

A
THESIS
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GEOCHEMICAL PROSPECTING STUDIES FOR BASE METALS
IN TANGANYIKA AND BURMA

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ABSTRACT

Geochemical dispersion patterns for lead and associated elements related to base metal mineralisation were studied at Bawdwin in Burma and at Mpanda in Tanganyika. Both areas have a similar, tropical climate.

In the Bawdwin area, surface anomalies were detected near two deposits covered by 90 - 200 ft. of relatively barren caprock. The variable degree and attitude of the rock fissuring are probably responsible for the inconsistent relationship between the surface anomaly peaks and the underlying mineralisation. The lead anomaly in residual soil occupies an area of about 0.5 sq. mile, the size of the weathered bedrock anomaly being somewhat smaller. Gravity creep is responsible for the asymmetrical dispersion pattern of lead in the soil on the steep slopes. Anomalous soil is also being eroded into the gullies and streams. The dispersion patterns of copper and zinc in the acid soil appear to have been considerably modified by leaching. Much of the zinc is entering the drainage in solution and is liable to be precipitated in fine sediment.

Contamination causes false, soil anomalies near former smelters at Bawdwin. This hazard can be overcome by deep soil sampling. The proportion of cold-extractable lead in contaminated soil is considerably higher than that in soil over mineralisation.

In the flat-lying terrain at Mpanda, lead anomalies in residual and colluvial soil extend for several thousand feet down-slope from sub-outcropping mineralisation. Mechanical dispersion accounts for the spreading of anomalous values in near-surface soil during the long period of weathering, while chemical factors may partly contribute to the equally extensive dispersion of lead in the underlying laterite. The concentrations of lead in the laterite have probably been derived from the overlying soil and also from bedrock mineralisation. Anomalies are developed in seasonal swamps and streams, by the erosion of anomalous soil.

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INTRODUCTION

These studies form part of the current research programme directed by Dr. J. S. Webb at the Geochemical Prospecting Research Centre, Imperial College, London. The geochemical prospecting problems discussed in this thesis are concerned with the primary and secondary dispersion of lead, copper and zinc from base metal deposits at Bawdwin and Mpanda. These areas are respectively situated in the Northern Shan States of Burma and the Western Province of Tanganyika. The climate in both areas is essentially sub-tropical. The terrain at Bawdwin, however, is mountainous, whereas a peneplained land surface extends over most of the Mpanda area.

The writer visited Mpanda from November 1956 to May 1957 and Bawdwin from November 1957 to May 1958. Some 11,000 soil, rock and stream sediment samples were collected during the course of the field work. Many of these were analysed under field conditions, although all critical analyses were done by the writer at Imperial College. For reasons which are explained in later sections, these studies are mainly concerned with lead, the principal ore metal in both deposits; relatively scant attention was paid to the dispersion of copper and zinc.

PREVIOUS WORK.

1. Bawdwin and Mpanda Study Areas.

The initial geochemical appraisal of the Bawdwin area was undertaken by J. S. Webb on samples and information provided by R. O. Morris (Unpub. Rept. dated November 1956). Webb's main

conclusions, which formed the basis of the writer's studies at Bawdwin, are quoted below:-

- "1. Lead and, to a less extent, copper give strongly anomalous values over blind and sub-outcropping mineralisation. Zinc does not appear to be a satisfactory indicator element.
2. Contamination from smelter slag is possible.
3. Soil sampling depth appears to be fairly critical, especially for lead in background areas. Samples should provisionally be collected below 18 ins. from the surface, where possible.
4. Further orientation sampling is required to determine:
 - (a) more reliable background data based on a greater number of samples from several localities;
 - (b) the extent of the anomalies in mineralised areas and the degree of relationship between peak values and the precise position of the blind mineralisation;
 - (c) the extent and seriousness of smelter slag contamination;
 - (d) the vertical distribution of metal in the soil profile in background and mineralised areas at different topographic levels (and hence, different thicknesses of overburden) and in areas of smelter slag contamination.
5. It is probable that soil sampling can aid in the location of blind mineralisation. Present data are insufficient to estimate the maximum depth at which a detectable "leakage" dispersion can reasonably be expected in all areas."

During the period the writer was at Bawdwin, Company personnel were prospecting for lead-zinc deposits by means of a reconnaissance drainage survey in other parts of the area (see Hunting Technical Services, 1959). This entailed the collection of wet sediment samples from stream beds at $\frac{1}{4}$ -mile intervals and their subsequent analysis for total lead and

cold-extractable zinc. This paper also gives some details and results of the geochemical prospecting survey undertaken by the writer near the mine (see Parts III and Appendix A).

The initial, geochemical appraisal of the Mpanda area, in Tanganyika, was carried out by J. S. Webb in April, 1956 (see also Webb, 1956). He emphasizes the necessity for further sampling in order to solve the following problems:

1. The limits of the lead-copper anomaly detected in residual soil over a mineralised shear zone which sub-outcrops on a low ridge.
2. Whether metal dispersions are detectable in flat-lying areas where freely-drained colluvial and seasonally-waterlogged swamp soils occur.

Since May 1957, two geochemical prospecting surveys, in which a large number of soil samples were analysed for lead, have been conducted by G. S. Carter and C. J. Windelschmidt in the Mpanda area. Details of their work are given in unpublished reports of the Tanganyika Geological Survey Department.

2. Other Tropical Regions.

Problems arising from the application of geochemical methods to prospecting for base metal deposits in non-tropical regions have been studied in considerable detail. Relatively little work, however, has been published concerning the secondary dispersion of copper and especially lead and zinc from mineralisation weathering under tropical conditions. In particular, hardly any attention has been paid to methods for discriminating between soil anomalies for lead due to contamination and those due to bedrock mineralisation.

According to Webb (1956), the base metal content of some

residual soils in un-mineralised areas in different parts of Africa varies with the nature of the parent material. He gives the range of values in soil over different sedimentary, metamorphic and igneous rocks as $> 5 - 110$ ppm Pb, $15 - 160$ ppm Zn and $10 - 150$ ppm Cu. Lead and zinc tend to be enriched in soil developed over shale whereas soil derived from basic rocks contains the most copper (see also Tooms, 1955; Jacobson, 1956; Coope, 1958). The same author also notes the variable tendency of lead towards enrichment in one or more soil horizons, such as the surface, organic-rich horizon of a latosol profile in Sierra Leone and the ferruginous-manganiferous B horizon of a latosol profile near the Argent Mine in South Africa.

A detailed study of the secondary dispersion of lead and zinc from sub-outcropping veins in the Nyeba district of Nigeria was made by Hawkes (1954). Although the pedology, topography and climate of both the Nyeba and Mpanda areas are somewhat similar, the geology is very different (see Part IV). The host rocks at Nyeba are of Cretaceous age and the ore is rarely oxidised below a depth of 70 ft. (Webb and Millman, 1950). Hawkes' work, which is also reviewed by Webb (1956), is summarised below.

1. Backgrounds[Ⓜ] for lead and zinc in lateritic, residual soil are $30 - 50$ ppm and 65 ppm respectively. Lead is enriched and zinc impoverished in soil with respect to parent bedrocks.
2. Lead is enriched and zinc impoverished in soil over mineralised shale. Both elements are impoverished in laterite as compared to soil and weathered shale.

[Ⓜ] Hawkes (1957) defines background as "the abundance of an element or any naturally occurring material in areas where the chemical pattern has not been affected by the presence of a mineral deposit"

3. Residual soils covering an extensive area contain anomalous concentrations of lead and zinc, peak values being 4% Pb and 1500 ppm Zn. In a more recent publication, Hawkes (1957) asserts that the zone of metal-rich soil over shale bedrocks leading away from the ore towards the drainage channel is well-defined. This pattern appears to be lacking on the other side of the deposit.
4. The dispersion of lead and zinc in alluvium covering another part of the orebody is exceedingly limited, being little more than the width of the vein itself. Metal values tend to increase with depth in alluvium over mineralisation.
5. Samples of native slag contain from 25 to 4000 ppm Pb and from 100 to 600 ppm Zn. Contamination from this source is very localised and can be visually recognised in most cases.
6. Drill core samples of shale and sandstone contain from 30 ppm to 8% Pb and from 70 ppm to 3% Zn. Core samples to the west of the ore zone have an abnormally high lead content of 180 ppm. Lead is enriched and zinc impoverished in weathered shale with respect to less decomposed rock.

Debnam (1954) studied the secondary dispersion of lead from sub-outcropping mineralisation in the Mt. Isa district of Queensland, his data being based on the cold-extractable lead content of lateritic soil samples. He considers that this technique, which utilises 0.01 N hydrochloric acid as the metal solvent, very adequately defines soil anomalies related to bedrock mineralisation. Anomalous soil often contains 200 times and, exceptionally 1000 times the amount of metal present in background soil. The secondary dispersion of lead at Mt. Isa is very extensive, some anomalies having a width of 800 ft. Factors influencing the breadth and strength of the soil anomalies include (a) the width and grade of the mineralised veins, (b) the topography, (c) the depth of overburden and (d) the low mobility of lead in the soil.

Robson (1956) investigated the primary and secondary

dispersion of traces of "heavy metal" (mainly zinc)²² from lead-zinc mineralisation in sheared, Pre-Cambrian rocks in the Besakay area, which is situated in a mountainous part of Madagascar. He found that there was little difference in the heavy metal content of soil samples taken at the surface and rock samples from adits. The dispersion of metal in the soil from a number of bedrock sources appears to be very restricted, being mainly effected by landslips. Strongly anomalous values of up to 1% heavy metal are related to sub-outcropping lead-zinc mineralisation. Spurious high values in soil in other localities, however, are merely considered to reflect the high, local background of copper in basic rocks.

There are also references in the literature to geochemical prospecting surveys for copper and zinc in French Equatorial Africa. According to Neltner et al (1958), soils near fault zones, which carry lead-zinc mineralisation, contain anomalous concentrations of copper and zinc, the extent of some of the soil anomalies being 1 kilometre. Hausknecht (1956), however, describes a negative stream sediment survey in another area.

According to Holman (1956), Jacobson (1956) and Webb (1956), the dispersion of copper in soils and stream sediments in mountainous country near the Kilembe Mine is very limited, although soil directly over mineralisation has a high copper content. In the peneplained Copperbelt area of Northern Rhodesia, however, rather different results were obtained by Tooms (1955), Webb (1956),

²² see footnote at the bottom of p. 120

Govett (1958) and Webb and Tooms (1959). They found that (a) lateritic soil and organic-rich swamp soil over mineralisation contains strongly anomalous concentrations of copper, (b) copper has been chemically dispersed in lateritic soil for a distance of several thousand feet from the bedrock source and (c) the dispersion of metal in swamps and streams is equally extensive. Work by Govett (1958) shows that the cold-extractable copper content of anomalous stream sediment and swamp soil is liable to considerable seasonal fluctuation.

According to Webb and Millman (1950), the "heavy metal" content of stream waters in the Nyebe district of Nigeria is also subject to extreme seasonal variation. Despite this tendency, however, anomalous concentrations near lead-zinc veins, where stream water carries up to 8 ppm heavy metal, were never completely suppressed. Atkinson (1957) also studied the seasonal variation in the "heavy metal" content of stream waters draining mineralisation in Angola. His data show that a dry season value of 0.03 ppm increases to 0.1 and 0.24 ppm after the first seasonal rainfall, although during the latter part of the rains, values tend to progressively revert to the dry season level.

3. Non-Tropical Regions.

During the past twenty years, a large number of research workers have investigated copper, lead and zinc dispersion patterns related to base-metal mineralisation in various parts of Central and Eastern Asia, Europe and North America. The climate of these areas ranges from semi-arid to sub-arctic. Their conclusions are summarised below, since they have some bearing on the writer's .

studies. Further work by other geologists and agricultural scientists concerning the specific factors that affect the mobility of copper, lead and zinc is discussed in Part VI. In addition to the published data, an unknown but very considerable amount of geochemical work has also been undertaken by mining companies, mainly in North America.

According to Morris and Lovering (1952), Hawkes (1957), Ginzberg (1957), Mukanov (1957), Rossman (1957), Webb (1958) and other authors, traces of metal migrate through wallrocks adjoining orebodies by two distinct mechanisms. One is termed diffusion, whereby trace elements penetrate dense, non-fractured rocks for relatively short distances (100 ft. or less) from the orebody. Where the country rock is well fissured, however, mineralising solutions penetrate for very considerable distances (up to 1700 ft.) away from the main site of metallisation.

Turning to secondary dispersion, Swaine (1955) and Vinogradov (1957) quote a large number of sources regarding the lead content of normal soils. The general mean is about 15 ppm, although the full range of values is of the order 2 - 200 ppm. The corresponding values for copper and zinc are 2 - 250 ppm and 2 - 300 ppm respectively. The considerable fluctuations in the base metal content of background soils is partly due to the very variable tendency for these elements towards enrichment in organic-rich, surface soil (see Part VI). Values of up to 1000 ppm Pb observed by Mitchell (1944) in some moorland soils in Scotland represent an extreme case of this surface enrichment phenomenon.

Notable papers on the dispersion of base metal in residual

soils near sub-outcropping mineralisation are those by Sergeev (1941), Huff (1952) and Solovov (1957). They found that on flat ground, symmetrical dispersion halos are developed over vein deposits. On slopes, however, the dispersion pattern tends to be asymmetrical, owing to the downslope movement of metalliferous particles by landslips, soil creep, sheet wash and frost heaving. The rate of movement is greatest at the surface and a characteristic, vertical pattern of metal distribution is developed within the soil (see Fig. 30A and also Sochevanov, 1958). Work by Huff (1952), Robertson (1956) and Boyle and Cragg (1957) in mountainous parts of North America shows that residual soil over mineralisation may contain more than 1% Pb, Cu or Zn, the ratio between highest and lowest values in different localities being 170:1, 106:1 and 11:1 respectively. The width of detectable lead anomalies in soil downslope from these veins, however, is extremely variable and ranges from 50 to several hundred feet.

The work of the afore-mentioned authors indicates that on steep hillsides, gravity-controlled mechanical dispersion governs the formation of secondary lead anomalies. The dispersion patterns of copper and zinc may be somewhat modified by chemical processes, depending on the environment (see Part VI). These modifying influences are also operative in areas of low relief where they may assume a greater importance than the mechanical agents of dispersion. Hawkes and Lakin (1949) give examples of zinc enrichment in the illuvial B horizon of podsolised profiles situated over zinc mineralisation in Tennessee.

The application of geochemical methods to the detection of

sub-outcropping lead-zinc deposits overlain by residual soil has met with much success in Asia and North America (Hawkes, 1957). The problem becomes more complex, however, when the deposit is situated at a considerable depth below the surface.

According to Almond and Morris (1951), Bradbury (1955), Brown and Meyer (1956), Kennedy (1956), Meisch and Nolan (1958) and Webb (1958), data obtained from the analysis of soils and surface rocks over some blind orebodies in Europe and North America are completely negative. No lead, zinc or heavy metal anomalies are detectable over the actual deposit, or over the outcrop of the ore structure. Over other blind orebodies, however, which lie at depths of 75 to 1000 ft. from the surface, successful results are reported by Lovering et al (1948), Almond and Morris (1951), Cooper and Huff (1951), Bradbury (1955), Kennedy (1956), Solovov (1957), Granier (1958) and Webb (1958). They attribute these to (a) the highly fractured state of the caprocks, (b) the favourable attitude of the fissures which enabled leakage dispersions to penetrate upwards with little or no lateral displacement and (c) the absence of any drastic, post-mineralisation re-distribution of metal by supergene or hypogene processes.

The processes whereby traces of metal are introduced into non-residual overburden are considered by Hawkes (1957) and Webb (1958) to include (a) mechanical incorporation during glaciation, (b) deposition from groundwaters and (c) movement in the vegetation cycle. Work by Chisholm (1950), Bischoff (1954), Kennedy (1956) and Ermengen (1957) shows that transported, glacial soils over

bedrock mineralisation in different parts of North America are characterised by a very much lower base metal content than is the case in areas of residual cover. According to Boyle and Cragg (1957), most of the copper and zinc leached from bedrock mineralisation in low-lying areas is dispersed for a considerable distance in the overlying soil, although lead remains close to its source (see also Cannon, 1955). Near the base of hill slopes, Sergeev (1941) found that anomalies in residual soil are buried beneath a considerable thickness of barren colluvium derived from higher ground.

The depth and extent to which soils are contaminated by lead from spoil dumps, industrial smoke and spray residues has received much attention in the past. According to Jones and Hatch (1937, 1945), Kennedy (1952), Scheltinga (1955), Robertson (1956), Hawkes (1957), Homer (1957), Webb (1958) and Canney (1959), contamination from these sources is restricted to the upper six or nine inches of the profile. The lateral extent of the contamination is more variable, however, and largely depends on the nature of the source. Robertson (1956) considers that spoil dump contamination of some soils in Montana is negligible, although Kennedy (1952) found that the drainage is contaminated within 200 ft. of similar material in Idaho. By contrast, Homer (1957) and Canney (1959) refer to the contamination of surface soils by lead and zinc within a radius of several miles of a group of smelters in Idaho.

Work by Hibbard (1940-a) and Mitchell (1955) indicates that some of the lead in contaminated soil is soluble in dilute

reagents, such as cold solutions of potassium chloride-acetic acid or 2.5% acetic acid. Unfortunately, they give no data regarding the total lead content of these soils, so the extractability of lead is not known. For that matter, the extractability of lead in un-contaminated soil has also received very little attention.

Owing to its relatively low mobility, lead tends to be mechanically rather than chemically dispersed by streams eroding anomalous soils. There are references in the literature to work by Kennedy (1956), James (1957), Webb (1958) and de Grys (1959) concerning the dispersion of lead in stream sediments in various parts of the British Isles and North America. According to Kvashnevskiya (1957), sediments in some streams and ravines near polymetallic deposits in Siberia contain up to 3% Pb and Zn and 0.1% Cu.

Waters draining mineralised ground tend to carry a much higher concentration of zinc and "heavy metal" as compared to lead (Hawkes, 1957). According to Hawkes and Bloom (1956), Hawkes et al (1956), Webb (1958) and de Grys (1959), much of the zinc precipitated from solution on finely-divided sediments occurs in a readily-soluble form. Sediments in the beds of streams draining some lead-zinc deposits in Eastern Canada and the Isle of Man contain up to 50 or 60 times the amount of cold-extractable zinc or "heavy metal" present in background stream sediments in the same localities. The contrast between anomaly peak and background values for total zinc and total "heavy metal", however, may be of a lower order.

Judging from the work of Cannon (1955), Salmi (1955) (1956)

and Webb (1958) in North America, Scandinavia and the British Isles, the organic-rich environment of swamps is most conducive to the accumulation of copper, lead and zinc. They found that some waterlogged peat soils over or close to bedrock mineralisation may contain as much as 4000 ppm Cu and Pb and 16% Zn. Factors contributing to the accumulation of these elements in such soils include (a) the residual enrichment of metal during the decay of vegetation and (b) precipitation from groundwaters.

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PART I.

TECHNIQUES.

a). SAMPLING METHODS AND SAMPLE PREPARATION.

1. Sample Collection

Standard methods were employed for the collection of soil, laterite and bedrock samples at Bawdwin and Mpanda: these are fully described in most of the papers already listed in the section concerned with previous work, so the details are only very briefly summarised below.

The term 'soil' is taken in its broadest sense to include all loose, structureless material; the term 'laterite' denotes brightly coloured indurated material enriched in sesquioxides (pages 130-131). The sub-outcropping bedrocks sampled in both field areas were usually more or less friable owing to their weathered condition. Relic geological structures, however, usually enabled weathered rocks to be distinguished from soil and laterite.

Most samples were taken from vertical channels cut down the sides of pits or trenches. The vertical distance represented by a given sample is variable, but was never less than 2 inches in 'spot' samples nor more than 24 inches in conventional channel samples. Each sample consists of about 150 grams of loose soil or chips of indurated laterite or weathered rock, collected in pre-numbered, waterproof Kraft paper envelopes. When sampling more than one horizon in a pit, the lowest horizon was always sampled first.

Sediment samples were taken from the beds of both seasonally-flowing and perennially-flowing streams with a trowel, and subsequently placed in similar paper containers to those used for storing soil samples.

"Spot" samples of altered and fresh rocks were taken from the walls of adits and also from borehole cores. At each point, about 150 grams of rock chips were taken from a "circular" area 6 inches in diameter. Before collecting a sample from the wall of an old adit, the site was first cleaned to a depth of 6 inches to remove any extraneous matter adhering to the wall.

2. Sample Preparation.

All samples were first allowed to dry in their containers in the sun.

Any soil aggregates were then broken down by gentle pounding in a porcelain mortar, and the sample sieved through a piece of 80-mesh bolting silk held in a perspex frame. The oversize fraction was only retained in the case of a very small number of samples, for the purposes of size-analysis experiments.

Soft, highly decomposed rocks with an appreciable content of fines were treated in the same manner as soil samples. Other rocks, however, were crushed till the whole sample passed an 80-mesh sieve. The crushing was done by hand in the field and by a mechanically operated jaw-crusher at Imperial College.

There is little information to be found in the literature regarding the most suitable method of preparing laterite samples for chemical analysis. Pendleton (1946) crushed Siamese laterite to pass a 2mm. sieve. Tooms (1955) suggests that samples of

sesquioxide-rich, nodular material in Copperbelt soils can be equally well prepared by partial grinding, till sufficient minus 80-mesh material is obtained for analytical purposes. Mather (1959), however, crushed the iron oxide nodules to minus 80-mesh before recombining them with fine loamy soil also present in samples of Sierra Leone duricrust.

The laterite is completely indurated and rock-like in some localities at Mpanda, and samples have to be partially crushed in order to obtain sufficient material for analysis. It is apparent from the data given in Table I that lead tends to be enriched in the finest clay-silt fraction as compared to the coarser nodules in four out of six samples so tested. This tendency, however, is probably due to the incomplete extraction of lead from coarse, ferruginous particles during the nitric acid digestion. When each size-fraction is first crushed to minus 200-mesh before analysis, the results indicate that equally large and significant concentrations of lead are present in the nodules as well as in the fine matrix (Table I). Having regard to the above considerations and to the work of others, it was therefore decided to crush every sample of laterite to minus 80-mesh, since partial grinding may tend to give highly spurious values (Table 5).

Five successive portions of ten sieved or crushed samples of soil, stream sediment, laterite and rock were tested for lead. The results showed that there was little or no variation in the replicate values obtained for each sample, which suggests that the above methods of sieving or crushing give well mixed material with a relatively homogeneous metal content.

TABLE I. Distribution of lead in size-fractions of laterite samples from mineralised and un-mineralised areas at Mpanda.

Sample No.	Area and Traverse No.	Lead content (ppm) of size-fractions B.S.S.				
		+20 -36	+36 -80	+80 -120	+120 -200	-200
1804	Kabungo	5 (10)	5 (10)	10 (10)	10 (10)	30 (30)
1668	Kasimba-C	20 (30)	10 (30)	10 (30)	10 (20)	10 (10)
3843/5	" " -A	200 (500)	250 (420)	300 (450)	300 (450)	470 (470)
1537	" " -6	350 (1100)	800 (1000)	700 (900)	700 (800)	1000 (1000)

Figures in parentheses denote the lead content of a split portion of each size - fraction which was crushed to minus 200-mesh prior to analysis.

b. ANALYTICAL METHODS EMPLOYED FOR COPPER, LEAD AND ZINC

All samples were analysed for total lead, and a much smaller number for cold-extractable lead, total copper, total and cold extractable zinc and cold-extractable heavy metal, in that order.

1. Estimation of Lead

(a) Total Lead

The methods used by the writer are described in Appendices B 1 & 2. A weighed portion (0.1 or 0.2g.) is first digested with 25% nitric acid for one hour, and the metal content of the acid extract subsequently estimated by a mixed colour or mono-colour dithizone procedure. About 95% of the samples were tested by the procedure which utilizes benzene as a solvent for the dithizone, which is considered to be more reliable than the other method involving the use of white spirit. The metal concentrations deter-

mined by both methods, however, give comparable orders of magnitude (J. D. Kerbyson and R. E. Stanton, pers. comm.). The productivity of the mixed-colour test is about 100 samples per operator per 8 hour day, providing that most of the samples in a batch require no more than a single determination.

(b) Cold-extractable Lead.

A cold test for lead was primarily required in order to discriminate between natural and contaminated soil anomalies. A very precise test was not considered essential for this purpose, and the procedure described in Appendix B.3 is highly tentative. It involves the shaking of a weighed portion of a sample (0.2g or 0.1g.) with either 5% nitric acid, or more rarely 0.25% citric acid, for a period of 30 seconds. Aliquots of this extract are then shaken with dithizone - benzene solution in the usual manner. This latter step is necessary in order to avoid the rapid oxidation of the dithizone - benzene layer by iron or organic matter, which occurs if the solution is shaken in the presence of the sample.

2. Estimation of Copper, Zinc and Heavy Metal

(a) Total Copper and Total Zinc

The modified procedure outlined by Stanton and Gilbert (1956), which embodies a preliminary potassium bisulphate fusion and subsequent analysis by dithizone in benzene, was used for the determination of total copper and total zinc (Appendices C1 & C2).

(b) Cold-extractable Zinc.

The technique followed for the estimation of cold-extractable zinc is given in Appendix C3. A weighed portion of a dry, sieved sample is shaken with ammonium acetate - sodium

thio-sulphate solution, and the amount of metal extracted is determined by the addition of successive increments of dithizone in benzene.

(c) Heavy Metal (Zn + Cu + Pb).

The procedure employed for the estimation of the cold-extractable heavy metal content of soil or sediment samples, which is described in Appendix C4, is based on the method of Bloom (1955), with the exception that benzene is used as a solvent for the dithizone. It closely resembles the technique used for the determination of cold-extractable zinc. When estimating the heavy metal content of stream waters (mainly ionic zinc), the sample is shaken with dithizone in benzene, either at the sample site or else in the laboratory, with no pH adjustment. This technique has been used by many research workers, and the details are given in Appendix C5 (see also Holman, 1956).

c). ANALYTICAL AND SAMPLING ERRORS FOR TOTAL LEAD.

The analytical and sampling errors have only been evaluated for total lead, the principal element with which these studies are concerned. The corresponding errors for cold-extractable lead, total copper, total zinc and cold-extractable zinc are not known.

1. Analytical Error.

(a) Statistical Reliability of the Analytical Technique as Determined by Craven's (1954) Method.

A statistical series is prepared by thoroughly mixing in different known proportions a sample containing a high concentration of the element in question with another sample having a much lower elemental content. The standard deviation is computed from the differences between the analytical and calculated values of the samples.

Three such series, each comprising 12 samples, were periodically analysed for total lead with batches of routine samples. The range of metal concentrations in the three series is 5 - 1200 ppm, 25 - 2500 ppm and 5 - 8500 ppm respectively. The mean accuracy, at the 95% confidence level, was usually found to be about $\pm 30\%$ and represents the reliability of discriminating between samples containing variable concentrations of lead.

(b) Reproducibility of Individual Determinations.

Some of the statistical series soil samples were also used as control samples, and during the course of these studies, they were re-analysed up to 50 times. The extent to which analytical values for a given sample are reproduced over an appreciable period of time can therefore be evaluated. It must be emphasized, however, that the data presented in Table 2 regarding the analytical reproducibility of some Bawdwin and Mpanda soil samples is based on the work of the writer and three other analysts.

Table 2. Replicate determinations for lead in some Bawdwin and Mpanda control samples

Bawdwin Samples			Mpanda Samples		
Sample No.	Mean Value (ppm)	Standard Deviation (%)	Sample No.	Mean Value (ppm)	Standard Deviation (%)
X (6) [*]	8500	13	4951 (27)	1200	18
U (6)	5000	12	4960 (26)	800	16
K (42)	2500	11	4957 (27)	650	16
D (43)	1000	11	4959 (28)	450	23
B (53)	520	13	4956 (28)	220	23
A (54)	250	14	4955 (26)	120	35
L (42)	120	23	4952 (30)	50	35
J (42)	25	58			

^{*}Figures in parentheses denote the number of times a sample was analysed.

Judging from the tendency of the percentage standard deviation to increase with decreasing metal content, the greatest analytical error would appear to occur at or below the 120 ppm concentration level, This is substantiated by the data obtained from the re-analysis of 458 routine soil and stream sediment samples (Table 3).

Table 3. Percentage agreement between the original and repeat analyses of some Bawdwin and Mpanda routine soil and stream sediment samples for lead.

Concentration Level (ppm)	No. of Samples	Percentage of repeat determinations:		
		Within $\pm 25\%$ of original	Within $\pm 50\%$ of original	More than $\pm 50\%$ of original
0 - 100	152	36	41	23
100 - 200	61	61	30	9
200 - 400	57	66	31	3
400 - 800	36	64	25	11
800 -1500	49	78	18	4
1500 -3000	47	65	34	1
3000 -6000	31	64	29	7
> 6000	25	76	20	4

Only 36% of the samples containing less than 100 ppm lead were identical to their original value or within $\pm 25\%$ of it on re-analysis, whereas 67% of the samples having a metal content of from 100 - > 6000 ppm agreed within $\pm 25\%$ of their original values.

In view of these data, an overall error of about $\pm 30\%$ is considered to be a representative of that normally obtained during routine analysis. There is a very definite tendency, however, towards poorer reproducibility at low concentration levels, especially in the range 0 - 100 ppm. This fact must always be taken into consideration when interpreting data from soil and stream sediment samples having

low metal contents.

The main factor contributing to the analytical error is incorrect colour - matching in the low (green-blue) colour range. In order to minimise the error from this cause, the practice of using a 0.2g. sample weight was adopted in the case of samples having a low metal content. This tends to reduce the colour-matching error by increasing the sensitivity.

2. Sampling Error.

(a) Variations in the Metal Content of Replicate Samples.

Freely-drained soil, waterlogged soil, stream sediment and weathered sandstone and tuff bedrock samples were replicated from three to five times at five sites over or near mineralisation in the Gurkha Hill, Meingtha Hill and Mt. Teddy areas at Bawdwin, and in the Simbo area at Mpanda. The results obtained from the analysis of the samples for lead are given in Table 4.

The sampling error cannot be quantitatively evaluated as the samples were analysed by four different operators whose analytical error during the determinations is not known. Certain trends, however, emerge from their data. The standard deviation²² increases from 6% in replicate soil samples from Pit 11 to 53% in replicate samples of weathered tuff samples from Pit 29.

The homogeneous metal content of the replicated soil and sandstone samples from Sites 6, 11, & 22 (S.D. = 6 - 12%) is in marked contrast to the more erratic distribution of lead in gully sediment, contaminated topsoil and tuff at the other sites (S.D. = 24 - 53%). The swamp soil samples from Traverse 22 were

²²Standard Deviation expressed as a percentage of the mean value for each set of samples.

replicated over a three month period during the rainy season and the analytical results show little or no variation in the total metal content of the samples that is related to seasonal changes.

TABLE 4. Lead contents of replicate soil, gully sediment and rock samples from Bawdwin and Mpanda.

Area	Sample Description and Depth.	Observed Values (ppm)		S.D (%)
		Range	Mean	
Meingtha - 11	Topsoil, 3 ins.	1300-1500	1380(5)	6
"	Sub-soil, 36 ins.	2200-2600	2450(5)	7
Gurkha Hill	Contaminated			
- 6	Sub-soil, 36 ins.	1300-1600	1380(5)	9
Simbo - 22	Swamp soil, 0-6 ins.*	50-60	55(3)	10
"	" 6-10 ins.*	60-70	65(3)	10
Meingtha - 11	Sandstone, 132 ins.	2000-2600	2350(5)	12
Meingtha	Gully sediment,			
- A2: A3	0-3 ins.	1000-1400	1220(5)	24
Gurkha Hill	Contaminated	7000-1.2%	8800(5)	25
- 6	topsoil, 3 ins			
Mt. Teddy	Tuff, 42 ins.	1700-5000	2780(5)	53
- 29				

Figures in parentheses denote the number of samples on which the mean value is based.

* Samples taken at different times over a period of 3 months.

The data from the Gurkha Hill samples indicate that lead is more erratically distributed in contaminated topsoil with respect to contaminated sub-soil, possibly because of the more variable concentration of very finely-divided smelting materials in the former horizon.

The greatest errors, however, will arise during the routine sampling of tuffaceous rocks. Judging from hand specimens, the spotty distribution of metal in the tuff samples from Pit 29 may be due to considerable variations in their feldspar content and in the degree of micro-fissuring, since both these features could have

conceivably controlled the primary deposition of traces of lead from hydrothermal solutions (Part II & III). By contrast, lead is much more evenly distributed in the more homogeneous sandstone at the base of Pit 11. The data obtained from the analysis of replicate samples of sandstone and tuff corroborate the general principle that lead tends to be very spottily distributed in heterogeneous rocks (Hawkes, 1957).

(b) Variations in the Metal Content within a Single Sample.

No freely-drained soil, weathered bedrock or laterite samples from Mpanda were replicated in a similar manner. An attempt was made, however, to ascertain whether or not metal is homogeneously distributed within 150 grams of sample material representing a vertical or lateral distance of 12 inches. This was done by sieving or crushing ten separate portions of a given sample and subsequently analysing them for lead.

There appears to be little or no variation in the metal content of successive sieved portions of one soil sample. Very considerable variations, however, were observed in metal content of ten successive crushed portions of four laterite and meta-dolerite samples (Table 5). The standard deviation, which varies from 30 - 98%, is again expressed as a percentage of the mean value for each sample. The analytical error, as determined by Craven's (1954) method, during the sample analysis was of the low order of $\pm 10\%$, so the observed variations in the metal content of the samples are considered to be the result of natural causes.

These data indicate that considerable errors are likely to arise during the routine sampling of laterite, and even larger errors

when sampling sub-outcropping meta-dolerite. On the basis of field observations, the extremely irregular distribution of lead in the meta-dolerite sample could conceivably be due to equally large variations in the extent of micro-fissuring. The precise causes of the erratic metallisation within the laterite samples are also not known. They could possibly be related to a correspondingly spotty distribution of ferric iron or manganese (Parts V and VI).

TABLE 5. Distribution of lead within individual laterite and meta-dolerite samples from Mpanda.

Sample No.	Area and Traverse	Sample Type	Observed values (ppm):		S.D. (%)
			Range	Mean	
1536	Kasimba - 6	Laterite	700-1500	1030(10)	30
2664	Simbo - W	"	520-2500	1050(10)	60
1667	Kasimba - C	"	25-120	40(10)	74
2143	Kasimba - (Near Pit 5)	Dolerite	400-1200	700(10)	98

Figures in parentheses denote number of samples on which the mean value is based.

3. Combined Sampling and Analytical Error.

According to Tooms (1955) and others, analytical errors far exceed those resulting from the rather imprecise nature of routine, geochemical sampling methods. The data in Table 4, which show that the error arising during the replication of soil, gully sediment and sandstone samples is less than the probable analytical error of $\pm 30\%$, further supports this contention. The very even distribution of lead in replicate soil samples illustrates the extent to which the parent material is mixed during soil formation, thereby eradicating much of the spottiness characterising the

primary dispersion of lead. This is one of the reasons why soil sampling is preferred to rock sampling in geochemical prospecting.

As regards laterite and heterogeneous rocks like tuff, meta-dolerite and possibly granite - gneiss, however, the sampling error appears to exceed the probable analytical error owing to the variable physical and mineralogical characteristics of these media. Nevertheless, in no instance cited above in Tables 4 & 5 is the combined analytical and sampling error of sufficient magnitude to eliminate anomalous values in a given set of replicate samples. The analytical and sampling methods described in Part I are, therefore, considered to be adequate for the purposes of these studies.

a). ADDITIONAL TECHNIQUES.

A very small number of samples were tested for pH, organic carbon, total iron and the solubility of lead. The size-fractions of a few samples were also separated by mechanical methods. The techniques used are fully described in Appendices D1-5. When considering the implications of data obtained from the analysis of size - fractions of soil and laterite samples for lead, separated by the dry-sieving method given in Appendix D5, it is necessary to take into account (a) the adhesion of fine particles to the coarser particles during sieving, and (b) the incomplete extraction of metal from coarse particles during the preliminary nitric acid digestion (see Tooms, 1955 and Table 1).

PART II.

GENERAL DESCRIPTION OF THE BAWDWIN AREA, NORTHERN SHAN STATES
OF BURMA.

a). PHYSICAL FEATURES, CLIMATE AND VEGETATION.

1. Physical Features.

(a) Location.

The Bawdwin Mine is situated in the Northern Shan States of Burma, 30 miles to the west of the town of Lashio (see Fig. 1). Most of the samples were taken near the mine, which is 3200 ft. above sea-level, although a relatively small number were also collected in the Loi-Mi, Manpat, Pangsan and Samrapani areas, which are situated at distances from 2 to 8 miles from the mine and whose altitudes range from 4000 feet at Samrapani to 4800 feet at Pangsan,

(b) Topography.

The terrain near the mine is extremely mountainous, the average difference in elevation between ridge-crest and valley-bottom being 800 feet and the average gradient of the hillsides about 40 degrees. The land surface is highly dissected, consisting of alternating gullies and spurs, these abutting the flatter ridge-crests. There is a certain uniformity of level about the principal hills, which Coggin Brown (1918) considers to represent the remnants of an old Tertiary peneplain known to exist in many parts of Eastern Asia. He also notes that the raised river terraines along the Sterne River are indicative of recent uplift. Away from the mine, the topography is similar but even more accentuated.

(c) Drainage.

The perennially flowing Sterne River bisects the Mine

area (Fig. 2). It is fed by numerous, small side-streams which flow through steep, rocky gullies during the monsoon. The whole area is being denuded with great rapidity, the deforestation within the last five hundred years having much accelerated the normal processes of erosion. The groundwater table undoubtedly lies at a considerable depth from the surface, away from the valley bottoms.

2. Climate and Vegetation.

(a) Climate

The climate is sub-tropical, with distinct wet and dry seasons. The S.W. Monsoon lasts from the beginning of May till October, and the average annual rainfall is about 50 inches. The temperature varies between 40°F. and 90°F., being at a minimum in December and January, and reaching a maximum in April and May.

(b) Vegetation.

Stamp (1925) divides the Shan States into regions characterised by (a) oak, teak and pine forests having local concentrations of bamboo, and (b) grassland areas with bracken and ferns. According to A. R. Overlander, the trees in the Namtu area include varieties of Quercus, Castanopsis, Acrocarpus, Anthrocephalus, Sarcosperma, Callicarpa, Terminalia, Dalbergia, Schleichera, and Bombax. Near the mine, the vegetation consists solely of grass and ferns, with a few scattered clumps of bamboo. The absence of trees near the mine is attributed mainly to deforestation by the Chinese who required charcoal for smelting purposes and, in part, to the toxic effects of furnace fumes. The grass grows to a height of nearly ten feet during the monsoon and is subsequently burnt off

during the dry season. Near the sites of former Chinese smelting furnaces to the west and south of the Sterne River, the vegetation **is exceedingly scant**, consisting of a few isolated ferns whose fronds have a very pronounced and abnormal silver colour; this may be due to the blighting of the plants by excessive quantities of metal in the topsoil.

b). GEOLOGY

The following brief description of the geology of the Bawdwin area is based on unpublished Company data as well as on the published work of La Touche and Coggin Brown (1909), Loveman (1917), Coggin Brown (1918), Dunn (1938), Clegg (1940), and Sommerlatte (1959).

1. Regional Geology.

The geological succession given below is taken from that established by Coggin Brown (1918) and by Clegg (1940):-

Alluvium and River - Terraces	Recent
NAMYAU SANDSTONE	Jurassic
PLATEAU LIMESTONE	Devonian
NAM HSIM SANDSTONE	Upper Silurian
PANGSAPYE GRAPTOLITE BEDS	Llandoveryian
NAUNG KANGYI SHALES	Ordovician
PANGYUN SANDSTONE	Cambro - Ordovician
BAWDWIN VOLCANICS	Cambrian ?
CHAUNG MAGYI SHALES	Pre - Cambrian
TAWNGPENG GRANITE	

The granite outcrops to the west of the area represented by Fig. 1, intruding highly metamorphosed Pre-Cambrian shales and phyllites; the sediments become progressively younger in age with increasing distance further to the east of the granite. The Bawdwin Volcanic Series, of possible Cambrian age, contains most of the known base metal deposits and outcrops near the mine as a three mile long inlier in the Cambro-Ordovician Pangyun sediments.

2. Lithology and Structure of the Mine Area.

(a) Lithology.

The late G.V. Hobson's geological map of the area near the mine is reproduced in Fig. 2, from which it can be seen that the main rock types consist of sandstone and tuff, with subordinate quartzite, quartz-porphyry and rhyolite. The origins of the tuffs are obscured by their intense hydrothermal alteration, but could possibly represent either original rhyolite, intrusive quartz-porphyry or volcanic ejectamenta (Coggin Brown, 1918; Clegg, 1940). The Bawdwin Volcanic Series has been further classified by G.V. Hobson as the Bawdwin, Loi-Mi and Nam-La tuffs and rhyolites.

The ore-bearing Bawdwin tuffs are light coloured and highly decomposed in their surface exposures. They exhibit a porphyritic texture, having a groundmass of quartz and orthoclase feldspar, with larger phenocrysts of orthoclase in varying stages of alteration to kaolinite and sericite. They sub-outcrop on Mt. Herschell, Mt. Teddy and on the southern and eastern slopes of

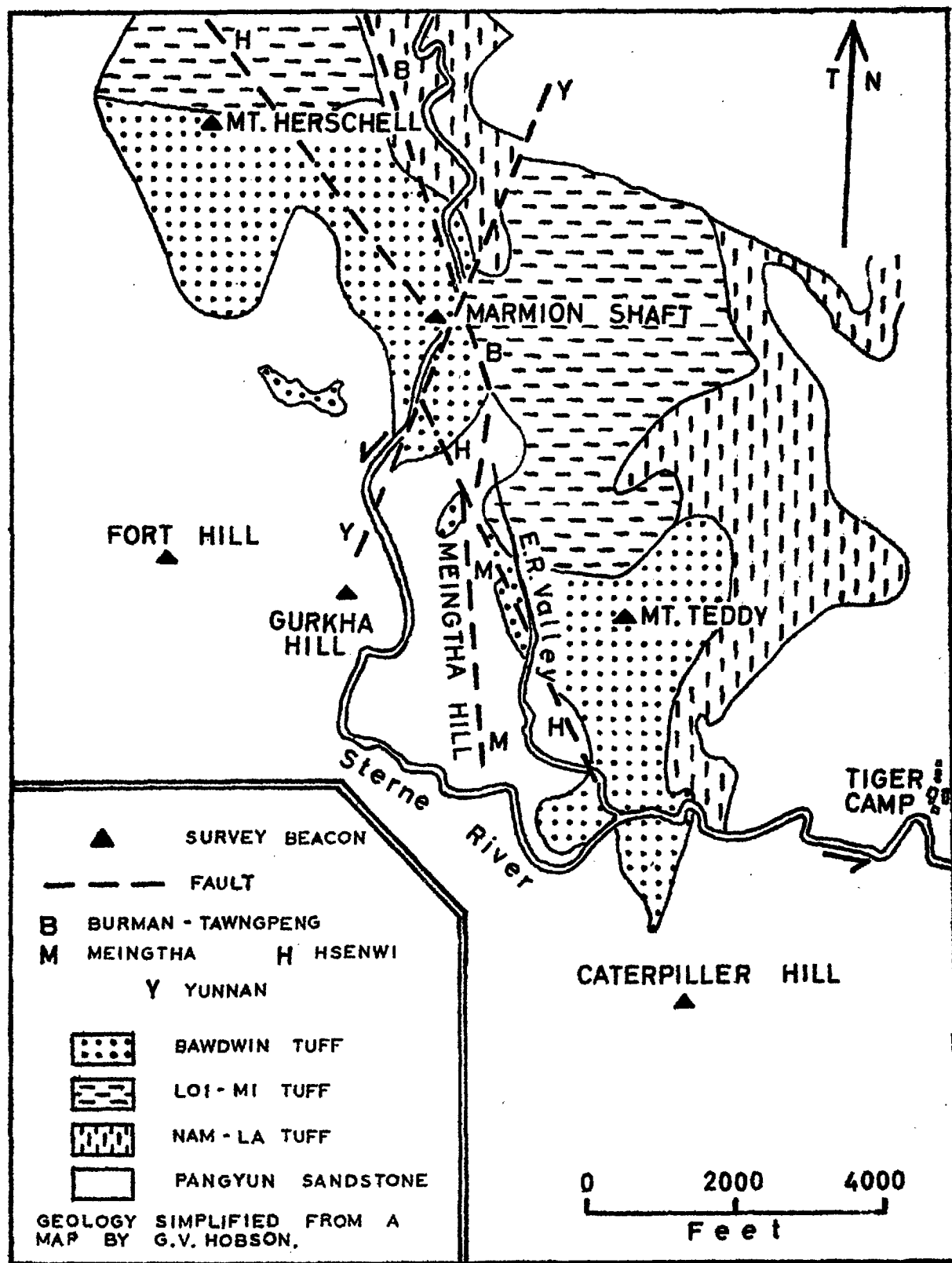


Fig. 2. GEOLOGY OF THE BAWDWIN MINE AREA.

Meingtha Hill, but are capped by Pangyun sediments in other parts of this latter area. The Loi-Mi tuffs sub-outcrop to the north of Mt. Herschell and Mt. Teddy. They appear to differ from the Bawdwin tuffs in being more decomposed and more even-grained. The Nam-La tuffs sub-outcrop to the east of the Bawdwin and Loi-Mi tuffs and have a much darker colour. The Pangyun Series comprises sandstone, with subordinate tuff, quartzite and argillaceous sediments. The sub-outcropping sandstones to the south and west of the Sterne River have a pink or red colour, whereas their surface exposures in mineralised parts of the Meingtha and Mt. Teddy areas show a white colour, possibly the result of hydrothermal alteration.

(b) Structure.

Throughout the area, both the angle and direction of dip are extremely variable. Little is known about the tectonics of the folding, although according to Clegg (1940), the Bawdwin Series has been folded into a dome-shaped structure. The locations of the principal faults are shown in Fig. 2, but it must be emphasized that they have been largely postulated on the basis of underground mapping; there appears to be little or no sign of these structures on the surface. The Burman, Tawngpeng and Meingtha faults are pre-ore in age and are displaced by the post-ore Hsenwi and Yunnan faults.

3. Base Metal Deposits.

(a) Primary Sulphides.

The main primary sulphide minerals at Bawdwin are galena and ~~sphalerite~~ **sphalerite**, with subordinate chalcopyrite. Other less common sulphides include boulangerite, bourmonite, gersdorffite, tennantite and tetrahedrite. The gangue minerals comprise ankerite, arsenopyrite, calcite, dolomite, feldspar, kaolinite, lollingite, pyrite, quartz and sericite.

The Shan, Chinaman and Meingtha orebodies are of the massive, replacement type and are believed to have been deposited from ascending hydrothermal solutions which penetrated the Burman - Tawngpeng-Meingtha shear zone and there replaced the shattered and highly favourable feldspathic tuffs. The Meingtha Lode is a blind deposit, being capped by a variable thickness of Pangyun sediments; its strike is north - south, and it has been proved for a distance of 4100 feet south of the Marmion Shaft. The location of the orebody coincides with that of the Meingtha Fault, which is shown in Fig. 2. The deposit has a width of 10 - 20 feet and a steep easterly dip and a northerly pitch. The hanging wall is better defined than the footwall and there is a gradual transition from ore to country rock to the east of the lode. According to Clegg (1940) and Sommerlatte (1959), the average tenor of the ore is 15% lead, 9% zinc, 2% copper, 1% nickel, 0.5% cobalt and 400 grams/ton of silver.

A small deposit, which contains about 12% lead and

which was formerly mined by the Chinese, is located in tuffaceous rocks near the confluence of the Sterne River and E.R. Valley; little is known of its structure (see Figs. 13 and 16).

Disseminated primary and oxidised sulphides are also found in the country rocks at varying distances from the main orebodies. Near the ore zone, the disseminated sulphides are considered to be the result of deposition of metal from the nearby "spent" residues of the hydrothermal solutions responsible for the massive deposits. (p. 95). In other areas, however, the disseminated mineralisation may merely be part of a stockwork system of small stringers and veinlets.

(b) Hydrothermal Rock Alteration.

Before, during, and after the emplacement of the Bawdwin ores, the country rocks were subjected to intense and widespread hydrothermal alteration by way of chloritisation, kaolinisation, sericitisation and silicification. Previous work indicates that the feldspars are altered to kaolinite in the ore zone and to sericite in the country rocks. There are a number of barite vein outcrops on top of Meingtha Hill and in other parts of the area, but it is doubtful if these are genetically related to the underlying lead - zinc deposit. (Loveman, 1917; Coggin Brown, 1918).

(c) Oxidation and Weathering.

The Bawdwin deposits are undergoing intense weathering. Partial oxidation of sulphides is reported at a depth of 850 feet

below the surface in the Chinaman deposit near the shaft. In the Meingtha Lode, partial oxidation extends for a distance of 400 ft. and more from the surface, the ore at a depth of 200 ft. being completely oxidised. The extent of the oxidation in the Bawdwin area as a whole, however, is very variable since galena disseminations are visible in sub-outcropping quartzite and tuff on Mt. Teddy. Moreover, large masses of relatively fresh galena occur at a depth of only 90 feet from the surface near the Sterne River.

The principal secondary ore minerals in the Bawdwin deposits are anglesite, cerussite, calamine and malachite. Azurite, brochanite, chalcocite, covellite, goslarite, massicot, malaconite and pyromorphite are also known in the underground workings.

Oxidation has been accompanied by the development of surface gossans in both mineralised and unmineralised parts of the area. The extent to which zinc is being leached from the oxidised parts of the deposits at the expense of the more insoluble ore metals is illustrated by Loveman's (1917) analysis of a groundwater sample from the Chinaman Lode. He found this sample to contain 800 ppm zinc as compared to only 30 ppm lead. Neither element was detected in a sample of water from a drainage tunnel 6500 feet away from the orebody.

c). PEDOLOGY.

All soils sampled by the writer are freely-drained.

1. Soils in Grassland Areas near the Mine.

(a) Soil Thickness

The thickness of the soil cover near the mine is extremely variable; only a few inches of soil occur on many of the steep hill-sides in the Mt. Teddy area, whereas the overburden is more than 15 feet thick on some of the flatter ridges on Gurkha Hill. Three or four feet is the average soil thickness for the area taken as a whole. In areas of comparable topography, there is a very definite tendency for much deeper soil profiles to develop over sandstone compared to those over tuff.

(b) Soils Developed over Sandstone.

The sandy, loamy sub - soil developed over Pangyun sandstone has a red - brown or red colour, the topsoil being characterised by brown and grey hues. The non - consolidated material is very stony, the percentage of weathered sandstone fragments markedly increasing with depth. A description of a typical weathering profile over white mineralised sandstone on Meingtha at Site 11 is given in Table 6. Soil profiles in un - mineralised or contaminated areas to the west or south of Meingtha Hill are very similar save for the red or pink colour of the parent sandstone.

The data in Table 6 show that the soil pH of Profile 11 remains constant at the 4.6 - 4.7 level. Similar values were also observed in soil samples from Profile 34, which is situated in the Loi-Mi area. The pH in Profile 6 on Gurkha Hill also remains essentially constant in depth, individual values ranging from 4.4 - 4.6.

TABLE 6. Weathering profile over white sandstone, Pit 11, Meingtha Hill.

Depth, inches.	Description	pH	Total Fe (%)	Organic Carbon (%)
0 - 1	Grey sandy clay, abundant grass roots.		2.59	2.60
1 - 3	Same, less vegetative matter.	4.6		2.31
3 - 12	Grey-brown sandy clay with some weathered sandstone fragments.		2.59	1.25
12 - 24	Brown sandy clay with increase in size and number of rock fragments.	4.6		0.31
24 - 36	Red-brown sandy clay as above.		2.88	
36 - 60	Red sandy clay as above.	4.6	3.17	0.07
60 - 84	" " " " "	4.7	4.03	0.13
84 - 108	" " " " "	4.6	4.61	0.06
108 - 120	Very soft, decomposed sandstone and very much red clay.	4.6		
120 - 132	Solid, weathered white sandstone.		0.57	

Sample Nos: 7748/61 (base of pit upwards)

When attempting to assess the true environmental pH of soils derived from the weathering of sandstone or tuff, it must be appreciated that the observed values were obtained in the laboratory some time after the samples had been collected. According to Huberty and Hass (1940) and other agricultural scientists, laboratory pH determinations are usually higher than those measured in the field. Moreover, Robinson (1951) notes the seasonal variation in the pH of soils and he considers values to reach a maximum during long continued spells of dry weather, during which season the present samples were collected. It is, therefore, most probable that the reaction of the Bawdwin soils is even more acidic than would appear to be the case from the data presented in this section.

The total iron content of the soil at Site 11 increases with depth from 2.6% to 4.6%, subsequently decreasing to 0.6% in the sub-outcropping sandstone. This typical trend is due to the residual concentration of iron at the expense of silica during lateritic weathering (see Mohr and Van Baren, 1954). By contrast, the organic carbon content, which reflects the amount of organic matter present in the soil, decreases from 2.6 % at the surface to 0.06% in the deeper horizons of the sub-soil, being mainly concentrated in the topsoil horizon. A similar decrease in organic carbon from 3.9% to 0.2% was also noticed in the other profile tested at Site 34.

(c) Soils Developed over Tuff.

The true colour of the much shallower, stony sub-soil derived from tuffaceous rocks is often masked by its appreciable organic matter content, but it is generally yellow over the Bawdwin and Loi-Mi tuffs, and brown over the Nam-La tuffs. A typical weathering profile over Bawdwin tuff at Site 29 on Mt. Teddy is described in Table 7, and is identical to weathering profiles over similar rocks in other localities.

The soils developed from the weathering of tuffaceous rocks at Site 29 on Mt. Teddy appear to be slightly less acid than those derived from sandstone. Moreover, the soil pH slightly increases with depth from 4.9 at the surface to 5.2 in the horizon above weathered bedrock. The sub-soil samples from this pit contain twice as much iron as the red coloured soil samples from Pit 11, although the tendency of iron towards enrichment in the sub-soil relative to the parent bedrock is similar. Their higher iron content is all the

more remarkable in view of their yellow colour, which may reflect the more hydrated condition of the iron sesquioxide minerals (de Craene and Laruelle, 1955).

TABLE 7. Weathering profile over Bawdwin tuff, Pit 29, Mt. Teddy.

Depth, inches.	Description	pH	Total Fe (%)	Organic Carbon (%)
0 - 1	Dark grey sandy clay, abundant grass roots.	4.9	3.91	4.10
1 - 3	Grey sandy clay, less vegetative matter.	4.9	3.91	3.52
3 - 12	Grey-brown sandy clay with numerous weathered tuff fragments.	5.0	4.46	2.34
12 - 24	Yellow-brown sandy clay with increase in size and number of rock fragments.	5.2	7.82	1.28
24 - 36	Yellow sandy clay, as above.	5.2	9.08	1.40
36 - 48	Solid, weathered grey tuff.		1.54	0.01

Sample Numbers 9828/34 (Base of pit upwards)

(d) Nature and Origins of the Soils.

There are no references in technical journals to the pedology of the Shan States of Burma. Furthermore, nothing is known of the distribution or the composition of the clay fraction within any of the Bawdwin profiles, so their true nature cannot be determined. The loamy lithosols on the hillsides near the mine are essentially residual, having developed through the weathering of arenaceous or tuffaceous rocks. Their residual characteristics, however, are being somewhat modified by the combined effects of soil creep, sheet wash and landslips in an area of such extreme physical relief and high rainfall. The regular contouring of the bare hillsides by

landslip "lines" attests to the importance of this latter mechanism in the lateral movement of soil down the hillsides.

The sandstone on Meingtha weathers to form a relatively deep profile, which to some extent protects the sub-soil from the extremes of erosion; the mixing of soil by landslip action within this type of profile cannot be visually detected. By contrast, the thinner soils derived from tuffaceous rocks appear to be in a more disturbed condition. The less residual nature of the overburden is very noticeable in the Mt. Teddy area, where the sub-soil has been completely eroded at some sites, being subsequently replaced by a few inches of grey colluvial soil, which now rests directly on weathered tuff.

2. Forest Soils

In the few pits that were examined, the sub-soil consists of brown sandy loam derived from the weathering of sandstone or shale, being overlain by grey-brown and grey topsoil. Nothing is known of their pH or iron content. There appears to be little difference between the organic carbon contents of the few forest topsoil samples tested and those of similar samples from the Loi-Mi and Mt. Teddy grassland areas (Fig. 32). This serves to illustrate the ability of grasses to contribute just as much organic matter to the soil under certain conditions as that supplied by leafy plants.

d). PREVIOUS MINING AND SMELTING ACTIVITY.

The effects of previous mining and smelting activity on the contamination of the soil near the mine are fully described in Part III. The Chinese first entered the area in the fifteenth century, and according to Loveman (1917), mined more than 1 million

tons of rock before they left in 1868. The presence of some 125,000 tons of slag in the area at the beginning of this century attests to the considerable tonnage of ore smelted by them near the Sterne River (La Touche and Coggin Brown, 1909). From time to time, considerable quantities of slag were removed from the valleys near the mine by marauding Kachins, who subsequently re-smelted it on the tops of the nearby hills.

Large scale mining was re-started by Europeans about 1912, when a smelter was erected at Namtu, six miles from the mine. Before the completion of the underground Tiger Tunnel, the ore was shipped from the mine to Tiger Camp by a narrow gauge railway which follows the course of the Sterne River.

PART III.

OBSERVED DISPERSION OF METAL IN ROCKS, SOILS
AND STREAM SEDIMENTS AT BAWDWIN.

a). SOILS AND WEATHERED ROCKS IN UN-MINERALISED AREAS.

The soils on Meingtha Hill are developed through the weathering of sandstone and tuff, so background values for these soils were determined by taking samples of similar soils in un-mineralised grassland areas near the mine, as far away as possible from any known deposits or sources of contamination. Since these studies are mainly concerned with lead, every sample was tested for this element, only a much smaller proportion of the samples being analysed for copper and zinc.

1. Lead Content of Soils in Grassland Areas.

(a) Weathering Profiles over Sandstone and Tuff.

Samples were taken from two profiles in the Loi-Mi and Herschell areas, where the bedrocks consist of un-mineralised Pangyun sandstone and Bawdwin tuff, and tested for copper, lead, and zinc (Table 8). The results indicate an enrichment of lead in the topsoil samples from both pits. Values decrease from 500 and 200 ppm respectively in the surface horizon of Profiles 33 and 34 (0 - 1 ins.) to 10 and 5 ppm in the weathered bedrock horizon. Zinc, however, shows only a slight tendency towards surface enrichment, while copper is evenly distributed throughout all horizons of these profiles.

TABLE 8. Distribution of copper, lead and zinc in weathering profiles over sandstone and tuff in un-mineralised grassland areas near Loi-Mi and Mt. Herschell.

Typical weathering profiles over sandstone and tuff are described in Tables 6 and 7.

Bedrock Types and Pit Nos:		Bawdwin tuff 33			Pangyun sandstone 34			
Sample Nos:		12562/8			3436, 9542/50			
Depth	Horizon	Metal content (ppm)			Horizon	Metal content (ppm)		
		Pb	Zn	Cu		Pb	Zn	Cu
0 - 1	Topsoil	500	70	25	Topsoil	200	60	5
1 - 3	"	400	70	50	"	170	60	5
3 - 12	"	250	50	70	"	120	50	5
12 - 24	Sub-soil	50	25	50	Sub-soil	25	40	5
24 - 36	"	25	25	50	"	10	40	5
36 - 48	"	25	25	50	"	10	40	5
		- -	- -	- -				
48 - 60	Weathered	10	25	25	"	5	50	10
60 - 72	Bedrock					5	40	20
						- -	- -	- -
72 - 84					Weathered Bedrock	5	50	10

(b) Lateral Variation in the Metal Content.

In order to establish the backgrounds for the topsoil and sub-soil horizons, further "spot" samples were then taken in other parts of the Loi-Mi, Herschell and Mt. Teddy areas from the following critical depths: (a) 3 inches, (b) 18 inches, and (c) 36 inches or in the soil horizon immediately overlying bedrock at sites where the overburden is less than three feet thick. They were collected in areas where the sub-outcropping rocks consist

TABLE 9. Lead content of soil, weathered sandstone and weathered tuff bedrock samples from un-mineralised grassland areas near the Bawdwin Mine.

Bedrock Type	Lead content (ppm) of samples:			Bed-rock Horizon (B)	Enrichment Factor in Topsoil: A/B
	Soil Horizons at:				
	3 ins. (A)	18 ins.	36 ins.		
<u>Red s.s.</u>					
No. of samples	52	33	66	12	
Range	80-400	10-100	5-80	5-25	
Median Value *	<u>200</u>	<u>25</u>	<u>25</u>	<u>10</u>	20
<u>White s.s.</u>					
No. of samples	17	6	30	6	
Range	150-400	25-80	25-80	5-25	
Median Value	<u>300</u>	<u>50</u>	<u>40</u>	<u>25</u>	12
<u>Bawdwin tuff</u>					
No. of samples	56	17	93	12	
Range	150-700	25-150	5-120	5-80	
Median Value	<u>400</u>	<u>50</u>	<u>40</u>	<u>40</u>	10

* The median is found to give the most prevalent concentration which, by definition, is the value for the normal background concentration of metal in un-mineralised rocks and soils.

of red sandstone, white sandstone and tuff, accompanied by corresponding samples of weathered sandstone and tuff at some points.

The analytical results for lead, which are summarised in Table 9, show that the mean metal content of soils derived from un-mineralised sandstone and tuff in grassland areas varies from 5 - 400 ppm. When these data are compared to those listed in the section concerned with previous work, it is apparent that background variations in the lead content of the Bawdwin soils considerably exceed those in some other regions, although even

greater fluctuations are known in some British soils (J. S. Webb, pers. comm.).

Judging from the data in Tables 8 and 9, lead appears to be enriched in soil with respect to weathered sandstone and tuff. This enrichment of metal is especially pronounced in the surface horizons of the profile. For example, topsoil samples contain from 10 - 20 times the amount of lead observed in weathered bedrock samples. The impoverishment of metal in these rocks is probably due to the gradual, residual accumulation of lead along with iron and other insoluble constituents during soil formation (Hawkes, 1954).

The surface enrichment of lead, however, is considered to be due to the past movement of metal in the vegetation cycle prior to de-forestation, for the following reasons. Firstly, five samples of charcoal and vegetation ash (grass and bamboo leaves) contain from 500 to 2000 ppm Pb. Secondly, the correlation between organic carbon and total lead in the few profiles studied is extremely close (Fig. 32). This question is further considered in Part VI.

The considerable variations in the lead content of topsoil samples from the area may be due to the effects of differential soil erosion on steep slopes and flatter spurs. No profile, however, appears to have been truncated to the point where surface enrichment is no longer detectable,

Soil developed over tuff contains slightly more lead than those derived from white sandstone and considerably more metal than those overlying red sandstone. Values observed in weathered bedrock samples also show a similar though less pronounced trend.

Research by Wedepohl (1956), Austin and Nackowski (1958) and others show that potash feldspars often contain more lead than other silicate minerals. The former author found that the average lead content of potash feldspars from some igneous rocks varies from 3 to 75 ppm, the mean value of 21 ppm being four times higher than that of quartz from sedimentary rocks. He reports even higher values of up to 450 ppm Pb (mean = 119 ppm) in potash feldspar from pegmatites. There is some doubt, however, as to whether or not lead substitutes for potassium in lattice positions (see also Goldschmidt, 1954; Tausson and Kravtshenko, 1956).

The enrichment of lead in feldspar could account for the higher values in tuff as compared to those in red sandstone. On weathering, the slight difference in the metal content of these parent materials becomes more accentuated. Further research is necessary to determine why weathering profiles over white sandstone contain more lead than those over red sandstone.

2. Lead Content of Soils in Forested Areas.

Soil and rock samples were also taken from other, more remote, forested parts of the Bawdwin area in order to establish that the surface enrichment of lead in grassland areas near the mine is not due to contamination. This was considered to be necessary in view of the comprehensive nature of the previous mining and smelting activity at Bawdwin. The data obtained from the analysis of these samples for lead are presented in Table 10.

TABLE 10. Lead content of soil, weathered sandstone, weathered tuff, weathered shale samples from un-mineralised, forested areas at Bawdwin.

Area and Bedrock Type	Distance from Mine (miles)	Lead content (ppm) of samples:			Enrich- ment Factor (T'soil /B'rock)
		Soil Horizons at:		Bedrock Horizon	
		3 ins.	36 ins.		
<u>Samrapani</u> (red sandstone)	4				
No. of samples		5	1	1	
Range		180-220			
Median		200	10	10	20
<u>Pangsan</u> (shale)	7				
No. of samples		11	2	2	
Range		80-250		5-10	
Median		120	5	5	24
<u>Loi-Mi</u> (tuff)	4				
No. of samples		1	1	1	
Median		350	10	10	35

The metal enrichment factors between bedrock and topsoil in the Loi-Mi, Pangsan, and Samrapani forested areas, where there is absolutely no indication of any previous mining or smelting activity, are 35, 24, and 20 respectively, whereas the corresponding factors in grassland areas near the mine only range from 10 to 20. This suggests that lead enrichment in surface soil near the mine is a natural phenomenon.

3. Copper and Zinc Contents of Soil in Grassland Areas.

As previously mentioned, zinc shows a slight tendency towards surface enrichment, but copper shows absolutely no tendency to decrease with depth in Profiles 33 and 34 (Table 8). In order to establish the mean background, a small number of soil and weathered bedrock samples from the Loi-Mi, Herschell and Mt. Teddy grassland areas were analysed for copper and zinc. The results are shown in Table 11.

The copper content of the soil samples ranges from 5 ppm to 150 ppm, being at a maximum over white sandstone and at a minimum over red sandstone. Metal is somewhat impoverished in weathered bedrock with respect to the overlying soil, but there appears to be no tendency towards surface enrichment. Zinc values are more constant, only fluctuating between the limits of 20 ppm and 80 ppm, although they appear to be slightly higher in the topsoil samples as compared to those from the sub-soil and weathered bedrock horizons.

TABLE 11. Copper and zinc contents of soil, weathered sandstone and weathered tuff samples from un-mineralised, grassland areas near the Bawdwin Mine.

Bedrock type	Copper content (ppm) :			Zinc content (ppm):		
	Soil Horizons:		Bedrock Horizon	Soil Horizons:		Bedrock Horizon
	3 ins.	36 ins.		3 ins.	36 ins.	
<u>Red s.s.</u>	2	2	2	2	2	2
No. of samples						
Range				60 - 80		20 - 50
Median	5	5	5	70		30
<u>White s.s.</u>						
No. of samples	5	5	2	5	5	2
Range	50-100	50-150	5-30	50-60	20-70	
Median	80	100	20	50	50	30
<u>B'win Tuff</u>						
No. of samples	5	5	5	5	5	5
Range			5-30	20-50		
Median	50	50	20	70	30	30

4. Estimated Background and Threshold Values for Prospecting Purposes.

(a) Lead.

Most of the subsequent sampling on Meingtha was carried out at depths of 18 and 36 inches in the sub-soil and only a relatively small number of samples were analysed for copper and zinc. The most important background value, therefore, is the average lead content of the sub-soil at these depths, which ranges from 25 ppm to 50 ppm (Table 9). Analytical errors at these levels are considerable, however, so the regional background is accordingly fixed at the 50 ppm level for working purposes.

Threshold is defined as the estimated upper limit of non-significant variations in the metal content of soil or rock in un-mineralised areas. Judging from the data given in Table 9, lead values in the sub-soil exceeding 100 ppm (twice background) are of possible significance in terms of mineralisation.

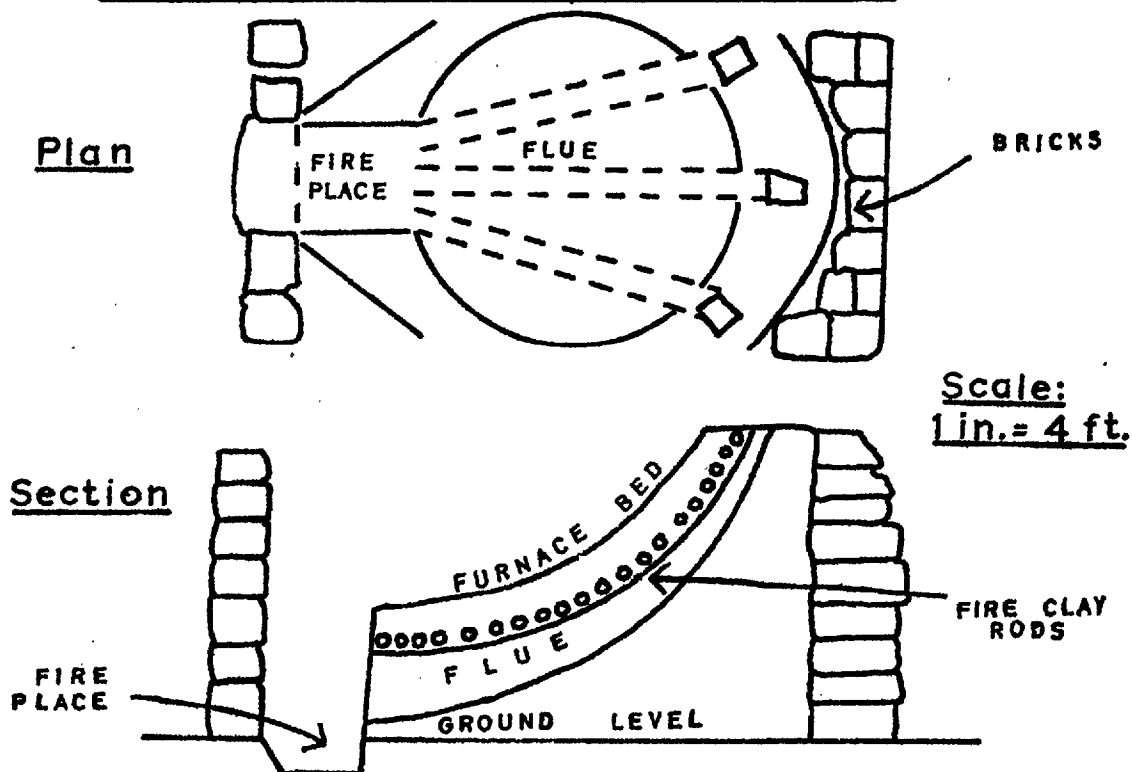
There are a number of small, isolated anomalies of doubtful

is not possible, however, to evaluate the contamination from these sources, which are strictly local in their effect, owing to the proximity of mineralisation and old smelting sites. Attention was consequently restricted to examining the effect of past smelting activity.

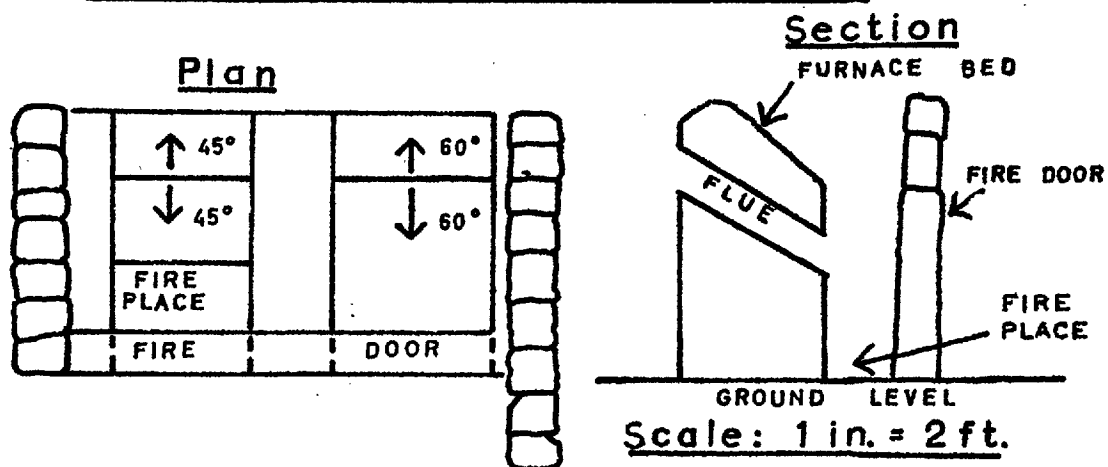
Many of the old Chinese and Kachin smelting furnaces were still intact when La Touche and Coggin Brown (1909) visited the area in 1907. According to their diagrams, the heights of the Chinese and Kachin furnaces were six feet and three feet respectively, occupying areas of approximately 84 square feet and 18 square feet (Fig. 3). No diagrams of old Chinese cupellation furnaces are reproduced; La Touche and Coggin Brown describe them as circular or square structures having a diameter or length of 2 ft. 2 ins. and 4 ft. 6 ins. respectively, and a height of from three to six feet. These furnaces, however, have since been destroyed. At the present time, the former smelting sites are only recognizable by the paucity of the vegetation and by the presence of relic smelting materials, principally slag and more rarely fireclay fragments, firebrick fragments, clay plugs and impregnations of charcoal in the topsoil. It is apparent from Table 13 that these smelting materials contribute lead to the soil, although slag is easily the most important in view of its very high metal content of ^{*} $\leq 20\%$ to more than 48% Pb (La Touche and Coggin Brown, 1909). Work by the writer shows that from 1% to 4% of the lead in the slag is

* The Chinese were only interested in recovering silver from the Bawdwin ores.

CHINESE SMELTING FURNACE



KACHIN SMELTING FURNACE



N.B. ALL STRUCTURES NOW COLLAPSED
AND BURIED

Fig. 3. FORMER SMELTING FURNACES
AT BAUDWIN.

AFTER LA TOUCHE AND COGGIN BROWN (1909).

soluble in water, which is of considerable significance as regards the contamination of the soil during the monsoon.

TABLE 13. Lead content of relic smelting materials.

Material	Chinese Smelters		Kachin Smelters	
	Total Pb (%)	Water-soluble Pb (%)	Total Pb (%)	Water-soluble Pb (%)
Slag	48.0	2.40**	20.0	0.20**
Charcoal	10.0 ⁺		7.0	
Fire Clay	10.0		no data	
Firebrick	9.0		0.9	
Clay Plugs	7.0		no data	

** Metal extracted by shaking a weighed portion of crushed slag with 10 ml. of water for a period of 30 seconds.

+ Charcoal samples from un-contaminated, background areas contain 0.05 and 0.1% Pb respectively.

2. Depth and Extent of the Contamination.

Two features of the contamination effect at Bawdwin considerably hinder the study of the dispersion of lead from a given centre. In the first place, small quantities of slag are scattered at random over the hillsides to the west and south of the Sterne River, although most of it is concentrated on the former smelting sites. Secondly, many of the old smelting sites are

enclosed by earthworks and trenches, which completely block the natural dispersion of metal in the soil in marginal areas. It is, therefore, impossible to select a single, isolated centre and sample a systematic grid in its general vicinity. The extent of the contamination can only be rather tentatively estimated by sampling carefully selected traverses over former smelting sites in localities where there are no earthworks and where the marginal ground appears to be free from slag. The depth and extent of the contamination are discussed jointly in each locality, since previous work has shown that these features are closely related to each other (p. 26).

The location of the eight profiles and six traverses sampled in the Caterpillar Hill, Fort Hill, Gurkha Hill and Herschell areas are shown in Fig. 4. So far as is known, the sub-outcropping sandstone and tuffs are un-mineralised.

(a) Fort Hill.

i. Profiles near Former Smelters.

Much slag, charcoal and firebrick fragments, representing the remains of old Kachin furnaces, were noted on the summit and on the upper slopes of Fort Hill. Data obtained from the analysis of samples from four soil profiles in the vicinity of a former smelting

(contd. on p. 72)

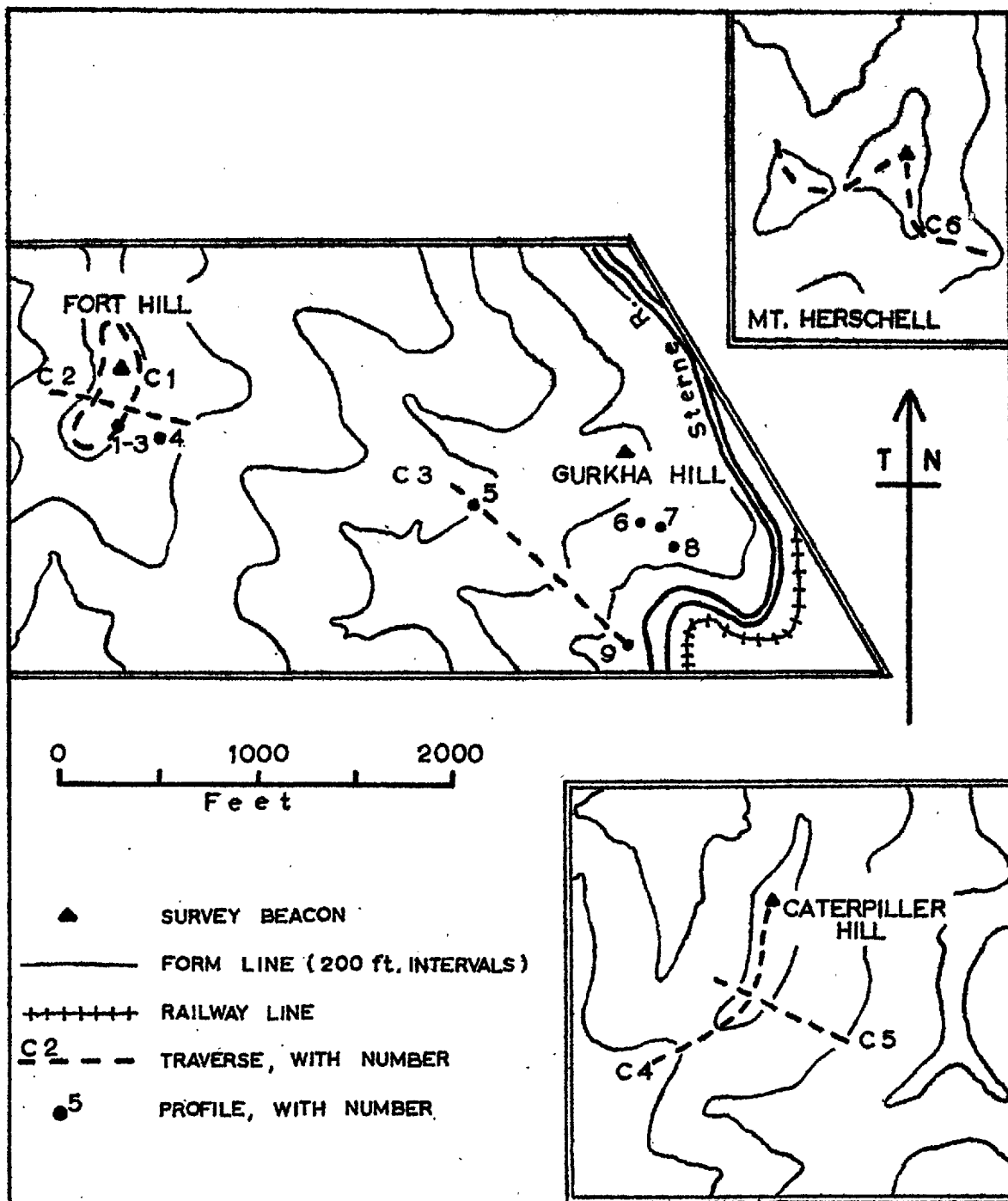


Fig. 4. CONTAMINATION STUDY AREAS AT BAWDWIN.

(SEE FIG. 2 FOR GEOGRAPHICAL LOCATIONS OF SURVEY BEACONS)

TABLE 14. Distribution of lead in soil profiles near a Kachin smelter on top of Fort Hill.

Pit Nos:	1	2	3	4
Distance from smelter:	0ft.E	5ft.E	15ft.E	200ft.E
Sample Nos:	1075/86,8746/8	11344/50	11356/62	1087/94
Depth (ins.)	Lead (ppm)			
0 - 1	3000	3500(43)	1800	700
1 - 3	2500 SC	3500(51)	1500	400
3 - 12	4000	4500(49)	2200 C	200
12 - 24	6000 SC	8000(66)	900	50
24 - 36	150 h	3000(63)SC	200	50
36 - 48	200 ⁺	2000(63)	<u>150</u>	50
48 - 60	150 ⁺	—	10 ^{##}	50
60 - 72	150 ⁺	10 ^{##}		<u>50</u>
72 - 96	<u>80</u> ⁺			5 ^{##}
96 - 108	5 ^{##}			

Figures in parentheses denote the percentage ratio of Cx : total Pb in each sample.

⁺ Somewhat altered sandstone. ^{##} hard, weathered red sandstone.

S = slag horizon C = charcoal horizon h = furnace hearth frags.

site near the top of the hill are given in Table 14.

Contamination extends to bedrock in Profiles 1 - 3, where individual values range from 150 ppm to 8000 ppm Pb. They tend to increase with depth from the topsoil into the sub-soil, reaching a peak at a depth of 12 - 24 inches below the daylight surface. The sub-outcropping red sandstone exposed at the base of each pit, however, has a background lead content of 5 - 10 ppm. Similar background values were also detected in bedrocks concealed by strongly anomalous soil in five other pits on the nearby Traverse C1. The extremely local effect of the sub-soil contamination from the smelter **relies** in Pit 1 is illustrated by the decrease in the lead content of the sub-soil below a depth of 12 inches from 4000 ppm to 400 ppm, in a distance of only ten feet. No samples could be taken to the east of Pit 3 owing to the presence of earthworks, so the full extent of the contamination from this source is not known. Data from Profile 4, however, which is situated about 185 feet further down the hill from Pit 3 and 100 feet below other smelting sites on the middle slopes of the hill, indicate that the contamination from these sources is solely confined to the topmost inch of the profile.

ii. Traverses C 1.

The very localised effect of the contamination from individual centres on Traverse C 1, which is situated on the topmost "smelting platform" around the summit of the hill, and the

extremely spotty distribution of lead in the soil are illustrated by the data presented in Fig. 5. These are based on the analysis of soil samples taken at 50 feet intervals and from depths of 3 inches, 18 inches and 36 inches below the daylight surface.

The range of sample values on this traverse is from 75 ppm to $> 2\%$ Pb, metal being somewhat enriched in the sub-soil with respect to the topsoil. The average lead contents of the samples taken from depths of 3 inches, 18 inches and 36 inches are 3640 ppm, 4730 ppm and 4930 ppm respectively. These values exceed the backgrounds for similar soils over red sandstone by factors of 18, 188 and 193 (Table 9). The higher metal content of the sub-soil is undoubtedly due to the burial of the slag fragments; according to La Touche and Coggin Brown (1909), the Kachins covered the Chinese slag with earth before re-smelting it.

iii. Traverse C 2.

Soil samples were also taken from similar depths and at intervals of 10 - 50 feet on Traverse C 2, which is oriented in a direction normal to the topographic contours (Fig. 5). Within the main smelting area the soil appears to be contaminated to depths in excess of 36 inches, and individual sample values range from 120 ppm to more than 2% Pb. The extent of the contamination in slag-free marginal areas, however, is very limited. At the eastern end of the traverse the metal content of sub-soil samples taken at a depth of 36 inches decreases from 2000 ppm to 25 ppm in a lateral distance

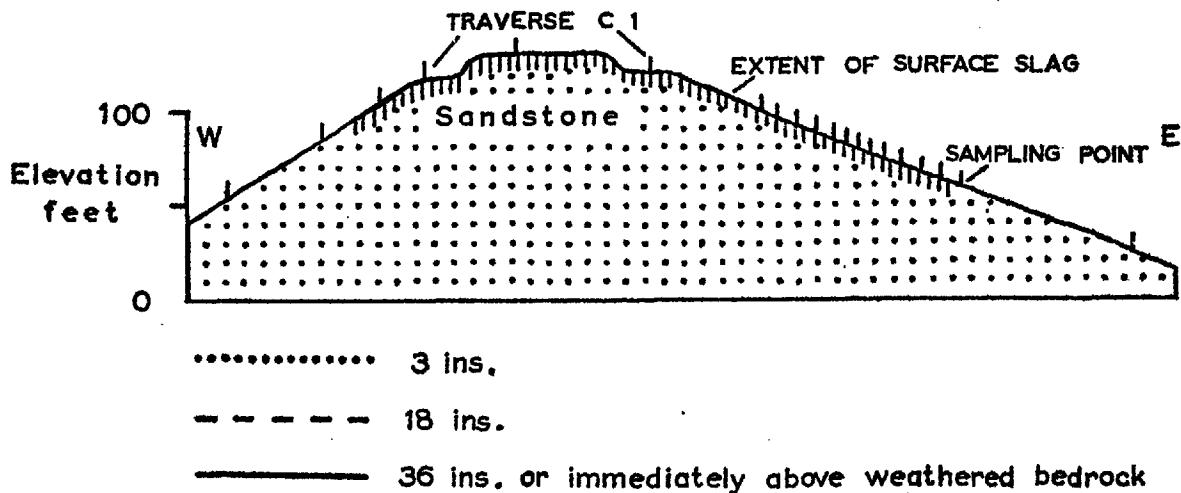
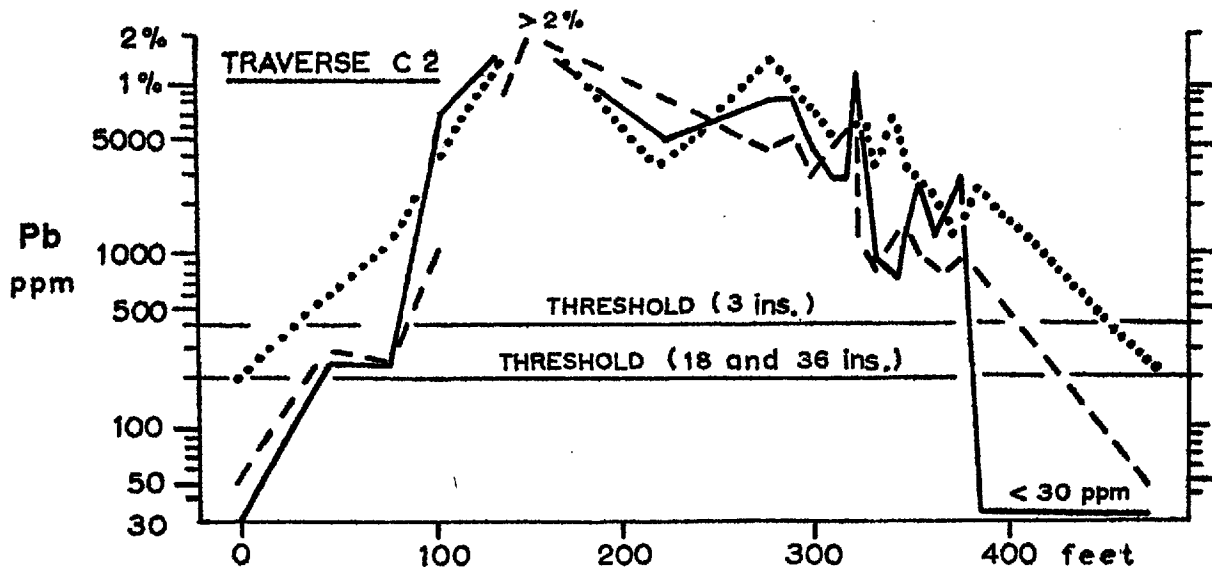
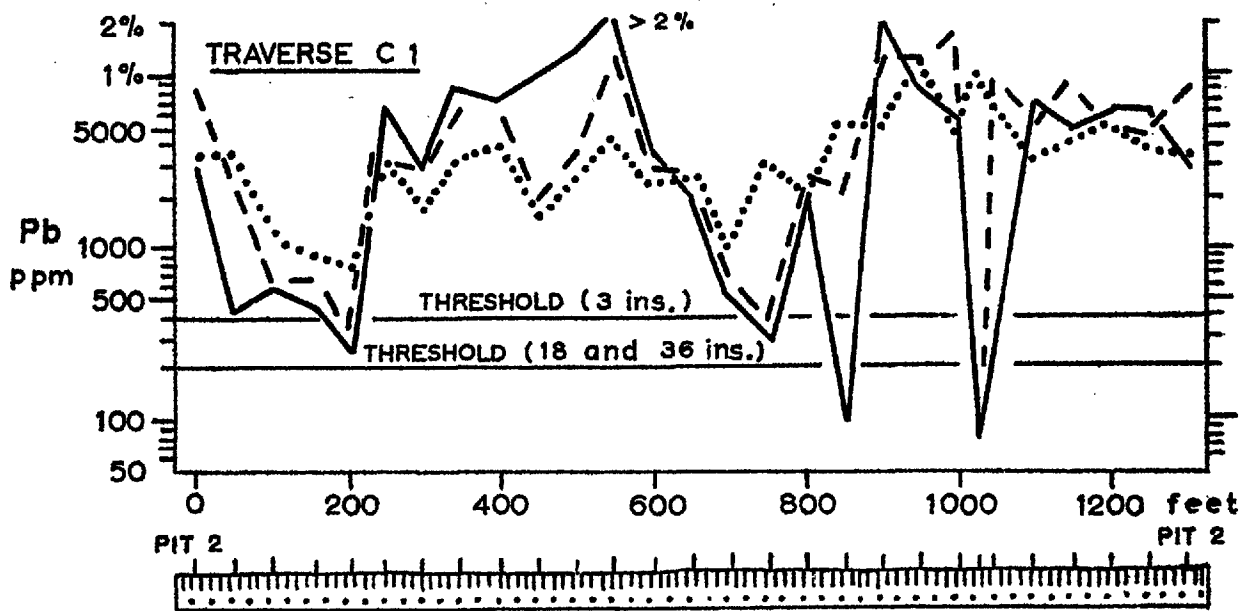


Fig. 5. LEAD CONTENT OF SOIL AT DIFFERENT DEPTHS IN A CONTAMINATED AREA ON FORT HILL.

of only 10 feet. The extent of the contamination in the same horizon on the western side of the smelting area is 50 feet. No samples were taken at closer intervals on this part of the traverse, but judging from the aforementioned data, the lateral extent of the sub-soil contamination may well be less than 50 feet.

The extent of the contamination in the topsoil at a depth of 3 inches below the daylight surface is somewhat greater than that in the sub-soil, owing to the dispersion of contaminated particles by winds and gravity creep, and also to the pollution of the surface soils by furnace fumes during former smelting operations. The data in Fig. 5, however, indicate that it does not exceed 100 feet both to the east and west of the smelting sites on top of the hill.

The very limited extent of the contamination in the soil bordering the smelting sites on Fort Hill is all the more remarkable when one considers the readily-soluble condition of some of the lead in the slag, the very acid soil reaction which theoretically favours the chemical dispersion of metal and the steep slopes. The chemical dispersion of lead during the monsoon is presumably restricted by the affinity of metal for charcoal, humus and sesquioxides, all of which abound in these soils (see Part VI). The apparently small extent of the gravity-controlled mechanical dispersion of metal is not due to the inability of soil particles to migrate down the hillsides, but rather reflects the very limited size of the anomaly source, i.e. the isolated, small (1 - 2 inch

diameter) slag fragments scattered over the surface and in the soil near the top of the hill.

(b) Gurkha Hill.

i. Profiles near Former Smelters.

The results obtained from the analysis of profile samples from the Gurkha Hill Pits 5 - 9 are presented in Table 15.

TABLE 15. Distribution of lead in soil profiles near former Chinese smelters on Gurkha Hill.

Pit and Sample Nos:	5 7571/87	6 25/35 3733	9 1917/24	7 7556/70	8 7552/3 386/96		
Depth (ins.)	Lead (ppm)			Depth (ins.)	Pb (ppm)	Depth (ins.)	Pb (ppm)
0-1	800	1.1% (45)	2.0%	0-1	1.4%	0-1	6000 C
1-3	500	7000 (46)		1-3	1.3%	1-3	1.1%
3-12	300	3500 (48)	4000	3-12	3%	3-12	1.1% C
12-24	100	1400 (71)	1000	12-19	10% SC	12-16	7000 C
24-36	25	1300 (77)		19-24	10% f	16-30	1.2% C
36-48	25	1100 (72)	400	24-27	2% h	30-48	2.5% P
48-60	25	900 (78)	<u>50[±]</u>	27-36	9000	48-56	3500
60-72	25	450 (89)		36-48	500	56-68	1200
72-84	25	400 (87)		48-60	400	68-80	650
84-96	25	300 (83)		60-72	350	80-92	450
96-108	25	50 [±]		72-96	270	92-120	150
108-132	25			96-120	250		
132-144	50 [±]						

Figures in parentheses denote the percentage ratio of cold extractable to total Pb in each sample.

* hard, weathered sandstone. f = fireclay. P = clay plug.
Other symbols given in Table 14.

Four out of five profiles appear to be contaminated to bedrock or to

a depth of ten feet in those pits that did not reach bedrock. The contamination in Pit 5, however, which is situated 170 feet upslope from the western limits of the smelting area, is confined to the topmost three inches of the profile. This is presumably because the sub-soil is not contaminated by slag, the topsoil pollution partly being due to the deposition of traces of metal from furnace fumes during former smelting operations. In Profiles 6 and 9, sample values respectively decrease from 1.1% and 2% Pb at the surface to 300 and 400 ppm Pb in the soil horizon overlying the sub-outcropping sandstone. Metal values reach a peak of > 10% and 2.5% respectively in the samples from Profiles 7 and 8 taken at depths of 12 - 24 inches and 30 - 48 inches below the surface. At the former site, the highest value was observed in a fire clay layer above the hearth of an old furnace, while in Pit 8 a clay plug was found in the horizon having the highest metal content. The burial of this furnace plug to a depth of 40 inches is probably due to both human and natural processes.

The deep penetration of the contamination into the slag-free sub-soil horizons in Profiles 6 - 9 may have been effected by the following mechanisms: (a) the percolation of dilute metalliferous solutions during the smelting of the ore, (b) the deposition of metal from rainwaters which are leaching it from slag fragments in the general vicinity of these pits and (c) the translocation of material within the profile in chemical solution

or as fine soil fractions washed down during the monsoon. One cannot entirely exclude the possibility that the anomalous values of 150 - 250 ppm Pb in the soil samples from a depth of ten feet in Pits 7 and 8 are due to the dispersion of lead from unsuspected bed-rock mineralisation. The absence of anomalous values in the bed-rock samples from Pits 6 and 9, however, shows that contamination can penetrate to depths of from five to eight feet by the aforementioned processes.

ii. Traverse C 3.

Traverse C 3 was sampled over the main smelting area on the slopes of Gurkha Hill in an E-W direction normal to the contours, at intervals of 50 feet. The data obtained from the analysis of soil samples taken at depths of 3 inches, 18 inches and 36 inches are presented in Fig. 6. The metallisation of the soil on Traverse C 3 appears to resemble that on Fort Hill Traverses C 1 and C 2 in one important respect, namely that contamination extends to a depth of more than 36 inches at all the sampling points inside the area where the Chinese formerly smelted ore. It has already been shown that lead is slightly enriched in the sub-soil samples from Traverses C 1 and C 2 relative to the topsoil samples. This is apparently not so on Traverse C 3, however, since the topsoil samples (av. = 1% Pb) contain more than twice as much metal as those from a depth of 18 inches (3800 ppm), and nearly ten times the amount of metal in the sub-soil samples from a depth of 36 inches

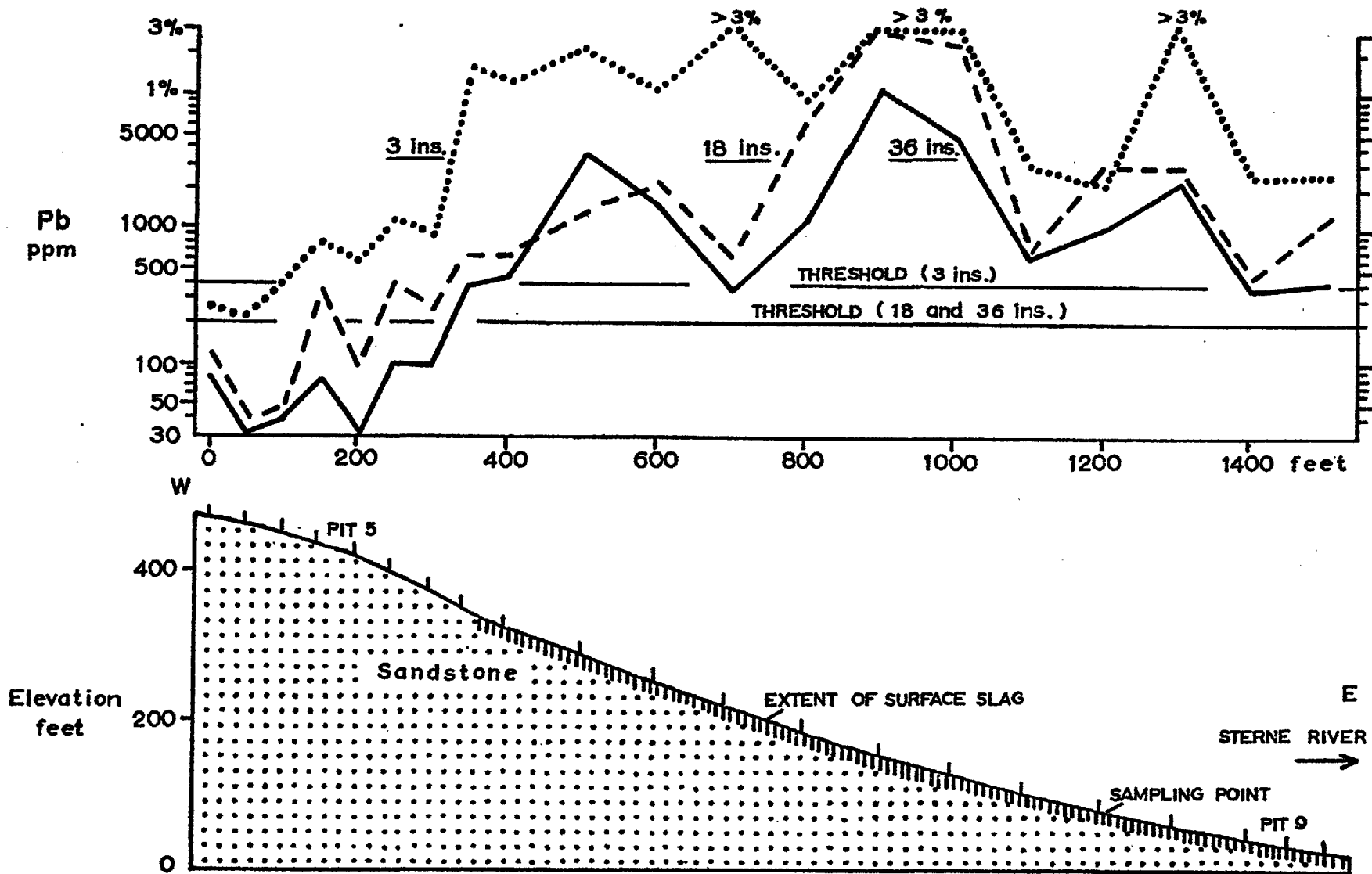


Fig. 6. LEAD CONTENT OF SOIL AT DIFFERENT DEPTHS IN A CONTAMINATED AREA ON TRAVERSE C 3, GURKHA HILL.

(1100 ppm). A comparison of the data from the three traverses also suggests that just as much lead is being contributed to the soil by the Kachin slag on Fort Hill in spite of its considerably lower metallic tenor (Table 13).

The extent of the contamination in the sub-soil to the west of the Gurkha Hill smelting sites is 50 feet, the closest distance between the sampling points on the traverse. The topsoil appears to be contaminated for a distance of 250 feet in this direction, however, which is somewhat greater than is the case on the Fort Hill Traverse C 2. The extent of the contamination in the sub-soil and topsoil to the east of the Sterne River cannot be determined owing to the houses between the river and the railway line. It may well exceed a distance of 250 feet in the topsoil, since the monsoon winds blow over the area from the S.W. for six months of the year.

(c) Caterpillar Hill.

The lead contents of samples taken from two traverses on the Caterpillar Hill at intervals of 50 feet and from depths of 3 inches, 18 inches and 36 inches are shown in Fig. 7. Traverse C 4 is located along the axis of the hill, crossing the former smelting area on the ridge-crest, while Traverse C 5 is oriented in a direction normal to the topographic contours.

The data from Traverse C 4 serve to illustrate the irregular pattern of metallisation in contaminated sub-soil.

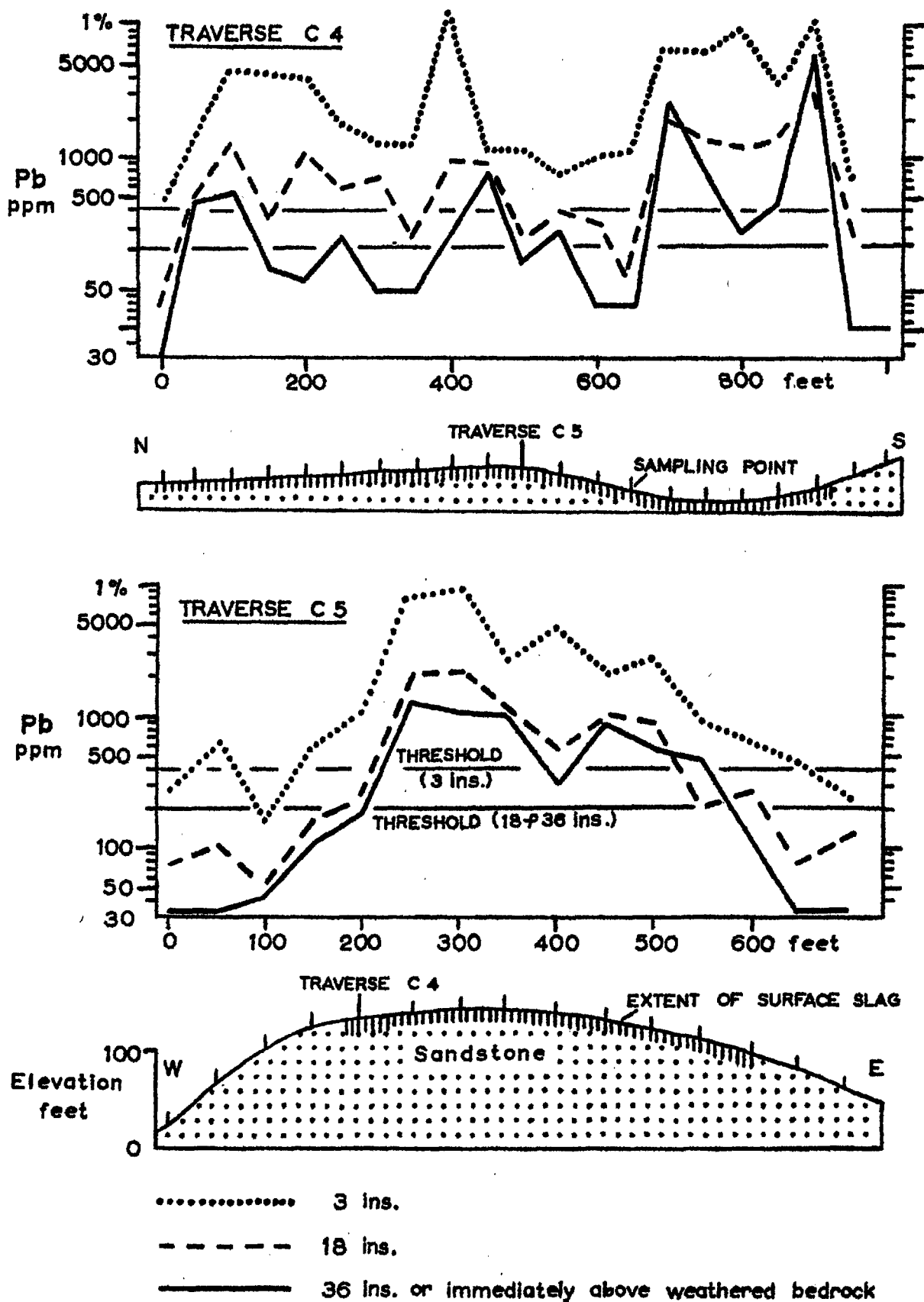


Fig. 7. LEAD CONTENT OF SOIL AT DIFFERENT DEPTHS IN A CONTAMINATED AREA ON CATERPILLER HILL.

Samples collected over old smelters contain as much as 6000 ppm Pb, whereas similar samples taken 50 ft. away from these sites have a lead content of only 50 - 75 ppm. Lead appears to be more evenly distributed in surface soil at a depth of 3 ins. on the two Caterpillar Hill traverses that were studied.

The lateral extent of the contamination on the eastern and western slopes of Traverse C 5 is similar to that observed on Fort Hill, i.e. 50 ft. or less in the sub-soil at depths of 18 and 36 ins. and 100 ft. in surface soil.

(d) Mt. Herschell.

Soil sampling in areas of intense contamination near former smelting sites on Caterpillar Hill, Fort Hill and Gurkha Hill would appear to be useless from the geochemical prospecting viewpoint. This is because all levels in the soil profile are contaminated by buried slag.

The data presented in Fig. 8, however, show that contamination from scattered, surface slag fragments on the summit of Mt. Herschell is confined to the surface horizons of the profile. Judging from these data, the presence of surface slag does not necessarily preclude the application of geochemical methods to prospecting for mineralisation in other parts of the Bawdwin area, provided all samples are taken at a depth of 36 ins. from the daylight surface.

3. Extractability of Lead in Contaminated Soil.

(a) Cold 5% Nitric Acid.

The work of Hibbard (1940) and Mitchell (1955), which has already been mentioned, suggests that some of the lead in contaminated soil is soluble in cold, dilute acids (pp. 26-27). A number of soil samples from contaminated areas at Bawdwin were accordingly tested for cold-extractable metal by the technique outlined in Appendix B 3.

As can be seen from Tables 14 and 15, the ratio of cold-extractable to total lead in samples from contaminated Profiles 2 and 6 increases with depth from 43% and 47% respectively at the surface to 63% and 83% in the soil horizon within twelve inches of bedrock.

The data obtained from the analysis of 80 soil samples taken at depths of 3 inches and 36 inches, from 40 pits in contaminated areas, are given in Table 16. The total metal contents of the samples range from 100 ppm to 1% Pb. For purposes of comparison, the results obtained from the analysis of 26 soil samples collected at similar depths in un-contaminated parts of the Meingtha area are also included in the table.

The results show that the ratio of cold-extractable to total lead in contaminated sub-soil samples only slightly exceeds that observed in the topsoil samples, the respective mean values being 60% and 53%. These high ratios are in

TABLE 16. Ratio of cold-extractable to total lead in contaminated and non-contaminated topsoil and sub-soil samples from Bawdwin.

Area and Bedrock Type	Sample Depth (ins.)	No. of Samples	Cx : Total Pb (%)		
			Min.	Max.	Mean
(a) <u>5% NITRIC ACID</u>					
Gurkha Hill ** (sandstone)	3 36	7 7	39 60	82 86	64 71
Caterpillar Hill ** (sandstone)	3 36	17 17	27 40	90 87	50 63
Fort Hill ** (sandstone)	3 36	16 16	37 37	64 66	52 52
Meingtha - A8 (tuff)	3 36	8 8	17 5	41 19	26 12
Meingtha - A 12 (sandstone)	3 36	5 5	17 3	25 6	19 5
(b) <u>0.25% CITRIC ACID</u>					
Caterpillar Hill	3	5	11	33	17
Fort Hill	36	5	10	31	22
Gurkha Hill					
Meingtha - A 8 and A 12	3 36	3 3	3 1	5 3	4 2

* contaminated area near old smelting sites

marked contrast to the much lower mean ratios of 9% and 23% observed in the non-contaminated sub-soil and topsoil samples from Meingtha Hill. Judging from these data, the extractability of lead in the soil therefore affords an additional method of discriminating

between "false" geochemical anomalies related to slag contamination and natural anomalies whose source is located in the sub-outcropping bedrocks. The contaminated anomalies are characterised by (a) high ratios of cold-extractable to total lead, which usually exceed 40%, and (b) the equally high extractability of lead in sub-soil samples as compared to topsoil samples. The results in Table 16, however, indicate that the extractability of lead in non-contaminated topsoil samples is three times as high as that in the sub-soil samples (see later).

(b) Cold 0.25% Citric Acid.

The extractability of lead in ten soil samples from Caterpillar Hill, Fort Hill and Gurkha Hill was determined by shaking weighed portions with 0.25% citric acid prior to analysis. It ranges from 11 - 33% (av. 17%) in the topsoil samples, while the corresponding figures for the sub-soil samples are 10 - 31% (av. 22%). These ratios also considerably exceed those found in six non-contaminated soil samples from Meingtha Hill, as can be seen from the data in Table 16.

4. Features of the Contamination Effect in Soils near Old Smelting Sites .

(a) Physical Features .

Slag, charcoal, firebrick, or clay plugs can be found on all smelting sites in the Caterpillar Hill, Fort Hill and Gurkha Hill areas. These relic smelting materials occur both on the

surface and at variable depths of up to 40 inches in the sub-soil.

(b) Pattern of Contamination in Soils.

Individual topsoil and sub-soil samples taken over or near former Chinese and Kachin smelters contain up to 2% Pb, this value exceeding the background values for similar topsoil and sub-soil samples from other areas by factors of 100 and 800 respectively. Lead is markedly enriched in the topsoil if the contamination is caused by surface slag fragments, old smelter fumes, or wind-borne dust. In other localities where slag fragments have been buried, however, sub-soil samples contain just as much or more lead than those from the topsoil horizon. The depth of contamination declines rapidly with increasing distance from the sites of former smelting furnaces wherein the whole profile is contaminated to bedrock. The lateral extent of contamination in the top-soil and sub-soil horizons away from the smelting sites on Fort Hill and Caterpillar Hill does not appear to exceed 100 feet and 50 feet respectively. The extent of the topsoil contamination, however, is 250 feet to the west of the Gurkha Hill smelting sites, and may well exceed this distance to the east of Gurkha Hill, on the other side of the Sterne River. The "false" anomalies due to contamination lack homogeneity, being characterised by the erratic distribution of high and low values at adjacent sampling points.

The few bedrock samples that were taken in contaminated areas have a background metal content of 50 ppm or less, even

though the overlying soil may carry several thousand ppm Pb.

(c) Mobility of Lead Introduced by Smelter Contamination.

Tests using 5% nitric acid disclosed that the ratio of cold-extractable to total lead in contaminated soil samples usually exceeds 40%, with a slight tendency to increase with depth. The ratio may reach 85% or more in relatively inorganic sub-soil samples containing very small concentrations of organic matter (< 0.07% organic carbon). From 10% to 33% of the lead in soil samples from contaminated areas is soluble in 0.25% citric acid.

These data indicate a relatively high mobility for lead introduced into the soil as a result of smelter contamination. The fact that lead descends deep into the soil profile below old smelting sites suggests that percolating rainwater is able to dissolve some of this metal and re-distribute it in depth.

c). SOILS AND ROCKS IN MINERALISED AREAS ON MEINGTHA HILL

The results of the preliminary orientation undertaken by J. S. Webb and R. O. Morris on Meingtha Hill showed that all horizons of one profile to the east of the Meingtha Lode contain anomalous concentrations of lead, copper and zinc, in that order. They also found that soil samples taken at a depth of 12 - 18 inches over the Meingtha Lode near the western end of Traverse A 12, and over smaller deposits near the eastern end of Traverse A 8, some 8000 feet further to the S.E., contain 300 - 5000 ppm Pb, 130 - 650 ppm Cu and 70 - 350 ppm Zn (Fig. 9). The width of both soil anomalies is greater than 300 feet.

This section is concerned with the more detailed study of the primary and secondary dispersion of copper, lead and zinc in these two localities on Meingtha Hill.

1. Extent of the Lead Anomaly in the Sub-soil on Meingtha and Mt. Teddy.

(a) Sample Depth, Sample Interval and Traverse Interval.

1. Sample Depth. The contamination on Meingtha appears to be strictly localised in its effects, which are confined to the following sources: (a) the former smelting sites along the Sterne River to the west of the hill, (b) the railway line, (c) the large quarries to the north of Traverse A 28, (d) isolated slag fragments and small spoil dumps on Ridge-Crest A, and (e) the somewhat larger dumps near railway cuttings at the southern

end of the hill (see Figs. 9 and 13). In order to avoid any risk of topsoil contamination from these sources, all samples were taken from the sub-soil horizon at a depth of 36 inches below the daylight surface except in areas of shallow overburden, when the soil horizon immediately overlying weathered bedrock was sampled instead. Judging from the data in the preceding section, all soil samples from this depth will be completely un-contaminated except within 50 feet of the old smelting sites along the Sterne River.

ii. Traverse Interval.

Since a greater thickness of soil occurs on the spurs as compared to the slopes and gullies, samples were only collected from ridge-crest and spur traverses in the first instance. Most of the spurs have an E-W trend, which so happens to be normal to the strike of the Meingtha Lode and some of the smaller deposits near the Sterne River. The traverse locations are shown in Fig. 9, from which it can be seen that the average distance between the traverses is about 300 feet. Conspicuous gaps in the sampling pattern in important areas were filled in by sampling additional traverses both parallel and normal to the topographic contours.

iii. Sample Interval.

The sample interval depends on the width and homogeneity of the soil anomalies. Judging from the results of the preliminary orientation, the width of the soil anomalies in both areas sampled

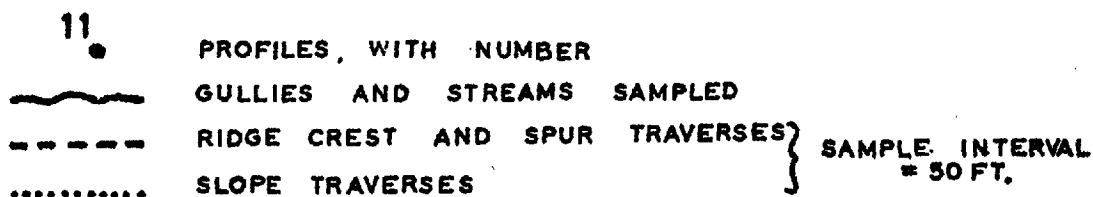


Fig. 9. SAMPLE LOCATION MAP OF THE MEINGTHA - MT. TEDDY AREA.

is greater than 300 feet. Later work by the writer showed that the full width of the soil anomalies in the Meingtha-Mt. Teddy area is as much as 6000 feet.

In the Meingtha area, homogeneity was assessed by collecting sub-soil samples at intervals of 5, 10, 20, 30 and 50 feet to the north, south, east and west of Pit 11 on Traverse A 12; the ground slopes at 30° to the east and west (Fig. 9). For comparison, samples of topsoil were also taken at every site. The analytical results for lead are given in Table 17.

TABLE 17. Lateral variation in the lead content of residual sub-soil and topsoil near Pit 11, Meingtha Hill.

Distance from corners of the 4 ft. square Pit 11 (feet)	Lead content of samples (ppm) :							
	North [⊥]		South [⊥]		East ⁺		West ⁺	
	S	T	S	T	S	T	S	T
0	2000	1400	2800	1500	2500	1400	2200	1600
5	1400	1200	4000	1600	3000	1400	2000	1500
10	2000	1400	4500	1600	2500	1700	1800	1200
20	1800	1500	4000	2000	3200	2000	1400	1000
30	2500	1400	6500	1800	3000	1700	1700	1000
50	1400	1500	3200	2000	2500	2000	1500	1000

S sub-soil samples from a depth of 36 inches.

T topsoil samples from a depth of 3 inches.

[⊥] ground surface generally level.

⁺ angle of slope approx. 30° .

Lead appears to be rather erratically distributed in the sub-soil near Pit 11, sample values ranging from 1400 to 6500 ppm Pb. These variations are presumably related to corresponding variations in the tenor of the bedrock mineralisation since individual soil samples are relatively homogeneous (Table 4). Furthermore, the lateral variation of lead in the sub-soil is no greater than the vertical variation in the metal content over a depth of 10 feet in Profile 11 itself, as can be seen from Table 18. By contrast, lead appears to be more evenly distributed in the topsoil horizon near Pit 11, and individual values never exceed the relatively narrow limits of 1000 - 2000 ppm.

The anomalous values in the soil samples from this locality are heterogeneous, but they remain well above the threshold value of 200 ppm Pb at all distances from the central site. Clearly, however, a very close sampling interval of 10 feet or so might be required to locate individual, spotty metal sources in the bedrocks. Having regard to the very considerable width of the known soil anomalies on Meingtha, a sample interval of 200 feet or more would have been adequate for the purposes of detecting these anomalies. A smaller sampling interval of 50 feet, however, was employed for the research study, in order to obtain a detailed picture of metal distribution in the soil.

(b) Analytical Results.

Most of the sub-soil samples taken over sandstone and tuff

on Meingtha contain anomalous concentrations of more than 200 ppm Pb (Fig. 34). Although the anomaly either fades to background near the Sterne River or else abuts the areas where ore was formerly smelted by the Chinese, it persists across the E.R. Valley on the eastern side of the hill (the distribution of lead in the sub-soil in the Mt. Teddy area lying to the west of E.R. Valley is discussed in Appendix A). It suffices to state at this juncture that the full extent of the secondary dispersion of lead in the residual sub-soil in the Meingtha-Mt. Teddy area is 6000 feet in a N-S direction, while it varies from 2000 to more than 5000 feet in an E-W direction. The total area occupied by anomalous sub-soil is about half a square mile.

There are ~~seven~~ localities on Meingtha where the metal content of the sub-soil samples exceeds 1600 ppm Pb (Fig. 34). The distribution of metal within Areas Ia, III and IV is studied in this section. An examination of the geological map given in Fig. 33 indicates that these anomalies are clearly related to the known, blind deposits in the sub-surface tuffs.

2. Meingtha Lode Area.

(a) Mineralisation in Depth.

There are no adits or drill cores exposing near-surface rocks above the Meingtha Lode or related deposits, so no primary dispersion studies were undertaken in the area. A small rise discloses the presence of $8\frac{1}{2}$ feet of oxidised ore, having a tenor of

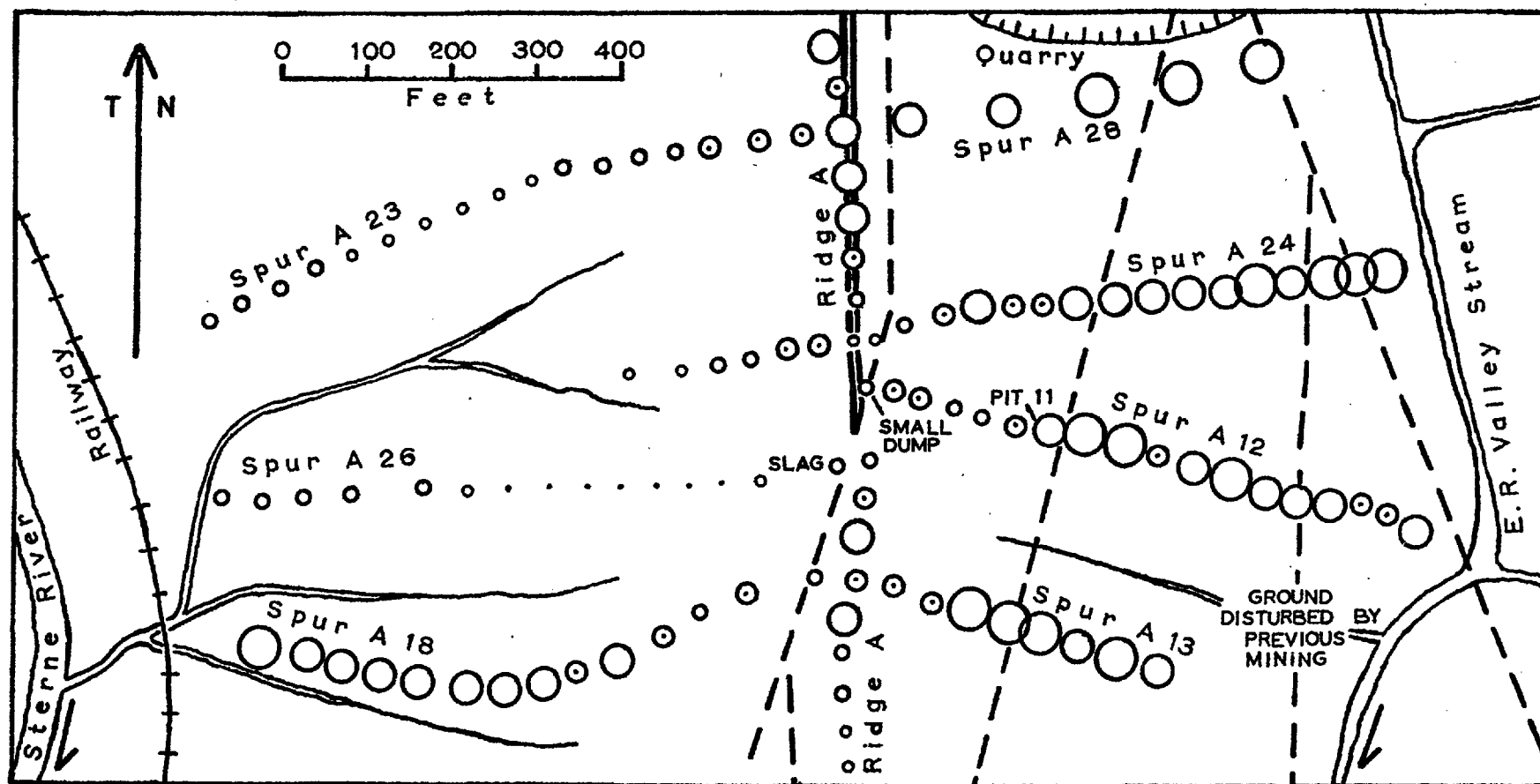
33% lead, 0.2% copper and traces of zinc, at a depth of 220 feet below the top of the hill. The oxidised ore at this level is characterised by an extremely high ratio of lead to zinc. With increasing depth into the primary ore, however, the ratio tends to become smaller and at a depth of 520 feet below the ridge-crest, the grade of the deposit is 15.4% Pb, 11.4% Zn and 1.2% Cu (Clegg, 1940).

(b) Lateral Dispersion in Sub-soil on Traverses A 12, 13, 18, 23, 24, 26 and 28.

i. Lead

Fig. 10 shows the detailed distribution of lead in sub-soil samples taken from a depth of 36 inches within Areas III and IV. Sample values are represented by symbols rather than by contours in view of the erratic lateral variations observed in the metal content of the sub-soil samples near Pit 11.

The width of the anomaly in a direction normal to the strike of the Meingtha Lode on the four traverses sampled exceeds 1300 feet. Anomalous values apparently persist into the Mt. Teddy area where further mineralisation probably exists in the Bawdwin tuffs. The metal contents of the sub-soil samples from the area shown in Fig. 10 range from 120 - 7000 ppm Pb. The peak value was detected in a soil sample taken over sub-outcropping tuffs on Traverse A 28. It exceeds the background and threshold values given in Tables 9 and 12 by factors of 175 and 35 respectively. Apart from this peak value, however, there appears to be little difference in the metal contents of the samples collected over



- GULLY
- PROJECTED SUB-OUTCROP OF BLIND ORE DEPOSIT 200 FT. BELOW THE SURFACE
- - - PROJECTED SUB-OUTCROP OF FAULTS KNOWN IN UNDERGROUND WORKINGS

LEAD CONTENT OF SOIL SAMPLES FROM A DEPTH OF 36 ins.

- | | |
|---------------|------------------|
| • < 200 ppm | ⊙ 800 - 1600 ppm |
| ○ 200 - 400 " | ○ 1600 - 3200 " |
| ○ 400 - 800 " | ○ 3200 - 7000 " |

Fig. 10. DISTRIBUTION OF LEAD IN THE SUB-SOIL ON RIDGE CRESTS AND SPURS NEAR THE MEINGTHA LODE.

arenaceous or tuffaceous rocks.

Although values range from 300 - 2000 ppm Pb in the sub-soil directly over the blind deposit on Ridge-Crest A, the anomaly peak on every E-W traverse is located between 300 and 500 feet to the east of the orebody. The peak values appear, however, to be spatially related to two faults known in underground workings, as can be seen from the geological cross-section presented in Fig. 11. The maximum values observed in this area are somewhat higher than those found in soil samples over blind orebodies in other regions, but judging from previous work, the tenor of soil values over blind deposits clearly need bear no relation to the tenor of the underlying deposit. For example, Granier (1958) reports that well defined peak values in soils directly over a blind, high grade, lead-zinc orebody in North Africa rarely exceed the comparatively low level of 100 ppm Pb.

ii. Copper and Zinc.

The data in Fig. 11 indicate that the peaks of the copper and zinc sub-soil anomalies on Traverses A 12 and A 26 are also not located directly over the Meingtha Lode. The lateral extent of the secondary dispersion of copper on these traverses is similar to that observed for lead, the width of the copper anomaly being more than 1100 feet. Individual samples contain from 150 - 500 ppm Cu, the contrast between anomaly peak and threshold being 2.5. The secondary dispersion of copper is characterised by the absence

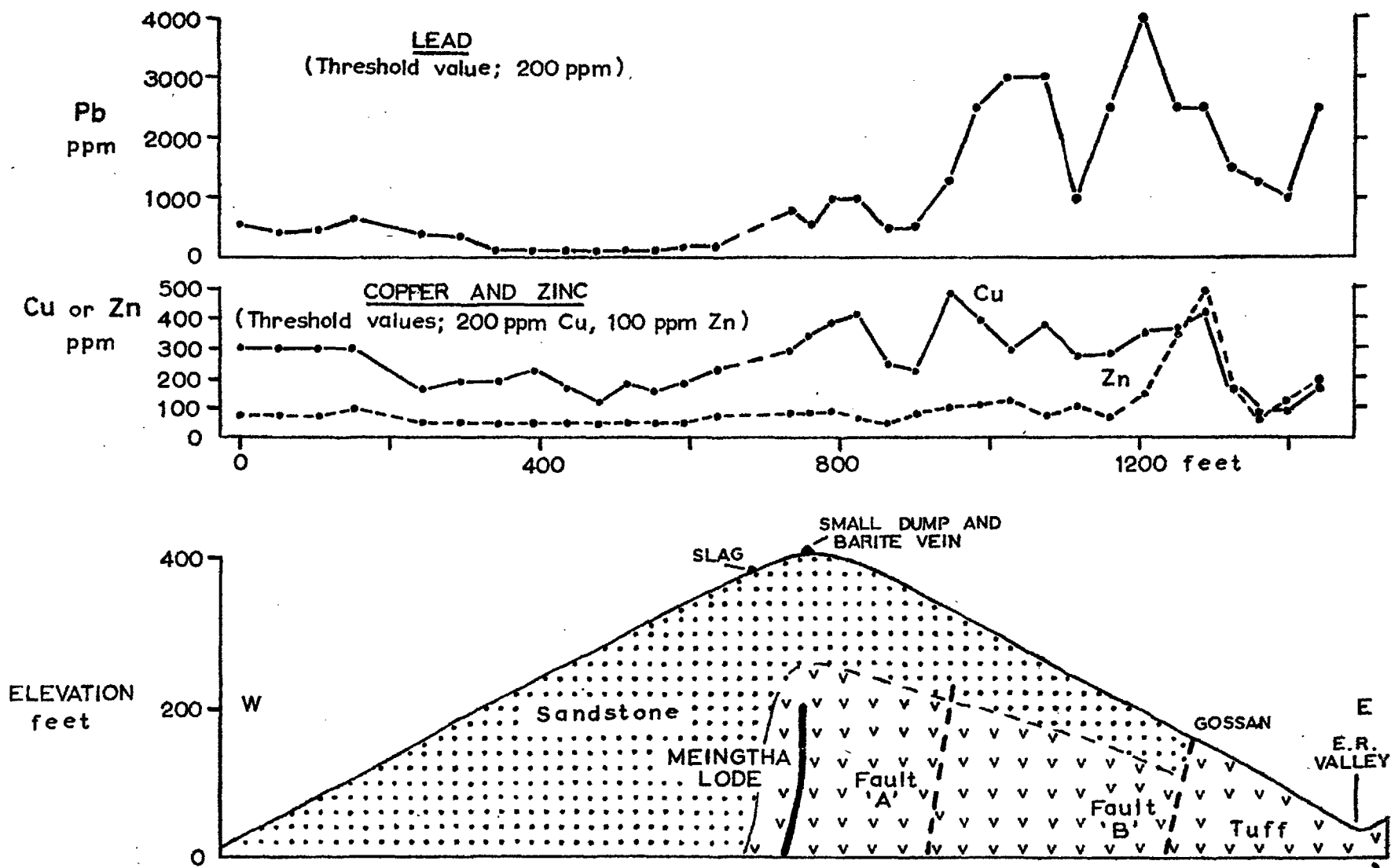


Fig. 11. DISTRIBUTION OF COPPER, LEAD AND ZINC IN SOIL AT A DEPTH OF 36 INS. ON TRAVERSES A 12 AND A 26, MEINGTHA HILL.

of well-defined peak values over any of the three major structures in the area.

The width of the zinc anomaly on Traverses A 12 and A 26 is 320 feet, so the secondary dispersion of zinc is more limited than that of either copper or lead. Sample values range from 70 - 500 ppm Zn. The anomaly peak, which exceeds threshold by a factor of 5, is located directly over Fault B.

(c) Lateral Dispersion of Lead in Soil and Weathered Bedrock, Traverse A 12.

Seventeen pits were dug to bedrock or a depth of 10 feet on Traverse A 12 in order to ascertain whether the lead anomaly is more clearly defined at other levels in the profile. The pits were spaced at 50 foot intervals down the 30° hillsides between the ridge-crest and E.R. Valley. The thickness of the overburden varies from a minimum of 2 feet in a profile over tuffaceous rocks to a maximum of more than 10 feet at sites where sandstone probably sub-outcrops. Soil samples were taken from depths of 3 inches, 12-24 inches and 48-60 inches below the daylight surface. Samples were also collected from the soil horizon within twelve inches of bedrock and from the top-most twelve inches of the bedrock itself in those pits that penetrated to these levels. A short trench was dug to a depth of 6 feet upslope from Pit 11 and similarly sampled at ten foot intervals. The analytical results are presented in Fig. 12.

i. Topsoil Horizon.

There are relatively small fluctuations between 1000 and

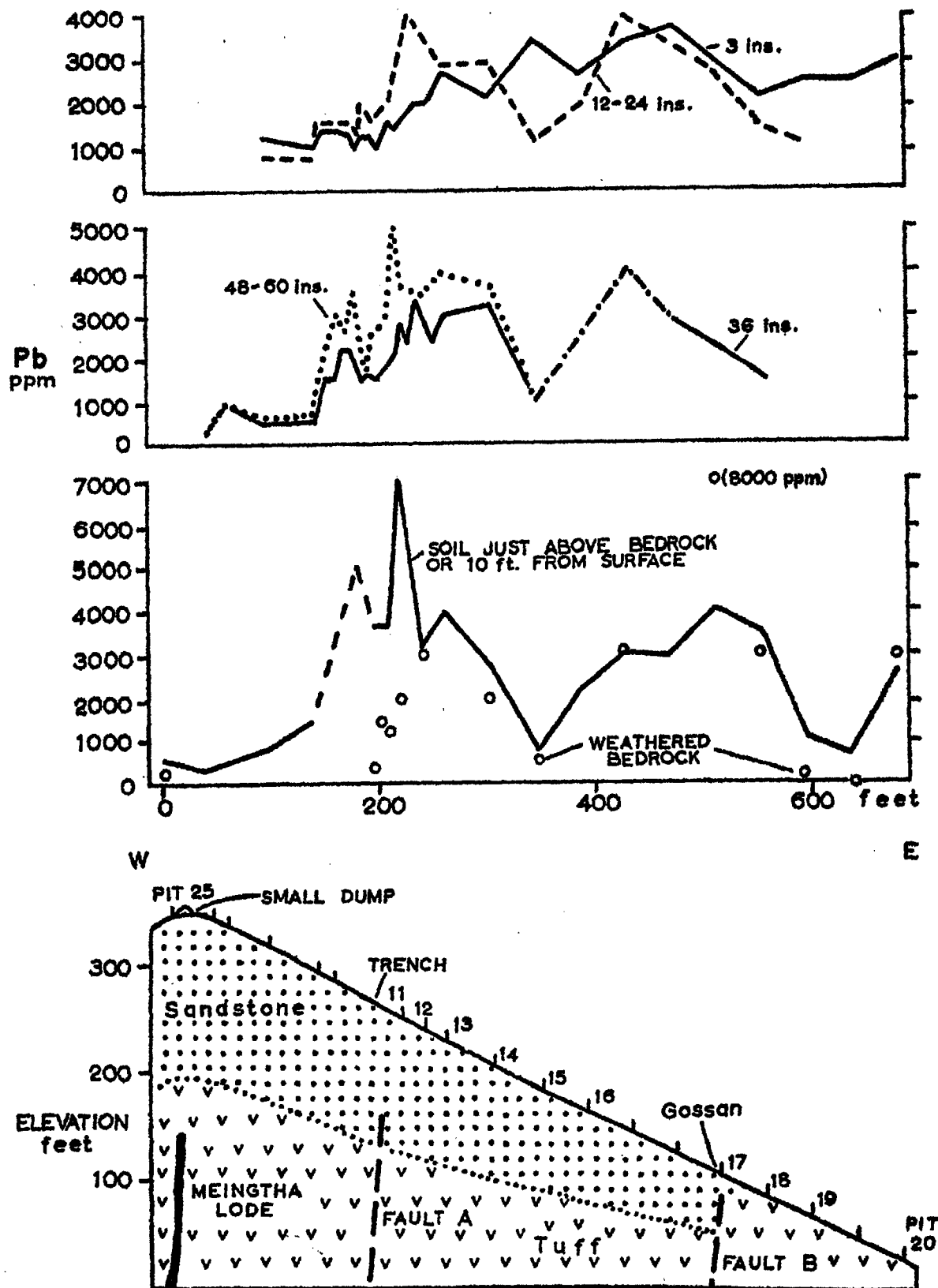


Fig. 12. DISTRIBUTION OF LEAD IN SOIL PROFILES ON TRAVERSE A 12, MEINGTHA HILL.
 (Threshold values; 400-600 ppm at 3 ins., 200 ppm for other horizons)

3500 ppm in the lead content of the topsoil horizon at a depth of 3 inches, which further corroborates the data in Table 17. Lead was also found to be evenly distributed in the topsoil on other traverses in the Meingtha-Mt. Teddy area. The even distribution of metal in the topsoil is believed to be due to thorough mechanical mixing of the surface soil by landslips, thereby eliminating the spottiness that is so characteristic of the deeper sub-soil horizons. Sample data from the topsoil horizon, however, would appear to be less satisfactory from the prospecting viewpoint than those from deeper levels in the profile, since they give no indication of the extremely variable tenor of the bedrock source of the anomaly.

ii. Sub-soil Horizons.

The lateral variation in the lead content of sub-soil samples collected at a depth of 12-24 inches is greater, the observed range of values being 700 - 4000 ppm. It is evident from Fig. 12 that there are two distinct anomaly peaks in this soil horizon. The trend towards the differentiation of a single anomaly into two separate peaks becomes somewhat more accentuated with increasing depth in the profile; sample values range from 250 - 7000 ppm Pb. The positions of the two anomaly peaks, which are located over or close to the projected sub-outcrop of Faults A and B, tend to fluctuate from one sub-soil horizon to another over a lateral distance of 20 - 100 ft. (see pp. 97-101).

iii. Weathered Bedrock Horizon.

Samples of weathered sandstone contain from 300 to 3000 ppm Pb, the corresponding range of values in the weathered tuff samples being 50 - 3000 ppm. Considerably higher values, however, of up to 1.1% Pb were detected in three samples of gossan from the base of Pit 17. As can be seen from Fig. 12, the dispersion pattern of lead in the weathered bedrock horizon resembles that in the soil, since samples taken over or close to the projected sub-outcrop of Faults A and B contain more metal than those from other sites. For example, the surface rocks directly over the blind Meingtha Lode at Site 25 only contain from 300 to 600 ppm Pb.

Near Pit 25, the sandstone is impregnated with small barite stringers, samples of which were found to contain 200 ppm Pb. Loveman (1917) and Coggin Brown (1918) consider that the barite veins in the sedimentary rocks at Bawdwin are in no way related to the lead-zinc mineralisation in the tuff (p. 50). It is possible, therefore, that this value merely reflects the high, local background of barite in the Bawdwin area. According to Wedepohl (1956), barite which is genetically related to lead mineralisation in different parts of the world usually contains 1% Pb or more.

In spite of extreme variations in the metal content of the weathered bedrock samples along Traverse A 12, the fact remains that every sample but one taken over a distance of 750 ft. is anomalous. The size of the bedrock source is undoubtedly one of the principal factors contributing to the extensive dispersion of lead in the soil

on this traverse. No galena was noticed in any of the pits to account for the high lead values in the weathered bedrock samples, presumably because the sulphide disseminations have been oxidised. Nothing is known, however, of the nature of the secondary lead minerals in these rocks. As previously mentioned, anglesite, cerussite, massicot, and pyromorphite are known in various parts of the Bawdwin Mine.

The salient features of the two natural soil anomalies over mineralisation on Traverses A 8 and A 12 are discussed on pages 111-4, where criteria are advanced to show that these anomalies are in no way due to contamination.

(d) Leakage Dispersions Related to Sub-surface Deposits.

The data from these traverses show that the anomaly peaks for copper, lead and zinc are displaced for a distance of 300 - 500 feet to the east of the Meingtha Lode, and do not occur directly over the blind deposit. According to Webb (1958), the ability to interpret leakage anomalies depends on the knowledge of the sub-surface geology. Any interpretation of the afore-mentioned data is accordingly limited by the paucity of information concerning the geology of the Meingtha area. In the first place, nothing is known of the lithology between the highest levels in the mine, where the deposit occurs in tuff some 200 ft. below the surface and the top of the hill, where Pangyun sandstone sub-outcrops. Secondly, the projections of Faults A and B into the near-surface rocks have not been traced, although it is conceivable that the gossan in Pit 17 represents the sub-outcrop of the latter structure (Figs. 11

and 12). Furthermore, it is not known whether Faults A and B are barren structures or whether they carry mineralisation in depth.

Judging from previous work in other areas (p. 25), the absence of peak values in surface rocks and derived soils directly over the blind Meingtha orebody is almost certainly due to the inclined attitude of the fissures in the caprocks and/or the denser nature of these rocks as compared to those further to the east. The nearly "spent" mineralising solutions responsible for the ore were, therefore, unable to penetrate vertically upwards into the sandstone.

It is possible that a greater part of the mineralising solutions were channelled laterally before leaking upwards to form the anomaly peak detectable at the present-day surface. On the other hand, the leakage dispersions may have penetrated up the steeply inclined Faults A and B from an additional source not connected with the known orebody. The relatively wide interval between the position of the surface anomaly peak and that of the Meingtha Lode serves as a further example of the inconsistent development of leakage dispersions related to blind deposits.

It is most unlikely that much post-mineralisation redistribution of lead, which is noted for its low mobility, has been effected by supergene processes in the soil and near-surface rocks on Meingtha Hill (see Part VI). The dispersion patterns of copper and zinc, however, may have been considerably modified as a result of leaching. It is not known whether this factor is responsible for the lower copper and zinc content of the soil and surface rocks

over the Meingtha Lode as compared to that of similar material further to the east.

Further work is necessary to ascertain whether any metal has been removed from the zone of intense rock alteration over the ore as a result of post-mineralisation hydrothermal activity (p. 173-4).

(e) Vertical Distribution of Lead in the Soil on Traverse A 12.

i. Weathering Profiles over Sandstone

Since the level of the groundwater table has always lain at a considerable depth below the surface, gravity-controlled mechanical dispersion is the major factor governing the formation of the lead anomaly in the residual soil. The form of mechanical dispersion halos in residual soils in other regions has already been mentioned on pages 23 and 24. Over mineralisation, values increase with depth. Further downslope, metal tends to become more and more concentrated in surface soil owing to gravity creep (see Fig. 30A).

The distribution of lead in six weathering profiles over sandstone on the middle slopes of Traverse A 12 is given in Table 18. The data suggest that the secondary dispersion pattern is somewhat complicated by the very variable tenor of the bedrock source. In Profiles 11 and 13, values increase with depth from 1400 and 2500 ppm to 7000 and 4000 ppm respectively in the deepest sub-soil horizon examined. This is presumably due to the high metal content of the sub-outcropping sandstone in the vicinity of the two pits. Further downslope, lead is slightly enriched in the sub-soil horizons of Profiles 12 and 14 at depths of

TABLE 18. Distribution of lead in weathering profiles over sandstone, Traverse A 12, Meingtha Hill.
Profile 11 is described in Table 6.

Pit Numbers	11	12	13	14	15	16
Sample Nos:	7748/61	9414/23	7762/8	7769/91	7782/ 7790	7791/ 7802
Distance downslope from Pit 11 (feet):		25	50	100	150	200
Depth (ins.)	Lead (ppm)					
0 - 3	1400 (20)	2000	2500	2200	3500	2500
3 - 12	1600 (12)	2500	2800	2500	3000	2500
12 - 36	2500 (4)	5000	3000	3000	1200	2200
36 - 60	3000 (6)	3000	4000	3500	1000	2500
60 - 84	3500 (5)	3000	4000	4000	700	2000
		(60-72ins)				
84 - 96	5000 (5)	3000*		2500		2000
		(72-84ins)				
96 - 108	6000 (4)			2000*	1000	2000*
108 - 120	7000 (2)				600*	
120 - 132	2000 (1)*					

Figures in parentheses denote the proportion of lead soluble in cold 5% nitric acid.

* hard, weathered bedrock.

12 - 36 ins. and 60 - 84 ins. respectively. The tendency for lead to decrease with depth at Site 15 is only apparent because of the relatively low metal content of the parent material. For example, 50 ft. downslope from Pit 15, lead appears to be evenly distributed throughout all horizons of Profile 16. The anomalous surface soil at this site has probably been derived from much further upslope, whereas the metalliferous particles in the sub-soil reflect the

higher metal content of nearby rocks as compared to those near Pit 15.

During the monsoon, it is possible that very fine, metal-liferous soil particles are washed down to deeper levels in the profile by percolating rainwater. It is very difficult, however, to estimate the amounts of metal so elutriated. Judging from the data in Table 19 regarding the distribution of lead in the size-fractions of soil samples from Profile 11, there does not seem to be any preferential concentrations of lead in the finest clay-silt fraction at any particular depth. This even distribution of lead

TABLE 19. Distribution of lead in size-fractions of soil samples from Pit 11, Meingtha Hill.

Depth (ins.)	Lead content (ppm) of size-fractions B.S.S:				
	+ 20 - 36	+ 36 - 80	+ 80 - 120	+ 120 - 200	- 200
0 - 3	1300	1500	1400	1500	2000
3 - 12	1800	1600	1500	1600	2000
12 - 24	2000	2200	2500	2200	2000
24 - 48	2200	2500	2000	2200	2500
48 - 72	4000	4000	3500	4000	4500
72 - 96	5000	4000	4000	5000	5000
96 - 120	7000	7000	5000	6000	7000

between both the coarse and fine size-fractions suggests that there is no pronounced illuvial horizon in the sub-soil at Site 11 wherein lead-rich clay particles are being deposited.

The water-soluble lead content of strongly anomalous soil

samples from Pit 11, as determined by the method described in Appendix D 4, is extremely low and does not exceed 1.5 ppm. It is not known, however, whether or not very small concentrations of lead are being chemically dispersed from the surface horizons to deeper levels in those profiles.

ii. Weathering Profiles Over Gossan and Tuff.

The distribution of lead in Profiles 17 and 18, which are respectively situated over gossan and tuff near the eastern end of the traverse, is rather different to that observed in Profiles 11 - 16 (Table 20). Sample values at these sites respectively decrease from 3500 and 2500 ppm at the surface to 2500 and 1200 ppm in the sub-soil at a depth of 12 - 36 inches, subsequently increasing to 4000 and 3500 ppm respectively in the deepest sub-soil horizons. These trends are presumably due to the topographic situations of Pits 17 and 18 towards the base of slope, rather than to the different nature of the parent material. The anomalous top-soil in both pits has probably been derived from further upslope, whereas the anomalous values in the sub-soil are probably related to metal sources in the underlying gossan and tuff. These data afford an example of the extent to which gravity creep modifies the distribution of metal in profiles over mineralisation in mountainous terrain.

The distribution of lead in Profiles 19 and 20, however, is very similar to that in Profiles 15 and 16. In the former pit, values uniformly decrease with depth from 2500 ppm Pb to 1000 ppm

TABLE 20. Distribution of lead in weathering profiles over gossan and tuff, Traverse A 12, Meingtha Hill.
A typical profile over tuffaceous rocks is described in Table 7.

Bedrock Types and Pit Nos:	Gossan 17	Tuff 18	Tuff 19	Tuff 20
Sample Nos:	7828/35	7836/44	7845/52	7859/62
Distance downslope from Pit 17 (feet):		50	100	200
Depth (ins.)	Lead (ppm)			
0 - 3	3500	2500	2500	3000
3 - 12	3000	2000	2200	2500
12 - 36	2500	1200	1000	2500
36 - 48	4000	1500	300 ^x	(12-24 ins.)
48 - 60	8000 ^x	1500	(36-60 ins.)	3000
60 - 84		2500	150 ^x	(24-48 ins.)
84 - 108		3500	550 ^x	
108 - 120		3000 ^x		

^x Weathered Bedrock

Lead content of gossan at 60 - 72 ins. and 72 - 84 ins.
= 1.1% and 0.2% respectively.

Pb, while the metal content of the soil samples from Pit 20
apparently remains constant at the 2500 - 3000 ppm Pb level.

Nothing is known of the distribution of lead in size-
fractions of soil derived from the weathering of tuffaceous rocks.
Data from soil samples taken over similar rocks from Pit 29 on
Mt. Teddy indicate that lead is just as insoluble in water as was
found to be the case in the samples from Pit 11.

(f) Vertical Distribution of Copper and Zinc in the Soil on Traverse A 12.

The vertical distribution of copper and zinc within some of the afore-mentioned profiles on Traverse A 12 is generally similar to that of lead (Table 21).

TABLE 21. Distribution of copper and zinc within weathering profiles over gossan, sandstone and tuff, Traverse A 12, Meingtha Hill.

Bedrock Types and Pit Nos:	Sandstone 11		Sandstone 14		Sandstone 15		Gossan 17		Tuff 18	
Depth (ins.)	Metal content (ppm)									
	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn
0-3	400	150	320	100	450	200	250	250	200	250
3-12	450	150	300	100	450	200	250	250	200	250
12-36	450	100	400	100	300	150	350	500	200	200
36-48	500	100	400	100	300	100	600	1400	200	120
48-60	750	120	550	120	300	100	2500	7000+	200	120
60-84	750	150	500	100	320	100			150	100
84-96	850	170	450	100	400	100			120	100
96-108	700	120	100	50+	400	100			120	100
108-120	550	120			50	25+			100	100+
120-132	50	25+			50					

+ Weathered Bedrock.
Metal content of gossan samples from depths of 60-72 and 72-84 ins. = 3000 and 500 ppm Cu and > 7000 and 3000 ppm Zn respectively.

At Site 17, however, where the gossan carries 3000 ppm Cu and > 7000 ppm Zn, the copper and especially the zinc content of the soil tends to increase markedly with depth, in direct contrast to lead (Table 20). This illustrates the extent to which leaching

has modified the secondary dispersion patterns for copper and zinc in these acid soils (see Part VI).

3. Sterne River Area.

(a) Primary Dispersion of Lead in Wallrocks.

The tuffaceous rocks on the northern and southern sides of the Sterne River, near its confluence with the E.R. Valley, are mineralised in places (see Fig. 13). The extent and tenor of the mineralisation, however, is much smaller than that constituting the Meingtha Lode, 3000 ft. or so further to the N.W. The largest deposit, which consists of a tabular, replacement body of galena, carrying 12% Pb, is exposed in Adits 7 and 12.

Cores from Boreholes Nos. 1 and 4, which were drilled near the two principal deposits, consist of fresh and weathered quartzite and tuff, with subordinate quartz-porphyry. Several zones of disseminated galena and chalcopyrite were penetrated by Borehole No.1, at distances of 25 to 150 feet from the collar of the hole. Only one mineralised zone, however, appears to have been intersected by Borehole No. 4.

Chip

/samples were taken at intervals of from 1 to 15 feet measured along the line of the boreholes, the average distance between successive samples being five feet or less. Any conclusions reached in this study are of necessity limited by (a) the poor core recovery (50%), (b) errors inherent in the rapid,"spot"

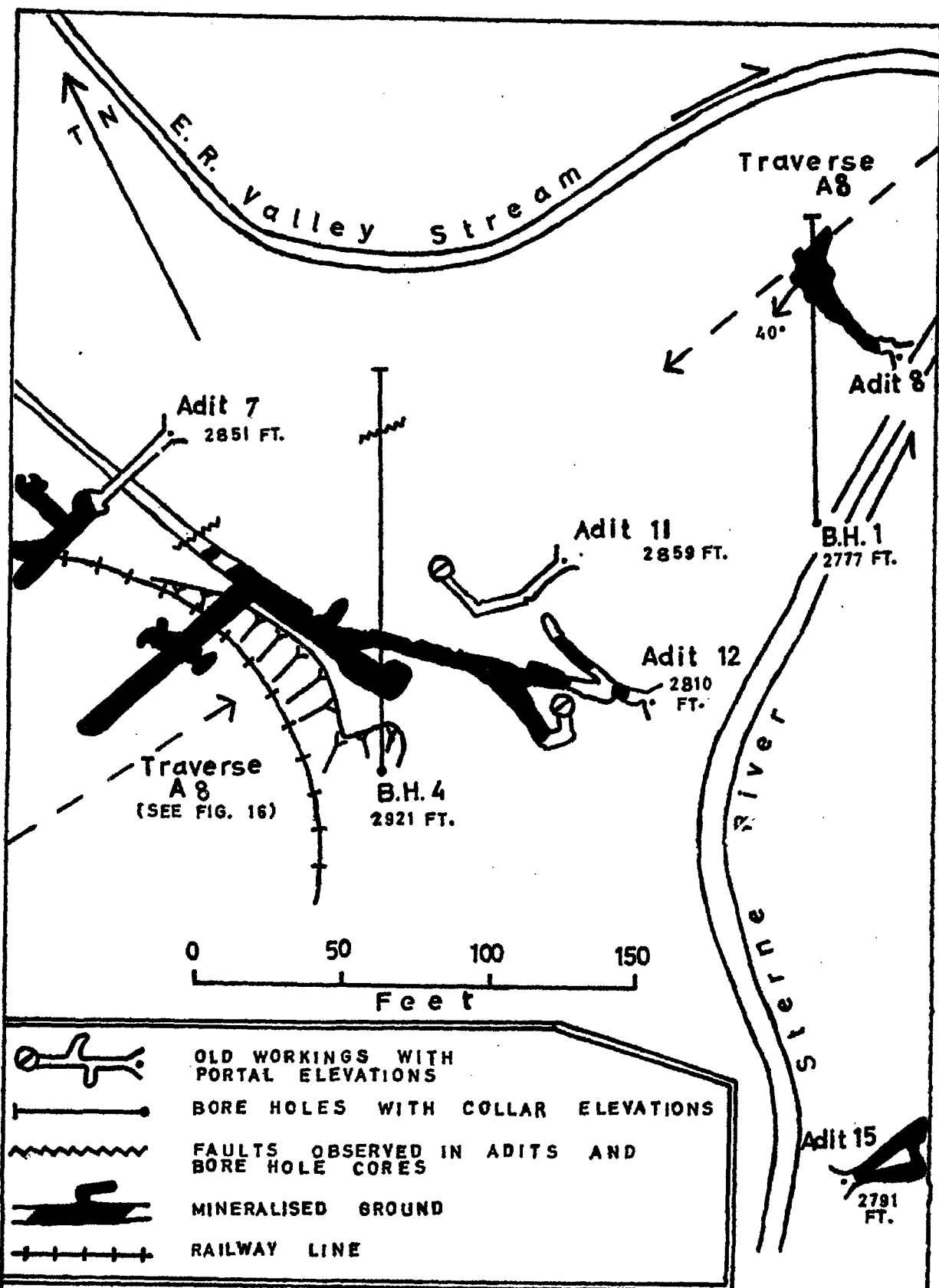


Fig. 13. OLD WORKINGS AND BORE HOLES NEAR THE STERNE RIVER, MEINGTHA.

sampling method employed, and (c) the distinct possibility of spotty metal distribution within samples of tuff.

i. Cores from Borehole No. 4.

The distribution of lead observed in Borehole No. 4 is shown in Fig. 14. Sample values range from 50 ppm to 1% Pb, the peak value being associated with the narrow zone of disseminated galena. Oxidised sulphide disseminations such as anglesite or cerussite are the probable cause of the anomalous metal concentrations in the samples from this borehole as well as from Borehole No. 1.

Although the lateral variation in the metal content of the samples is very appreciable, their average lead content of 400 ppm is above the background level. Metal appears to be equally concentrated in both the gritty tuff samples and the feldspathic quartzite samples.

Samples from the cores 50 - 80 feet above the galena deposit in Adit No. 12 contain from 200 to 1000 ppm Pb, but similar values were detected in samples from other parts of the hole, beneath which there do not appear to be any orebodies (Fig. 14). The absence of a well-defined anomaly peak over the deposit is probably due to the inclined attitude of the fissures in the hanging wall.

There is, however, a marked decrease in the metal content of the samples N.E. of the fault shown in Fig. 14, sample values decreasing from 1100 ppm to 50 ppm over a distance of 34 feet. A similar decrease from 6000 ppm in the fault-zone itself

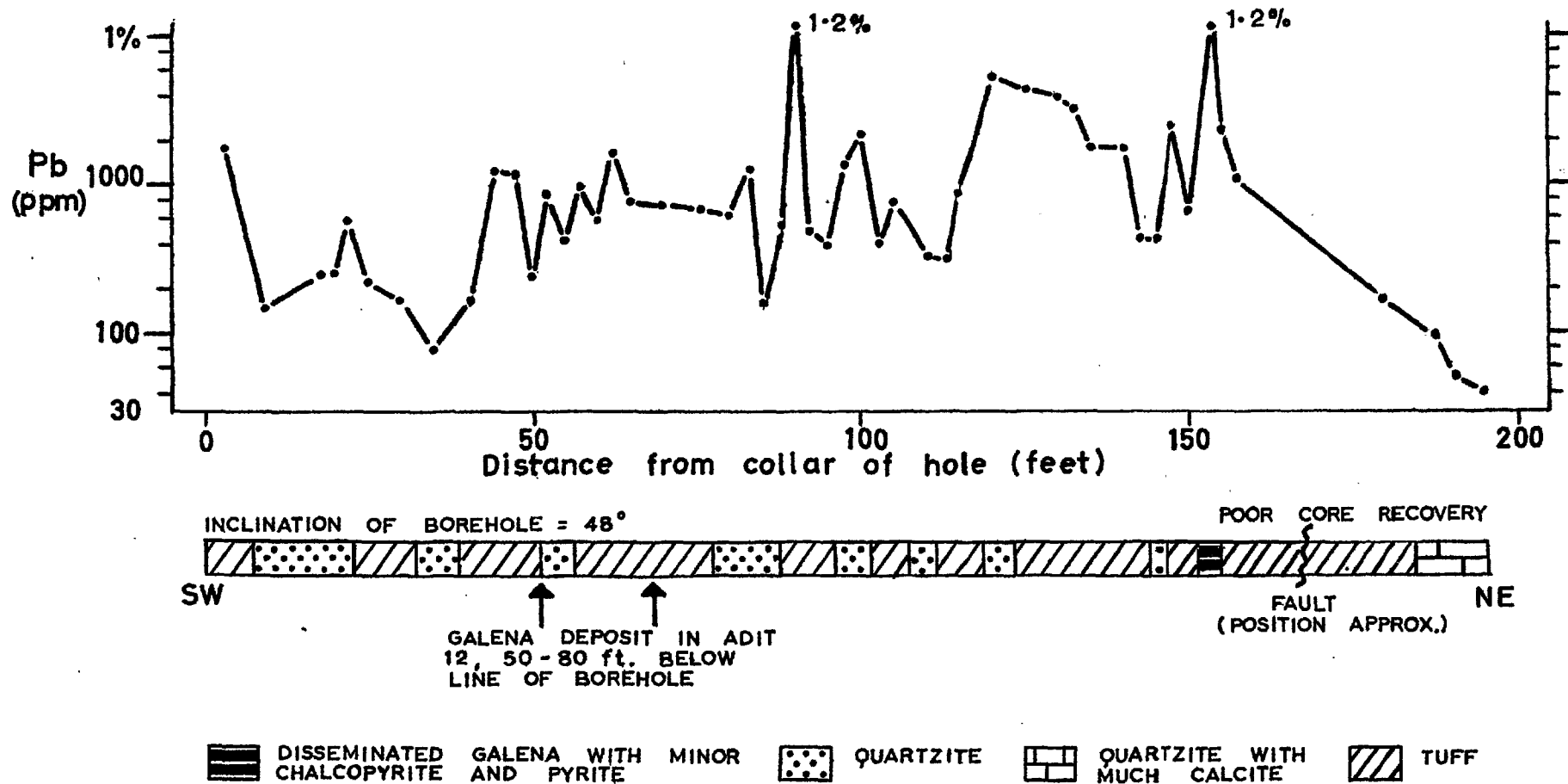


Fig. 14. DISTRIBUTION OF LEAD IN CORE SAMPLES FROM BOREHOLE NO. 4, STERNE RIVER AREA.

to 200 ppm in quartzite ten feet further to the north was observed in samples taken from the walls of Adit No. 12. Judging from the work of Morris and Lovering (1952), the logarithmic decay in the metal content of the samples to the N.E. of the fault suggests a primary diffusion of lead in the more massive rocks away from the main site of metallisation. The heterogeneous dispersion halo in the other parts of the borehole, however, is presumably due to the deposition of traces of metal from circulating, mineralising solutions that penetrated through fissures in the quartzite and tuff.

ii. Cores from Borehole No. 1.

The data presented in Fig. 15 show that the cores from Borehole No. 1, some 170 feet further to the east, have a somewhat higher, average metal content of 1000 ppm Pb. Individual values range from 30 ppm in calcareous quartzite to more than 10% in samples with much galena. Lead appears to be equally distributed between the well-fissured feldspathic quartzite, gritty tuff and quartz-porphry, but it is definitely impoverished in the denser calcareous rocks. There is a marked variation in the metal content of samples taken at a distance of 91 - 125 feet from the collar of the hole. At these points, samples with much galena contain 2% and > 10% Pb respectively. Values uniformly decrease, however, to a level of 30 - 50 ppm Pb within a lateral distance of 5 and 15 feet respectively from these zones, which suggests a very limited dispersion of lead in the denser rocks away from the main sites of metal deposition.

Some of the core samples are heavily kaolinised and

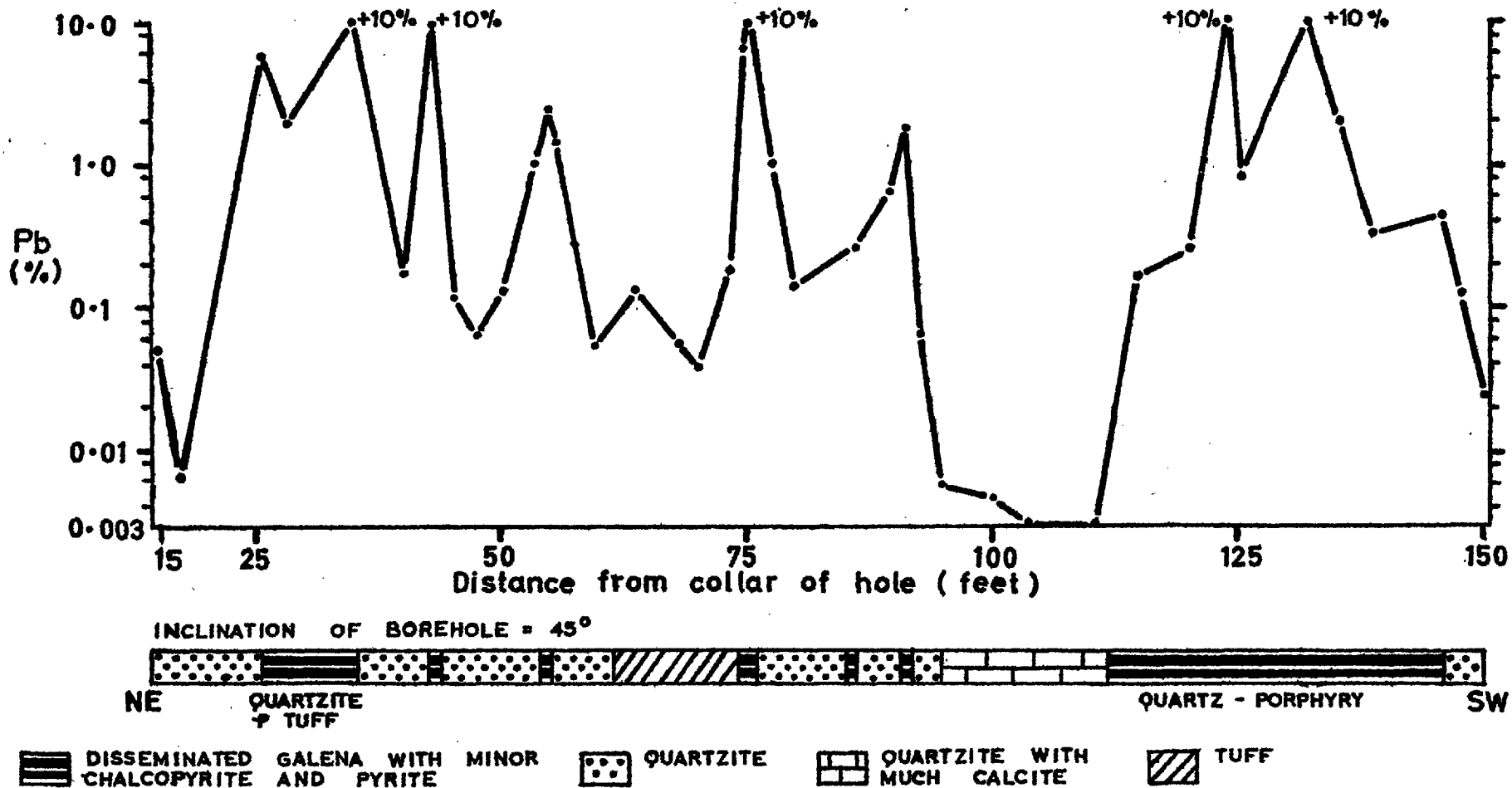


Fig. 15. DISTRIBUTION OF LEAD IN CORE SAMPLES FROM BOREHOLE NO. 1, STERNE RIVER AREA.

limonitised, but equally high values were detected in both ferruginous and non-ferruginous rocks as well as in hard and soft rocks. The distribution of lead in both borehole cores does not, therefore, appear to be affected by the hypogene and supergene processes responsible for the wallrock alteration in the area.

iii. Wallrocks in Adit No. 11.

Adit No. 11 is situated 50 feet above the level of Adit No. 12, some 40 feet further to the north (Figs. 13 and 16). It penetrates much altered and heavily limonitised ^{tuff.} Spot samples, which were collected at five feet intervals from one of the adit walls, contain 1500 - 7000 ppm Pb. The highest values were detected in samples near the end of the adit, where much limonite was also observed. The possible significance of these data is further discussed in a later paragraph, when the dispersion of lead in the tuff bedrocks sub-outcropping on the crest of Spur A 8 is considered.

iv. Wallrocks in Adit X, E.R. Valley.

Spot samples were collected at 5 feet intervals from the walls of Adit X, which is situated some 2200 feet NNW of the Sterne River area (Fig. 9). The rocks exposed in this adit consist of dense, non-calcareous quartzite. Disseminated galena was noted near the portal. The uniform and logarithmic decay in the metal content of the samples from $> 2\%$ to 100 ppm Pb within a distance of 30 feet serves as a further example of a diffusion type halo.

(b) Lateral Dispersion of Lead in Sub-Soil and Weathered Bedrock, Traverse A 8.

The secondary dispersion study in the Sterne River area

was carried out on Spur A 8, whose crest passes over the deposits previously described and the lines of Boreholes Nos. 1 and 4 (see Fig. 13). Soil samples could only be taken from the crest of the spur owing to its very precipitous sides, which slope down to the Sterne River and E.R. Valley. The exact structure of the deposit in Adit No. 12 is not known. Judging from the map of the area, the main mineralised zone appears to trend in a NNW-SSE direction approximately normal to the axis of the spur. The largest orebody dips at a high angle to the west.

Contamination presents a more serious problem in the Sterne River area, for the following reasons. Firstly, the Chinese were mining these deposits for a considerable period of time, although the absence of slag indicates that they smelted the ore in another locality. Secondly, a thin layer of earth and rock rubble covers the surface for about 50 feet to the east of the railway cutting.

The only data included in this study are those obtained from the analysis of samples taken from the sub-soil horizon at a depth of 36 inches and from the sub-outcropping, weathered tuff. The sampling interval varies from 5 feet over the anomaly peak to about 20 feet on the other parts of the traverse. The analytical results are presented in Fig. 16, together with a geological cross-section of the area.

1. Weathered Bedrock.

The full extent of the dispersion of lead in the underlying bedrocks on Traverse A 8 is not known as samples were only

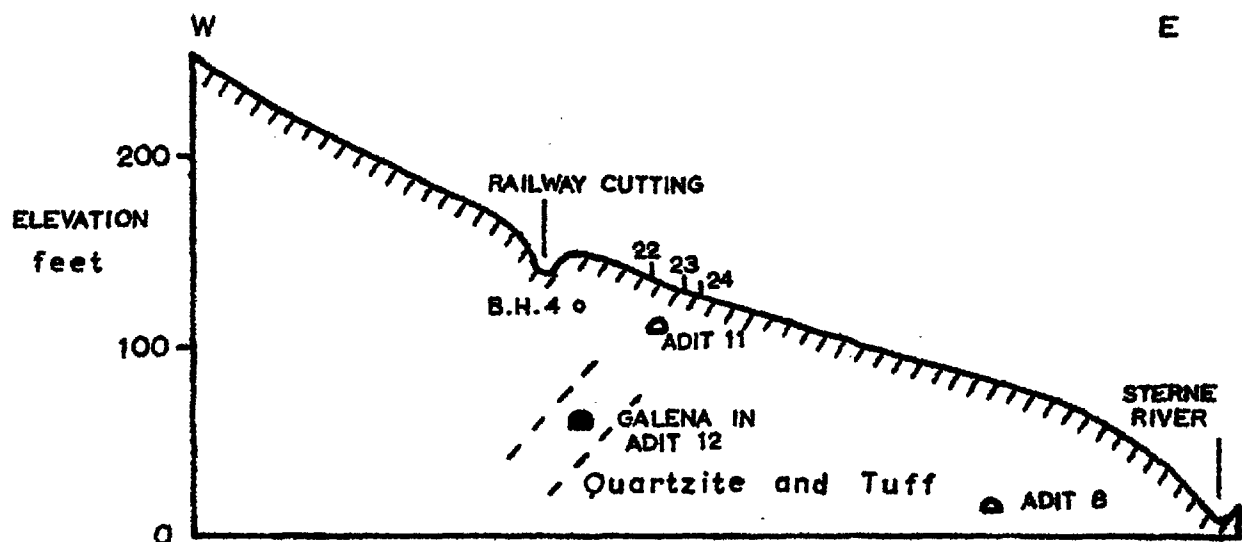
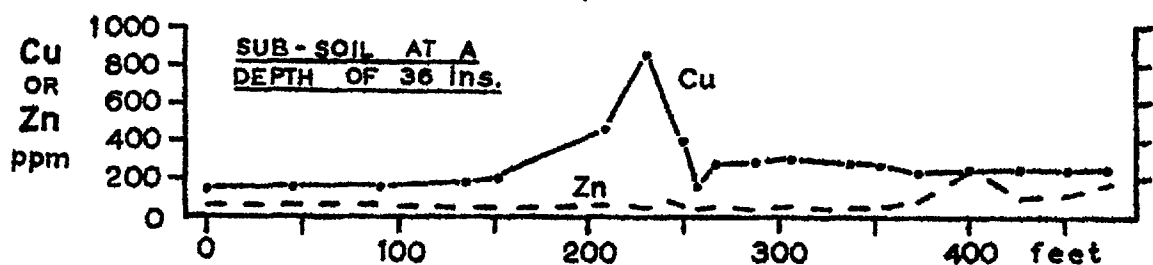
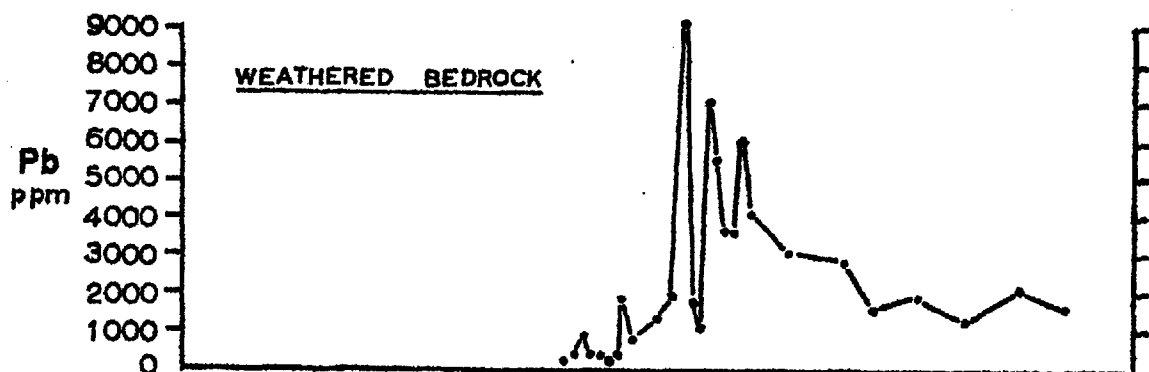
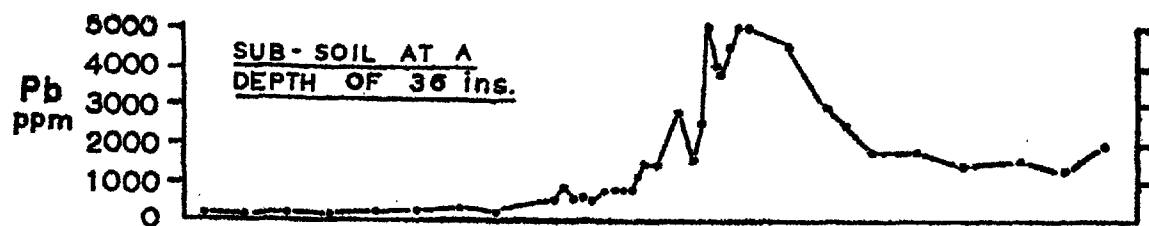


Fig. 16. DISTRIBUTION OF COPPER, LEAD AND ZINC IN SOIL AND WEATHERED TUFF BEDROCK, TRAVERSE A 8, MEINGTHA HILL.

(Threshold values; 200 ppm Cu, 200 ppm Pb, 100 ppm Zn)

collected to the east of the railway cutting, where the observed range of values fluctuates between the limits of 250 ppm and 9000 ppm. No galena was noticed in any of the pits; the source of the sub-soil anomaly probably consists of oxidised sulphide disseminations in the sub-outcropping tuff.

As would be expected, lead is rather erratically distributed in the weathered bedrock at some sites near the anomaly peak, both laterally and vertically. For example, the lead contents of two samples from the uppermost twelve inches in the weathered tuff bedrock differ by as much as 1600 and 9000 ppm over a lateral distance of only five feet, the rock at the latter site being more limonitised and possibly more fractured. Even greater lateral variations, however, in the heavy metal content of dolomite outcrops above a blind orebody in Arizona are reported by Cooper and Huff (1951). They note that a value of 2300 ppm in fissured rock decreases to 75 ppm in non-fissured rock over a horizontal distance of six feet. Although the lateral variation in the lead content of the bedrocks on Traverse A 8 is considerable, the data in Fig. 16 show that an anomalous concentration of metal is present at every point sampled.

Bedrock samples taken directly over the galena deposit in Adit No. 12, 90 feet below the crest of the spur, contain 200-1000 ppm Pb. Higher values of up to 9000 ppm were observed, however, in the sub-outcropping tuffs at Site 24, slightly to the east of and 25 feet above Adit No. 11.

At Sites 23 and 24, the lead content of the sub-outcropping

tuff uniformly decreases from 2000 ppm and 9000 ppm respectively to 900 and 3500 ppm within a vertical distance of four feet. A different trend was noted at Site 22, however, where lead appears to be erratically distributed in the topmost four feet of the weathered tuff bedrock at the 900 - 2700 ppm level (see also Profile 19, Table 20). It is not known whether the erratic, vertical distribution patterns of lead in the tuff at these four sites is due to the effects of weathering or whether they merely represent spotty, primary dispersions resulting from the variable degree of rock fissuring (p. 150 and 185).

xi. Sub-Soil.

Lead appears to be very slightly enriched in the sub-soil with respect to the parent tuff. The generally close agreement between the lead contents of the sub-soil and bedrock samples, however, is in marked contrast to the considerable differences in the metal contents of these media in the deeper profiles on Traverse A 12.

The lead contents of the sub-soil samples between the ridge-crest and the valley bottom range from 120 ppm to 5000 ppm. To the west of the railway cutting, values gradually decrease to background. The full width of the anomaly exceeds 320 ft; soil samples from the eastern end of the traverse still contain strongly anomalous concentrations of lead. The peak of the soil anomaly is displaced for a distance of 60 feet to the east of the main galena deposit in plan (Fig. 16). This relatively small distance

is in marked contrast to the displacement of the soil anomaly peak for a distance of 300 - 500 feet to the east of the Meingtha Lode on Traverses A 12, A 24 and A 28.

iii. Relationship of the Surface Anomaly Peak to the Underlying Deposit.

Judging from the cross-sectional data in Fig. 16, the oxidised sulphide disseminations in the wallrocks in Adit No. 11 and in the sub-outcropping tuffs to the east of Site 24 may well represent the up-rake projection of the steeply-dipping galena deposit in Adit No. 12. This orebody is not, therefore, a "blind" deposit in the strictest sense of the term, even though its sub-outcrop on the crest of the spur is not characterised by a conspicuous gossan. As a result, the lateral distance between the position of the sub-soil anomaly peak and that of the massive sulphides in Adit No. 12 is relatively narrow. One should not, therefore, compare the data from Traverse A 8 to those from the traverses sampled over the Meingtha Lode, which is capped by a considerable thickness of unfavourable Pangyun sandstone.

(c) Lateral Dispersion of Copper and Zinc in the Sub-soil on Traverse A 8.

The sub-soil samples taken between the ridge-crest and the valley bottom contain 120 - 800 ppm Cu (Fig. 16.) Although the width of the copper anomaly is similar to that of the lead anomaly, the contrast between threshold and anomaly peak is only four-fold, whereas peak lead values exceed threshold by a factor of 25 (Table 12). The copper anomaly peak, however, is apparently

displaced for a distance of only 35 feet to the east of the main ore-body in plan, which suggests that copper is a useful indicator element for pinpointing this type of base metal deposit.

Feebly positive results were obtained from the analysis of the sub-soil samples from Traverse A 8 for zinc. The width of the zinc anomaly is only 100 feet, and the peak value just exceeds threshold by 50 ppm. The low zinc values are probably due both to leaching of metal by meteoric water as well as to the rather low tenor of the primary ore.

4. Evidence against Contamination being responsible for the Meingtha Soil Anomalies.

The features of contaminated soil anomalies near former smelting sites to the west and south of the Sterne River have already been mentioned. The Meingtha anomalies are not considered to be in any way due to contamination, for the following reasons.

(a) Relationship between Soil Anomaly and Bedrock Geology

The anomalous values in the soil samples from Traverses A 8 and A 12 are associated with equally high values in the parent sandstone and tuff. The primary concentrations of lead in the weathered bedrocks are likewise related to known, sub-surface mineralisation. By contrast, no anomalous values were observed in bedrock samples collected on Fort Hill, where the overlying soil is heavily contaminated and contains several thousand ppm Pb.

(b) Homogeneity of the Anomalies.

The even distribution of lead in the topsoil samples from Traverse A 12, whose values range from 1000 to 3500 ppm, is in marked contrast to the data from contaminated areas, which show variations of 600 ppm to 2% over comparable distances (Figs. 5 - 8 and 12). The distribution of metal in the sub-soil samples on Traverses A 12 and A 8 is less even, but anomalous values still persist for a distance of more than 1300 feet and 320 feet respectively. Near former smelters, however, values decrease from 1% to background within a distance of 50 feet or less.

The very broad secondary dispersion pattern of lead on Meingtha Hill could conceivably be due to the fact that the area was once one large smelting site. This contention can be completely discounted, however, in view of the paucity of relic smelting materials in the area.

(c) Extractability of Lead in the Soil.

i. Cold 5% Nitric Acid.

The ratio of cold-extractable to total lead within Profile 11 on Meingtha decreases from 20% at the surface to 2% in the soil horizon overlying weathered bedrock (Table 18). This trend is in marked contrast, however, to the tendency for the extractability of metal to increase with depth in contaminated profiles (Tables 14 and 15).

Judging from the data in Table 16, lead appears to be present in a considerably less extractable form in the ten

soil samples taken from Traverse A 12 than is the case in similar samples from contaminated areas. The average ratio of cold-extractable to total lead in contaminated topsoil exceeds that in non-contaminated topsoil by a factor of 2, while there is a seven-fold difference in the respective extractabilities of metal in the sub-soil samples. The extractability of lead in the soil samples collected over tuffaceous rocks on Traverse A 8 appears to be slightly higher than that of the samples taken over sandstone on Traverse A 12. It would be unwise to place too much emphasis on any absolute values obtained by the rather crude technique given in Appendix B3, however, since sub-soil samples from un-contaminated areas at Bawdwin are not always characterised by such low extractabilities. For example, the data in Table 45 show that up to 28% of the metal in sub-soil samples collected from apparently un-contaminated localities on Mt. Teddy occurs in a readily-extractable form.

The possible forms in which lead is present in the Bawdwin soils are further considered in Part VI. The extreme contrast between the high extractability of metal in recently contaminated soil, however, and the much lower extractability of residual lead in the samples from Traverses A 8 and A 12 is stressed at this stage. The differing extractability of lead in the two environments apparently corroborates the principle enunciated by Boyle (1959) that other things being equal, the bond strength of lead increases with ageing.

ii. Cold 0.25% Citric Acid

Six topsoil and sub-soil samples from three pits on Traverses A 8 and A 12 were also analysed by the method utilising 0.25% citric

acid as the metal solvent. The results, which are given in Table 16, also show that the extractability of lead in the Meingtha samples is considerably lower than is the case in contaminated soil.

d). DRAINAGE SYSTEM.

The sediment and water in the Sterne River and E.R. Valley, the only two perennial streams draining known mineralisation, are heavily contaminated. The scope of any geochemical drainage study at Bawdwin is, therefore, extremely limited, being confined to a small gully (A2-A3) on Meingtha Hill and to two small streams (NQ and RQ) on Mt. Teddy, where nothing is known of the sub-surface geology (see Fig. 9).

The gully serves merely as an outlet for surface runoff, so samples from the bottom of the gully were analysed for total lead. Sediment samples from Streams NQ and RQ were also tested for total lead.

In this area, attention was also paid to the dispersion of zinc in the drainage, since this element appears to be in the process of active leaching from oxidising mineralisation at Bawdwin. As previously mentioned, the significance of the cold-extractable "heavy metal" (mainly zinc) content of stream sediments was first pointed out by Hawkes and Bloom (1956). The efficacy of this approach has since been demonstrated in geochemical work in a number of other areas (p. 27). For this reason and also because of lack of time, the wet sediments on Mt. Teddy were tested for cold-extractable

zinc rather than for total zinc.

1. Dispersion of Lead in Dry Gully-Bottom Soils.

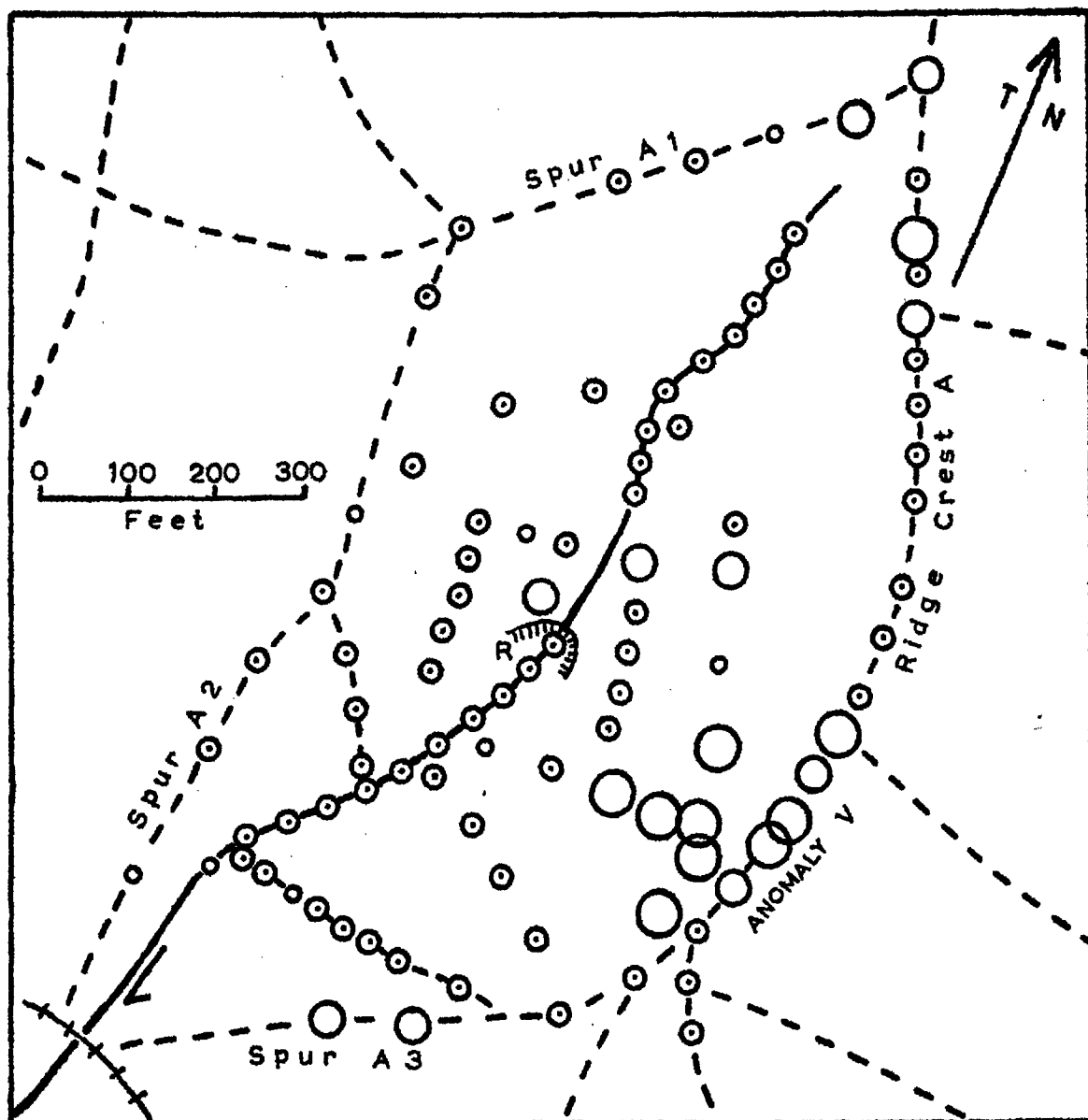
(a) Background Gully, Mt. Herschell.

Samples were collected from a depth of 0 - 3 inches along the bottom of a gully having a length of about 1000 feet in a non-contaminated and un-mineralised part of the Herschell area. On analysis for lead, the samples, which consist of eroded soil, were found to contain from 120 to 300 ppm Pb. Background is reckoned as the median value, which equals 200 ppm, and threshold is empirically estimated as 400 ppm Pb.

(b) Gully A2-A3, Meingtha Hill

The gully between Spurs A 2 and A 3 on the western slopes of Meingtha Hill is well incised and attains a depth of 30 feet in places. The transported material on the gully floor consists of eroded soil. Pairs of samples were taken from a depth of 0 - 3 inches along the accessible parts of the gully, at intervals of 50 feet. Sampling was stopped at a point 250 feet north of the railway line in order to avoid contamination from this source as well as from the former smelting sites situated to the south of the railway line (Fig. 17). The residual bank soils on either side of the gully, were also sampled, wherever these are present and accessible.

The analytical results, which are plotted in Fig. 17, show that the metal content of the samples fluctuates between the limits of 800 and 1600 ppm Pb, the contrast between anomaly peak and threshold being four-fold. The corresponding range in the bank soil



————— GULLY A 30
 - - - - - RIDGE CREST OR SPUR
 CLIFF
 + + + + + RAILWAY LINE

LEAD CONTENT OF SOIL AND GULLY
BOTTOM SAMPLES TAKEN AT DEPTHS
OF 3 ins. AND 0-3 ins. RESPECTIVELY:

○	400 - 800	ppm
⊙	800 - 1600	"
◯	1600 - 3200	"
◯	3200 - 8000	"

Fig. 17. DISTRIBUTION OF LEAD IN GULLY BOTTOM AND SURFACE SOILS, MEINGTHA HILL.

samples is 400 - 1300 ppm Pb. There appears to be a slight difference in the average metal contents of the 19 bank soil samples and the 38 gully samples, since their respective mean values are 850 and 1150 ppm.

The agreement between the average lead content of 32 topsoil samples collected in the area during the prospecting study, however, and that of the gully samples is remarkably close (Fig. 17).

Excluding the samples from the actual ridge crests and from the area defined by/^{Peak}Anomaly V, the average metal content of the topsoil samples taken on the slopes of Spurs A 2 and A 3 is 1100 ppm. This figure is only 50 ppm lower than the mean value of the gully samples mentioned above.

One can, therefore, conclude that the gully-bottom material is, in effect, a composite sample of the topsoil covering the surrounding hillsides. The anomalous metal contents of 1000 - 1600 ppm Pb in the samples to the south of Site R are somewhat lower, however, than the very high values of 3000 ppm or more observed in the topsoil samples constituting/^{Peak}Anomaly V, which is situated near the ridge crest some 400 feet above the gully. This serves to illustrate the necessity of following up any values exceeding the threshold of 400 ppm in gully samples by more detailed sampling of the residual soils covering the adjacent hillsides.

2. Dispersion of Lead and Zinc in Stream Drainage Courses.

(a) Background Streams at Manpat.

Samples of bank soil, active sediment and stream water were taken from small streams in an un-mineralised part of the Manpat area,

at the close of the dry season. The analytical results for total lead, cold-extractable zinc and heavy metal are given in Table 22. The rocks exposed in the stream beds consist of weathered Chaung Magyi shales.

It will be noted that the background lead value of 100 ppm for wet stream sediment at Manpat is less than the corresponding value of 200 ppm for the Herschell gully samples. This could be due to the fact that the topsoil at Manpat has a lower lead content

TABLE 22. Metal content of water, active sediment and bank soil samples collected from background streams in the Manpat area at the close of the dry season (April).

	Stream Water Heavy Metal ($\mu\text{g}/\text{litre}$)*	Metal content (ppm) :		
		Active Sediment		Bank Soil +
		Total Pb	Cx Zn	Total Pb
No. of Samples	26	24	24	26
Range of Values	< 1 - 2	10 - 270	1 - 3	25 - 170
Median Value	1	100		100

* $\mu\text{g}/\text{litre}$ = micro-grams per litre or parts per billion.
 + Samples taken from the top of the bank to bedrock or water level.

than at Herschell. On the basis of the data in Table 22, the local threshold for lead in wet stream sediment and bank soil is fixed at 200 ppm. The corresponding values for cold-extractable zinc in stream sediment and heavy metal in water are 3 ppm and $2\mu\text{g}/\text{litre}$

respectively.

(b) Streams NQ and RQ. Mt. Teddy.

Samples of wet stream sediment and bank alluvium were taken from two small side Streams RQ and NQ, which are situated in the Mt. Teddy area. These streams flow westwards through exceedingly rocky channels into the E.R. Valley (Fig. 9). They drain part of the area represented by Anomaly 11, wherein the soil and sub-outcropping quartzite and tuff bedrocks contain up to $> 2\%$ and 0.6% Pb respectively (Fig. 34 and Table 44). Samples were taken at three sites on Stream RQ and at two sites on Stream NQ, the distance between samples being 100 - 200 feet. Water samples could only be taken from the lower courses of both streams, since the volume of flowing water is reduced to a mere trickle towards the end of the dry season.

i. Stream RQ.

The dispersion of lead in the sediments and alluvium in Stream RQ does not appear to be affected by the oxidised sulphide disseminations at Site 2, since the downstream samples contain no more lead than those upstream from the exposure (Table 23). Sample values range from 3200 ppm to $1\% \text{ Pb}$, these values exceeding threshold by factors of 16 and 50 respectively. Much of the lead-rich material constituting the minus 80 mesh fraction of the sediment and alluvium samples represents fine soil particles scoured off the valley sides during the monsoon. The amount of lead being contributed to the fine fractions of the sediment from solution or from colloids is not known, since no water sample was tested for total lead. It is

probably small, however, on account of the low solubility of lead. The average lead content of the 12 drainage samples from Stream RQ is 6000 ppm, which is considerably higher than the average value of 2800 ppm for the 46 soil samples taken on nearby Spurs Q2, Q2a and R1.

TABLE 23. Metal content of alluvium, active sediment, and water samples from Streams NQ and RQ in the Mt. Teddy area towards the close of the dry season (March).

Site	Distance from E.R. Valley (feet)	Stream Water % Heavy Metal ($\mu\text{g/litre}$)	Metal content (ppm) :			
			Active Sediment %		Alluvium	
			Total Pb	Cx Zn	Total Pb	
					N.Side	S.Side
STREAM RQ. (S. Nos. 8560/73)						
1	300	350	7000	> 150	5000	4000
2	400	PYRITE - MALACHITE DISSEMINATIONS IN FISSURED QUARTZITE ON N. SIDE OF STREAM.				
3	500	No data	4000	45	1.0%	8000
4	700 (near source)	"	3200	45	6000	6000
STREAM NQ. (S. Nos. 8652/6						
5	100	25	2500	34	no data	
6	300 (near source)	No data	2200	15	"	

% Mean of duplicate samples.

This divergence is in contrast to the very close agreement between the lead content of the topsoil and gully-bottom samples taken between Spurs A 2 and A 3 on Meingtha Hill. This apparent enrichment of

lead in the wet sediments and alluvia could conceivably be due to the preferential accumulation of the lead-rich fraction in alluvially sorted material in the valley bottom.

The effects of the mineralisation at Site 2 on the secondary dispersion of heavy metal and cold-extractable zinc are illustrated by the following trends. Firstly, the stream water 100 feet downstream from the deposit contains 350 $\mu\text{g/litre}$. * Secondly, the active sediment samples from Site 1 contain more than three times the amount of cold-extractable zinc detected in similar material further upstream at Sites 3 and 4. This is presumably due to the deposition of zinc in the fine fractions of the sediments at Site 1 from stream water solutions. It is of course possible that the bank soils downslope from the oxidising sulphide disseminations may have an appreciable cold-extractable zinc content. Unfortunately, the banks were not sampled at this point. The values observed in the sediment samples from Sites 3 and 4, however, exceed the local threshold level at Manpat by a factor of 15. This fact, coupled with the anomalous concentrations of lead in the soil and bedrock on the nearby spurs suggests that this part of the Mt. Teddy area is mineralised (see Appendix A).

The anomalous concentrations of lead and zinc in the sediment

* This represents only the ionic metal content. The total amount of heavy metal migrating in the stream waters can only be determined by evaporating a given water sample to dryness and analysing the residue.

samples of this stream (RQ) are not considered to be due to contamination, as no slag or old workings were noticed by the writer in the valley bottom or on Spurs R and Q. Furthermore, the possibility of fume contamination can be discounted. According to Coggin Brown (1918), no ore was smelted by the Chinese in the nearby E.R. Valley, where there does not appear to be any sign of former smelting activity.

ii. Stream NQ.

The lead contents of the sediment and alluvium samples from Stream NQ are lower than those in the samples from Stream RQ. This could well reflect the smaller concentrations of metal in the soil covering Spur N, where soil samples were rarely found to contain more than 1600 ppm Pb. The lower cold-extractable zinc content of the wet sediment samples is presumably related to the lower metal content of the groundwaters feeding Stream NQ, although it still exceeds threshold by a factor of 8. The heavy metal content of the stream water at Site 5 is also considerably lower than that at Site 1. Even so, its heavy metal content of 25 μg /litre is well above the threshold level of 2 μg /litre.

PART IV.

GENERAL DESCRIPTION OF THE MPANDA AREA, WESTERN
PROVINCE, TANGANYIKA TERRITORY.

a). PHYSICAL FEATURES, CLIMATE AND VEGETATION.

1. Physical Features.

(a) Location.

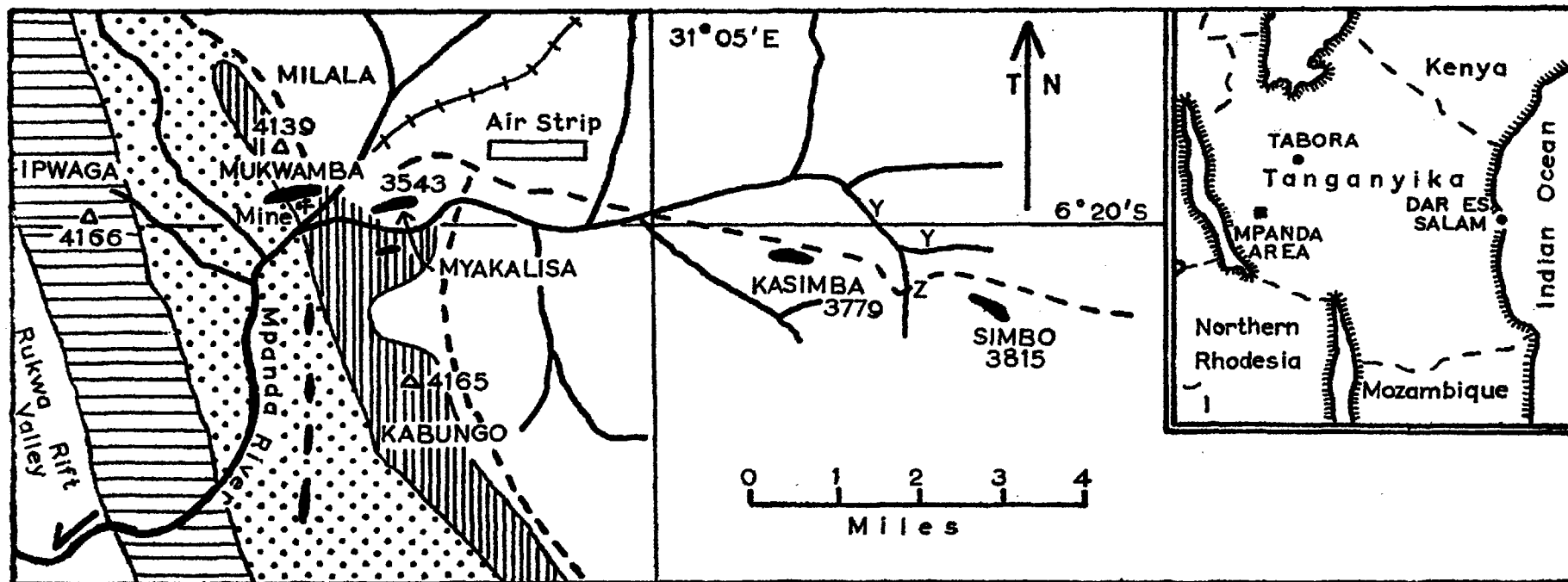
The Mpanda area is situated in the Western Province of Tanganyika, some 470 miles S.W. of Tabora (Fig. 18). During the studies, samples were taken from the Ipwaga, Kabungo, Kasimba, Milala and Simbo areas. The altitudes of these localities vary from 3650 - 3850 feet. The Kasimba and Simbo areas are known to be mineralised, while the Ipwaga, Kabungo and Milala areas are reputedly barren.

(b) Topography.

The eastern part of the Mpanda area consists of a flat peneplained surface, which Stockley (1939) considers to be of Miocene age. The peneplain is characterised by gradients of 1° or less and similar physiographical conditions obtain over much of Central and Western Tanganyika. Isolated, low ridges occur at Kasimba, Simbo, Milala and Myakalisa, which are flanked by gentle 15° slopes. Their heights rarely exceed 100 feet above general level of the peneplain. The relief of the western part of the area represented by Fig. 18 is somewhat more extreme; the NNW-SSE trending range of hills rising above 4000 feet marks the edge of the Rukwa Rift.

(c) Drainage.

Although the Mpanda River, which drains the area, is perennial, its westerly flowing tributaries are seasonal and



LEGEND

- Δ 4166 HILL, WITH SUMMIT ELEVATION
- - - ROAD
- SUPERFICIAL DEPOSITS
- SHEAR ZONE

- DRAINAGE COURSE
- RAILWAY LINE
- BIOTITE - GNEISS AND AMPHIBOLITE, ETC.
- QUARTZ - MICA - SCHIST, ARGILLITE, QUARTZITE, AMPHIBOLITE, META - CALCAREOUS, ETC.
- META - QUARTZITE, BIOTITE - GNEISS, META - DOLERITE, ETC.

GEOLOGY SIMPLIFIED FROM MAPS BY STOCKLEY (1939) AND POUSSIN AND McCONNELL (1950).

Fig. 18. GEOLOGY OF THE MPANDA AREA, WESTERN PROVINCE, TANGANYIKA.

only carry an appreciable volume of water during the latter part of the rainy season. These drainage ways are bordered by mbugas or grass-covered, seasonally-waterlogged swamps up to several hundreds of feet wide. In the flat ground of the mbugas, a main drainage course can only be located where there is an incised stream channel; elsewhere, the complete lack of relief gives no indication of channelled drainage.

The exact depth of the groundwater table below the tops of the low ridges is not known. It probably lies at no great depth in view of the seasonal waterlogging of the mbugas, which are situated no more than 170 feet or so below the ridge-crests. Observations by the writer in the Kasimba lowlands during the latter part of the rainy season indicate that the top of the groundwater table lay at depths of 12 and 13 feet below the surface at distances of 900 and 2000 feet respectively from the axis of the ridge. The depths to which the groundwater table retreats during the dry season are not known.

2. Climate and Vegetation.

(a) Climate.

The area has a sub-tropical climate, with alternating wet and dry seasons. The rainy season lasts from November to May, the mean annual rainfall being about 37 inches. The temperature varies from about 50°F to 90°F, being lowest during the dry season.

(b) Vegetation.

Away from the grassy mbugas, the area is covered by the Brachystegia - Isoberlinia type of woodland which extends over most of Western Tanganyika (Gilman, 1949). According to Milne (1947), this plant association in comparable areas near Tabora is characterised by such trees as Brachystegia and Isoberlinia, with minor Afrormosia, Albizzia, Combretum, Dombeya, Ficus, Ostryoderris, Sterculia and Strychnos.

b). GEOLOGY.

The description of the geology of the Mpanda area is based on the work of Stockley (1939) and Poussin and McConnell (1950).

1. Regional Geology.

The geological succession at Mpanda is:-

ALLUVIUM		Quaternary
Eluvial and fan slope detritus		"
Mbuga clay		
Laterite and sands of the Miocene		
peneplain		Late Tertiary
	- Unconformity -	
BASIC DYKES		?
BUKUBAN SANDSTONE		Upper Pre-Cambrian to
		Lower Palaeozoic
	- Unconformity -	
ACID and BASIC DYKES		Pre-Cambrian
QUARTZ REEFS AND LEAD-SILVER-		"
COPPER-GOLD and TUNGSTEN		
MINERALISATIONS		
ALASKITE GRANITE and OTHER		
INTRUSIVES		
IKULU META-SEDIMENTS		Basement Complex
KABUNGU PARA-GNEISS and		"
ORTHO-GNEISS		

The Bukoban sandstones outcrop to the north of the area represented by Fig. 18, but are believed to have once covered the whole region. The Archaean rocks consist of acid intrusives, basic intrusives and highly metamorphosed amphibolite, granite-gneiss, dolerite, phyllite and quartzite. Their outcrops are mainly confined to the NNW-SSE trending belt of hilly country to the west of Mukwamba Hill. The Archaean formations contain the known lead and tungsten deposits.

2. Lithology and Structure of the Mukwamba - Simbo Area.

(a) Lithology.

To the east of Mukwamba Hill crystalline rocks only outcrop on the low ridges at Myakalisa, Kasimba and Simbo, where they consist of soft, decomposed granite-gneiss and harder meta-dolerite. Superficial deposits cover the surrounding lowlands; a few sampling pits cut through the overburden to the north and south of Kasimba Ridge exposed intensely weathered granite-gneiss and phyllite.

(b) Structure.

The lead-copper mineralisation in the Mukwamba - Simbo area occurs in E-W trending shear zones, whose widths vary from about 60 to 330 feet, and which dip to the south at an angle of 60° . It is not known, however, whether the four shear zones are separate structures or are part of a single, continuous structure over a distance of $8\frac{1}{2}$ miles. According to Poussin and McConnell (1950), the E-W shearing, which took place after the folding of the basement complex, is believed to have resulted from an overthrust

whereby the southern block has over-ridden the northern block.
are
N-S shears/also known to the south of Mukwamba, outside the limits
of the study area.

3. Base Metal Deposits.

(a) Primary Sulphides.

The dominant primary ore mineral in the Mukwamba - Simbo deposits is galena, with minor chalcopyrite and occasional argentite and gold; arsenic, antimony and zinc sulphides are practically unknown. Gangue minerals include quartz and siderite in varying proportions, with some barite, calcite, hematite and pyrite. The largest deposit has been mined at Mukwamba and carries 6.5% lead and 0.6% copper. The ore either occurs as fissure veins or as replacements of crushed material in the shear zone, which served as the main channel-way for the mineralising solutions.

Little is known about the distribution of copper and lead in the Myakalisa, Kasimba and Simbo deposits, but the mineralisation is believed to occur in a disseminated form. The age and origins of the Mpanda deposits have yet to be established, but they may be related to the alaskite granite which was intruded at a relatively late period in the pre-Bukoban cycle.

(b) Oxidation and Weathering.

The present land surface is considered to be nearly the same as the pre-Bukoban peneplain surface. The deposits have consequently been weathered in two distinct periods separated

by a very considerable interval of geological time. Furthermore, the Bukoban sedimentation may have occurred during, or been preceded by arid, saline conditions (Poussin and McConnell, 1950).

It is, therefore, not surprising to find that the near-surface part of the deposits are intensely weathered, with tongues of complete oxidation extending to a depth of 1500 feet below the present water table in the Mukwamba area. The aforementioned authors note the very heavy leaching of copper and lead from many outcrops. The principal secondary ore minerals are anglesite, cerussite and the carbonates and oxides of copper.

c). PEDOLOGY.

The superficial deposits covering the ridges and surrounding lowlands consist of loam soil, laterite and pallid sand. Darker coloured clay and sand predominate in the seasonally-waterlogged mbugas. The locations of the weathering profiles in the Kasimba area that are described below are given in Figs. 19 and 20.

1. Thickness of the Overburden.

The thickness of the soil covering the low ridges at Mpanda is very variable. It ranges from a few inches over sub-outcropping meta-dolerite near some of the ridge crests to 7 or 8 feet over decomposed granite-gneiss, which weathers to produce a deeper soil profile. The average thickness of the ridge soil is about 4 feet.

The overburden in the lowlands, however, is considerably thicker and was never found to be less than 5 feet thick. Most of the pits on Traverse 0 expose weathered bedrock at depths of 8 to 12 feet below the surface (Fig. 19). No pits were dug to greater depths than 12 feet, but it is most probable that this figure by no means represents the maximum thickness of the freely-drained soils in the Mpanda lowlands. The thickness of the soil in the mbugas is not known.

2. Freely-drained, Residual Ridge Soils.

The nature of the parent bedrock has little effect on the colour and texture of the residual, lateritic soil covering the low ridges at Mpanda. The surface material consists of grey-brown loam, the sub-soil being more stony and possessing a redder colour. A typical weathering profile over basic gneiss near the top of Simbo Ridge is described in Table 24.

TABLE 24. Weathering profile over basic gneiss, Pit 28, Simbo Ridge.

Sample Nos.	Depth (ins.)	Description	pH
1047	0 - 5	Dark grey-brown sandy clay with fragments of weathered gneiss.	6.1
1048	5 - 17	Brown sandy clay, with increase in size and number of rock fragments.	
1049	17 - 36	Red-brown sandy clay, as above	5.9
1050	36 - 48	Red sandy clay, as above.	
1051	48 - 58	Same.	6.0
1052	58 - 70	Red clay and lenses of iron-stained quartz.	
1053	78 - 80	Weathered basic gneiss.	

The pH of the soil at Site 28 remains more or less constant at 5.9 - 6.1 with increasing depth. In Profiles 1 and 23, however, which are situated over granite-gneiss on Ipwaga Hill and Kasimba Ridge, the pH tends to decrease slightly with depth from 6.4 to 5.8 and 7.0 to 6.0 respectively (Table 25).

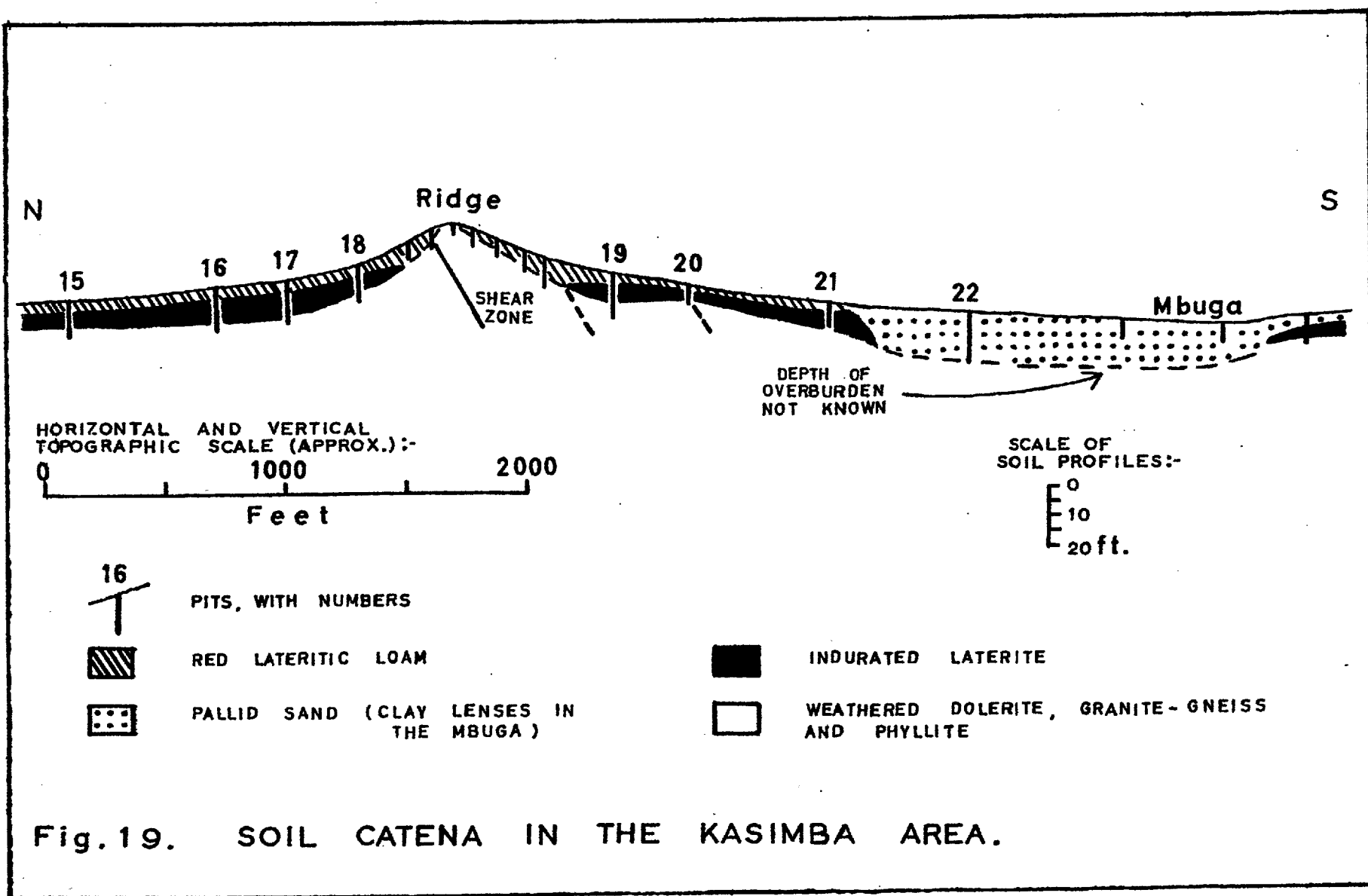
TABLE 25. Weathering profiles over granite-gneiss, Pit 23, Kasimba Ridge (samples collected and described by J.S. Webb).

Sample Nos.	Depth (ins.)	Description	pH	Total Fe (%)	Organic Carbon (%)
1215	0 - 4	Black-brown topsoil.	7.0	8.93	2.02
1216	4 - 12	Brown sub-soil.	6.3	9.76	1.53
1217	12 - 37	Red-brown rubble zone, with yellow laterised patches towards the basal boulder zone.	6.1	12.30	0.65
1218	36 - 60	Same.	6.0	12.57	0.35

The tendency for iron to increase with depth from 8.9 to 12.5% and for organic carbon to markedly decrease with depth from 2% to 0.3% is normal in lateritic soils of this type.

3. Freely-drained, Colluvial Lowland Soils.

The overburden between the ridges and mbugas at Mpanda consists of (a) soft, lateritic clay loam which changes into hard, indurated laterite with increasing depth and (b) pallid, sandy soil whose lower horizons may or may not be lateritised. The observed catenary association of soils in the Kasimba area is illustrated in Figs. 19 and 22. There appears to be a gradual transition from red-brown or brown clay loam, through pallid sand, to dark



coloured mbuga clay and sand with increasing distance from the ridge. Similar trends were also noticed in the Simbo area (Fig. 27).

(a) Lateritic Clay-Loam Soils and Laterite.

The colluvial red-brown and brown loams differ from those on the ridges in two respects. Firstly, they appear to be much less rubbly. Secondly, they contain an indurated laterite horizon between the upper soil horizons and the underlying bedrock.

TABLE 26. Weathering profile over granite-gneiss, Pit 19, Kasimba Lowlands.

Sample Nos.	Depth (ins.)	Description	pH	Total Fe (%)	Organic Carbon (%)
<u>A horizon</u>					
739	0-7	Dark grey-brown sandy clay with some rock rubble.	6.4	2.57	0.73
740	7-19	Brown sandy clay.	6.2	3.46	0.49
741	19-31	Red-brown sandy clay.		3.46	
742	31-48	Same.	6.4	3.28	0.22
<u>B horizon</u>					
743	48-60	Red-yellow, mottled, indurated laterite.	6.2	8.65	0.14
927	60-72	Same.	6.2	9.52	0.07
928	72-84	Same.		11.82	0.01
1140	84-96	Yellow-brown mottled, indurated laterite.	5.8	9.81	0.01
1141	96-108	Same.	5.8	8.01	0.01
1142	108-120	Same.	5.8	11.25	0.08
<u>Weathered bedrock horizon</u>					
1143/7	120-180	Highly decomposed, grey granite-gneiss with some red and yellow clay.		4.98	0.09

Judging from the data in Table 26, the pH of the loam soil samples from Pit 19 is similar to that of the loam soils on the ridges. The values given for the indurated laterite samples, however,

refer to determinations made on crushed material, and are, therefore, not strictly comparable.

The low organic carbon content of the topsoil from Profile 19 is presumably due to the effects of tillage, since the pit is situated in a maize field to the south of Kasimba Ridge. These low values are in no way typical of the topsoil horizon in other, non-cultivated lowland areas. As would be expected, organic carbon is impoverished in the hard laterite with respect to the overlying loamy soil.

The most striking difference between the colluvial soil samples from Pit 19 and the residual soil samples from Pit 23 lies in their very contrasting iron content, which is nearly four times higher in Pit 23. The red-yellow and yellow-brown mottled appearance of the laterite in Pit 19 is typical of the Mpanda area as a whole. Although iron is enriched in the hard laterite with respect to both the overlying loamy soil and the highly decomposed granite-gneiss, the laterite samples from Pit 19 do not appear to contain as much iron as those from the deeper soil horizons of Profile 23. More data are necessary, however, before it can be ascertained whether the loamy sub-soil on the ridges always contains more iron and other sesquioxides than the hard laterite developed over comparable rocks in lowland areas.

(b) Pallid Sandy Soils with or without a Lateritised Horizon.

The pallid soils in the Mpanda lowlands consist of white or light brown sand, with a variable clay content and little or no rock rubble. Laterite may or may not be developed in

the deeper horizons of this type of profile. Where laterite does occur, it is characterised by relics of pallid sandy soil representing material incompletely lateritised. A typical profile near the edge of the mbuga, situated to the south of Kasimba Ridge, is described in Table 27.

TABLE 27. Weathering profile over granite-gneiss, Pit 22, Kasimba Lowlands.

Sample Nos.	Depth (ins.)	Description
464.	0 - 6	Black sand.
463	6 - 18	Brown sand.
462/60	18 - 48	Light brown sand.
459/53 and 555	48 - 144	White sand.
	144 - 156	Highly decomposed and very acid granite - gneiss and some white sand.

No pallid soils were tested for pH, organic carbon, or total iron. According to Milne (1947), who studied similar soils in the Tabora area, the pH of pallid Tabora sand is 5.5 - 5.75. In view of the identical pH of the ridge soils in both areas, it seems reasonable to suppose that the pH of the pallid soils at Mpanda may lie within or close to these limits.

4. Seasonally-waterlogged Mbuga Soils.

Pallid sands persist almost to the centre of the mbugas where they grade into dark coloured clay or sandy clay, with local gleyed horizons. The thickness of the upper, dark-coloured, organic-rich horizon exceeds 54 inches in Profile 13, which is located in an mbuga between Kasimba and Myakalisa (Table 28). Nothing is known of the nature of the deeper, perennially

TABLE 28. Mbuga soil profile, Pit 13, Kasimba-Myakalisa Lowlands.

Sample Nos.	Depth (ins.)	Description
2335/6	0 - 24	Dark brown clayey sand.
2337	24 - 36	Brown-black clay, slightly sandy in places.
2338	36 - 54	Brown-black sandy clay. Water at a depth of 54 inches.

waterlogged soil horizons in the central parts of any of the mbugas at Mpanda. Milne (1947) notes that the sub-soil in the Tabora mbugas contains rusty, ferruginous concretions, the dark-coloured topsoil having a pH of 5.7.

The darker colour of the mbuga soil at Mpanda may be due to the fact that this material contains more organic matter than the freely-drained soil nearer the ridges.

5. Origins of the Soil Complex at Mpanda.

According to Milne's original definition (1935, 1936), a soil catena is a compound soil unit in which a chain of profile differences occur in a regular manner (see also Morrison, 1948). Milne emphasizes the close dependence on the topography. The uniformity of the parent material is of subordinate interest, although more diverse catenas will be formed in areas of contrasting lithology. He also notes that the soils in Western Tanganyika are not very closely related to the present-day climatic conditions, and that the rocks now exposed on the hills are not the only source from which the soils were derived.

The topographic succession of soil types in the Tabora area, which is evidently very similar to that at Mpanda, is considered by Milne (1947) to result from: (a) the lateral transport of slowly eroding material, and (b) profile development in situ. The whole complex is proceeding towards the elimination of its youngest members, namely the mature red earth and the primary hill loam.

(a) Lateral Transport of Slowly Eroding Material.

The soil covering the ridges at Mpanda is residual. The deeper horizons of the overburden in the lowlands may also be partly residual, but the near-surface material probably consists of colluvium which has been derived from higher ground (p.18). Although the rate at which soil is being eroded is relatively slow, the very long period of weathering is sufficient for a considerable, lateral movement of material to have taken place (see Part V).

(b) Profile Development.

The profiles on the ridges are either truncated or less mature owing to the present day active erosion. It is impossible to visually distinguish between the A horizon or zone of leaching and the B horizon or zone of accumulation (see Mohr and Van Baren, 1954). Profile differentiation in the lowlands, however, is more pronounced and an illuvial B horizon, consisting of indurated laterite, has been developed over an extensive area. This is overlain by near-surface, loam soil which probably represents the eluvial A horizon (Table 26).

According to Milne (1947), Pendleton (1946), Prescott

and Pendleton (1952) and de Craene and Laruelle (1955), similar laterite horizons at Tabora in Western Tanganyika and in Siam, Australia and the Belgian Congo have originated as a result of the following weathering process. Iron, aluminium and manganese are dispersed from higher levels in the soil profile to the groundwater table surface. Here, they meet further quantities of the same elements which have been leached or colloiddally dispersed from the underlying bedrocks. Iron, aluminium and manganese are then precipitated as hydrous oxides when the water content of the sub-soil zone of seasonal saturation is reduced and air is re-admitted. During the dry season, the sesquioxides become irreversibly fixed and hardened. Further accessions take place during subsequent wet seasons and a considerable thickness of sesquioxide-rich material is formed over a long period of time. Relatively insoluble soil constituents such as quartz sand or gravel also become mechanically incorporated in the laterite during its formation. The emergence of hard laterite at the surface is generally considered by these authors to be due to the erosion of the overlying soil.

The Mpanda laterite may have originated in this manner during an earlier period, when the wet season level of the groundwater table was somewhat higher than it is today. There can be little doubt that the A horizon of the soil covering the Mpanda lowlands consists of colluvial material. It is also probable that much of the underlying B horizon consists of lateritised colluvium rather than of lateritised, residual soil. The weathered bedrock horizon of lowland profiles at Mpanda is, therefore, not designated

as the

C horizon in subsequent tables.

a). PREVIOUS MINING AND AGRICULTURAL ACTIVITY.

No samples were taken within one mile of the mill tailings dump at Mkwamba and the railway line linking the Mine with Tabora (Fig. 18). A small spoil dump on the lower slopes of Kasimba Ridge does not appear to be contaminating the soil since (a) lead is not enriched in the surface horizons of the profile near the dump and (b) the lead content of the surface soil does not increase with increasing proximity to the dump. Similar trends were also observed near the Mpanda-Tabora road, which passes to the north of Kasimba and Simbo Ridges.

During the course of the studies, a few topsoil samples were collected from a maize field to the south of Kasimba Ridge. The soil in the field has been disturbed to a depth of 12 inches by native hoeing, but any effect on the secondary dispersion pattern of copper, lead and zinc appears to be negligible (see also Tooms, 1955).

PART V

OBSERVED DISPERSION OF METAL IN ROCKS, SOILS

AND STREAM SEDIMENTS AT MPANDA

a). FREELY-DRAINED SOILS AND WEATHERED ROCKS IN UN-MINERALISED AREAS.

Soil samples were taken on ridge slopes and from the lowlands over granite-gneiss, amphibolite, dolerite and phyllite in un-mineralised areas near Ipwaga, Kabungo, Kasimba and Milala (Fig. 18). These samples cover a range of conditions similar to those encountered in the vicinity of the mineralisation studied at Kasimba itself.

1. Lead Content of Residual and Colluvial Soil and Laterite.

(a) Weathering Profiles over Acid and Basic Rocks.

The results obtained from the analysis of samples from residual soil profiles over granite-gneiss, amphibolite and dolerite on Ipwaga Hill and on a small ridge near Kabungo Hill are given in Table 29. They show that there is no tendency for lead to be enriched in the topsoil relative to the sub-soil. Values appear to be equally distributed at the 10 - 20 ppm level throughout all soil horizons of Profiles 1, 2 and 3. This is in marked contrast to the enrichment of lead observed in the surface horizons of back-ground soil profiles at Bawdwin.

The data also indicate that lead is not enriched in the soil with respect to the parent bedrock. Furthermore, the lead content of soil samples from the weathering profile over granite - gneiss is very similar to that of the samples from Pits 2 and 3, where the sub-outcropping bedrocks consists of amphibolite and dolerite respectively.

TABLE 29. Distribution of copper, lead and zinc in residual soil profiles over granite-gneiss, amphibolite and dolerite in un-mineralised areas at Ipwaga and Kabungo.

Bedrock Type and Pit Numbers:		Granite-gneiss 1			Amphibolite 2		
Sample Numbers:		4425/30 and 4653			4654/9		
Depth (ins.)	Description	Metal content (ppm)					
		Pb	Cu	Zn	Pb	Cu	Zn
0 - 8	Dark grey-brown loam,	15	50	25	15	70	25
8 - 20	Brown loam.	15	50	25	15	70	25
20 - 32	Red-brown loam grading into rubbly red clay.	10	70	25	15	70	25
32 - 41	Rubbly red clay.	10	70	10	15	70	25
41 - 55	Rubbly red clay in Pit 1, weathered amphibolite in Pit 2.	15	70	25	20	70	50
55 - 60	Weathered granite-gneiss in Pit 1.	15	50	10			

Bedrock Type and Pit Numbers		Dolerite 3		
Sample Numbers:		443/5		
Depth (ins.)	Description	Metal content (ppm)		
		Pb	Cu	Zn
0 - 6	Dark grey-brown loam.	10	150	25
6 - 24	Red-brown and red loam.	10	150	25
at 24	Hard, weathered dolerite.	10	100	25

Judging from the data in Table 30, lead also shows no tendency towards enrichment in any particular horizon of the pallid, sandy soil profile at Site 5 (Kabungo lowlands).

Moreover, there appears to be virtually no difference in the lead content (10 ppm) of the pallid sand samples as compared to that of the samples from the residual soil Profiles 1 - 3.

TABLE 30. Distribution of copper, lead and zinc in colluvial soil profiles over granite and phyllite in un-mineralised areas at Kasimba and Kabungo.

<u>Pit No. 14</u>		<u>Granite</u>			
Sample Nos.	Depth (ins.)	Description	Metal content (ppm)		
			Pb	Cu	Zn
782	0 - 12	Black sand.	10	25	25
783	12 - 18	Brown-black sand.	10	25	25
784	18 - 34	Dark-brown sand.	10	25	10
785	34 - 46	Pale brown sand.	10	25	10
786	46 - 58	" " "	10	25	10
787	58 - 71	White sand, and quartz rubble.	<u>10</u>	<u>25</u>	<u>10</u>
788	71 - 75	Weathered granite.	5	25	5

<u>Pit No. 4</u>		<u>Phyllite</u>		
Sample Nos.	Depth (ins.)	Description	Lead content (ppm)	
		<u>A horizon</u>		
376	0 - 9	Dark grey - brown loam.	5	
377	9 - 16	Brown loam.	5	
378	16 - 28	Light brown loam.	5	
		<u>B horizon</u>	---	
379	28 - 40	Red-brown nodular, mottled, hard laterite.	25	
481	40 - 52	"	80	
482	52 - 64	"	40	
545	64 - 76	"	60	
546	76 - 88	"	80	
547	88 - 100	"	25	
876	100 - 112	Same, some quartz rubble.	10	
		<u>Weathered bedrock horizon</u>	---	
877/9	112 - 144	Intensely weathered phyllite with quartz veinlets.	10	

The value of 5 ppm Pb observed in the colluvial, loamy soil samples from the A horizon of Pit 4 is comparable to those in the samples of residual soil and pallid, sandy soil from the Ipwaga and Kabungo areas. Lead appears to be markedly enriched, however, in the hard laterite, which has an overall metal content of 45 ppm Pb, as compared to the overlying soil and underlying weathered phyllite. The erratic distribution of lead in individual laterite samples from the area has already been mentioned (p. 41). The data in Table 30 also suggest that the vertical distribution pattern of the lead in the laterite or B horizon over un-mineralised rocks is equally irregular, since values range within the wide limits of 10 - 80 ppm. Clearly therefore, the erratic distribution of lead in laterite is a fact that must be borne in mind when considering data obtained in samples taken from this horizon.

(b) Lateral Variation in Metal Content.

Soil samples were collected from a number of sites in un-mineralised areas from a depth of 12 - 24 inches, in order to establish the regional background for lead in residual and colluvial soil. Samples of weathered granite-gneiss, amphibolite and meta-dolerite were also taken from a smaller number of pits in the same localities. The background for laterite is based on the analysis of samples, each representing a vertical distance of 12 inches, from five pits. These were dug to bedrock or to a depth of five feet in the hard laterite horizon.

There appears to be little or no difference between the

lead content of (a) residual soil samples collected over acid and basic rocks, and (b) residual soil samples, colluvial loam soil samples and pallid, sandy soil samples. The data in Table 31 show that the average lead content of soil samples from a depth of 12 - 24 inches is 10 ppm. This figure agrees very closely

TABLE 31. Lead content of freely-drained soil, laterite and weathered granite-gneiss, phyllite, amphibolite and dolerite bed-rocks in un-mineralised areas at Mpanda.

	Lead content (ppm)		
	Loam Soil and Pallid Sand (12-24 ins.)	Laterite	Weathered Bedrock
Number of Samples	332	27	23
Range of Values	5 - 50	5 - 100	5 - 20
Median Value	10	40	5

with the background values of 5 - 10 ppm Pb noted by J. S. Webb and A. P. Fawley during the original geochemical appraisal of the area in 1956. It is also very similar to the mean value of 15 ppm Pb for world-wide, normal soils (p. 23).

The mean lead content of laterite samples (40 ppm) is considerably higher than that of the loam soil, pallid sand and weathered bedrock samples (Table 31). The enrichment of lead and iron during the formation of laterite in Nigeria has been noted by Hawkes (1954), who found that some laterite samples in un-mineralised areas contain as much as 220 ppm or eight times the amount

of lead present in the parent diorite bedrock. Wedepohl (1956) also refers to the accumulation of lead in the laterite horizon during rock weathering; his work is further discussed in Part VI.

2. Copper and Zinc Contents of Residual and Colluvial Soil and Laterite.

(a) Weathering Profiles over Acid and Basic Rocks.

The data in Tables 29 and 30 indicate that copper and zinc are also evenly distributed throughout all horizons of Profiles 1 - 3 / ^{and 14.} There appears to be little difference in the zinc content of the soil samples from the profiles over acid, basic and intermediate rocks. The soil samples taken over dolerite (Profile 3), however, contain considerably more copper than those from the weathering profiles over granite-gneiss and amphibolite.

(b) Lateral Variation in Metal Content.

A smaller number of the soil, laterite and weathered bedrock samples were also tested for copper and zinc (Table 32).

Soil samples collected in areas where un-mineralised dolerite sub-outcrops contain ~~3-7~~ times as much copper as similar samples taken over amphibolite and more acidic rocks. Tooms (1955), Webb (1956), Coope (1958) and others have noted the enrichment of copper in lateritic soils over basic rocks with respect to those derived from acid rocks in other parts of Africa. Copper also appears to be enriched in the laterite as compared to the overlying soil and underlying bedrocks at Mpanda.

TABLE 32. Copper and zinc contents of freely-drained soil, laterite and weathered phyllite, granite-gneiss, amphibolite and dolerite bedrocks in un-mineralised areas at Mpanda.

Bedrock Type	Copper (ppm)			Zinc (ppm)		
	Loam Soil	Laterite	Bed-rock	Soil	Laterite	Bed-rock
<u>Granite-gneiss and phyllite</u>						
No. of samples	20	11	9	20	7	6
Range of values	10-100	50-150	10-100	10-70	25-70	5-25
Median value	30	100	30	40	30	10
<u>Amphibolite</u>						
No. of samples	5		5	2		2
Range of values	50-70	No data	50-100	25-50	No data	50-70
Median value	60		70	40		60
<u>Dolerite</u>						
No. of samples	2		2	2		2
Range of values	150-300	No data	100-300	10-25	No data	
Mean value	200		200	15		25

The range of values observed in the very small number of soil samples tested for zinc is 10 - 70 ppm. Judging from the limited data in Table 32, soils derived from granite-gneiss and amphibolite contain slightly more zinc than those developed over dolerite. Zinc appears to be enriched in both loam soil and laterite with respect to the underlying gneiss

and phyllite. According to Hawkes (1954), this element may or may not be enriched in laterite formed from un-mineralised rocks in Nigeria.

3. Estimated Background and Threshold Values for Prospecting Purposes.

(a) Lead.

The background for lead in both loam soil and pallid, sandy soil at Mpanda is taken as the median value of the 332 samples that were analysed, namely 10 ppm. The threshold value for lead in these soils is arbitrarily fixed at 20 ppm. Only 7% of the soil samples taken in un-mineralised areas were found to have a higher metal content. Analytical errors at the 20 ppm level, however, are considerable (p. 38). This fact should be borne in mind when interpreting data from the soil anomalies related to known mineralisation in the Kasimba - Simbo area.

The backgrounds for lead in laterite and weathered bedrock, based on the analysis of a very much smaller number of samples, are 40 ppm and 5 ppm respectively (Table 31). No sample of laterite from un-mineralised areas was found to contain more than 100 ppm, which is tentatively assumed to represent the threshold value for lead in this medium. The corresponding threshold for lead in weathered granite-gneiss, phyllite, amphibolite and dolerite bedrocks is 20 ppm.

(b) Copper and Zinc.

The zinc threshold for loam soil and laterite, which is also based on the analysis of a very small number of samples, is 70 ppm. This figure represents the upper limit of the observed variations in the metal content of samples from un-mineralised areas.

As regards copper, however, the very limited data in Table 32 indicate that it is necessary to discriminate between (a) background loam derived from acid and intermediate rocks, (b) background loam over basic rocks, and (c) background laterite. The thresholds for these media are respectively fixed at the 100 ppm, 300 ppm and 150 ppm levels. The various thresholds for copper, lead and zinc are summarised below in Table 33.

TABLE 33. Thresholds for copper, lead and zinc in freely-drained soil, laterite and weathered bedrock at Mpanda.

Sample type:	Threshold value (ppm)		
	Loam Soil and Pallid Sand	Laterite (over acid rocks)	Weathered Bedrock
<u>Lead</u> Acid and Basic Rocks	20	100	20
<u>Copper</u> Acid Rocks	100	150	100
Basic Rocks	300	No data	300
<u>Zinc</u> Acid and Basic Rocks	70	70	70

b). FREELY-DRAINED SOILS AND WEATHERED ROCKS IN MINERALISED AREAS
AT KASIMBA AND SIMBO

There appears to be little or no difference in the lead content of residual soil on the ridges and colluvial soil covering the surrounding lowlands in un-mineralised parts of the Mpanda area, although lead is enriched in the laterite horizon. When interpreting the data regarding the metal content of similar soils in a mineralised environment, however, due allowance must be made for the different origins of the soil types and their positions in relation to the groundwater table.

This section is concerned with the lateral and vertical distribution of metal in residual soil, colluvial soil and indurated laterite in the Kasimba and Simbo areas (Fig. 18). Two separate E-W shear zones sub-outcrop on these low ridges, dipping at an angle of 60° to the south.

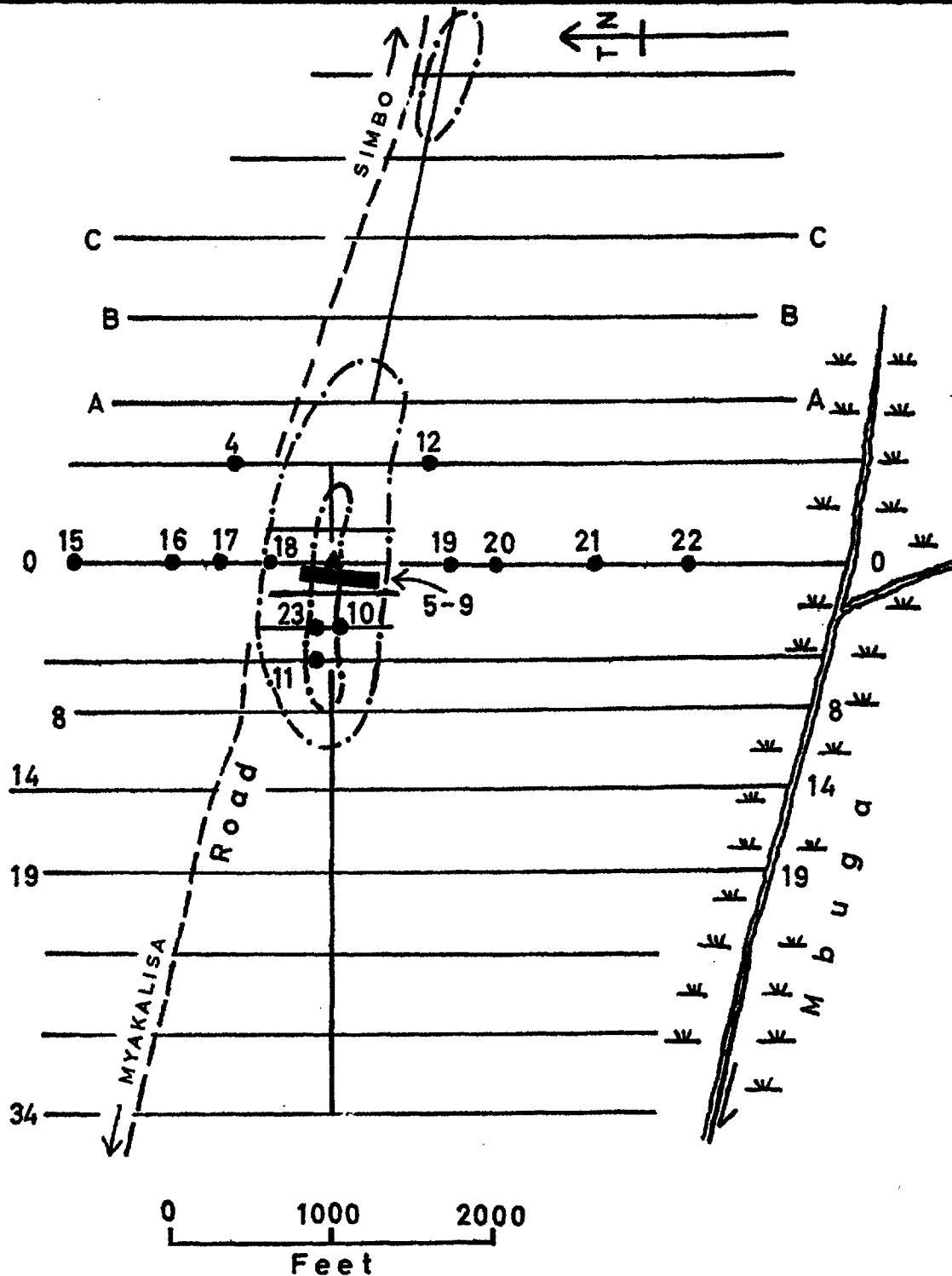
Most of the samples were collected in the Kasimba area, where the preliminary orientation by J. S. Webb and A. P. Fawley disclosed the presence of anomalous concentrations of lead and copper in residual loam on the ridge (see also Webb, 1956). The anomalies persist southwards for a distance of 300 feet into the lowlands, although sample values abruptly decline in this direction.

The location of all samples collected by the writer in the Kasimba area are shown in Fig. 20.

1. Kasimba Ridge.

(a) Residual Soil Profiles over Dolerite and Gneiss.

Profile samples were taken at 5 feet intervals from the



- ▲ SURVEY BEACON
 ● 4 PIT, WITH NUMBER
 TRENCH
 34 ——— TRAVERSE, WITH NUMBER
 - - - - - OUTLINE OF KASIMBA RIDGE
 SAMPLE INTERVAL: RIDGE 50 FT., LOWLANDS 200 FT.

Fig. 20. SAMPLE LOCATION MAP OF THE KASIMBA AREA.

walls of an old trench. This trench was dug through the residual overburden on the ridge in a direction normal to the strike of the mineralised shear, for a distance of 370 feet. The thickness of the soil varies from a few inches to 6 or 7 feet, being at a minimum over dolerite and at a maximum over granite-gneiss.

i. Lead.

Judging from the analytical results presented in Fig. 21, lead appears to be very evenly distributed in the soil over the shear zone and shows no tendency towards enrichment in any particular horizon of the profile. The average lead content of the topsoil samples taken from a depth of 0 - 6 inches is 560 ppm. The corresponding values of the sub-soil samples collected from depths of 12 - 24 inches and within 12 inches of weathered bedrock are 660 ppm and 710 ppm respectively.

Typical trends observed in the trench profiles are illustrated by the data in Table 34, the positions of Profiles 5 - 9 being given in Fig. 21. Values tend to (a) increase with depth, (b) attain a maximum in certain sub-soil horizons and (c) remain constant in depth, over both weathered dolerite and granite-gneiss. One factor influencing the distribution of lead in the residual soil is the extremely variable tenor of the bedrock source (Fig. 21 and p. 151). Another factor is the downslope movement of soil particles under the influence of gravity. This is presumably responsible for the peak values detected in the sub-soil horizons of some profiles and the even distribution of lead in the soil at other sites.

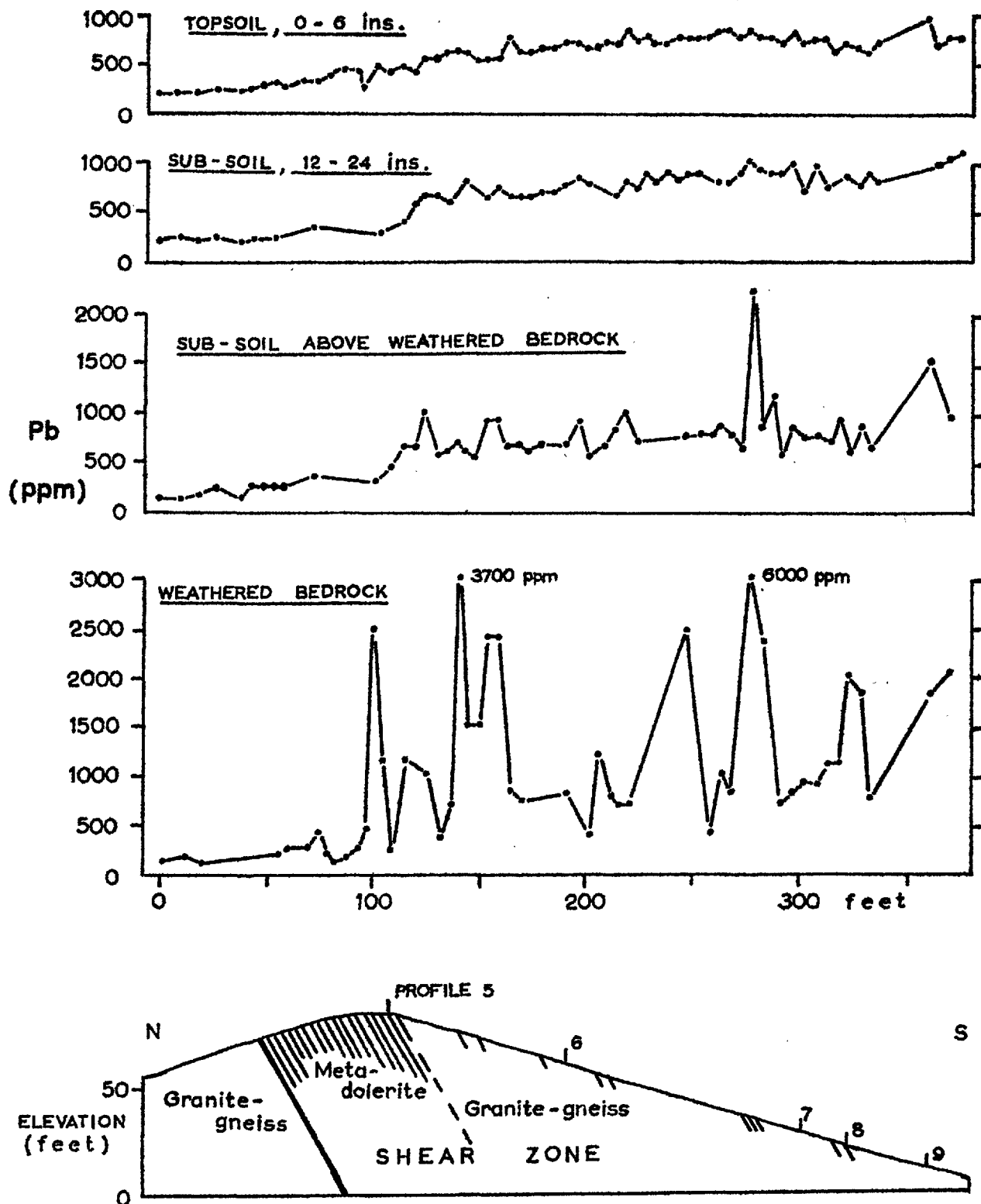


Fig. 21. DISTRIBUTION OF LEAD IN SOIL PROFILES ON KASIMBA RIDGE.
(Threshold; 20 ppm for all horizons)

TABLE 34. Distribution of lead within freely-drained, residual soil profiles over dolerite and granite-gneiss, Kasimba Ridge. A residual soil profile which is very similar to those shown below is described in Table 24.

Bedrock Type:	Dolerite	Gneiss	Dolerite	Gneiss	
Pit Nos:	5	6	7	8	9
Distance from Ridge Crest (ft.):	10	92	207	227	265
Sample Nos:	3293/6	2915/21	3163/8	3190/6	3215/8
Depth (ins.)	Lead content (ppm)				
0 - 6	370(s)		700(s)	700(s)	1000(s)
6 - 12	370(s)	700(s)	750(s)	820(s)	1100(s)
12 - 24	450(s)	800(s)	700(s)	700(s)	1500(s)
24 - 36	200 ^W	1200(s)	600(s)	800(s)	1700 ^W
36 - 48		1000(s)	700(s)	2000 ^W	
48 - 60		750(s)	900 ^W		
60 - 72		650(s)			
72 - 84		800 ^W			

(s) denotes soil. ^W denotes weathered bedrock.

A distinct feature of the vertical distribution of lead in the soil exposed in the trench is the lack of any tendency towards surface enrichment. Lead is also not enriched in surface soil near the base of the slope, the reasons for this being further considered in Part VI.

A soil sample taken from a depth of 6 - 18 inches in Pit 10, which is situated towards the western end of the ridge, contains more lead (1450 ppm) than those from the surface (900 ppm) and deeper

sub-soil horizons (650 ppm) of the profile. This enrichment, however, is evidently not due to any appreciable accumulation of lead in the - 200 mesh clay-silt fraction (Table 35). On the contrary, lead

TABLE 35. Distribution of lead in size-fractions of soil samples from Pit 10, Kasimba Ridge.

A description of the soil horizons in this pit is given in Table 25.

Depth (ins.)	Lead content (ppm) of size-fractions (B.S.S.)				
	+ 20 - 36	+ 36 - 80	+ 80 - 120	+ 120 - 200	- 200
0 - 6	1100	1400	1100	900	900
6 - 18	2500	1900	1600	1400	1400
18 - 42	900	800	700	900	800
42 - 66	700	500	500	600	500

appears to be markedly concentrated in the coarsest + 36 mesh fraction of the sample from a depth of 6 - 18 inches. The distribution of lead in size-fractions of residual soil at other sites was not studied, so it is not known whether these very puzzling data are typical for ridge soil in the Mpanda area. Webb (1956) also found lead to be similarly enriched in the coarse fractions of soil in the B horizon of a latosol profile near the Argent Mine in South Africa.

The average lead content of the soil samples from the trench is about 650 ppm. The corresponding value for the weathered bedrock samples is 1050 ppm, so lead appears to be impoverished in soil as compared to the parent material. This latter figure is rather tentative, however, for the following reasons. In the first place, lead is very erratically distributed in weathered

dolerite and granite-gneiss. For example, the metal content of 10 replicate chip samples of weathered dolerite near Profile 5 varies from 400 to 1200 ppm (Table 5). Secondly, the value of 1050 ppm only refers to the topmost twelve inches of the sub-outcropping dolerite and gneiss. At some sites, values tend to decrease with depth in the weathered bedrock horizon.

This occasional feature, which was also observed in some parts of the Bawdwin area, raises doubts as to whether the concentrations of lead in the surface rocks have a primary origin or whether they have been introduced during the course of secondary dispersion from a source higher up the slope. In the absence of deep pits, it is not possible to resolve this problem, which is discussed in Part VI.

ii. Copper and Zinc.

In the seven profiles studied, copper tends either to increase with depth or else to remain constant in this direction. The zinc content of the soil is so low that no definite trends can be discerned in any one profile.

(b) Lateral Dispersion of Lead in Residual Soil and Weathered Bedrock

All soil and weathered bedrock samples from the trench contain anomalous concentrations of lead. The metal content of soil samples taken at depths of 0 - 6 ins. and 12 - 24 ins. increase southwards towards the base of slope, from 170 to 1000 ppm and from 200 to 1100 ppm respectively (Fig. 21). A similar increase was also observed in the sub-soil horizon within 12 ins. of weathered bedrock, although erratic highs of up to 2200 ppm Pb were detected at a few sites. This latter value exceeds threshold by a factor of 110.

The lead content of the weathered bedrock samples from the trench ranges from 50 to 6000 ppm, the contrast between peak and threshold values being 300-fold. As can be seen from Fig. 21, metal values are liable to extreme variation over very small distances, in marked contrast to the more even distribution of lead in the overlying soil. Nevertheless, values also tend to increase southwards.

(c) Extractability of Lead in Residual Soil.

The results obtained from testing 18 soil samples from Kasimba and Simbo Ridges for cold-extractable lead are presented in Table 36. Inspection of the data shows that there is little difference in the extractability of lead in organic-rich surface soil and more inorganic sub-soil, since the mean ratios of cold-extractable to total metal are 40% and 30% respectively. These relatively high values

TABLE 36. Ratio of cold 5% nitric acid-soluble to total lead in non-contaminated, residual soil samples from Kasimba and Simbo Ridges.

Soil Horizon	No. of samples	Ratio of cold-extractable to total Pb (%)		
		Minimum	Maximum	Mean
Topsoil ^x	9	30	50	40
Subsoil +	9	20	40	30

^x Sample depth varies from 0 - 3 ins. to 0 - 12 ins.
 + " " " " 24 - 36 ins. to 36 - 48 ins.

are not in any way due to contamination, whose effect in the area is

negligible. Further work is necessary to determine why more of the lead in the Mpanda sub-soil samples is soluble in cold, 5% nitric acid than is the case in the sub-soil samples from Meingtha Hill, which have a lower pH and a lower iron content (cf. Table 16).

2. Extent of the Anomaly in Near-surface Soil at Kasimba,

(a) Sample Depth, Sample Interval and Traverse Interval.

The data in Fig. 21 indicate that a sampling depth of 12 - 24 inches is adequate for the purposes of defining the soil anomaly in the Kasimba area.

These data also show that the width of the lead anomaly in the residual soil exposed by the trench is more than 370 feet. Moreover, the anomaly detected by J. S. Webb and A. P. Fawley in residual soil some 500 feet north of the trench has a comparable width. Clearly therefore, this extensive anomaly could be outlined by collecting samples at intervals of 200 feet or more from traverses spaced at 500 feet intervals.

It is evident from Table 37, however, that the metal content of the soil near Pit 11, which is situated near the western end of the ridge, is rather heterogeneous (Fig. 20).

Values in the 17 soil samples, which were taken at intervals of 10, 25, 50 and 100 feet to the north, south, east and west of the pit, range from 300 to 1000 ppm Pb. These variations are presumably related to corresponding variations in the tenor of the bedrock mineralisation. In order to obtain a detailed picture

TABLE 37. Lateral variation in the lead content of residual and colluvial soil samples collected at a depth of 12 - 24 inches near Pits 11 and 12 at Kasimba.

Distance from Pit Centres (feet)	Lead content (ppm)							
	North		South		East		West	
	11	12	11	12	11	12	11	12
0	300	120	300	120	300	120	300	120
10	500	150	600	100	500	120	500	150
25	600	150	400	100	600	100	400	150
50	700	100	500	100	500	100	600	100
100	1000	100	300	170	500	100	400	100

Pit 11 situated 50 ft. S of the ridge crest (15° slope).
Pit 12 " on level ground.

of metal distribution in the ridge soil, samples were, therefore, collected at intervals of 50 feet from traverses situated 200 feet apart. Each traverse was oriented in a direction normal to the strike of the shear zone.

The soil anomaly in the lowlands, however, occupies a very considerable area and these intervals were increased to 200 feet and 500 feet respectively. Judging from the data in Table 37, lead is more evenly distributed in the colluvial soil near Pit 12, 1400 feet to the S.E. of Pit 11. In this locality sample values do not appear to fluctuate outside the relatively narrow limits of 100 - 170 ppm Pb.

(b) Analytical Results.

i. Lead

The samples taken from 17 traverses in the Kasimba area were

first analysed for lead. The results are presented as a geochemical contour map in Fig. 23, the traverse locations being given in Fig. 20. A soil map of the area, based on observations made at every site at a depth of 12 - 24 inches, is also shown in Fig. 22.

The most salient feature of the secondary dispersion of metal at Kasimba is the marked decline in metal values away from the ridge (see also Fig. 25). This undoubtedly reflects the non-residual nature of the soil covering the surrounding lowlands. Values in residual soil range from 10 ppm near the eastern end of the ridge to 2000 ppm at its western extremity. Every sample from the central and western parts of the ridge has an anomalous metal content. Factors contributing to the breadth of the soil anomaly on the ridge include (a) the extensive primary dispersion of lead in sheared bed-rocks (see Fig. 21) and (b) the gravity-controlled mechanical dispersion of metal down the northern and southern slopes during the long period of weathering.

Samples of colluvial loam from lowland sites to the west and south of the ridge contain up to 250 ppm Pb (Fig. 22). No sample of pallid sand, however, which covers the ground nearer the mbuga, was found to contain more than 80 ppm Pb. Furthermore, there appears to be a definite relationship between the 20 ppm geochemical contour and the boundary between clay loam and pallid sand north of the mbuga. The lower metal content of the pallid sand is mainly due to its greater distance from the anomaly source on the ridge.

The size distribution of lead in colluvial soil samples

Fig. 22

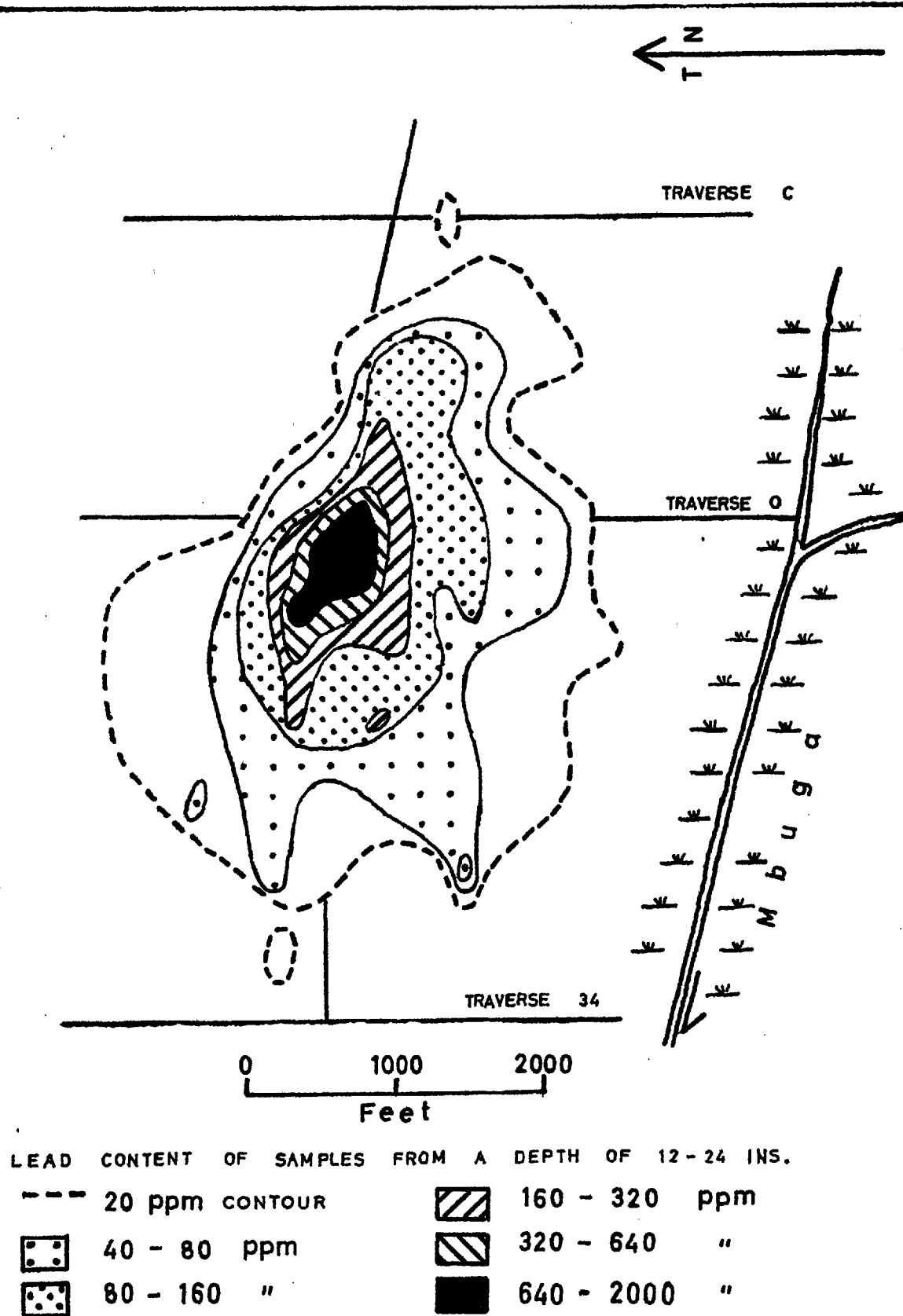


Fig. 23. LEAD ANOMALY IN NEAR-SURFACE SOIL AT KASIMBA.

taken at a depth of 12 - 24 inches from three sites in the Kasimba-Simbo lowlands is rather different to that observed in the residual soil samples from Pit 10 (Table 38). Metal is only slightly en-

TABLE 38. Distribution of lead in size-fractions of colluvial soil samples collected at a depth of 12 - 24 inches in the Kasimba-Simbo lowlands.

Sample No.	Soil Type and Traverse No.	Lead content (ppm) of size-fractions (B.S.S.)				
		+ 20 - 35	+ 36 - 80	+ 80 - 120	+ 120 - 200	- 200
2166	Lateritic loam (W)	150	120	150	170	230
3842	Lateritic loam (A)	70	50	70	70	120
2669	White sand (090)	5	5	5	10	50

riched in the clay-silt fraction (- 200 mesh) of the two lateritic loam samples, possibly because the sesquioxides with which lead is associated are both coarse and fine grained. Most of the lead, however, appears to be concentrated in the - 200 mesh fraction of the pallid sand sample from Traverse 090.

According to Milne (1947) very similar pallid sandy soils at Tabora are losing clay to the mbugas (p. 134). If this is also the case in the Kasimba-Simbo area, the elutriation of fine, metalliferous particles could contribute to the low lead content of the pallid sand.

Pits were deepened to bedrock or to the top of the laterite

horizon in some of the areas where the soil at a depth of 12 - 24 inches has a background lead content. No anomalous concentrations of lead, however, were detected in the deeper soil horizons. The 20 ppm contour in near-surface soil appears, therefore, to define the full extent of the Kasimba soil anomaly shown in Fig. 23. The anomaly trends for 4500 feet in a WNW-ESE direction and attains a maximum width of 3300 feet. The mechanisms responsible for this extensive secondary dispersion of lead are considered in the next part of this section, when the data obtained from lowland pits dug to bedrock on Traverse 0 are presented and discussed.

ii. Copper and Zinc.

All soil samples from Traverse 0 were tested for copper and zinc (see Fig. 24). The copper content of the samples varies from 10 - 200 ppm, the peak value being located over the dolerite which forms the footwall of the shear zone on the ridge. This peak value is not considered to be of any significance in terms of mineralisation, however, since soil samples collected over un-mineralised dolerite at Kabungo and Milala have an equally high metal content. Moreover, the copper content of soil samples taken over acid rocks in the shear zone, further to the south, only exceeds the threshold of 100 ppm at two sites. These results suggest that, to all intents and purposes, copper merely serves as an indicator of basic rocks. and is of little use in prospecting for mineralisation at Kasimba. The copper content of the soil and surface rocks on Kasimba Ridge has undoubtedly been much reduced as a result of leaching by meteoric waters.

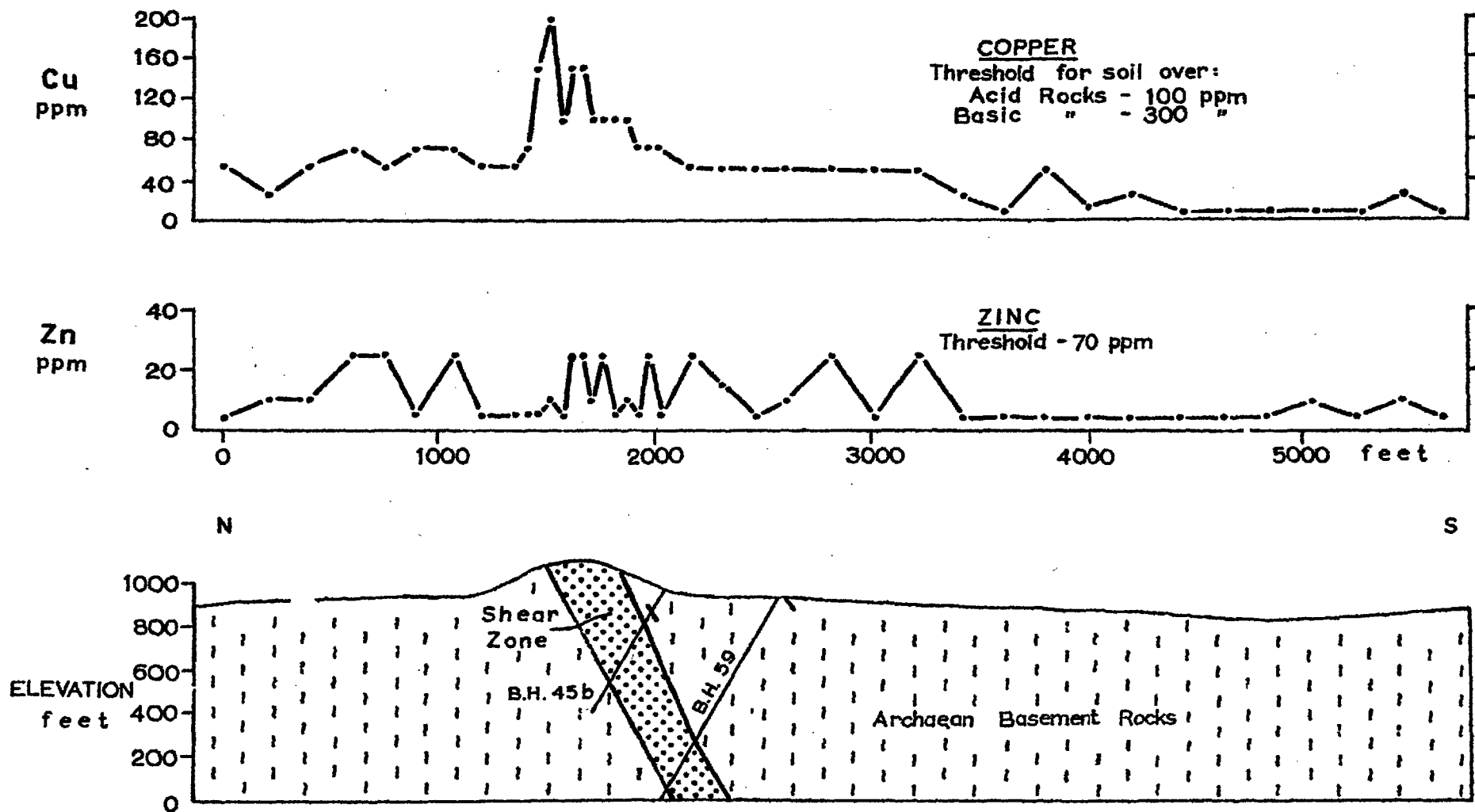


Fig. 24. DISTRIBUTION OF COPPER AND ZINC IN SOIL SAMPLES TAKEN AT A DEPTH OF 12-24 INS., TRAVERSE O, KASIMBA AREA.

Completely negative results were obtained for zinc; no sample from Traverse 0 was found to contain more than 25 ppm, which is well below the threshold of 70 ppm.

3. Kasimba Lowlands.

(a) Colluvial Soil Profiles over Gneiss, Gossan and Phyllite.

Profile samples were taken from Pits 15 - 21, which are situated at intervals of 300 to 600 feet to the north and south of Kasimba Ridge. Indurated laterite, from four to seven feet thick, was encountered in every pit beneath a cover of loamy colluvium (see Fig. 19).

i. Lead

Judging from the data in Fig. 25, the lead anomaly in near-surface soil and laterite on Traverse 0 is confined to the area between Pits 18 and 21. The distribution of lead in lowland profiles 18 - 21 is given in Table 39.

There appears to be little difference in the metal content at different levels in the A horizon of these profiles, although lead is very erratically distributed in the underlying B or laterite horizon. Nevertheless, two distinct trends emerge from these data. Firstly, values increase with depth, from 100 ppm in the A horizon of Profile 20 to 650 ppm in the B horizon and to 1000 ppm in the gossan, which may be one of the bedrock sources of the soil anomaly in this area (p. 163). Secondly, lead is markedly enriched in the B horizon of the other profiles, the respective lead contents of the A, B and

(continued on p. 159)

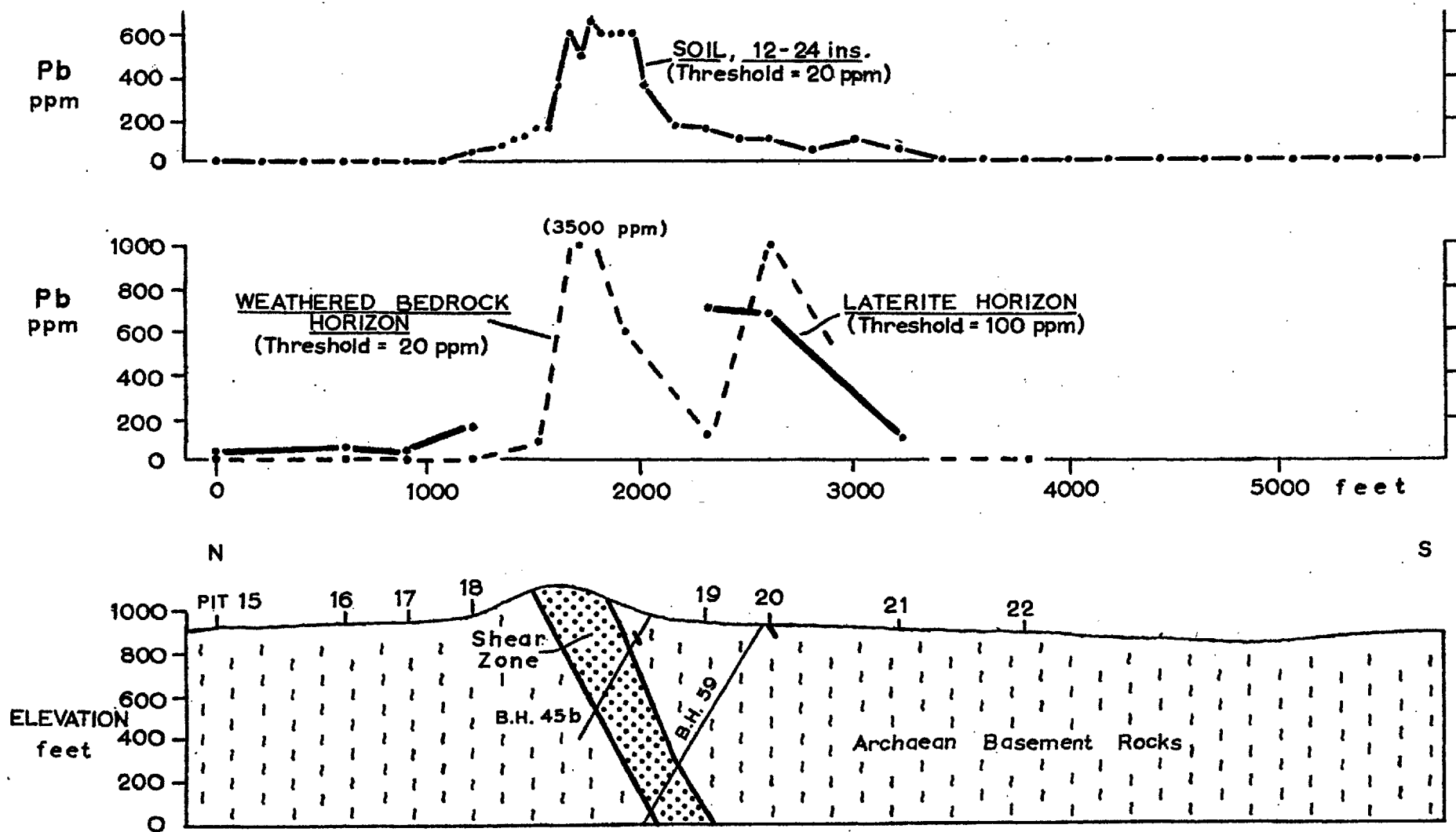


Fig. 25. DISTRIBUTION OF LEAD IN SAMPLES OF SOIL, LATERITE AND WEATHERED BEDROCK, TRAVERSE O, KASIMBA AREA.

TABLE 39. Distribution of lead within colluvial soil profiles, Traverse O, Kasimba lowlands.

A full description of Profile 19 is given in Table 26.

Pit Nos. and Bedrock Types:		19 Granite-gneiss			21 probably granite-gneiss	
Distance from Ridge Crest (feet):		700 S			1600 S	
Depth (ins.)	Horizon	Sample Nos.	Pb (ppm)	Ratio of CX:Total Pb (%)	Sample Nos.	Pb (ppm)
0-7	Loamy Soil(A)	739	80	50	576	50
7-19	"	740	120	50	577	50
19-31	"	741	150	50	578	40
31-48	"	742	100	50	579/80	50
48-60	Laterite(b)	743	500	12	738	150
60-72	"	927	700	14	929	170
72-84	"	928	1000	12	930	120
84-96	"	1140	900	16	1545	70
96-108	"	1141	350	18	1546	40
108-120	"	1142	800	14		
120-180	Weathered Bedrock	1143/7	100	40	Probably	< 40 ppm.

Pit Nos. and Bedrock Types:		18 Phyllite			20 Gossan	
Distance from Ridge Crest (feet):		400 N			1000 S	
Horizon	Depth (ins.)	Sample Nos.	Pb (ppm)	Depth (ins.)	Sample Nos.	Pb (ppm)
Loamy Soil (A)	0-12	367	40	0-8	372	80
"	12-24	368	40	8-13	373	120
				13-24	374	100
Laterite (B)	24-36	369	170	24-36	433	1000
"	36-54	370	200	36-48	454	700
"	54-66	371	100	48-60	451	300
	66-86	425	20			
Weathered Bedrock	86-108	426	10	60-72	552	1000

weathered bedrock horizons being 70 ppm, 400 ppm and 50 ppm. The enrichment of lead in the laterite represents the normal tendency for trace elements to accumulate along with iron and other sesquioxides in the illuvial B horizon of soil profiles away from the bedrock source of an anomaly (see Table 26 and p. 24).

The immediate source of the lead in the B horizon of Profiles 18 - 21 cannot be stated with certainty, apart from the fact that some metal has been derived from the overlying A horizon. In Profile 19, 50% of the lead in samples from the A horizon is soluble in cold 5% nitric acid (Table 39). Only 12 - 18% of the metal in the laterite samples, however, is extractable in cold nitric acid. This suggests that lead is present in a different form in the B horizon owing to its deposition from solution by co-precipitation with and adsorption on sesquioxides. The significance of the extremely close correlation between iron and lead in the illuvial B horizon of Profile 19 is further considered in Part VI (see also Fig. 31).

The size distribution of lead in laterite appears to be similar to that already described for colluvial loam. Metal is slightly enriched in the minus 200-mesh fraction of the few samples tested. The data in Table 1, however, indicate that appreciable concentrations of lead also occur in the nodules as well as in the fine matrix.

ii. Copper and Zinc.

Copper and zinc also follow lead in Profiles 18 - 21, although anomalous values are confined to the B horizon of Profile

20 (Table 40). In this profile, the copper contents of the soil, laterite and gossan horizons are 30, 150 and 800 ppm respectively, the corresponding values for zinc being 25, 100 and 220 ppm. The gossan sample contains more copper and zinc than any other rock sample collected in the Kasimba area.

Copper and zinc are enriched in the B horizon of the other profiles. The low zinc values in laterite samples from these pits undoubtedly reflect the scarcity of this element in the primary

TABLE 40. Distribution of copper and zinc within colluvial soil profiles, Kasimba lowlands.

Pit Nos. and Bedrock Types:	18 - 19 - 21 Phyllite and Gneiss		20 Gossan	
	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)
<u>Loamy Soil (A)</u>				
Range	25 - 70	5 - 25	25 - 50	15 - 25
Mean	50	15	30	25
<u>Laterite (B)</u>				
Range	25 - 150	5 - 70	125 - 200	75 - 120
Mean	90	50	150	100
<u>Weathered Bedrock</u>				
Range		15 - 50		
Mean	70	30	800	220

mineralisation at Kasimba. The Kasimba deposit may also have a low, primary copper content. A further contributory factor, however, could be the effective leaching of copper from the oxidised zone of

the deposit before the initiation of the present weathering cycle.

(b) Lateral Dispersion in Colluvial Soil and Laterite.

i. North and South of the Ridge, Traverse 0.

The width of the lead anomaly in near-surface soil at a depth of 12 - 24 ins. on Traverse 0 is 2300 ft. (Fig. 25). The anomaly peak of 650 ppm, which is very clearly defined, is situated in residual soil over the sub-outcropping shear zone on the southern slopes of the ridge. Values decline abruptly to the north and south of the ridge, however, and no sample of lowland colluvium contains more than 170 ppm Pb.

This extensive dispersion of lead in A horizon soil reflects the long period of time during which mineralised ground on the ridge has been gradually eroded. Both mechanical mixing of residual and colluvial material and the leaching of metal are probably responsible for the absence of any well-defined peak values over the gossan in Pit 20. As a result of these processes, the lead content of the near-surface soil at this and other lowland sites no longer bears any direct relationship to that of the sub-outcropping rocks.

Any conclusions concerning the dispersion of lead in the laterite are rather tentative, for the following reasons. In the first place, samples were collected at the wide interval of 300 - 600 ft. Secondly, the threshold value of 100 ppm for laterite is based on the analysis of a comparatively small number of samples (Table 31).

The width of the laterite anomaly between Pits 18 and 21

is 2200 ft. Samples taken from different levels in the B horizon of these profiles contain from 20 to 1000 ppm Pb, the contrast between peak and threshold values being 10-fold (Table 39). The anomaly peak is located at Sites 19 and 20, where the average metal content of the laterite samples is 700 and 650 ppm respectively. To the north of Pit 18, the lead content of the B horizon decreases from 120 ppm to background (20 ppm) over a distance of 300 ft. The laterite terminates to the south of Pit 21, where its average metal content is 110 ppm Pb (see also Fig. 19). It is not known, however, whether the anomaly persists to the point where laterite grades into pallid sand or whether values fade to background in the B horizon itself only a short distance from this pit.

The very similar widths of the A and B horizon anomalies suggest that much of the lead in the laterite has been derived from the overlying colluvium. The possibility cannot be overlooked, however, that some metal has been deposited in the laterite from laterally-moving groundwaters. If this assertion is correct, the principal source of the lead would also be the mineralisation on the ridge.

A further possibility is that small quantities of lead have been derived from additional bedrock sources underlying the soil to the south of the ridge. As can be seen from the cross-section in Fig. 25, B.H. No. 59 intersects the shear zone at a

depth of 700 ft. from the surface near Pit 19, the intervening ground apparently consisting of barren granite-gneiss and meta-dolerite. No cores from this or other bore-holes were available at the time of the writer's visit, so it cannot be affirmed whether these rocks carry small, primary concentrations of lead not detectable by conventional methods of chemical analysis. The slightly anomalous values (100 ppm) in the weathered gneiss at the base of Pit 19 could, therefore, have a primary or secondary origin. Nevertheless, data from B.H. No. 45b show that disseminated galena and chalcopyrite occur outside the main shear zone (Fig. 25). The gossan in Pit 20 may be another example of oxidised mineralisation of this type and, therefore, a further source of the lead and copper present in the overlying laterite.

Further information concerning the sub-surface geology and the distribution of lead in other lowland profiles is required before the origin of lead in the laterite can be determined in full detail.

ii. West and East of the Ridge, Traverses 14, 19 and B.

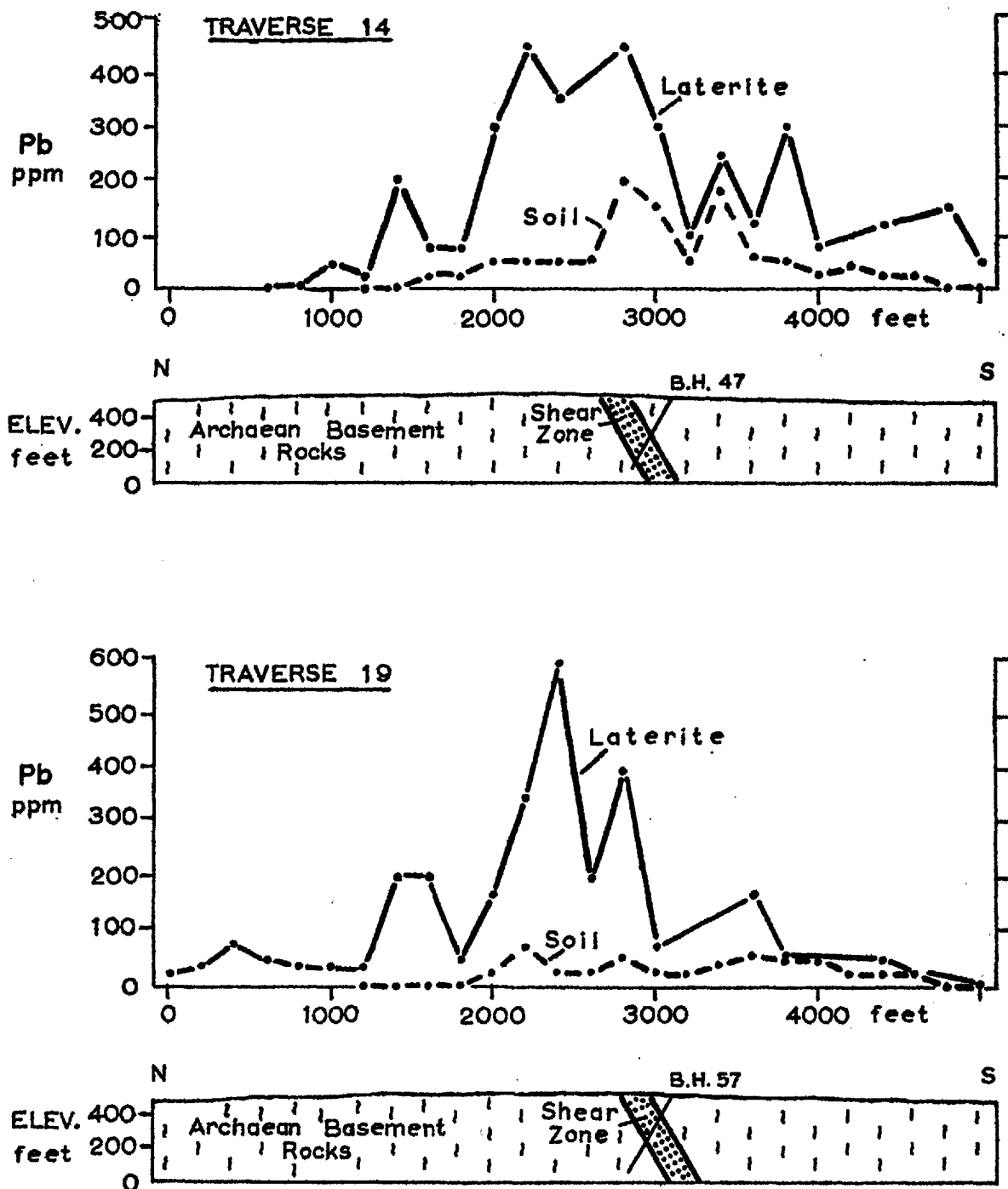
Samples of laterite were taken by auger at 200 ft. intervals on three lowland traverses, in order to determine whether the lead anomaly is more clearly defined in the B horizon than is the case in the A horizon. Traverses 14 and 19 are situated at distances of 300 ft. and 1800 ft. respectively, from the western end of the ridge, while Traverse B is situated 300 ft. or so from its eastern extremity (Fig. 20). Most of the samples ^{were} collected at a depth of 48 - 60 ins., although some had to be taken from shallower depths where exceptionally hard laterite was encountered. At a

small number of sites, no laterite was found, even at 6 ft., the maximum depth penetrated by the auger.

The lead content of the laterite samples from Traverses 14 and 19 ranges from 10 - 450 ppm and 10 - 600 ppm respectively (see Fig. 26). The data corroborate those from Traverse 0, in two respects. Firstly, lead is enriched in laterite, samples of which contain five times the amount of metal present in the overlying colluvium. Secondly, there appears to be little difference in the widths of the A and B horizon anomalies. These extend to the north and south for distances of 3200 ft. and 3600 ft. respectively on Traverse 14, the corresponding distances on Traverse 19 being 2600 ft. and 2200 ft.

The peak of the laterite anomaly on Traverses 14 and 19 occurs either directly over, or slightly to the north of, the projected sub-outcrop of the shear zone (see cross-section in Fig. 26). Core logs from B.H. Nos. 47 and 57, which were drilled near these traverses before the writer's visit, refer to sporadic disseminations of galena and chalcopyrite in the sheared rocks.

Much of the lead in the laterite has undoubtedly been derived from the overlying A horizon, by chemical and/or mechanical processes. It is also possible that a proportion of the lead has been deposited in the B horizon from ground-water solutions. In this event, possible sources of metal could include the mineralisation on the ridge and/or the mineralisation in surface rocks immediately beneath these traverses. This latter source is quite feasible, since laterite samples from Traverse B to the east of the ridge,



SOIL SAMPLES TAKEN AT A DEPTH OF 18 - 24 ins.
 LATERITE SAMPLES COLLECTED BY AUGER, MOSTLY FROM
 A DEPTH OF 48 - 60 ins.

Fig. 26. DISTRIBUTION OF LEAD IN SAMPLES OF COLLUVIAL SOIL AND LATERITE, TRAVERSES 14 AND 19, KASIMBA AREA.

where the shear zone may either peter out or else be un-mineralised, have a background lead content. This very unusual tendency for lead to migrate in solution, even for short distances, is further considered in Part VI. However, it must be stressed that, in the absence of deep pits to bedrock on Traverses 14 and 19, no definite conclusions can be drawn from these data.

4. Extent of the Anomaly in Near-surface Soil at Simbo.

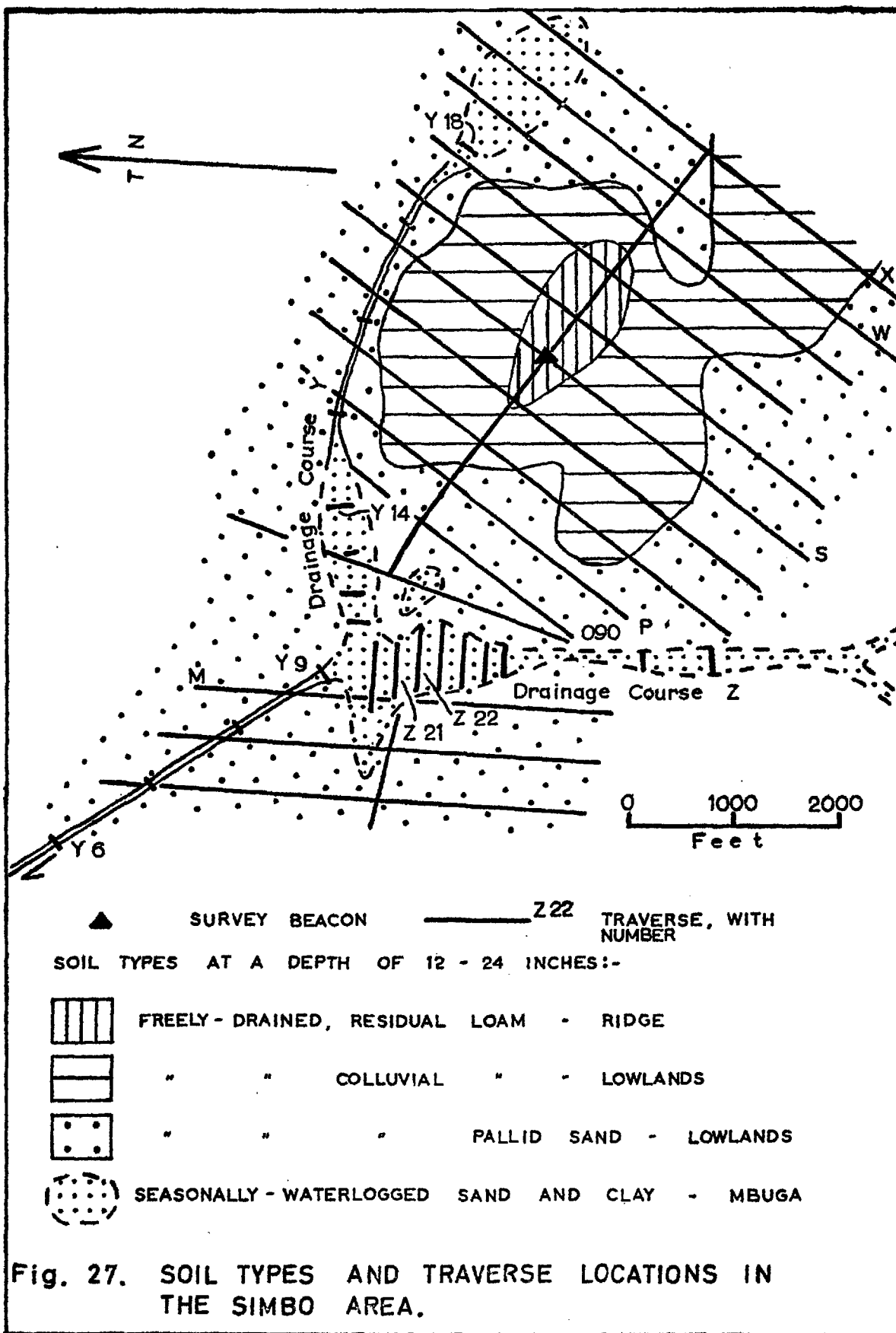
(a) Sample Depth, Sample Interval and Traverse Interval.

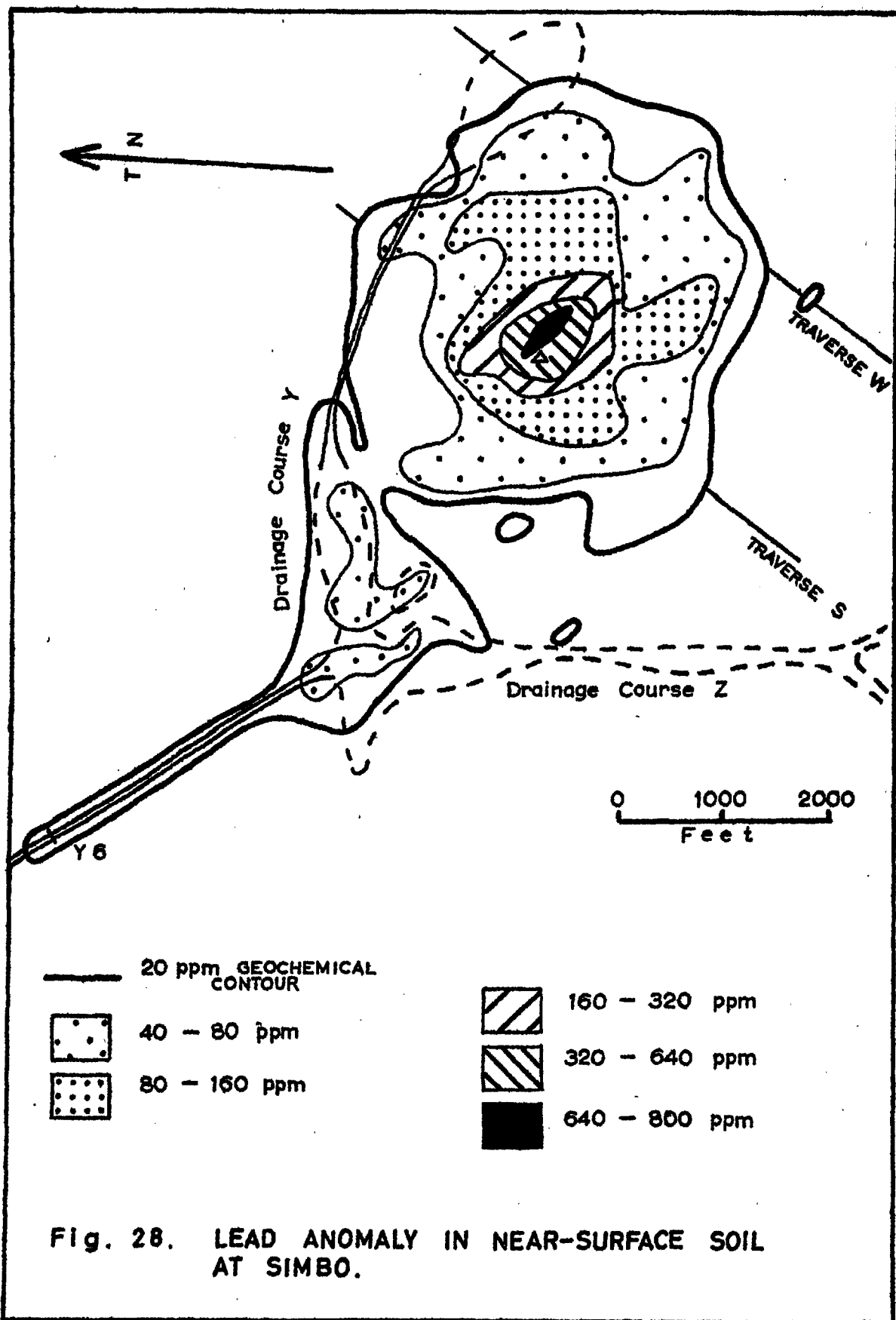
Soil samples were taken at a depth of 12 - 24 ins. from 14 traverses in the Simbo area. Each traverse was oriented in a direction normal to the strike of the shear zone on the ridge, the distance between traverses being 500 ft. The sample interval varied from 100 ft. on the ridge to 200 ft. in the surrounding lowlands. The soil types in the Simbo area and the traverse locations are shown in Fig. 27.

(b) Analytical Results.

The near-surface soil anomaly at Simbo has a width of 4000 ft. and extends for a distance of 9000 ft. along the strike of the shear zone on the ridge (Fig. 28). It is, therefore, more extensive than the Kasimba anomaly, although the 40-fold contrast between peak and threshold values is lower. Nevertheless, there appears to be a distinct resemblance between the dispersion patterns for lead in both areas. In the first place, residual soils on Simbo Ridge carry up to 800 ppm Pb, whereas no sample

Fig. 27





of colluvial soil from the lowlands was found to contain more than 220 ppm Pb. Secondly, the clay loam contains more lead than the pallid sand, whose metal content does not exceed 80 ppm Pb (Fig. 27).

The Kasimba anomaly fades to background between the ridge and the mbuga (Fig. 23). At Simbo, however, anomalous values persist all the way to the mbugas situated further to the NE and W of the ridge. The distribution of lead in the mbugas is considered in the next section.

ii. Copper and Zinc.

The copper contents of samples from Traverses S and W vary from $< 10 - 200$ ppm, the peak values occurring in samples of residuum collected over basic rocks. The corresponding range for zinc is $< 10 - 50$ ppm, this latter value being below the threshold level of 70 ppm. These data further emphasize the extremely limited significance of copper and zinc as indicators of bedrock mineralisation in the Kasimba-Simbo area.

c). DRAINAGE SYSTEM

The scope of this study is severely limited by the waterlogged state of the ground near the drainage courses during the rainy season. It was rarely possible to examine the soil in the mbugas below a depth of 12 ins. Moreover, no streams drain the central parts of the Simbo soil anomaly. The only drainage courses in the area (Y and Z) are situated on the extreme northern and western fringes of the soil anomaly (Fig. 28).

The sediments and bank soils in incised stream channels were sampled in the conventional manner. Where the drainage courses were ill-defined, surface soil samples (0 - 12 ins.) were collected at 10 - 50 ft. intervals across the lowest point of the mbuga.

Every sample was analysed for total lead, but no time was available to test the samples for cold-extractable metal. The advantages of using a supplementary, cold-extraction technique for one of the more soluble, "pathfinder" elements also present in the ore has already been demonstrated at Bawdwin. Such techniques are not feasible at Simbo, however, for the following reasons.

In the first place, the mineralisation contains virtually no zinc, so the cold-extractable zinc test is of no use in this area. Secondly, an attempt was made to determine the cold "heavy metal" content of a small number of mbuga soil and stream sediment samples by the procedure given in Appendix C 4 (p. 250). The results are very unsatisfactory, however, since background samples appear to contain just as much cold-extractable "heavy metal" as those from the Simbo area. The correlation between total copper and cold-extractable "heavy metal" in the samples studied is very close. The spuriously high "heavy metal" values in background soil and sediment may, therefore, be due to the high concentration of copper in un-mineralised basic rocks that are believed to sub-outcrop near many of the Mpanda drainage courses.

1. Mbuga Soil and Stream Sediment in Background Areas.

(a) Mbuga Soil Profiles.

Four soil samples taken between the surface and a depth of 54 inches in Pit 13, which is situated in a mbuga to the west of Kasimba, have an identical lead content of 5 ppm (Table 28). Similar trends were also observed in other seasonally-waterlogged soil profiles.

(b). Lateral Variation in the Metal Content.

Data obtained from the analysis of 110 soil samples taken from a depth of 0 - 12 ins. in background mbugas show that the lead content of both clay and sand samples is of the same order of magnitude and that wet samples from the lowest parts of the mbuga contain no more lead than those from marginal sites (Table 41). Also, there appears to be virtually no difference in the lead content of stream sediment and bank soil samples from incised drainage channels in un-mineralised areas.

TABLE 41. Lead content of stream sediment, bank soil and mbuga soil samples from background drainage courses at Mpanda (samples collected during the rainy season).

	Lead content (ppm)		
	Stream Sediment	Bank Soil *	Mbuga Soil (0-12 ins.)
No. of Samples	16	18	110
Range of Values	5 - 10	5 - 10	5 - 25
Median Value	10	10	5

* Samples taken from the top of the bank to bedrock or water level.

The backgrounds of 5 ppm for lead in mbuga soil and 10 ppm in stream sediment are in close agreement with those established for freely-drained soils in the Mpanda area. The threshold for both mbuga soils and stream sediments is arbitrarily estimated at 20 ppm Pb.

2. Mbuga Soil and Stream Sediment in the Simbo Area.

(a) Seasonal Variation in the Metal Content.

Data from a pit on Traverse Z 22, as well as those from other traverses, show that there is no significant variation in the total lead content of mbuga soil and stream sediment samples which were replicated at monthly intervals during the rainy season (Table 4). Results obtained from the analysis of drainage samples for total lead are, therefore, considered to be strictly comparable, even though the samples were collected at different periods.

(b) Mbuga Soil Profiles.

Lead appears to be evenly distributed throughout the top-most 36 ins. of the one profile studied in Mbuga Y, since sample values only range from 40 to 50 ppm. In the absence of pits to bed-rock, the source of the metal in the near-surface horizon of this and other profiles cannot be stated.

There appears to be no difference in the lead content of dark, organic-rich, surface soil and more pallid, sandy soil at a depth of 3 or 6 - 12 ins. in Mbugas Y and Z (Fig. 29).

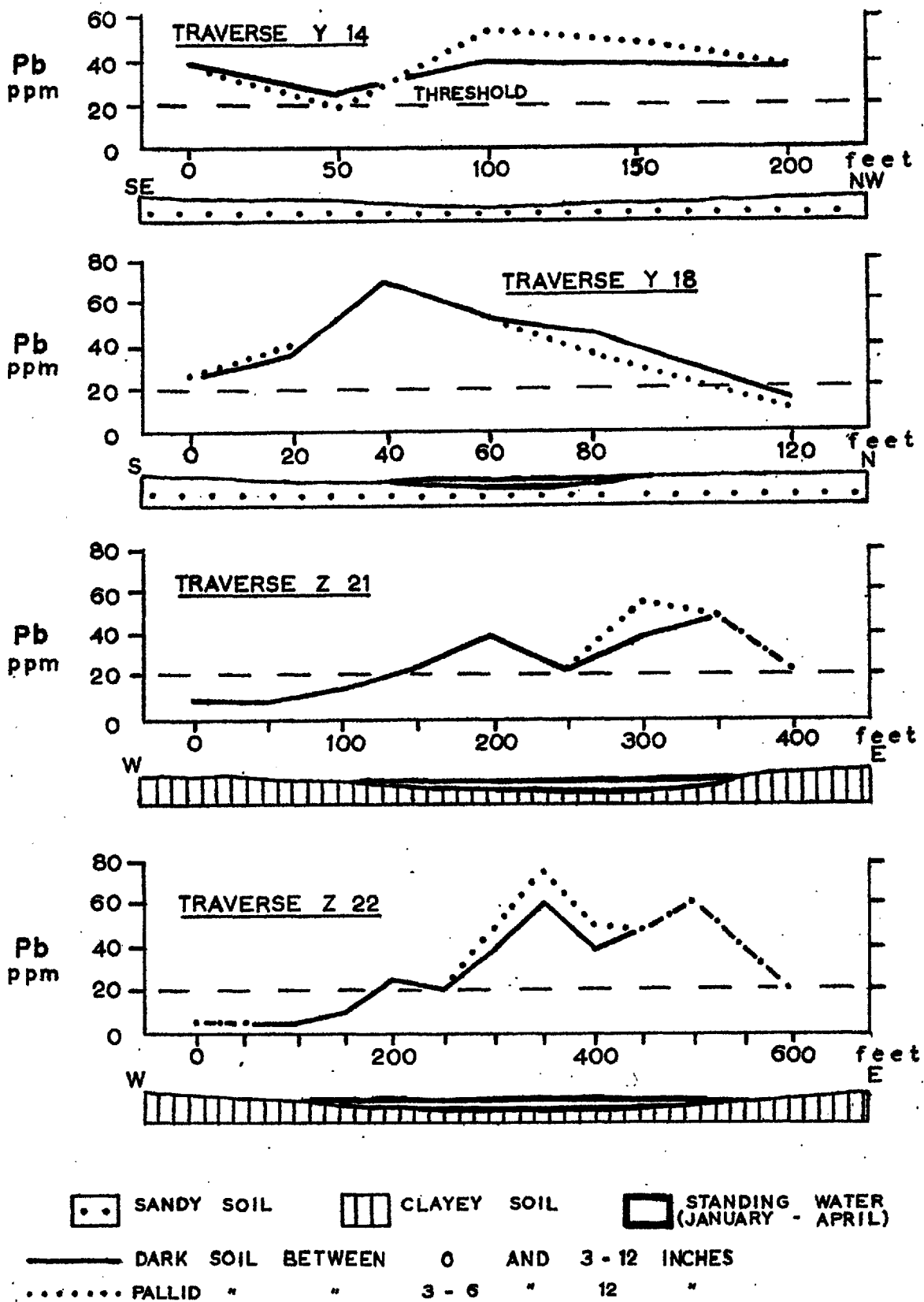


Fig. 29. DISTRIBUTION OF LEAD IN SURFACE SOIL, MBUGAS 'Y' AND 'Z', SIMBO AREA.

(c) Lateral Dispersion in Drainage Courses Y and Z.

The positions of the traverses and sampling points along Drainage Courses Y and Z are shown in Fig. 27; the traverse interval varied from 200 to 1000 ft. and the sample interval from 10 to 50 ft.

Judging from the data in Fig. 29, soil samples taken from the lowest part of the mbuga on Traverses Y 14, Y 18, Z 21 and Z 22 have a slightly higher lead content than those from marginal sites. This tendency is most pronounced on Traverse Y 18, where values increase from 15 and 25 ppm on the edge of the mbuga to 70 ppm in the centre. It is impossible to interpret correctly these and other data from the Simbo mbugas, however, since nothing is known of the distribution of metal in sub-surface soil. The anomalous concentrations of lead in near-surface soil probably represent material that has been mechanically eroded from higher ground during the long period of weathering. It is also possible that small amounts of metal, leached from mineralisation further upslope, have been deposited in the organic-rich mbuga soil.

The length of the dispersion train in the sediment and waterlogged soil in Drainage Course Y is 10,000 ft. (Fig. 30). The lead content of the sediment samples ranges from 20 ppm to 75 ppm, the corresponding values for the mbuga soil samples being 20 - 100 ppm. There appears to be virtually no difference in the metal content of dark or light coloured samples and clayey or sandy samples. The close agreement in the lead content of duplicate samples of stream sediment collected at each site reflects the equally close

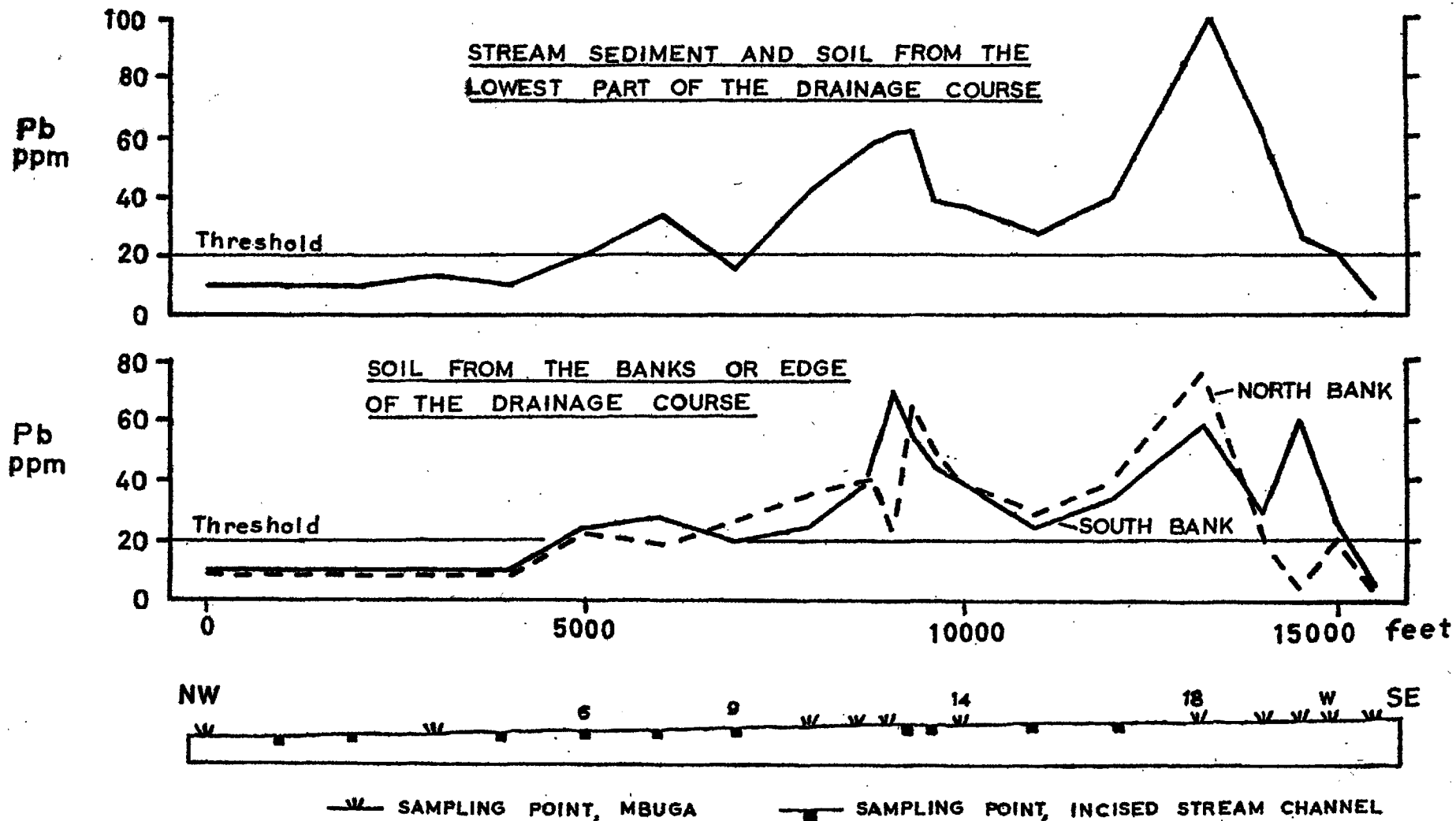


Fig. 30. DISTRIBUTION OF LEAD IN STREAM SEDIMENT AND MBUGA SOIL, DRAINAGE COURSE 'Y', SIMBO AREA.

agreement between the metal content of both stream banks. The dispersion of lead in bank soil is just as extensive as that in stream sediment and the anomaly in both media fades to background downstream from Site Y 6. The stream sediment anomaly is considered to result mainly from the erosion of the margins of the Simbo soil anomaly, as defined by the 20 ppm geochemical contour in Fig. 28.

Anomalous values appear in Drainage Course Z as it passes onto anomalous soil (Fig. 28). These continue downstream for a distance of 1200 ft. to the confluence with Drainage Course Y, whose head waters lie entirely within the same soil anomaly.

PART VI.

FACTORS CONTROLLING THE DISTRIBUTION OF METAL IN ROCKS, SOIL
AND STREAM SEDIMENT AT BAWDWIN AND MPANDA.

a). PRIMARY DISPERSION IN WALLROCKS.

Judging from previous work, the primary dispersion of traces of metal from orebodies depends on the composition and state of the mineralising solutions and on the permeability and chemically reactive nature of the wallrocks. It is accepted that the ores at Bawdwin and Mpanda were deposited from hydrothermal solutions, probably at relatively low temperatures. The composition of the mineralising solutions in the two areas, however, appears to have been rather different. The ratio of Pb : Cu: Zn in the primary ore in the Meingtha Lode is about 8: 1: 4, whereas in the disseminated mineralisation Kasimba and Simbo the ratio is about 7: 1: tr.

According to La Touche and Coggin Brown (1909), Loveman (1917) and Coggin Brown (1918), the principal factors controlling the emplacement of the Bawdwin ores were the existence of favourable structures for the mineralising solutions and the presence of replaceable, feldspathic rocks in the shear zone. These factors undoubtedly governed the dispersion of trace elements in the wallrocks enclosing the deposits. In addition, the effects of more chemically reactive, calcareous rocks on the dispersion of metal in the Sterne River area must also be taken into consideration.

The widespread primary dispersion of lead in the surface rocks on Meingtha Hill and Mt. Teddy reflects their fissured nature. The variable degree of rock fracturing in these areas may be responsible for both large and small-scale irregularities in the dispersion pattern. On the one hand, lead values tend to reach a

peak in soil derived from the weathering of rocks near the Hsenwi Fault and the two smaller N-S faults further to the west (Figs. 33 and 34). On the smaller scale, lead is most erratically distributed in quartzite and tuff penetrated by B.H. Nos. 1 and 4 over a distance of only 150 ft. (Figs. 14 and 15). The appreciable fluctuation in the lead content of five replicate samples of weathered tuff from Pit 29 on Mt. Teddy represents an extreme case of local spottiness (Table 4).

There is little doubt that lead was able to penetrate for considerable distances in fissured rocks away from the main site of metallisation. In relatively dense rocks, however, lead appears to have diffused for distances of only 5 - 30 ft. (p. 104 and 106).

The high lead values detected in feldspathic tuff and quartz-porphyry in the Meingtha - Mt. Teddy area are not surprising, since La Touche and Coggin Brown (1909) and others consider the mineralising solutions to have always attacked feldspar in preference to quartz. As previously mentioned, the degree of micro-fissuring is assumed to be the main cause of the equally high values detected in some samples of sandstone. Another possibility, however, is that pre-mineralisation hydrothermal activity rendered the sandstone and quartzite more favourable to replacement by mineralising solutions, although no field data are available to substantiate this assumption. Detailed studies are necessary to assess the possible effects of hydrothermal rock alteration on the distribution of lead in wall-rocks at Bawdwin. In this connection it is interesting to note that in Utah, Almond and Morris (1951) believe argillising solutions

to have caused a transfer of lead from the zone of intense hydrothermal rock alteration to the zone of less intense alteration further away from the orebody.

The lower metal content and exceedingly restricted dispersion of lead in calcareous rocks in the E.R. Valley and Sterne River areas is due, in part, to rapid neutralisation of percolating, acid (?) solutions in the calcareous environment and, in part, to the denser nature of the rocks.

At Mpanda, the main factor governing the deposition of copper and lead was the existence of zones of intense shearing in the crystalline rocks. These shear zones are believed to have served as channel-ways for the mineralising solutions (Poussin and McConnell, 1950). In fact, no deposits are known to occur outside the various E-W and N-S shear zones in the area. The extreme, local variations in the lead content of weathered dolerite and granite-gneiss on Kasimba Ridge are most probably related to the variable degree of rock fracturing (Table 5 and Fig. 21). The tendency for lead to occur in rather **higher** concentrations in granite-gneiss as compared to meta-dolerite may partly be due to the greater ease with which the feldspathic gneiss was replaced by the mineralising solutions.

As would be expected, copper occurs in markedly higher concentrations in basic rocks as compared to acid rocks in both mineralised and un-mineralised areas. It is not known, however, to what extent the deposition of copper from hydrothermal solutions may have added to the high, normal background content of the

meta - dolerite on Kasimba Ridge.

b). SECONDARY DISPERSION IN SOIL AND STREAM SEDIMENT.

The secondary dispersion of copper, lead and zinc and their mobility in the superficial environment are governed by a number of inter-related physical, chemical and biological factors (Hawkes, 1957). Of these factors, the dynamic and solvent properties of water are by far the most important in bringing about the mechanical and chemical dispersion of traces of metal from oxidising mineralisation.

Both study areas have an appreciable rainfall, although the mean annual precipitation of 50 ins. at Bawdwin exceeds that at Mpanda by some 13 ins. The essential difference between the two areas, however, is the very contrasting topography and the much longer period of time for which the Mpanda deposits have been weathered (pp. 44, 122 and 186).

1. Mechanical Dispersion.

The principal mechanical dispersing agents at Bawdwin and Mpanda are gravity and water. The important effects of these factors on the dispersion of metal are considered below. Other dispersing agents, whose significance is strictly local, include wind and grass fires.

The work of Carney (1959) and others shows that wind plays an important part in spreading metal contamination (p. 26). This is also the case at Bawdwin, where the lateral extent of contamination

has undoubtedly been increased by aeolian transport of metalliferous fumes and ashes. Even so, the contamination is apparently confined to the topmost few inches of the profile and is localised to within 250 ft. of the source. At Bawdwin, the burning of grass may tend to concentrate lead in the first few inches of the profile. During these fires the more volatile hydrocarbons are burnt off, leaving behind a metal-rich, ashy residue (p. 61). Part of the ash is subsequently incorporated in the soil, thereby adding to its metal content.

(a) Movement of Material in the Soil.

The asymmetrical dispersion pattern of lead on the 30° slopes of Traverse A 12 indicates a considerable lateral movement down the side of Meingtha Hill, to the east of Faults A and B (pp. 97-102). Over a bedrock source the metal content of the soil increases with depth. Further downslope, however, values decrease with depth as a result of soil creep. The relationship between metal distribution in soil profiles and topography is illustrated by the idealised diagram, which is shown in Fig. 30A and which is reproduced from Huff (1952).

The precise distances to which anomalous soil is being moved down the side of Meingtha Hill by soil creep, landslips and sheet wash cannot be determined owing to the appreciable width of the bedrock anomaly. However, the data discussed in Appendix A indicate that the lateral displacement of anomalous soil on the 35° slopes of the Mt. Teddy Traverse Q 2 extends for a distance of 300 ft. and

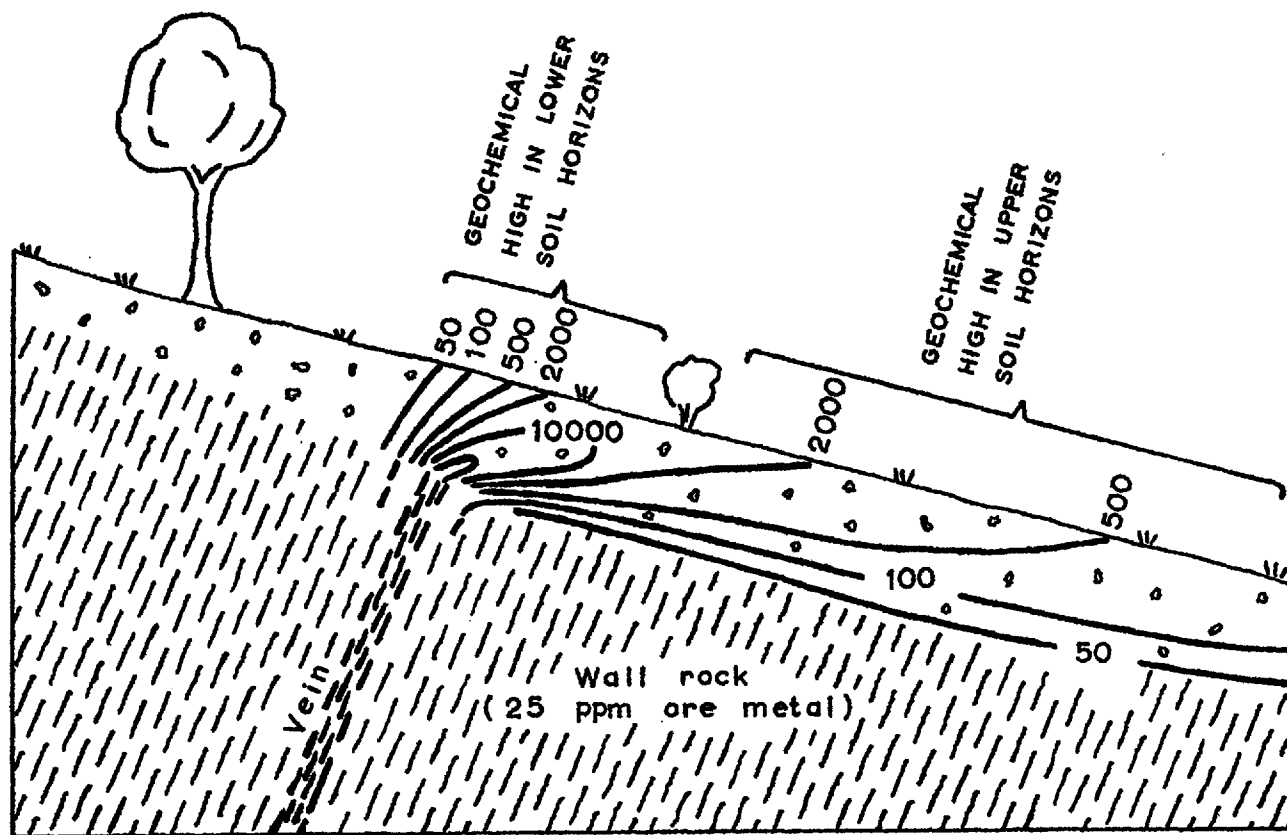


Fig.30a. MECHANICAL DISPERSION HALO IN RESIDUAL SOIL.
after Sergeev (1941) and Huff (1952)

CROSS SECTION OF HYPOTHETICAL COPPER, LEAD OR ZINC VEIN AND ITS GEOCHEMICAL ANOMALY PRODUCED BY MECHANICAL DISPERSION IN RESIDUAL SOIL. CONCENTRATION BOUNDARIES OF VEIN METAL GIVEN IN ppm.

more (Fig. 35).

At Mpanda, the actual rate at which soil is being eroded is much slower than is the case in the mountainous terrain near the Bawdwin Mine. Nevertheless, the land surface is much more senile and the lateral movement of metal by mechanical processes has been very considerable. The lead anomaly in near-surface soil extends for several thousand feet downslope from the mineralisation on Kasimba and Simbo Ridges (Figs. 23, 25 and 28).

It has already been shown that there is no tendency towards the gravity-controlled surface "enrichment" of lead in soil profiles downslope from mineralisation on Kasimba Ridge (Fig. 21 and Table 39). Leaching of metal from the surface soil and/or elutriation of fine soil particles to deeper levels in the profile during the long period of weathering may be responsible for this trend.

(b) Mechanical Dispersion in the Drainage.

The very close agreement between the mean lead contents of surface soil on the slopes and unsorted sediment in Gully A2 - A3 illustrates the extent to which soil is being eroded off the sides of Meingtha Hill and funnelled down the gullies (Fig. 17 and p. 116). There appears to be a rather different state of affairs, however, in the perennial Stream RQ on Mt. Teddy. Here lead appears to be enriched in wet sediment and alluvium with respect to the soil on the sides of Spurs R and Q (p. 119). In the absence of data to the contrary, this is presumed to be due to the enrichment of lead-rich particles in the sediment by selective eluviation in the stream

environment and not to the deposition of metal from solution.

The full extent of the dispersion of metal in Gully A2-A3 and Streams NQ and RQ could not be determined owing to the possibility of contamination further downstream. It was, therefore, impossible to study the dilution effect of bank collapse on the distribution of lead in dry gully and wet stream sediments outside the limits of the Meingtha - Mt. Teddy soil anomaly.

In the Simbo area, the erosion of barren bank soil may reduce anomalous values rapidly to background, downstream from the soil anomaly. The data presented in Fig. 30, however, are rather tentative and should be substantiated by more detailed sampling.

2. Chemical Dispersion.

Chemical dispersion is undoubtedly responsible for the mobility of copper and zinc at Bawdwin (p. 102 and 114). The soil on Meingtha Hill contains 14 times ^x more lead than zinc, whereas the ratio of Pb : Zn in the primary ore is about 2 : 1 (p. 49). Moreover, the ratio of Pb : Zn in groundwater in the Chinaman Lode is about 1 : 27. These data suggest that little lead has been leached from the soil and surface rocks during weathering. Some solution of lead, however, has been effected by the metabolic activity of plants. Moreover, chemical processes contribute to

^x This figure is based on the analysis of 163 soil samples taken over, or in the vicinity of, the Meingtha Lode on Traverses A 12 and A 26.

the spreading of contamination from former smelters.

Turning to the Mpanda area, chemical dispersion also accounts for the mobility of copper during the long period of weathering. Judging from previous work, which is discussed in this section, lead is generally considered to be a relatively immobile element. Nevertheless, there are grounds for believing that chemical dispersion of lead has taken place at Mpanda, even though on a relatively small scale (see also Poussin and McConnell, 1950). Firstly, the ratio of Pb : Cu in galena-chalcopyrite mineralisation at Kasimba and Simbo is about 7 : 1 ^X, whereas the corresponding figure for near-surface soil is approximately 4 : 1. Secondly, it is difficult to explain the marked enrichment of lead in the illuvial B horizon downslope from mineralisation unless one assumes that lead has been leached as well as elutriated from the overlying A horizon (pp. 157-9). The lower extractability of lead in the B as compared to the A horizon of Profile 19 may be due to the different form in which metal occurs in the laterite owing to its precipitation from solution (p. 159). Furthermore, it is also possible that anomalous lead values in the B horizon of non-residual soil on lowland Traverses 14 and 19 are reflecting mineralisation in the underlying rocks (p. 164). If this assumption is correct, there can be little doubt that lead has migrated upwards in solution before being deposited in the laterite.

^X Based on data from borehole core logs and the analysis of 26 soil samples taken on Kasimba and Simbo Ridges. The ratio of Pb : Cu in the ~~Mukwamba~~ deposit is 10 : 1 (p. 126).

The leaching of various trace elements from oxidising mineralisation largely depends on the environmental pH and Eh and on the solubility of salts (Garrels, 1954; Hawkes, 1957). Once in solution, the mobility of a chemical element is governed by a number of factors. Apart from changes in the environmental pH and Eh, these include co-precipitation, sorption on finely-divided organic and inorganic materials, the formation of stable complexes, the metabolic activity of plants and micro-organisms and the precipitation or aggregation of colloidal suspensions by electrolytes. Although by no means complete, some data on factors controlling the mobility of metal were obtained at Bawdwin and Mpanda. These data are discussed below.

(a). Hydrogen-ion Concentration.

i. Lead.

Few data have been published by agricultural scientists regarding the factors affecting the mobility of lead in the soil, presumably because of the very limited agricultural significance of this trace element. There are, moreover, conflicting opinions concerning the relationship between soil pH and the availability of lead to plants. According to Scheltinga (1955), the pH is of more than theoretical significance in that the availability of lead only very slightly decreases with increasing alkalinity. Shawarbi (1952) refers to the higher solubility of lead in very acid soils, which can be decreased by the addition of lime or organic matter (Bear, 1948). By contrast, David et al (1955) consider lead to be more available to plants at a high pH (8.0) since they believe that this element

occurs in some Australian soils as the carbonate or basic carbonate. They were unable to substantiate their contention, however, by solubilising lead in a saturated solution of carbon dioxide.

According to Britton (1942), Pb^{2+} is precipitated from dilute solutions of simple salts at a pH of 6.0. It must be emphasized, however, that this value for the pH of hydrolysis is based solely on laboratory experiments and may be very different in nature (see Hawkes, 1957). At Bawdwin, the pH of soil samples, which varies from 4.4 to 5.2, lies below the value of 6.0. The relatively low pH may, therefore, be largely responsible for any leaching of lead that has taken place in the soil in this area. The acid conditions obtaining in the sub-soil would also favour the extraction of metal by deep-rooted vegetation (pp. 197-199).

The observed soil pH at Mpanda ranges from 5.8 - 7.0, which straddles the pH of hydrolysis for Pb^{2+} of 6.0. As previously mentioned, the significance of this latter value is purely theoretical. Nevertheless, it is possible that changes in the environmental pH on either side of 6.0 may have played some part in the leaching of lead from mineralisation and its subsequent precipitation in the B horizon at other sites.

Judging from the data in Table 42, there appears to be a degree of positive correlation between soil pH and the extractability of lead in Profiles 23 and 28, which are located on Kasimba and Simbo Ridges respectively. In Profile 23 both the pH and the ratio of cold-extractable to total lead decrease with depth, whereas the pH

TABLE 42. Relationship between pH and the extractability of lead in 5% nitric acid in Mpanda Profiles 23 and 28. Profiles 23 and 28 are described in Tables 25 and 24.

Sample No. and Type	Depth (ins.)	pH	Total Pb (ppm)	Gx Pb (ppm)	Gx:Total Pb (%)
<u>Profile 23, Kasimba Ridge</u>					
1215 Organic-rich top-soil	0 - 4	7.0	1100	500	45
1216 Lateritic sub-soil	4 - 12	6.3	1000	400	40
1217 " "	12 - 36	6.1	900	300	33
1218 " "	36 - 60	6.0	1000	300	30
<u>Profile 28, Simbo Ridge</u>					
1047 Organic-rich topsoil	0 - 5	6.1	250	100	40
1049 Lateritic sub-soil	17 - 36	5.9	400	140	35
1051 " "	48 - 58	6.0	450	180	40

and proportion of cold-extractable metal remain essentially constant in Profile 28. It does not necessarily follow, however, that the extractability of lead in these samples is solely conditioned by the pH. Thus, the organic carbon content in this profile decreases with depth (see Table 25 and Fig. 32). Metal extractability could also depend on other factors which were not studied, such as the clay content.

ii. Copper and Zinc.

The pH of hydrolysis for Cu^{2+} , which is 5.3 (Britton, 1942), lies above the observed pH range of soils at Bawdwin but lies below the corresponding range at Mpanda. The theoretical significance of this

value, however, is illustrated by the work of Lucas (1948) and Peach (1941). The former author notes that copper tends to be precipitated in soils having a pH of more than 4.7, while the latter author found that small quantities of copper are still present in solution in soils possessing a pH of 6.0 (see also Hawkes, 1957). Nevertheless, it is probably safe to assume that, although metal is being leached in the vicinity of oxidising sulphides in both areas, copper is more mobile in the soil at Bawdwin than is the case at Mpanda.

According to Thorne et al (1942), Knowles (1945), Aldrich and Tyrell (1951), Scharrer and Hofner (1958) and other agricultural scientists, zinc is also readily leached from acid soils. Laboratory experiments performed by Britten (1942) indicate that the pH of hydrolysis for Zn^{2+} is 7.0.

This relatively high value lies well above the pH of the Bawdwin soil samples. There is, accordingly, little doubt that the low environmental pH in this area is largely responsible for the high mobility of zinc. Widespread leaching of metal due to acid conditions would account for the very low zinc content of soil and surface rocks on Meingtha Hill over a high grade deposit in depth (p. 92 and Table 21). Similarly acid conditions obtain in the soil near former smelters on Gurkha Hill, where no soil sample was found to contain more than 300 ppm Zn despite the fact that the slag in this area may carry up to 17% Zn.

Nothing is known of the pH of sediment or water samples from Streams NQ and RQ in the Mt. Teddy area at Bawdwin, so the possible

relationship between pH and the zinc content cannot be stated. Judging from previous work by Kennedy (1956), Theobald et al (1958) and other geologists in North America, the pH to some extent controls the partition of zinc between sediment and water in streams draining mineralised ground.

(b) Solubility

i. Lead

Judging from previous work, which has been mentioned on p. 24 and p. 27, lead appears to be a considerably less mobile element than copper and zinc (see also Garrels, 1954). Cases are known, however, of the movement of lead in a soluble form, even if on a very limited scale (p. 196).

For example, data quoted by Konstantinov (1954) show that ground-waters draining some polymetallic deposits in the Altai and Caucasus Mountains contain up to 9 ppm Pb and more. Near one deposit, the lead content of groundwater progressively decreases from 75 to 0.4 ppm over a distance of 3 kilometres, whereas the pH increases from 3.48 to 7.48. He considers these and other data to indicate that lead is by no means a totally insoluble element. He also discusses the possible forms in which lead can migrate in solution. Apart from the bicarbonate form, which is also mentioned by Rankama and Sahama (1950), these include the chloride, plumbojarosite ($\text{PbO} + \text{Fe}_2\text{O}_3 + \text{SO}_4$), bisulphide and organic forms. Konstantinov's views, however, are refuted by Betekhtin (1954), who stresses that lead moves as finely-divided, colloidal suspensions rather than in true solution.

The immobility of lead at Bawdwin probably stems from two causes. The first is related to the known stability of galena with respect to chalcopyrite and sphalerite (Garrels, 1954; Hawkes, 1957). Secondly, anglesite and cerussite, which are the principal secondary lead minerals in oxidised ore in underground workings, possess considerably lower solubilities than the sulphates and carbonates of copper (Table 43). Much of the lead in the surface rocks and derived soils over mineralisation may possibly be present as the carbonate and/or the sulphate, although these minerals could not be visually recognised ^x.

The water-soluble lead content of 11 strongly anomalous soil and weathered bedrock samples from Pits 11 and 29, which was determined by the procedure described in Appendix D 5, is of the order 0.5 - 1.5 ppm (Table 18 and p. 99-100). This value appears to be very similar to the figure of 0.78 - 2.3 ppm Pb calculated from the solubility data for cerussite given in Table 43.

It would be unwise, however, to conclude from the foregoing considerations that no lead whatsoever is being leached from the soil and surface rocks over mineralisation at Bawdwin. In point of fact, Loveman (1917) found that a groundwater sample collected 400 ft. from the surface in the Chinaman Lode contains as much as 30 ppm Pb. The enrichment of lead in the topmost 12 ins. of the weathered bedrock horizon in some Meingtha pits may also represent metal precipitated in sandstone and tuff from normal soil moisture.

The chemical dispersion of lead in contaminated areas at ^x Ginzberg and Mukanov (1956) performed experiments which showed that much of the lead in some Kazakhstan soils occurs in magnetic, ferruginous minerals and also as iron-stained cerussite, which was detected by micro-chemical methods.

TABLE 43. Solubility of some copper, lead and zinc minerals and compounds in water at a pH of 7. After Emmons (1917), Smirnov (1954), Wedepohl (1956), Hawkes (1957) and Lukashev (1958).

Mineral or Compound	Solubility at 18 - 37.5°C (mg./litre)
$Pb_5 Cl (PO_4)_3$ - pyromorphite	0.03
$Pb (OH)_2$	0.50
$Pb CO_3$ - cerussite	1.0 - 3.0
$2 CuCO_3 \cdot Cu (OH)_2$ - azurite	7.0
$CuCO_3 \cdot Cu (OH)_2$ - malachite	12.0
$Pb SO_4$ - anglesite	27.0 - 42.1
$Zn CO_3$ - smithsonite	49.0 - 107.0
$Pb Cl_2$	$10^3 \times 9.7 - 10^3 \times 17.9$
$Cu SO_4$	$10^3 \times 172.0$
$Zn SO_4$	$10^3 \times 340.0 - 10^3 \times 531.2$

Bawdwin represents a very specialised case, leaching being due to the water-soluble nature of the lead compounds present in the slag (p. 68).

In the Mpanda area, Poussin and McConnell (1950) refer to the heavy leaching of copper and lead from many outcrops, which they consider to be due to the fact that the near-surface part of the deposit has been weathered for two distinct periods of time. The first is believed to have occurred during the pre-Bukoban era and the second, since at least Miocene times, if not earlier. These authors contend that chlorine was introduced as a new element in the surface

reactions after the end of the first oxidation period. If this assumption is correct, the formation of soluble chlorides would undoubtedly increase the mobility of lead (Table 43). It is interesting to note that Taylor (1958) also attributes the mobility of lead at Broken Hill in Northern Rhodesia to a former period when arid conditions obtained in the area.

When the climate at Mpanda became more humid, chlorides would have tended to give way to other less soluble forms. Even if the solubility of lead was relatively low, the time available was considerable and is probably by far the most important factor explaining the apparent mobility of lead in the Kasimba - Simbo area.

ii. Copper and Zinc.

The instability of sphalerite and the high solubility of the sulphate are, like pH, major factors contributing to the mobility of zinc at Bawdwin (Table 43). Loveman (1917) detected 800 ppm Zn and 2600 ppm SO_4 in groundwater in the Chinaman Lode ^X. These data provide an example of the very considerable quantities of zinc and sulphate that are being transported in solution in the vicinity of oxidising mineralisation. Anomalous concentrations of 0.02 - 0.35 ppm "heavy metal" in the water in Streams NQ and RQ on Mt. Teddy may be due to the leaching of zinc from possible, disseminated (?) mineralisation in the area drained by the streams. These values, however, refer to ionic zinc and should not be compared to Loveman's

^X Loveman found no detectable quantities of zinc or sulphate in groundwater 6500 ft. from the Chinaman orebody (p. 51).

figure for total zinc from the Chinaman Lode, the highest grade zinc deposit known at Bawdwin (p. 120).

Loveman reports no detectable quantities of copper in the one groundwater sample examined. This could reflect the very low copper content of the zone of oxidation in the orebody. According to Clegg (1940), the grade of the Chinaman deposit as a whole is only 0.4% Cu as compared to 16.1% Zn and 25% Pb. Nothing is known of the copper content of groundwater and stream water in other parts of the Bawdwin area. Nevertheless, chalcopyrite is less stable than galena, and copper sulphate is considerably more soluble than anglesite (Table 43). Moreover, previous work, which is discussed on pp. 21-22, indicates that a considerable movement of copper can take place in a soluble form in environments possessing a pH comparable to that on Meingtha Hill.

At Mpanda, the low copper content of soils and surface rocks is most probably the result of effective leaching to a considerable depth over a long period of time.

(c) Adsorption on and Co-precipitation with Hydrous Iron Oxides

i. Lead

According to Toth (1955) and other agricultural scientists, the true nature of the adsorption mechanism is imperfectly understood. This phenomenon is believed to result from (a) attractive forces between sorbate and sorbent ions, (b) the existence of residual valencies on the surface of the sorbent, (c) chemical reactions between the sorbate and sorbent and (d) the electrical conductance of the sorbent.

So far as lead and the sesquioxides of iron are concerned, laboratory experiments performed by Rozhkova and Shcherbak (1956) show that considerable quantities of lead are sorbed on both synthetic ferric hydroxide and on brown iron ore. Goldschmidt (1937, 1954) and Wedepohl (1956) refer to the concentration of lead in certain soil horizons, which they believe to be partly due to the adsorption of lead on hydrous iron oxides. The latter author notes that some ferruginous bauxites in France contain ten times more lead than those in which iron is impoverished.

Co-precipitation is another mechanism whereby trace elements are removed from solution (Hawkes, 1957). Whether this is due to the simple occlusion of trace elements in the precipitating sesquioxides, or to the substitution of cations for Fe^{3+} in lattice positions, is another matter. Whereas the occlusion of traces of lead is readily conceivable, co-precipitation by substitution is faced with two problems. The first is to what extent were the hydrous iron oxides at Bawdwin and Mpanda precipitated in crystalline form or as amorphous compounds that subsequently acquired a crystalline structure. Secondly, the radius of Pb^{2+} is $1.24 - 1.29\text{\AA}$; this is too large to permit Pb^{2+} to substitute for Fe^{3+} , which has a radius of only $0.64\text{\AA}$ (Green, 1959). The Pb^{4+} ion has a smaller radius of $0.84\text{\AA}$. However, the existence of this ion under the present-day environmental conditions in both study areas is rather unlikely. (p. 200).

The distribution of iron in Profile 11 at Bawdwin closely resembles that of lead, both elements being enriched in the sub-soil as compared to the topsoil and weathered bedrock horizons (Tables 6 and 18). A similar pattern of metal distribution was observed in Profile 29 on Mt. Teddy. This relationship between lead and iron, which appears to be nearly linear, could be due to two rather different weathering processes (Fig. 31). On the one hand, solute Pb^{2+} ions derived from oxidising galena in the initial stages of weathering, may have been adsorbed on and/or co-precipitated with ferruginous sesquioxides. On the other hand, iron and lead could have become progressively enriched during pedogenesis at the expense of more soluble constituents like zinc and silica. In view of the relatively immobile nature of lead at Bawdwin, the latter alternative is considered to be the more likely, although it is, of course, conceivable that small amounts of metal are held in hydrous iron oxides.

It is possible that lead has been deposited from solution in the laterite horizon downslope from mineralisation at Mpanda (p.179). Despite the erratic distribution of lead and iron in the B horizon of Profile 19, the data in Fig. 31 show that an almost linear relationship exists between these elements (Tables 26 and 39). This could well result from the adsorption of lead on pre-existing sesquioxides and also from the co-precipitation of lead with iron during the formation of the laterite. More data are required, however, to substantiate such an assumption. In the first place, the correlation is based on only six samples collected from the B horizon of one

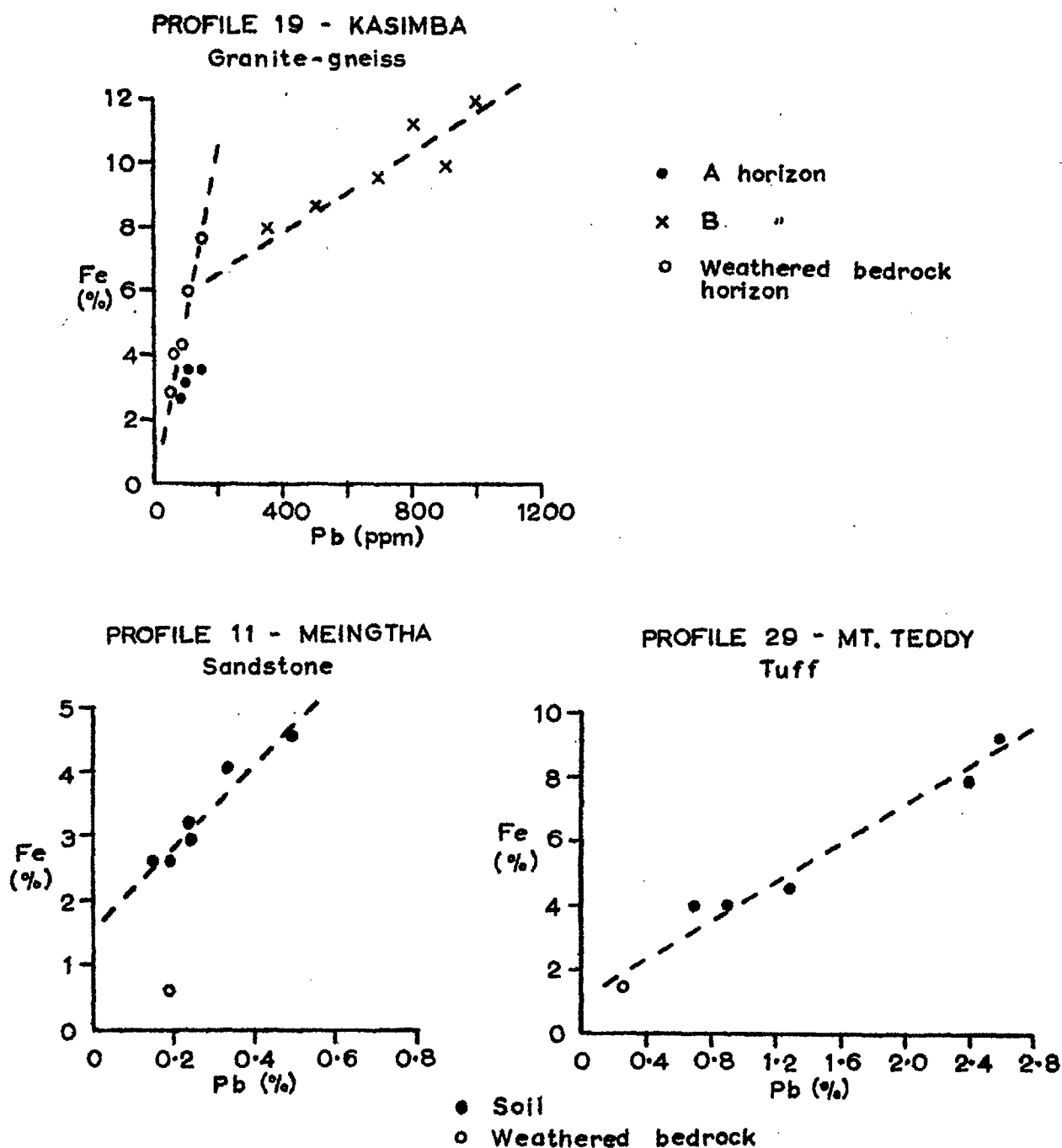


Fig. 31. CORRELATION BETWEEN IRON AND LEAD IN SOIL PROFILES AT BAWDWIN AND MPANDA.

lowland profile. Secondly, other factors which were not studied, such as changes in the environmental Eh and adsorption on manganese sesquioxides, could also contribute to the fixation of lead in the laterite.

There also appears to be a correlation between lead and iron in the A and weathered bedrock horizons of Profile 19 (Fig. 31). However, the extractability data from this profile suggests that lead may occur in a different form in the B as compared to the A and weathered bedrock horizons. The sympathetic relationship between lead and iron in loam soil and decomposed gneiss may, therefore, be largely coincidental. Moreover, there is no correlation between these elements in Profile 23 on Kasimba Ridge, since iron tends to increase with depth whereas lead remains constant in this direction (Tables 25 and 42).

Another method of approach is needed to establish the forms in which lead occurs in the inorganic fractions of loam soil and in weathered bedrocks at Bawdwin and Mpanda. In this connection, Ginzberg and Mukanov (1956) used (a) heavy liquids, (b) an electromagnetic separator and (c) micro-chemical procedures in order to determine the forms in which copper, lead and zinc occur in some Kazakhstan soils (see footnote, p. 185).

ii. Copper and Zinc.

Copper also follows iron in the two Bawdwin Profiles 11 and 29 and is slightly enriched in the B horizon of soil downslope from mineralisation at Mpanda. J. S. Tooms and J. S. Webb have noted

the association of copper with ferruginous laterite horizons in Rhodesian latosols. Jacobson (1956) considers that finely-divided iron and manganese sesquioxides in comparable soils in Uganda have sorbed and hence fixed much of the copper dispersed from bedrock mineralisation. At least 50% of the copper in anomalous, eroded soil from the same area is apparently held in hydrous iron oxides (J. S. Webb and R. E. Stanton, pers. comm.).

Judging from the very low zinc content at all levels in the profile on Meingtha Hill, the leaching of zinc owing to the low pH is of much greater significance than the adsorption of metal on sesquioxides. There appears to be no correlation between iron and zinc in Profiles 11 and 29. This does not necessarily imply, however, that no zinc is held by hydrous iron oxides in the soil at Bawdwin. On the contrary, previous work by Ginzberg and Mukanov (1956), White (1957) and others, indicates that much of the zinc (30 - 60%) in the inorganic fraction of soil is fixed by iron oxides.

The deposition of zinc in stream sediment on Mt. Teddy could be partly due to adsorption on and co-precipitation with hydrous iron oxides. The amount of metal removed from solution by these mechanisms, however, cannot be predicted. The work of Theobald (1958)^{et al} provides an example of the co-precipitation of zinc with iron and manganese in the drainage system. They found that freshly-precipitated iron and manganese hydroxides on the bed of a Colorado creek carry very considerable concentrations of zinc and other metals. The writer

noticed a similar phenomenon in the E.R. Valley at Bawdwin, just below the point where part of the mine drainage enters the stream. In this locality, samples of freshly-precipitated, orange-coloured ferric hydroxide were found to contain $> 1\%$ Pb and $> 0.5\%$ Zn.

It is considered that, like lead, the secondary dispersion of copper and zinc in both study areas, is controlled in part by co-precipitation with and/or adsorption on ferruginous sesquioxides.

(d) Effects of Organic Matter

i. Lead

The tendency for organic matter to restrict the dispersion of lead in the soil at Bawdwin is illustrated by the fact that contamination is largely confined to the surface horizons of the profile downslope from former smelters and also by the pronounced surface enrichment of metal in background soil. The surface enrichment of lead in contaminated areas could be partly due to the adsorption of solute lead ions on humus, which possesses a very high base exchange capacity. A further factor contributing to the immobilisation of lead in surface soil throughout the Bawdwin area may be the formation of relatively insoluble organo-metal compounds.

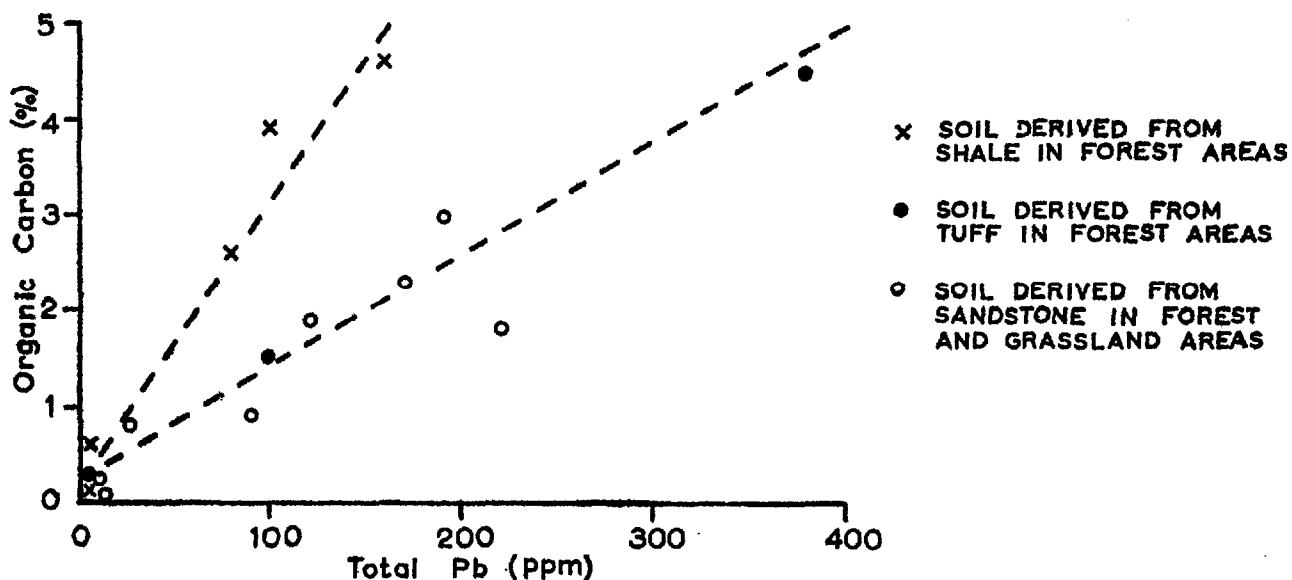
According to Goldschmidt (1937, 1950), Hawkes (1957) and Vinogradov (1957), lead and other trace elements added to surface soil from decaying vegetation may form organo-metal complexes with humus. These complexes may consist of salts of organic acids and/or chelation compounds, although their true nature is imperfectly understood (Krauskopf, 1955). Judging from the work of Hasler

(quoted by Beckwith, 1955) and data cited by Konstantinov (1954) and Vinogradov (1957), lead is more strongly bonded by organic soils than most other divalent metals. This firm bonding undoubtedly contributes to the retention and even enrichment of lead in many surface soils.

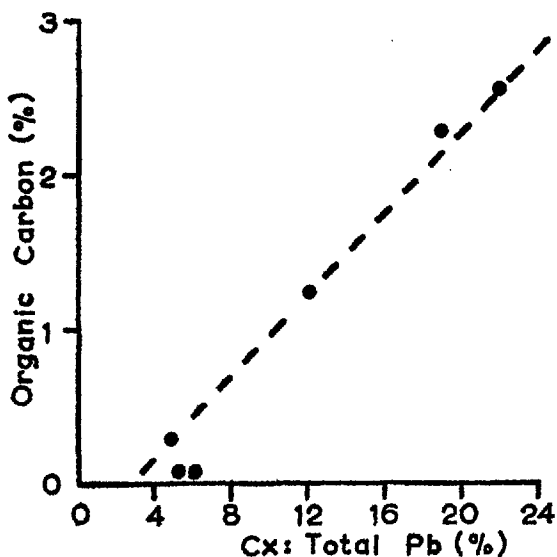
According to Singakova (1945), however, the greater part of the lead is associated with the sandy-clayey mass of some Russian soils. Butler (1954) considers accumulations of insoluble lead sulphide to be responsible for enrichment of lead in the surface horizon of some freely-drained Lancashire soils. Webb (1958) refers to the erratic tendency of lead towards enrichment in some British and North American soils. He believes that this behaviour of lead is partly controlled by the ^{nature of the} vegetation and the resulting, organic decomposition products.

The correlation between total lead and organic carbon in background soil in forested and grassland localities at Bawdwin is very close (Fig. 32). The nature of the bedrock appears to have some effect on the relationship between lead and organic carbon, since the plotted values observed in samples taken over shale do not fall on the line joining those for samples taken over sandstone and tuff. Nevertheless, a correlation between lead and organic carbon exists in every profile that was studied, which suggests that organo-lead compounds may be present in surface soil in un-mineralised parts of the area (Tables 9 and 10).

PROFILES 34-37. LOI MI AND PANGSAN



PROFILE 11 - MEINGTHA
Grassland



PROFILE 23 - KASIMBA
Woodland

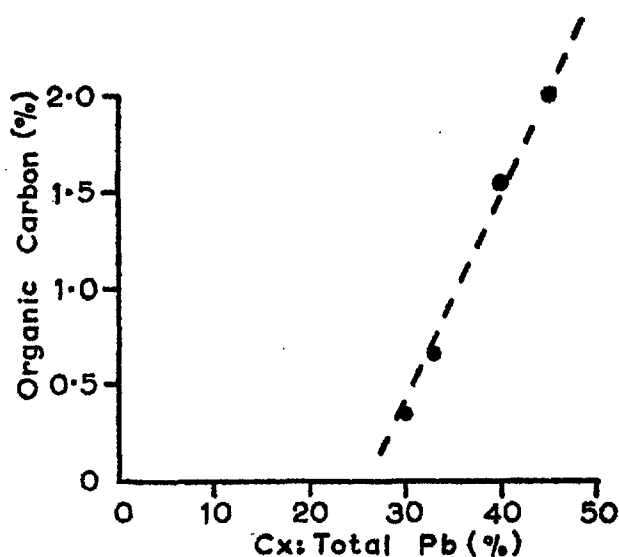


Fig. 32. CORRELATION BETWEEN ORGANIC CARBON, TOTAL LEAD AND THE RATIO OF COLD-EXTRACTABLE TO TOTAL LEAD IN SOIL PROFILES AT BAWDWIN AND MPANDA.

There is no reason why similar compounds should not occur in surface soil over mineralisation, since the vegetation is comparable to that in the Loi-Mi area. The linear relationship between organic carbon and the ratio of Cx : Total Pb in Profile 11 appears to confirm this assertion (Fig. 32). The data in Tables 16 and 45 also indicate that lead is associated with organic compounds in surface soil in other parts of the Meingtha-Mt. Teddy area. The higher extractability of lead in the topsoil with respect to the more inorganic sub-soil could be due to the more unstable nature of organo-lead complexes in 5% nitric acid.

There appears to be an antipathetic relationship between total lead and organic carbon in background soil at Mpanda. Moreover, no correlation exists between the ratio of Cx: Total Pb in Profile 28, although there is a linear relationship between these quantities in Profile 23 (Fig. 32 and Table 42). Further research is necessary to show whether organo-lead complexes occur in surface soil over mineralisation at Mpanda and also to confirm the existence of these compounds in the soil at Bawdwin. In this connection, Erikson et al (1954) solubilised up to 12% Cu, 2% Pb and 0.5% Zn in some petroliferous rocks with benzene, which they consider to reflect the truly organic nature of such compounds.

In non-tropical environments organic matter also plays an important part in the solution of trace elements in the soil. According to Merhlich and Drake (1955), this is due to the fact that many organic anions form highly stable, complex ions with some metallic

cations by a process of chelation (see also Beckwith, 1955). The solution then behaves as though these cations were not present. Lovering (1934), Morris and Lovering (1952) and Konstantinov (1954) note the ability of natural organic acids and their alkali salts to dissolve lead from oxidising mineralisation. Under tropical conditions, however, Mohr and Van Baren (1954), Van Schuylenburg and Van Rummelen (1955) and other pedologists believe that soil solutions have a marked excess of CO_2 over organic acids. Nevertheless, it cannot be definitely assumed that organic acids have played absolutely no part in the leaching of copper and lead from mineralisation at Mpanda, where the vegetation is different from that at Bawdwin (p. 124). But it is quite feasible to assume that the leaching of copper, lead and zinc in both areas is partly conditioned by the solvent properties of meteoric water enriched in CO_2 .

The effects of organic matter on the dispersion of lead in the Simbo mbugas cannot be predicted, since nothing is known of the metal content or nature of the deeper soil horizons and underlying bedrocks. Judging from the afore-mentioned considerations and previous work by Salmi (1955), Cannon (1955) and Webb (1958), the organic-rich environment in these mbugas would tend to restrict the mobility of lead (pp. 27-28).

ii. Copper and Zinc.

As previously mentioned, the leaching of copper and zinc from both organic-rich and relatively inorganic soils at Bawdwin is

most probably due to the solubility of these metals in the pH range 4.4 - 5.2. No data are available to show whether the formation of soluble organo-metal complexes also contributes to the mobility of copper and zinc.

The adsorption of zinc on organic matter in the sediment in Streams NQ and RQ may be one of the factors responsible for the deposition of metal from stream water solutions. De Grys (1959) observed correlations between organic carbon and zinc in the sediments of some Manx streams, although her work indicates that the adsorption of zinc by organic matter is no more than one of the factors controlling dispersion of zinc in the drainage.

(e) Metabolic Activity of Vegetation.

i. Lead.

Previous research, notably by Goldschmidt (1937, 1950) shows that many trace elements are absorbed by vegetation, these being subsequently returned to the soil by leaf-fall or on the decay of the plant (see also Hawkes, 1957). Repetition of this process over a long period of time leads to the progressive enrichment of lead and other trace elements commonly observed in some forest and woodland soils. According to Carlisle and Cleveland (1958), who discuss the work of a number of other authors, the uptake of trace elements by plants in this manner depends on factors related to the plant and on the physical and chemical properties of the soil and soil solutions, particularly the pH and the nature of the clay minerals.

Despite the fact that lead does not appear to be necessary

to plant nutrition, the data of Scharrer (1944), Webb and Millman (1951), Lounamaa (1956) and others indicate that many types of plants extract this metal from both tropical and non-tropical soils. Moreover, high concentrations of up to 3000 ppm Pb in coal ash are believed to be partly due to the absorption of lead by plants during the formation of the seam (Goldschmidt, 1950; Wedepohl, 1956).

The following criteria attest to the metabolism of lead by plants throughout the Bawdwin area. In the first place, the few vegetation samples that were collected from background areas contain from 500 to 2000 ppm Pb in the ash (p. 61). Secondly, lead is markedly enriched in the surface horizons of all background profiles (p. 61 and 64). The surface enrichment of lead downslope from the bedrock source of the Meingtha soil anomaly is mainly due to the effect of gravity creep rather than to the metabolic activity of vegetation. However, the proportion of cold, acid-soluble lead appears to decrease with depth in every profile that was studied on Meingtha Hill (Tables 16, 18 and 45). These data are considered to reflect the association between lead and organic matter in the soil arising from the movement of metal in the vegetation cycle.

The vegetation near the mine now consists almost entirely of grass and other shallow-rooted plants, which cannot have played any part in the extraction of lead from the deeper horizons of the sub-soil. The absorption of metal from the sub-soil by deep-rooted plants presumably took place prior to the de-forestation of the area by the Chinese. It is reasonable to assume that oaks, which flourish in

the primary forests further away from the mine, once covered the entire Bawdwin area (p. 45). Hibbard (1940 -b), Harbaugh (1950) and Carlisle and Cleveland (1958) note the capacity of oak for assimilating lead and zinc from some North American soils. The acid soil reaction and the existence of oaks and other favourable species are, therefore, considered to have provided the necessary conditions for the movement of lead in the vegetation cycle near the mine.

No vegetation samples from the Mpanda woodlands were tested for lead, so it cannot be stated whether lead is being extracted from the soil by plants. Judging from the absence of surface enrichment in background areas and the tendency for the ratio of Cx : Total Pb to decrease only slightly with depth in anomalous profiles, vegetation appears to have little effect on the distribution of lead in the soil (Tables 29 and 36).

ii. Copper and Zinc.

In contrast to lead, copper and zinc are considered to be beneficial to plants in reasonably small concentrations. Nothing is known of the distribution of copper and zinc in vegetation at Bawdwin and Mpanda. The absence of surface enrichment in the former area does not necessarily signify that these metals were not dispersed through the agency of vegetation, as any copper and zinc added to the soil by decaying plant material could well have been leached (Tables 8 and 11).

(f) Other Factors.

The effects of other factors, such as (a) adsorption on the sesquioxides of manganese and clay minerals, (b) changes in the

environmental Eh, (c) the formation of soluble inorganic complexes, (d) metabolism by micro-organisms and (e) colloidal dispersion can only be assessed by further research. Judging from previous work in other areas, which is discussed below, these factors may have some bearing on the secondary dispersion of copper, lead and zinc at Bawdwin and Mpanda.

The sesquioxides of manganese are probably present in the soil in both study areas, where the environmental conditions would favour the formation of kaolinite rather than of montmorillonite during the weathering of primary silicate minerals. According to Ljunggren (1955), some Swedish bog ores of manganese contain more copper, lead, zinc and other trace elements than those of iron. In this connection, he notes that freshly-precipitated manganese dioxide is a stronger adsorbent for certain ions as compared to ferric hydroxide. Rozhkova and Shcherbak (1956) and Rozhkova and Serebriyakov (1958), found from laboratory experiments that considerably more lead is sorbed on phosphorite, montmorillonite and lignite than on kaolinite. They attribute this to the limited chemical affinity of lead for kaolinite and to the relatively small surface area of this mineral, which is noted for its rather low base-exchange capacity.

There is some doubt as to whether any forms of lead apart from Pb^{2+} exist under conditions similar to those at present obtaining in the Bawdwin and Mpanda areas. According to Goldschmidt (1954) and Krauskopf (1955), Pb^{4+} only occurs in hot arid climates where the pH and Eh tend to be abnormally high. These conditions may

also be necessary for the formation of plumbates, which Oertell and Prescott (1944) consider to be the form in which lead occurs in some ironstone gravels in Southern and Western Australia. Wedepohl (1956), however, believes that lead may be present in some lateritic soils and ferruginous bauxites as Pb^{4+} adsorbed on iron oxides and/or as plattnerite (PbO_2). Vinogradov (1957) gives the pH of hydrolysis for Pb^{4+} as 7.2, so the plumbic ion may be slightly more mobile than the plumbous ion, which hydrolyses at a pH of 6.0.

The association between base metal and both iron and organic matter has been mentioned on earlier pages. Mohr and Van Baren (1954) consider micro-organisms to be largely responsible for the decomposition of humus in tropical soils, while Hawkes (1957) refers to the role of micro-organisms in the precipitation of iron and manganese in soil and stream sediment. According to Cannon (1955), copper, lead and zinc are readily assimilated by algae growing in mine drainage water. She also alludes to the reducing action of bacteria in some New York peat bogs, which results in the precipitation of the sulphides of lead and zinc.

Much work has been published concerning the formation of complex ions and the precipitation or aggregation of colloids by electrolytes. These data are based, however, on laboratory experiments and very little is known about the possible significance of these factors on the natural dispersion of copper, lead and zinc (Garrels, 1954; Hawkes, 1957).

PART VII.

SUMMARY AND CONCLUSIONS.

This study is based on the analysis of 11,000 soil, stream sediment and rock samples which were collected from the Bawdwin and Mpanda areas. These areas are respectively situated in the Northern Shan States of Burma and the Western Province of Tanganyika. All samples were tested by rapid methods of dithizone analysis for lead, a smaller number being analysed for copper and zinc.

The analytical error for lead appears to be greatest at or below the 120 ppm concentration level (Tables 2 and 3). Data obtained from the analysis of replicate soil, rock and gully sediment samples indicate that lead is more heterogeneously distributed in weathered dolerite, weathered tuff and laterite than is the case in other materials (Tables 4 and 5).

I. BAWDWIN.

a). ENVIRONMENTAL CONDITIONS.

At Bawdwin the terrain is mountainous, with deeply incised gully and river drainage. The climate is sub-tropical, the yearly rainfall being about 50 ins. Grassland vegetation predominates near the mine, but primary forest covers the surrounding areas.

The geology consists of a faulted series of Cambro-Ordovician sandstones and tuffs (Fig. 2). Galena and sphalerite, tabular, replacement bodies occur in zones of intensely sheared tuff. The grade of the principal deposits is about 15% Pb, 9% Zn and 2% Cu. Weathering is generally intense at the surface, but the depth of oxidation tends to be rather variable.

The overburden consists of residual, loamy soil, whose thickness ranges from a few inches on steep slopes over tuff to 15 ft. or more on flat spurs over sandstone.

Considerable mining and smelting has taken place, ancient work by the Chinese dating back to the fifteenth century.

b). METAL DISPERSION PATTERNS.

1. Soils and Rocks.

(a) Background Areas.

Background values for lead, copper and zinc are summarised in Tables 8 - 11. Lead shows a marked tendency towards surface enrichment in un-mineralised grassland and forested areas, whereas copper and zinc are evenly distributed throughout all horizons of the profile. Soils derived from tuff and white sandstone contain more copper and lead than those developed on red sandstone.

Threshold values for lead and zinc in the sub-soil are 200 and 100 ppm respectively (Table 12). The corresponding value for copper is 50 ppm in soil over red sandstone and 200 ppm in soil over tuff and white sandstone.

(b) Contaminated Areas.

Contamination of the soil is one of the principal problems of applying geochemical methods in the Bawdwin area. The chief source of the contamination is the former smelters along the Sterne river and along the crests of ridges and spurs further to the west and south. Surface and buried slag is the most common relic

smelting material and carries from 20 - 48% Pb, of which 1 - 4% is soluble in water (Table 13).

In the immediate vicinity of former smelters, the whole profile is contaminated by lead, the maximum depth of overburden examined being 10 ft. (Tables 14 and 15). The depth of contamination rapidly diminishes on passing away from the source. Surface contamination extends downslope for distances of 100 to 250 ft. and more (Figs. 5 - 7). Lead tends to be very erratically distributed in contaminated soil and peak values rise to 10% Pb, although the metal content of the underlying rocks remains within the background range of 100 ppm Pb.

Contamination arising solely from slag scattered on the surface is confined to the topsoil horizons (Fig. 8).

More than 40% of the total lead in contaminated soil is usually extractable with cold 5% nitric acid (Table 16). The mean ratios of acid-soluble to total lead in sub-soil and topsoil samples are 60% and 53% respectively, as compared to 9% and 23% in non-contaminated but otherwise similar soil.

(c). Mineralised Areas.

Most of the soil samples from the Meingtha-Mt. Teddy area, which were taken on all ridge-crests and spurs at 50 ft. intervals and from a depth of 36 ins. to avoid local contamination, contain anomalous concentrations of lead (Figs. 9 and 34). The soil anomaly occupies an area of about 0.5 sq. mile and peak values rise to 7000 ppm Pb on Meingtha and to 2.6% on Mt. Teddy, the contrast

between peak and threshold values being 35-fold and 130-fold respectively.

Anomalous values in the soil on the eastern side of Meingtha Hill appear to be related to the known, blind Meingtha Lode and Sterne River deposits (Figs. 33 and 34). The metal dispersion patterns are treated separately, since the geology is rather different. The former orebody is covered by 200 ft. of relatively barren sandstone, whereas the tuffaceous host rocks actually sub-outcrop near the Sterne River (Figs. 11 and 16).

i. Meingtha Lode Area.

There appears to be little difference in the lead content of sub-soil samples taken at a depth of 36 ins. over both sandstone and tuff near the Meingtha Lode. Peak values apparently occur in sub-soil over two sub-surface faults which are situated from 200 to 500 ft. east of the orebody, rather than in sub-soil directly over the deposit itself (Figs. 10 and 11). A similar tendency was noted on the traverse studied in greatest detail (A 12), where the anomaly at other levels in the sub-soil and also in the weathered bedrock horizon shows two well-defined peaks. These are situated over, or in the vicinity of, Faults A and B (Fig. 12). No anomaly peak, however, is developed in the surface soil on this traverse.

Bedrock samples taken over a distance of 750 ft. between the ridge crest and the valley bottom have an anomalous lead content. The size of the bedrock source is undoubtedly one of the major factors contributing to the extensive dispersion of lead in the over-

lying soil. Another factor is active soil creep, which causes the anomaly to extend downslope, particularly in near-surface horizons. The pattern of lead distribution is further complicated by the variable tenor of the bedrock source (Tables 18 and 20).

The width of the copper anomaly in the sub-soil near the Meingtha Lode is comparable to that for lead, but peak values only rise to twice threshold (Fig. 11). The dispersion of zinc, however, is more limited. The anomaly peak, which exceeds threshold by a factor of 5, appears to be located directly over Fault B (Fig. 11). The dispersion patterns of copper and zinc in the soil appear to have been somewhat modified as a result of leaching (Table 21).

ii. Sterne River Area.

In the Sterne River area, which lies 3000 ft. S.E. of the Meingtha Lode, the tuffaceous rocks are mineralised in places (Fig. 13). Little is known of the structure or nature of these relatively minor deposits. They are believed to consist of tabular, replacement bodies of galena.

The analysis of core samples from boreholes drilled near two of the deposits shows widespread, anomalous lead values (Figs. 14 and 15). No clearly defined anomaly peak is developed in that section of one of the boreholes (No. 4), which passes 50 - 80 ft. above a body of massive galena. The erratic distribution of lead over much of the ground covered by the boreholes is almost certainly due to the deposition of traces of metal from hydrothermal solutions circulating through fissures in the wallrocks. Peak values rising above 10% Pb

are associated with zones carrying disseminated galena.

Weathered tuff samples from the spur traverse crossing the mineralised zone show a very erratic distribution of lead, although the metal content of the overlying soil tends to be more homogeneous (Traverse A 8, Fig. 16). The lead content of weathered tuff and sub-soil samples taken in the vicinity of the underlying deposit exceeds threshold by factors of 45 and 25 respectively. Copper also shows a tendency to reach a peak in the sub-soil over mineralisation, but the data for zinc are negative (Fig. 16).

iii. Interpretation of the Origin of the Anomalies in the Meingtha Area.

The Meingtha soil anomalies are not considered to be in any way due to contamination, for the following reasons:

- a) Values extend beneath the soil into the sub-outcropping sandstone and tuff, whereas weathered bedrocks underlying contaminated soil have a background lead content (cf. Tables 14 and 15).
- b) Lead tends to be more homogeneously distributed in soil over mineralisation than is the case near former smelters (Figs. 5 - 7, 11, 12 and 16).
- c) The average ratios of cold 5% nitric acid-soluble to total lead in sub-soil and topsoil samples from contaminated areas exceed those in similar samples from the Meingtha anomalies by factors of 10 and 3 respectively (Table 16).

Both soil anomalies are considered to result from the weathering of surface rocks, which carry traces of lead deposited from hydrothermal solutions. These concentrations probably represent

leakage dispersions from known mineralisation. Precise interpretation of the data, however, is hampered by the fact that very little is known of the sub-surface geology. Near the Meingtha Lode, the surface anomaly appears to coincide more closely with the vertical projection of two un-mineralised faults than with that of the blind ore-body which lies about 200 - 500 ft. further to the west. It is possible, however, that the mineralising solutions responsible for the ore may have been channelled laterally before leaking upwards to form the anomaly detected at the present-day surface. In the Sterne River area, the connection between the anomaly at the surface and the up-dip projection of the mineralised zone, 90 ft. below, is much clearer.

(b) Metal Dispersion Patterns in the Drainage System.

i. Dry Gullies.

There is a 4-fold contrast between peak lead values in dry gully sediment on Meingtha Hill and the threshold value of 400 ppm. The anomalous train, which extends for a distance of more than 1100 ft. down one gully, is considered to be due solely to the erosion of the soil anomaly since the mean lead contents of gully sediment and surface soil on adjoining slopes are identical (Fig. 17).

ii. Perennial Streams.

Because of intense contamination, it was not possible to study the natural dispersion of metal in the perennial streams draining known mineralisation on Meingtha.

Threshold values for stream sediment are 200 ppm Pb and

3 ppm cold-extractable Zn (Table 22). These data were obtained from streams draining un-mineralised shales in the Manpat area, some 10 miles from the mine. The water in these streams carried up to 2 $\mu\text{g/l}$. "combined heavy metal" $\times$. Sediments from two small streams draining possible mineralisation on Mt. Teddy contain up to 1% Pb and > 150 ppm cold-extractable zinc (Streams NQ and RQ, Table 23). The stream waters also contained from 25 to 350 $\mu\text{g/l}$ "heavy metal". The streams are eroding a soil anomaly on the adjoining slopes. The fact that the sediment contains more lead than the soil is considered to be due to the relative accumulation of metal in the alluvially-sorted sediment. The high zinc content, however, is probably the result of metal leached from mineralisation and deposited in the sediment after the groundwater solutions had joined the surface drainage.

II. MPANDA.

a). ENVIRONMENTAL CONDITIONS.

The Mpanda study area has a flat, peneplained surface with a few, isolated, low ridges. Large tracts of ground near the drainage courses are subject to seasonal waterlogging and are known as mbugas. The climate is sub-tropical with an annual rainfall of about 37 ins. Woodland vegetation prevails away from the grassy mbugas.

$\times$ Mainly zinc.

Granite-gneiss, meta-dolerite and amphibolite, of Pre-Cambrian age, are the predominant rock types (Fig. 18). Galena-chalcopyrite mineralisation occurs in E-W shearzones as fissure veins or replacement deposits at the Mukwamba Mine and as disseminations at Kasimba and Simbo. These latter areas lie 6 and 8½ miles respectively along strike from the Mukwamba deposit. Oxidation extends to a considerable depth and the near-surface part of the deposits are believed by Poussin and McConnell (1950) to have been extensively weathered during two distinct geological periods.

The thickness of the overburden ranges from a few inches over meta-dolerite on the ridges to 12 ft. and more in lowland areas. The soils vary from residual, lateritic loam on ridges to colluvial loam with an indurated B horizon, pallid sand and organic-rich mbuga soil in the lowlands. These soils are related to form a catenary succession which possibly results from profile development in situ coupled with lateral transport of slowly-eroding material during the long period of weathering.

b). METAL DISPERSION PATTERNS.

1. Rocks and Freely-drained Soils.

(a) Background Areas.

Background values for lead, copper and zinc are given in Tables 29 - 32. There is no tendency for these elements to be enriched in surface soil, but lead and, to a lesser extent, copper and zinc, are markedly concentrated in the B horizon of all lowland profiles

in un-mineralised areas. There appears to be no difference in the lead content of residual loam over acid and basic rocks, colluvial loam and pallid sand. Soils derived from basic rocks, however, contain considerably more copper than those overlying acid rocks.

The threshold value for lead in loam soil and weathered bedrock is 20 ppm, while in laterite the threshold is tentatively estimated at 100 ppm (Table 33). The corresponding values for copper in residual soil over acid and basic rocks are 100 ppm and 300 ppm, respectively; the laterite threshold in weathering profiles over acid rocks is intermediate at 150 ppm Cu. The threshold for zinc in all types of soil is 70 ppm.

(b) Mineralised Areas.

i. Kasimba Area.

The near-surface soil anomaly at Kasimba occupies an area of 0.3 sq. mile. Centred on the ridge, anomalous lead values extend out onto the lowlands on all sides (Figs. 20, 22 and 23). On the southern slopes of the ridge, the average lead contents of samples taken at depths of 0 - 6 ins., 12 - 24 ins. and within 12 ins. of weathered bedrock only vary between the relatively narrow limits of soil 550 - 700 ppm (Fig. 21). The peak values, which exceed threshold by a factor of 110, occur towards the base of slope. Despite being extremely irregular, bedrock values, which show a 300-fold contrast, are also greatest in this zone.

Coarse fractions of the soil contain more lead than the finer fractions (Table 35), but there is no marked tendency for metal to be enriched in any particular soil horizon (Fig. 21 and

Table 34). It was found, however, that maximum values were generally encountered in the underlying bedrocks, although at some sites the lead content decreased again on passing a few feet deeper into weathered granite-gneiss and meta-dolerite.

Salient features of the secondary dispersion pattern in the near-surface, colluvial soils of the lowlands are the marked decline in lead values on passing away from the ridge and the relative enrichment of lead in clay loam as compared to pallid sand (Figs. 22 and 23). The latter trend is most probably due to the closer proximity of the loam soil to the anomaly source, i.e. the ridge, although elutriation of fine, metalliferous particles from the pallid sand may be a contributory factor.

Lead is enriched in the B horizon of lowland soil profiles situated to the north and south of the shear zone. At one point, however, sub-outcropping gossan was encountered, which appears to contain somewhat more metal than the overlying laterite and considerably more metal than the loam soil in the near-surface A horizon, (Table 39).

The tendency for lead to be slightly enriched in the finest fraction of colluvial loam and laterite is opposite to that found in residual, ridge soil (Tables 1 and 38).

To the north and south of the ridge, the B horizon anomaly extends for approximately the same distance as the A horizon anomaly, the contrast between peak and threshold values being 10-fold (Fig.

25). Much of the metal in the laterite has probably been derived from the overlying loam soil. The possibility arises, however, that some lead has been deposited in the B horizon from laterally-moving groundwaters, which leached metal from mineralisation on the ridge. The geology beneath the lowland soils is very incompletely known and it is also conceivable that additional sources occur in the rocks to the south of the shear zone.

Data from two lowland traverses crossing the strike extension of the shear zone to the west of Kasimba Ridge indicate that the A and B horizon anomalies have a comparable width, but that lead values are higher in the latter (Fig. 26). To the east of the ridge, the shear zone may peter out under the lowlands since a traverse of laterite samples showed only background metal contents.

Comparison of the results obtained east and west of the ridge suggests that the laterite anomalies to the west could be reflecting mineralisation in the sub-outcropping, sheared rocks (Fig. 26). It is possible, of course, that the concentrations of metal in the B horizon may have been derived from the same source as those in the A horizon, i.e. the ridge further upslope. In this case, however, one would have also expected a similar pattern of metal dispersion both to the east and west of the ridge in view of the very similar topography.

Turning to copper and zinc, data show that the former element only serves as an indicator of the distribution of basic rocks on the ridge crest, there being no anomaly over mineralised,

acid rocks on the southern slopes (Fig. 24). All the near-surface soil samples tested appear to have a background zinc content. Both metals tend to be enriched in the B horizon, but to a much less degree than lead (Table 40).

ii. Simbo Area.

The size of the lead anomaly in near-surface soil (0.65 sq. mile) at Simbo is greater than is the case in the Kasimba area, although peak values are of a somewhat lower order of magnitude (Figs. 27 and 28). There is virtually no difference in the other features of the dispersion patterns for lead, copper and zinc in both areas.

2. Metal Dispersion Patterns in the Drainage System.

Lead is evenly distributed throughout all horizons of background mbuga soil profiles that were examined to a depth of 54 ins. Threshold for lead in mbuga soil and stream sediment is 20 ppm (Table 41).

The Simbo soil anomaly extends onto the mbuga, which passes within 1200 ft. of the ridge at its nearest point (Figs. 27 and 28); maximum values recorded in the mbuga were of the order of 100 ppm Pb. Lead shows no tendency towards enrichment in organic-rich surface soil, but samples taken from the centre of the mbuga contain slightly more lead than those from marginal sites (Fig. 29). The anomalous concentrations of lead in near-surface soil in the mbuga probably represent material eroded from higher ground. This cannot be established with absolute certainty, however, since nothing is known of the distribution of lead in sub-surface soil below a depth of 36 ins.

Anomalous values were also detected in the sediment of the stream which flows through the mbuga (Fig. 30), the lead content of the sediment and bank soil samples being of the same order of magnitude. It appears that the sediment anomaly is due solely to the erosion of feebly anomalous soil, as the drainage train decays rapidly to background where the stream leaves the anomaly and flows out onto background terrain.

III. FACTORS INFLUENCING METAL DISPERSION.

a). PRIMARY DISPERSION.

The main factors controlling the emplacement of the Bawdwin deposits and, hence, the primary dispersion of traces of metal in the adjoining wallrocks, were the existence of favourable structures and the presence of replaceable feldspars in the tuff. The widespread dispersion of lead in the sub-outcropping sandstone and tuff on Meingtha and Mt. Teddy is probably due to the ease with which mineralising solutions were able to penetrate the well-fissured rocks. Variations in the degree of rock fracturing may be the cause of both large and small-scale irregularities in the primary dispersion pattern. Where the rocks are un-fissured, however, the dispersion of lead is limited to distances of only 5 - 30 ft; the fact that values decay logarithmically on passing away from the main site of metallisation indicates a diffusion of metal from a short-lived source.

The existence of zones of intense shearing also governed the emplacement of the Mpanda deposits. As at Bawdwin, extreme,

local variations in the lead content are probably related to the variable degree of rock-fissuring.

b). SECONDARY DISPERSION.

1. Mechanical Dispersion.

The principal mechanical dispersing agents in both study areas are gravity and water. Other dispersing agents, whose significance is strictly local, include wind and grass fires. Near former smelting sites at Bawdwin, the lateral extent of contamination in surface soil has undoubtedly been increased by the aeolian transport of metalliferous fumes and ash. The burning of grass near the Bawdwin Mine may also tend to increase slightly the lead content of the surface soil.

The asymmetrical pattern on Meingtha and Mt. Teddy is a clear indication of the movement of anomalous soil towards the valley bottom as a result of soil creep, landslips and sheet wash. Mechanical erosion continues in the drainage system and is responsible for the development of anomalous trains in dry gullies, where the sediments appear to consist of essentially unsorted material. On entering the streams, however, the eroded soil is subject to sorting, which results in the selective accumulation of lead-rich particles in the sediment.

Soil erosion is also taking place at Mpanda, although at a much slower rate than is the case in the Bawdwin area. Nevertheless, both the amount of material and the distance it has been

moved mechanically during the long period of weathering have been very considerable. Thus, the near-surface soil anomaly extends for a distance of 2000 ft. downslope from the source on Kasimba and Simbo Ridges, as compared to some hundreds of feet at Bawdwin (cf. Figs. 23, 28 and 35). In the Simbo area the sediment anomaly arises from the mechanical erosion of marginal parts of the soil anomaly by stream waters.

2. Chemical Dispersion

The very low ratio of Zn : Pb in soil compared to that in the primary ore at Bawdwin indicates that chemical processes are of much greater importance as regards the dispersion of zinc than is the case with lead. Further evidence of the chemical dispersion of zinc is found in the anomalous content of stream sediment and water (Table 23).

Possible evidence for the chemical dispersion of lead at Mpanda includes (a) the tendency for the ratio of Cu : Pb in soil to exceed that in the mineralisation at depth, (b) the marked enrichment of lead in the illuvial B horizon downslope from mineralisation (Fig. 25 and Table 39) and (c) the different, less readily-extractable form in which metal occurs in the B as compared to the A horizon of lowland profiles (Table 39). Moreover, it is also possible that anomalous values in the B horizon of non-residual soil to the west of Kasimba Ridge are reflecting mineralisation in the underlying, sheared rocks (Fig. 26). It would be extremely important if this

were so, since it could imply that lead has migrated upwards in solution before being deposited in the laterite.

(a) Hydrogen-ion Concentration.

The soil pH at Bawdwin and Mpanda ranges from 4.4 to 5.2 and from 5.8 to 7.0 respectively, the theoretical pH of hydrolysis for Cu^{2+} , Pb^{2+} and Zn^{2+} being 5.3, 6.0 and 7.0. It is, therefore, difficult to decide to what extent pH may control the dispersion of lead in the soil, but there can be absolutely no doubt that the more acid soil environment at Bawdwin is responsible for the high mobility of copper and zinc.

(b) Solubility.

Under the conditions prevailing at Bawdwin, the main oxidation products of galena are anglesite and cerussite. Both these minerals possess extremely low solubilities and in view of the youthful nature of the weathering environment, it is unlikely that much lead has been removed by leaching. The fact that some solution of lead is taking place, however, is shown by the content of 30 ppm Pb recorded by Loveman (1917) in groundwater in the Chinaman Lode.

The chemical dispersion of lead near former smelters at Bawdwin is probably due to the water-soluble nature of the lead compounds in the slag (Table 13).

The apparent mobility of lead at Mpanda is attributed to the formation of soluble chlorides in past, arid epochs and to the very long period of weathering.

Factors contributing to the leaching of copper and zinc at Bawdwin and to the leaching of copper at Mpanda include the relative instability of chalcopyrite and sphalerite in the zone of weathering and the high solubility of the sulphates of copper and zinc (Table 43). The abnormally high content of 800 ppm Zn observed by Loveman (1917) in groundwater in the Chinaman Lode illustrates the mobility of zinc in the Bawdwin area.

(c) Adsorption on and Co-precipitation with Hydrous Iron Oxides.

At Bawdwin, the correlation between lead and iron in two profiles is most probably due to the relative accumulation of two rather immobile elements during weathering, although it is possible that small quantities of lead are held on hydrous iron oxides (Fig. 31).

There appears to be an almost linear relationship between lead and iron in the B horizon downslope from mineralisation at Kasimba (Fig. 31). Having regard to the greater mobility of lead in the Mpanda area, this association could possibly result from the adsorption of lead from solutions on hydrous iron oxides and/or the co-precipitation of lead with iron during the formation of the laterite.

Copper also follows iron in the Bawdwin profiles, presumably because much of the copper in anomalous soil is fixed by ferruginous sesquioxides. Adsorption and co-precipitation are believed to control partly the dispersion of copper in the soil at Mpanda and the dispersion of zinc in the drainage system at Bawdwin, where samples of freshly-precipitated ferric hydroxide hold more than 0.5% Zn.

(d) Effects of Organic Matter.

The tendency for organic matter in the soil at Bawdwin to immobilise lead is illustrated by the pronounced surface enrichment of metal in background areas (Tables 8 - 10). It is not definitely known whether organo-lead compounds occur in the soil. The following data, however, suggest that such is the case. Firstly, there appears to be an almost linear relationship between total lead and organic carbon in background soil (Fig. 32). Secondly, an equally close correlation exists between organic carbon and the ratio of cold-extractable to total lead in anomalous soil on Meingtha and Mt. Teddy (Fig. 32, Tables 16, 18 and 45).

The tendency for the extractability of lead to decrease with depth is not so apparent at Mpanda, where the vegetation is different (Table 36).

Adsorption of zinc on finely-divided organic matter may be a further factor contributing to the removal of soluble metal from stream waters at Bawdwin.

(e) Metabolic Activity of Vegetation.

There is little doubt that lead has been extracted from the sub-soil at Bawdwin by vegetation and returned to the topsoil when the vegetable matter decayed. The reasons for believing this are (a) high lead values in vegetation, (b) the tendency for the total metal content of background soil to markedly decrease with depth and (c) a similar tendency for the extractability of lead in soil over

mineralisation. Since the vegetation near the mine now consists of relatively shallow-rooted grass, it is probable that the extraction of lead from deeper horizons in the sub-soil took place prior to de-forestation.

Judging from the absence of any surface enrichment of lead at Mpanda, the metabolic activity of vegetation has little effect on the distribution of metal in the soil.

The absence of copper and zinc surface enrichment at Bawdwin suggests that any metal returned to the surface by decaying vegetation has been leached.

(f) Other Factors.

No experimental data are available to show whether adsorption on clays and manganese oxy-hydrates, changes in the environmental Eh, the formation of soluble inorganic complexes, metabolism by micro-organisms and colloidal dispersion have any effect on the secondary dispersion of metal in both study areas.

IV. RECOMMENDED PROSPECTING PROCEDURE.

A number of fundamental problems meriting further attention have been mentioned on previous pages. These include (a) the effect of post-mineralisation hydrothermal activity on the distribution of lead in wallrocks (p. 173), (b) the factors governing the extractability of lead in the sub-soil at Bawdwin and Mpanda (p. 152 and 241) (c) the mode of occurrence of lead in the soil (p. 191 and 195).

and (d) the effects of adsorption by clay minerals and manganese sesquioxides, and of changes in the environmental Eh, on the secondary dispersion of copper, lead and zinc (p. 199-201).

A more detailed knowledge is also required of the dispersion of lead and zinc in stream sediment, stream water and bank soil under conditions that prevail in the Bawdwin area. Nevertheless, the techniques described in Part III and Appendix A have served as the basis for prospecting surveys at Bawdwin and could equally well be applied in comparable areas elsewhere (see Hunting Technical Services, 1959).

The analysis of (a) stream water for heavy metal, (b) stream sediment for total lead and cold-extractable zinc and (c) gully sediment for total lead affords a rapid method of scanning large tracts of mountainous country for possible lead-zinc mineralisation. The drainage reconnaissance is followed by systematic soil sampling and the analysis of the samples for total lead in areas where significant anomalies are detected in the drainage. In the absence of contamination, the dispersion pattern outlined by samples from a depth of 12 - 24 ins. will generally reflect the distribution of anomalous concentrations of metal in the underlying bedrocks, even where the overburden is comparatively thick (Fig. 12). If contamination is suspected, prospecting is still possible in soils away from former smelting sites, provided that samples are taken from a depth of 36 ins. where possible and that a cold-extractable lead test is employed

to distinguish between true and false anomalies (Tables 16 and 45).

The procedures given in Part III and Appendix A merely outline the bedrock source of the soil anomaly. Surface geochemical methods alone cannot distinguish between anomalous values due to a large mineralised stockwork system of stringers and veinlets on the one hand and those due to leakage dispersions from massive replacement deposits on the other (p. 242).

At Mpanda, further work along the following lines is necessary in order to improve the prospecting technique for this area and also for other areas possessing similar environmental conditions.

In the first place, information is required about the distribution of lead in the deeper horizons of soil in mbugas situated over and downslope from mineralisation. The lead content of stream water, stream sediment and bank soil in drainage courses passing closer to mineralisation than those at Simbo also needs to be studied. Secondly, more data is required about the lead content of near-surface soil, laterite and weathered bedrocks in the lowland areas surrounding Kasimba and Simbo ridges. In particular, it is essential to confirm whether the anomalous values in the laterite to the west of Kasimba Ridge are reflecting mineralisation in the underlying rocks. This information will show if lead anomalies related to bedrock mineralisation are detectable in the deep, colluvial overburden covering the Mpanda lowlands.

Till these data are available, the procedures discussed

in Part V will serve as a method of prospecting for mineralisation sub-outcropping on low ridges, which have been undergoing gradual denudation over a very considerable period of time (pp. 152-153). Since the lead anomaly in near-surface soil extends downslope for a distance of several thousand feet, the analysis of stream sediment and mbuga soil for lead can be used as a means of discriminating between mineralised and un-mineralised areas (Figs. 27 and 28). In areas of low drainage density, however, additional samples should be taken from a depth of 12 - 24 ins., at intervals of 200 ft., from traverses spaced 500 or even 1000 ft. apart. In mineralised areas, the lead content of near-surface soil will tend to increase with increasing proximity to the anomaly source, reaching a well-defined peak in residual soil directly over or in the immediate vicinity of bedrock mineralisation (Figs. 23, 25 and 28).

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APPENDICES.

A. GEOCHEMICAL PROSPECTING SURVEY FOR LEAD IN THE MEINGTHA - MT. TEDDY AREA AT BAWDWIN.

1. Analytical and Sampling Methods.

The dimensions of the sampling grid in the Meingtha - Mt. Teddy area and the distribution of lead in the soil in the immediate vicinity of Pit 11 have already been discussed on pp. 85-88 (see also Table 17). Soil samples were taken from the sub-soil horizon at a depth of 36 inches below the surface or immediately above weathered bedrock in those parts of the Mt. Teddy area where the overburden is shallow. A small number of surface soil and weathered bedrock samples were also collected in key areas. The sampling interval was 50 ft. and traverses were run down all ridge crests and spurs (Fig. 9).

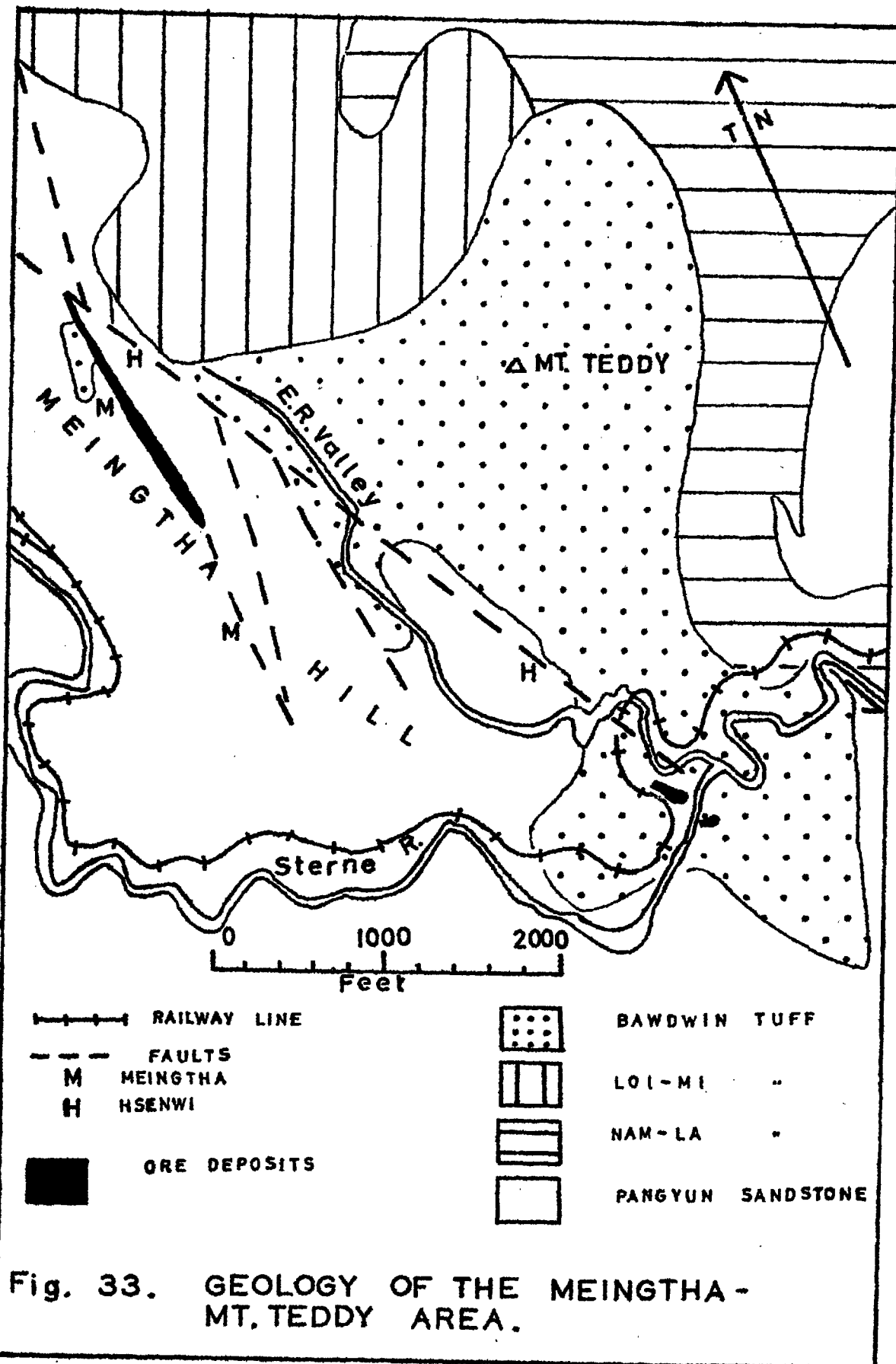
All soil and rock samples were analysed for lead, which is evidently the most satisfactory indicator of mineralisation at Bawdwin.

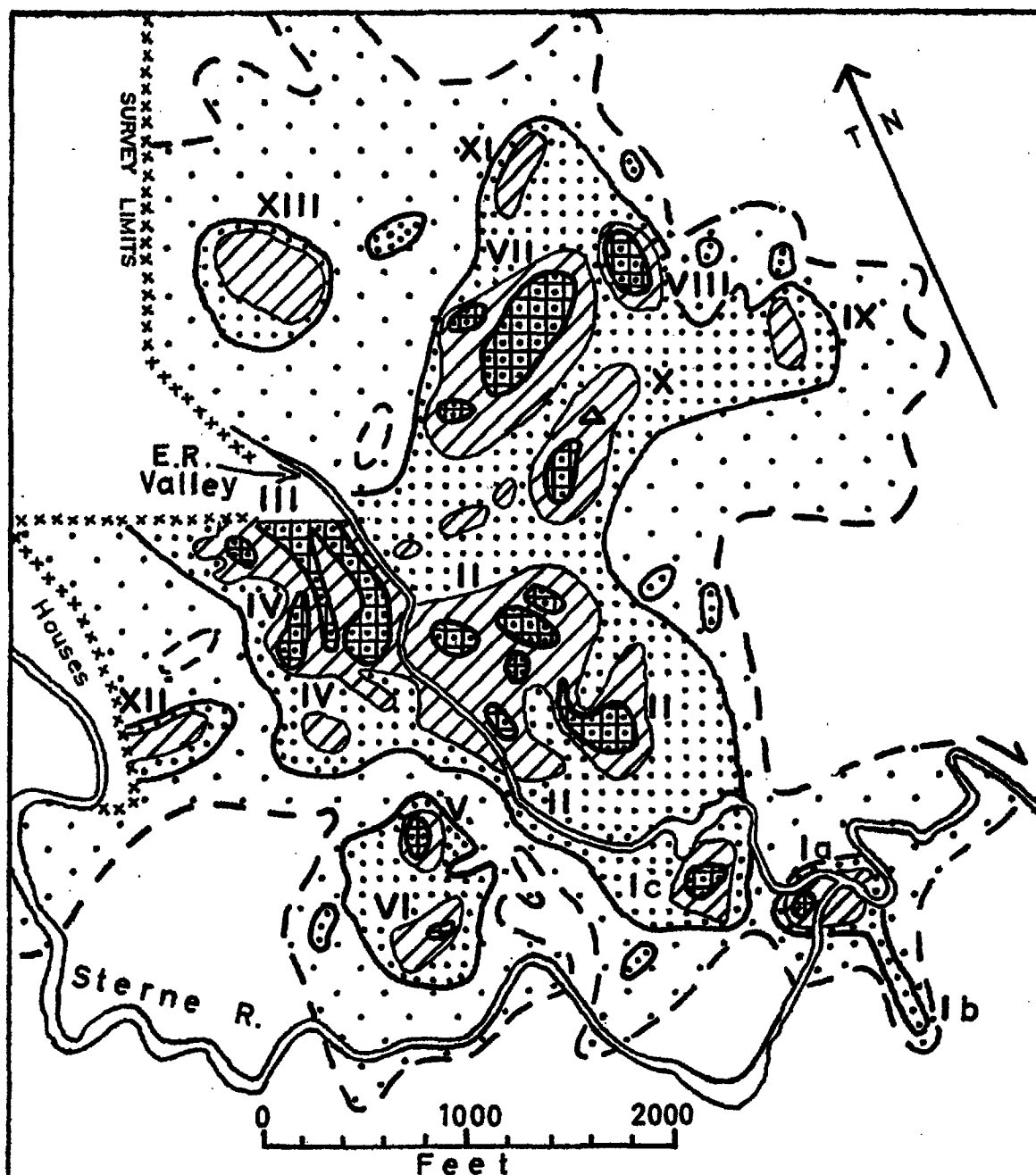
2. Dispersion Pattern in the Soil

The small-scale geochemical contour plan in Fig. 34 represents a simplified, overall picture of the distribution of lead in the sub-soil, while the geology of the area is given in Fig. 33.

The soil over an area of about 0.5 sq. mile on Meingtha and Mt. Teddy has an anomalous lead content exceeding the threshold of 200 ppm Pb. Within this large area, there are 15 clearly defined zones or peak anomalies wherein the mean lead content of the soil ranges from 1600 to 6400 ppm (Fig. 34 and Table 44). Three of these peak anomalies (Ia, III and IV) are situated over or close

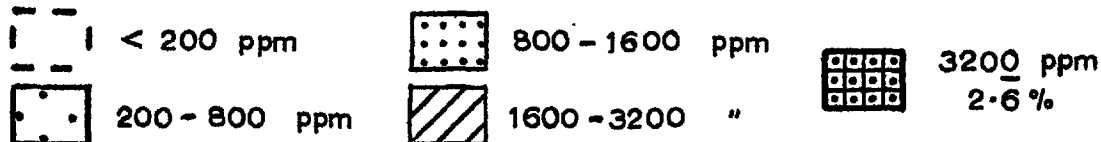
Fig. 33





III PEAK ANOMALY NUMBER

LEAD CONTENT OF SAMPLES FROM A DEPTH OF 36 INCHES:-



N.B. CONTAMINATED SOIL ANOMALIES ALONG THE STERNE RIVER NOT SHOWN ABOVE.

Fig. 34. LEAD ANOMALY IN THE SUB-SOIL IN THE MEINGTHA - MT. TEDDY AREA.

TABLE 44. Lead content of sub-soil and weathered bedrock samples constituting Peak Anomalies I-XIII, Meingtha - Mt. Teddy area.

Peak Anomaly No.	Bedrock Type	Range of Values (ppm):			
		Sub-soil		Bedrock	
		Max.	Mean	Min.	Max.
Ia ^X	Bawdwin Tuff	6000	2500	400	9000
Ib	"	2500	1600 (4)	no data	
Ic	"	5000	2700 (17)	25	3700 (5)
II	"	> 2%	3400 (80)	5	> 2% (27)
III ^X	"	3500	3000	70	1.1%
IV ^X	Pangyun Sandstone	5000	3000	600	3000
V	"	1.2%	4700 (12)	1500	4000 (3)
VI	"	4000	2000 (11)	no data	
VII	Bawdwin Tuff	2.6%	3600 (44)	700	1% (12)
VIII	"	1.2%	6400 (10)	2700	1.6% (4)
IX	"	4500	2800 (10)	no data	
X	"	1%	3200 (31)	no data	
XI	Bawdwin and Loi-Mi Tuff	3500	2300 (6)	"	
XII	Pangyun Sandstone	3200	2000 (11)	"	
XIII	Loi-Mi Tuff	4500	2700 (19)	"	

^X Peak anomalies over or close to known mineralisation (see Part III).

Figures in parentheses denote number of samples analysed for lead.

to known mineralisation and have been fully discussed in Part III. The remaining 12 peak anomalies, whose existence was not previously suspected, are considered below.

(a) Relationship with Bedrock Lithology.

On the basis of bedrock lithology, the Meingtha and Mt. Teddy peak anomalies can be classified into three groups. One group (V, VI and XII) was detected in soil derived from Pangyun sandstone, on the S.W. and W. slopes of Meingtha Hill. Peak Anomalies Ib, Ic,

11 and VII-XI were detected in soil over Bawdwin tuff in the Sterne River and Mt. Teddy areas. It is interesting to note that the area outlined by the 800 ppm geochemical contour on Mt. Teddy appears to coincide approximately with the outcrop of Bawdwin tuff mapped by the late G.V. Hobson.

The parent rocks in the area constituting Peak Anomaly XIII consist of Loi-Mi tuff. Soils derived from Nam-La tuff on the E. slopes of Mt. Teddy, however, appear to have a background metal content (Figs. 33 and 34).

(b) Relationship with Possible Faults.

i. Peak Anomalies near the Hsenwi and Meingtha Fault Zones.

There appears to be a definite spatial relationship between the position of Peak Anomalies 1b, 1c, 11, 111, V and VI and the possible extension of the Hsenwi and Meingtha Fault zones (Figs. 33 and 34). This does not necessarily imply, however, that a corresponding genetic relationship also exists between the peak anomalies and the fault zones, (p. 242-243).

Peak Anomalies 1a, 1b, 1c, 11 and 111 are situated near the Hsenwi Fault zone, on the eastern and western sides of the E.R. Valley. The average lead contents of these peak anomalies range from 1600 to 3400 ppm, Peak Anomaly 11 being the most extensive and also possessing the highest tenor. Soil and weathered bedrocks in these areas contain up to 2% Pb and more (Table 44).

Peak Anomalies V and VI were detected in the vicinity of the Meingtha Fault zone, their respective mean lead contents being

4700 and 2000 ppm. The latter peak anomaly may be the more significant, since it lies due south of the N-S trending orebody (Figs. 33 and 34). Peak values in soil and weathered bedrocks in Area V are 1.2% and 4000 ppm respectively. The overburden in Area VI is very thick (> 10 ft.) and insufficient time was available to determine the range of values in the parent bedrocks.

ii. Other Peak Anomalies.

Peak Anomalies VII-XI, whose tenor ranges from 2300 to 6400 ppm, occupy a very considerable area on the N and N.E slopes of Mt. Teddy. Peak values in the soil and weathered bedrocks in this area rise to 2.6% and 1.6% Pb respectively.

Peak Anomalies XII and XIII have a low tenor and a small lateral extent. They are isolated from the three groups of peak anomalies described above.

(c). Width of Detectable Anomalies in the Soil on Mt. Teddy.

Judging from the data in Fig. 35, anomalous values in the soil persist for a distance of more than 300 ft. downslope from the bedrock source on Spur Q 2. Over the mineralised (?) tuff there appears to be little difference between the metal content of the soil and weathered bedrock horizons. Further downslope, however, soil samples contain from 1200 - 3500 ppm Pb whereas no sample of quartzite or tuff bedrock was found to contain more than 150 ppm Pb. The spur terminates at Stream RQ, some 320 ft. below the bedrock source, so the full distance to which the anomaly might have extended down a larger slope cannot be estimated.

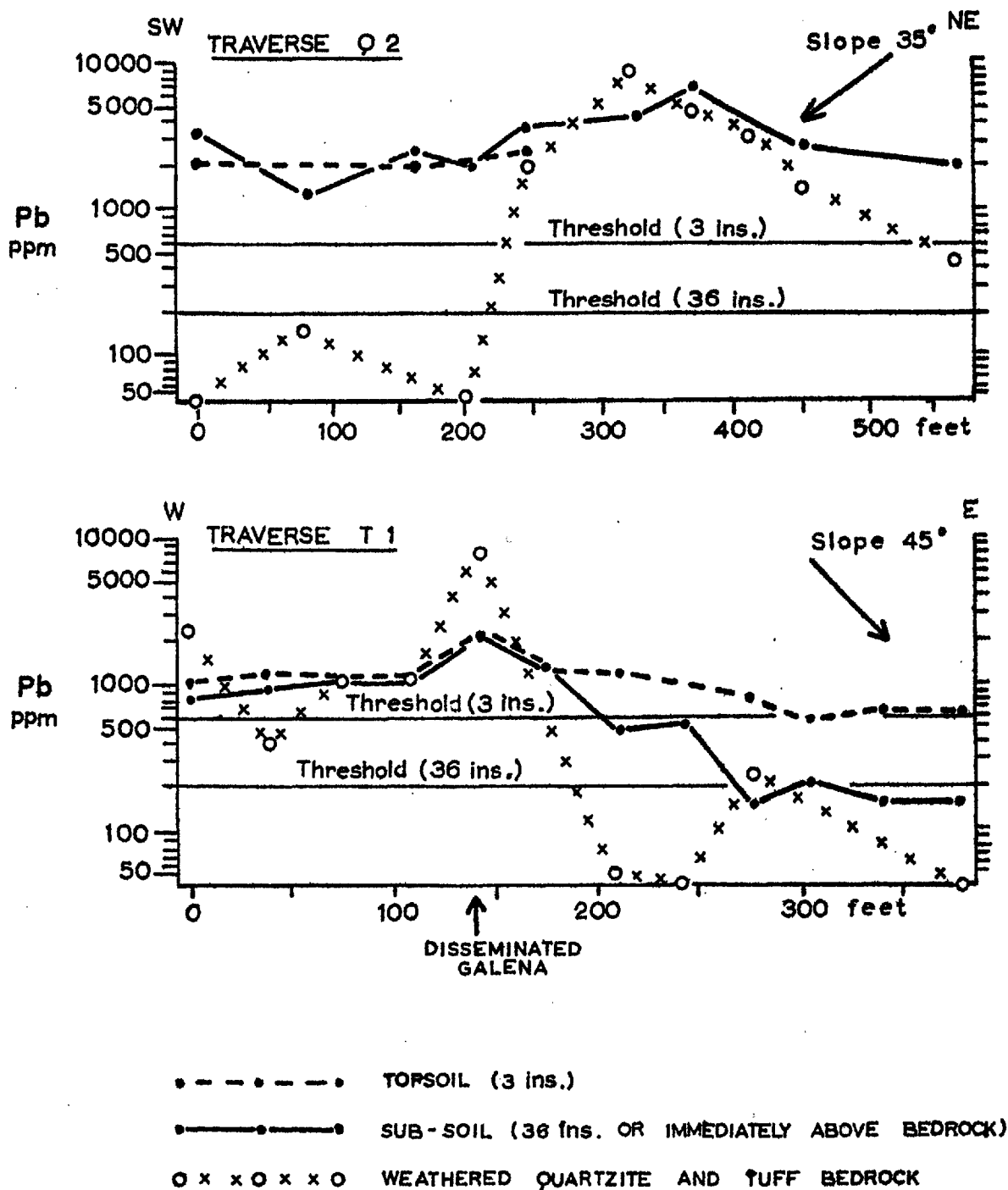


Fig. 35. DISPERSION OF LEAD IN SOIL AND WEATHERED BEDROCK, TRAVERSES Q 2 AND T 1, MT. TEDDY.

The movement of lead in the sub-soil on Traverse T 1, however, is more restricted and the anomaly only extends for a distance of 150 ft. downslope from a zone where the tuff contains disseminated galena, (Fig. 35). The corresponding width of the anomaly in surface soil at a depth of 3 ins. is 200 ft. The gradient (45°) along Traverse T 1 is some 10° or so steeper than that on Traverse Q 2; the more limited dispersion of lead probably reflects the smaller size of the bedrock source.

(d) Discrimination between True Anomalies and False Anomalies due to Contamination.

The methods used to prove that the soil anomalies detected on Traverses A 8 and A 12 are not due to contamination also apply in other parts of the Meingtha - Mt. Teddy area (pp. 111-114). First-ly, there appears to be very little slag or other smelting materials on Meingtha Hill and none whatsoever on Mt. Teddy. Secondly, the data in Table 44 indicate that anomalous values in the sub-soil samples from Meingtha and Mt. Teddy are related to bedrock sources. Moreover, the secondary dispersion of lead on Meingtha and Mt. Teddy is characterised by broad, homogeneous, areal patterns and not by the extremely erratic distribution of high and low values, such as is the case near former smelters.

The marked contrast between the high extractability of lead and in sub-soil samples from contaminated areas/the low extractability of metal in similar samples from Traverses A 8 and A 12 on Meingtha Hill has already been emphasized. (Table 16). Three pairs of topsoil and sub-soil samples from Peak Anomalies 1c, 1l and V-VIII were accordingly

tested for cold-extractable Pb by the technique utilising 5% nitric acid as the metal solvent. The results are presented in Table 45.

TABLE 45. Extractability of lead in soil samples from Peak Anomalies Ic, 11 and V-VIII.

Peak Anomaly No.	No. of samples tested	Cx : Total Pb (%)					
		Topsoil (3 ins.)			Sub-soil (36 ins. or above weathered bedrock)		
		Min.	Max.	Mean	Min.	Max.	Mean
Ic	3	23	28	25	7	11	9
11	3	16	25	21	8	14	11
V	3	9	17	14	5	5	5
VI	3	40	53	45	4	17	9
VII	4	12	37	24	4	28	20
VIII	3	4	8	7	1	6	4

The high ratios of 40 - 53% in topsoil samples from Peak Anomaly VI may possible be due to contamination from the railway line and former smelting sites, some 400 ft. further to the south. Contamination does not appear to be responsible for the anomalous values in the sub-soil samples, however, since the proportion of Cx : Total Pb in any one sample does not exceed 17%. Similarly low values (1 - 14%) were also observed in sub-soil samples from Anomalies Ic, 11, V and VIII.

It is not known why as much as 28% of the lead in sub-soil samples from Area VII, where there is absolutely no sign of previous mining or smelting activity, is soluble in cold 5% nitric acid. One possible reason could be that organic matter is dispersed to a greater

depth in the sub-soil in this locality than is the case in other parts of the Meingtha - Mt. Teddy area (Tables 6 and 7, p. 194-195).

3. Significance of the Anomaly in terms of Possible Mineralisation.

The sub-soil anomaly on Meingtha and Mt. Teddy is not considered to be due to contamination. It covers a far greater area than the parent metal source in sandstone and tuff bedrocks on account of extensive downslope distortion.

Judging from geochemical data obtained on Traverses A, A 12, A 13, A 23, A 24 and A 26, which pass over a known orebody lying 200 ft. from the surface, even relatively feeble leakage dispersions exceeding 300 ppm Pb may be of some significance (Figs. 10 and 11). On the other hand, peak values of 1600 - 5000 Pb coincide more closely with the position of a smaller deposit situated 90 ft. below the crest of Spur A 8 (Fig. 16). These inconsistent relationships emphasize the difficulty of interpreting leakage dispersion anomalies on the basis of geochemical data alone (pp. 95-97).

The bedrock source of the soil anomaly in other parts of the Meingtha - Mt. Teddy area presumably consists of oxidised sulphide disseminations. These disseminations, however, could merely be part of a large stockwork of small stringers and veinlets. The possibility of ore in depth in Areas 1b, 1c, 11 and V-XIII depends on whether favourable structures, which could have canalised the ascending hydrothermal solutions into a large deposit, were available during the mineralisation period. This is a geological problem and cannot be solved by surface geochemical methods.

Peak Anomalies 1c and 1l would seem to be the most significant in view of their close proximity to the Hsenwi Fault. Peak Anomaly VI may also be of interest since it is situated on the possible strike extension of the Meingtha Lode. Nothing is known, however, of the sub-surface geology in the area defined by Peak Anomalies VII-XI. Further geological work is necessary to ascertain whether any major faults occur in this area before the significance of these peak anomalies can be assessed.

B. ANALYTICAL METHODS FOR LEAD.

Very dilute solutions of dithizone in benzene or white spirit tend to be rather unstable. When working in a tropical climate, the writer found that the best analytical results are obtained if the working solutions are renewed every 4 hours or so, although the more concentrated stock solution remains stable for several days.

1. Total Lead using Benzene as the Dithizone Solvent (after Stanton and Gilbert, 1956).

(a) Procedure.

1. Weigh 0.1 or 0.2g. of sieved sample into a 16 x 150 mm. test tube previously calibrated at 3 and 10 ml.
2. Add 3 ml. of 25% nitric acid and digest for one hour.
3. Dilute to 10 ml. with de-mineralised water and mix by shaking.
4. Pipette a 2 ml. aliquot into 10 ml. of buffer solution contained in a 19 x 150 mm. test tube previously calibrated at 10 ml.
5. Add 5 ml. of 0.0008% dithizone in benzene or toluene, cork the tube. and shake vigorously for 30 seconds.

6. Compare with standards similarly prepared.
7. If the colour of the dithizone exceeds the top standard, repeat from Stage 4 with a smaller aliquot. For an aliquot of 0.5 ml. or less, add also 1 ml. of 7.5% nitric acid to maintain the pH.
8. If the reaction colour is above the ^{top} standard on a 0.1 ml. aliquot, dilute the original sample solution obtained at Stage 3 as required. Then take suitable aliquots to which 1 ml. of 7.5% nitric acid is also added.

(b) Preparation of Reagents.

i. Standard Solution.

Dissolve 0.08 g. lead nitrate in water containing one drop of nitric acid and dilute to 500 ml. with de-mineralised water. Dilute 5 ml. of this solution to 100 ml. with more de-mineralised water (1 ml. = 5 μ g. Pb).

To ten test tubes containing 10 ml. of buffer solution, add respectively 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5 μ g. Pb and 1 ml. of 7.5% nitric acid. Add 5 ml. of 0.0008% dithizone in benzene and shake vigorously for 30 seconds. If increased productivity is required, the top standard can be increased to 7.0 μ g. Pb and the intermediate 0.5 μ g. standards omitted, although this step tends to increase the analytical error.

ii. Buffer Solution.

Dissolve 284 g. tri-ammonium citrate and 20 g. hydroxylamine hydrochloride in 1 litre of de-mineralised water, and add 5 ml. of 0.04% thymol blue. Add ammonia till the indicator changes to a distinct blue, and then add 18 g. potassium cyanide. Purify with 0.01% dithizone in carbon tetrachloride followed by chloroform extractions

and three final extractions with carbon tetrachloride, when the organic phase should be colourless.

iii. Dithizone Solution (0.0008%).

Dissolve 32 mg. dithizone in 400 ml. benzene or toluene. Dilute 40 ml. of this stock solution to 400 ml. with more benzene or toluene.

iv. Thymol Blue (0.04%).

Dissolve 0.1 g. thymol blue (sodium salt) in 250 ml. of de-mineralised water.

v. Nitric Acid Solutions.

25% nitric acid: dilute 125 ml. concentrated acid to 500 ml. with de-mineralised water.

7.5% nitric acid: dilute 30 ml. of 25% acid to 100 ml. with de-mineralised water.

5% nitric acid: dilute 25 ml. concentrated acid to 500 ml. with de-mineralised water.

2. Total Lead using White Spirit as the Dithizone Solvent.

(a) Procedure.

Stages 1 - 4 as for previous test.

5. Adjust the pH by adding 2N ammonia till the solution has a permanent blue-green colour.

6. Add 5 ml. dithizone in white spirit and shake for 12 seconds.

7. Compare with standards. Repeat on a smaller aliquot if the colour of the dithizone is above the top standard.

(b) Preparation of Reagents.

i. Standard Solution.

To eight test tubes containing 10 ml. of buffer solution and 2 ml. of

7.5% nitric acid, add 0, 0.5, 1.0, 1.5 3.5 μ g. Pb. Adjust the

pH as described above. Add 5 ml. of 0.001% dithizone in white spirit and shake for 12 seconds.

ii. Buffer Solution.

Dissolve 250 g. of tri-ammonium citrate, 50 g. potassium cyanide and 40 g. hydroxylamine hydrochloride in 900 ml. de-mineralised water. Add 15 ml. of 0.01% thymol blue followed by 2N ammonia until the solution has a blue-green colour. Add 35 ml. of thymol blue and purify with 0.01% dithizone in carbon tetrachloride followed by chloroform extractions and three final extractions with carbon tetrachloride. Dilute to 5 litres with de-mineralised water.

iii. Dithizone Solution (0.001%).

Prepare a 0.2% solution of dithizone in chloroform, and dilute to 400 ml. with distilled and purified white spirit (see Holman, 1956).

3. Provisional Method for the Determination of Cold-Extractable Lead.

(a) Procedure.

1. Weigh 0.1 or 0.2 g. of sieved sample into a test tube previously calibrated at 10 ml.
2. Add 10 ml. of 5% nitric acid, cork the tube and shake vigorously for 30 seconds.
3. Allow the solution to settle.
4. Pipette a 2 ml. aliquot into 10 ml. of buffer solution contained in a 19 x 105 mm. test tube previously calibrated at 10 ml.* Then proceed as for Stages 5 - 8, Appendix B 1.

* If 0.25% citric acid is used as the metal extractant in Stage 2, add also 1 ml. of 7.5% nitric acid to maintain the pH.

(b) Preparation of Reagents.

As for Appendix B 1.

C. ANALYTICAL METHODS FOR COPPER, ZINC AND "HEAVY METAL".

1. Total Copper (after Stanton and Gilbert, 1956).

(a) Procedure.

1. Weigh 0.1 g. of sieved sample into a 16 x 150 mm. test tube.
2. Add 0.5 g. of potassium bisulphate (by scoop) and fuse to a quiet melt.
3. Add 5 ml. of 1N hydrochloric acid ^X and warm to complete solution of the melt. Then add 5 ml. of de-mineralised water and mix well.
4. Pipette a 1 ml. aliquot into 5 ml. of buffer solution contained in a 19 x 150 mm. test tube previously calibrated at 5 ml.
5. Add 5 ml. of 0.001% dithizone in benzene. Cork the tube and shake vigorously for 2 minutes.
6. Compare with standards similarly prepared.
7. If the reaction colour is above the top standard, repeat on a smaller aliquot.

(b) Preparation of Reagents.

i. Standard Solution.

Dissolve 0.2 g. copper sulphate (A.R) in water, add 50 ml. 1N hydrochloric acid and dilute to 500 ml. with de-mineralised water. Dilute 5 ml. of this solution to 100 ml. with more de-mineralised water (1 ml. = 5 μ g. Cu).

^X Dilute 40 ml. of concentrated acid with 400 ml. of de-mineralised water.

To ten test tubes containing 5 ml. of buffer solution, add respectively 0, 0.5, 1.0, 1.5 4.5 μ g. of copper. Add 5 ml. of 0.001% dithizone in benzene and shake vigorously for two minutes.

ii. Buffer Solution.

Dissolve 243 g. tri-ammonium citrate and 100 g. hydroxylamine hydrochloride in 700 ml. de-mineralised water. Purify with 0.01% dithizone in carbon tetrachloride followed by chloroform extractions till the organic phase is colourless. Make up to 1 litre with de-mineralised water.

iii. Dithizone Solution (0.001%).

Dissolve 40 mg. dithizone in 400 ml. of benzene. Dilute 40 ml. of this stock solution to 400 ml. with more benzene.

2. Total Zinc (after Stanton and Gilbert, 1956).

(a) Procedure.

As for copper, except that the test tubes are shaken vigorously for 60 seconds in Stage 5.

(b) Preparation of Reagents.

i. Standard Solution.

Dissolve 0.05 g. zinc in 5 - 10 ml. of concentrated hydrochloric acid and dilute to 500 ml. with de-mineralised water. Dilute 5 ml. of this solution to 100 ml. with more de-mineralised water (1 ml. = 5 μ g. Zn).

To eight test tubes containing 5 ml. of buffer solution, add respectively 0, 0.5, 1.0, .15 3.5 μ g. of zinc. Add 5 ml. of 0.001% dithizone in benzene and shake vigorously for 60 seconds.

ii. Buffer Solution.

Dissolve 125 g. sodium thiosulphate pentahydrate and 310 g. sodium acetate trihydrate in about 600 ml. of de-mineralised water. Add 10 ml. of glacial acetic acid. Purify with 0.01% dithizone in carbon tetrachloride followed by carbon tetrachloride extractions till the organic phase is colourless. Dilute to 2 litres with de-mineralised water.

iii. Other Reagents.

As for copper.

3. Cold-Extractable Zinc.

Further work is currently being undertaken at the G.P.R.C., with a view to improving the technique described below,

(a) Procedure.

1. Weigh 0.2 g. of sieved sample into a 19 x 150 mm. test tube previously calibrated at 5 ml. and then at every additional 2 ml.
2. Add 5 ml. of buffer solution.
3. Add 2 ml. of 0.001% dithizone in benzene from a wash bottle, cork the test tube and shake vigorously for 60 seconds.
4. Allow the layers to settle, adding one drop of ethyl alcohol if necessary to break the dispersion.
5. Compare the colour of the benzene extract with standards.
6. If pink, repeat Stages 3 and 4 until the easily-matched blue-grey tint is obtained.
7. If still pink after the addition of 10 ml. of dithizone solution, repeat Stages 1 - 6 using a smaller sample weight.
8. Record total ml. of dithizone added (V ml.) and the concentration of zinc in the matching standard (A μ g.).

$$\text{ppm cold-extractable zinc} = \frac{A \times V}{5 \times \text{sample weight (grams)}}$$

(b) Preparation of Reagents.

As for total zinc (Appendix C 2).

4. Cold-Extractable "Heavy Metal" (Zn + Cu + Pb).

The procedure described below is a modified version of the technique developed by Bloom (1955).

(a) Procedure.

As for cold-extractable zinc, except that the test tubes are shaken for 30 seconds in Stage 3.

(b) Preparation of Reagents.

i. Buffer Solution.

The buffer solution is identical to that described in Appendix B 2, except that it contains no potassium cyanide.

ii. Other Reagents.

As for total zinc (Appendix C 2).

5. "Heavy Metal" in Stream Water.

Further work is at present being undertaken at the G.P.R.C. with a view to improving the following procedure, which represents a modified version of the test developed by Huff (1948).

(a) Procedure.

1. Add 50 or 100 ml. of clear stream water to a 100 ml. graduated Pyrex glass cylinder.
2. Add 0.5 ml. of dithizone in benzene (dropwise) from a wash bottle protected with aluminium foil.

3. Stopper the cylinder and shake vigorously for 30 seconds.
4. Lay the cylinder on its side for 1 minute to allow the layers to settle.
5. Observe the colour of the organic phase.
6. If the reaction colour is other than green or blue-green, repeat Stages 2 - 5 with successive 1 ml. increments of dithizone (shaking for 15 seconds after each addition) till the easily-matched blue-grey tint is obtained.
7. Record total ml. of dithizone added.

If desired, the "heavy metal" content (μ g. zinc equivalents per litre) can be obtained from the formula:

$$\frac{A \times V}{5 \times \text{volume of sample (ml.)}}$$

8. Collect a fresh sample and repeat Stages 2 - 6 in order to check the analytical reliability.

(b) Preparation of Reagents.

As for total zinc. When testing stream waters in the field, it is advisable to keep the dithizone solution in a thermos flask, transferring small quantities to the wash bottle before each determination is made.

D. OTHER TECHNIQUES.

1. Determination of pH.

1. Weigh 5 g. of sieved soil into a 50 ml. capacity boiling tube.
2. Add 25 ml. of distilled water (CO_2 free), cork the tube and shake for one hour.
3. Pour the liquid into a small beaker (50 or 100 ml. capacity).
4. Place the electrodes of the meter, which has been previously balanced against a buffer solution of known pH and take a reading.

2. Determination of Organic Carbon (after Allison, 1935).

(a) Procedure.

1. Weigh 0.5 g. of sieved soil into a 250 ml. conical flask.
2. Add 10 ml. of potassium dichromate solution and 10 ml. concentrated sulphuric acid.
3. Heat over a low flame for about 25 seconds. The temperature should not exceed 175°C. Allow the flask to cool thoroughly, then add 100 ml. distilled water and about 5 g. sodium fluoride.
4. Titrate with 0.2N ferrous ammonium sulphate, using three drops of diphenylamine as an indicator. The colour of the dichromate changes from yellow to inky blue and then to light indigo.*
5. Continue titration by the dropwise addition of ferrous ammonium sulphate till the solution has a permanent green colour.
6. Make a blank determination in an exactly similar manner.

$$\% \text{ organic carbon} = \frac{20(\text{blank titre} - \text{soil titre})}{\text{blank titre}} \times 0.138$$

(b) Preparation of Reagents.

i. Potassium Dichromate Solution.

Dissolve 19.618 g. potassium dichromate in one litre of distilled water.

ii. Ferrous Ammonium Sulphate (0.2N).

Dissolve 78.6 g. of ferrous ammonium sulphate in one litre of distilled water containing 20 ml. concentrated sulphuric acid.

iii. Diphenylamine Indicator.

Dissolve 0.5 g. diphenylamine in 100 ml. concentrated sulphuric acid and pour carefully into 20 ml. of cold, distilled water.

* If the initial solution has a greenish tinge before the addition of ferrous ammonium sulphate, repeat Stages 1 - 5 using a smaller sample weight.

3. Determination of Total Iron (after Vogel, 1948).

(a) Procedure.

1. Accurately weigh about 0.2 g. of sample into a test tube.
2. Add 0.5 g. potassium bisulphate and fuse to a quiet melt.
3. Add 10 ml. of 6N hydrochloric acid and warm to a complete solution of the melt.
4. Filter into a graduated cylinder. Wash the residue with 6N acid till the washings are colourless. Combine the washings with the original filtrate.
5. Make up the volume to 25 ml. with distilled water, transfer to a conical flask and heat to boiling.
6. Add concentrated stannous chloride (dropwise) to the hot solution. Complete the reduction by the dropwise addition of dilute stannous chloride till the solution is colourless or has a faint green tinge.
7. Cork the flask and cool rapidly under tap water.
8. Add 10 ml. of 5% mercuric chloride solution, when a milky white precipitate should result. If not, repeat Stages 1 - 7.
9. Add 100 ml. of 2N sulphuric acid, 2.5 ml. of phosphoric acid and 6 - 8 drops of diphenylamine indicator.
10. Titrate slowly with 0.1N potassium dichromate till the colour of the solution changes to grey-green. Then add dichromate dropwise till a permanent blue-violet colour appears, stirring thoroughly after each addition of dichromate.

$$\% \text{ Fe} = \frac{0.1 \times 0.0558 \times \text{ml. titre}}{\text{sample weight (grams)}}$$

(b) Preparation of Reagents.

i. 6N Hydrochloric Acid.

Dilute 540 ml. of the concentrated acid to one litre with distilled water.

ii. Stannous Chloride.

The concentrated solution is prepared by dissolving 12 g. of tin or 30 g. of stannous chloride in 100 ml. of concentrated hydrochloric acid and

making up the volume to 200 ml. with distilled water. For the dilute solution, combine one volume of the concentrated solution with two volumes of 1 : 1 hydrochloric acid.

iii. 5% Mercuric Chloride.

Dissolve 25 g. mercuric chloride in 500 ml. of distilled water.

iv. 2N Sulphuric Acid.

Dilute 56 ml. of the concentrated acid to one litre with distilled water.

v. Potassium Dichromate (0.1 N).

Weigh out accurately 4.9 g. of dry A.R. potassium dichromate, and dissolve in one litre of distilled water.

vi. Diphenylamine Indicator.

See Appendix D 2.

4. Determination of Water-soluble Lead.

1. Weigh 5 g. of sample into a 50 ml. capacity boiling tube, then add 25 ml. of de-mineralised water.
2. Cork the tube and shake for one hour.
3. Filter the solution through a fine filter paper and estimate the lead content of the filtrate by the procedure described in Appendix B 1, except that 1 ml. of 7.5% nitric acid is added to all aliquots to maintain the pH.

5. Partial Size Analysis.

1. Place about 150 g. of dry soil or stream sediment in a porcelain mortar, removing the stones and pebbles. Lightly pound with a pestle to break up the soil aggregates.
2. Transfer the sample to a nest of five sieves having the following mesh sizes (B.S.S.):
20, 38, 80, 120 and 200 $\frac{1}{2}$
3. Shake the sieve nest for five minutes.
4. Separate and weigh the six sized-fractions.

X Mesh Size (B.S.S.):	20	38	80	120	200
Diameter (mm.)	1.04	0.53	0.20	0.11	0.05
