats district is unconformably overlain by Miocene concretionary greensand (8, p. 19) In the same report it is stated that between Wellsford and Mahurangi, greensand unconformably caps hydraulic limestone. In 1914 J. Henderson notes the occurrence of pebbles derived from the hydraulic limestone and associated rocks in the overlying sandstones as evidence of unconformity (60, p. 157).

8 *Mahurangi (Warkworth) District.* — In 1881 Cox gives a section showing strong unconformity at Wilson's (site of lime and cement works) between Cretaceo-tertiary hydraulic limestone and Lower Miocene greensand (8, p 19) He further states that at Matakana South Head firestone is unconformably overlain by greensand, &c , and that " outside the Mahurangi North Head breccia conglomerate occurs containing fragments of slate, quartz, and white granular limestone, which gives additional proof, if it were needed, of the unconformity of these beds to the hydraulic limestone " (p 29) He also gives a section showing strong unconformity between the hydraulic limestone and Miocene strata west of Little Omaha, near Cape Rodney (p. 31) In 1882 Cox again describes an unconformity in the Mahurangi district, shown by horizontal limestones resting on steeply dipping

chalk-marl and hydraulic limestone (9, p. 24) Two years later McKay confirms the existence of a pre-Miocene unconformity near Warkworth, and gives a section similar to Cox's illustrating the unconformity at Wilson's (11, pp 105, 106) In 1914 J Henderson reports unconformity between probable Miocene and Cretaceous rocks, in the following terms: "Although the relationships of the hydraulic limestone and the green sandstones are nowhere within the district shown clearly in section, the discordance of the formations is proved by the numerous coarser bands which occur in the sandstones, containing waterworn pebbles of hydraulic limestone, calcareous marl, and, rarely, carbonaceous shale derived from the denudation of the hydraulic limestone and associated beds" (60, p 157).

9 *Wade District*—In 1884 McKay reports that on the banks of the Orewa River "Cretaceo-tertiary rocks are unconformably overlain by soft dirty greensandstones" (11, p 104) Some years later Park confirms the presence of an unconformity in this locality by a section given without any comment (13, p 226) This, however, he supplies in 1911 and 1912 (48, p. 545, and 50, p 493).

Summary of North Auckland Data—Cox, McKay, and Park agree in observing angular unconformity between Miocene and Cretaceo-tertiary strata, and show it as very sharp in several sections—for example, at Komiti Point (Cox and Park), at Wilson's near Warkworth (Cox and McKay), and Orewa River (McKay and Park) The existence of a basal Miocene conglomerate containing pebbles derived from the hydraulic limestone and other rocks of probable Cretaceous age is demonstrated by Hector, Cox, and Henderson Again the wide overlap of the Miocene strata on the pre-Cretaceous (Trias-Jura) rocks here as elsewhere in New Zealand is highly significant As a whole, the evidence for unconformity between Miocene and all older rocks appears to be conclusive Cox and Park agree in finding an unconformity between the Whangarei limestone and the hydraulic or chalky limestone, but the supporting evidence is unsatisfactory, and at a later date Park takes quite a different view (45, p 95)

II Waitemata, Drury, and Waikato Districts

In 1871 Hutton contends that the Tertiary rocks south of Auckland exhibit two unconformities—one between the brown-coal measures of Eocene age and the Aotea Series of Oligocene age, the other between the Aotea rocks and the Waitemata Series of Upper Miocene age (19, and see also 22) In 1882 Cox reports a probable unconformity near Howick (9, pp 95, 96). In 1884 McKay, supported by Hector, suggests an unconformity at the horizon of the Parnell grit (11, pp 106, xviii, 12, p xxxviii)—that is, in the Waitemata Series—and assigns the beds below the grit to the Cretaceo-tertiary system Park rejects the supposed unconformity at the Parnell-grit horizon, but believes that there is one at the base of the Waitemata Series (12, p 158; 31, pp. 391–99). In 1892, however, he maintains that there is conformity to the base of the Cretaceo-tertiary (32, p. 381). Subsequent papers by E. K Mulgan (37) and C E Fox (38) deal very hardly with the Parnell-grit unconformity, an attitude which is in agreement with the writer's observations, though it must be admitted that at St George's Bay there is a minor local unconformity, indicated by the wedging-out of several feet of the beds underlying the grit Neither Mulgan nor Fox seems to support unconformity in any part of the Tertiary sequence as developed near Auckland, and Clarke's paper of 1905 (40), together with his latest

statement, contributed to Marshall, Speight, and Cotton's paper of 1911 (47, pp 396–99), appears to dispose of the unconformity believed by Hutton to exist between the Aotea (Papakura) Series and the Waitemata rocks. No evidence other than Hutton's concerning the supposed discordance between the Aotea Series and the brown-coal measures is available, but apparently it was observed by him at a single point only, in fault-broken country (19, pp. 246, 247), and therefore additional data are necessary before it can be accepted. On the other hand, it cannot be rejected without further investigation.

III. GISBORNE – EAST CAPE DISTRICT.

In 1877 Hector distinguished the Tawhiti beds of supposed Lower Tertiary age from the Turanganui Series of Cretaceo-tertiary age, and gave sections showing unconformities between the two sets of rocks (3, pp. xvi and xvii; map and sections opposite p. xvi). His sections also show a strong discordance between Upper Tertiary and Cretaceo-tertiary rocks in localities where the Tawhiti beds are absent. McKay, in the same year, described evidence of unconformity at several points in a post-Cretaceous horizon, his strongest point being that at Whareponga, "behind the church, an unconformable junction between the marls with concretionary masses and the younger rocks is seen" (3, p. 121). In 1887 McKay perceived unconformity between the Tawhiti beds and the Turanganui Series at Akuakua (Akuaku), and between the former rocks and the Waipiro Series at Riparua (Reporua) (13, section on p. 218). Inland he discovered thick beds of conglomerate containing igneous boulders in the Lower Miocene rocks of the Ihungia and Mata Rivers, but so far as can be judged from his report did not regard the occurrence as significant of stratigraphical break. In 1901, however, he placed an unconformity in the Gisborne district between rocks of supposed Cretaceous age and undoubted Miocene strata. Conglomerates similar to those just mentioned, and containing boulders of limestone derived from the underlying strata, he considered to mark the base of the Miocene (36, p 24). J. H. Adams, however, as the result of a detailed survey over the limited area included in the Whatatutu Subdivision, came to the conclusion that the so-called Cretaceous rocks of that part of the Gisborne district were conformable to the overlying Miocene strata, and, although confirming McKay's description of the conglomerate, did not recognize it as evidence of unconformity (44, pp 12, 18–20). Marshall, as the result of field examinations and of palaeontological work, confirmed Adams's statements (44, pp 21–23; see also 47, p. 393). Neither Marshall nor Adams found any fossils of Cretaceous aspect in the Whatatutu district, but McKay's statement that *Inoceramus* occurs in concretions in the bed of the Waipaoa River has since been confirmed by at least two observers—one a geologist of repute—and, in addition, a belemnite has been found on Waitangi Hill by Mr. M P. Poole, of Tuparoa. During a visit to the Gisborne district in January, 1914, the writer, guided by Mr. John Mouat, saw numerous specimens of *Inoceramus* near Motu Falls, at a point about five miles from the north-western corner of the Whatatutu Subdivision. The fossils occur in a dark mudstone, probably corresponding in horizon to the clay shale forming the lowest portion of Adams's Whatatutu Series (44, pp. 12–13).

Summary.—The available evidence strongly supports the presence of an unconformity below the Miocene strata of the Gisborne–East Cape district.

IV. Hawke's Bay

In 1877 McKay records that Cretaceo-tertiary (probably Miocene) rocks unconformably overlie Secondary rocks four miles north of Waimirima (Waimarama) and at Paonui Point (4, p 47) In his sections (opposite p. 50) various apparently unconformable contacts of the two sets of rocks are shown. Some of these, however, are probably merely discordant juxtapositions due to faulting. A few years later McKay states that the Te Aute limestone rests unconformably on the upturned edges of Cretaceo-tertiary strata at Mount Vernon (near Waipukurau) and elsewhere (7, pp. 71, 72, and sections opposite p. 72) In 1887 he redescribes the so-called Cretaceo-tertiary rocks north of Waimarama as Tertiary beds surrounding an isolated outcrop of Cretaceo-tertiary or young Secondary rocks (13, p 191), and in a section (p 192) shows strong unconformity between Upper Miocene and Cretaceo-tertiary strata near the Tukituki River

Summary.—The available evidence leads to the conclusion that the lower part of the Oamaru Series* is probably not developed in the Hawke's Bay district, and that there is a strong unconformity between the Upper Miocene and late Mesozoic rocks.

V. East Wellington.

In 1877 Hector found that the Cretaceo-tertiary rocks of eastern Wellington were "overlain unconformably by the Hawke's Bay Series, forming the Taipos" (3, p ix) Next year McKay reported that there was an unconformity in the Wairarapa district between the Upper Miocene and the Taipo beds, regarded by him as of Lower Miocene age (6, p 20) The writer must here remark that, although Miocene fossils have been collected from supposed Taipo beds near Tinui, there can be little doubt but that the true Taipo beds are of pre-Miocene if not pre-Tertiary age In 1888 Park reported an unconformity at the Blairlogie gas-spring between Miocene and probable Cretaceous rocks (14, p 21) which, according to the writer's observations in 1910, overlie the Taipo sandstones (43A, p 2) There may, however, be a fault at this point, so that until further examination has been made the field evidence for physical unconformity remains inconclusive. Park's statement of 1904 (39, p 412) that in the Mangapakeha Valley there is an unconformity between sandy clays with Tertiary fossils and soft shaly claystones with probable *Inoceramus* presumably has reference to the Blairlogie section McKay considers that Hutchinson Quarry beds of reputed Eocene (*i.e.*, probably Miocene) age occur near Cape Palliser, and apparently regards them as unconformable to the Cretaceo-tertiary strata of the neighbourhood (7, pp 80, 81)

Summary.—As in Hawke's Bay, the lower part of the Oamaru Series appears to be absent from the East Wellington district. Though everything points to strong unconformity between the Upper Miocene and the late Mesozoic strata, more field-work is required in order to establish it as a fact of observation

VI Marlborough and South-east Nelson.

Von Haast in 1871 records an unconformity between the "Amuri Bluff beds" and the "*Scalaria* beds" at Kaikoura and near the Jed River

* Unless otherwise stated, the Oamaru Series of this paper includes Hutton's Pareora System.

(1A, p 39, and sections vii, viii, and xvi). According to his section xv, the Weka Pass stone rests discordantly upon Saurian conglomerate "one mile above junction of Eden River with Waiau-ua" (Dillon River).

The sections accompanying Hutton's report of 1877 on the north-east part of the South Island (3, opposite p. 56) show physical unconformity between Amuri limestone and overlying Tertiary beds at the Conway River, Amuri South Bluff, east head of Kaikoura Peninsula, and Flaxbourne (Ward). In the same volume, however, Hector states that at Kaikoura "a corrugated concretionary disturbance of the calcareous beds has given rise to an apparent unconformity" (3, p. xi), and that he is unable to satisfy himself "of any stratigraphical break between the Amuri limestone and the overlying Grey Marls" (p x) McKay, reporting on the Cape Campbell district in the same year, states that the Awatere beds rest with high unconformity on the greensand and Amuri groups (4, p. 186). He also mentions conglomerates containing boulders both of Awatere and of Amuri rocks (p. 190). Similar conglomerates exposed in the Mead River and elsewhere are described by Hector and McKay as resting discordantly on Grey Marl, Weka Pass stone, or Amuri limestone (12, pp. xvi, xxxiv *et seq.*, 113 *et seq.*; sections on pp 81, 82, 85, 90, 94, 95, 96, 103, &c.) The age of this conglomerate they consider to be post-Miocene. McKay has sections on pages 88 and 89 showing probable unconformity between Tertiary strata and Amuri limestone near Flaxbourne (Ward) On page 83, after discussing the apparent discontinuity at Kaikoura Peninsula between the Amuri limestone and the overlying Grey Marl, he comes to the conclusion that their relations are conformable In his Progress Report of 1887 (13, pp. ix *et seq.*) Hector again mentions that there is no unconformity immediately above the Amuri limestone at Kaikoura, as Hutton supposes. In 1890 McKay again describes what he calls the "Great Post-Miocene Conglomerate" as unconformably younger than the Awatere beds. In several sections he shows it resting discordantly on the Grey Marl (15, pp. 170, 171, 175), and in one as in contact with the Amuri limestone (p. 173; see also 12, pp. 81, 82). C. A. Cotton, however, considers that the conglomerate in localities examined by him conformably succeeds the Grey Marl, and ingeniously accounts for included masses of Grey Marl, Amuri limestone, &c., by supposing that they are derived from a block of adjacent territory which was faulted and uplifted whilst conformable deposition proceeded at its base (57, p 360). Although Cotton observed several facts supporting his "hypothesis of block-faulting with the restriction that the faulted block alone moved," the very strongest evidence is required in order to establish the correctness of such a startling explanation, which involves a differential elevation "of perhaps as much as 12,000 ft" (57, p. 359).

Summary—Since Hector and McKay disagree with Hutton concerning the horizon of a supposed unconformity separating Miocene from older rocks, and since Cotton finds no evidence of a stratigraphical break (other than that involved in block-faulting of part of the area), disconformity must be considered unproved Hence detailed field-work is necessary to establish the truth or otherwise of any hypothesis.*

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* In December, 1915, the writer visited Kaikoura Peninsula and Amuri Bluff, and there obtained clear evidence of an unconformity between the Amuri limestone proper and an upper band of limestone corresponding to the Weka Pass stone. At Kaikoura appearances also support the view of a local stratigraphical break or period of non-deposition with slight erosion between the upper limestone and the Grey Marl.

VII. North Canterbury.

1. *Waipara and Weka Pass District.*—The Waipara–Weka Pass district has been frequently examined, and much has been written concerning supposed unconformities at various horizons from early Tertiary upwards. In 1869 Hector published some brief remarks on the geology of the Waipara district (1, pp x–xiii). He mentions an unconformity which on Hutton's authority is to be understood as occurring between the Grey Marl and the Mount Brown beds, though the description might almost equally well apply to the contact of the Amuri limestone with the Weka Pass stone (see also 39, p. 413). McKay and Park (in early reports) also place a stratigraphical break at this horizon. The evidence, however, appears to be very slender, and probably at most justifies the opinion that only slight local unconformity is present * This seems to be the opinion of von Haast (1A, pp 14, 16; 21, p. 306), who also in his earliest report suggests a local unconformity above the Grey Marl (1A, p. 17) †

In 1877 Hutton describes in clear terms what he believes to be the unconformable junction of the Weka Pass stone with the underlying Amuri limestone (3, pp 43, 44). In 1885 he repeats this statement, with additional data in its favour (24, pp 269–70). Hector, in his Progress Report of 1877 (3), expresses his inability to convince himself of the unconformity. Von Haast in 1879 discusses the question, and decides that there is no break of any consequence, but, somewhat strangely, does not refer to the views of other observers (21, pp. 297–98). In 1887 (13, pp. 78 *et seq*) and in 1892 (16, pp. 98, 102) McKay unequivocally opposes the supposed unconformity Park in 1888 perceives evidence of change in the conditions of deposition, perhaps accompanied by a degree of elevation, but not of true unconformity (14, pp. 28, 31, &c) In 1904 Park agrees with Hutton (39, p. 413), but in 1905 shifts the unconformity to the upper surface of the Weka Pass stone (41, pp. 542, 546). Marshall, Speight, and Cotton cannot see any evidence of unconformity in the younger rock-series of the Waipara and Weka Pass districts In 1912 J. A Thomson observes "apparent conformity in section throughout the Waipara district" (52, p. 8) Owing, however, to palaeontological evidence of the Tertiary age of the Weka Pass stone having been discovered—or, rather, rediscovered—by Thomson and Cotton, Park in 1912 returns to Hutton's view (50, pp 496–97) An examination lately made by the writer has convinced him that the upper surface of the Amuri limestone has been eroded, and that local unconformity (disconformity) at least is present (63, p 92) On palaeontological grounds there is reason for believing that the unconformity represents a considerable time interval. Further evidence, however, is required before one can assert with any degree of confidence that the break extends from the Cretaceous to the Oligocene or Miocene, as inferred by Hutton and Park

2. *Motunau (Stonyhurst) District* —In 1877 Hutton shows an unconformity at Motunau between Amuri limestone and Tertiary rocks (3, section vi, opposite p. 56), and in 1885 gives further data (24, pp 270–71)

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* Since this was written the writer has seen clear evidence of at least a local unconformity between the Grey Marl and the Mount Brown beds in the valley of the Weka Creek

† Von Haast's section of 1871 (1A, opposite p. 18) shows violent unconformity near Boby's Creek between the Grey Marl and underlying beds. A fault, however, is the cause of the structure interpreted by von Haast as an unconformity. (See 14, section on p. 30, and map opposite same page)

McKay in 1881 confirms this by a section, three miles north of Motunau, which shows the Amuri limestone followed unconformably by Mount Brown and Pareora beds (8, p. 115). He also reports that the Teredo limestone (a part of the "Cretaceo-tertiary" sequence) is in unconformable contact with Tertiary rocks Marshall, Speight, and Cotton, however, state that a careful examination of the creek section fails to reveal any discordance (47, p 392).

3. *Trelissick Basin*—According to McKay's report of 1881, the Trelissick basin contains a fairly complete succession of Cretaceo-tertiary, Upper Eocene, and Lower Miocene rocks, with unconformities between the main divisions (8, p 60 *et seq*). The map and sections in this report are stated to be the work of Hector in 1872 (p. 54). In 1887 Hutton also considers that there are two unconformities in the Cretaceous and Tertiary rocks, but apparently disagrees with McKay as to the horizon of the upper one (26, p 408) In 1905 Park finds himself unable to reach any definite conclusion concerning unconformity (41, p. 534). Marshall, Speight, and Cotton state that the interpretation is very difficult owing to disturbances caused by volcanic action, but no undoubted unconformity can be seen (47, p. 392). In a recent paper Speight again takes a similar view (61, p 342)

Summary —Although palaeontological data strongly support unconformity between Cretaceous and Tertiary rocks in North Canterbury, the recorded stratigraphical evidence is inconclusive, the weight of authority being possibly in favour of conformity. The writer, however, has observed what is at least local unconformity at Weka Pass, and can see little or no reason, other than the opposition of Hector, McKay, and Marshall, why Hutton's view should not be at least provisionally accepted for this important section.

VIII West Coast of South Island.

1 *Collingwood and West Wanganui (Westhaven).*—In this district bituminous and brown coals exist in two horizons, separated by a considerable thickness of strata, which, so far as known, consist of shale, sandstone, and conglomerate In 1883 Cox places the bituminous coal in the Lower Greensand (Cretaceous) Series, and the brown coal in the Cretaceo-tertiary sequence (10, pp 71–72). His sections, however, show the two coal-bearing formations as conformable On the other hand, he states that the calcareous rocks at a higher horizon are probably unconformable to the coal-bearing series, the evidence for this consisting in overlap on the eastern side of the Whakamarama Mountains (p. 73). He admits, however, that in the West Wanganui section no unconformity can be traced.* A few years later Park reports that the bituminous and brown coals both belong to one conformable series, the Cretaceo-tertiary (15, p. 238). In 1910 he places both coal horizons in his Waimangaroa Series of Upper Eocene age (45, pp 310–12). From the data at present available, it seems that in the Collingwood district there is at least 2,000 ft of fresh-water strata containing a number of thin coal-seams, the uppermost of which are pitch, and the lowest bituminous in character A bore recently drilled at Rakopi, on the east side of West Wanganui Inlet (now known as Westhaven), passed through no fewer than seventy-three seams of coal from 3 in to 1 ft. 9 in.

* As a matter of fact, overlap does exist south of West Wanganui Inlet.

in thickness, and finally reached granite at a depth of 1,421 ft. The brown coal of the district is at a considerably higher horizon, and may or may not be separated from the pitch and bituminous-coal series by an unconformity. At present no evidence for discordance other than overlap and analogy with areas farther south can be brought forward.

2. *Westport District.*—The writer has lately published evidence in favour of an unconformity (disconformity) between the Oamaru Series of approximate Miocene age and the bituminous-coal measures of probable Eocene age (58, pp. 271 *et seq* ; 62, pp. 58–88). Angular discordance (clino-unconformity) between the two sets of strata has not been observed, and the most striking evidence of a stratigraphical break consists in the presence of numerous pebbles of coal and carbonaceous shale, derived from the bituminous-coal measures, in the basal and occasionally in the higher beds of the Oamaru. The latter series widely trangresses the Eocene strata, in such a manner as might well be considered proof of unconformity were it not that New Zealand conditions are so peculiar that overlap alone can hardly ever be regarded as a decisive criterion. In at least two localities, however, upper Oamaru beds rest on the Eocene beds to the exclusion of the lower portion of the Oamaru formation (58, p. 275 ; 62, pp. 92–93), and at the mouth of the Fox River Miocene strata unconformably overlie a breccia conglomerate correlated with the Hawk's Crag breccia, the lowest member of the bituminous-coal measures (58, pp. 274–75).

3. *Greymouth District* —Von Haast in 1861 evidently thought that the series of rocks having the Cobden limestone as its upper member rested unconformably on bituminous-coal measures (18, p. 109), and this view was quoted with approval by Hutton in 1887 (29, pp. 268–69). In 1873 McKay discovered strata containing detrital coal, which at that period he thought were below the Cobden limestone and were indicative of unconformity with the coal-measures (3, pp. 77 *et seq.* ; 35, p. 7). In 1901, however, he placed the detrital-coal beds above the Cobden limestone (35, p 8), an horizon where he considered there was independent evidence of a stratigraphical hiatus. In 1909 and 1911 the writer showed that McKay's original view was the correct one (43, p 13 ; 46, pp. 63, 66, &c.), and in the course of field-work found that no break of any kind existed above the Cobden limestone in the Greymouth district * As at Westport, angular discordance has not been detected, and the chief evidence for unconformity between the writer's Greymouth Series (equivalent to Oamaru and Paieora beds) and the bituminous-coal measures of Eocene age consists in the presence of immense quantities of detrital coal in the lowest, or Omotumotu, beds of the Greymouth Series, as originally announced by McKay In 1911 Marshall, Speight, and Cotton regard the evidence as inconclusive (47, pp. 392–93), and in 1912 Marshall, writing alone, takes the same view (55, p. 68).

4. *South Westland* —Rocks of Tertiary or possibly in part of Cretaceous age have been described by Cox and von Haast as occurring near the mouth of the Paringa River Owing to the presence of a conglomerate con-

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* McKay at one locality observed a difference of strike between the Cobden limestone and so-called nummulitic limestone (3, p 75). The writer examined the same locality, and came to the conclusion that a fault or other disturbance accounts for the discordance of strike, which is not very great. The "nummulitic" limestone is really an *Amphistegina* limestone (46, pp 68, 71). At Greymouth a clear and continuous section shows it in perfect conformity with the Cobden limestone.

taining boulders from an underlying lithographic limestone, Cox suspected a stratigraphical break, but was not certain (4, p. 83). Von Haast spent some time in the locality (21, pp. 160 *et seq*, 299–300), but made no definite statement regarding the conglomerate or other evidence of unconformity. The Paringa section is complicated by the presence of volcanic lavas and tuffs. For this reason it is not likely to furnish clear evidence of the presence or absence of unconformity in the purely sedimentary strata of the district.

Summary.—The stratigraphical evidence for a hiatus between the Miocene and Eocene (bituminous-coal measures) rocks of the Westport and Greymouth districts appears conclusive to the writer. The palaeontological data (see 46, 62), though not strongly in favour of unconformity, do not oppose it The difference between the somewhat scanty Eocene fauna and the Miocene fauna is probably quite as great as that between the latter and the present-day fauna.

IX. OTAGO.

1. *Oamaru District.*—The presence of stratigraphical breaks in the Tertiary rocks of the Oamaru district has been affirmed at various times. Hector and McKay believe that an unconformity separates the Hutchinson Quarry beds from the underlying Oamaru limestone (5, pp. ix, 57–58). In 1885 Hutton discusses the matter, and reaches the conclusion that no definite discontinuity exists (25, pp. 560–64). With this view most other observers are practically in accord. In the writer's opinion, slight local unconformities connected with the volcanic eruptions during Miocene times at Oamaru Cape and elsewhere may be present, as indicated by Park (41, p. 502) and again by Marshall and his colleagues (47, p. 405), but these cannot invalidate the substantial unity of the Tertiary rocks of the district

2 *Shag Point*—In 1872 and 1877 von Haast reports that between the boat-harbour and the mouth of Shag River are sections showing discordance between the coal-bearing rocks and a Tertiary series (2, p. 150; 3, p 25) From later reports, especially one by McKay (13, p. 11), it would appear that von Haast was mistaken with regard to the existence of a break in these sections Hutton in 1875 states that in the Shag Point district there is a complete unconformity between the Waipara coal-measures and the Tertiary rocks (20, pp. 50, 103), and in various later papers retains this view (*e g*, 30, p 379, &c). Cox, in his report of 1883, does not mention any stratigraphical break, and maps von Haast's Tertiary rocks with the Cretaceo-tertiary Series. He describes a fault which obviates the necessity of assuming an erosional unconformity (10, pp. 55–56). In various reports McKay consistently supports Cox's view (11, pp. 58, 63; 13, pp 10 *et seq.*) In 1904 Park is positive that the Miocene rocks of the Shag Point district are unconformable to the underlying coal-bearing series (39, p 414), and reaffirms this statement in 1910, 1911, and 1912 (45, p. 116; 48, pp. 541–45; 50, pp. 493–95). Marshall, Speight, and Cotton, however, can find no evidence of discontinuity, and accordingly support McKay (47, p. 393). On the other hand, according to A. G. Macdonald, there is "no room for doubt as to the unconformity of the beds" (53, p 1037). Unquestionably, at Shag Point both Cretaceous and Miocene rocks are present, apparently in unconformable relations; but, since no actual contact has been observed, it is possible that, as suggested by Cox.

a fault is the true explanation of the supposed discordance. It is also possible (1) that no fault is present, or (2) that unconformity as well as a fault exists

3. *Green Island and Brighton.*—The Cretaceo-tertiary age of the Green Island and Brighton coal-seams was naturally assumed by the Geological Survey of Sir James Hector's time This view was supported by the discovery of *Belemnites lindsayi* in an impure pebbly limestone almost immediately overlying the Brighton coal. Near Green Island the occurrence of the clearly Tertiary and apparently conformable Caversham sandstone in an horizon high above the coal has led most observers, including the writer, to consider the coal as of Tertiary age, the presence of a belemnite at Brighton being regarded as anomalous Park, however, explains the situation as due to unconformity between the Brighton and Green Island coals (45, pp. 90, 315–17, 50, p 496) The writer still believes the coals to be of one age, but is now inclined to suppose that the Green Island coal is late Cretaceous, and that there is an unconformity in some upper horizon. Since the Brighton limestone is a beach deposit, its absence from the Green Island district is not hard to explain. The possible stratigraphical break, owing to the amount of clay burdening the surface almost everywhere in the critical area, will be hard to discover. What appears to be an unconformity, but only a very slight one, is visible between marl and overlying greensand at the Burnside marl-pit The greensand contains a few poorly phosphatic pebbles. Since, however, phosphatic concretions or beds, and to a smaller extent glauconite, are frequently associated with unconformities (56, pp 46, 71, 215–17), a careful examination of the phosphatic horizon, which is exposed elsewhere in the Kaikorai Valley, may be recommended as likely to yield evidence of value

4. *Kaitangata.*—Hutton observed that the upper surfaces of the Kaitangata coal-seams are in places eroded, and covered by a conglomerate containing pieces of coal (20, p. 106) He does not, however, regard this as evidence of other than local unconformity, of no importance In 1911 Park gives reasons, partly founded on field-work by A G Macdonald, for believing that an unconformity similar to that at Shag Point exists between Tertiary and Cretaceous coal-bearing strata, but is not able to report actual contact of the two sets of beds (48, pp. 544–45) Shortly after he reaffirms his position, in order to meet criticism by Marshall (49, p 318). The writer's own observations show that coal-seams belonging to two distinct horizons occur in the Kaitangata and adjoining districts, as previously stated by A G Macdonald, who places both horizons in the Waipara Series (53, p 1089). Unconformity between these is probable, but cannot be regarded as demonstrated

General Summary and Conclusions.

In sifting the evidence presented by the various writers who have been cited on the previous pages, the chief difficulty arises in separating what was probably seen in the field from what was inferred While the actual observations demand credit, the inferences made in the literature are by no means of equal value Thus we find sections drawn without any indication of the blanks filled in by the ideal extension of actual outcrops In some cases parallel bedded strata are shown as gently diverging immediately below the outcrops, and thus a possibly unwarranted inference of unconformity is given support In one or two instances faults seem to be a

much more likely explanation of discordant contacts than unconformity as supposed by the observer. The irreconcilably opposing interpretations of critical sections offered by the several groups of workers add much to the difficulties of the student, and, combined with the knowledge that various errors have been made, induce a spirit of scepticism, and incline him to reject the observations made by those with whom he happens not to be in sympathy. Until, however, the field exposures and other data upon which past observers relied have been critically re-examined it would be a mistake to follow such an inclination. Various examples of older work being cast aside by a later investigator (who in some cases was also the original observer), and subsequently found to be practically correct, could be cited.

The following conclusions have been reached by the writer :—

(1.) That there are various local unconformities in the rock-successions discussed Some investigators have hastily assumed one or more of these to be major unconformities, whilst others have denied their existence altogether

(2) That, since in no locality are marine Cretaceous rocks known to be in contact with marine Eocene rocks, no definite opinion as to the existence or non-existence of unconformity between Cretaceous and Eocene can be formed The absence of such contacts, however, favours unconformity.

(3.) That in all parts of New Zealand there is a decided unconformity between the Miocene and any Eocene or older rocks present. The evidence for this is most unmistakable in North Auckland and on the west coast of the South Island.

From these opinions it also follows that—

(4) The Cretaceo-tertiary theory of Hector is untenable as a working hypothesis applicable to all New Zealand; for, although proof of unconformity between the marine Cretaceous and the marine Eocene is still wanting, evidence of conformity is equally far to seek In any case, the inclusion of the whole or the greater part of Hutton's Oamaru System in the Cretaceo-tertiary is an error which has led to great confusion.

(5) In like manner the modification of the Cretaceo-tertiary hypothesis advanced by Marshall, Speight, and Cotton is unsustainable, for unconformities do exist between Cretaceous and Pliocene, and, moreover, the investigators named have made various extremely questionable correlations. On the other hand, they show considerable respect for palaeontological evidence, have disproved various erroneous correlations of other writers, and have clearly demonstrated the essential unity of the Oamaru and Pareora systems of Hutton.

(6) In those localities where the unconformity reported by Hector and his colleagues between the Cretaceo-tertiary and the Eocene happens to coincide with the lower limit of the Miocene rocks it has a real existence, but elsewhere is either non-existent, or local, or requires further investigation

(7.) The unconformity frequently reported by the old Geological Survey between the Eocene and the Miocene generally coincides with the boundary between Hutton's Oamaru and Pareora systems, and therefore is either non-existent or is represented only by a slight local unconformity.

(8) Hutton may or may not have been right in placing an unconformity at the top of the Cretaceous. He was right, however, in placing an unconformity at the base of the Oamaru System or Series.

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