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THE RESIDUAL HYPOTHESIS FOR THE FORMATION OF JAMAICAN BAUXITE

- A CONSIDERATION OF THE RATE OF LIMESTONE EROSION.

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Abstract

Sinclair has recently suggested that the Jamaican bauxite deposits originated as an insoluble residue resulting from the solutional erosion of the White Limestone. A figure of 780 feet is given for the thickness of limestone erosion necessary to give the required volume of bauxite deposits.

The present work give figures for the concentration of calcium and magnesium for a number of streams draining from the White Limestone of north-central Jamaica. Considerations of the current rate of evapo-transpiration are also given. The contemporary rate of erosion expressed in terms of overall surface lowering is between approximately 70 and 40 mm/1,000 years. If this rate is projected into the past the bauxite deposits could have resulted from the solutional erosion of the White Limestone in a period of between 3 1/2 and 6 million years. A discussion of the most likely major errors and assumptions is also presented.

INTRODUCTION

Recent work by Sinclair (1966) considered the details of the genesis of the Jamaican bauxite deposits. An estimate of the overall bauxite reserves and associated deposits was expressed as equivalent to a layer of terra rossa approximately eight inches thick over the surface of the White Limestone outcrop (Sinclair, 1966, p. 29). Figures for the insoluble residue and density of the White Limestone were also presented (Sinclair, 1966, tables 1 and 2). If the Jamaican bauxite deposits represent a residual soil formed by the weathering of the White Limestone it is then possible to calculate the thickness of limestone necessary to produce eight inches of residual soil. Calculations presented by Sinclair (1966, p.30) give a figure of 780 feet as an estimate of the White Limestone removed. Further (Sinclair, 1966, p. 30) states that the erosion of this thickness of limestone since the Middle Miocene uplift is a reasonable postulate.

Sinclair does not cite any specific figures for the rate of erosion of the limestone either under present conditions or estimates of the rate of erosion in the past. The results presented below discuss the rate of solutional erosion of the White Limestone under contemporary conditions.

A measure of the solutional erosion of a limestone region can be obtained by considering the amount of calcium and, in many cases, magnesium carried off in solution by the waters draining the area. If the density of the limestone and the run-off from the region are also known it is possible to calculate the volume of limestone removed. Corbel (1959, p.98) produced a simple formula which permits the volume of limestone transported from an area in solution to be calculated. The original formula considered only the calcium and ignored the magnesium which is also removed in solution. The formula was later modified by Williams (1963, p. 435) to take account of both calcium and magnesium. This is a necessary modification as the majority of limestones are dolomitized to some degree.

Thus to obtain a figure for the time required to remove the 780 feet of White Limestone postulated by Sinclair as necessary to account for the observed Jamaican bauxite deposits three quantities are necessary.

- (i) the density of the limestone
- (ii) the quantity of calcium and magnesium removed in solution per unit volume.
- (iii) a figure for the run-off of the area concerned.

The formula as proposed by Williams (1963) for a catchment composed solely of limestone is as follows:

$$X = \frac{E(T_c + T_m)}{D}$$

10D

Where X = amount of limestone removed by solution in cubic metres/  
year/ sq. kilometre.

$T_c$  = mean  $\text{CaCO}_3$  content in parts per million (hereafter p.p.m.)

$T_m$  = mean  $\text{MgCO}_3$  content in p.p.m.

D = mean density of limestone in  $\text{g/cm}^3$

E = effective annual run-off in decimetres (dm)

Sinclair (1966, p.28) obtained a figure for the mean density of the White Limestone of 151 lb./cu.ft. ( $2.42 \text{ g/cm}^3$ ).

#### CALCIUM AND MAGNESIUM HARDNESS

During the period from November 1966 to September 1967 water samples were collected from nine sites along the north central coast of Jamaica. These sites were located between the White River to the east of Ocho Rios and the Laughlands Great River at Llandovery (see Fig. 1). All of these rivers drain from the White Limestone region of the parish of St. Ann and it is assumed that the whole catchment of these rivers is composed of White Limestone. The samples were analysed for their calcium and magnesium content by means of titration with E.D.T.A. (Schwarzenbach, 1957, and Smith and Mead, 1962, 209-211). The number of samples analysed and the mean calcium and magnesium values for each of the sites are presented in Table 1. The calcium and magnesium values are expressed in terms of calcium carbonate and magnesium carbonate as well as total hardness (the sum of calcium and magnesium carbonate).

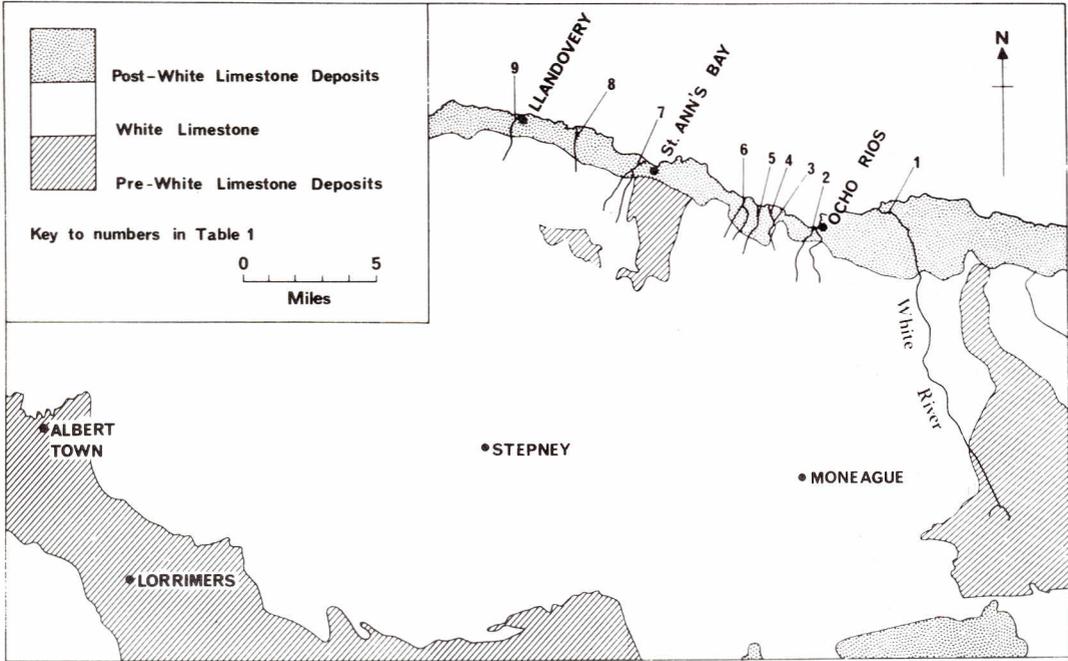


Fig. 1: Sample Locations.

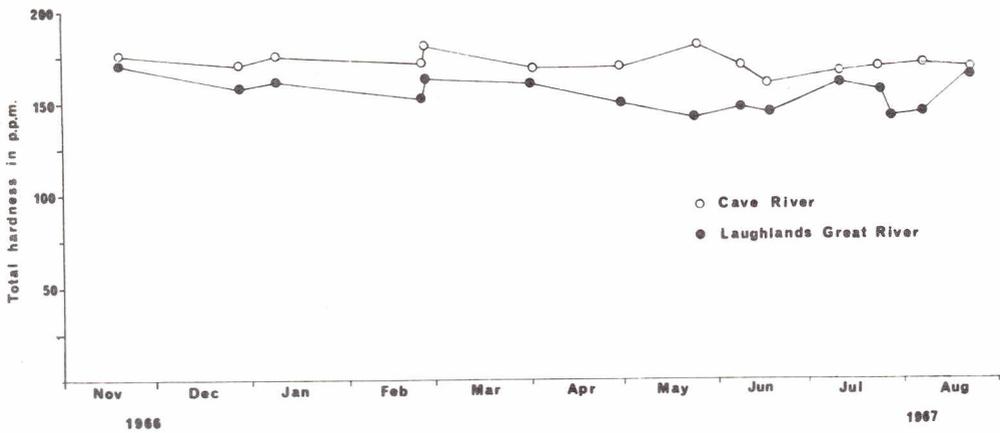


Fig. 2: Plot of water hardness.

Table 1: Mean hardness values.

Sampling Site.	CaCO <sub>3</sub> in p.p.m.	MgCO <sub>3</sub> in p.p.m.	Total Hardness in p.p.m.	Number of samples.
1. White River.	156	23	179	6
2. River at The Ruin, Ocho Rios.	158	21	179	15
3. River to the West of Ocho Rios.	163	25	188	14
4. Cave River	149	24	173	14
5. Dunns River	132	23	155	15
6. Roaring River	154	23	177	13
7. River to West of St. Ann's Bay	151	21	172	13
8. River near Mile Post 49.	154	27	181	12
9. Laughlands Great River. Llandoverly	131	24	155	15

There was little variation in the hardness values at any individual site throughout the period of observation. (Table 2). The samples were collected under a variety of discharge conditions including a number at times of storm discharge. Unfortunately no absolute discharge records were available for any of these rivers. The base flow of the rivers sampled varied very considerably from site to site but there was no significant relationship between size and hardness.

Figure 2 illustrates the total hardness values obtained for two of the sites, namely the Laughlands Great River at Llandoverly and the Cave River to the east of Dunn's River. These two examples are considered typical of all the sites sampled.

Thus it would seem a tenable hypothesis to suggest that the mean of the values given in Table 1 could be assumed to represent the hardness values necessary for substitution in the formula (outlined above) to obtain a value for the rate of erosion. The mean total hardness for the rivers draining the White Limestone of this section of the island is 173 ppm consisting of 150 p.p.m. CaCO<sub>3</sub> and 23 p.p.m. MgCO<sub>3</sub>.

#### CALCIUM HARDNESS IN RELATION TO MAGNESIUM HARDNESS

It is worth noting that the hardness figures for other spring sites associated with the White Limestone in other parts of Jamaica appear to be similar to those given above. Results related to the White Limestone of the eastern parts of the parish of St. James are

Table 2: Detailed analyses of calcium and magnesium hardness of samples collected from the sites listed in Table 1.

Date.	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Nov. 19th	150 23	168 21	170 27	153 23	133 23	158 21	160 25	123 42	133 38
Dec. 28th		163 30	163 30	153 19	133 25	163 21	153 15	130 34	138 21
Jan. 9th		163 21	160 27	150 25	138 23	163 23	158 23	138 23	138 23
Feb. 25th	163 27	165 13	163 30	148 25	145 15	163 21	145 19	135 23	133 21
Feb. 26th		163 21	168 23	155 27	133 23	160 21	180 23	140 21	140 25
Apr. 2nd	153 19	160 23	150 21	153 19	133 19	140 23	138 17	138 17	143 19
Apr. 30th	158 17	158 23	173 21	148 23	135 25	138 25	148 19	150 30	130 21
May 24th	150 15	155 21	158 23	153 30	125 19	138 23	148 17	160 30	120 23
June 8th		158 19	168 27	145 27	123 25		138 23	173 23	130 19
June 17th		153 23	168 23	140 23	120 25	138 25	135 19	200 34	123 23
July 10th		153 23	164 23	145 24	131 24	163 30	150 21	183 25	135 27
July 23rd		156 26	152 29	142 28	128 24	163 26	145 19	178 17	130 29
July 27th		151	167 24		131 26	162 21			124 21
Aug. 5th		144		156 15	141 23				120 26
Aug. 21st	161 34	161 22	159 27	149 21	132 26		167 29		150 18
	Ca Mg								

All hardness figures are in p.p.m.

given in Smith (1969, Table 5.2 and Figs. 5.9 and 5.10). For example the spring near Dromilly (grid ref. 299533) has a mean total hardness figure of 172 p.p.m. calcium hardness 154 p.p.m.  $\text{CaCO}_3$  and magnesium hardness of 18 p.p.m.  $\text{MgCO}_3$ . The ratio of calcium to magnesium from the sites in eastern St. James and from the sites listed in Table 1 from St. Ann is remarkably constant. This may indicate that the ratio of calcium to magnesium in the bedrock is comparable to that obtained from an analysis of the water samples. The difficulty in verifying this statement is the paucity of published data relating to the calcium to magnesium ratio of the bedrock. However, work undertaken by the author on the limestones of western Scotland (Smith, in litt) for which both water and bedrock analyses are available demonstrates that in that region there is close agreement between the two ratios.

#### EFFECTIVE RUN-OFF

The remaining variable necessary to obtain an estimate for the rate of limestone solutional erosion is a measure of the effective run-off. Effective run-off can be defined as the precipitation less the actual evapotranspiration, for the purposes of this paper measured in terms of mean annual figures. For the areas of White Limestone outcrop there is virtually no surface run-off. The effective run-off is by means of subterranean flow of which a proportion at least appears at spring sites listed in Table 1. Full discharge records for the sites sampled are not available and if they were it would not be possible to delimit the catchment area of any individual river as there is no simple method of obtaining information on the extent of the subterranean drainage net. It is possible to calculate values for the effective run-off although it should be stressed that such values are best considered as estimates.

A number of rainfall recording stations are located in the White Limestone area under consideration. The long term mean monthly rainfall figures for these stations are given in the Handbook of Jamaica (Anon., 1965, 42-62) and a rainfall atlas for Jamaica is also available (S.R.C. Jamaica, 1963). Additionally Sweeting (1956, p.2) in a study of the hydrology of the White Limestone states that the mean annual rainfall for this part of the island varies between 75 and 100 in. per year. The calculations for evapotranspiration described below necessitate monthly mean rainfall figures but of the rainfall stations for which such figures are available most are located at altitudes below that of the main White Limestone surface. This lower altitude leads to a rain shadow effect and the rainfall totals of such stations are an under-estimate of the rain falling on the greater part of the White Limestone catchment. With this problem two rainfall stations have been selected, namely Albert Town and Stepney. The former has a mean annual rainfall of 79.12 in. (Anon., 1965, p.44) and the latter a mean annual rainfall of 60.81 in. (Anon., 1965, p.46). The mean annual rainfall for the area as a whole is thought to fall within the rainfall range of these two stations.

Evapotranspiration is a difficult quantity to measure or estimate. Various workers have outlined empirically derived formulae for the calculation of potential evapotranspiration (Khosla, 1952, Holdridge, 1959) but considerable differences may exist between the actual and potential evapotranspiration values, (Thorntwaite and Mather 1957).

This is particularly the case when individual months have a moisture deficit i.e. the potential evapotranspiration is in excess of the precipitation. The figures obtained using two formulae for the calculation of potential evapotranspiration (Table 3) are obtained by the methods described by Khosla (1952) and Holdridge (1959). A method for the calculation of effective run-off that does not rely solely upon considerations of potential evapotranspiration is given by Thornthwaite and Mather (1957, p. 185-311). This method allows for the effects of monthly moisture deficits, soil moisture storage, cover type of vegetation, latitude and its effect regarding length of daily sun hours. All the values for potential or actual evapotranspiration presented below in Table 3 are summations values for individual months to give an annual figure. In all the calculations the temperatures used are the long term monthly means for Lorrimers Banana Research Station (Anon., 1965, p. 39) which is situated at an altitude of 2,847 ft. These temperature figures have been used as the altitude of this station is comparable to the elevation of the major part of the White Limestone under consideration. The results for effective run-off as obtained from Khosla (1952), Holdridge (1959) and Mather (1957) are given in Table 3.

Table 3: Potential Evapotranspiration and Effective Run-off Figures at two stations in Jamaica.

	Potential Evapotranspiration		Effective Run-off		
	Khosla	Holdridge	Khosla	Holdridge	Thornthwaite & Mather
Albert Town			30.28	28.92	37.72
	48.84	50.20			
Stepney			11.97	10.61	21.91

All figures are annual means and are in inches.

The values used in the calculations for the rate of solutional erosion of the White Limestone are those obtained by using the Thornthwaite and Mather method which is considered to be the best available method applicable to the area and data available.

#### RATE OF LIMESTONE EROSION

The mean density of the White Limestone as obtained by Sinclair was  $2.42 \text{ g/cm}^3$ . The mean calcium hardness value,  $T_c$ , is taken as 150 p.p.m.  $\text{CaCO}_3$ . The mean magnesium hardness value,  $T_m$ , is taken as 23 p.p.m.  $\text{MgCO}_3$ .

The effective annual run-off value for the precipitation figures for Albert Town obtained from the Thornthwaite and Mather formula is 37.72 in. (9.58 dm). The corresponding figure for Stepney is 21.91 in (5.57 dm).

Substitution of these figures in the formula of Corbel with its modifications by Williams gives the following values for the thickness of limestone removed.

Albert Town	68.5 mm/1,600 yr.
Stepney	39.8 mm/1,000 yr.

Using these figures the time necessary to remove the 780 feet of White Limestone postulated by Sinclair is  $3.47 \times 10^6$  yr. for Albert Town and  $5.98 \times 10^6$  yr. for Stepney.

#### ASSUMPTION AND MAJOR SOURCES OF ERROR

##### (a) Climate.

In presenting any estimate concerning the rate of erosion in the past the major assumption relates to an assessment of previous climatic conditions. Rarely it is possible in tropical latitudes to do other than assume that conditions in the recent past were similar on balance to those of the present. No detailed outline of the palaeoclimatology of Jamaica or the Caribbean exists for the period of the last five million years or so. In calculating the evapotranspiration estimates the precipitation figures are more critical than those of temperature. The generalised climatic situation for the recent past of the tropics indicates that temperature figures are unlikely to have changed significantly. Any major errors in the suggested time period are most likely to be due to unwarranted assumptions regarding precipitation.

##### (b) Hardness figures.

If climatic conditions changed in the past it is possible that the hardness figures would have shown some sympathetic variation. This is not thought to have been the case within the range of climatic change likely to have been experienced in the last million years.

There is also a possibility that the drainage from the White Limestone area under consideration does not all emerge at the surface to flow from the spring sites sampled. A proportion of the flow may emerge in submarine springs the existence of which is known around the coasts of the island (personal communication, Geological Survey). This is not thought to be a major source of error as such water would probably have a similar hardness to that emerging at inland spring sites. The constancy of the hardness figures can be interpreted as indicating a form of 'saturated' value with the prevailing processes responsible for the solutional erosion of limestone in the region.

##### (c) Erosion other than that of a solutional nature.

In Sinclair's work the implicit assumption is made that none of the insoluble residue of the weathered White Limestone is removed by erosional processes. This is clearly not the case as some of the insoluble residue is removed as suspended load by the water emerging at the springs sampled. No quantitative estimates are available for the sediment removed in this manner although attention was drawn to this process by Zans (1959, p.127 - 129). It is difficult however, to see how a reliable estimate of the insoluble residue removed in this manner could be obtained. This omission indicates that the thickness of limestone necessary to yield the suggested residue is an underestimate by a factor that is indeterminable.

The present work is an overestimate of the removal time as it is concerned solely with the solutional erosion of the limestone and discounts entirely other forms of erosional activity that are operative on limestone and non-limestone terrain alike. Material is transported from the White Limestone by processes other than that of solution such as suspended and traction stream load. The removal of material from a unit area of White Limestone by means other than solutional erosion is probably less than is the case for a comparable area of non-limestone terrain. This would be particularly true for material removed by normal river transport as traction (or bed) load. The subterranean nature of the drainage lines in the White Limestone would probably carry less traction load due to the restricted cave passages and sumps through which the streams flow. A sump situation would tend to act as a setting pool for coarser grades of sediment. It is not possible to give any realistic measure of this overestimate.

#### CONCLUSION

The assumptions present difficulties in stating an absolute value for the time necessary for the removal of the 780 feet of White Limestone suggested by Sinclair as necessary for the formation of the bauxite deposits by a residual hypothesis. If the major assumption is permitted that climatic conditions, especially rainfall, have remained relatively constant over the period, the limestone could have been removed by solutional processes alone in a period of  $3\frac{1}{2}$  to 6 million years. Fluvial transport of material other than of a solutional nature would cause this estimate to be reduced but to some extent this is balanced by Sinclair's assumption that none of the weathered insoluble residue of the limestone was removed from the region.

It would seem a valid overall conclusion that the removal of the thickness of White Limestone necessary for the residual weathering of bauxite genesis in Jamaica is possible in the time since erosion is presumed to have commenced in the mid-Miocene. The most reliable absolute age for the mid-Miocene is 12 million years for the upper boundary and 18-19 million years for the lower (Funnell, p.190, 1964). This would seem to allow an ample margin to cover the assumptions and errors likely to affect the figures presented.

#### ACKNOWLEDGEMENT

The fieldwork on which this paper is based was undertaken whilst the author was a temporary staff member of the Department of Geology and Geography at the University of the West Indies. I would like to thank all the staff of the department for their valuable assistance and for the generous use of departmental equipment.

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PROVENANCE OF THE RICHMOND FORMATION FROM SOLE MARKS

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Abstract

The orientations of sole marks in the Richmond Formation have been measured at several localities in the fault-bounded Wagwater Trough. A comparison of fault orientation and sole mark orientation is given. Two directions of sole marks predominate, one parallel with and one normal to the present boundary faults of the trough and these directions are preserved throughout the swing of the trough from an east, southeast trend to a south, southeast trend. This suggests that subsidence of the trough between these faults may have continued during deposition of the Richmond Formation.

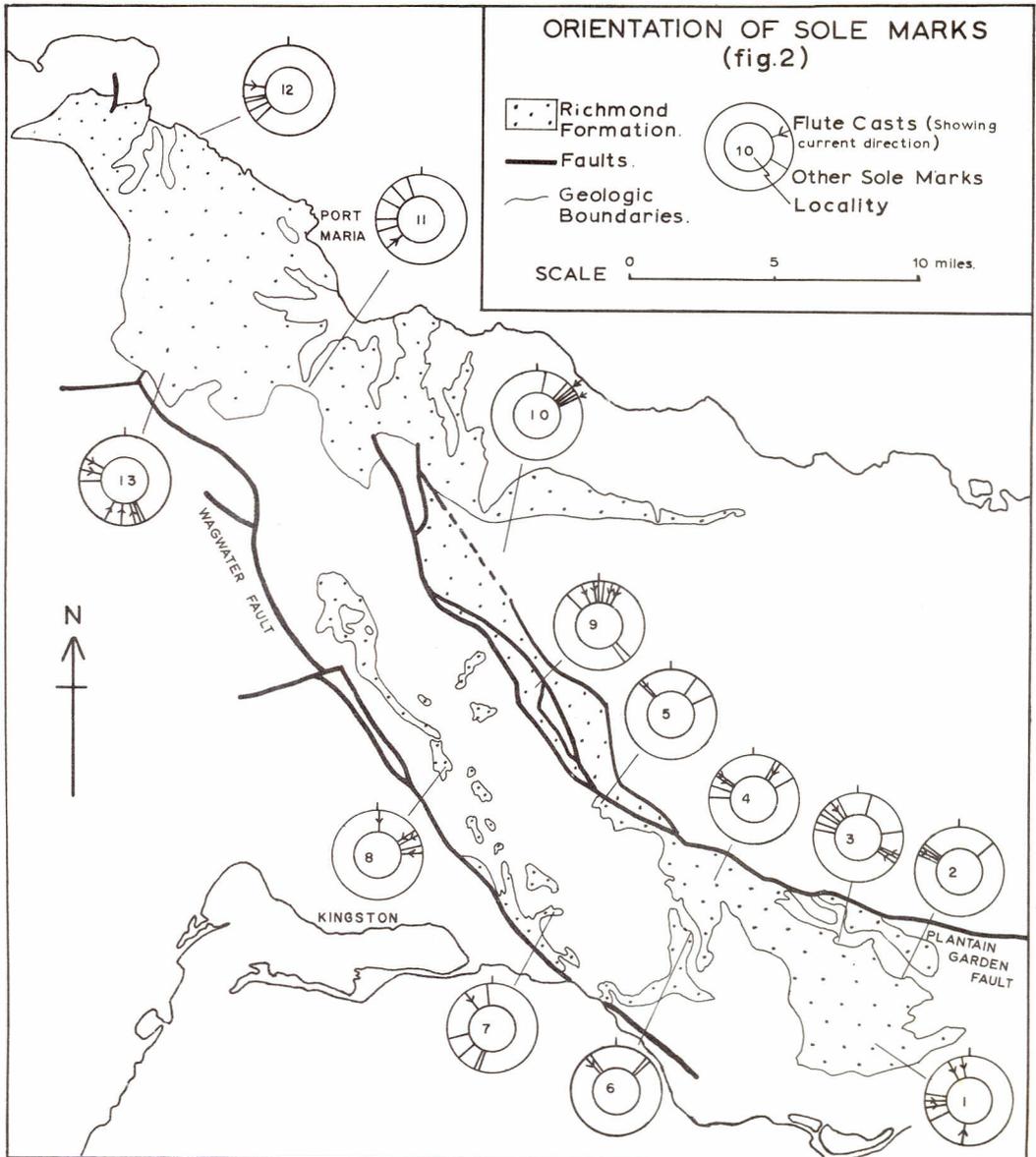
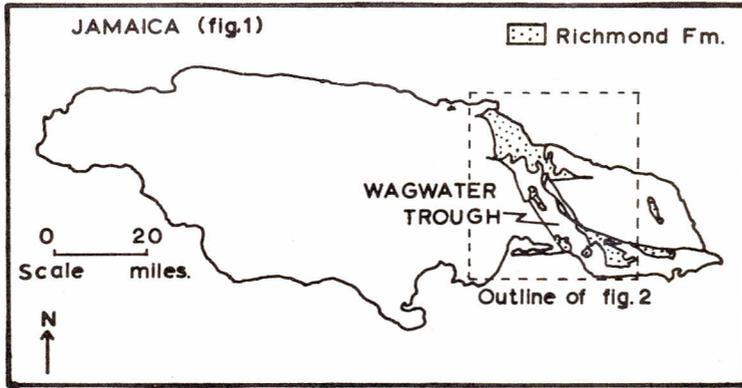
INTRODUCTION

This paper is a preliminary appraisal of directions of sediment transport in the Richmond Formation as revealed by sole marks. The formation is made up of interbedded sands silts and shales showing graded bedding and sole marks. It has some similarities, in places, to a flysch sequence.

The data presented were collected on short excursions and emphasis must be laid on the preliminary character of this article. Sole marks are rarer than might be expected in the Richmond Formation. At any one locality there may be only one bed displaying bottom structures in a sequence containing up to twenty coarse horizons with graded bedding.

METHODS AND LIMITATIONS

During this study we have selected only good examples of flute casts and groove casts. With flute casts it is possible to determine the direction of the current but with groove casts only the sense of current movement could be determined. The diagram (Fig. 2) indicates which are flutes and which are grooves; where grooves are closely associated with flutes we have assumed the direction of movement was the same in each case. No stratigraphic control could be exercised owing to the paucity of fossils so it is not possible to tell from what level in the Richmond the readings came.



Most of the strata bearing sole marks were not horizontal. It was therefore necessary to make some assumption in determining the original attitude of the structures. Where no other evidence is available we have assumed that the beds were rotated about their strike into their present attitude. Where folds were seen the structures were unrolled about the fold axis and the plunge of the fold axis allowed for plunges of up to  $45^{\circ}$  were found in some areas (Cummins 1964). The folding appears to be parallel or concentric and not similar because there is no noticeable change in thickness around fold hinges (Ramsay, 1961). Corrected sole mark data has been plotted on a map showing the distribution of the Richmond Formation (Fig. 2). We are aware of the possible errors, such as more than one movement being involved, but in view of the difficulty of determining such movements have adopted the simplest procedure for returning the structures to their supposed original attitude. So far no evidence has been found to suggest that more than one phase of tectonic folding has affected the Richmond Formation though there may be a case for distinguishing between the slump folding as seen in Mahogany Vale and the type of folds seen on the roadside east of Gordon Town. Faulting appears to have continued throughout the Tertiary on the same fractures. Our results show some sensible pattern after correction suggesting that the rocks in any one area have not undergone a very complex set of rotations and that if there were several phases of movement affecting one region they have been approximately coaxial.

#### THE RICHMOND FORMATION

The Richmond Formation is largely confined to a northwest trending belt, The Wagwater Belt, which is bounded on two sides by faults (Fig. 2). It consists of alternating sandstones and shales with a few limestones. In some areas, particularly around Port Maria, conglomerates are common (Zans, et.al. 1962).

It has been likened to the Alpine Flysch deposits, (Treichman 1924) and Chubb (1960) noted that the geological setting was similar to that of the Dauphinois Trough of the Alps. The sandy members are often graded and bottom structures such as flute casts, groove casts and load casts can be seen. This suggests that they were deposited by turbidity currents.

It is not rich in fossils, however, according to Robinson (1964 page 48) "The upper part of the Richmond yields an assemblage corresponding to the "Globorotalia" palmerae zone considered to be of latest early Eocene age"; a statement which seems to be in accordance with molluscan evidence (Woodring 1966).

It was deposited after a late Cretaceous orogenic episode (Chubb 1960) in a trough situated between two contrasting regions. To the east the Cretaceous rocks of the Blue Mountain Inlier are largely of marine origin and in some localities have been highly metamorphosed and deformed. They are associated with serpentinites and intruded by

granodiorites. To the west the predominant Cretaceous rock type consists of volcanics which have been deformed to a lesser extent in the late Cretaceous Orogeny. They have also been intruded by granodiorite. Although younger than the main upheaval, the Richmond Formation has been affected by the Tertiary movement in Jamaica which resulted in it being folded and faulted. The faults bounding the belt in which the Richmond is now found may have begun to develop towards the end of the Cretaceous because they seem to have been active during the deposition of the Richmond Formation.

#### MEASUREMENTS

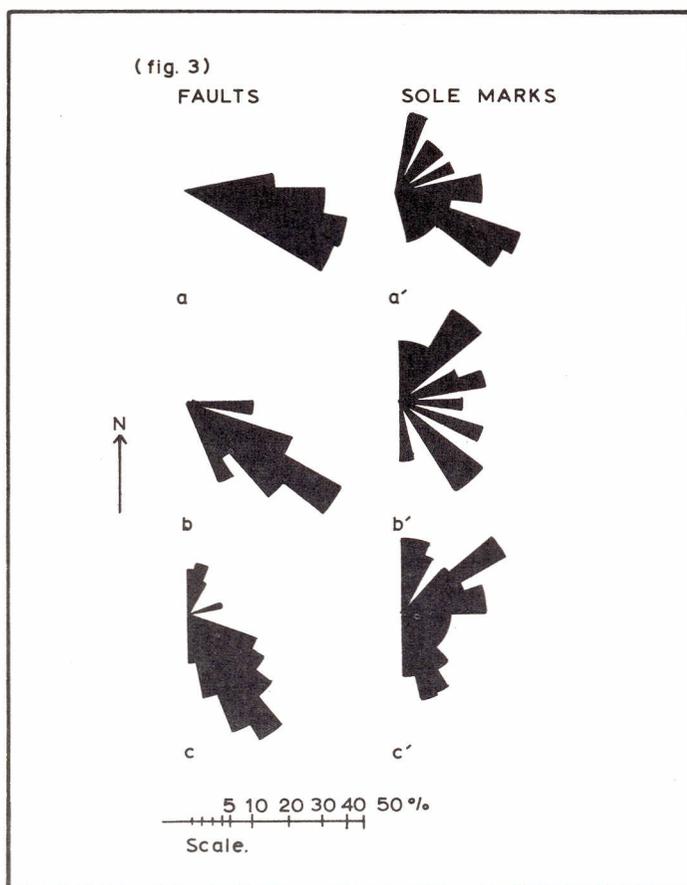
The measurements were made along roadside section and grouped together as follows. Each inset on Figure 2 is numbered and the readings which make up each one were collected in the following localities. All maps referred to are the Jamaica 1:50,000 series, third edition.

- (1) Roadside section near Petersfield, St. Thomas; grid reference 718366 to 719368, sheet N.
- (2) Roadside section near the Negro River Bridge; grid reference 725379, sheet N.
- (3) Roadside section just west of Trinityville; sheet N grid reference 715385 and a series of outcrops from this locality to New Monklands; sheet N grid reference 703392.
- (4) Road sections from southwest of Cedar Valley; sheet L grid reference 699393 to just west of Windsor Forest; Sheet L grid reference 686397.
- (5) Road section between Mahogany Vale Footbridge; grid reference 677407, and Hagley Gap; grid reference 683406, sheet L.
- (6) Road section near Cocoa Walk on the Yallahs River; sheet L grid reference 686387.
- (7) Roadside section, Dallas; grid reference 652398 and northeast of Newstead; grid reference 660386, sheet L.
- (8) The Newcastle road; grid reference 644415, sheet L.
- (9) From west of Silver Hill Gap; grid reference 501433 sheet L to Clydesdale; grid reference 663429, sheet L.
- (10) Road section on the road from Hardware Gap to Buff Bay at Balcarres; grid reference 653457 to 654459, sheet K. Note that on the 1:250,000 geological map of Jamaica this locality is shown as being within the Cretaceous, however, it is clearly Richmond Formation lithology and molluscs which are typical of the Richmond that have been found there.
- (11) Near Annotto Bay; Grid reference 616489 to 618494, sheet K.
- (12) The beach east of Port Maria; grid reference 593533 to 595532, sheet K.
- (13) The area round Richmond, the type locality of the Richmond Formation. Grid reference 596505, west Albany, 589484 south of Richmond, near Richmond Farm Prison and 609495 near Belfield works, southwest of Belfield Hlat, sheet K.

#### RESULTS AND CONCLUSIONS

The results show that the Richmond Formation contains sole marks which exhibit a pattern consistent with the idea of turbidity currents flowing off the sides of a trough and then along the axis.

The rose diagrams (Figure 3) show a comparison of the strike of faults which bound the Wagwater Trough on both sides and the directions obtained from measuring sole marks. The fault directions have been taken from the



1:250,000 geological map of Jamaica. The area in any one segment shows the percentage of the total length of fault which is orientated in that direction. Three separate areas have been chosen, the northwest trending zone, the east-west trending zone and the zone which is intermediate between the two. In each case there is a correlation between orientation of the faults and one of the maxima of the current directions. This may mean that the basin of deposition was very similar in shape to the present outcrop area and that it may therefore have been controlled by the present fault pattern. The area between the Wagwater and Plantain Garden Faults was probably subsiding during the deposition of the Wagwater Conglomerates and the Richmond Formation. Another maxima on the diagrams showing sole mark orientation indicates the flow of sediments from the sides of the trough. Direction of Current Movement is not indicated on these rose diagrams but it is clear from the insets on Fig. 2 that the material came in from both sides of the trough.

The directions recorded indicate the present shape of the outcrop may be related to the original basin of deposition. There are two main directions

recorded in most areas which indicate flow from the sides of and parallel to the present fault-bounded water Belt in which the Richmond Formation is now found. In general, as the strike of the trough changes from northwest-southeast to east-west the current directions change accordingly (Figs. 2 & 3). The rose diagrams in Figure 3a, b & c relating strike of the trough to the current directions shows that this correlation by no means an exact one. The currents seem to have come from both sides of the trough and although they travelled in both directions along the trough, perhaps fanning out at the foot of the slope, the principal direction was from the northwest and west.

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## THE CRETACEOUS ROCKS OF BLUE MOUNTAIN PEAK, JAMAICA \*

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Abstract

A conformable sequence of about 1,400 ft of Upper Cretaceous mudstones, tuffs and sandstones in the upper part of the track leading to the summit of Blue Mountain Peak, Jamaica, is described. The fossiliferous Blue Mountain Shale of previous authors occurs in the top half of this sequence. The oldest rocks are found at the summit itself which appears to be situated on an anticlinal axis. The track exposes the strata in the western limb of this fold.

## INTRODUCTION AND PREVIOUS WORK

The highest point in the Blue Mountains, and hence in Jamaica, is Blue Mountain Peak. The height of the trigonometric point, which occurs near to but not actually at the summit, is given on the Yallah's Valley Catchment, 1:5,000 Sheet No. 30 Water Commission map of 1961 as 7,448 ft above K.G.C. Datum (50 ft below Mean Sea Level); the highest point was measured by Abney level as approximately 10 ft higher. Unlike most of the Blue Mountain area which is difficult of access and little visited, the Peak is connected by a bridle path to the west from the hostel at Thitfield Hall and large numbers of hikers ascend the Peak each year. Solid rocks outcrop sporadically along the path, but except for the last mile are much obscured by slipped material and no continuous sequence can be made out. In contrast, the final mile or so of the track to the Peak shows a more or less continuous exposure of solid rock.

Since 1924, when fossils were first discovered on the track by Stockley, several geologists have collected additional material (see Chubb 1961). The first ascription of an (Upper) Cretaceous age to the fauna was by Trechmann (1929). Chubb (1961) published a review of the previous literature and an analysis of the fauna which he concluded was of Maestrichian age (*ibid.* p.6). More recently Kauffman (1966, p. 38) has implied a somewhat earlier dating of the fauna. No large scale map of the area has hitherto been published. On the 1:250,000 geological map of Jamaica (First Provisional Edition, 1958) a small patch of Cretaceous rocks was shown immediately west of the Peak though the area of the Peak itself was shown as (intrusive) andesite. The Geological Survey Department's Annual Report for 1961 (1962, pp. 6 - 7) records a summarised succession of the rocks north-eastwards from the Blue Mountain Fault based on the assumption of a regional dip to the north-east.

\* Publication authorised by the Director of Geological Surveys

## STRATIGRAPHY

According to our mapping, a conformable sequence some 1,400 ft in thickness can be made out in the area of the Peak (Fig. 1). The oldest rocks outcrop at the summit itself. These are red tuffaceous arkoses and arkosic sandstones, fine-grained for the most part, with some shales but also pebbly sandstones and conglomerates. As these rocks form the highest point in Jamaica it is therefore surprising that they are soft and friable and only poorly indurated. About 100 ft of these rocks were encountered, with no base seen.

Stratigraphically above these sandstones is a thick sequence of red and purplish shales and mudstones, probably about 300 ft thick, but it is difficult to estimate this exactly due to contortions and small scale folding which are well seen on the track. Thin beds of tuff also occur as do thin partings of brown mudstone.

These red beds are succeeded by 350 ft of massive grey, green and purple tuff and conglomerate. A small excavation showed that the junction between the shales and tuffs was a sharp, but apparently normal, sedimentary contact dipping to the north-west (Fig. 1). The tuffs are highly feldspathic and probably of andesitic composition; the conglomerates are composed of rounded pebbles of similar material. No bedding was visible in the rocks as exposed in the track. In comparison with the rocks previously described, they are well indurated.

The tuffs and conglomerates are succeeded by grey and greenish-grey, brown-weathering, blocky siltstones or silty mudstones - the contact is sharp but apparently conformable. It is in these beds that the previously mentioned fossils were found and thus these siltstones constitute the Blue Mountain Shale of Chubb (1961). The 'shale', which is 300 ft thick, dips to the west or south-west and the footpath zigzags to and fro across it (Fig. 1), thus explaining records of fossils being collected from heights varying from about 6,500 ft to 7,000 ft (Chubb 1961). The accounts of Matley (Matley and Higham 1929, p. 448) and Trechmann (1929) which Chubb (*ibid.* p. 1) considered conflicting are found to be in agreement. Rather it was Chubb's calculations, apparently based on the idea that the shale was horizontal, and Zans notion that the shales dipped to the north-north-east (*ibid.* p. 2) that were in error.

The Blue Mountain Shale is overlain by tuffs and conglomerates similar to those that occur below. The contact is sharp and conformable as may be seen at two places on the zigzag path. The tuffs are approximately 200 ft thick but become increasingly argillaceous in the top part and pass up into grey, brown-weathering, siltstones similar to the Blue Mountain Shale. Because the junction tends to be gradational, the boundary between the two lithologies, especially in the lower part of the track section, is somewhat arbitrary. Probably no more than 30 ft of the upper siltstones were seen, but for the purposes of the cross-section (Fig. 2) they were presumed to be somewhat thicker. Neither the thickness of the siltstones nor the formation overlying them is known because the section is terminated to the west by a fault.

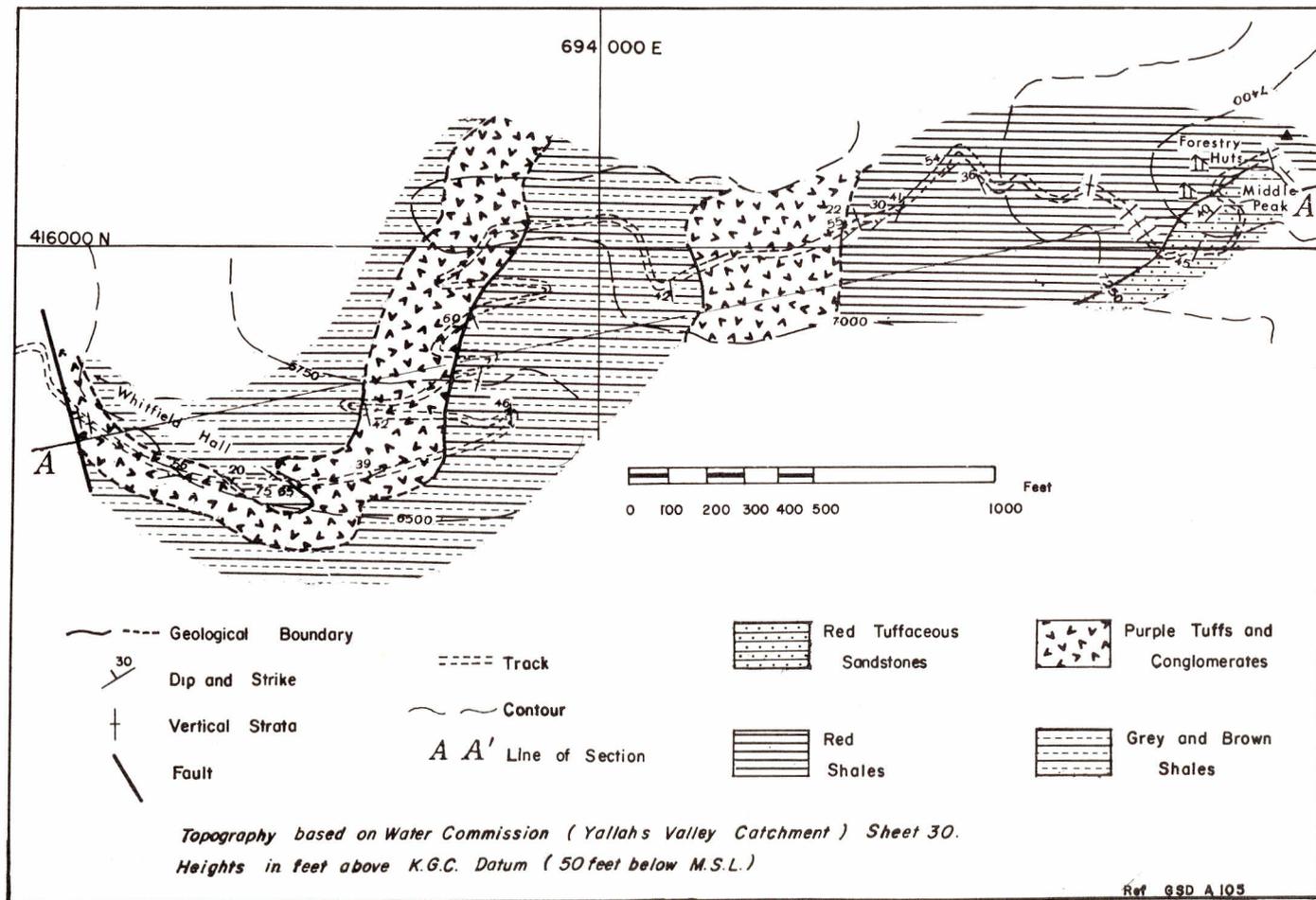


Fig. 1: Geology along the traverse to the Peak.

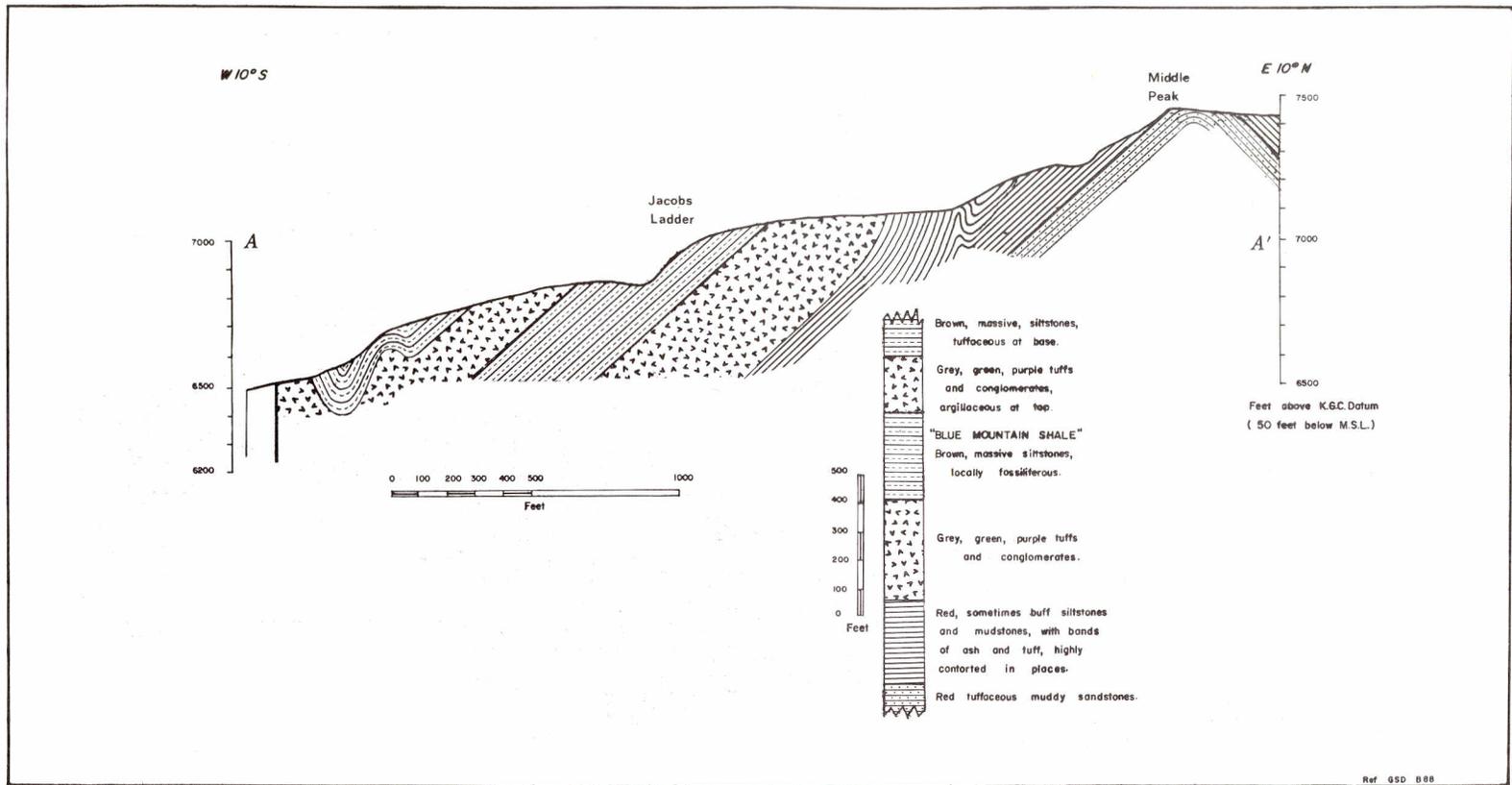


Fig. 2: Cross-section of traverse to the Peak.

## STRUCTURE

A major anticlinal axis appears to coincide with the Peak (Figs. 1 and 2) though, since exposures soon die out east of the summit, one cannot be sure of this. A subsidiary syncline is indicated by the mapping in the western part of the map. The mapping was not sufficiently extensive to make any accurate assessment of fold directions. The evidence for the fault at the western end of the section is provided by the sheared condition of the beds, their vertical attitude and a well-marked physical depression which corresponds to a prominent lineament in aerial photographs of the area. The trend of the fault is north-north-west, whilst the drag features associated with it suggest that it is a normal fault with a downthrow to the east.

## ACKNOWLEDGEMENTS

We wish to express our thanks to Messrs. D. K. B. Rose and P. Lyew-Ayee for their assistance in the field, and to Mr. J. B. Williams, the Director of the Geological Survey Department, for permission to publish this account.

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PHILLIPS GULLY COBALT PROSPECT \*

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Abstract:

A small occurrence of secondary cobalt/copper mineralisation, known since the mid 19th century, was investigated by geochemical soil prospecting and trenching followed by drilling. Good areal agreement was obtained for soil anomalies in cold and hot copper, cobalt and zinc. The corehole results were disappointing but as a pilot study the investigation is regarded as useful and although no economic mineralisation was indicated, the existence of more extensive low grade stratigraphically controlled mineralisation is not ruled out.

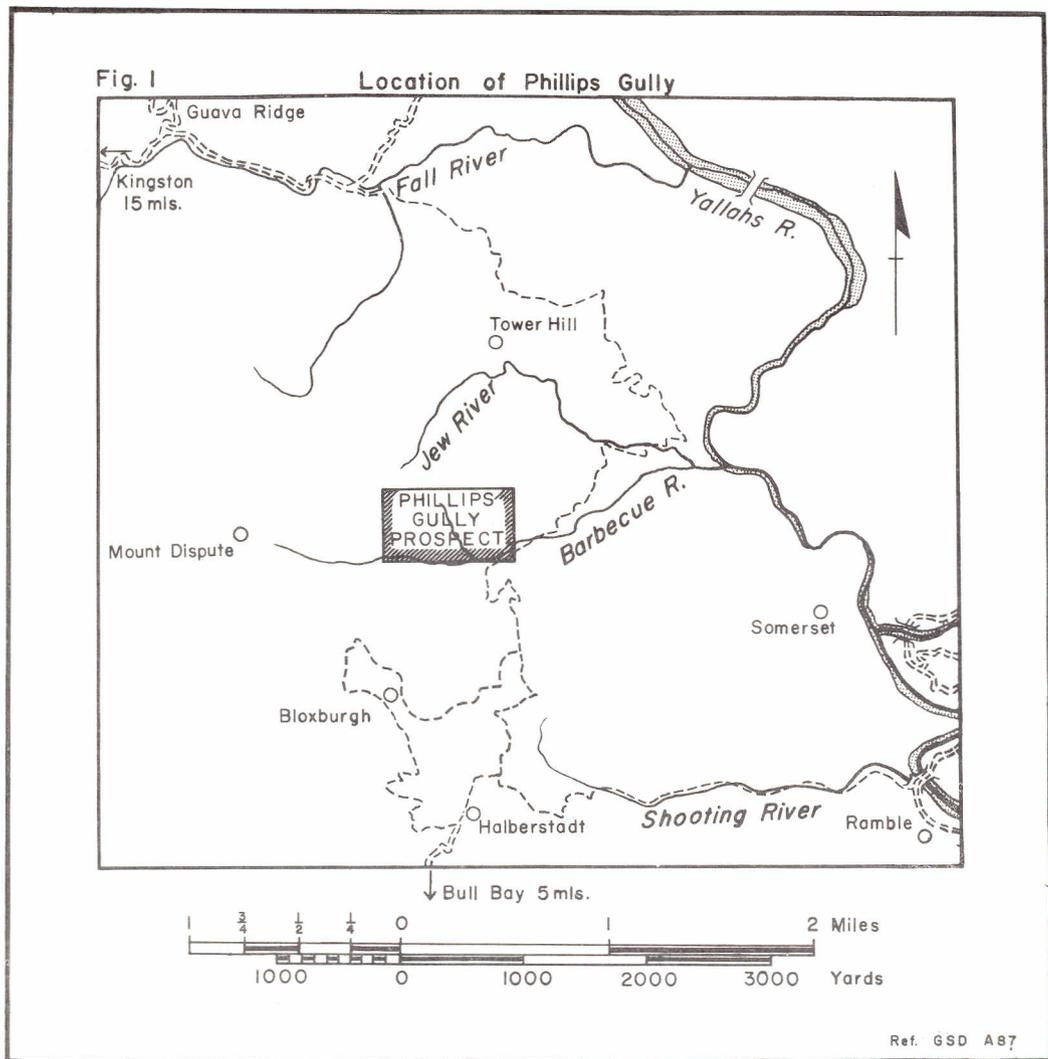
INTRODUCTION

This prospect is situated in a small gully on the northern side of Barbecue Valley opposite Plantain Gully in southeast St. Andrew (fig. 1). Reference was made to this deposit by Sawkins (1869, p. 36) who described the mineralization as "sulphuret of a steel-grey colour associated with conglomerates, etc., also as a sulphate of a fine rose-pink colour encrusting shale and is probably a decomposed condition of the former." Elsewhere (op. cit. pp. 98, 99) he identifies the primary minerals as "smaltine" and "cobaltine" and infers that they are to be found disseminated in the sediments and that a metallic grey ore of cobalt occurs in segregations associated with calcite.

Zans (1951, p. 18) in reference to this deposit, points out that it was mined, presumably unsuccessfully, in the 19th century, by the owner of the property, the Hon. Alexander Fyfe, presumably for the cobalt minerals. In Zans' opinion (op. cit.) "the occurrence appears, however, to be of small extent and is more of mineralogical than economic interest." This may be indeed the case, but as the Geological Survey drill was already operating in the Barbecue Valley, it was decided to carry out a limited investigation of this rather unusual occurrence.

As the site stands today, there is a spoil-heap to the east of the Gully on which can be found shales, sandstones and grits of the Lower Eocene Wagwater Formation with an abundance of malachite, azurite, and limonite, separately, or combined in a gossany form; coarse calcite and crystalline erythrite, usually associated; and pyrite with chalcopyrite.

\* Publication authorised by the Director of Geological Surveys.



We have not been able to identify any primary cobalt arsenide (skutterudite) or arseno-sulphide (cobaltite) in either the spoil-heap material or in fresh rock exposed by subsequent trenching. By the nature of the deposit, cobaltite, being a high temperature mineral, is unlikely to occur here, but skutterudite is possible, especially in view of the calcite-erythrite association in veins. There is no sign of an adit above this spoil-heap. The only adit at present visible is about one hundred feet west of the spoil-heap on the right side of the gully. This is now about thirty feet long and does not appear to be the source of the spoil-heap material however, as the only visible mineralization in this working is pyrite: it would appear to be an exploratory adit as it is oriented down the dip of a horizon rich in pyrite mineralization. A departmental manuscript report dated 1953 by B. R. G. McGrath describes this adit as being then 80 feet long and at about 60 feet from the entrance was "a very small vein of Cobalt." He too was of the opinion that

the spoil-heap was from another adit not then visible. The rocks exposed on the site comprise a series of fairly well bedded, light grey grits, sandstones and mudstones below a massive medium conglomerate. These clastics are a part of the Barbecue Beds of the Lower Eocene Wagwater Formation. About 100 to 150 feet above the site, igneous Newcastle Volcanics lie on the conglomerate. The dip of the sediments is towards the west and north-west at a shallow angle. A northwest to southeast shear zone is suspected, running across the site near the bottom of Phillips Gully.

#### GEOCHEMICAL SOIL SURVEY

The initial geochemical soil survey on the Phillips Gully prospect was carried out in the course of the extensive Barbecue Valley soil survey in 1965-1966. At that time interest was centered on the well defined areas of anomalous soil copper on the southern side of the valley. That investigation formed the subject of a previous report (Black and Bailey, 1968).

At the close of the Barbecue investigation it was felt that the spectacular secondary copper and cobalt mineralization on the Phillips Gully spoil-heap, associated with a few anomalous soil copper values on either side of the gully, merited more detailed attention. The cold extractable copper values are shown on an isograd map of Phillips Gully and environs in Fig. 2. The threshold value was taken here as 100 ppm. and sample locations with anomalous values are shown as solid circles. About 150 samples were taken in this small study area. 100 of the samples were then submitted to a commercial laboratory in Canada where cobalt, molybdenum, lead, zinc, and total copper were determined. The analytical results are shown in figs. 3, 4 and 5 respectively. Thresholds were determined by inspection: total copper, 500 ppm; cobalt, 90 ppm; Zinc, 250 ppm. On this basis, anomalous results are shown as solid circles. Sample points where anomalous lead (over 60 ppm) and molybdenum were recorded are signified qualitatively on the zinc and cobalt maps respectively by "Pb" and "Mo". The isograds were then constructed and, as can be seen, discrete areas of anomalous values are distinguishable. Note that the spoil-heap values have been used qualitatively rather than quantitatively in the construction of the isograds, as they are not representative of soil values.

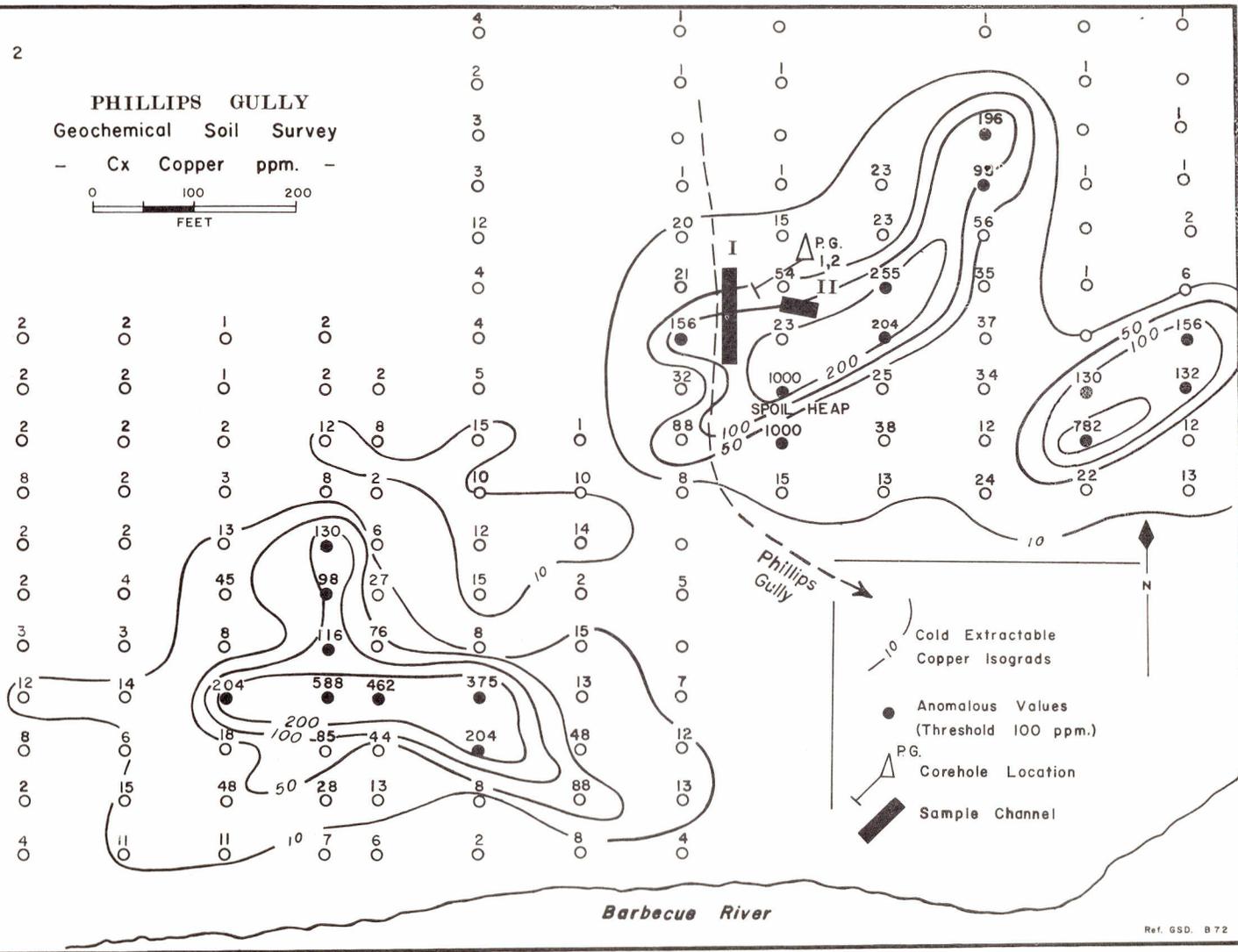
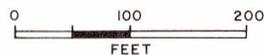
Inspection of the plots shows that 3 samples contain anomalous Co, Mo, Pb, Zn, Cu; 7 samples contain anomalous Co, Pb, Zn, Cu; and 9 samples contain anomalous Co, Zn, Cu. The contoured areas of the different metals show a common pattern. The dominant orientation is NE-SW with a minor WNW-ESE elongation. The former probably relates to the strike and the latter to shearing.

Of particular interest here is the comparison of the cold extractable and total copper. The 50 ppm contour on the cold extractable copper plot coincides approximately with the 400 ppm contour on the total copper, and defines approximately the same area (note that the threshold of anomalous values was taken as 100 ppm and 500 ppm copper respectively). There is obviously less dispersion of the copper which can be determined by cold extractable methods and for this reason, the anomaly may be more sharply defined. On the other hand the total copper values give more detailed information as can be seen by a comparison of figs. 2 and 5.

Fig. 2

**PHILLIPS GULLY**  
Geochemical Soil Survey

- Cx Copper ppm. -



*Barbacue River*

27

## TRENCHING

In order to sample the in situ mineralization and also assist in locating the drill-site on this prospect, a 35 foot trench (No. I) was cut across the old spoil-heap. Bedrock was found at a depth of about 3 feet, near the top of the spoil-heap, in the form of bedded mudstones and fine sandstones with malachite and azurite staining. A brecciated zone with coarse calcite and crystalline erythrite was also exposed. No primary cobalt minerals were found. The trench was channel sampled at 5 foot intervals, and the copper and cobalt analyses are shown in table 1.

Table 1. Analyses of Samples from Channel No. I.

	Sample No.	Total Copper %	Total Cobalt %
N-West	450001	0.90	0.66
	450002	0.24	0.66
	450003	0.08	0.18
	450004	6.00	0.07
	450005	0.40	0.11
	450006	4.00	0.07
S-East	450007	<u>4.20</u>	<u>0.01</u>
		Av. <u>2.46</u> %	<u>0.17</u> %

(Sampling Interval = 5 feet)

The relatively high copper values in these samples may be explained by the fact that this trench was cut along the strike of a zone in which there is a degree of secondary enrichment. Nearly all the mineralization is in the form of malachite, azurite (chessylite) and erythrite. As suspected from the outcrop in the trench, the copper is richer at the south-east end and the erythrite is confined to the north-west extremity where it is associated with coarse calcite in the shear zone which cuts across the site. It should be noted that this trench was not excavated to sample the grade of the prospects but to assist in siting the first corehole. However the analyses give some indication of the tenor of secondary mineralization at this site.

A ninety foot section of fairly fresh rock exposed in Phillips Gully about 100 feet west of the first trench was channel sampled (No. II) across the strike at 5 foot intervals, and the analyses of these samples gives a much better indication of the tenor of copper and cobalt mineralization to be expected at depth on this prospect (see table 2). The channel extended from just below the conglomerate at a heavily pyritised horizon, on the same level as the old exploratory adit referred to above, down to the flood plain of the Barbecue River. The 35 foot section MH 11 to MH 17 averaging 1.4% copper is obviously the most interesting part, and is almost entirely composed of hard, grey, bedded sandstones. Within this section is a twenty foot interval averaging 0.13% of cobalt.

The locations of trenches I and II are shown on the isograd maps.

Fig. 3

### PHILLIPS GULLY

#### Geochemical Soil Survey

— Cobalt ppm. —

(Anomalous Molybdenum values shown as Mo)

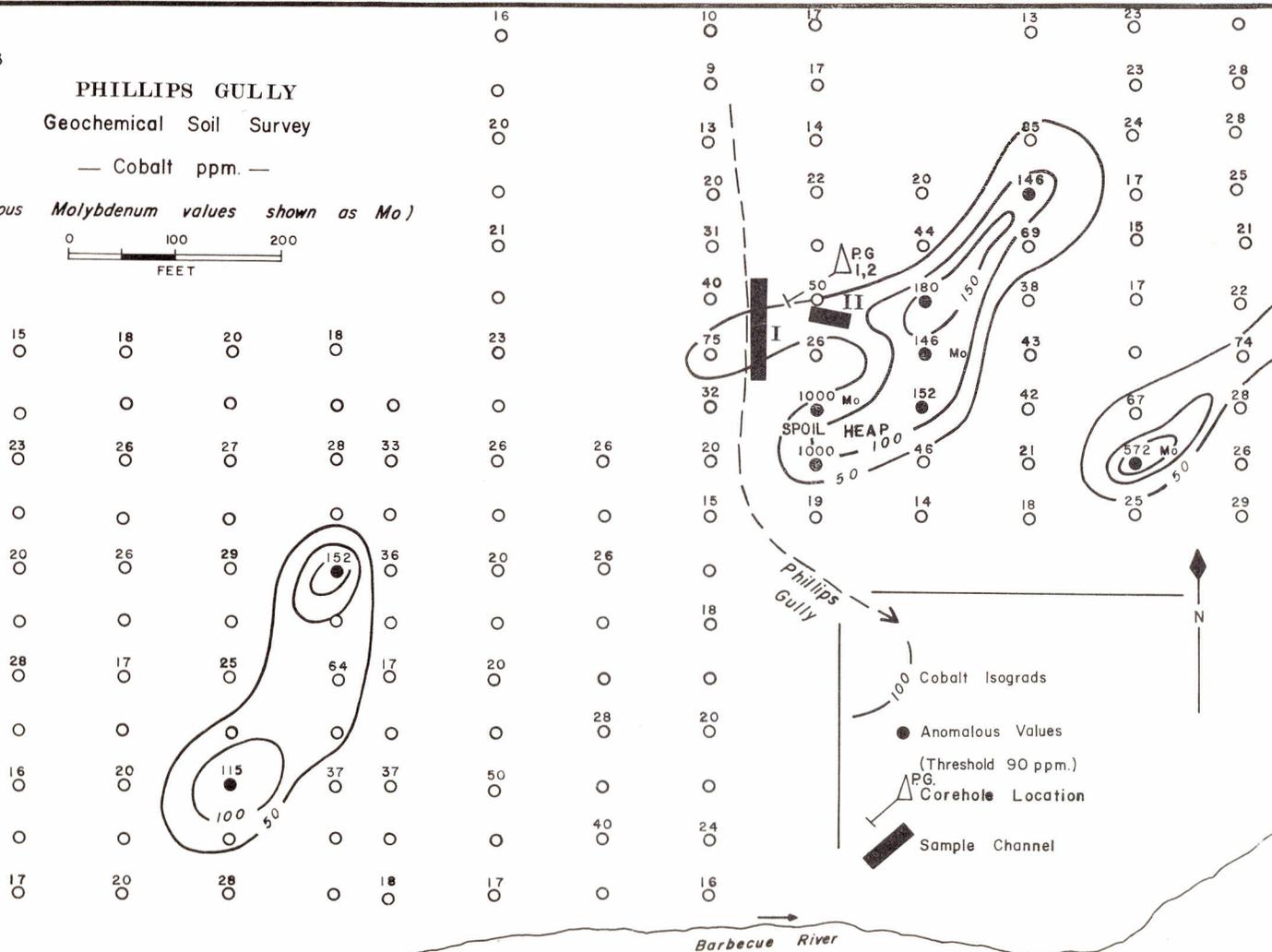
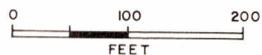
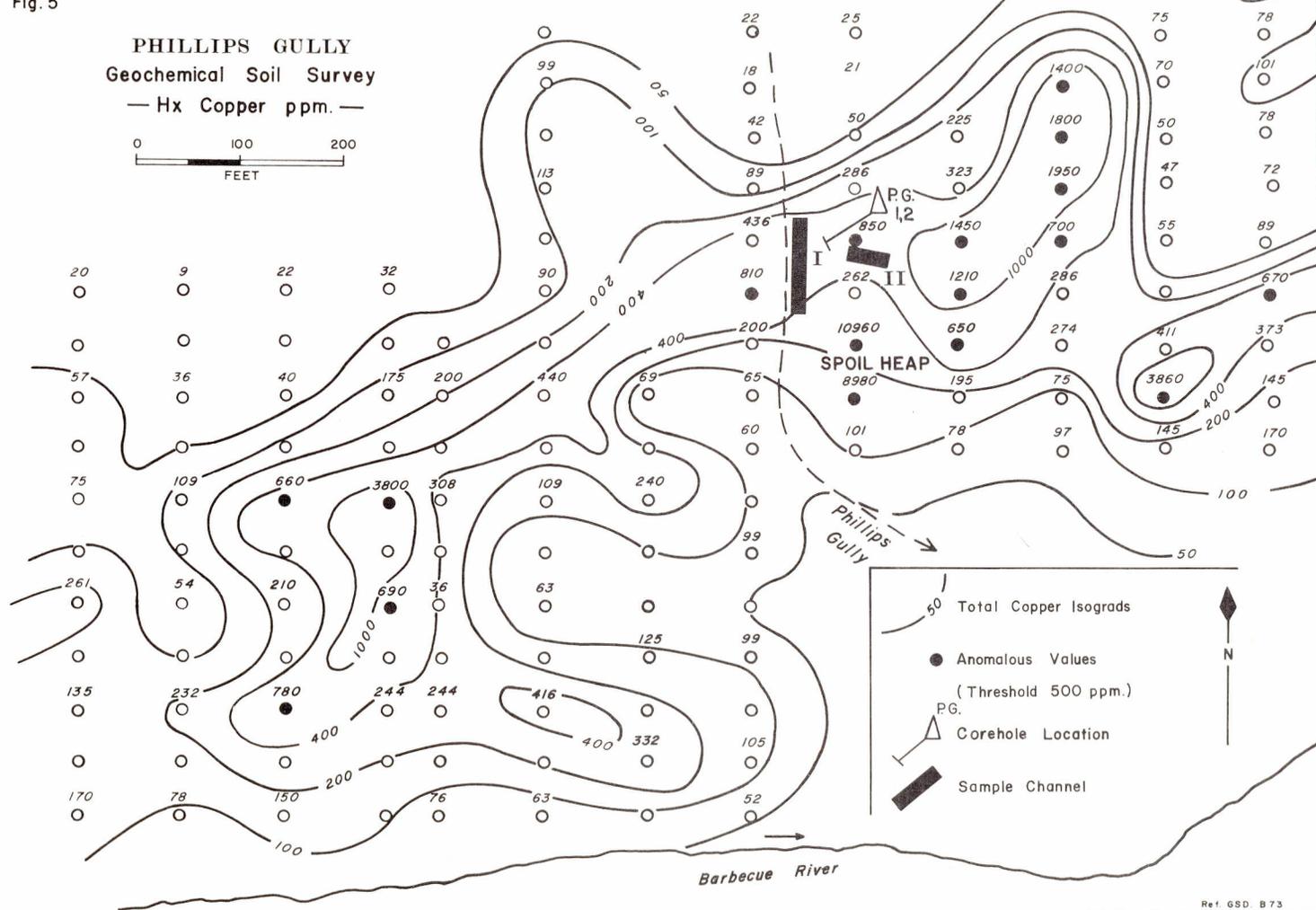




Fig. 5

PHILLIPS GULLY  
Geochemical Soil Survey

— Hx Copper ppm. —



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Table 2: Analyses of samples from Channel No. II

	Sample No.	Total Copper %	Total Cobalt %
Top of Gully North	MH 18	0.12	0.01
	MH 17	1.00	0.04
	MH 16	2.40	0.17
	MH 15	1.16	0.29
	MH 14	0.17	0.03
	MH 13	1.26	0.01
	MH 12	1.38	0.01
	MH 11	2.10	0.01
	MH 10	0.36	0.02
	MH 9	0.15	0.01
	MH 8	0.70	0.03
	MH 7	1.48	0.02
	MH 6	1.12	0.00
	South Bottom of Gully	MH 5	0.05
MH 4		0.06	0.00
MH 3		0.05	0.00
MH 2		0.06	0.02
MH 1		<u>0.30</u>	<u>0.02</u>
		Av. <u>0.80</u> %	<u>0.04</u> %

(Sampling Interval = 5 feet)

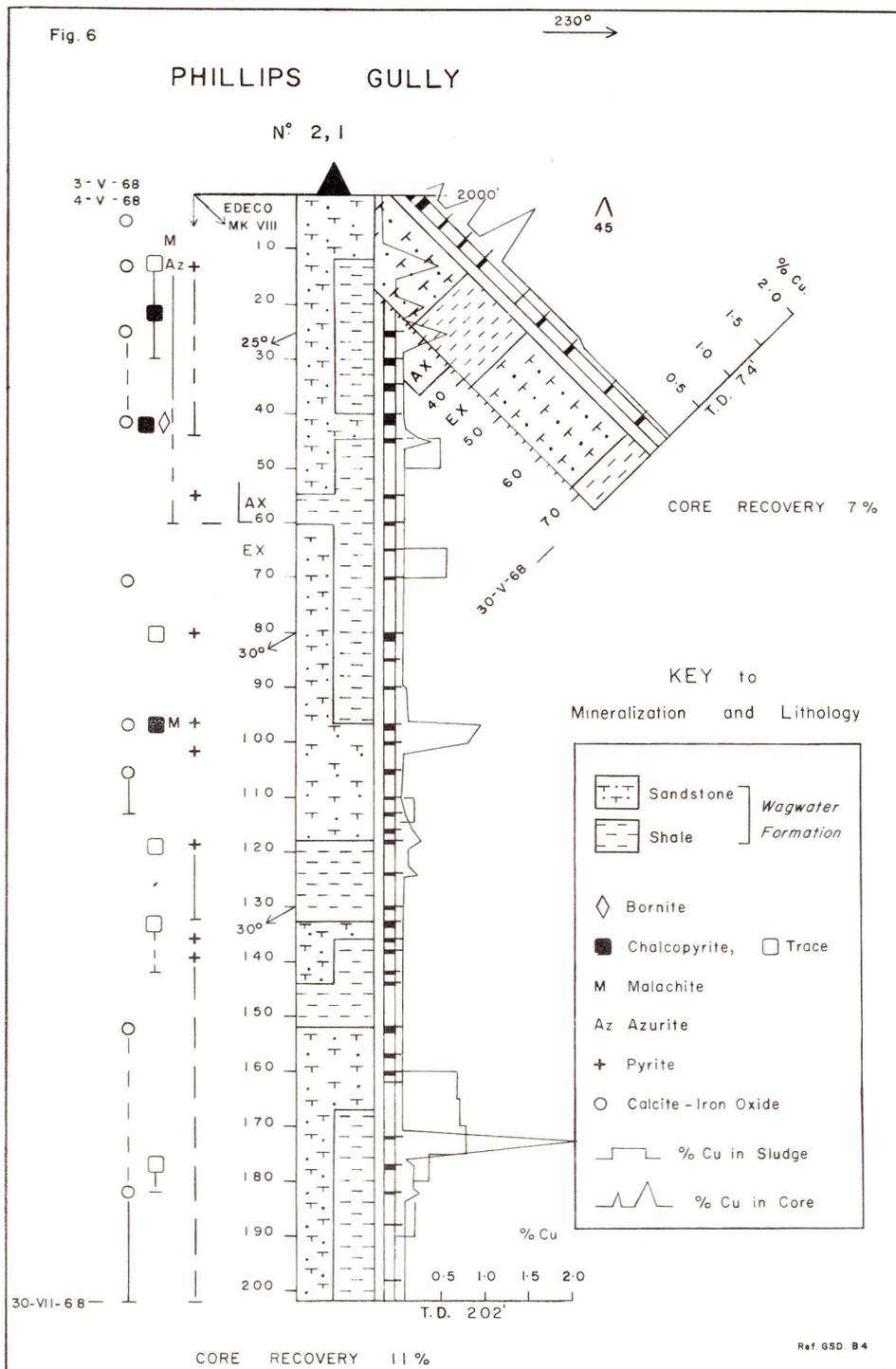
## COREHOLES

Two holes were drilled from this site, one inclined at  $45^{\circ}$  on an azimuth of  $230^{\circ}$ , and the other vertical. Both cored sediments of the Lower Eocene Wagwater Formation. No cobalt mineralization was detected in the examination and analysis of these cores.

Phillips Gully No. 1 (Fig. 6)

This corehole was aimed to core beneath the mineralized sediments exposed in the trench excavated across the top of the old spoil-heap. As mentioned in the foregoing, secondary copper, and erythrite associated with calcite were exposed in this trench. Furthermore, extensive sulphide mineralization is known to occur in the Gully about 100 feet west of the drill site.

The drill passed through 27 feet of fairly well bedded, grey, medium to coarse grained sandstones with malachite and azurite mineralization. Fifteen feet of barren olive-grey mudstones were then cored, followed by another interval of bedded medium sandstones. The hole was abandoned at 74 feet in black laminated shales without having encountered any significant mineralization. There was no sign of the expected erythrite/calcite zone, nor of primary sulphide mineralization in the sandstones. The laboratory analyses of the cores confirmed this, the only copper being in the zone of secondary mineralization occurring in the top 25 feet. Core recovery was very poor at 7%, the average copper content of the cores being 0.2%.



Phillips Gully No. 2 (Fig. 6)

This vertical hole was commenced on the same location as No. 1 and passed through a similar surface section of the light grey, medium grained sandstones with malachite and azurite staining. Core recovery in this hole was also poor - 11% - but it was eventually taken to a depth of dark greenish grey, clean sandstones alternating, and interbedded with olive-grey bedded mudstones. The dip in the cores averaged 30°. Pyrite mineralization is ubiquitous in this hole. Iron oxide and manganese oxide occur from surface down to 110 feet, and below 150 feet the sediments appear to be carbonatised. Apart from malachite/azurite staining within the first fifteen feet, and a minor occurrence of bornite at 40 feet, copper mineralization is entirely disseminated chalcopyrite. The three zones with the greatest concentration of visible copper sulphide are 15 - 20 feet, 96 - 100 feet and 178 - 182 feet. Laboratory analyses confirmed these zones showing average values of 0.5% over 10 feet; 0.9% over 2 feet; 2.1% over 1 foot. The average copper content throughout the hole was 0.2%. Sludge copper content was low, generally less than 0.5%, but the higher values confirmed the position and tenor of the core mineralization. The sludge averaged 0.2% over the hole.

From an examination of the log (Fig. 6) it is clear that the chalcopyrite is more abundantly disseminated in the sandstones than in the shales. It may be significant that the highest values occur in sediments which have the appearance of being altered by carbonatisation. Throughout this corehole no cobalt mineralization was observed, neither primary nor secondary.

This last corehole can be regarded as encouraging. So far as could be seen, the strata were neither sheared nor fractured. The sulphide mineralization occurs in a finely disseminated state in the coarser clastics. Some degree of lithological or stratigraphical control is indicated which opens up possibilities of far greater extent and tonnage of mineralization than was heretofore expected.

## CONCLUSIONS

The presence of copper cobalt mineralization is confirmed by this small investigation but it is clear that, as was suspected before, the extent of the known mineralization is restricted to the immediate vicinity of Phillips Gully. Although some relatively high grade samples were encountered the overall tenor of copper and cobalt is too low to indicate economic exploration. As a pilot study however, this investigation is regarded as having usefully indicated the type and tenor of mineralization in Wagwater sediments adjacent to the Newcastle Volcanics. Further, it appears that although shearing has caused some segregation of mineralization there is some stratigraphic control which affords the possibility of a much greater extent of mineralization if it can be traced.

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## FIELD EXCURSION

TO

THE BROOKS AND BITO GYPSUM QUARRIES, EASTERN ST. ANDREW

3rd May, 1970  
Leader D. W. Holliday

Twenty-four members and friends met at the entrance to the Harbour View Drive-in Cinema and then proceeded via Bull Bay to the office of Jamaica Gypsum Ltd. overlooking the Brooks gypsum quarry. Here, Mr. M. D. Lewes, Mining Manager of the Company, briefly reviewed the history of gypsum mining in Jamaica and gave details of mining methods and of the destinations and future uses of the rock quarried.

The gypsum deposits mined at the Brooks and Bito Quarries occur within the Wagwater Trough, a belt of thick early Tertiary (probably mainly Lower Eocene) sediments and volcanic rocks. Mapping in progress by members of the Geological Survey Department suggests that the stratigraphy of the rocks in this belt is more complicated than the simple sequence suggested in Zans et. al. (1962), being a "multi-decked sandwich" made up of alterations of the various sedimentary facies with intercalated volcanic rocks (Halberstadt Volcanics and Newcastle Porphyry).

The relationship of the gypsum to the other rocks of the Wagwater Trough has been a subject of considerable controversy. Zans (1951, 1958) thought that the gypsum was in the form of diapiric bodies intruded from below. Burke and Robinson (1963) accepted Zans' evidence for intrusion but listed objections to derivation from below and sought a source in younger rocks. Putlitz (1961) thought the gypsum was in situ, but he seems to have believed that the gypsum and associated sediments were deposited during Miocene or Pliocene times, after the sediments and volcanics of the Wagwater Trough were deformed. Bergey (1966) led a Jamaica Geological Society excursion to the Halberstadt Gypsum Quarry, owned by the Caribbean Gypsum Company Ltd., situated approximately two miles to the northeast of the Brooks and Bito Quarries. Here, he demonstrated that the gypsum was interbedded with Eocene rocks; several gypsum beds with intervening Wagwater Conglomerate, together totalling several hundred feet in thickness, were overlain by more conglomerate and underlain by Halberstadt Limestone. This suggested that previous views relating to the gypsum in the Brooks and Bito quarries were incorrect. Indeed the initial purpose of the present excursion was to demonstrate that the sequence observed by Bergey (1966) could be recognised in these two quarries and that the gypsum here is also interbedded with Eocene sediments, probably at the same horizon, and forms an integral part of the Eocene sequence in southeastern St. Andrew. Secondly it was intended to demonstrate sedimentary structures within the gypsum with a view to determine its depositional environment. Finally it was proposed to look at some of the evidence for diagenetic mineralogical changes within the gypsum,

especially relating to the formation of gypsum from anhydrite.

The party proceeded to the southwest corner of the Brooks Quarry where at several places red and purple conglomerates and sandstones (Wagwater Conglomerate) overlie gypsum with a thin (0-2 ft.) gradational zone between them. No signs of disturbance or movement were visible at this contact. Throughout the gypsum, here 200 ft. thick, and in the conglomerate, steep southerly dips are recorded. Later, the junction between the gypsum and the underlying limestones and shales of the Halberstadt Limestone was examined at two localities on the north side of the quarry, though at neither place was a completely clean contact visible. Not only do the two units dip steeply to the south, but the disposition of outcrops is such that if any plane of movement exists between them then it must be parallel to the bedding. There is evidence for some disturbance at this junction but this could well be the result of the solution of gypsum. Indeed the southerly dipping (50-70°) surface between the gypsum and limestone occurs on a south facing slope and is likely to be a prominent channel for percolating waters during times of rainfall. In this respect, Mr. Lewes remarked that, during the working of the quarry, a layer of "dirt" thinning downwards was always found between gypsum and limestone. Thus the gypsum is interbedded between limestone (at the base) and conglomerate above. That these beds are in fact Eocene in age has been confirmed by mapping, and by Dr. E. Robinson's discovery of the gasteropod Velates sp. in the limestone just below the gypsum.

Throughout its full thickness in the Brooks Quarry, the gypsum shows a nodular structure, i.e. the gypsum occurs as nodules with only small amounts of matrix (siliceous clastic material, carbonate minerals, or sometimes only organic matter) between them. The nodules are mainly ovate in cross-section, flattened in the plane of bedding, probably as a result of compaction of initially spherical nodules (Shearman and Fuller, 1969). All gradations were visible from single nodules (= nodular structure of Maiklem, Bebout and Glaister, 1969, pp. 202-3) to rocks showing the so-called chicken-wire structure (= mosaic structure of Maiklem et. al., 1969, pp. 210-11) in which individual nodules are separated by only a very thin but continuous mesh of matrix. At many horizons this structure grades into a similar structure - here called wispy structure - in which individual nodules are still more or less recognisable but the matrix no longer forms a continuous mesh and occurs only as thin discontinuous wisps. In a few instances complete coalescence of nodules occurs and the nodular structures is no longer visible. Such gypsum is here referred to as structureless in preference to Maiklem et. al.'s (1969, pp. 214-5) term massive since the gypsum in the quarry is also massive in the already widely accepted sense of McKee and Weir (1953), i.e. splits into units more than 4 ft. thick. Clearly the use of the same term in two different senses in describing the same outcrop could lead to confusion. At any one horizon the structure is more or less uniform with only minor variation, though elsewhere the variation is locally extreme, nodular grading to structureless within two or three inches. In some cases irregular masses of red conglomerate with only sporadic

development of nodules are found within the gypsum. The origin of nodular forms of gypsum (and anhydrite) has been the subject of much recent discussion. They are thought to be the result of early diagenetic interstitial precipitation of calcium sulphate minerals within unconsolidated sediments (e.g. Murray, 1964; West, 1965; Holliday, 1966) and indeed are similar to modern diagenetically formed evaporites in the sabkhas (arid area supratidal flats) of the Trucial Coast (Shearman, 1966). Since the gypsum in the Brooks Quarry occurs between the shallow marine limestones (including reefs) of the Halberstadt Limestone below and red continental alluvium (Wagwater Conglomerate) above, a sabkha origin for the gypsum would appear probable.

In the central and deeper parts of the quarry, gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) gives way to anhydrite ( $\text{CaSO}_4$ ). That the gypsum is a replacement of anhydrite is clearly seen in the field where gypsum invades the anhydrite along joints and cracks; this relationship is confirmed by examination of thin sections. Elsewhere in the world it is frequently found that gypsum is a near-surface replacement of sub-surface anhydrite (Murray, 1964; Holliday, 1970). Such secondary gypsum commonly occurs in two contrasting forms (Holliday, 1970) and both are visible in the Brooks Quarry. Small euhedral porphyroblasts of gypsum, usually no more than a few millimetres long are scattered randomly throughout the anhydrite at many localities and show no relationship to joints and thus formed independently of the circulation of recent meteoric waters. In contrast, fine grained alabastrine gypsum (Type 1 hydration texture of Holliday, 1970), which makes up the bulk of the deposit, typically forms along joint planes and thus is related to ground water circulation. Chicken-wire and other structures in the anhydrite are undisturbed by the replacement and indicate, along with other petrographic evidence, that gypsification is here a volume for volume process. Whether anhydrite was the primary calcium sulphate mineral or whether it developed from a gypsum precursor, cannot be decided on any local evidence so far available. No anhydrite pseudomorphs after gypsum have been observed. However, by analogy with the sediments of the Trucial Coast sabkhas, it would seem likely that the anhydrite was at least in part derived from the solution of earlier gypsum (Butler, 1969; Kinsman, 1969).

The party left the Brooks Quarry and proceeded by car up the hillside to the Bito Quarry, a few hundred yards to the north. At the entrance to the 1245 ft. level a good view of the quarry was obtained and this enabled members to see that the stratigraphical sequence in the quarry was similar to that previously seen. The dip of the beds in the Bito Quarry is also broadly to the south, but at a much lower angle, and this allows a tongue of Halberstadt Limestone to outcrop between the two quarries. The structure in this second quarry is more complex, however, as a syncline plunging to the south runs through the quarry bringing Halberstadt Limestone and Volcanics to outcrop both to the east and west of the gypsum. Wagwater Conglomerate and Newcastle Porphyry outcrop above the gypsum towards the top of the hill. A certain amount of hillwash obscures the gypsum and some interbeds of Wagwater rocks and Halberstadt Volcanics were seen.

Proceeding along the 1245 ft. level, attention was drawn to a highly flattened and compressed chicken-wire structure, common in this quarry. A plan view of bedding planes shows nodules with shapes similar to that previously seen but showing a tendency to elongation in a preferred direction. Sections normal to bedding show extremely flattened and elongated nodules. Opinion favoured flowage during folding rather than compaction due to overburden as the cause of the compressed structures, but there was some dispute as to the quality of the evidence for this conclusion. "Pinch and swell" structures discovered by Dr. R. V. Burne were taken as further evidence of flowage and this was confirmed by Dr. E. Robinson's discovery of loose blocks which showed that small-scale folding of the compressed nodules had also taken place. This structure was found in both gypsum and anhydrite, indicating that flowage took place prior to the formation of secondary gypsum. This is confirmed by the presence of randomly scattered and undisturbed gypsum porphyroblasts within the anhydrite. Preliminary petrographic examination of anhydrite with this structure shows slightly elongated grains of anhydrite with preferred orientation. If the flowage occurred at the same time as the deformation of the Wagwater Trough rocks (late Miocene), then this would provide a maximum age for the formation of the porphyroblastic gypsum.

After lunch, when liquid refreshment was generously provided by the Gypsum Company, most members dispersed leaving a smaller group who made a short stop on the access road to the quarries at a point (66983833) where spectacular examples of porphyroblastic gypsum, up to 1.5 cm long, showing strong 001 cleavage and sometimes forming rosette aggregates, were collected. Copper mineralization of Halberstadt Volcanics was also noted as well as some possible occurrences of copper and ferrous sulphates.

The party then drove east for some miles to a quarry near Grants Pen (677367) to see mudstones and siltstones of the Grants Pen Member (Yellow Limestone Group - Middle Eocene) which contain seams up to 1 ft. thick of fibrous gypsum. Elsewhere these beds also contain arrow-head twin crystals of gypsum, and calcite and gypsum pseudomorphs after hopper-faced crystals of halite (Zans, 1958). Examples of the latter were collected by a few members from an overgrown section at milepost fourteen on the return to Kingston.

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## CORRESPONDENCE

The Editor

May 22, 1970.

Dear Sir:

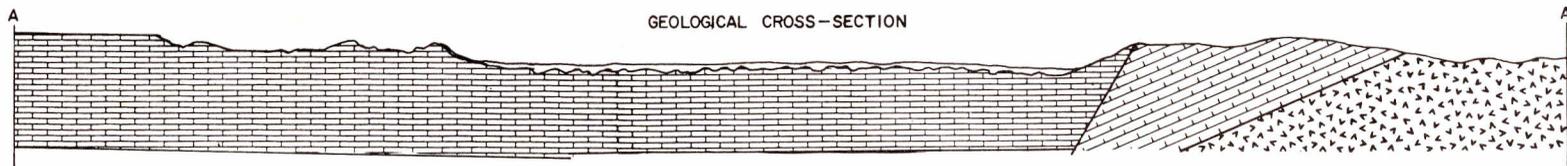
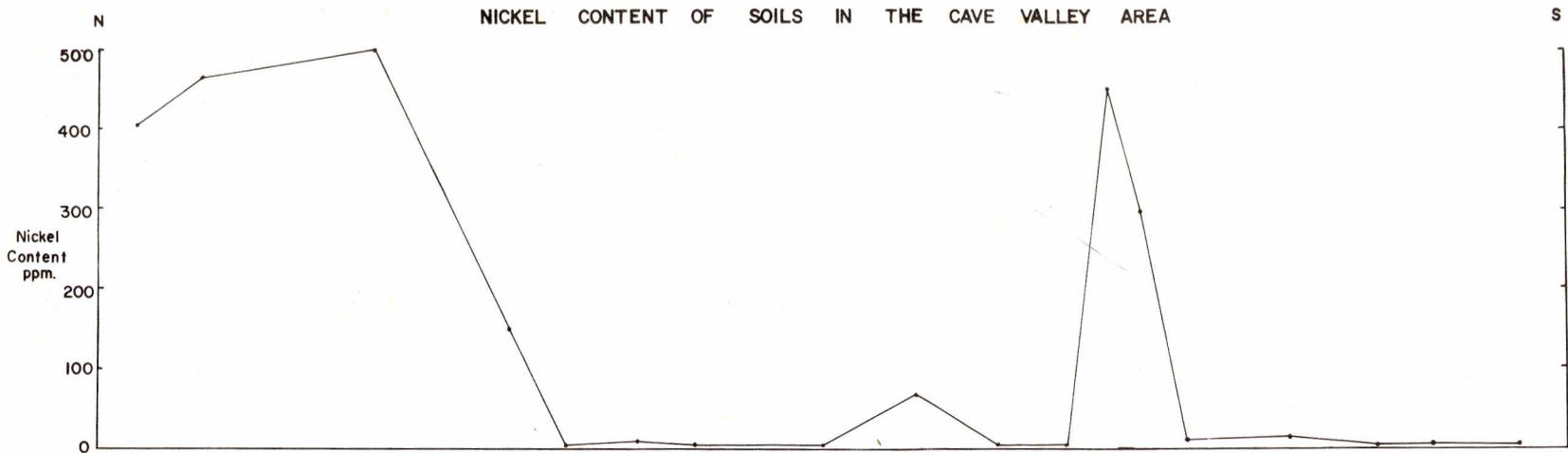
I have just seen a copy of Volume IX of the Journal containing my paper on nickel in the soils of Cave Valley and have noticed a drafting error which rather drastically affects the sense of Figure 2. Cave Valley is underlain by White Limestone and the high nickel values in the soils occur on the slopes around the valley where the White Limestone rises above the clay deposits of the valley floor as is shown correctly on Figure 1. However, Figure 2 shows the valley to be underlain by Yellow Limestone which, of course, does not weather to give nickeliferous bauxitic soils.

Perhaps you can publish a brief note in your next issue pointing out the mistake in the legend accompanying Figure 2.

Best regards,

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| 3/4 | 1/2 | 0 | 1 | 2 miles

vertical exaggeration x 2

- |                      |                  |
|----------------------|------------------|
| Alluvium             | Yellow Limestone |
| Cretaceous Volcanics | White Limestone  |

Fig. 2: (Revised). See Sinclair's letter on p. 41.

