ART. LII.—*On the Geology of the Clarendon Phosphate-deposits, Otago, New Zealand.*

By ARTHUR R. ANDREW, B.Sc., A.O.S.M., Laboratory, Otago University School of Mines.

Communicated by Professor James Park.

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Plates IV–VIII.

INTRODUCTORY.

The Limestone Quarries.—The Millburn district is well known throughout Otago by reason of its deposits of limestone, which have now been worked for more than thirty years. Numerous quarries have been opened up in various parts of the district, but there are only two in active operation at present—that of the Millburn Lime and Cement Company, near the Millburn Railway-station, and Wilson's quarry, close to the main road and about half a mile north of Millburn. The lime derived from the burning of the limestone is for the most part used for agricultural purposes, the Millburn Company alone producing lime suitable for building. The company has large works at Dunedin, and send there by rail all the lime they require for making cement; "land lime" nevertheless constitutes the bulk of their output. I understand that this company has been considering the possibility of using their limestone in the manufacture of calcium-carbide. As will be noted below, some of the limestone in their quarry contains a small amount of phosphoric acid, and in quarrying great care will be needed lest any of this stone should be sent to the carbide-works. In the manufacture of calcium-carbide from limestone, any phosphorus present associates with the carbide, and, when the latter is acted on by water to generate acetylene, forms compounds which mingle with the gas and burn with the production of a most disagreeable odour. The limestone is not used as a building-stone, as it is broken up into small blocks by the planes of lamination, stratification, and jointing, which are well defined and set close together.

Other Workings.—Other rocks in the district are also of economic importance, though in a less degree. The schist which forms the floor on which the later deposits were laid down is occasionally used for building walls and fences—a purpose for which its flaggy nature renders it suitable. The basalt which forms the cap of the hills is quarried and used for road-metal. In the early days of the diggings in Otago, the discovery of gold to the north near Lake Waihola caused a rush to set in thither, but it soon passed on, as the gold was not present in payable quantities.

Failure to recognise the Nature of the Phosphate.—It has long been considered possible that deposits of phosphate of lime should occur in this neighbourhood. It is stated that Sir James Hector, then Director of the Geological Survey, believed that a careful search would reveal the presence of rock-phosphate. Those who did search for it seem to have looked only for dark-coloured coprolite-deposits. Massive outcrops of rock-phosphate, some 20 ft. high, are plainly to be seen at several places. The manner in which the deposits escaped recognition now seems marvellous. A specimen of the phosphate was to be seen in the Otago Museum, labelled "decomposed limestone from Clarendon." The lime-burners found that the "decomposed limestone" crackled loudly in the kiln, and would not burn as it should have done. They sent a sample to their analyst, who estimated the calcium-carbonate in it; finding it low, he reported that the limestone was of poor quality, and not worth burning: he did not dream of testing for phosphate. One of the lime-burners, however, persisted in burning the decomposed along with the fresh limestone, and though he apparently used poor material for his work, still, the lime he produced gave just as good results to the farmer.

Discovery of the Phosphate.—Meanwhile, Mr. Ralph Ewing, of Whare Flat, Dunedin, had been travelling in America, and had inspected the phosphate-deposits of Florida. Returning to New Zealand, he speedily realised the true nature of the "decomposed limestone," and in June, 1902, he announced his discovery. Then the lime-burner and the farmer understood why the poor limestone made just as good a land-manure as the ordinary limestone.

In the neighbourhood the discovery naturally excited keen interest, and now the apparent reluctance to recognise the deposits of phosphate was succeeded by a great eagerness on the part of some of the landowners to discover them on their property. One farmer had heard that some of the phosphate is white and soft. In his fields there was a white, soft clay, formed by the weathering of the mica-schist which lay all around: he jumped to the conclusion that his "find" was phosphate. After some days (spent largely in receiving the congratulations of his less fortunate neighbours) he sent a sample to an analyst: his hopes vanished. Another landowner had heard that some phosphate was hard and flinty—so was a quartzite which lay in abundance around his house: he likewise drew a conclusion of his own. And yet a third thought that a reddish clay on his property might prove to be a red variety of the eagerly sought rock: the clay was due to the weathering of a basalt rich in iron.

Previous Investigation and Literature.—The district has been exceptionally free from geological investigation, and until the discovery of rock-phosphate attracted little attention. In 1862 Dr. Lauder Lindsay is reported to have delivered a lecture on "The Geology of the Tokomairiro and Clutha Districts," and to have mentioned the limestone at Millburn. I have been unable, however, to see an account of his lecture. In the Report of the Geological Survey for 1873* the "calcareous sandstone of Waihola Gorge" was mentioned, but no description was given. In 1875 Captain F. W. Hutton gave a passing notice to the limestone of Millburn†; he mentioned the occurrence of "an isolated patch of limestone on the side of the road at Waihola Gorge"; he noticed the occurrence in it of *Ostrea wullerstorfii* and *Lima lævigata.* Sir James Hector travelled through the district, but apparently saw nothing worth mentioning. In his "Outlines of New Zealand Geology"‡ there is no reference to Millburn or neighbourhood. In 1902, soon after the discovery of the rock-phosphate, Professor James Park§ visited the locality, and his report on the geology of the phosphate-deposits, published in 1903, was the first systematic description of the geology of this district.

Physical Geography.—To the south of Dunedin there is a line of coast-hills, varying in height from 500 ft. to 1,400 ft. Shut off by these hills from the sea are two long, somewhat narrow plains—the Taieri and the Tokomairiro—along the length of which run the main road and the Main Trunk Railway. The drainage of these plains finds an outlet to the sea through narrow gorges in the coast-hills. On the western side of the plains the hills rise abruptly, but between Clarendon and Millburn they jut far out towards the east, separating the two plains from each other, and forming the Waihola Gorge—the former name for Millburn. It is at the base of the protruding part of these western hills that the rock-phosphate mostly occurs. On the southern (Millburn) side of the gorge the hills rise sharply at first till the crown of the spur is reached, and then the spur runs in a north-west direction, attaining its greatest height at the Trig. Q. From the trig. another long spur runs down in an

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* Report Geological Survey N.Z. (1873-74): Progress Report xiii.

† Captain Hutton, "The Geology of Otago" (1875), p. 48.

‡ Sir J. Hector, "Outlines of New Zealand Geology" (1886).

§ Professor James Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 391.

easterly direction on the north boundary of the district, reaching the plain opposite Cemetery Hill. Between this spur and the former one the hills descend somewhat more abruptly to the plain. In the neighbourhood of the gorge a small cross-spur runs northward parallel to the road; the western flank of this spur was the site of the original discovery of rock-phosphate, and is now the scene of the greatest activity in the quarrying of the rock.

FORMATIONS OF THE DISTRICT.

7. Rock-phosphate	Secondary origin	Recent.
6. Sandstone	Secondary origin	Recent.
5. Alluvium	..	Pliocene.
4. Basalt	Oamaru formation	Lower Tertiary.
3. Calcareous series	Oamaru formation	Lower Tertiary.
2. Grits and conglomerates	..	Lower Tertiary.
1. Foliated schist	Kakanui formation	Silurian (or older).

Summary.—The basement rock of the district consists of the foliated mica-schist which constitutes the greater part of the Province of Otago. On this basement thin patches of grit and conglomerate are irregularly distributed. Above these come glauconite sands, which gradually merge upwards into the limestone as they become less and less glauconitic. Above the limestone, which lies practically horizontal, there occur in various places a brown sandstone and patches of rock-phosphate, usually occurring together; their outcrops roughly follow the contour-lines, but rise towards the north-west along with the limestone. In many places the limestone is absent, the rock-phosphate then resting directly on the glauconite sands. The sandstone and the rock-phosphate are confined to the outer margin of the limestone, and do not extend beneath the basalt-flow which caps the western hills and forms occasional outliers on the hills of the eastern side. The low-lying portions of the schist are covered by the alluvium of the Taieri and the Tokomairiro Plains.

SCHISTS.

Character of the Schist.—This rock may be properly termed a "chloritoid mica-schist."* In the hand-specimen muscovite is clearly seen along the foliation planes, but under the microscope it is scarcely apparent, the rock being then seen to consist mainly of alternating folia of chlorite and quartz. The quartz often surrounds fibrous masses of chlorite, which are elongated in a direction parallel to the plane of foliation. Rutile

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* Rosenbusch, "Elemente der Gesteinlehre," p. 517.

is in many places quite abundant as minute inclusions in the quartz, mostly as stout prisms, but also as long narrow crystals. Many of the quartz crystals show by their undulose extinction that the rock has been subjected to great strain; the folia occasionally are contorted and puckered, but this character is not frequently observed.

Occurrence.—For a rock of such a great age the schist lies very flat, the average dip being about 10° in a westerly direction (W. 10, N. 10). The difference in the dips between the schists and the overlying limestone affords the only evidence of the unconformity that exists between these formations. Near Kiln Point the schist is traversed by two sets of approximately vertical joints which strike N. 13° W. and S. 13° E., and W. 22° N. and E. 22° S. respectively. The schist contains no trace of organic remains. The hills on the east of the gorge are composed entirely of schist; on the western side it is found outcropping from beneath the limestone in a few localities, as at the base of Cemetery Hill, between Cemetery Hill and Kiln Point, and near Sutherland's quarry. The schist forms the basement rock of the district, and to the north-west of the Trig. Hill it passes out from beneath the overlying formations and extends westward throughout the greater part of Otago.

Age.—Within the district we get no information as to the age, except that it is older than the limestone; it forms part, however, of the foliated schists of Otago, which Sir James Hector* in 1875 considered as a Kakanui formation of Upper Silurian age. In 1872 Captain F. W. Hutton† considered them as a Tuamarina formation, but in 1875‡ he considered them identical with the Upper Silurian Kakanui formation of Hector. In 1885 Captain Hutton§ classed the Kakanui formation as the lower part of the Takaka system, and thus of Silurian age. In 1886 Hector|| considered that they were the result of the metamorphism of Silurian and even younger rocks. In 1891 Hutton,¶ as the result of a more complete investigation, revised his former opinion and stated that they were of Archæan age. In 1896 Hutton repeated his former assertion, that they were Archæan. Professor Park refers the schists to the Silurian. Thus the geological age of the schist is dubious, the authorities on the subject being unable to agree as to whether it belongs to the Archæan or to the Silurian.

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* Hector, Quart. Journ. Geol. Soc. (1865), vol. xxi, p. 128.

† Hutton, Rep. Geol. Explor. N.Z. (1872–73), p. 31.

‡ Hutton, "Geology of Otago" (1875), p. 32.

§ Hutton, Quart. Journ. Geol. Soc. (1885), vol. xli, pp. 194, 198.

|| Hector, "Outline of New Zealand Geology" (1886), p. 83.

¶ Hutton, Trans. N.Z. Inst. (1891), vol. xxiv, p. 358.

Grits and Conglomerates.—The grits are tabloidal or flaggy in structure, and are composed of angular grains of quartz cemented by iron-oxide—limonite. Under the microscope the quartz-grains are seen to possess the same characters as the quartz-crystals of the subjacent chloritoid mica-schist—rutile needles, chlorite inclusions, and sometimes undulose extinction; muscovite is also seen in the grit. The quartz-grains of the grit have been derived in past geological times from the disintegration of the schist. In the conglomerate the quartz pebbles are well rounded, and as much as 0·75 in. in diameter. No fossils have been found in either grit or conglomerate.

These beds are seen only occasionally, as the surface-soil hides their outcrop; it is unlikely, however, that they attain any great thickness. They may be seen in two small cuttings on the road near Sutherland's farm (west of the Millburn lime quarry); they are also seen north-west from there on the hills in the schist country, and again they are seen north of Kiln Point. As seen at these places the thickness of the beds is never more than 1 ft., but near Sutherland's farm there are surface boulders of conglomerate 2 ft. and 3 ft. in diameter. These beds are more extensively developed ten miles to the south of Millburn, in association with the coal-seams of Fortification.

The only evidence of the age of the grits in the district is the fact that they underlie the calcareous limestone which is part of the Oamaru formation. As in the case of the schist, we must go outside the district to determine their age. In 1875 Hutton* considered the coal-grits, of which the Millburn grits are part, to belong to his Oamaru formation, of supposed Oligocene age. In 1880 Hector† considered the "island sandstone, forming the cover of the most important coal-bearing formations of New Zealand," as part of his Upper Greensand, of Lower Eocene age. In 1886 Hector‡ considered the island sandstone as part of his Cretaceo-tertiary system, comprising practically all the coal-measures of New Zealand. Professor Park in 1902 referred the grits to the base of the Oamaru formation, which he placed in the Upper Eocene.

CALCAREOUS SERIES.

Occurrence.—The calcareous series follows the grits and conglomerates in conformable succession, the different members of the series being quite conformable to one another. Over most of

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* Hutton, "Geology of Otago" (1875), p. 47.

† Hector, "Corals and Bryozoa of the Neozoic Period in New Zealand" (1880), by J. E. Tenison-Woods: Pref., p. vi.

‡ Hector, "Outline of New Zealand Geology" (1886), p. 59.

the district they lie almost horizontal, though a slight inclination towards the south is noticeable on comparing the altitudes of the outcrops at different points. As the outcrop recedes from the plains, however, it becomes more and more elevated: this is best seen on the western outcrops, where the limestone rises 300 ft. in a horizontal distance of a mile; at the highest outcrop the dip is seen to be S. 42°, E. 8°. On the east side of the road the calcareous strata dip steeply towards the schist, the dip varying from 15° to 45° in an easterly direction (E. 10° S.). There are three sets of well-developed joints, which aid the quarryman greatly in his work.

The top of the calcareous series has a very irregular surface of projecting pinnacles and deep depressions, which have been formed by the action of percolating waters containing carbonic-acid gas (CO_2); these have carried away the calcium-carbonate in solution, the greatest action having taken place along those channels where the percolation was strongest. As the mode of weathering throws considerable light on the question of the origin of the rock-phosphate, I will not describe it fully until discussing the origin.

Millburn Quarry.—The calcareous rocks are well seen in the Millburn quarry. The sequence of the various bands here was worked out in full, as I hoped to find a similar sequence in the other limestone outcrops of the districts. A general but not an exact resemblance was found; and I publish here the result of this work, in the hope that future workers may be aided by it in attempting to trace the sequence of the various bands in this district, and perhaps also in other districts. The typical sequence consists of the following, starting from the top:—

H (30 ft.). Siliceous limestone with glauconite-grains throughout; *Brissus* (*Meoma*) *crawfordi* the chief fossil.
G (3 ft.). Hard limestone, less siliceous than H, with few fossils and no glauconite-grains.
F (2 ft.). Hard tough limestone, fairly siliceous: *Ostrea wullerstorfii* in abundance.
E (6·5 ft.). Tough limestone with *Magellania sinuata.*
D (3 ft.). Very pure knubbly limestone, with broken fragments of shells of *Brachiopoda.*
C (42 ft.). Pure white limestone, with *Brissus* (*Meoma*) *crawfordi, Pecten hochstetteri,* and remains of vertebrates.
B (35 ft.). Limestone, pure at first, but becoming more and more glauconitic towards the base, where it merges into A.
A. Unknown thickness of glauconite sands, with very few well-preserved fossils.

Band H.—From the top of the pinnacles of the quarry to about 30 ft. below the rock consists of a limestone containing an appreciable quantity of sand-grains and a few glauconite-grains. On treating a fragment of the rock with cold dilute hydrochloric acid (HCl), and examining under the microscope the finer residue which passed through a 90-mesh sieve, the insoluble matter was seen to consist of grains of quartz, limonite, and glauconite. One very interesting grain was thus isolated: it was a rock-fragment which originally had consisted of two well-developed crystals, one of plagioclase, the other of hornblende. The grain had been derived from a holocrystalline rock of very probably dioritic affinity. It is interesting to note that nowhere near the district is there now to be found a rock capable of furnishing such a grain. A partial analysis of the limestone gave:—

Insoluble gangue	5·50
*Phosphoric acid (P_2O_5)	0·15
Not determined	94·35
	100·00
*Equivalent of calcium-phosphate, $Ca_3(PO_4)_2$	0·33

This band contains a large number of fossils, of which *Brissus* (*Meoma*) *crawfordi* is the most common. The following fossils were identified from this band: (1) *Nodosaria subsimilis*, Stache; (2) *Cristellaria rotulata*, Lamarck; (3) *Textularia agglutinans* (?), d'Orbigny; (4) hexactinellid sponge; (5) *Graphularia robinæ* (?), McCoy; (6) *Actinometra*, sp.; (7) *Cidaris*, sp.; (8) *Echinus enysii*, Hutton; (9) *Brissus* (*Meoma*) *crawfordi*, Hutton; (10) *Liothyrina gravida*, Suess; (11) *Magellania lenticularis*, Deshayes; (12) *Pecten fisheri*, Zittel; (13) *Pecten hochstetteri*, Zittel.

Band G.—This consists of 3 ft. of a hard siliceous limestone —less siliceous, however, than H, and with no glauconite-grains. The laminæ are close together, and the only organic remains to be seen are fragments of shells.

Band F.—This band, which is only 2 ft. thick, is markedly siliceous, and splits with difficulty. *Ostrea wullerstorfii* is confined to this band, and is very conspicuous. The fossils identified were (1) *Liothyrina gravida*, Suess, sp.; (2) *Ostrea wullerstorfii*, Zittel.

Band E.—This is a tough limestone, 6½ ft. thick, with the laminæ somewhat indistinct. It is speckled with glauconite, especially in its lower portion; in the latter I came across a small coprolite, rich in phosphate of lime. The conspicuous fossil of this band is *Magellania sinuata*, the others being but rarely found; those identified were (1) *Magellania sinuata*, Hutton; (2) *Pecten hochstetteri*, Zittel; (3) *Pecten williamsoni*, Zittel; *Scalaria browni*, Zittel; (5) *Scalaria lyrata*, Zittel.

Band D.—This is a rough knubbly limestone, 3 ft. thick, which in general appearance looks very much like a coarse conglomerate, with limestone pebbles and matrix. The pebbles of this conglomerate are about 3 in. in diameter, and slightly rounded; they consist of a pure white limestone, probably identical with that of band C. The limestone forming the matrix of these pebbles is less pure and is freely speckled with glauconite; it resembles the limestone of band E, immediately above. The junction of this band with the subjacent C is not so clearly defined as its junction with the overlying E. It forms a strongly marked band around the face of the quarry, and has a slight dip (0° 43′ in a direction E. 9° N.).

In former times, after band C had been laid down, it would seem that it had been raised to near the level of the waves, which pounded fragments off its upper surface, rounded them, and spread them evenly out. Afterwards, conditions having changed, the coral mud which now forms band E was deposited over the area; it first filled up the spaces between the rounded fragments and then spread itself over them to a depth of 6½ ft. The only fossil traces found in D consist of fragments of the shells of *Brachiopoda.* This band is also distinguishable in Wilson's quarry, but is not so clearly marked.

Band C.—This is the principal band at the Millburn quarry, where it extends 42 ft. upward from the floor. It is regularly laminated, the laminæ being from 2 in. to 5 in. apart. When freshly quarried the laminæ often show a faint pink or greenish tint, which rapidly disappears on exposure. An analysis of this limestone gave the following:—

Insoluble gangue	2·21
Lime (CaO)	54·12
* Carbon-dioxide (CO_2)	42·86
† Phosphoric acid (P_2O_5)	0·018
	99·208
Equivalent to—	
* Calcium-carbonate	97·41
† Calcium-phosphate..	0·039

The following fossils were identified from this band: (1) *Nodosaria subsimilis*, Stache; (2) *Cristellaria rotulata*, Lamarck; (3) *Textularia agglutinans* (?), d'Orbigny; (4) *Cidaris*, sp.; (5) *Brissus* (*Meoma*) *crawfordi*, Hutton; (6) *Serpula*, sp.; (7) *Magellania lenticularis*, Deshayes; (8) *Magellania sinuata*, Hutton; (9) *Magellania marshalli,* nov. sp.*; (10) *Cucullea alta,* Sowerby; (11) *Pinna distans,* Hutton; (12) *Pinna neozelanica,* Gray; (13) *Pecten beethami,* Hutton; (14) *Pecten chathamensis* (?), Hutton; (15) *Pecten diffluxus,* Hutton; (16) *Pecten fischeri,* Zittel; (17) *Pecten hochstetteri,* Zittel; (18) *Pecten williamsoni,* Zittel; (19) *Lima colorata,* Hutton; (20) *Crepidula* (*Janacus*) *unguiformis,* Lamarck; (21) *Natica callosa* (?), Hutton; (22) *Voluta,* sp.; (23) *Notidanus gigas,* Sismonda; (24) *Odontaspis incurva,* Davis, sp.; (25) *Lamna* (?) *lanceolata,* Davis; (26) *Lamna,* sp.; (27) *Oxyrhina von haastii,* Davis; (28) *Trygon* (?) *ensifer,* Davis; (29) *Squalodon grateloupi* (?), Pedroni.

Band B.—As we descend from the base of the pure white limestone C the rock becomes more and more glauconitic, and less and less calcareous, till it passes gradually into the glauconite sands A, 35 ft. below. The transition is very gradual, and no definite line can be assigned as the junction between the pure limestone C and the glauconitic limestone B. Planes of stratification are well marked in this band, the laminæ being horizontal and about 3 in. apart. This band is not quarried, as the large proportion of glauconite renders it of inferior quality.

The fossils identified in this band were—(1) *Orbitolites,* sp.; (2) *Cristellaria rotulata,* Lamarck; (3) *Textularia agglutinans* (?), d'Orbigny; (4) *Cidaris,* sp.; (5) *Serpula,* sp.; (6) *Pecten diffluxus,* Hutton; (7) *Pecten hochstetteri,* Zittel; (8) *Lima colorata,* Hutton; (9) *Odontaspis incurva,* Davis, sp.; (10) *Lamna* (?) *lanceolata,* Davis; (11) *Carcharodon auriculatus,* Blainville.

Band A.—This, the glauconite sand, is composed of small rounded grains of glauconite with an admixture of quartz and calcite. It is devoid of stratification, and its thickness could not be determined.

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* *Magellania marshalli.*—Length, 2 in.; breadth, 1 95 in.; height, 0·80 in. Shell orbicular, smooth or with a few concentric markings near the margin; margins even; valves equally convex; beak solid, slightly curved and laterally keeled; foramen complete and of moderate size; deltidium large, conspicuous, and formed of two plates; loop elongated and reflected; medial septum of dorsal valve very prominent. This species is most closely allied to *M. concentrica,* which Hutton (Cat. Tert. Moll. N.Z., p. 35) describes as "shell oval, concentrically striated . . . length, 1·65 in.; breadth, 1·30 in.; height, 0·80 in." *M. marshalli* differs in being orbicular and flatter in shape, and in not having concentric striations over its whole surface. The only other described species to which *M. marshalli* is at all similar is *M. lenticularis,* from which it is distinguished by the characters of beak and foramen, which in the latter are—"beak small, recurved; foramen very small." This is a hitherto undescribed species, and I have much pleasure in naming it *M. marshalli,* after Dr. Marshall, of Otago University.

The following fossils were identified in this band, but the specimens collected were very much weathered and mutilated: (1) *Serpula*, sp.; (2) *Venus oblonga* (?), Gray; (3) *Dentalium mantelli*, Zittel; (4) *Turbo granosus* (?), Lamarck.

Professor Park* separated the calcareous series at Millburn into (*a*) limestone, (*b*) glauconitic sandstone. As stated above, however, the glauconitic limestone B affords such a gradual and complete transition between the two that it seems hardly possible to say where the glauconite sand ends and where the limestone begins. Hence I have thought it better to consider the sand as forming the termination of the calcareous series.

Glauconite or Chlorite ?—Dr. Maclaurin,† of the Colonial Laboratory, in publishing an analysis of a sample of limestone from this quarry, and apparently from the upper part of band B, describes it as "a whitish limestone dotted with a large number of greenish-black particles (chlorite)." Professor Park‡ had before this described the mineral as glauconite. I isolated a small quantity of the mineral and made a partial analysis of it, as under:—

Silica	49·41
Water (combined)	10·20
Not determined	40·39
	100·00

According to the analyses of different samples given by J. D. Dana,§ the amount of silica in chlorite (penninite) lies between a maximum of 35·31 per cent. and a minimum of 29·89 per cent. The mineral cannot therefore be chlorite (penninite); not is it possible for it to be any other member of the chlorite group of minerals, for stilpnomelane contains the highest percentage of silica, and that amount never exceeds 45·61 per cent. On the other hand, the published analyses of glauconite show an amount of silica ranging from 46·58 to 52·86 per cent., and in the mineral we are considering we find 49·41 per cent.—well within these limits. Again, paying attention to the amount of combined water in the minerals, we obtain further proof that our mineral is glauconite and not chlorite. In chlorite (penninite) the amount of water ranges between 11·74 and 16 per cent., both figures being higher than that found with the Millburn mineral. The analysis confirms Professor Park's determination.

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* Professor James Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 394.

† Maclaurin, 36th Ann. Rep. Col. Lab. (N.Z.), 1903, p. 9.

‡ Professor James Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 394.

§ J. D. Dana, "System of Mineralogy," pp. 683, 653, 658.

The appearance of the grains under the microscope is that of glauconite, not chlorite. They are rounded, and green-coloured with a tinge of yellow, with a faint scarcely perceptible pleochroism. In a few of the sections examined the mineral is seen filling the chambers of *Cristellaria rotulata.*

Age of the Series.—All the species that are found fossil in the district occur at the Millburn quarry. They show that this series should be correlated with the Oamaru formation.* Out of the thirty-five species which I determined at Millburn, thirty had been described from the Oamaru formation in other districts. As to the geological age of this Oamaru formation, opinions are divided. In 1850 Dr. Mantell, Professor Morris, and Professor R. Jones considered it either Eocene or Upper Cretaceous. In 1865 Dr. Hector† considered it Miocene. In 1865 Dr. Zittel and Dr. Stache considered the northern equivalents of this formation as Oligocene or Upper Eocene. In 1866 Hector split up the formation, calling some Upper Pliocene, some Lower Pliocene, and some Miocene. In 1870 Hector‡ considered the Oamaru rocks as Upper Tertiary; the Waitaki, Tokomairiro, Caversham, and Wakatipu rocks as Lower Tertiary. In 1871 Hector§ placed the Oamaru formation as the closing member of his Cretaceo-tertiary system. In 1872 Hutton considered the Waitaki and Wakatipu members as Lower Oligocene, and the Oamaru, Caversham, &c., members as Upper Eocene. In 1875 Hutton|| considered it doubtful whether the Oamaru formation was Upper Eocene or Lower Miocene, but he inclined to the latter belief on account of the presence of forms such as *Carcharodon megalodon.* In 1879 Von Haast¶ considered it Upper Eocene. In 1880 Hector** called it Upper Eocene, and has kept to that opinion ever since. In 1885 Hutton†† considered it Oligocene, and has repeated that opinion. In 1902 Park‡‡ referred it to the Upper Eocene.

The question of age thus seems to be narrowed down to an issue between the closely allied Upper Eocene and Oligocene, with high authority supporting each opinion.

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* Hutton, "Geology of Otago" (1875), p. 46.

† Hector, Quart. Journ. Geol. Soc. (1865), vol. 4, p. 128.

‡ Hector, "Catalogue Colonial Museum" (1870).

§ Hector, Trans. N.Z. Inst. (1871), vol. iv, p. 245.

|| Hutton, "Geology of Otago" (1875), p. 54.

¶ Von Haast, "Geology of Canterbury and Westland" (1879), p. 315.

** Hector, Preface to Tenison-Wood's "Corals and Bryozoa of New Zealand" (1880), iii; "Outline of New Zealand Geology" (1886), p. 53.

†† Hutton, Quart. Journ. Geol. Soc. (1885), vol. xli, pp. 194, 206; Trans. N.Z. Inst. (1899), vol. xxxii, p. 169.

‡‡ Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 393.

BASALT.

Occurrence.—The basalt sheet overlies the calcareous series and forms the cap of the higher hills. It is practically continuous on the west side of the main road, running down from the Trig. Q to the lower levels. Outliers occur at Cemetery Hill, Kapiti, and behind Strain's farm. Beneath Trig. Q it must be at least 300 ft. in thickness.

Character.—The basalt is finely grained, with a sharp clean fracture. At Cemetery Hill it has a columnar structure with rude hexagonal jointing. Under the microscope the rock from Cemetery Hill is seen to consist of broad plates of a basic plagioclase wrapping round and enclosing crystals of augite, anomite, magnetite, olivine, and serpentine. The plagioclase, which forms the greater part of the groundmass, is a very basic variety, probably bytounite. Augite is the most common coloured constituent of the rock, and has the usual characters. Anomite, a rather unusual variety of biotite, occurs here in irregular flakes with intense pleochroism. Magnetite is very abundant. Olivine is not at all common, and neither is its decomposition product serpentine. I looked carefully for apatite in every slide, but was unable to see it; neither did micro-chemical tests reveal the presence of phosphorus.

Nearly thirty slides were examined from various parts of the district to see if there was any variation in the basalt. Differences were detected, but these were not of great importance. At Stony Knob magnetite is not so abundant as at Cemetery Hill, and occurs chiefly as specks and granules, not crystals; anomite is less abundant; the broad plates of plagioclase are not so conspicuous; while well-defined feldspar-laths with albite twinning become common. At Trig. Q plagioclase is abundant as minute stout lath-shaped albite twins; anomite is entirely absent. Near Williamson's magnetite becomes very abundant; olivine becomes common, while the plagioclase is present only as albite twins, anomite is entirely absent. At Strain's and near J. Gray's farm the rock is much altered by weathering: the feldspars are abundant as stout crystals; the augite is mostly decomposed; the olivine is changed to serpentine; and the whole mass of the rock is stained a yellowish-red by iron-oxide. At Table Hill, however, four miles south-west from Millburn, the structure changes to that of a fairly coarse dolerite, with labradorite as the most prominent phenocryst; augite is here confined to the groundmass, which contains no glass; magnetite and olivine are common.

Chemical Investigation.—On treating the powdered basalt with dilute hydrochloric (HCl) or sulphuric (H_2SO_4) acids, gelatinization takes place in a most pronounced manner. A pinch of about 0·5 gramme powder was placed in a test-tube and covered with 0·5 in. of 50 per cent. HCl. It was brought to the boiling-point and then allowed to cool; by the time it was cool it had formed a thick jelly, and test-tube could be inverted at an angle of 45° from the vertical; five minutes later it could be held upside down without any movement of the jelly taking place. To the hot solution obtained by boiling the powder with HCl, H_2SO_4 was added; part was allowed to stand for some days, when a quantity of gypsum needles were thrown down; part was at once evaporated to dryness on a glass slide, and crystals of gypsum and halite were then detected under the microscope.

A sample of the powder was next boiled for five minutes with dilute HCl, filtered and well washed; the residue contained colloid silica, which was dissolved by boiling for fifteen minutes in strong KHO; this residue was then filtered and washed, and the filtrate evaporated to dryness. Each of the three portions thus obtained was separately analysed, with the following result:—

—	Insoluble in HCl.		Soluble in HCl Solution.
	Insoluble in KHO. Gangue.	Soluble in KHO. Colloid Silica.	
Silica	22·74	17·36	5·52
Alumina and iron ..	9·05	..	23·10
Magnesia	2·85	..	6·42
Lime	5·19	..	4·42
Soda	2·40	..	0·79
Potash	1·06	..	0·25
	43·29	17·36	40·50
	Total = 101·15		

The powder that was not dissolved by the HCl was found under the microscope to consist of augite and a little magnetite, so that the minerals which dissolved so readily were plagioclase, olivine, and magnetite.

The results of analyses of the basalt are as follows:—

—	1.	2.	3.	4.	5.
SiO_2 ..	42·19	45·02	44·91	44·04	45·62
TiO_2 ..	0·87	0·87	0·87	0·87	..
Al_2O_3 ..	18·00	17·78	17·59	17·79	32·15
Fe_2O_3 ..	7·73	6·61	8·07	7·47	
FeO ..	8·67	8·72	9·08	8·82	
MgO ..	7·06	6·29	6·41	6·59	9·27
CaO ..	9·27	8·76	7·88	8·64	9·61
Na_2O ..	3·15	3·82	3·37	3·45	3·19
K_2O ..	1·05	1·16	1·58	1·26	1·31
H_2O ..	1·35	1·57	1·54	1·49	0·20
	99·34	100·60	101·32	100·42	101·35

1. From Stony Knob. 2. From Stony Knob: S.G. = 2·957. 3. From Stony Knob. 4. Average of 1, 2, and 3 5. Cemetery Hill: sum of results of the last table. (Only one estimation of TiO_2 was made.)

These results show that the basalt is 2 or 3 per cent. poorer in CaO than a normal basalt, but otherwise it coincides fairly closely with standard analyses, such as those given by Rosenbusch.*

Age of the Basalt.—Captain Hutton† considers that toward the end of his Oamaru formation great volcanic activity took place in the neighbourhood of Dunedin, resulting in the basalts at, *inter alia*, "the head and both sides of Waihola Lake." This flow is connected with the basalt-flow at Clarendon, and we may consider the latter as belonging to the close of the Oamaru formation, and thus either Upper Eocene or Oligocene. There is no evidence in this district to show what interval of time elapsed between the deposition of the calcareous series and the extrusion of the basaltic flow. Captain Hutton does not give the evidence on which he bases his opinion of the age of the eruptive rocks round Dunedin; he does, however, show that the volcanic activity at Oamaru was of this age. Professor Park mentions that the basalt rests on the mica-schist, and on different members of the Oamaru formation, which was elevated and denuded prior to the emission of the flow. For this reason he places the eruption of the basalt in the Upper Miocene or Pliocene.

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* Rosenbusch, "Elemente der Gesteinlehre," p. 322.

† Hutton, "Geology of Otago" (1875), p. 56.

ALLUVIUM AND SANDSTONE.

Alluvium.—Over the low-lying parts of the district the alluvial deposits of the Taieri and Tokomairiro Plains overlie the foliated schist; their thickness must be considerable, but it could not be determined in this district. Captain Hutton considers the alluvium of these plains as of Pliocene age.

Sandstone.—At several parts of the district a brown sandstone is found above the limestone. It outcrops clearly in two places—at J. Gray's farm, and on the western hill which juts out to form Waihola Gorge; elsewhere the sandstone reveals its presence only by loose boulders on the surface. Professor Park* considers that this is an original formation, deposited in shallow water on top in succession to the limestone. He says, "From the upper surface of the limestone to the basalt cap there is an interval of 120 ft. to 150 ft., apparently occupied by a yellowish-brown sandstone, the character and disposition of which could not be ascertained on account of its outcrop being obscured by a heavy slope deposit of black earth mixed with sand. In the Oamaru and Weka Pass districts, where the sequence of Lower Tertiary strata is very complete and characteristic, the Oamaru and Weka Pass calcareous sandstones, which, as we have seen, are the time-equivalents of the Millburn limestone, are followed quite conformably by the Hutchison quarry or Mount Brown beds, which consist of yellowish-brown calcareous sandstone containing a rich assemblage of marine forms. This overlying series is so closely associated with the Oamaru series that it cannot be regarded as a separate formation, but only as the closing horizon of the Oamaru series itself. Until something more definite is ascertained about the sandstone lying above the limestone on the Horse-shoe Estate, it may be correlated with the Hutchison quarry horizon of the Oamaru formation."

A careful examination of the district has led me to differ from the above views of Professor Park, and has forced me to believe that the sandstone was not laid down as sandstone, but that it is a secondary deposit, formed, where conditions were favourable, from the weathering of the subjacent limestone. When the limestone weathered away, the quartz-grains in it were left behind and formed sands, which were afterwards cemented together by iron-oxide to form a compact sandstone. The following are the reasons which have induced me to differ from Professor Park's views, and to advocate the theory of a secondary origin:—

1. In this sandstone we do not find several features which we ought to find in a normal sandstone deposited in shallows by

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* Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 396.

running water, or spread over a land-area by torrential rains. (*a.*) No traces of stratification, false bedding, ripple-marking, &c., are to be found. (*b.*) The joints are poorly developed and not at all distinct. (*c.*) No fossils whatever have been found. Of course, many true sandstones do not contain fossils, but the Millburn sandstone has been provisionally correlated with the "Hutchison quarry-beds, which in places contain a rich assemblage of marine fauna," and this fauna the Millburn sandstone does not contain, so far as is known at present

2. Sandstones are relatively hard rocks, and offer great resistance to the agencies of denudation: hence in horizontal stratified rocks we find sandstone bands marked by terraces and cliffs. The Millburn sandstone is extremely hard and compact; had it been laid down in Lower Tertiary times, as Professor Park thinks, it would now form prominent outcrops above the limestone. Instead, we find "an interval of 120 ft. to 150 ft., apparently occupied by a sandstone . . . . its outcrop being obscured by a heavy slope deposit." The two outcrops that do occur are far indeed from being prominent. The Millburn sandstone, then, does not form outcrops as it should do supposing that it was formed in Lower Tertiary times.

3. Glauconite-grains are fairly abundant in the sandstone. A normal sandstone is laid down in shallow water on the margin of a land-area, and does not often contain glauconite, which is a mineral characteristic of deposits formed in deep water. On the other hand, a small number of grains of sand may be carried out to deeper waters, where coral mud is being deposited, accompanied by glauconite: this would form a limestone containing a small amount of silica and glauconite.

4. At the Millburn quarry I found that the depressions of the limestone are filled with brown sands, which are derived from the weathering of the subjacent limestone. Water containing carbon-dioxide has dissolved away the calcium-carbonate and left behind the insoluble quartz and glauconite, the glauconite gradually losing its green colour as it decomposes to form ferric oxide. That these brown sandstones have been derived from the weathering of the limestone is certain, for it is not uncommon to find patches of green sand still undecomposed in their midst, and the latter are undoubtedly formed from the limestone. They are afterwards, I believe, cemented together by iron-oxide, derived partly from the weathering of the glauconite, partly perhaps from ferruginous percolating waters. The percolating waters of this district do contain iron, as is shown by the occurrence of at least two ferruginous springs flowing from beneath the basalt cap.

5. The grains of the sandstone are identical in character with those of the top band of limestone at Millburn quarry. On dissolving away the calcium-carbonate of the limestone in cold dilute HCl, and on examining the residue, the quartz-grains of both limestone and sandstone are seen to be similar—the same shape, the same size, the same colour. Glauconite-grains occur in both. The sandstone contains much more limonite than the limestone, but that is to be expected on the supposition of its subsequent cementation with iron-oxide.

6. The brown sandstone often contains a small amount of lime-phosphate; often, too, as at the Millburn Company's phosphate-workings, grains of sand are cemented together by lime-phosphate to form a poor-grade rock-phosphate (25·87 per cent.). Let us assume that the sandstone is a Lower Tertiary deposit, and this fact will lead us into difficulties. It is not probable that the sandstone would originally be phosphatic, for it contains no fossils; and a sedimentary rock, if phosphatic, has derived its phosphate of lime from the numerous animals which inhabited its seas. The limestone contained many fossils, and also a small amount of phosphate, disseminated through it, as has been shown above. The basalt, which lay on top of everything else, contained no phosphate. The sandstone then, containing no phosphate, lay then above the limestone, which alone could supply it. To-day we find that the sandstone does contain phosphate. How did it acquire it? The percolation of water has been downward, and away from the sandstone; there has been no upward percolation of water, nor has there been any other means of transferring the calcium-phosphate: and yet the sandstone has received a certain amount from the limestone. The extreme difficulty of accounting for this fact suggests that, after all, perhaps the sandstone did not originally lie above the limestone.

There is no exposure of rocks in the district which shows the contact of sandstone with either basalt or limestone—a contact which would probably throw great light on the question as to whether the sandstone is an original or a secondary formation. But the reasons given above make me of the opinion that it would probably support my view if it did exist.

ROCK-PHOSPHATE.

Character.—The rock-phosphate is an amorphous nodular deposit, found either in pockets on the upper surface of the limestone, or, where the latter is absent, on top of the underlying glauconite sands. When the limestone is present we always find the masses of rock-phosphate separated from it by thin layers of clay, while thin bands of phosphatic clay are abundant among the hard nodules. The weight of these nodules varies from 1 lb. or 2 lb. up to several tons.

The physical and chemical properties of the rock-phosphate vary greatly: its colour varies from white to dark-yellow; its hardness from 1 to 8; its specific gravity from 2·068 to 2·988; its percentage of contained tribasic calcium-phosphate from 20 (and even lower) to 80 per cent. A detailed description of several varieties will render this more evident:—

a. (H = 6·5, SG = 2·915).—To the eye this variety suggests the appearance of marble; it is white, hard, of dull lustre, and contains grains of quartz and glauconite; it is a rich variety, containing from 65 to 80 per cent. calcium-phosphate—$Ca_3(PO_4)_2$.

b. (H = 8, SG = 2·988).—This is yellow, finely grained, and flint-like; it breaks with a conchoidal fracture, has an enamel-like lustre, and often a banded character; it is high-grade, containing from 70 to 75 per cent. $Ca_3(PO_4)_2$.

c. (H = 5·5, SG = 2·910).—A yellow variety like *b*, but coarser-grained, not flint-like, and never with a banded appearance; it also is of good quality.

d. (H = 6, SG = 2·816).—This is the very siliceous "grit phosphate," which is in fact a sandstone cemented together by lime-phosphate; it often contains enclosed nodules of the *b* variety, and in places is found incrusted with hyalite, a form of opal; it is poor in phosphate, containing only from 20 to 30 per cent. $Ca_3(PO_4)_2$.

e. (H = 1, SG = 2·446).—This is a pure-white, chalky, unctuous variety, rich in phosphate, of which it contains about 75 per cent.

f. (H=1, SG=2·068).—This variety can scarcely be termed rock-phosphate, as it is only a finely laminated phosphatic clay which has hardened to a slight extent, and now occurs in irregular seams among the masses of hard rock-phosphate.

The first four are the most common; when they are "burnt" the iron which they contain is converted to ferric oxide, which gives them a pink or reddish colour. Under the microscope the yellow varieties are seen to have no trace of crystalline structure; they are almost opaque in thin sections, a dull-brown colour being transmitted only in the very thinnest places; quartz and glauconite grains occur throughout.

Analyses.—The following table of analyses will show the chemical composition of these phosphates:—

—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
Gangue	9·51	2·80	9·2	7·3	16·0	21 0	6 8	4·5	11·9	2·1	1 5	32·1	1·48	3 90	60·12
Alumina	8·06	6·49	4·2	3·4	5·0	4·1	4·0	2·5	4·9	1·4	2·6	8·0	5·30	6·20	5·79
Iron-oxide														3·28	3·41
Magnesia	0·40	0·85	..	..	..	..	..	..	0·9	..	..	..	0·50	0·65	..
Lime	40·82	46·48	47·7	48·3	42 6	39 9	44·6	49 0	44·4	..	..	..	48 25	45·10	15·61
Alkalis	0·70	0·90	..	..	..	..	..	..	0·7	..	..	..	..	..	..
Combined water ..	1·01	0·02	3·1	3·8	3·4	..	2 5	..	1·7	..	..	..	..	..	..
Moisture	3·81	1·30				1 6	3·5	..	1·1	..	..	..	4·60	2·25	1·15
*Phosphoric acid ..	30·89	35·05	32·1	32·9	30·0	29 0	31·4	32·6	30·2	36·7	34·4	18·0	35·38	33·65	11·39
Carbonic acid ..	3·78	4·80	2·7	3·0	3 0	4·4	3·9	..	2·9	..	..	..	3 20	4·29	3·72
Sulphuric acid ..	0·30	0·34	..	..	..	..	..	..	Trace	..	..	..	†	‡	..
	99·28	99·21	99·0	98·7	100·0	100·0	96·7	88·6	98·7	..	..	..	98·91	99·32	101·19
*Equivalent of $Ca_3(PO_4)_2$	67·44	76·52	69·9	71·6	65·3	63·3	68·7	71·2	65·9	80·2	75·1	39·3	76·59	73·44	25·87

†13 contains trace of chlorine. ‡ 14 contains traces of chlorine and fluorine.

The analysts for the above were: 1 and 2, Millburn Lime and Cement Company; 3, 4, 5, and 6, Professor J. G. Black, Otago University; 7, J. S. Maclaurin, D.Sc., F.G.S., Wellington, New Zealand; 8, W. Mills, Bramford, North Ipswich; 9, J. A. Pond, Auckland, New Zealand; 10, 11, and 12, O. Grothe, Ph.D., Ocaha, Florida, U.S.A.; 13, author, chalky variety (*e*); 14, author, yellow variety (*c*); 15, author, grit variety (*d*).

Iron and Alumina.—The large amount of iron and alumina in this phosphate will probably constitute an objection to it in the eyes of the agriculturist. Alumina, when present in a phosphate, is combined with part of the phosphoric acid, the latter being thus rendered unavailable for assimilation by plants, and for conversion into superphosphate of lime; this happens at Yorke's Peninsula, South Australia,* and in the Lower Greensand, England†: iron has an effect similar to that of alumina. Moreover, the superphosphate produced when iron and alumina are present is usually sticky and claggy.‡ The Clarendon phosphate contains a larger amount of these objectionable iron and aluminum oxides than do those of most other countries, as will be seen from the following table. It is with these foreign phosphates that the New Zealand phosphate must compete, if it is to be exported to any extent.

Locality.	Iron and Alumina			Authority.
	Maximum Percentage	Minimum Percentage.	Mean	
Belgium ..	1·20	0·90	..	Penrose, U.S. Geol. Surv. Bull. 46, p. 106.
North France ..	..	..	3·20	Ditto, p. 41.
Russia ..	3·47	0·32	..	„ p. 46.
South Carolina ..	6·00	1·00	..	„ p. 70.
North Carolina ..	..	..	0·56	„ p. 72.
Ocean Island ..	..	..	0·46	Danvers Power, "Mineral Industry," vol. x, p. 523.
Pleasant Island	..	..	0·51	Ditto, p. 523.
South Australia	6·26	1·00	..	Brown, Rep. Geol. Surv. S. Aus., 3/2/1902 and 2/7/1902.
North Wales ..	8·86	6·89	..	Penrose, U.S. Geol. Surv. Bull. 46, p. 83.
Upper Greensand (Eng.)	12·11	4·61	..	Ditto, pp. 97, 91.
Lower Greensand	8·82	3·35	..	„ p. 101.
Clarendon ..	9·58	1·40	5·24	

Excess of Lime.—There is another feature of the chemical composition of these phosphates which, possessing a certain theoretical interest, may be noted here. F. Danvers Power,§ in his report on the Ocean and Pleasant Island phosphates, says, "As is always the case, there is an excess of lime (CaO) over the acids present that are capable of combining with it; supposedly, this excess is an organic combination." Whatever

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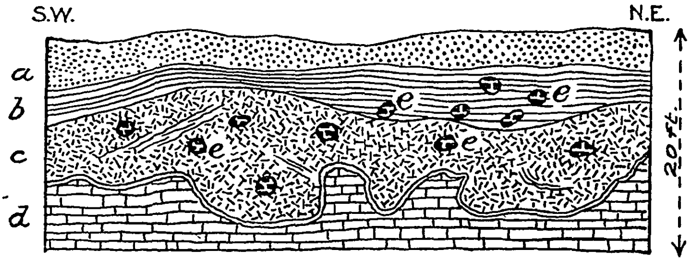
* Brown, Rep. Govt. Geologist South Australia, 3rd February, 1902.
† Penrose, U.S. Geol. Survey Bull. 46, p. 102.
‡ Penrose, U.S. Geol. Survey Bull. 46, p. 83.
§ Danvers Power, "Mineral Industry for 1901," vol. x, p. 533.

the cause of the phenomenon, it is interesting to note that the Clarendon phosphate is similar in this respect to the deposits of Ocean and Pleasant Islands. After making corrections for other bases in the phosphate it is found that the CaO present is always greater than the CaO which would be required to neutralise the acids in the phosphate, thus: Ocean Island, the excess is 6·8 per cent.; Pleasant Island, the excess is 6·8 per cent.; Clarendon No. 1, the excess is 2·4 per cent.; Clarendon No. 2, the excess is 6·1 per cent.; Clarendon No. 13, the excess is 7·8 per cent.; Clarendon No. 14, the excess is 9·4 per cent.

OUTCROPS IN THE DISTRICT.

1. *Williamson's Farm.*—The outcrop has not yet been located, but surface boulders and pebbles are abundant in the fields below the road-line at some distance above Williamson's.

2. *Kiln Point.*—At this, the first outcrop worked, the phosphate rests on the irregular surface of the limestone, the face exposed being about 12 ft. high. The rock is mainly the high-grade white variety, but it is mixed with brown sands and phosphatic green sands and clays, which diminish the average content of calcium-phosphate to such an extent that this outcrop has now been abandoned in favour of the Round Hill quarry Rock-phosphate is exposed in a trench to the north of the point, where it consists chiefly of the grit variety, mixed with phosphatic clays; mammillary incrustations and cavities lined with phosphorite are common in the trench.



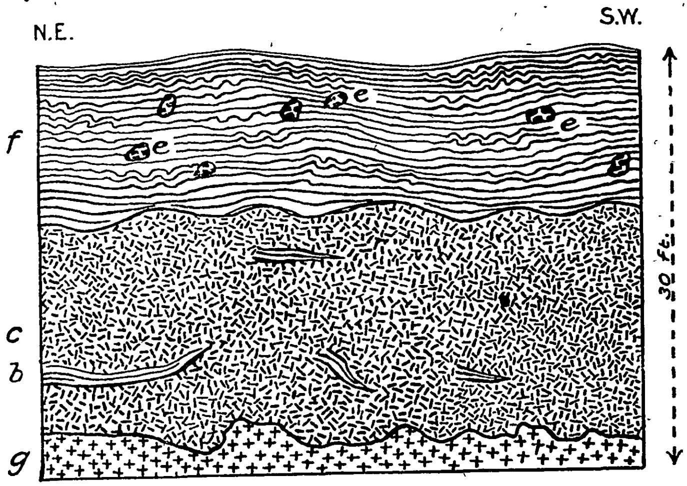
FACE OF QUARRY AT KILN POINT.

a. Brown sands. *b.* Green phosphatic sands. *c.* Rock-phosphate. *d.* Limestone. *e.* Basalt-fragments.

A special feature of this outcrop is the presence of fragments of basalt, from 0·5 in. to 4·5 in. in diameter, which are imbedded in the middle of the rock-phosphate. They have the same characters as the basalt which is found a few yards farther up the hill, and have probably slipped down from there. They show clearly that the formation of the rock-phosphate was subsequent to the pouring-out of the basaltic lava which now caps the hills. They indicate, moreover, that the formation was some considerable time after that—in fact, not until the surface features of the district had assumed practically their present form—for not until a hill was formed would basalt-fragments be able to slip down that hill and mingle with limestone and sands lying at a lower level.

3. *Horseshoe Bush.*—Close to the Horseshoe Bush two small outcrops have been exposed, but only a few tons of phosphate have been mined.

4. *Discovery Point.*—It was at this point, opposite the present workings of Round Hill quarry, that the original discovery of the rock-phosphate was made. The phosphate here rests on top of the glauconitic limestone; it has not been mined to any extent.

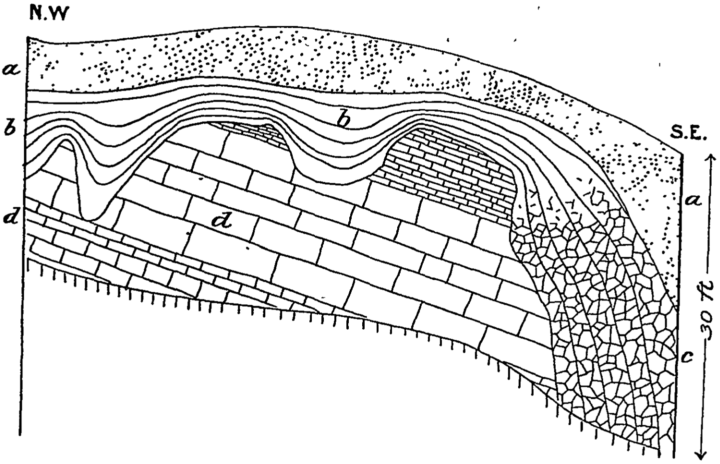


FACE OF QUARRY AT ROUND HILL.

b. Green phosphatic sands. *c.* Rock-phosphate. *e.* Basalt-fragments. *f.* Overburden (clay). *g.* Glauconite sands.

5. *Round Hill Quarry.*—This is now the scene of greatest activity in the district. During 1902 (*i.e.*, during the seven months following the discovery) between 2,000 and 3,000 tons of phosphate were mined from the Kiln Point and Round Hill

quarries,* chiefly from the latter; since then operations have been restricted to the Round Hill workings, but I am unable to quote the amount extracted. The phosphate lies here directly on top of the glauconite sands, the limestone being entirely absent. At the base of the deposit there is a mass of yellow nodules, usually separated from each other by phosphatic green-sands; above this comes an irregularly undulating band of soft clayey phosphate, often containing glauconite; above this again come hard yellow nodules. Irregular small lumps of sandstone often occur amid the phosphate, and large masses of white phosphate, more massive than the yellow nodules, are frequent; incrustations of phosphorite are occasionally found. The workmen often find bones and teeth in the clays and sands among the phosphate; never yet, to my knowledge, have they found any such organic fragment in the centre of the hard rock-phosphate, so that a concretionary origin round an organic nucleus cannot be assigned to it. The bones which are found are in a very decomposed and broken state, and will rarely bear handling; they belong to species of an extinct Cetacean family comprising *Squalodon* and *Zeuglodon*; the teeth are those of sharks, and are also much broken up. Teeth of *Carcharodon auriculatus* and of species of a *Lamna* were recognised from this quarry.



FACE AT WILSON'S QUARRY.
a. Brown sands. *b.* Green phosphatic sands. *c.* Rock-phosphate. *d.* Limestone.

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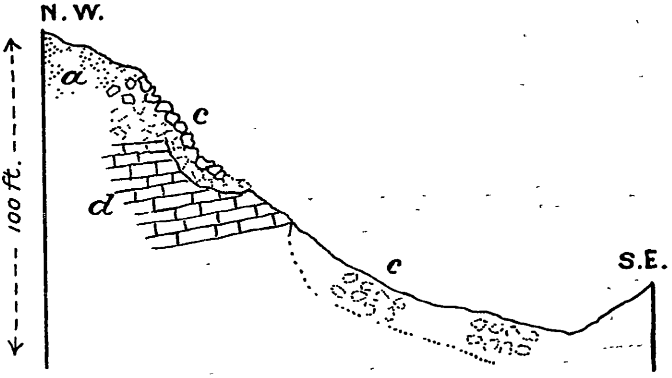
* New Zealand Mines Report for 1902, p. 24.

6. *Wilson's Quarry.*—The phosphate is here very low-grade, and is not worked. It consists of a phosphatic clay, in places 35 ft. high, which contains about 20 per cent. $Ca_3(PO_4)_2$. Desiccation has caused the clay to crack irregularly, and many of the fissures are now being filled up with white incrustations of phosphorite. The deposit rests on the irregular surface of the limestone, and is accompanied by phosphatic greensands.

7. *Kapiti Quarry.*—Phosphate is found here; it is not worked, and its mode of occurrence is not clear.

8. *Strain's Farm.*—Phosphate is reported from here, but was not seen by me.

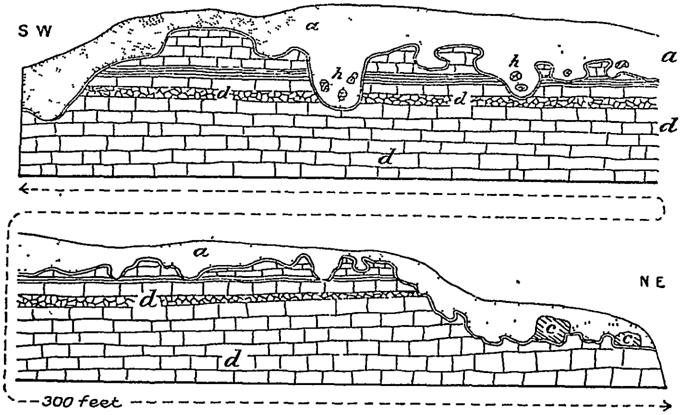
9. *Macdonald's Outcrop.*—Some few tons of phosphate have been mined from here; it rests on the glauconite sands, and a face about 50 ft. long and 10 ft. high has been cleared.



MILLBURN PHOSPHATE-WORKINGS: Section right-angles to face.
a. Brown sands. *c.* Rock-phosphate. *d.* Limestone.

10. *Millburn Company's Phosphate-workings.*—A considerable amount of work has been done here. A great deal of the phosphate is of the grit variety, but the other forms are also found; incrustations of phosphorite are common. The deposit rests on the irregular surface of the limestone; bones and teeth are found in it, among the former being the lower jaw of a Balænid whale. A large surface-slip has taken place, resulting in masses of phosphate sliding down the hillside to a level 50 ft. below: these masses are easily mined, and have been worked to a considerable extent.

11. *Millburn Lime Quarry.*—Two boulders of phosphate occur here, resting on the irregular surface of the limestone. On the spur across the gully, north-west from the quarry, there is a prominent outcrop of phosphate, which so far has not been worked.



Face at Millburn Lime Quarry.

a. Brown sands. *c.* Rock-phosphate. *d.* Limestone. *h.* Phosphatic clay nodules.

12. *Campbell's.*—Opposite Sutherland's quarry, on the north bank of a small creek, there is a massive outcrop of rock-phosphate, 20 ft. high, resting on the limestone; it has not yet been worked.

13. *Quill's.*—A few tons of phosphate have been taken from here, but apparently there is not much of it.

14. *J. Gray's.*—This has been worked to a slight extent, but the phosphate, which here rests on glauconite sands, is low-grade, patchy, and composed mostly of grit phosphate and clays.

Origin of the Rock-phosphates.

Several theories have offered themselves as explaining the origin of these deposits: they may be summed up as follows:—

(1.) That the boulders were transported to their present position from a distance, by an agency such as running water.

(2.) That they were formed *in situ*, as the result of concretionary action around some nucleus.

(3.) That they were formed *in situ* by deposition of phosphoric acid (P_2O_5) from ascending waters.

(4.) That they were formed *in situ* by deposition of P_2O_5 from descending waters which derived their P_2O_5 from the basalt.

(5.) That they were formed *in situ* by deposition of P_2O_5 from percolating waters which derived their P_2O_5 from the limestone.

(6.) That they were formed *in situ* by the concentration of the phosphatic contents of the limestone—a process due to ordinary weathering and the action of meteoric waters.

(7.) That they were formed by the combined action of the methods outlined in the last two theories. This combination theory is the one I see most reason to support.

1. *Transportation Theory.*—This is extremely improbable. The phosphate boulders are separated from the limestone and from each other by bands of phosphatic clay and by layers of sand. Running water would most probably have been the agency by which the boulders were transported, if they were transported at all. It is scarcely possible that a violent stream capable of moving a boulder of 2 or 3 tons weight would deposit that boulder on a thin stratum of clay or sand. Much more likely is it that the stream would sweep away clay and sand and deposit the boulders on the bare surface of the limestone. I have not observed a single instance of this direct contact of limestone and rock-phosphate; I have always found a layer of clay or sand between the two. Moreover, the presence of basalt-fragments imbedded in the phosphate at Kiln Point is sufficient to disprove the theory, for it shows that the rock-phosphate was formed after, and probably a long time after, the extrusion of the basalt.

2. *Concretionary Theory.*—It is not at all probable that the rock-phosphate was formed by concretionary action around some nucleus, in a manner analogous to the coprolites of the Upper and Lower Greensands of England. None of the Clarendon nodules have been found to contain organic nuclei, and the sharks' teeth and other organic fragments at Round Hill, &c., always lie on the clays, and not imbedded in the hard nodules.

3. *Ascension Theory.*—The occurrence of phosphorite and perhaps staffelite as stalactites and as incrustations on the walls of cavities suggests that an aqueous solution of phosphoric acid must have played, and must still be playing, some part in the formation of the phosphate. Could this solution have risen from below? No, it could not, for in many places the phosphate rests on the surface of unaltered limestone; had the solution risen from below it would first have acted on the lower layers of limestone, converting the calcium-carbonate to

calcium-phosphate, and the process would then have extended itself upwards. As we find the phosphate above and the carbonate below, it is tolerably certain that the process is extending itself downward, and is due to descending solutions.

4. *Basalt Theory.*—That the deposits were formed *in situ* by the deposition of P_2O_5 from descending waters which derived their P_2O_5 from the basalt. I do not think it possible that the overlying basalt could have supplied the P_2O_5 necessary. No phosphorus-bearing mineral was detected in the microscopic examination, and micro-chemical tests likewise failed to reveal the presence of any such mineral.

5. *Limestone Theory.*—That the deposits were formed by the deposition of P_2O_5 from percolating waters which derived their P_2O_5 from the limestone. It is certain that the phosphoric acid was derived from the limestone. We have seen that organic remains rich in phosphorus are found in the latter, and that, moreover, a small amount of phosphate is distributed throughout its mass. I think that a deposition from waters is in part responsible for the formation of the phosphate, but that it is subordinate and subsequent to a concentrating action.

6. *Concentration Theory.*—That the deposits were formed by the concentration of the phosphatic contents of the limestone, by the weathering action of waters containing carbonic and perhaps other organic acids, which dissolved out the calcium-carbonate of the limestone, but left behind the much less soluble calcium-phosphate.

7. *Combination Theory.*—That the process just outlined was followed by the deposition of P_2O_5 from percolating waters which had leached out their P_2O_5 from the limestone. The mode of weathering of the limestone at the Millburn quarry lends a great amount of support to this view. The surface of the limestone is carved out into a number of deep "guts," leaving lofty pinnacles and overhanging shelves of limestone—an appearance which at first suggests a striking unconformity with the brown sands which fill the depressions. The sculpturing, however, is almost wholly if not entirely due to chemical erosion.

On the outer parts of the pinnacles, where exposed to wind and rain, the limestone has in many places weathered to a crumbly brownish sandstone, containing comparatively a small percentage of $CaCO_3$. Along the laminæ the weathering has progressed more quickly. Isolated "floaters" of limestone are found in the middle of the brown sands; they are blocks of limestone which have offered great resistance to the weathering process, and are now entirely surrounded by clays and sands, in the midst of which, still horizontal, they seem to float. A sample was taken from the interior of one of these floaters, where it was least weathered; it was partially analysed, as also was a sample of absolutely fresh limestone of the same band (H). The analyses gave:—

	Fresh Limestone.	"Floater."
Gangue (mostly quartz) ..	5·50	27·09
*Phosphoric acid	0·15	0·22
Not determined	94·35	72·69
	100·00	100·00
*Equivalent of $Ca_3(PO_4)_2$ ..	0·33	0·48

These analyses prove, then, (1) that the limestone H contains when fresh a small amount of phosphoric acid disseminated through its mass; (2) that the ordinary process of weathering, which carries away the calcium-carbonate in solution, does not carry away the calcium-phosphate to an equal extent, so that the latter tends to concentrate in the residue.

The "Gut" at Millburn.—Brown and green sands and clays fill the hollow between two pinnacles, and protect the limestone surface from the atmosphere, but not from percolating waters. In the deepest central "gut" the limestone is found to have a thin veneer, about 0·75 in. thick, of a pulverulent weathered limestone (C_1). Outside this veneer comes 6 in. of a green glauconitic and phosphatic sand (C_2), the whole of this layer being laminated with fine streaks of not yet completely weathered limestone, arranged rudely parallel to the present limestone surface. Outside C_2 is found a varying thickness of yellow-green very sandy clays (C_3), laminated parallel to the surface of the limestone, the laminæ being from 0·06 in. to 0·25 in. apart, and composed of alternating green and yellow bands. These clays line the limestone wherever the latter is protected from the atmosphere—on pinnacles, in hollows, and on the under-side of projecting ledges alike. A tough yellow richly phosphatic clay (C_4) is found in the midst of the yellow-green clays; it is sometimes in bands, more often in irregular patches and nodules.

The following analyses will show the manner in which the concentrating action has taken place. The limestone has been deprived of its $CaCO_3$; the quartz, glauconite, and to a great extent the lime-phosphate, being insoluble, have been left behind and concentrated to form C_1 and then C_2. Then the C_2 has been separated into two parts, the lime-phosphate tending to segregate into the clayey nodules C_4, surrounded by yellow-green clayey sand C_3. This differential action is due to water, which has acted by dissolving and then reprecipitating some of the lime-phosphate.

—	Veneer on the Limestone. C_1.	Glauconite Sands C_2.	Yellow-green Clayey Sand. C_3.	Tough Yellow Segregations. C_4.
Silica ..	9·24	59·08	74·15	44·92
Fe_2O_3 and Al_2O_3	3·00	18·05	15·10	21·72
CaO ..	44·29	6·72	2·28	12·09
H_2O ..	14·80	10·20	7·70	13·50
*P_2O_5 ..	0·77	5·65	1·22	7·75
CO_2 ..	29·74	..	..	..
	101·84	100·16	100·45	99·98
*Equivalent of $Ca_3(PO_4)_2$	1·68	12·32	2·66	16·90

The above analyses show that a concentration has taken place. If we change their form slightly they show us also that the calcium-phosphate is not absolutely insoluble, and that even in the process of concentration some of it has been carried away in solution. In the concentration and solution it is safe to assume that the silica (SiO_2) is not carried away nor affected by any chemical action. We are thus enabled to recalculate the analyses on the basis of constant SiO_2 : *e.g.*, if a body (x) contains 1 part per 100 of an unchangeable substance (m), and a quantity of it is partly dissolved away, resulting in a product (y) which contains 5 parts per 100 of m, then it is clear that the product y results from 5 times its weight of the original x. On recalculating thus from the analyses we find that 186 parts of C_1 have weathered to 29 parts of C_2, which have differentiated into 14 parts C_3 and 15 parts C_4. The following table gives the amounts of the constituents of each of these products :—

—	186 Parts C_1 ontaining	change to 29 Parts C_2 containing	which split into 14 Parts C_3 containing	and 15 Parts C_4 containing	the total of C_3 and C_4 containing
SiO_2 ..	17·11	17·11	10·37	6·74	17·11
Al_2O_3 and Fe_2O_3	5·60	5·36	2·10	3·25	5·35
CaO ..	82·48	2·03	0·28	1·81	2·09
P_2O_5 ..	1·45	1·72	0·17	1·16	1·33
CO_2 ..	55·10	..	..	..	..
H_2O ..	24·26	2·78	1·08	2·04	3·12
	186·00	29·00	14·00	15·00	29·00

The C_1 column does not tally exactly with the results from the other columns, and this is probably due to errors in the chemical analysis. It must be remembered also that any errors that do occur in the analysis are almost doubled in the case of C_1, while they are diminished in the case of the others, roughly in the proportion of 3 to 1 and 6 to 1 respectively. Noticing the other columns only, we see that the iron and alumina, like the silica, are not removed by the weathering process, 5·35 resulting from 5·36. The amount of moisture (H_2O) is of no importance in this inquiry, though apparently it also does not change much. P_2O_5, however, has been abstracted, 1·33 resulting from 1·72. This difference is too great to be merely due to error in analysis. It is clear, then, that phosphoric acid has been dissolved out from the clays; it joins the downward circulation, and is redeposited where conditions are favourable.

Stages of Process.—The amount of action that has taken place in this gut at Millburn is small, but the full sequence of operations is clearly seen. At Wilson's quarry the process is more advanced, and has resulted in the formation of a large quantity of phosphatic clays, which are now being cemented together by the redeposition of the phosphoric acid as lime-phosphate in the cracks which traverse the clay. The process has reached its final stage at the Round Hill quarry, where all the calcium-carbonate of the limestone has been dissolved away, its place being now occupied by a mass of rock-phosphate. The final stage has likewise been reached on the right-hand side of the limestone quarry at Millburn, where now two boulders of hard rock-phosphate, in the middle of the brown sands, rest on the chemically eroded surface of the limestone.

Objections.—The objections which may be advanced against this theory are, I think, the following:—

1. That the process outlined cannot account for large quantities of rock-phosphate such as are found at Round Hill. To explain such a large occurrence it is only necessary to suppose that the original limestone at that point contained a very great number of organic remains, such as bones, &c., and this supposition is upheld by the occurrence of numerous bone-fragments among the phosphate at Round Hill.

2. That the rock-phosphate ought to be always accompanied by brown sands or sandstone. As a matter of fact it usually is, though it is not necessary that it should be so; the original limestone now eroded away may at one place have been rich in phosphate, poor in silica: this would produce a rock-phosphate with very little sandstone about. Conversely, the original limestone at another place may have been rich in silica, poor in or destitute

of phosphate: this would produce a sandstone with no rock-phosphate in its neighbourhood.

Conclusions.—My conclusion, then, is that the rock-phosphate has been formed by the action of meteoric waters slowly weathering away a limestone containing a small amount of lime-phosphate, leaving most of the latter behind, but dissolving some and reprecipitating it where conditions were favourable. Where the limestone originally contained a large amount of lime-phosphate, owing to abundance of vertebrate remains, there the rock-phosphate will be found in greatest abundance. Where the limestone originally contained practically no phosphate, there its weathering will give rise to no deposits of rock-phosphate. The limestone owes its contained lime-phosphate to the presence of organic remains, especially those of vertebrate animals; the distribution of these is of an irregular nature; the weathering of such a limestone ought to give rise to irregularly distributed deposits of rock-phosphate: this is what we find.

Professor Park,* in his account of the Clarendon phosphates, does not hazard any opinion as to how these particular deposits originated. He says, "The formation of phosphate-deposits is generally believed to have been due to the leaching or lixiviation of phosphate-bearing rocks by waters containing carbonic and other organic acids, followed by the subsequent concentration of the phosphate under favourable conditions. In some cases they deposited their calcium-phosphate in caverns formed in limestone or calcareous sandstone, and the subsequent removal by solution of the walls of the caverns, either wholly or partially, left the phosphate in the remaining sands."

Similar Theories Abroad.—The theory advanced above resembles the theories which have been advanced to explain the origin of other deposits of lime-phosphate. Accounting for the phosphatic beds near Mons, Belgium, F. L. Cornet† says, "These phosphates have been formed from the concentration of phosphatic matter, originally disseminated in the lime-carbonate, the concentration having been effected by the action of water containing carbonic acid."

C. W. Hayes,‡ accounting for the white phosphate of Tennessee, sums up thus: "The original lime-phosphate . . . accumulated with other sediments, either segregated in beds or disseminated through limestones and shales. . . These were attacked by percolating surface waters which contained carbonic and other organic acids, and which dissolved the $CaCO_3$,

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* Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 400.

† Cornet, Quart. Journ. Geol. Soc., vol. xlii (1886), p. 337.

‡ Hayes, U.S. Geol. Surv., 17th Ann. Rep., part ii, p. 547; 21st Ann. Rep., part iii, p. 479.

and in less quantity the $Ca_3(PO_4)_2$. The carbonate was carried away; the phosphate was redeposited, the form of the deposits being modified by local conditions."

Comparison with Other Deposits.—The phosphates of South Carolina[*] consist of waterworn nodules, much bored by marine animals; phosphatic casts of the interior of shells are abundant. The North Carolina phosphates[†] are in part like the South Carolina deposits, but there is also a phosphatic conglomerate with teeth, bones, nodules, and quartz pebbles all well rolled and rounded and cemented together. The Alabama deposits[‡] are, like those of South Carolina, composed of shells, phosphatic nodules, shell-casts, and fossils, all much worn and broken, usually flat in form, and more phosphatized on one side than the other. The nodular depositis of Florida[§] rest on the uneven surface of a calcareous rock, being associated with shells and sands. At one of the quarries the soft calcareous rock gradually blends at a depth of 3 ft. or 4 ft. into a massive compact phosphate rock, similar in appearance to the phosphatic fragments above, except that it is a solid mass; it is probably the ledge whence the fragments were derived, the phosphatic pebbles and the sand being due to deposition on the eroded surface of the calcareous rock. Carnot,[||] however, holds a different opinion of these Florida deposits. He considers them of concretionary origin; he emphasizes the high percentage of CaF_2, and argues that the concretionary action is due to the concentrating action of salt water. The phosphates of the West Indies, at Aruba and Sombrero,[¶] and also those of Ocean and Pleasant Islands,[**] were originally coral limestones, now converted into phosphate by the percolation of waters containing phosphoric acid derived from the overlying deposits of bird-guano. The deposits of Ottawa (Canada),[††] and of many other localities, occur as veins of apatite in very old igneous rocks, mostly of Archæan age. The phosphates of Wales[‡‡] consist of apatite veins and of amorphous nodular deposits; the latter contain numerous remains of animal life, and are due to the phosphatization of a calcareous bed. In England[§§] the de-

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[*] Penrose, U.S. Geol. Surv. Bull. 46, p. 61.

[†] *Ibid*, p. 70.

[‡] *Ibid*, p. 75.

[§] *Ibid*, p. 78.

[||] Carnot, "Annales des Mines" (1896), vol. x, p. 228.

[¶] Park, Trans. N.Z Inst. (1902), vol. xxxv, p. 401.

[**] Danvers Power, "Mineral Industry for 1901," vol. x, p. 533.

[††] Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 400.

[‡‡] Penrose, U.S. Geol. Surv. Bull. 46. p. 80.

[§§] Sollas, Quart. Journ. Geol. Soc. (1872), vol. xxviii, pp. 397–400; Fisher, Quart. Journ. Geol. Soc. (1873), vol. xxix, p. 55.

posits consist almost entirely of nodules which are composed of phosphatized animal matter, while those in the neighbourhood of Taplow and Lewes* are phosphatic chalks of sedimentary origin. Those of the Somme in France† are also chalk-deposits, the phosphate being "a sedimentary chalk derived from the disintegration of a vast granitic phosphatic continent." Near Mons, in Belgium,‡ the phosphate-deposits are also with Cretaceous chalk. They consist of a coarse-grained rock formed of a mixture of grains of calcite and small-sized pebbles of phosphate; they are due to a concentration by water of a limestone originally containing a small amount of lime-phosphate. In Algeria and Tunis§ the phosphates occur in nodules in marl or as phosphatic limestone.

Though not precisely similar to any other known deposit, the Clarendon-Millburn phosphate bears greatest resemblance to those of Florida, U.S.A. The local phosphate, however, contains only a trace of fluorine, and has no shell-traces; the calcareous rock does not become highly phosphatic in depth; and the mode of origin is different from either of the two theories advanced to explain the Florida deposits. In all these points it differs from the Florida phosphate, so that, after all, the similarity is not so very marked.

Mining and Treatment.—At Round Hill quarry the phosphate is blasted out with gelignite, the holes for the charges being very difficult to bore, on account of the hard nature of the rock. Very little hand-sorting takes place in the quarry, the rock being immediately loaded into trucks or "boxes" and drawn to the burning-ground, where it is built up with broadleaf timber into large piles. The burning extends throughout several days, and deprives the rock of its moisture, thus rendering it brittle so that it can be more easily pulverised, and also effecting a small saving in the cost of its railway carriage to Burnside, a few miles south of Dunedin, where some of it is treated with a spray of dilute sulphuric acid to partly convert it into superphosphate of lime. This chemically treated phosphate commands a higher price than the phosphate which has not been so treated. The former is more rapid in its effect on the crops, as the superphosphate is at once ready for assimilation by plants, while the phosphate in the crude, unsprayed rock has

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* Teall, Proc. Geol. Assoc., vol. xvi, p. 369.

† Henri Laone, "Sur l'Origine des Phosphates de Chaux de la Somme" (1903).

‡ Penrose, U.S. Geol. Surv Bull. 46, p. 105. Cornet, Quart. Journ. Geol. Soc. (1886), vol. xlii, p. 325.

§ Park, Trans. N.Z. Inst. (1902), vol. xxxv, p. 400.

to be slowly converted by the action of humic and other acids before it is available for absorption.

Prospects of the Industry.—The amount of rock-phosphate occurring in the district cannot be accurately estimated at present. As the original phosphate to which it owes its origin was probably irregular in its distribution, so we must expect our deposits of rock-phosphate to be irregularly distributed along the outcrop of limestone. The question whether the phosphate will occur between the already located outcrops cannot at present receive a satisfactory answer; in some places it will, in others it will not; the position of these respective places can only be determined by further prospecting. From its origin it follows that the phosphate will not extend inwards under the protecting basalt cap; and for this reason also it follows that there is a greater chance of its occurring in quantity under a gently sloping surface than under a steep one, for in the former case a much greater width of limestone has been exposed and subjected to the actions which lead to the formation of the phosphate. Until prospecting affords more information about the extension of the outcrops it would be useless to attempt an estimate of the quantity in sight.

The sale of the phosphate will, in my opinion, be confined to New Zealand. To compete in foreign markets, high-grade rock-phosphate must contain at least 77 per cent. of calcium-phosphate—$Ca_3(PO_4)_2$—and its amount of alumina and iron must be low. A reference to the list of analyses in this paper will show that it will be difficult to guarantee that any large quantity of the phosphate fulfils these requirements. Other countries, moreover, owing to their more favourable geographical position, are better enabled to command the foreign markets. In New Zealand the phosphate will have to compete against the imported guanos, and against agricultural limes produced by the burning of limestone; against these it is capable of holding its own, and of making progress.

Other districts in New Zealand may also contain unrecognised deposits of phosphate of lime. The discovery at Clarendon was followed by the discovery of a smaller deposit at Enfield, near Oamaru, but we have not heard much about this. Limestone occurs in quantity throughout New Zealand, chiefly in the South Island; and its surface, especially where eroded to any great extent, should be carefully examined for rock-phosphate. The phosphate had been overlooked at Clarendon for many years, and it may still be overlooked in some other locality. It is easily mistaken for limestone, flint, &c., according to the variety met with. It would be well worth while to submit to qualitative chemical analysis any peculiar-looking rock-fragment found in the neighbourhood of limestone or of glauconitic sands.

In conclusion, I should like to express my gratitude to Mr. R. Ewing, of the Clarendon Phosphate Company, and to Mr. F. Oakden, of the Millburn Lime and Cement Company, for their kindness in allowing me to make use of several of their analyses of rock-phosphate, and for their unvarying courtesy during the examination of the deposits. To Professor Park for his lucid and instructive report, to Dr. Marshall, Dr. Benham, Mr. A. Hamilton, and Mr. D. B. Waters for their valuable advice and assistance during the preparation of this paper, my warmest thanks are due.

EXPLANATION OF PLATES IV–VIII.

Plate IV.

Fig. 1. *Squalodon grateloupi* (?): *a*, premolar, showing enamel; *b*, crown of worn molar; *c*, section of *b* close to top of crown; *d*, section of *b* nearer the fangs; *e* and *f*, molars.
Fig. 2. Balænoid whale, dentory: *a*, view from above; *b*, view along jaw.
Fig. 3. *Magellania marshalli*: *a*, both valves; *b*, side view.

Plates V–VII.

Fig. 1. Glauconitic limestone (B).
Fig. 2. Glauconitic limestone.
Fig. 3. Basalt, Stony Knob, crossed nicols; × 80 dias.
Fig. 4. Basalt, Williamson's, crossed nicols; × 80 dias.
Fig. 5. Basalt, Cemetery Hill, crossed nicols; × 80 dias.
Fig. 6. Sandstone; × 80 dias.

Plate VIII.

Geological map of Clarendon-Millburn district, with ideal section.

Art. LIII.—*The Gem Gravels of Kakanui; with Remarks on the Geology of the District.*

By J. Allan Thomson, B.Sc., Rhodes Scholar.

Communicated by Geo. M. Thomson.

[*Read before the Otago Institute, 14th November,* 1905.]

There have long been in the collections of the Otago Museum and of the Otago School of Mines specimens of sands from Kakanui, labelled "gem sands." The late Professor Ulrich, Director of the Otago School of Mines, was of opinion that gems would some day be found at Kakanui, evidently being struck by the association of minerals which these sands contained. Their investigation seems desirable both from a theoretical and a practical point of view. In the investigation of