COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES

GEOLOGY AND GEOPHYSICS.

RECORDS.

RECORDS NO. 1951/61.

A GEOLOGICAL RECONNAISSANCE OF THE NEW HEBRIDES

by

H. B. Owen.

A GEOLOGICAL RECONNAISSANCE OF THE NEW HEBRIDES

by

H.B. Owen.

RECORDS NO. 1951/61

CONTENTS PAGE

A GEOLOGICAL RECONNAISSANCE OF THE NEW HEBRIDES

by

H.B. Owen.

RECORDS No. 1951/61

SUMMARY

The New Hebrides group of islands trend north-north westerly from Aneityum Lat. 20°12'S; Long. 169°43'E, to North Island of the Torres group, Lat. 13°13'S; Long. 166°35'E.

The group is part of the volcanic arc flanking the great Tertiary orogene which sweeps north-westerly through New Guinea, and the Malay archipelago and may be traced through the Himalayas to as far as the European Alps. Vulcanism has continued from early or pre-Miocene time until the present day, and the islands are composed of andesite, basalt, agglomerate and tuff with unconsolidated ash and cinder cones. Uplift associated with the regional folding has lifted submarine volcanic rocks, veneered with coral to heights of at least 2000 feet above sea level.

Rumours of mineral deposits were investigated with negative result, and an examination of solfataric sulphur deposits on the island of Vanua Lava showed that these deposits contain only a few hundred tons of high grade sulphur, and are of no commercial significance. The disparity between the writer's and previous estimates is believed to be due to (a) extremely optimistic estimates by earlier observers, and undue reliance placed by them on continuing deposition of sulphur at active fumarole and (b) marked decrease in activity since the discovery of the sulphur last century permitting the normally rapid oxidation of the sulphur to outstrip the rate of deposition.

INTRODUCTION.

The presence of native sulphur on the slopes of Mt. Suretamatai, Vanua Lava Island, Banks Group has been known since 1887 or earlier, and many claims, most of them extravagant, have been made regarding the potential value of the deposits. More recently manganese has been reported on the island of Maewo (also known as Aurora), and there have been unsubstantiated rumours of the presence of nickel, chromite, copper, cobalt, gold and coal, as well as sulphur on islands other than Vanua Lava.

With the examination of the sulphur and manganese deposits as the principal object, the writer visited the New Hebrides from 7th July to 14th August 1951, and took the opportunity of following up the rumoured occurrences of economic minerals as far as circumstances permitted.

It was not intended that every island in the New Hebrides group should be visited, but that the inspection should be limited to those islands reputed to contain sulphur, manganese and nickel deposits. In any event it was rightly considered that the irregularity of inter-island transport would impose a limitation on the scope of the investigation within the time available. Visits were made to Tanna, Eromanga, Efate, Espiritu Santo, Maevo and Vanua Lava. Unfortunately no opportunities arose to land on Aneityum or Gaua (Santa Maria) and only a small portion of Eromanga was seen.

Administration of the Group is conducted jointly by Britain and France, which Powers have set up a Condominium Government to control native affairs, public works, health, post-office and Customs. Nationals and ressortissants of either nation are controlled and protected by separate national Administrations. The islands are neither British, French, nor Anglo-French territory. The land, where not alienated, belongs to the native inhabitants and presumably mineral rights are the property of the land-owner; in the absence of Government or Crown Land there is no provision whereby mineral rights are reserved to the Government.

Excluding the small islands of the Torres group the New Hebrides consist of 14 larger islands listed below in order from north to south.

	Approx. Area sq. Miles.	
Vanua Lava	85	)
Gaua (Santa Maria)	85	) Banks group
Espiritu Santo	1500	
and Malo	70	
Maevo (Aurora)	90	
Oba	105	
Pentecost (Aragh or Raga)	125	
Malekula (Mallicolo)	800	
Ambrym	180	
Epi (Tasiko)	100	
Efate (Sandwich)	300	
Eromanga	330	
Tanna	150	
Aneityum	50	

The group, which includes many smaller islands, lies between Latitudes 13 and 21 degrees south and longitudes 166 and 171 degrees east. Vila, on the island of Efate is the principal town and seat of Government and is 1450 nautical miles by air from Sydney travelling via Noumea Santo (or Luganville), the only other town in the group, is on the southern coast of Espiritu Santo, 150 nautical miles by air north-north-west from Vila.

The islands are mountainous; the highest point in the group, according to Australian Aeronautical Sheet D12, is an unnamed peak on Santo which rises to 6195 feet, and in the whole Group there are fifteen peaks of 3000 feet or more. The thickness of the vegetation and rugged terrain impose great difficulties on attempts to penetrate to the sparsely inhabited interiors of even the smallest islands.

GENERAL GEOLOGY

The geological history of the Group is relatively simple, though each island has its own peculiar characteristics.

Broadly the history of the Group is one of volcanic activity continuous from Miocene or earlier times to the present day, and rapid discontinuous uplift. The Group lies to the east of the main Tertiary fold ridge and has been little affected by major orogenic forces. The emergence of the islands above sea level is due largely to the accumulation of great thicknesses of volcanic debris on the ocean floor and to a lesser extent to epeirogenetic uplift related to the Tertiary orogeny.

In some instances, e.g. Efate, vulcanism ceased before the first uplift took place with the result that submarine volcanics have been covered with a veneer of coral. On the other hand continuing volcanic activity, as at Tanna, and Ambrym for example has buried the raised coralline limestones beneath tuff, agglomerate or flows.

The early geological history of the islands has been strikingly demonstrated in very recent years by a renewal of volcanic activity in the sea near Tongoa. On 22nd September, 1948 steam and mud were observed to be shooting up from the sea at latitude 16°50'S, longitude 168°12'E about 4 or 5 miles off the coast of Tongoa. The activity continued for a week or so and then ceased, only to be renewed with greater intensity in about April 1949. By the end of that year a cone approximately one mile in diameter at sea-level and 300 feet high had been built up; at this stage volcanic activity ceased. (1) By now the new island, somewhat prematurely named Karua, has been reduced by rain and wave action to a shoal awash at high water. (2)

Presumably this will provide a platform on which coral will gain a footing unless its growth is prevented by renewed volcanic activity.

The uplifts have been relatively rapid followed by periods of stability during which new fringing reefs of coral have grown, only to be raised in turn and the process repeated.

Ideally the islands have the outward form of a stepped pyramid veneered with coral limestone, but two major modifications exist. One is due to the building of a large mass of volcanic material above sea level before the coral could obtain a foothold, and the other, already mentioned, is brought about by continued vulcanism which has piled agglomerate and, less commonly lava upon the coral terraces. Gaps in the coral veneer have permitted deep dissection of the underlying and comparatively weak tuffs and agglomerates. To this cause much of the rugged topography of Efate is due.

Tectonics. The group lies on the south-eastern flank of the great fold-ridge which trends north-westerly through northern New Guinea and continues half-way around the globe to southern Europe. The New Hebrides group forms part of the volcanic arc which runs parallel to the principal fold axis.

The oldest rocks seen by the writer on Efate are fine marine tuffs probably early Pliocene in age, and these have been tilted to dips of about 20 degrees in an easterly direction, but later beds overlying these unconformably have not been tilted, indicating that later uplift has been vertical.

Very rapid changes of level affecting limited areas have taken place in historical times, but these are ascribed to local volcanic effects and not believed to be closely related to regional folding.

VULCANISM & SEISMOLOGY.

Active, dormant and extinct, (or apparently extinct) volcanoes exist in the group.

Active volcanoes, or those which have been active within the past century include Yasour on Tanna, Ambrym, Lopevi and the submarine example near Tongoa mentioned above.

The writer was fortunate in being able to visit Yasour which may be inspected at close quarters. This volcano is a daughter cone rising from the floor of a large caldera. It is characterised by the high temperature of its andesitic lava, and by the violent changes of land level in the immediate vicinity which have taken place during the past 75 years.

---

(1) Extracted from records made by W.B. Roberts, Meteorological Officer, Vila.

(2) Admiralty Chart 1570 published prior to 1905 shows an island built up in 1897 by a submarine volcano about 5 miles north of Tongoa and 2 miles east of the south-eastern tip of Epi. This position is in the same locality as Karua. Mawson (1905) mentions that the volcanic island of 1897 was soon reduced to a shoal.

Ambrym was not visited by the writer but on one occasion due to a change in the prevailing south-easterly wind a good distant view was obtained from the air. A dense column of black smoke rose at least 5,000 feet above the summits of Mounts Benbow and Marum (4,380 feet) before being lost to sight in cloud. This volcano has a record of destruction of life and property, and is, at the time of writing, again in violent eruption. As in the vicinity of Yasour, marked changes of land level accompany volcanic activity on Ambrym.

Lopevi is an ash cone about 3 miles in diameter at sea-level and 4755 feet high. Several times since European settlement in the islands incandescent lava has overflowed from the small crater at the summit and streamed down to the sea (Mawson, 1905), but in 1939 lava burst through the southern side of the cone (N.I.D., 1944).

Dormant volcanoes include Mt. Suretamatai on Vanua Lava where activity is limited to solfataras emitting jets of super-heated steam, and boiling springs which combine to join the scalding torrent of the south branch of Sulphur River.

Steam and seepages of hot water also occur in the vicinity of Yasour on Tanna, and Mawson (op cit) records permanently hot ground in the island of Tongoa, and hot springs on Efate.

Craters of extinct volcanoes are a common feature of almost every island in the group. It is reported that a crater on the summit of Oba is filled with water, and the Admiralty chart shows a large crater lake on Gaua.

Earthquake shocks of low intensity are common. Apparently at long intervals shocks are sufficiently severe to cause damage to buildings.

Local opinion relates all tremors to volcanic activity and observations by many people have established that severe shocks felt at a distance of many miles coincide with renewed activity of Ambrym. The writer experienced one shock at Santo at 1.55 am. local time 18th July 1951, at a distance of 90 miles from Ambrym. The shock, which was accompanied by a loud sharp noise dying away in a rumble, shook steel frame buildings. A shock of this intensity cannot be attributed directly to explosive vulcanicity, but may be due to the sudden relief of tension at depth brought about by movement of the magma which feeds the volcanoes.

It is obvious that some of the shocks are related to the folding and uplift taking place in the vicinity of the group.

MINERAL RESOURCES

Largely due to the proximity of New Caledonia and superficial general resemblances of vegetation and topography, rumours of mineral wealth in the New Hebrides have persisted for many years. Enquiries made among many residents failed to find any person who had first hand knowledge of mineral deposits.

The oldest rocks identified in the group are agglomerates and tuffs which grade upward into Miocene limestones containing Lepidocyclina. These limestones have been intruded by andesite and buried beneath later eruptive rocks. (Mawson, op.cit).

Nothing the writer saw is likely to be older than Miocene. The fine marine tuff noted near Havannah Harbour on Efate is similar to that described by Mawson as overlying the Lepidocyclina limestone.

In view of the comparatively recent age of the New Hebrides the prospects for discovery of mineral deposits of economic importance must be regarded as poor.(1)

The most persistent reports have been of manganese, nickel and sulphur, whilst mention has also been made of coal, copper, chromite, gold and tin.

MANGANESE.

Manganese-ore occurs on the island of Maevo near Betarara on the western coast.

Maevo (or Aurora) is a long narrow island approximately 32 miles in length from north to south by a maximum width of 4 miles. It is extremely mountainous and is skirted along the western coast by a narrow coastal plain ranging in width from about ½ mile to a mere strip of beach below cliffs.

At Novorovo (10 miles south of Betarara) a precipitous gorge was followed for a distance of about 1 mile easterly to a height of 330 feet above sea level, when further progress was barred by a vertical cliff. No rock outcrops were seen in the river bed and all boulders were of volcanic origin. At the river mouth coarse basaltic agglomerate forms a narrow vertical ridge which has been pierced by wave-cut caves now raised a few feet above high water mark.

One short vein of ferruginous manganese ore, about ¼ inch thick was found in a joint in the agglomerate, and a place where a similar, but softer, seam had been gorged out by the native for making ceremonial paint was pointed out.

At Betarara boulders of coralline limestone containing irregular veinlets and blebs of manganese ore are found in the river bed. This river was followed up for about a mile and about twenty similar boulders, very sparsely distributed were seen. At the furthest point reached the stream had exposed sub-horizontal tuffs(?) which were deeply weathered to mottled gritty clay. The manganiferous limestone was not seen in situ. A few specimens of powdery manganese ore stated to be from the New Hebrides were seen in Noumea. It was stated that they were part of a parcel of about 60 pounds weight which had been collected over a period of several months by a trader who had an exaggerated idea of the value of manganese ore. It is believed that these specimens were found on Malekula.

NICKEL.

Unsubstantiated rumours of nickel on Aneityum and Eromanga have been in circulation since before the beginning of this century.

The writer was unable to visit Aneityum which is the southernmost island of the group, but a remarkably clear view was obtained from the summit of Yasour on Tanna 50 miles to the north-west.

The island presents the rugged profile typical of the other volcanic islands, and on the north-east and east coasts high-level terraces appear to be developed. Mawson (op.cit). during a short visit to Aneityum in 1903 records that all rocks in

(1) It is believed that De La Rue, a French geologist who worked in the New Hebrides some 12 or 14 years ago identified serpentine similar to that of New Caledonia, but his report is not available at the time of writing and the statement cannot be verified.

the area he examined are eruptive; he comments on the absence of raised coral reefs. The writer landed at Dillon Bay on the west coast of Eromanga and climbed the coral terraces to the rolling grassed plains which have a general elevation of 700 to 1000 feet. Also a good view of the south-west and west coasts was obtained from close inshore. At Dillon Bay near sea-level the raised coral is underlain by remnants of an ash cone. At 300 ft. above sea level an artificial break in the thin coral veneer exposed fine tuff containing few water worn pebbles. Above this point to the highest point ascended (750 feet) only coral could be seen. The surface of the higher points on the plain is composed of red-brown soil containing travertine, indicative of coral.

Along the coast, coral terraces and flat-topped hills which presumably are capped with coral rise to heights of at least 800 feet. Underlying tuffs and flows can be seen in places.

The highest points on Eromanga are Mounts Williams in the north and Robertson in the south each approximately 3000 feet; each appears to be wholly composed of volcanic rocks. Native tradition is that the active volcano on Tanna was stolen from Eromanga before the advent of white men. No evidence of the discovery of nickel on this island could be elicited by enquiries among European residents of the New Hebrides.

SULPHUR.

Sulphur is associated with active or recently active volcanoes on Tanna, Ambrym, Gaua (Santa Maria) and Vanua Lava.

Tanna

Steam is emitted from several points on the slopes of the cone of Yasour volcano which is in the south-eastern part of the island. Surrounding these points the surface rocks which are mainly ash and bombs of glassy vesicular andesite, have been decomposed to a white pug which in places underlies a thin superficial cover of red clay. These patches are slightly elevated above the general surface and are usually about six feet or less in diameter. Not all these areas have an open steam vent, but they are readily recognised both by appearance and the heat of the ground. In some of the mounds thin seams of sulphur of very limited horizontal extent are intercalated between the layers of red and white clay. The thickest seam observed had a maximum thickness of 4 or 5 inches, was lenticular in section, and surrounded an active solfatara.

The whole group of solfataras occur on the south-eastern flank of the cone within an area about 200 feet by 100 feet, of which area the clay and sulphur mounds cover less than 5 per cent. Another small group of steam jets was observed from the top of the cone issuing from flat ground on the southern side of the volcano. These were not visited. The steam issuing from the fumaroles did not smell of either hydrogen sulphide or sulphur dioxide.

Ambrym. The volcano on Ambrym is active with periodical outbursts of great violence. It is improbable that any sulphur deposits are on a greater scale than those on Yasour, and the record of destruction by this volcano is a strong deterrent to economic exploitation. One resident described the sulphur as "small pockets", others had never heard of sulphur on the island.

Gaua or Santa Maria. This island is composed entirely of volcanics. From the sea, coarse agglomerates overlain by lava can be seen. Reports of the sulphur are discouraging.

D.S. Askew who represented Australian mining interests in the Banks Islands is quoted by K.C. Church (1932) in a report

to the Broken Hill Pty. Co. Ltd. as advising that the sulphur occurred at an elevation of 1500 feet among hot mud pools and fumaroles. It is significant that although Askew was very favourably impressed with the Vanua Lava deposits he took no steps to secure or test the sulphur on Gaua after visiting the island.

A former Government official who had seen the deposits on Gaua and those on Vanua Lava stated that the former were insignificant in comparison.

Vanua Lava. Many optimistic claims have been made regarding the quantities of sulphur available in the solfataric crusts on the eastern slopes of Mt. Suretamatai.

Estimates of reserves range from the extreme figure of not less than 1,500,000 tons made by J.J. Rendle to the sober estimate of 4,000 tons by K.C. Church in 1931. Other estimates of pure sulphur made by people who were not entirely disinterested, and may therefore be excused a degree of exaggeration, lie between the extremes of 5,000 and 60,000 tons. Also much stress has been laid on the importance of suspended sulphur in the water of Sulphur River which is fed by boiling springs from near the solfataras.

The sulphur occurs at two localities and the deposits are known as Whitford's and Frenchmen's.

Whitford's deposit was not seen by the writer but it has been described in some detail by Church (op cit), from whose report the following description is taken.

> A group of solfataras occur within an area measuring 400 feet by 80 feet. The surface of this area consists of andesitic basalt decomposed to a white clay containing spheroids of partly weathered rock, and a few large rectangular blocks. Sulphur is being formed at fumaroles to give small circular domes. An examination was made to a depth of 6'6" into the side of one sulphur crust where its position on a creek bank gave a good exposure. The excavated material was hot and consisted of sulphur to a depth of three feet with small veins of sulphur in the decomposed rock below. Of three shallow hand bores put down in the sulphur crusts only one intersected an appreciable thickness of sulphur which in this instance was 2 feet thick.

Mr. Church estimated the total sulphur in Whitfords deposit to amount to 300 or 400 tons.

Frenchmen's deposits are north of Whitford's at elevations between 1200 and 1800 feet. Access to the deposits is difficult. From Nalgauhat (various spellings are used) on the coast north of Port Patteson a track leads west through an old cocoanut plantation (at present in proceds of being reestablished) for about one mile to the foot of the mountain, and thence continues for about three miles of difficult climbing on steep slippery ground, crossing several sharp spurs, and ultimately negotiating a mile of the scalding water of Sulphur River in a narrow gorge.

The solfataras occur grouped within an area of bare ground occupying the steeply sloping left bank of the hot branch of the Sulphur River. The sulphur builds up about narrow vents from which steam issues, and in extreme cases forms an irregular mound of yellow sulphur 4 to 5 feet high and 8 feet in diameter at the base. When the vent becomes plugged the sulphur mound deteriorates to a low dome-shaped heap one foot or less in height weathered to

a grey colour.

The sulphur mounds are surrounded by rock (basalt or andesite) weathered to white and grey clay containing kernels of deeply weathered rock with recognisable basaltic texture.

A grey and white friable siliceous material containing veins and blebs of sulphur immediately surrounds and underlies the sulphur mounds.

Within a few inches to a foot or so of the mounds, the sulphur contained in the siliceous aureole may amount to a substantial proportion, but at greater distances the percentage becomes inappreciable.

The siliceous material results from the intense chemical attack on the colcanics by hot sulphurous solutions which have completely removed all basic and alkaline elements leaving a mass of loosely coherent silica.

The somewhat similar siliceous crust which covers, or replaces, old sulphur mounds is believed to be due largely to the residual accumulation of insolubie matter originally present in the sulphur and partly to replacement by silica contained in the hot gases of the solfataras. It is perhaps significant that the old encrusted mounds are but a fraction of the height of active sulphur mounds which occupy a similar area. This observation strongly suggests that with the cessation of sulphur deposition, the sulphur is lost by oxidation and leaves behind it a much smaller volume of silica.

The total area of bare ground, which is bounded on the south by the river and on the north by dense vegetation, amounts to approximately 15 acres and contains about 90 sulphur mounds of which the majority represent old inactive fumaroles with a greater or lesser degree of weathering of the sulphur. It is difficult to estimate with high accuracy the total quantity of comparatively pure sulphur available but clearly it must be small. The largest mound is estimated to contain above ground level about 400 cubic feet of sulphur equivalent to 20 tons, and the three next largest deposits contain about 4 or 5 tons each. Allowing an average of 2 tons for each of the smaller mounds, which is probably a generous figure, the total sulphur in situ in the solfataras does not exceed 200 tons. Shallow excavations made in the outer edges of the cones disclosed irregular veins and patches of sulphur in a siliceous matrix, to a depth of only a few inches but examination of the base of a cone formed on a steep slope showed fine disseminated crystalline sulphur impregnating the decomposed rock at a depth of 3 feet below the base of the pure sulphur crust. Where the edges of active fumaroles were probed it was found that the ground was very hot at six inches below the surface and consequently accumulation of sulphur could not be expected.

No reliable estimate of the quantity of sulphur present as impregnations could be made without sampling by boring at close intervals, and the writer was unable to do this.

It is evident however that this sulphur will be present to a limited depth only (Church, op cit . obtained a sample from 3' to 6'6" containing 25 per cent sulphur), and will be restricted in horizontal extent to within a few feet of a fumarolic vent.

The hot branch of the Sulphur River is fed by boiling springs which issue above the main sulphur area described, and form a small hot pool which overflows into the river channel. Several small fumaroles with sulphur crusts emitting steam occur about the margins of the pool. The water in the river is slightly

turbid due to suspended clay stirred up in the pool, and, further downstream, additional clay is derived from the rapidly decomposing rock of the channel bed. The writer's visit was made during the dry season when the river was not diluted with meteoric water nor contaminated with clay washed in from the steep banks, nevertheless the water contained but little suspended matter most of which was clay. The water has a distinctly acid taste and smells faintly of hydrogen sulphide.

MISCELLANEOUS MINERALS.

Traces of cobalt, copper, manganese, nickel, iron and the more volatile metals lead, zinc, tin and bismuth have been found in fumarolic deposits in Europe and North America, and in fact, most ore-forming minerals have been found in volcanic sublimates, though such deposits are not usually of economic importance. There is no reason to doubt that the New Hebrides Group with its long history of vulcanism contains similar traces of metals, which may have been redistributed under the influence of weathering.

Magnetite occurs very widely distributed throughout the volcanic rocks as small grains, and, when freed from the rock by weathering and transported to the coast, has been concentrated by wave action to form the black sand beaches which are common throughout the Group. A sample of natural concentrate from a beach in Meli Bay Efate contained 64 per cent magnetite and a sample from Tanna contained both magnetite and ilmenite.

Pyrite also occurs fairly commonly as disseminated grains in some of the volcanic rocks, and it is probably that this brassy yellow mineral has been mistaken for gold.

Search for laterite or bauxite was constantly kept in mind although the youth of the volcanics was regarded as precluding the development of a complete laterite profile. An example of immature lateritic weathering was observed on Efate at an altitude of about 1500 feet. A distinct mottled zone underlying a partially developed ferruginous capping occurred in kaolinized bedded tuffs.

CONCLUSION

The writer's estimate of sulphur resources om the island of Vanua Lava is very much lower than any made previously. It is believed that the reasons for this are two-fold. First, the early estimates were made by persons who were interested in the commercial possibilities of the sulphur deposits and consequently their reports were not unbiased. Some credence must be placed on their descriptions of the deposits, although their interpretations are more open to question. Secondly, it appears that the rate of sulphur deposition may have greatly declined during the past 50 years with the result that removal of sulphur by weathering has outstripped deposition of fresh material. The early descriptions including one by B. Dunstan, formerly Chief Government Geologist of Queensland, contain references to sulphur cones 15 to 20 feet high, and the water of Sulphur River being yellow with suspended sulphur at the river mouth, which is in strong contrast with the writer's observations.

The more recent report by Mr. Church, already mentioned, describes the pure sulphur crust as "2 to 4 feet in thickness and also mentions that "the deposition of sulphur is at present going on, but severe weathering washes the sulphur away as fast as it is formed". The report also touches on the question of sulphur in the river water and states that at the mouth, owing to "recent freshets nothing unusual was noted, except that small particles of sulphur were observed in the river sands, at least five miles from the sulphur deposits".

At present there are no sulphur cones exceeding 5 feet in

height, and the great majority are collapsed heaps of sulphur less than 1 foot high and coated with siliceous weathering products. The Sulphur River contains only a minute amount of total suspended matter most of which is white clay.

The volume of sulphur on Vanua Lava falls short by a factor of one hundred or more of the quantity necessary to constitute a deposit of economic value. In addition to this overwhelming consideration, added difficulties are imposed by lack of access, heat, steeply sloping unstable ground, and need for selective extraction of the sulphur mounds.

REFERENCES

Church, K.C., 1932 Sulphur-Whitford Estate-Vanua Lava. Report to Broken Hill Pty.Co.Ltd. 13th Jan. 1932. Unpublished.

Mawson, D., 1905 The geology of the New Hebrides. Proc.Linn.Soc.N.S.W. 30 pp. 400-485.

N.I.D., 1944 PACIFIC ISLANDS. Geographical Handbook Series, Vol. III, Western Pacific. Naval Intelligence Division, Admiralty.