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BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS.

RECORDS.

1961/36

A SURVEY OF THE PHOSPHATE DEPOSITS OF BELLONA ISLAND, 1960.

by

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SUMMARY

The island of Bellona in the British Solomon Islands, surveyed in 1958 by the Bureau of Mineral Resources was revisited by the author with a party from the British Phosphate Commissioners during November, 1960.

During the 1958 survey the main phosphate deposits were delineated by hand auger drilling. 6 deposits were recognized and were named A to F (See Plate 1). The first three deposits, A, B and C, are of phosphatic clay; D is of phosphatic clay underlain by a thin layer of incoherent phosphate; E is of phosphatic clay underlain by incoherent phosphate and oolitic phosphate; F is of oolitic phosphate.

During the 1960 survey the phosphate deposits were further tested by pit sinking, auger drilling and close pattern auger drilling. Testing was concentrated in the areas of oolitic phosphate (F) and incoherent and oolitic phosphate overlain by phosphatic clay (E). Information obtained during this testing suggested that part of area E would make a suitable quarry site and this has been separated as area T (See Plate 1). Testing at the west end revealed an area of oolitic phosphate (X) similar to that at F.

The oolitic phosphate of Deposits F and X occurs in chimneys in the limestone surface rather than in large depressions. These chimneys vary a great deal in diameter and depth. Towards the centre of Deposit F the chimneys are 3 to 4 feet in diameter and more than 30 feet deep but at the edges of the deposit they are only 1 or 2 feet in diameter and probably less than 10 feet deep. Deposit X is thought to be generally similar but was not fully tested.

Deposit T is in a single large depression, an oval basin with a narrow deep trough along its axis. Most of the best grade phosphate lies in this narrow trough. The limestone floor under Deposit T appears to be more regular than that underlying the oolitic phosphate of Deposits F and X.

There is probably about 500,000 tons of higher grade phosphate in deposits T, F and X which could be exploited.

Incoherent phosphate and oolitic phosphate appear to have been formed from limestone under attack by phosphatic solutions derived from avian guano. Later the phosphatic clay appears to have formed from the oolitic phosphate by reaction with alumina and iron oxides which have been constantly washed in on top of the phosphate deposits as the limestone of the rim has weathered.

INTRODUCTION

During November 1960 the author accompanied a party from the British Phosphate Commissioners in a visit to the island of Bellona in the British Solomon Islands Protectorate. The party consisted of Mr. W. Adams, Assistant General Manager, Mr. R. Greene, Islands Department Manager, Mr. J. Stott, Assistant Shipping Manager, Mr. J. Fraser, mechanic, Mr. G. Calvert and Mr. D. Bryce, surveyors and Mr. K. Lovitch, assistant. The New Zealand Commissioner, Mr. Tennant, was with the party for a week. The party was on the island from November 2nd to November 19th. The M.V. 'Coral Queen', under the command of Capt. Farlander, was chartered for the earlier part of the survey; the return voyage to Honiara was made in the M.V. 'Moala'.

BELLONA ISLAND

General

Bellona Island is situated ninety miles south of Guadalcanal, at a position 159° 50' E, 17° 15' S. It is one of the smallest islands in the British Solomon Islands Protectorate, being only six miles long and two miles wide, elongated east-south-east. The nearest neighbouring island is Rennell, twenty miles to the east-south-east.

There is a reasonable anchorage for small vessels at Ahanga which was carefully surveyed during this visit to see if it could be used by large vessels with deep-sea moorings.

Bellona is inhabited by about 500 people of Polynesian descent. Their villages are spaced out along a wide central track which runs the length of the island and gives good access to the low lying central area. This track could be easily adapted for use by motor transport. The initial 200 yards from the beach is steep and rough and would need blasting to reduce the slope and level the uneven surface. There are also a few places where low outcrops of limestone (one to two feet high) occur on the track; a light motor cycle and bicycles were carried up the initial slope and used during this survey, however. Along the greater part of its length the track is now wide enough to take a jeep.

Fairly dense rain forest covers much of the island particularly round the rim, but large areas in the centre have been cleared and are cultivated.

Fresh water is scarce on Bellona. There are a few places where springs of fresh water enter the sea just above high water mark, for example at Ongoba in One Bay, at Tinngoa at the east of Bellona, and at Angau. The island people collect rain water for washing and drinking.

Previous Investigations

Bellona was discovered by Captain Butler of the 'Walpole' in 1801. At that time the island was inhabited by people whose descendents live there today. However the legends of these people speak of 23 generations of the chiefly family of Bellona from the time the first Chief, Kaituu, arrived and conquered the previous inhabitants of the island.

Although the neighbouring island of Rennell was investigated by Stanley in 1927 (Stanley, 1929) and traces of phosphate were noted, Bellona does not seem to have been investigated until 1956 when both Bellona and Rennell were visited by Grover (Grover, 1957, 1958a, 1958b). On Bellona he found nodular, crustified and mammilary phosphate rock in viens and cavities in the limestone cliffs near Ahanga at the north-west end of the island, and a clayey material from a pit near Ngotokanava village was found to contain phosphate equivalent to 50% tricalcium phosphate.

A second visit was made by Grover later in the same year and over 30 pits were sunk to depths up to 20 feet. Later a more extensive programme of pitting was carried out which showed that a large tonnage of phosphatic material existed and that, although the bulk of the material was highly aluminous, high grade oolitic and incoherent phosphate occurred at the base of the deposit in places.

During 1958 the phosphate deposits were delimited by a programme of hand auger drilling designed to cover the central valley floor by the Bureau of Mineral Resources Phosphate Survey. The results of this survey have been presented as a report in the Record series (White and Warin, 1959). Much of the general description of the deposits and discussion of the mode of formation need not be repeated here, the purpose of this report being to record the new information obtained during the 1960 survey and discuss briefly conclusions regarding the origin, the tonnage and availability of the deposits that can be drawn from this new information.

A new map of Bellona Island has been drawn with the aid of improved air photographs - this map is included as Plate I with this report.

Physiography.

Bellona Island is an elevated coral atoll raised to approximately 250 feet above sea level. It is elongated in an east-south-east direction and consists of a relatively narrow, flat central depression surrounded by a wide, double rim of limestone. There is a higher, flat, limestone platform at the east and west ends of the central valley floor. Deposits X and F, of oolitic phosphate, are situated on these platforms.

TYPES OF PHOSPHATE IN THE BELLONA DEPOSIT.

In the phosphate deposits of Bellona four types of phosphate occur:

(1) Phosphatic clay
(2) Oolitic phosphate
(3) Incoherent phosphate
(4) Coherent phosphate

Phosphatic clay is a yellow-brown to brown friable clay with the consistency of drying putty. It appears to be permeable and becomes sticky, rather than plastic when wet.

The clay varies a great deal in its phosphate content but from 15 to 21% P_2O_5 is common. The higher grade clay is commonly lighter in colour. The other main constituents of the clay are alumina and iron oxides.

Oolitic phosphate is made up of hard spherical grains up to ⅛ in. or rarely ¼ in. in diameter. The oolites are generally in a matrix of phosphatic clay.

Oolitic phosphate commonly contains 25 to 30% P_2O_5 and is low in alumina and iron oxides. Mineralogically the oolites are of collophane.

Incoherent phosphate occurs with the oolitic phosphate on Bellona and is a white or off-white friable material is quite crumbly when dry and becomes pasty when wet. It is high grade phosphate with commonly 35% P_2O_5.

Coherent phosphate occurs as pebbles, in cracks in limestone and replacing larger pieces of limestone. The pebbles are hard, their surfaces commonly mamilated and broken surfaces have the typical soapy appearance and unctuous feel of collophane. Coherent phosphate is of collophane with only minor impurities and contains about 35% P_2O_5.

RESULTS OF TESTING

Deposits Examined During 1958 Survey.

On the basis of the 1958 auger drilling results it was possible to delineate 6 deposits on Bellona; these were lettered A to F. Deposits A, B and C are of phosphatic clay; D is of phosphatic clay underlain by a thin layer of incoherent phosphate; E is of phosphatic clay underlain by a considerable thickness of incoherent and oolitic phosphate; F is of oolitic phosphate. These deposits are as shown on Plate 1 with the exception that the original Deposit E is now divided into two, Deposits E and T.

Deposits Examined During 1960 Survey.

The testing of the 1960 survey was mainly concentrated at the east end of the central valley in Deposits E and F. This resulted in the separation of a new Deposit,T, from Deposit E and in further definition of the boundaries, depth, and general manner of occurrence of Deposit F.

Reconnaissance traverses during the 1958 survey and Grover's original survey, suggested that more oolitic phosphate might be found on the platform area at the western end of the central valley floor, in a similar position to that occupied by Deposit F. Some auger drilling was undertaken there during the 1960 survey and the deposit named Deposit X.

Detailed descriptions of the work in these three Deposits, F, F and X follow.

TESTING

Three methods of testing were used during this survey;

(1) Pits were dug, chiefly at the east end in the deposits of oolitic phosphate (F) and of incoherent phosphate overlain by phosphatic clay (T).

(2) Auger drilling to extend or intensify the drilling of the 1958 survey;

(3) Auger drilling on close grids at selected localities.

Pits

28 pits were sunk. The first pits were 30' x 8' in surface area but later smaller pits, 20' x 8' and 6' x 6' were used. The depth of the pits varied as an attempt was made to reach the limestone surface in each pit. The approximate positions of the pits are shown on the map, Plate 1, and plan views of some of the pits are shown on Plate 2. Figures 1, 2, 3 and 4 are from various pits and will be discussed later.

The pits showed that the oolitic phosphate of Deposit F is all contained in chimneys in a very irregular limestone surface. The chimneys vary in abundance and in diameter but are never so numerous and so wide that they intersect and produce isolated pinnacles of limestone. On the other hand it was found in deposit T that a considerable depth of oolitic and incoherent phosphate overlies a relatively even limestone floor.

Auger drilling.

Most of the auger drilling of individual holes on a broadly spaced grid was at the west end of the island to cover areas that had been missed during the 1958 survey. This drilling ('X' drilling and 'V' drilling) is shown diagramatically in Plate 2 and is given in full in Table I.

This drilling showed that the phosphatic clay of Area A does not extend significantly to the west of the limit of the 1958 drilling. The 1960 'X' drilling however showed that a considerable tonnage of oolitic phosphate in chimneys exists on the platform area near Matahanua village.

Pattern Auger Drilling.

At selected localities in the oolitic phosphate and in the incoherent phosphate overlain by phosphatic clay patterns of closely spaced auger holes were put down in order to determine the average depth of the phosphatic material and the degree of pitting of the underlying limestone surface.

The holes were placed 10 feet apart along lines spaced 10 feet apart. In the first of these test areas drilled (Test Area A) 54 holes were attempted; later it was found that 12 holes, 3 rows of 4 holes, were sufficient for the purpose.

The test areas of close drilling showed the extreme complexity of the limestone surface in the areas of limestone chimneys; test areas were a useful check on the information obtained by pitting in areas where clay overlies oolitic and incoherent phosphate.

The results of this drilling are given in full in Table I, are summarized in Table II and shown diagramatically in Plate 2.

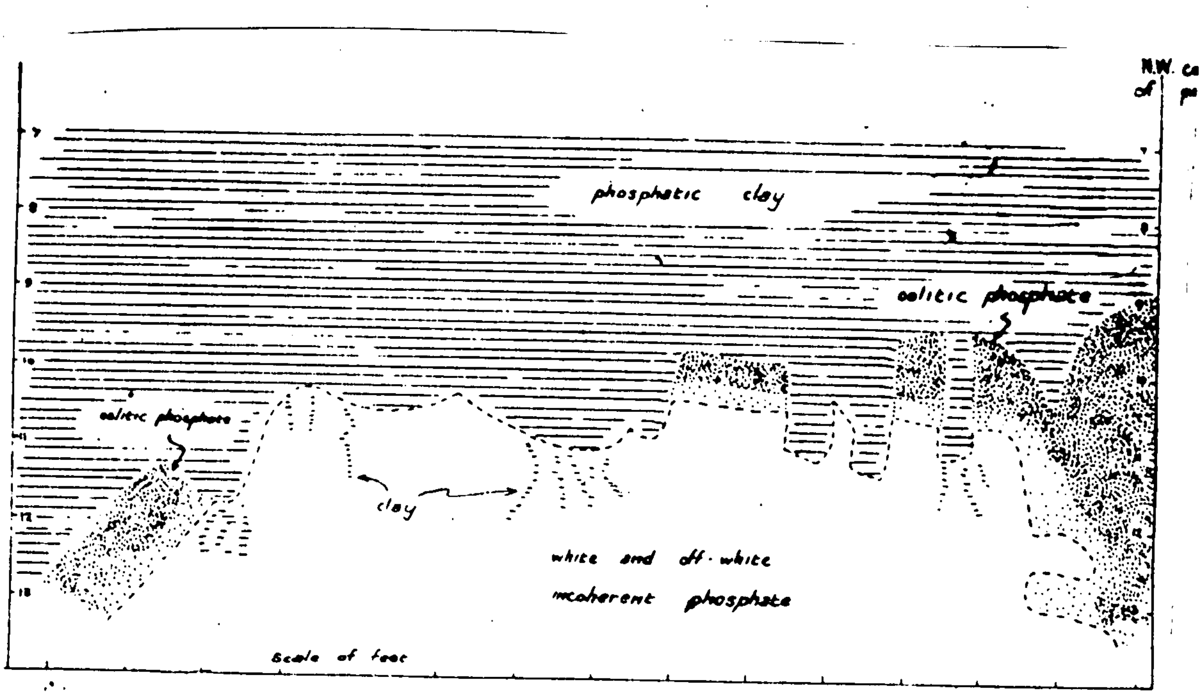


Fig No 1 Pit No. 6, West face.

Fig. No. 1.

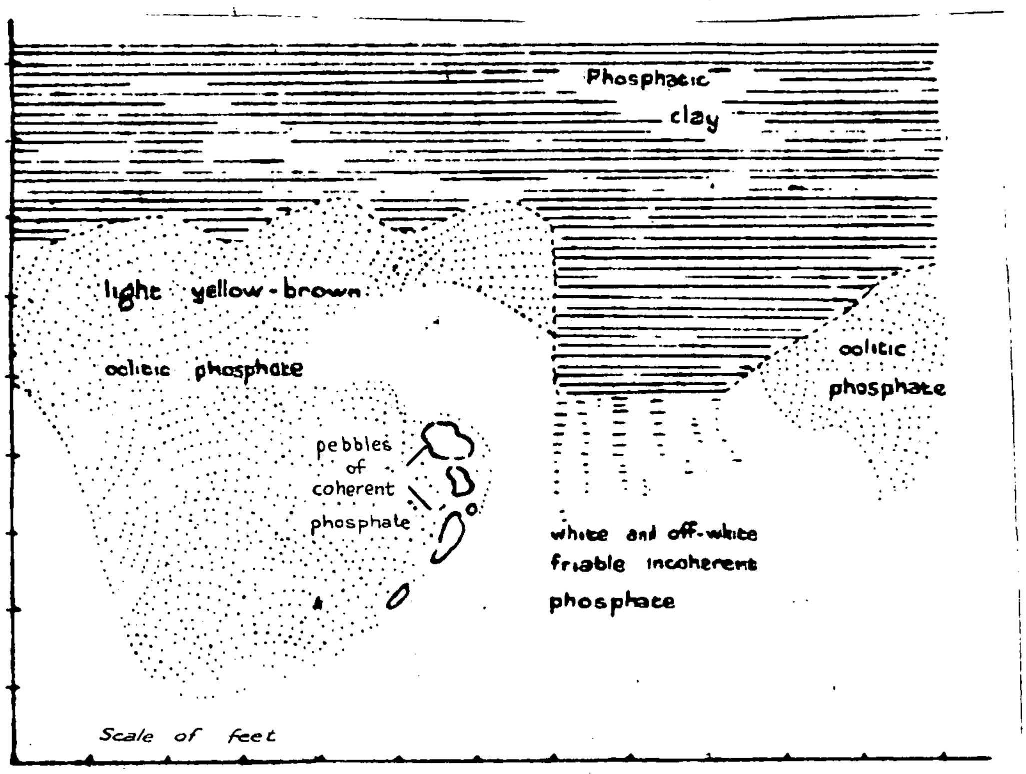


Fig. No. 2

DEPOSIT T

In the report of the 1958 survey Deposits E and F were shown as a continuous deposit, separated simply for convenience of description. In this survey the main part of Deposit E has been re-named Deposit T, E being retained for the two small areas of phosphatic clay at the west end of Deposit T. Deposit F as shown on Plate 1 is substantially the same as in the earlier report (White and Warin, 1959).

In Deposit T a thick blanket of phosphatic clay overlies a deposit of oolitic phosphate and white to off-white incoherent phosphate. The contact of the incoherent phosphate with the underlying limestone was not exposed by the pits, but auger drilling into the floor of the pits suggests that the surface of the limestone is relatively even and not eroded into chimneys or pinnacles. The incoherent phosphate immediately above the limestone is diluted with fragements of weathered limestone intimately mixed with phosphate. The contact of the incoherent and oolitic phosphate with the overlying clay is shown in Figures 1 and 2. The clay either directly overlies the incoherent phosphate or else is separated from it by a layer of oolitic phosphate of variable thickness. The oolitic phosphate is much lighter coloured and finer against the incoherent phosphate although the contact is sharp; the contact of the oolitic phosphate with the overlying clay is very clearly defined and has flecks of pasty white phosphate along the surface of contact.

The original (1958) reconnaissance auger drilling gave long intersections of incoherent phosphate in this area; for example, hole 58 intersected 15 feet of incoherent phosphate below 13 feet of clay. The pits of the present survey have confirmed that these depths represent a genuine thickness of high grade phosphate and are not caused by low angle intersection of phosphate clinging to the sides of pinnacles or chimneys.

Fig. No. 3

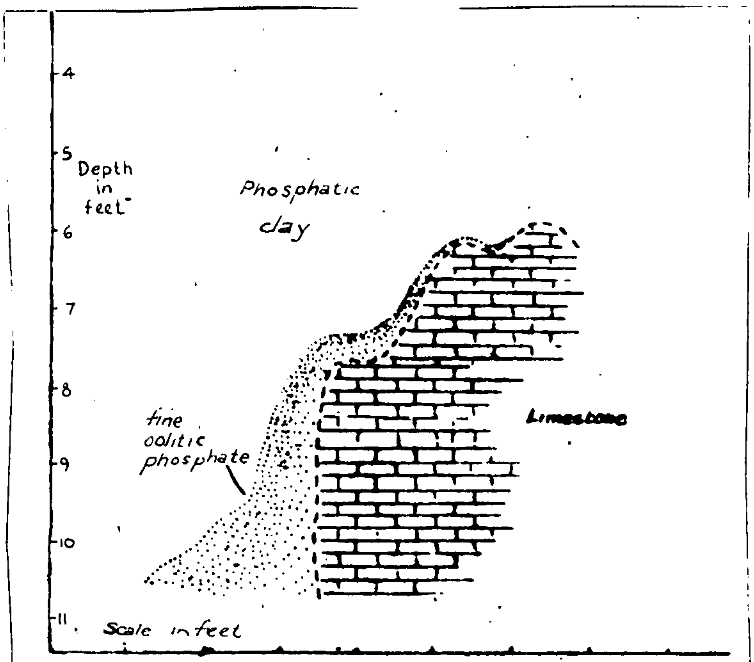


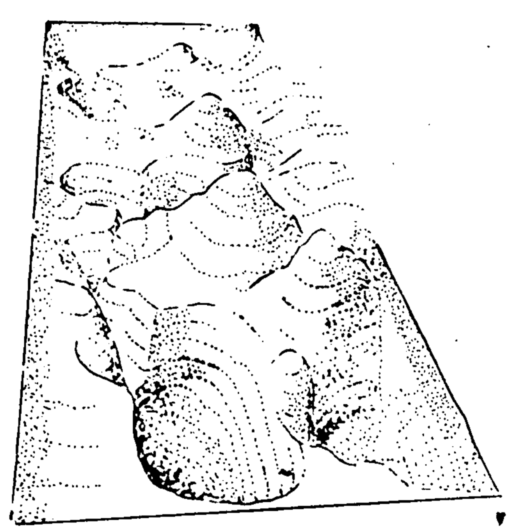
Fig No. 3 **Part of East wall, Pit No 5.**

Good air-photo cover of Bellona became available only after the survey had been completed but the boundaries of deposit 'T' shown on the map, Plate I, have been constructed with this additional aid. The present topography shows a basin which clearly repeats the basin structure of the underlying limestone. The basin structure is borne out also by the depths of pits and auger drilling at various places in the deposit. The basin is elongated east/west and has a deep trough along its axis in which the deepest oolitic and incoherent phosphate lies. The gradient at the eastern end of the basin appears to be very steep and the deepest part of the axial trough may be close to this end, near pit 4. At the west end and to the north and south the basin appears to shelve out more gradually. There may be another deep part to the trough near 58. The oolitic phosphate and incoherent phosphate are commonly more than 10 feet thick in this narrow central trough. At pit 5, about 110 yards south of the axis of the trough, however, the incoherent phosphate and oolitic phosphate have become very thin (less than 2 feet) - see Fig. 3.

<u>Tonnage and grade.</u>

Samples collected during the survey have not yet been examined chemically or mineralogically, but the average grade (23 determinations) of incoherent phosphate sampled during the 1958 survey was 33.8% P_2O_5 and that of oolitic phosphate (70 determinations) was 29.9% P_2O_5 (White and Warin, 1959).

The tonnage available will be accurately estimated by Mr. Adams of the British Phosphate Commissioners in his report. Very roughly however the central deep trough of deposit T is about 600 yards long and between 100 and 150 yards wide and the average depth of oolitic or incoherent phosphate in it is about 10 feet. Calculating the tonnage on the basis of 25 cu. ft. of phosphate per ton, the amount of phosphate available is about 300,000 tons.



Limestone surface exposed in Pit No 2
(from a field sketch)

Fig No 4

Fig. No. 4.

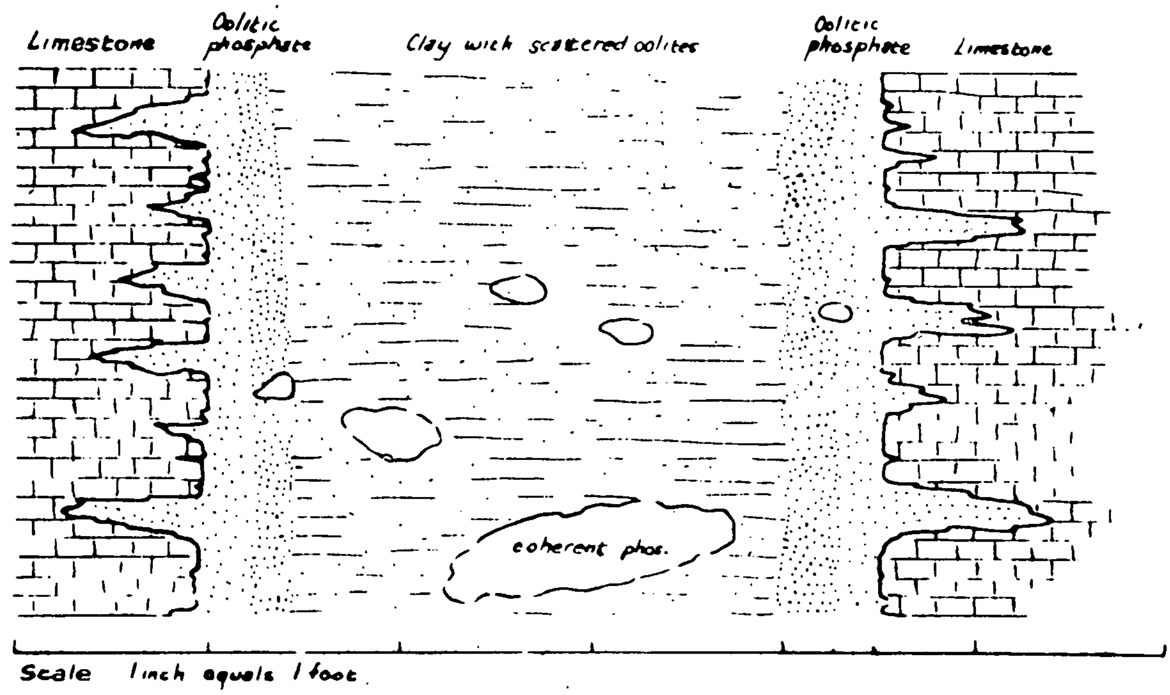


Fig No. 5 Generalized vertical section through chimney, Pit No 2.

Fig. No. 5

DEPOSIT F

Pits sunk in deposit F show that the oolitic and pebble phosphate which make up the deposit are entirely contained in chimneys; nowhere does there appear to be any larger depressions similar to that of deposit T; moreover the chimneys vary markedly in width in a way that is difficult to predict.

Auger drilling from test areas in deposit F is shown diagramatically in Plate 2; the plan views of pits on the same plate attempt to show the topography of the limestone surface. Pits 1 and 2 are in the centre of the area and show widely spaced chimneys 3 to 4 feet in diameter; pit 3, about 100 yards to the north of pit 1, shows closer spaced but very narrow chimneys (less than 2 feet in diameter). Figure 4 is from a field sketch of the limestone surface exposed in pit 2. It shows the stumpy pyramidal pinnacles of limestone which are characteristic of the first two or three feet below the soil surface and then the vertical, commonly neatly circular, chimneys which occur below that. An attempt was made to reach the bottom of the two main chimneys in pit 2, using a hand auger; the first was drilled to a depth of 30 feet until large phosphate boulders prevented further progress; the second was drilled to a lesser depth and again had to be discontinued because of phosphate boulders. Drilling at d4 in test Area C reached 28¾ feet before striking phosphate boulders. It seems likely that in the central part of Deposit F the chimneys are wide and deep, as at pit 2, but that they rapidly become narrower and shallower towards the north and south edges of the deposit and towards the east and the sloping ground to the west which links Deposits F and T.

The material in the chimneys in Deposit F is mostly oolitic phosphate and phosphate pebbles, and sometimes quite large boulders, (2' x 1' x 1'). The pebbles and boulders appear to be of cemented oolites. The centres of the wider chimneys contain quite a lot of phosphatic clay, (see Fig. 5). The oolitic phosphate close to the limestone is lighter coloured and fills horizontal irregularities in the wall of the chimney; under these small overhangs the individual oolites are coarser (up to $\frac{3}{8}$ inch in diameter), less regularly shaped, and they fit very intimately into minor furrows in the limestone surface.

Nowhere do the individual chimneys coalesce to form winding passages between limestone pinnacles.

Tonnage and Grade.

The average grade of oolitic phosphate determined from samples taken during 1958 has already been given - 29.9% P_2O_5.

The possible tonnage of phosphate present in this type of deposit is extremely difficult to assess. The depth of the chimneys is not adequately known, since none was bottomed; it is difficult to form an accurate idea of the volume occupied by limestone to that occupied by phosphate; and the width of the chimneys seems to vary rapidly from place to place. Clearly also the width of the chimneys is an important factor in determining the accessibility of phosphate which may be present.

The tonnage can be estimated very roughly by supposing that the central part of the deposit, which contains chimneys wide enough to be worked, is about 540,000 square feet in area (1800 feet long by about 300 feet wide.) The average depth of the chimneys can only be guessed since none was bottomed. Two in the central area were followed to near 30 feet but drilling had to be discontinued because of large phosphate boulders. If the average depth of the chimneys is taken as 15 feet and a cut of 2/3 of the total volume made to account for space occupied by limestone the exploitable tonnage is 100,000 tons. It can be safely assumed therefore that there is at least 100,000 tons of exploitable oolitic phosphate in Deposit F.

DEPOSIT X

Deposit X was tested during the survey by hand auger drilling at convenient points along existing tracks supplemented by two holes along cut traverse lines. This deposit was not drilled at all during the 1958 survey though the presence of oolitic phosphate in chimneys in this area had been noted by Grover (Grover 1958) and in the report of the 1958 survey.

Matahanua village is on a flat platform about 110 feet above sea level between the north and south arms of the limestone rim. To the north-west the platform falls away steeply to the sea without the usual intervening rim; to the south-east the platform falls away gently towards the lower parts of the central valley floor at Ngotokanava village and farther east. The oolitic phosphate occurs on this platform mostly to the east of Matahanua.

The deposit appears to be similar to Deposit F at the east end, both as regards its position and make up. There seems to be no clay in any of the chimneys of Deposit X however; the oolitic phosphate here is quite clean and runs easily - auger drilling had often to be discontinued before reaching limestone because of caving.

A village pit at X shows that the chimneys in the limestone are about 3 feet in diameter there. By analogy with Deposit F, it seems most likely that chimneys closer to the centre of Deposit X would not be narrower than this.

Tonnage and Grade.

The considerations mentioned under this head in the section on deposit F apply with equal force to this deposit. Using the same method as outlined for Deposit F it seems that Deposit X also contains at least 100,000 tons of exploitable oolitic phosphate.

ECONOMIC CONSIDERATIONS

It was estimated from the auger drilling of the 1958 survey that the Bellona deposits contained 4,500,000 tons of phosphatic clay with an average grade of 22.2% P_2O_5 and 700,000 tons of oolitic and incoherent phosphate with an average grade of 30.3% P_2O_5 (White and Warin, 1959). This figure of 700,000 tons included the incoherent phosphate at the base of deposit D which could not be won unless the overlying phosphatic clay was also extracted.

The 1960 survey was concerned only with higher grade phosphate of Deposits F, X and T. Probably only about 500,000 tons of oolitic and incoherent phosphate with an average grade of about 30% P_2O_5 could be won from these three deposits.

The new estimate of 100,000 tons for oolitic phosphate available in deposit F has been calculated on the assumption that only the central part of the deposit could be quarried as the pits revealed that chimneys rapidly become too narrow to be worked towards the edge of the deposit. Again with Deposit T only the central part of the deposit has been considered where the high grade material is thick enough to make it worth while to remove a considerable thickness (commonly more than 12 feet) of phosphatic clay as overburden.

At present only the oolitic and incoherent phosphate, in which the phosphate is combined chemically with calcium, can be considered for the manufacture of superphosphate. If any method of treatment can be found for the phosphatic clay, in which the phosphate radical may be chemically bound to aluminium, the reserves of useful phosphate on Bellona would be greatly increased.

Recently, experiments on the heat treatment of phosphatic material high in alumina from Bellona have been made by the Mineral Resources Division of the Overseas Geological Surveys, London. (Anon. 1960). These preliminary experiments suggest that clays containing the mineral crandallite, a hydrated calcium aluminium phosphate, respond to a simple heat treatment at about 550°C. The mineral is broken down and the phosphate becomes 'available' - i.e., soluble in ammonium citrate solution. Such heat treated material might provide a useful phosphate fertilizer for direct application.

At present however, of the total tonnage of approx. 700,000 tons of phosphate suitable for the manufacture of superphosphate, only 500,000 tons with an average grade of about 30% P_2O_5 is readily available.

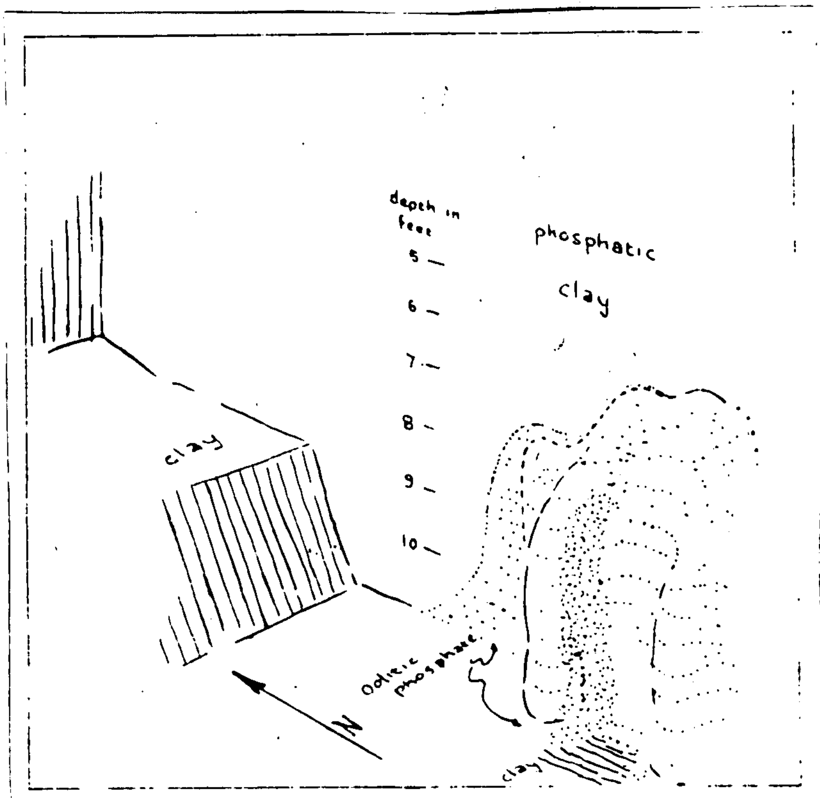


Fig No. 6 Part of Pit No 5

Fig. No. 6

FORMATION OF THE PHOSPHATE DEPOSITS.

The general mode of formation of the phosphate of Bellona is fairly clear although there are still some details that are baffling.

From the work in 1958 the following sequence of events was proposed;

(a) The original atoll was raised above sea level and given a slight tilt down to the north-west. As the lagoon dried, drainage continued along the axis of the island from the higher south-east end; finally the lagoon disappeared, the drainage became underground and the main drainage axis was marked by a series of solution hollows, sink holes and collapse structures in the limestone.

(b) The uplifted atoll was colonised by herdes of breeding sea-birds and a thick deposit of guano accumulated, mainly on the inner slopes of the island rim. Solutions from the guano attacked the limestone and lagoon debris to form a mantle of tricalcium phosphate with a partly concretionary or oolitic structure.

(c) The phosphate mantle was eroded and, together with iron oxides and alumina derived from solution erosion of unaltered limestone, was washed down into sink holes along the axis of the island eventually forming a thick blanket deposit of loose oolitic phosphate on the old lagoon floor.

(d) Choking of the sink holes by the insoluble phosphate caused swamps to form. In the more acid conditions of the swamps the oolites decomposed; some phosphate was lost in solution to the sea through the underground drainage, and much recombined with the alumina and iron oxides to form the clay.

The sequence of events given above is probably correct in essence. The relationships revealed in pits, particularly in Deposit T, give a more detailed knowledge of the replacements that have taken place.

From the evidence provided by the pits in Deposit F (Fig. No. 5) I suggest that the oolitic phosphate of this deposit has been formed by the replacement of limestone in situ (See description of Deposit F). In Deposit T (Fig. Nos. 1 and 2) also I suggest that the incoherent phosphate and the oolitic phosphate have been formed by replacement of limestone in situ. I suggest that phosphatic solutions acting on the limestone form oolitic phosphate when some alumina and iron oxides are present and incoherent phosphate when none are present.

The phosphatic clay, however, appears to have formed at the expense of the oolitic phosphate. A thin section of a sample of the phosphatic clay taken during the 1958 season strongly suggests that oolites are breaking down within the clay; and the manner in which the clay cuts through the underlying oolitic phosphate (See Fig. Nos. 1 and 2) in Deposit T suggests that the oolitic phosphate is breaking down to form clay.

The following sequence of events is suggested to explain the relationships seen in Deposit T;

(a) The atoll was uplifted and drainage initiated and developed in the manner described by White & Warin (1958).

(b) The uplifted atoll was colonized by hordes of breeding sea birds whose droppings accumulated as guano. Solutions from the guano attacked the limestone, particularly in the hollows in the central valley floor, and, in conjunction with the small amounts of residual soil that were already present on the surface of the limestone, formed a blanket of oolitic phosphate.

(c) From then on two constituents were added to the deposit:

(1) Alumina and iron oxides - the insoluble residues of the solution erosion of the limestone, and

(2) soluble phosphate leached from the guano.

The alumina and iron oxides were added to the top of the deposit; the soluble phosphate percolated through the deposit converting the upper layers of the sesquioxides, to phosphatic clay, and then percolating through the oolitic phosphate to convert the limestone to incoherent phosphate.

(d) Climatic changes, probably towards the close of the Pleistocene removed the bird population and from then on only the alumina and iron oxides would be added to the deposit. Under these conditions some of the oolitic phosphate has broken down to form more clay.

The complex surfaces revealed in section in Pit No. 6 (Fig. No. 1 and No. 2) and other pits in Deposit T may be due to solution weathering and consequent minor collapses in the limestone beneath the deposit.

A major point of difference between the explanation advanced here and that advanced by other authors to explain other phosphate deposits is that other authors have generally supposed that the 'Karrenfeld', the pitted, uneven limestone surface underlying the deposits, was first created by subaerial erosion and later the irregularities in the 'Karrenfeld' were filled by phosphate. Here I have suggested that the irregularities of the limestone surface (notably the chimneys of Deposits X and F) were formed at the same time and by the same processes which formed the phosphate.

ACKNOWLEDGEMENTS.

I would like to acknowledge the assistance given to the survey by the Senior Geologist of the British Solomon Islands Geological Survey, Mr. J.C. Grover, and personally I would like to thank the British Phosphate Commissioners personnel who took part in the survey, in particular Mr. Adams and Mr. Lovitch with whom I worked most of the time and Mr. Greene on whose shoulders fell most of the work of organizing the survey.

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TABLE I

Logs; pattern auger drilling

Rows lettered, holes in each row numbered.
Ts = Topsoil
o, op = oolites, oolitic phosphate.
peb. = pebble phosphate
c = phosphatic clay
p = incoherent white to off-white phosphate. Lst. = limestone
Depths in feet.

TEST AREA A. 54 holes, 6 row of 9 holes.

a1	½	Ts,o	b1	1	Ts,o
a2	2¼	1¼Ts,o; 1c,o	2	1½	Ts,o
3	5½	1¾Ts; 3¾c,o	3	¼	Ts,o
4	¾		4	15½	1½Ts, 14c
5	¼	Ts	5	¼	Ts,o
6	¼		6	1	Ts,o
7	¼		7	1¾	1½ Ts,o; ¼c
8	0	Lst.	8	1	Ts
9	0		9	1	Ts
c1	1¾	Ts; o	d1	0	Lst.
2	0	Lst.	2	1¼	
3	2¾	2½Ts,o; ¼c,o	3	¼	
4	2	1¾Ts,o; ¼c,o	4	1¼	Ts
5	¾	Ts,o	5	¾	
6	¾	Ts,o	6	1	
7	2¾	1¾Ts,o; 1c,o	7	½	
8	¾	Ts,o	8	0	Lst.
9	1	Ts,o	9	2¼	1¾Ts, ½c
e1	0	Lst.	f1	2	Ts
2	1¾	Ts	2	1¾	Ts
3	10½	1½Ts; 9c	3	0	Lst.
4	4	1¼Ts; 2¾c	4	¾	
5	¾	Ts	5	¼	
6	1¼	Ts	6	1	
7	0	Lst.	7	¼	Ts
8	2	Ts	8	¼	
9	½	Ts	9	½	

TEST AREA B. 27 holes, 3 row of 9 holes.

a1	12¾	1¼Ts,o & peb; 11½c, o & peb.
2	1	Ts,o
3	¾	Ts,o
4	14	1Ts,o; 13 o.p. & peb. Not bottomed
5	½	Ts,o
6	3	Ts,o & peb
7	1½	Ts,o
8	1¾	Ts,o
9	1½	1Ts,o; ½c,o,peb
b1	¼	Ts,o
2	1	Ts,o
3	4	1Ts,o; 3c,o, & lage pebbles
4	¾	Ts,o
5	5½	1½Ts,o; 4c,o
6	12	1½Ts,o; 10½ op. Caving, not bottomed
7	¼	Ts,o
8	7¾	1¼Ts,o; 6½c,o,peb.
9	3¾	Stopped by large pebbles
c1	¼	Ts,o
2	6	1½Ts,o; 4½c,op,Lst.
3	½	Ts
4	1¼	Ts
5	1¾	1¼Ts, ½op
6	½	Ts
7	7½	1¼Ts; 6¼op; caving not bottomed
8		Stopped by large phosphate boulders at 3¾.
9		

TEST AREA C. 36 holes, 6 rows of 6.

a1	10¾	1½Ts,o,peb. 9¼op,c &
2	½	Ts,op
3	1¾	1½Ts,op; ¼ op,c
4	1½	Ts,op
5	1½	Ts,op
6	2	1¾Ts,op; ¼op,c.
b1	1½	1¼Ts,op; ¼op,c
2	5	1Ts,op; 1¾op,c; 2¼op
3	14¼	1¼Ts,op; 13op,c & pe
4	4	1Ts,op,peb; 2op,c,pe
5	5¾	1Ts,op; 4¾op,c
6	2	1¾Ts,op; ¼op,c
c1	1¼	1¼Ts,op
2	2¼	1Ts,op; 1¼op
3	1¼	¾Ts,op; ½op,c
4	3	1¼Ts,op,peb; 1¾op,c
5	8	1Ts,op,peb.
6	2½	1¼Ts,op; 1¼op,c
d1	2½	1¼Ts,op; 1op,c; ¼op.
2	5½	1Ts,op; 4½op,c.
3	1¾	1½Ts,op; ¼op,c.
4	28¾	1½Ts,op; 27¼op,c with peb.
5	-	
6	4¼	1Ts,op and peb; ¼op,peb.
e1	1¾	1¼Ts,op.
2	1¼	Ts,op,peb.
3	¾	Ts,op.
4	2	1Ts,op; 1op.
5	1	Ts.
6	7¾	1Ts,op; 3op,c,peb; 3¾ op,peb.
f1	3½	1Ts,op, 2½op; peb.
2	7	1½Ts,op,peb; 5½op,peb.
3	4	1½Ts,op,peb; 2½op,peb.
4	3¼	1½Ts,op,peb; 1¾op,peb.
5	9	2Ts,op,peb; 7op,peb.
6	4¾	1¼Ts,3½op,peb - not bottomed.

TEST AREA D. 20 holes 4 rows of 5 holes.

a1	1	Ts
2	1	Ts & peb
3	½	Ts, o & peb
4	1	Ts, peb, c
5	1¼	Ts
b1	1	Ts
2	2	Ts
3	0	Ts
4	1	Ts
5	1	Ts
c1	9¾	1½Ts; 3¼c; 5op, c
2	1¾	Ts
3	1	Ts
4	1½	Ts
5	1¼	Ts, c
d1	1	Ts
2	1¼	Ts, c
3	¾	Ts
4	1¼	¾Ts, ½c
5	½	Ts

TEST AREA E. 12 holes 3 rows of 4.

a1	½	Ts
2	2	1Ts, op, peb; 1op, c, peb
3	14	1½Ts, op, peb; 3½c, op; 9op
4	11	2½Ts, op. 8½p, c
b1	1	Ts, o
2	¾	Ts, o
3	½	Ts, o
4	8	1½Ts, op, peb; 2op, c, peb; 4½op, peb
c1	0	Lst.
2	1¼	Ts, o
3	1	Ts, c, o
4	2½	1½Ts, o, 1op, c, peb

TEST AREA F. 12 holes 3 rows of 4.

a1	2	1Ts,1c
2	$5\frac{1}{2}$	$1\frac{1}{4}$Ts, $4\frac{1}{4}$c
3	$\frac{1}{4}$	Ts
4	$\frac{1}{4}$	
b1	$1\frac{1}{4}$	Ts
2	$\frac{1}{2}$	Ts
3	$\frac{1}{4}$	Ts
4	1	Ts
c1	$1\frac{1}{4}$	Ts
2	$1\frac{1}{2}$	Ts,c
3	$\frac{1}{2}$	Ts
4	$1\frac{1}{4}$	Ts

TEST AREA G. 16 holes, 4 rows of 4.

a1	$2\frac{1}{2}$	1Ts,op,$1\frac{1}{2}$op,peb
2	$1\frac{1}{2}$	$1\frac{1}{2}$Ts,op
3	$1\frac{3}{4}$	Ts,op,c
4	3	$1\frac{1}{2}$Ts,op; $1\frac{3}{4}$op,c,peb
b1	$1\frac{1}{4}$	Ts,op,c
2	$1\frac{1}{4}$	Ts,op
3	2	1Ts,op; 1op,c
4	$\frac{1}{4}$	Ts
c1	3	1Ts,op,peb. 2op,c,peb
2	$2\frac{3}{4}$	1Ts,op; $1\frac{3}{4}$op,c
3	1	Ts,op,peb
4	$2\frac{1}{4}$	Ts,op,peb
d1	$\frac{3}{4}$	Ts,op
2	1	Ts,op
3	$\frac{3}{4}$	Ts,op
4	$3\frac{3}{4}$	1Ts,op; 2op,c $\frac{3}{4}$op

TEST AREA H 12 holes 3 rows of 4

a1	10	1Ts; 3c,op; 3op,c; $\frac{1}{2}$op
2	$\frac{1}{4}$	Ts
3	$11\frac{3}{4}$	$1\frac{1}{2}$Ts,op; $6\frac{1}{4}$op,c; 4op
4	$3\frac{1}{4}$	$1\frac{1}{4}$Ts,op; 2op,c
b1	4	1Tsop; 3op
2	2	1Ts,op; 1op
3	$7\frac{1}{2}$	$1\frac{3}{4}$Ts,op; $4\frac{1}{4}$op,c; $1\frac{1}{2}$op
4	$\frac{3}{4}$	Ts,op
c1	$1\frac{3}{4}$	Ts,op
2	$1\frac{1}{4}$	Ts
3	2	Ts,op
4	$3\frac{3}{4}$	1Ts,op,peb; $2\frac{1}{4}$,op,peb.

TEST AREA I. 12 holes, 3 rows of 4.

a1	$1\frac{1}{4}$	Ts,op,peb
2	$1\frac{1}{4}$	Ts,o,c
3	$\frac{1}{4}$	Ts
4	$13\frac{1}{2}$	1Ts,$5\frac{1}{2}$c,op; 7op,peb. Not bottomed
b1	$7\frac{3}{4}$	2Ts,op; $5\frac{3}{4}$c,op
2	$\frac{1}{4}$	Ts
3	13	$1\frac{3}{4}$Ts,op; $7\frac{3}{4}$c,op,$3\frac{1}{2}$op,peb
4	$1\frac{1}{2}$	Ts,o
c1	2	$1\frac{1}{4}$Ts,op,peb; $\frac{3}{4}$op,c
2	$\frac{1}{4}$	Ts
3	$14\frac{1}{2}$	2Ts,o; $1\frac{1}{2}$c,op; 11op,c
4	$\frac{3}{4}$	Ts,o

TEST AREA J. 12 holes, 3 rows of 4.

a1	$7\frac{3}{4}$	$1\frac{1}{2}$Ts,$6\frac{1}{4}$c,op
2	$\frac{1}{2}$	Ts
3	3	$1\frac{1}{4}$Ts,op; $1\frac{3}{4}$op,peb
4	$6\frac{3}{4}$	1Ts,op;$2\frac{1}{4}$c,op; $3\frac{1}{2}$op
b1	$\frac{1}{4}$	Ts
2	$\frac{3}{4}$	Ts
3	1	Ts,op
4	$16\frac{3}{4}$	$1\frac{1}{2}$Ts,op; $15\frac{1}{4}$c,op→ op
c1	$\frac{1}{2}$	Ts
2	$1\frac{1}{4}$	Ts,op
3	$\frac{3}{4}$	Ts
4	3	$\frac{3}{4}$Ts,op; $2\frac{1}{4}$op,peb

TEST AREA K - All limestone outcrops.

TEST AREA L 12 holes, 3 rows of 4. 3 obscured.

a1	$5\frac{1}{2}$	$1\frac{1}{2}$Ts; $3\frac{1}{2}$c,op,peb; $\frac{1}{2}$op
2	$5\frac{3}{4}$	$1\frac{3}{4}$Ts,3c,op,peb; 1op
3	$1\frac{1}{2}$	Ts,op
4	$1\frac{1}{2}$	$\frac{1}{2}$Ts,1op,peb,c
b1	$2\frac{1}{4}$	Ts,op,peb
2	4	some p
3	$\frac{1}{4}$	Ts
4	$5\frac{1}{4}$	2Ts,op,peb; $2\frac{1}{2}$op,peb,c; $\frac{3}{4}$p,op
c1	$5\frac{1}{4}$	$1\frac{1}{4}$Ts,op; $2\frac{1}{2}$op,c; $1\frac{1}{2}$op,p. Many large pebbles.
2		obscured by pit.
3		
4		

TEST AREA M. 12 holes, 3 rows of 4.

a1	1½	Ts
2	½	
3	1½	
4	6½	1Ts,3½c,2op
b1	¼	Ts
2	1	
3	½	
4	¼	
c1	¼	Ts
2	1	
3	1¼	
4	½	

TEST AREA N. All Limestone outcrop.

TEST AREA O. All Limestone outcrop.

TEST AREA P. 12 holes, 3 rows of 4, 3 attempted.

a1	14½	1½Ts; 7½ c; 2¾p
a2	17½	similar to a1
a3	16¾	

TEST AREA Q. 12 holes, 3 rows of 4.

a1	11	1Ts,op; 6¾c,o; 3¼p
2	11	1½Ts; 9½op,c
3	5	1¾Ts; 1½c, 1¾p
4	5	¾Ts, 2op,c; 2¼op
b1	¾	Ts,op
2	4¾	1¾Ts; 1½op, c; 1½op
3	6	1½Ts,op; 2½op,c; 1op; 1p
4	7¾	2Ts,op; 3½op,c; 1op; 1¼p
c1	2¾	1Ts,op; 1¾op,c
2	5¾	1Ts,op,peb; 2¾op,c;
3	3¾	1½Ts,op; 1¾op,c;½op
4	5½	¾Ts,op; 2¾op,c; 2op & peb.

TEST AREA R. 12 holes, 3 rows of 4, 4 holes obscured.

a1	6¼	5¼c; 1op	b1	14½	c & many pebbles
2	3¾	2¼c; ½op	2	3½	c
3	9¾	8¾c; 1op	3		obscured by pit.
4	2¾	c	4		
c1	9½	9c,½op			
2	16	6c; 10op & peb.			
3		obscured by pit			
4					

TEST AREA S 12 holes, 3 rows of 4

a1	$\frac{1}{2}$	Ts	b1	$\frac{1}{2}$	Ts	c1	1	Ts
2	2		2	$\frac{1}{2}$		2	$\frac{1}{2}$	
3	$\frac{1}{2}$		3	1		3	$\frac{3}{4}$	
4	$\frac{1}{2}$		4	1		4	$\frac{1}{2}$	

TEST AREA W_1 12 holes, 3 rows of 4. 4 attempted

a1	$18\frac{1}{2}$	2Ts, 10c $6\frac{1}{2}$p
a4	16	2Ts, 11c 3p - not bottomed.
b4	$11\frac{3}{4}$	2Ts, 8c, $1\frac{3}{4}$p
c1	16	2Ts, 8c 6p

TEST AREA W_2 12 holes, 3 rows of 4.

a1	$\frac{3}{4}$	Ts	b1	8	$1\frac{1}{2}$Ts; $6\frac{1}{2}$op, c	c1	$\frac{3}{4}$	Ts
2	$\frac{3}{4}$		2	$1\frac{1}{2}$	Ts	2	2	
3	$1\frac{1}{2}$		3	1	Ts	3	2	
4	1		4	$\frac{3}{4}$	Ts	4	1	

TEST AREA W_4 12 holes, 3 rows of 4; 5 attempted.

a1	16	2Ts; $9\frac{1}{2}$c; $4\frac{1}{2}$p. Not bottomed.
2	$17\frac{1}{2}$	2Ts; 8c; $7\frac{1}{2}$p
3	Not attempted	
4	16	2Ts; 7c; 7p

b line not attempted

c1	14	2Ts; 7c, 5p
2	Not attempted	
3	Not attempted	
4	6	2Ts, 4c - not bottomed.

TEST AREA W_5 12 holes, 3 rows of 4. 5 attempted.

a1	5	$1\frac{1}{2}$Ts; $3\frac{1}{2}$c
2	Not attempted	
3	Not attempted	
4	$7\frac{1}{2}$	$1\frac{1}{2}$Ts; 6c

b1, 2, 3		Not attempted.
b4	7	$1\frac{1}{2}$Ts, $5\frac{1}{2}$c - very thin (1") layer p.

c1	$6\frac{1}{4}$	$1\frac{1}{2}$Ts; $4\frac{1}{2}$c; $\frac{1}{4}$p
2	Not attempted	
3	Not attempted	
4	6	$1\frac{1}{2}$Ts; $4\frac{1}{2}$c

TEST AREA W_6		12 holes, 3 rows of 4. 3 attempted.
a1	21	2Ts,15c,4p
a4	4	2Ts,2c - not completed.
c1	16½	2Ts, 14½c - not completed.

TEST AREA W_7		12 holes, 3 rows of 4.
a1	6¼	1½Ts 4¾c
2	¾	Ts
3	½	Ts
4	2¾	1½Ts; 1¼c
b1	1¼	Ts
2	5¾	1Ts; 4¾c
3	1¾	Ts
4	9½	2Ts; 7½c
c1	1¾	Ts
2	1¼	Ts
3	1½	Ts
4	19	2Ts, 17c

'X DRILLING

X_1	9	op & peb
X_2	9½	op & peb. Not bottomed
X_3	14½	op & peb caving, not bottomed.
X_4	9½	op & peb caving, not bottomed.
X_5	9	op & peb
X_6	11¼	op & peb. Not bottomed. X_7 not recorded.
X_8	15¾	op & peb
X_9	7	op & peb
X_{10}	0	Lst.
X_{11}	6½	op & peb. Not bottomed.
X_{12}	6¾	op & peb
X_{13}	13¾	op. Not bottomed; abundant limestone outcrops.
X_{14}	0	Lst.
X_{15}	5½	op

V. DRILLING

V_1	14	3Ts; 8½c; 2½op
V_2	12½	2Ts; 10½c
V_5	2½	1¼Ts; 1¼c
V_9	8½	2Ts; 6½c
V_{11}	4	1½Ts; 2½c
V_{12}	5	¾Ts; 4¼c
V_{15}	10	2Ts; 8c, op
V_{17}	13	2Ts; 11c, peb at 6 feet.
V_{21}	6½	1Ts, 5½c, op
V_{24}	2	1Ts; 1c
V_{25}	6	2Ts; 4c, op

TABLE 2 SUMMARY OF AUGER DRILLING

Test Area	Number of Holes attempted	Number of Holes deeper than 3 feet	Average depth of deeper holes. (feet)	Material
A	54	3	$10\frac{1}{2}$	c
B	27	9	9	op, peb, c
C	35	14	9	op, peb
D	20	1	$9\frac{3}{4}$	c, op
E	12	3	11	op
F	12	1	$5\frac{1}{2}$	c
G	16	1	$3\frac{3}{4}$	Ts, op
H	12	7	$7\frac{1}{4}$	op, c
I	12	4	$12\frac{1}{4}$	op
J	12	3	$10\frac{1}{2}$	op, c
K	Limestone	outcrop		
L	9	5	5	op, peb, p
M	12	1	$6\frac{1}{2}$	c, op
N	Limestone	outcrop		
O	Limestone	outcrop		
P	3	3	16	c, p
Q	12	10	$6\frac{1}{2}$	op
R	8	7	9	op
S	12	0	All limestone with top soil	
W_1	3	3	$15\frac{1}{4}$	op, p
W_2	12	1	8	op, c
W_3	Not drilled - probably mainly limestone outcrops.			
W_4	4	4	16	c, p
W_5	5	5	$5\frac{3}{4}$	c, p
W_6	2	2	19	c, p
W_7	12	4	10	c

c = phosphatic clay

op = oolitic phosphate

p = incoherent off white to white phosphate.

Ts = Topsoil

PLATE 2

F39/16

TEST AREA
N.E. corner showing pattern of limestone outcrop
Scale 1 inch to 10 feet
Depth in feet
A
B
C
D
E
F
G
H
I
J
L
M
P
Q
R
S
W_1
W_2
W_4
W_5
W_6
W_7
X drilling
V drilling
Pit No. 2
Pit No. 1
Pit No. 3
Pit No. 11
Pit No. 13
SCALE 1 inch equals 5 feet
REFERENCE - Pit diagrams
Limestone within 3 ft of surface
Pit continued to depth indicated in phosphatic material
Areas shown blank are near vertical limestone of chimney walls, or shallow chimneys completely excavated
BELLONA I.
Hand Auger Drilling and Plans of Pits, 1960 Survey
REFERENCE - auger drilling
Topsoil
Phosphatic clay
Oolitic phosphate
Oolitic phosphate and clay
Incoherent white to off white phosphate
Phosphate pebbles
Hole discontinued because of caving or large pebbles or very stiff phosphate and limestone. Other holes bottom on limestone.
Vertical scale 1 inch equals 10 feet