Low-density geochemical reconnaissance in Peru to delineate individual mineral deposits

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Synopsis
Stream-sediment sampling with analysis of the −80 BSS mesh fraction was the principal method used for geochemical reconnaissance exploration of part of the Western Cordilleran polymetallic belt in northern Peru. The area, which comprises 25 000 km² of highly dissected terrain, was thought to be particularly favourable for copper porphyry mineralization. An initial spacing of one sample every 10 km, along suitable drainage channels, was selected on the basis of an orientation survey (which included consideration of logistic factors), and proved adequate for the successful detection of large individual deposits in this environment. Various methods of data processing were investigated; simple graphical procedures were effective in the interpretation of the results of this type of drainage reconnaissance.

Four important new centres of copper mineralization were discovered by anomalous dispersion trains up to 19 km in length. Consequently, the three known major deposits in northernmost Peru can be seen as part of a more extensive mineralized belt, probably extending into Ecuador. It is concluded that, in certain circumstances, geochemical drainage surveys based on densities as low as one sample per 25 km² can be effective for identification of discrete deposits, in addition to delineation of mineralized districts or belts.

A geochemical drainage reconnaissance of part of the Andean belt of northern Peru was undertaken, mainly from 1969 to 1971 in conjunction with regional geological mapping, under a technical cooperation programme between the United Kingdom and Peru. The objectives were the preliminary exploration of the northern sector of the Western Cordillera and assessment of the overall mineral potential of this poorly known part of the polymetallic province.

A detailed, systematic geochemical survey of the whole region was impracticable within the time and resources available; therefore, after an initial orientation survey, representative stream-sediment sampling was undertaken at a low density to delineate discrete mineral deposits of possible economic significance. Principal assumptions were, first, that a sample represented the whole area of the drainage basin above the site,[9,19] and, second, that metal dispersion from large orebodies of the copper porphyry type would remain anomalous for considerable distances downstream, given favourable conditions of active erosion and drainage.[5,6,8,9] It was also thought that significant anomalies related to important mineralization would be identifiable without subdivision of the data into geochemical populations on the basis of lithology or other parameters, since at the density chosen most samples would relate to two or more lithologies.

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To achieve some degree of control and uniformity in the geochemical reconnaissance of this unexplored region, sample sites were pre-selected at the required intervals and on the basis of stream order.[12] Analysis was carried out only for the relatively few elements likely to be of prime importance. Initially, simple graphical-statistical methods were employed to interpret the data and define areas for more detailed exploration. Subdivision into geochemical populations, based on geological and physiographical parameters, was carried out later to assess the value of such grouping techniques in interpretation of the data from this low-density mineral reconnaissance survey.

Situation and physical characteristics of region

The area, which covers some 25 000 km² of deeply dissected terrain astride the continental divide in northern Peru, includes most of the Western Cordillera between the coastal desert in the west and the sub-tropical Marañon canyon in the east (Fig. 1). The altitude ranges from

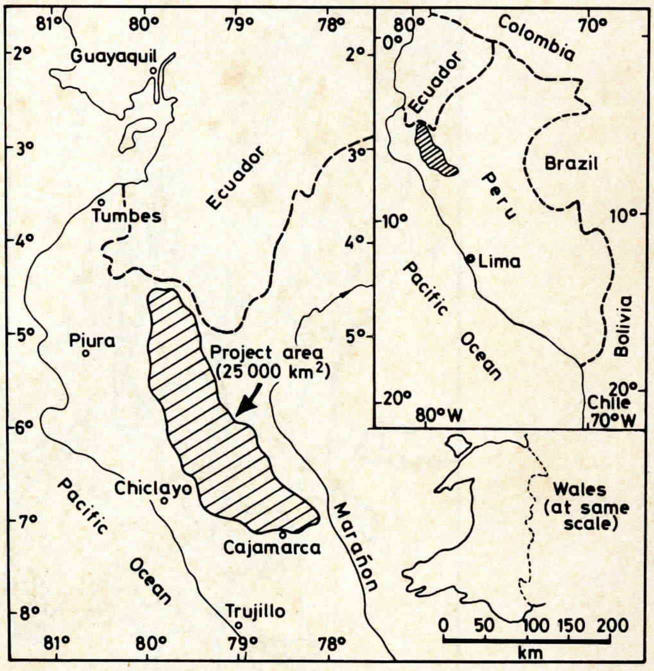


Fig. 1 Location of project area

< 200 m to > 4500 m; vegetation varies from none through hill scrub to thick mountain and sub-tropical forest. The mountain belt has a temperate to cold climate. The western (Pacific) slope is almost totally dry; precipitation increases generally northwards and eastwards.

Many of the short streams on the Pacific side of the continental divide are ephemeral; few of the major rivers maintain a perennial flow. Almost all of these are youthful, have steep to very steep gradients and in many places contain very little deposited sediment of any sort. Streams on the Amazonian side generally flow for much of the year, and the main rivers maintain a considerable perennial flow. Most are youthful, but several rivers with the characteristics of old age have been preserved on remnants of uplifted, mature erosion surfaces.

Geological summary

The area covers part of the main Andean orogenic belt and is geologically complex. It includes part of the westward bulge of the Andes known as the 'Huancabamba deflection': this reflects the southern end of a structurally positive geanticline, along which the Andean strike changes from the northwesterly Peruvian trend to northerly, preparatory to swinging to the northeasterly Ecuadorian trend further north.[4] Lower Palaeozoic metamorphics, various Mesozoic sediments — particularly Cretaceous limestones and clastics — and Tertiary volcanics are exposed, together with the Lower Tertiary plutonics of the coastal batholith and other isolated intrusives (Fig. 2).

survey was designed to locate other discrete mineral deposits, rather than to delineate broad mineralized provinces or belts, as that has been successfully achieved previously.[1,7,15]

Orientation surveys

DISPERSION FROM A KNOWN COPPER PORPHYRY

Michiquillay, a proven orebody of more than 500 000 000 tons with a grade of 0.7% Cu, lies in the south of the project area near Cajamarca.[10] No exploitation had been undertaken at the time of

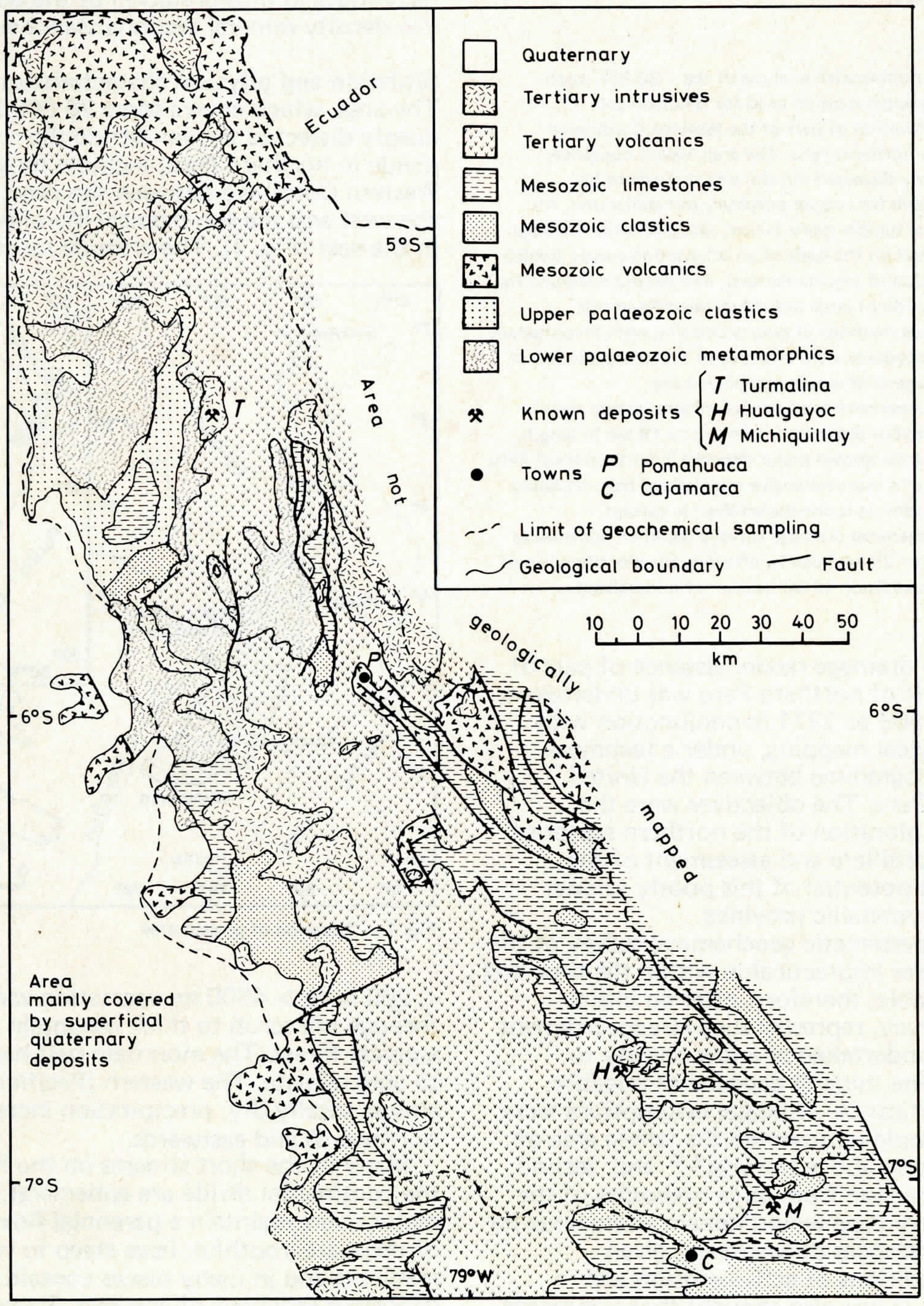


Fig. 2 Generalized geology of Western Cordillera, northernmost Peru

The major mines or mining districts of Michiquillay (copper porphyry), Hualgayoc (polymetallic veins) and Turmalina (breccia-pipe) are located in the area.[2,4] This northernmost sector of the Western Cordilleran polymetallic belt was therefore considered likely to contain other, perhaps similar, and hitherto unknown deposits. Accordingly, the low-density geochemical drainage

the orientation survey, which comprised detailed sampling (at 100- to 200-m intervals) of the main drainage channels around the orebody. The distributions of high levels of copper, and to a lesser extent molybdenum, in the −80 BS mesh fraction of the stream-sediment samples were found to be erratic, but geochemical dispersion below the deposit was recognizable for considerable distances despite the presence of limestone country rocks. With few exceptions, hot-extractable copper and molybdenum values were higher than local

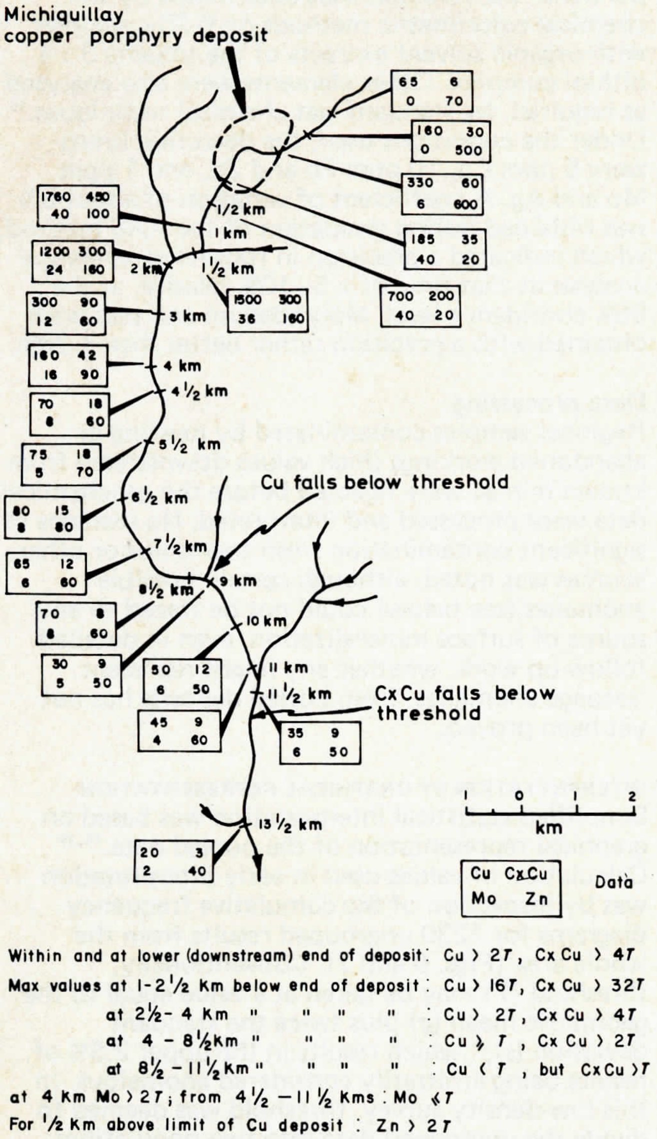


Fig. 3 Orientation survey at Michiquillay copper porphyry: threshold (*T*), upper limit of local background values

background (10–50 ppm Cu and 1–6 ppm Mo) for at least 8 km, and cold-extractable copper values for almost 12 km (Fig. 3). High zinc (and cold-extractable heavy metal) results were found in the marginal samples above the orebody – perhaps a reflection of a primary dispersion halo. The general correlation between hot- and cold-extractable metal data suggests that the mode of secondary dispersion was dominantly by chemical means (solution), rather than mechanical. It was concluded that a deposit of the same order of magnitude as Michiquillay, in a more or less similar environment, should give a recognizable stream-sediment anomaly for about 8–12 km. Sampling at a separation of not more than 10 km, and preferably closer (5–8 km) in a limestone environment, was therefore chosen for the regional survey. Cold-extractable results show rather better contrast than hot-extractable data (Fig. 3): routine determinations were therefore carried out on (sieved) regional samples.

LITHOLOGICAL AND SEASONAL FACTORS

An initial attempt to ascertain the effects of lithology on geochemical dispersion met with little success, since little reliable geological information was available at the commencement of the survey. From inspection of the data it was confirmed that thick limestone formations, which produce alkaline waters (pH 7.5–8.2), would tend to reduce copper solubility, and thus to shorten anomalous dispersion trains.

Various streams were also sampled at different periods during the first year of regional collection, to assess seasonal factors. Evidently, geochemical values can be affected to some extent, but seasonal variations (Table 1) are small compared with overall data variability, including inherent sampling and analytical errors.

Regional sampling

Sediments from sixth-order and large fifth-order rivers were considered to be derived from drainage basins that were too large for meaningful geochemical interpretation. Short second-order and all first-order tributaries had drainage basins that covered areas too small for reconnaissance survey purposes. Stream-sediment collection was therefore restricted to the longer second-order, and to third-, fourth- and the upper parts of fifth-order channels. By a determination of the average lengths and numbers of streams of different order (Fig. 4),

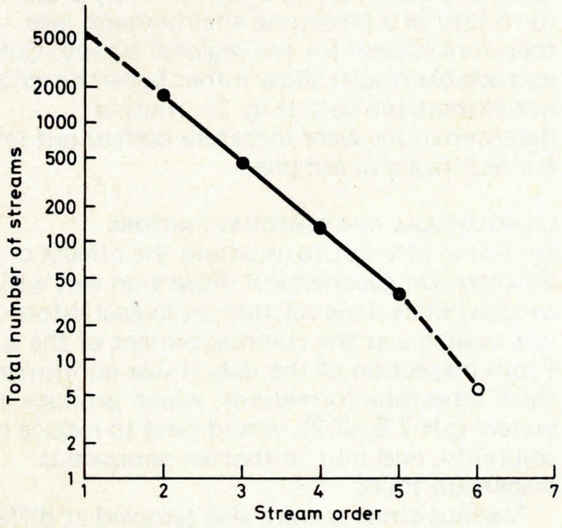
Table 1 Effects of seasonal factors on analytical data from regional samples

Late dry-season (minimum flow)			Early wet-season			Late wet-season (maximum flow)		
Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
	Collector A			Collector B			Collector B	
40	30	140	40	30	130	40	50	150
30	40	150	30	30	190	–	–	–
70	40	100	55	30	90	–	–	–
70	70	150	80	70	150	90	70	150
40	40	70	35	40	70	40	50	80
–	–	–	15	30	140	20	20	200
–	–	–	15	40	200	20	30	240
30	40	40	45	40	60	–	–	–
40	40	40	55	10	50	–	–	–
20	40	70	25	30	80	–	–	–
55	30	50	55	30	50	–	–	–

– Locality not sampled at appropriate season.

some 10 000 km of drainage channels were identified as suitable for sampling, at approximately 10-km intervals, which resulted in a mean minimum density of 1 per 25 km^2 (1 per 10 square miles). This spacing was improved in limestone environments, so that 1260 pre-selected sites were sampled.

In dry channels, the latest river-transported silt or fine sand from just below the surface was collected. In flowing streams, sampling relatively close to banks was necessary, as the centre of the



No: Pacific drainage	1084	261	70	20	4
No: Amazon drainage	762	201	58	18	2
Average length, km	3	6	11	16	40
Range of lengths, km	1-12	3-20	5-35	8-40	20-85
	Range sampled				

Fig. 4 Frequency of stream order[12] and range of drainage channels sampled during regional collecting

channel generally yielded nothing except coarse grit. The amount of material collected varied between 0.25 and 0.5 kg, theoretically according to grain-size but in practice rather irregularly. Wet or dry sample sieving at site was tested in early orientation work, but was not of sufficient advantage to be adopted for regional collection. Routine measurements of pH at sample sites could not be made, but one example of the importance of this factor was documented during follow-up work. Fig. 5 shows the rapid increase in extractable heavy metals from sediments below the influx of relatively more alkaline (higher pH) waters, which evidently caused a decrease in the solubility and mobility of lead and zinc, with a consequent increase in geochemical contrast below the tributary junction.

Analytical methods

Samples were returned to the laboratory for drying. After sieving, the −80 mesh material was split into two halves, of which one was retained for analytical training purposes. A small proportion of the other half was used to carry out rapid cold-extractable tests,[3,11] and the remainder was sent for atomic absorption spectrophotometry (AAS) analysis. Analysis of the −150 mesh fraction would have required collection of very large samples, and was considered impractical for the regional survey.

Copper, lead, zinc and silver were determined by standard AAS analysis at the I.G.S. laboratories, London. The metals were extracted with a 3 + 1 mixture of nitric and perchloric acids on 0.5-g portions. Molybdenum was determined by wet chemical colorimetric methods on 0.25-g samples with organic solvent extracts of the toluene 3 : 4 dithiol complex. Other elements were also analysed as required, by standard wet chemical techniques.[18] Under the conditions used, the detection limits were 5 ppm Cu, 10 ppm Pb and Zn, and 1 ppm Mo and Ag. A coefficient of variation of about 5% was obtained during evaluation of the AAS method, which indicated a precision in routine geochemical analysis at that time of ± 5—10% relative, at the 95% confidence level. Molybdenum analyses were obtained with a precision rather better than ± 20%.

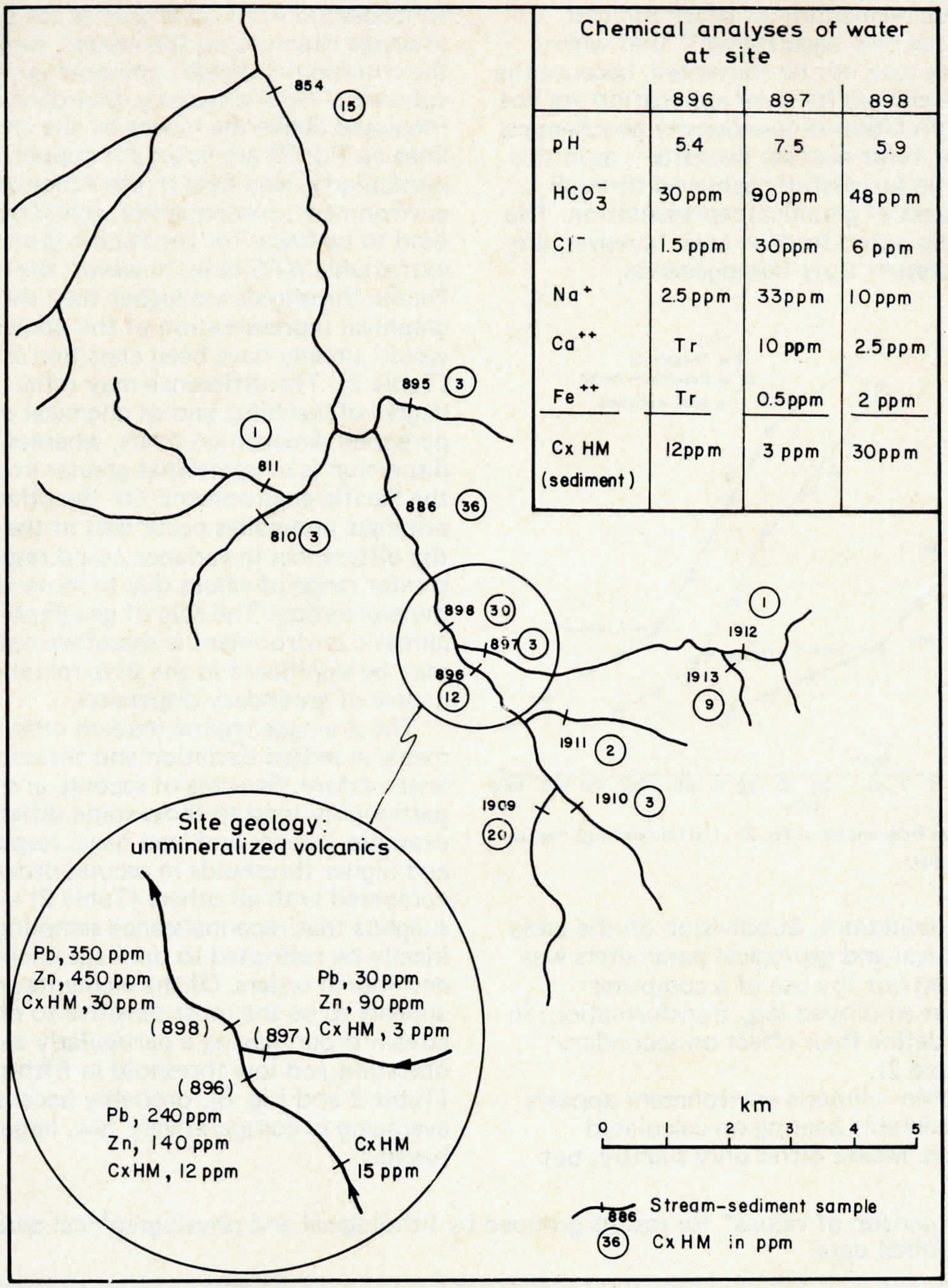
Data processing

Regional samples contaminated by existing or abandoned workings (high values downstream from known mines) were rejected before the geochemical data were processed and interpreted. No instance of significant contamination from townships or other sources was noted, although certain possible anomalies (see below) could not be traced to any source of surface mineralization, even in detailed follow-up work; whether any might represent 'seepage anomalies' from buried deposits has not yet been proved.

INTERPRETATION BY GRAPHICAL REPRESENTATION

Simplified statistical interpretation was based on graphical representation of the pooled data.[14,19] Calculation of values used in early interpretation was by inspection of the cumulative frequency diagrams for 1230 ungrouped results from the whole area (Figs. 6 and 7). Conventionally, threshold (T) may be taken at a value equal to the geometric mean (g) plus twice the standard deviation (s),[9] which results in the upper 2.5% of results being arbitrarily considered anomalous. In this low-density survey, threshold was deemed to divide the ungrouped data into two populations: the higher values (above threshold) perhaps reflect mineralized environments anomalous in terms of regional background. Lower (background) values may represent one or more populations, almost certainly unrelated to mineralization.

The main part of the copper population has an approximately lognormal distribution, which gives a straight cumulative frequency line at low values in the logtransform (Fig. 6). The break of slope, however, indicates an excess of high values compared with an ideal overall lognormal pattern, and reflects the level above which copper values were considered anomalous (4% of the total population) — threshold was taken at the inflection point, 70 ppm Cu. A 'conventional' threshold value at $g + 2s$ could be read off the main line of slope produced to higher values, giving 90 ppm at 2.5%; but this takes no account of the break in slope, which was considered to reflect either two separate populations (divided at the break point as drawn in Fig. 6) or at least some departure from lognormality (positive skew). Calculated values that assume a truly lognormal distribution are therefore not necessarily more appropriate for meaningful interpretation than those derived from inspection of the cumulative frequency diagram.



	896	897	898
pH	5.4	7.5	5.9
HCO_3^-	30 ppm	90 ppm	48 ppm
Cl^-	1.5 ppm	30 ppm	6 ppm
Na^+	2.5 ppm	33 ppm	10 ppm
Ca^{++}	Tr	10 ppm	2.5 ppm
Fe^{++}	Tr	0.5 ppm	2 ppm
Cx HM (sediment)	12 ppm	3 ppm	30 ppm

Fig. 5 Example of effect of pH on metal precipitation and anomaly intensity

Data for other elements were treated in a similar way; but following Lepeltier's[14] reasoning, thresholds were empirically fixed at the conventional $g + 2s$ value if the upper inflection points on the cumulative frequency diagrams occurred below the 2.5% level, so that the possibility that anomalous results might be overlooked was reduced. The thresholds obtained in this way for early interpretation of the data were: 70 ppm Cu (inflection), 8 ppm CxCu ($g + 2s$) and 8 ppm Mo ($g + 2s$), from Fig. 6; 80 ppm Pb ($g + 2s$), 150 ppm Zn (inflection), 2.5 ppm Ag (inflection) and 10 ppm CxHM (inflection), from Fig. 7.

INTERPRETATION OF GROUPED DATA

Statistical methods such as rolling mean, trend surface and factor analysis are useful for the interpretation of geochemical data in many cases.[17] Reasonably uniform sample coverage and analytical results for numerous elements are prerequisites for maximum effectiveness of these methods, although statistical treatment of low-density data has been

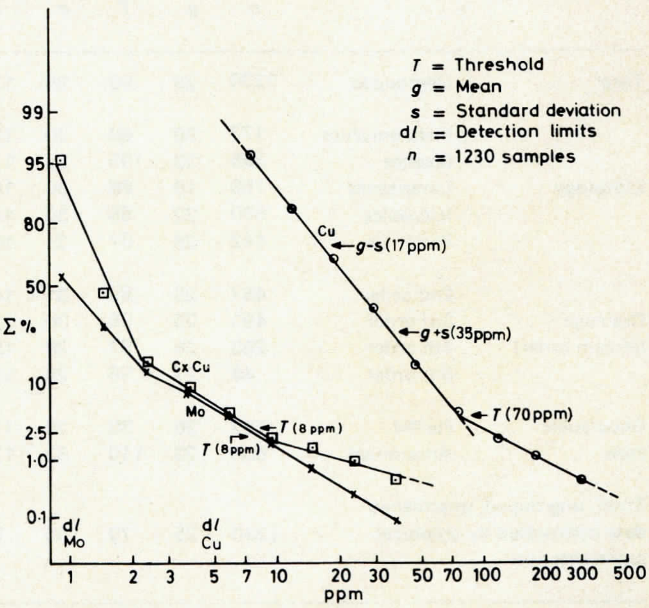


Fig. 6 Cumulative frequencies of Cu, CxCu and Mo results (0.2 log class intervals) (see also Fig. 9)

employed in the delineation of broad mineral districts.[1,7] It has also been shown[19] that where such techniques may not be warranted, because the principal requirements for their application are not satisfied, interpretation of low-density geochemical data in the search for discrete deposits – as in this survey – may be successfully achieved through simple procedures of graphical representation. The results from this varied Andean area, however, are unlikely to represent truly homogeneous

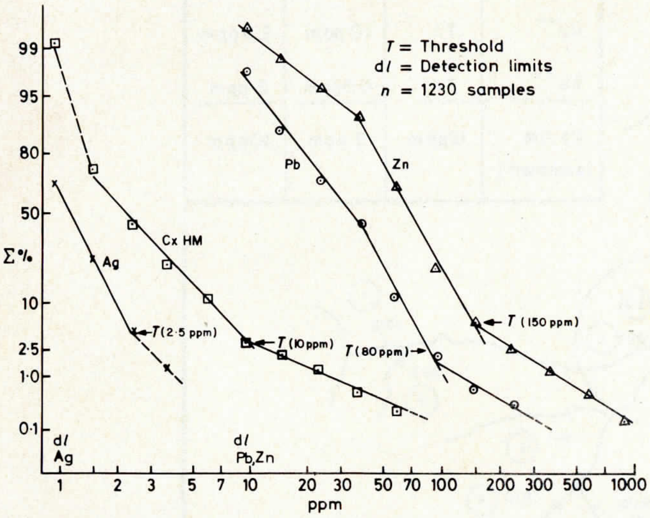


Fig. 7 Cumulative frequencies of Pb, Zn, CxHM (and Ag) results (0.2 log class intervals)

geochemical populations. Subdivision on the basis of physiographical and geological parameters was therefore carried out (by use of a computer programme that employed $\log_e$ transformation) in an attempt to define their effect on secondary dispersion (Table 2).

The geographic–climatic environment appears to have a considerable bearing on calculated threshold values. Means differ only slightly, but variances are in all cases greater for the perennial drainage channels on the wetter, Amazonian side of the continental divide compared with the ephemeral Pacific streams. Standard deviations (depicted above the means by the lengths of thin lines on Fig. 8) are larger for copper, zinc and, particularly, lead data in the Amazonian environment; consequently, calculated thresholds tend to be lower for the Pacific group. For hot-extractable AAS data, however, the calculated Pacific thresholds are higher than those derived by graphical representation of the pooled data, and would already have been classified as anomalous (Table 2). The difference may reflect a higher degree of leaching, and of chemical mobility in the perennial Amazonian rivers, whereas mechanical dispersion is of somewhat greater importance in the Pacific environment. On the other hand, several principal anomalies occur east of the divide, so that the differences in variance could result from a greater range of values due to more widespread mineralization. The role of geographical and climatic environment is therefore not proved, but may be significant in the determination of the course of secondary dispersion.

The drainage regime (stream order) affects the mean, standard deviation and threshold values to a lesser extent. Streams of second- and fifth- order particularly tend to show some differences: for example, copper and lead have, respectively, lower and higher thresholds in second-order streams compared with all others (Table 2) – perhaps this suggests that reconnaissance sampling should ideally be restricted to drainage channels of third and fourth orders. Of the elements analysed, zinc appears to be the most sensitive to differences of stream order, having a particularly small standard deviation and low threshold in fifth-order rivers (Table 2 and Fig. 8), probably because of simple averaging in comparatively few, large drainage basins.

Table 2 Comparison of values* for results grouped by lithological and physiographical parameters and for ungrouped (pooled) data

Parameter	Group	No	Cu		Pb		Zn		Ag		Mo		CxHM		CxCu	
		n	*g*	*T*	*g*	*T*	*g*	*T*	*g*	*T*	*g*	*T*	*g*	*T*	*g*	*T*
Total	Ungrouped	1230	25	93	30	135	67	230	1.8	5	1.8	6	3.5	11	2.5	7
	Metamorphics	173	30	88	30	125	75	105	1.6	4	1.5	5	3.6	8	2.8	6
	Clastics	235	33	105	33	170	80	260	1.9	5	1.9	8	4.0	11	2.8	7
Lithology	Limestones	150	19	66	39	147	61	242	2.2	6	2.0	8	3.2	10	2.3	6
	Volcanics	530	22	85	30	140	62	223	1.8	4	1.8	6	2.4	12	2.5	8
	Plutonics	142	28	97	21	109	61	150	1.5	4	1.7	7	3.5	8	2.7	7
	2nd order	487	25	89	31	146	63	234	1.8	4	1.7	6	3.5	10	2.5	6
Drainage	3rd order	492	25	98	30	131	69	218	1.8	5	1.8	6	3.6	11	2.6	8
(stream order)	4th order	203	26	97	29	133	70	241	1.8	5	1.9	7	3.5	12	2.7	9
	5th order	48	27	98	26	134	63	148	1.8	4	1.9	5	3.2	9	2.6	7
Geographic zone	Pacific	722	26	80	28	115	68	208	1.8	5	1.7	6	3.5	9	2.5	6
	Amazonian	508	23	110	33	170	64	254	1.8	5	1.9	7	3.5	13	2.7	9
Total, ungrouped, unscreened data interpreted by graphical representation		1230	25	70	35	80	70	150	1	2.5	1	8	2	10	2	8

*Calculated by computer, with $\log_e$ transformation (unscreened), and values of $x + 1$ (one greater than analytical result), so as to include results below detection limits, despite small, absolute bias introduced in low-value means and thresholds (i.e. for Ag, Mo, CxCu, CxHM).

Wider variations result when the data are grouped into the five principal lithological categories (Fig. 8). Mean and threshold values are higher in populations that relate to clastic sediments than in those for volcanic or plutonic environments in which mineralization normally occurs (Table 2); the reason for this is not clear, but may be partly artificial, since highly anomalous (contaminated) values, mainly from the igneous groups, were rejected. Low mean and threshold values for copper in the limestone population were confirmed, but the volcanic group also shows comparatively low values. Other notable features, which may reflect primary geochemical differences or controls, include the small variance and low threshold of zinc in a metamorphic environment, and very low mean and threshold values for lead in plutonic rocks, in contrast to a high lead mean in the limestone

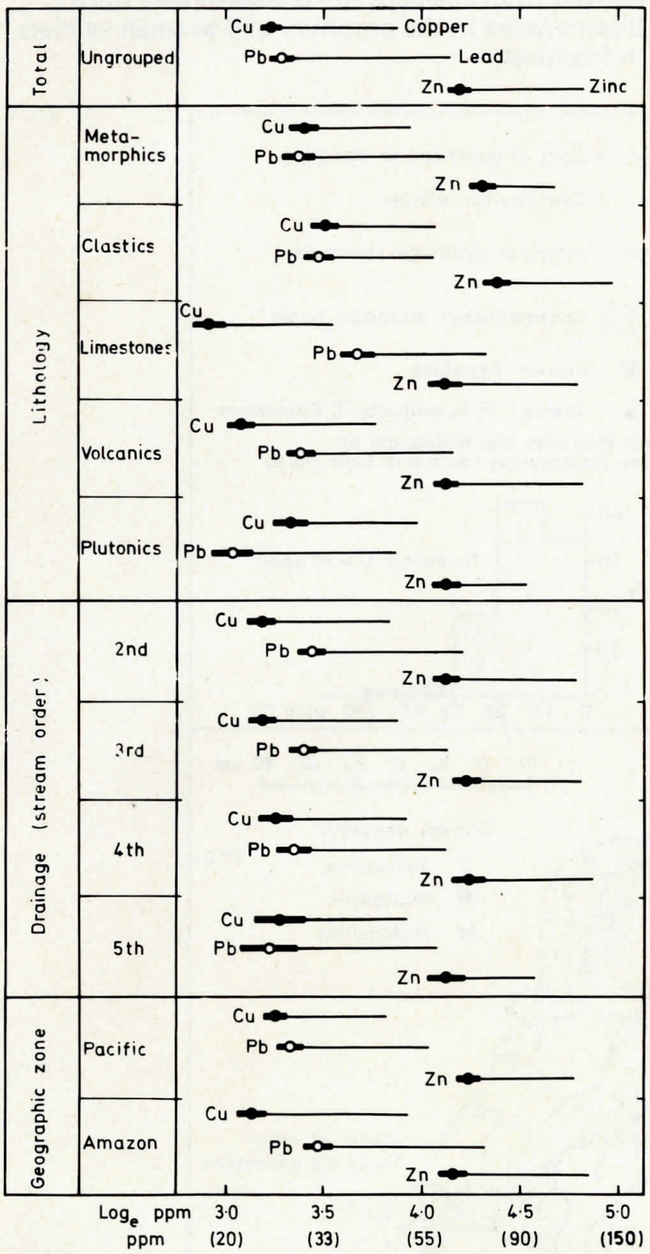


Fig. 8 Mean values (circles), standard errors of means (thick lines, plotted from circle edges) and half standard deviations (thin lines, above means) for grouped data

population (Table 2 and Fig. 8).

Since the principal objective was the discovery of individual mineral deposits, differences due to lithological control were considered to be of practical significance only if they were so large as to conceal possibly anomalous results in secondary dispersion patterns. Where a grouped population shows a true threshold level lower than that obtained graphically for the pooled data, there can be a real danger that significant anomalies may be overlooked. Of the hot-extractable AAS data, only copper in the limestone environment and zinc in the metamorphic population have such lower thresholds. But the difference between the 'copper-in-limestone' threshold (66 ppm) and the value derived by graphical representation of the pooled data (70 ppm) is small (Table 2). Two zinc–molybdenum anomalies in metamorphic terrain were traced to minor manganiferous and limonitic quartz veinlets: it is therefore unlikely that marginal anomalies related to significant zinc or molybdenum mineralization have been overlooked.

Data presentation and anomalies

The distribution patterns of elements over the large region covered by this low-density survey were represented in the form of isoline maps compiled on a lognormal basis, relative to threshold, as, for example, in the case of copper (Fig. 9). Where present, lower value inflection points on cumulative frequency curves – e.g. at 2 ppm Mo and CxCu (Fig. 6) and at 40 ppm Pb, 37 ppm Zn (Fig. 7) – were used to subdivide the results. Empirical lognormal divisions, based on threshold and on percentiles related to standard deviation from the means, were employed for lognormally distributed background data (i.e. those without lower inflections). Results above threshold were divided into 'possibly anomalous' ($> T$) or 'probably anomalous' ($> 2T$): the latter were further classified by inspection in order of priority for detailed investigation. Where a concentration of 'possible anomalies' was found, the area was selected for further regional sampling at closer spacing (one per km).

PRINCIPAL ANOMALIES

Several impressive copper anomalies were detected in widely separated areas during the regional exploration programme. Two (La Granja and Cañariaco) exhibit secondary dispersion trains longer than that from the Michiquillay copper porphyry. Dispersion from a third (Pandachi) is evidently much reduced, probably because of the local lithological (limestone) environment.

La Granja (A1)

Copper values of more than twice threshold persist for more than 12 km below the source area at La Granja, and even 19 km downstream the level remains at around threshold. Mineralization covers a relatively large area, and also gives rise to a weak molybdenum anomaly. Soil sampling and shallow pitting (along ridges and bases of slopes) yielded erratic but encouraging results, with values of 500–800 ppm Cu prevalent over the altered quartz-porphyry intrusive. .

Complex hydrothermal metasomatism evidently included important sericitization and minor argillization. Supergene limonite is widespread; in places this is jarositic and probably developed from low-grade pyritic ore, but much is hematitic and distinctly suggests derivation from significant copper mineralization. Fresh sulphides, including chalcocite which formed during a period of secondary enrichment, have been preserved locally near the surface. La Granja has many characteristics which suggest that it may be a large disseminated deposit of the copper porphyry type; no drilling has yet been carried out.

Cañariaco (A2)
Stream-sediment samples 17 km below the mineralized zone at Cañariaco yield anomalous copper results in a fourth-order river which, over that distance, descends from 3400 m to 1100 m. These physical conditions rather than primary factors, such as grade of mineralization, may account for the low maximum contrast. Geological reconnaissance proved that Cañariaco was an alteration zone related to a tonalitic porphyry stock intruding andesitic volcanics. Lead and, to a lesser extent, zinc also become anomalous near the source area, perhaps an indication of primary metal zoning around this characteristic alteration zone. Further detailed exploration, including preliminary drilling, has shown Cañariaco to be a typical copper porphyry and outlined more than 300 000 000 t of ore of a grade between 0.45 and 0.8% Cu.[16]

Pandachi (A3)
The copper anomaly at Pandachi has a high contrast, but persists for only a relatively short distance downstream. Values fall below threshold within 6 km, probably because a thick sequence of limestone below the source area results in relatively alkaline water and, therefore, in reduced copper solubility. A detailed geochemical survey showed, however, highly anomalous results ($> 16T$) in the first-order streams that drain a small porphyritic dacite stock. Alteration consists mainly of silicification, propylitization and sericitization; limonite which is hematitic and may be partly derived from chalcopyrite is widespread, both disseminated in the porphyry and as small veinlets in fractures.

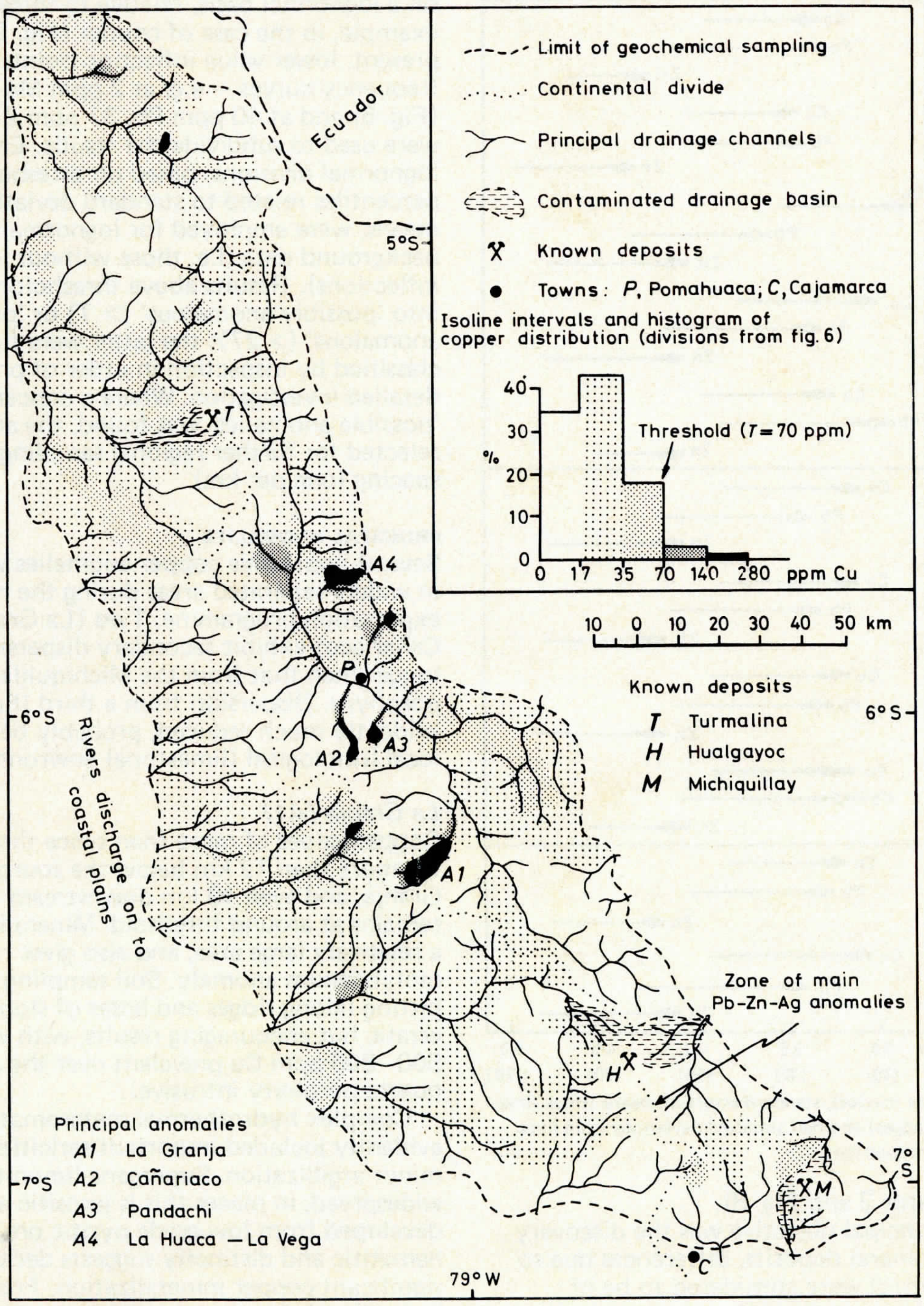


Fig. 9 Secondary dispersion of copper in stream sediments (divisions derived from Fig. 6)

La Huaca — La Vega (A4) and the Pomahuaca region

Nine anomalies were located in the Pomahuaca region, which suggested that the area might constitute a mineralized district. More detailed sampling was therefore carried out. The main drainage anomaly (A4 at La Huaca — La Vega) proved to originate, at least partly, from disseminated mineralization associated with two altered tonalitic quartz-porphyries; the first intruded Lower Tertiary dacitic volcanics close to a major north—south fault, and the second 'on' the edge of the granodioritic Pomahuaca batholith. Several of the other anomalies seem to reflect minor vein deposits that surround the stocks or 'occur along' the same fault. The upper section of the main anomaly was subsequently traced to its source, and evidently reflects yet another alteration zone (Paramo) to the east of the area mapped.[20] La Vega is small; the mineralization comprises disseminated pyrite and chalcopyrite with important molybdenite. La Huaca covers an area of some 4 km^2, and shows much greater secondary (chalcocite) enrichment, with values of up to 3% copper.[20] Recent mapping, trenching and some preliminary drilling indicate that this deposit is considerably larger and of higher grade than Cañariaco; evidently it contains enriched ore beneath a relatively thin leached overburden. It may prove to be one of the most important copper porphyry orebodies in northernmost Peru.

OTHER ANOMALIES

Various other Cu—Mo and Cu—Pb—Zn—Ag anomalies were delineated. In the extreme north, there are unproved geochemical indications of Cu—Mo mineralization at Lanchipampa (Fig. 10). A significant cluster of lead—zinc—silver anomalies, south of the existing Hualgayoc mining area (Fig. 9) and apparently unrelated to known or abandoned mines, may represent an extension of this important mineralized district. Most other minor (low-priority) anomalies were subsequently shown to be derived from sub-economic vein mineralization associated with the coastal batholith or with more isolated stocks intruding the Tertiary volcanics.

Conclusions

The reconnaissance exploration of a rugged area of some 25 000 km^2 for individual mineral deposits was accomplished through a low-density (and hence low-cost) geochemical drainage survey, which led directly to the discovery of several major

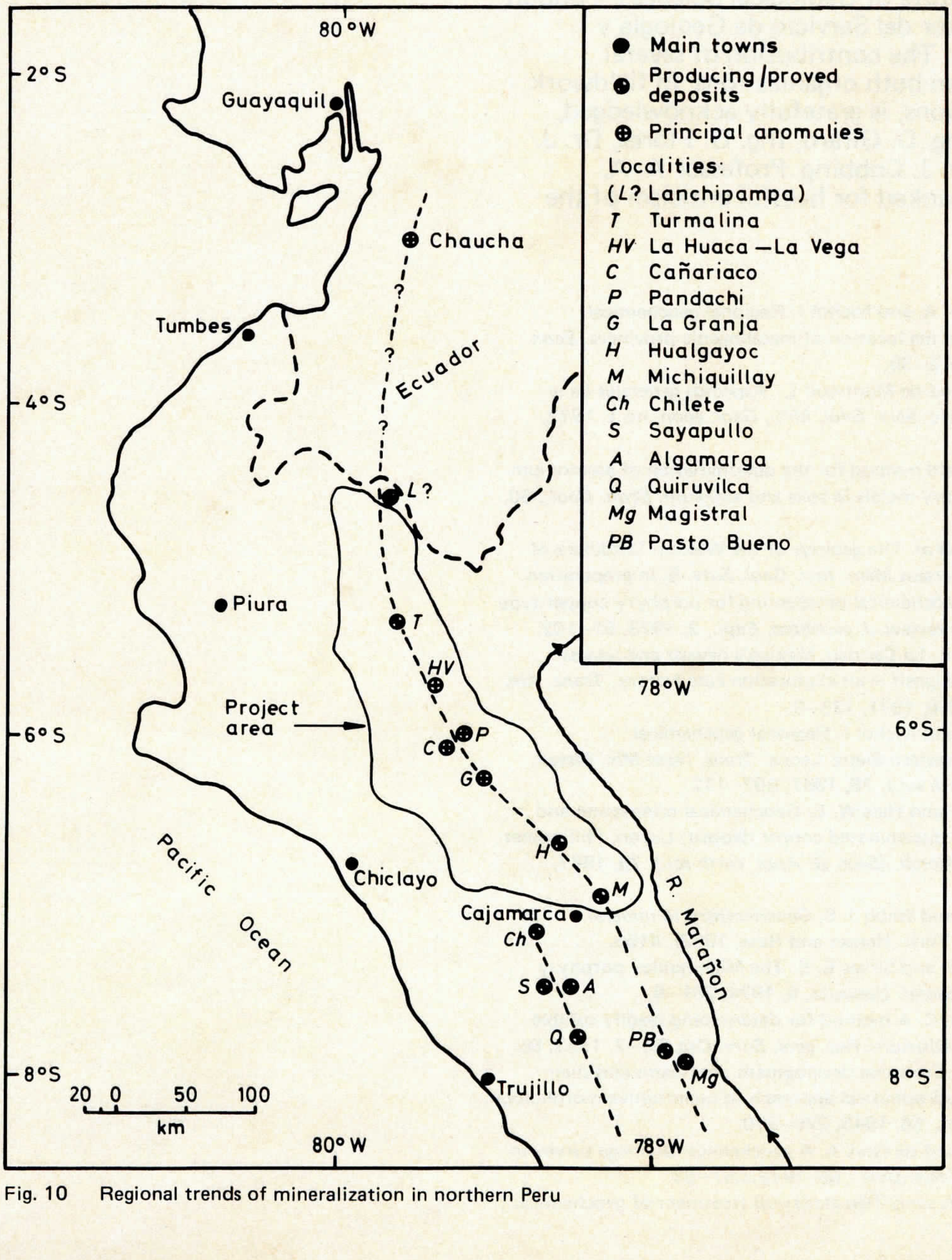


Fig. 10 Regional trends of mineralization in northern Peru

centres of mineralization. Under favourable conditions the use of similar reconnaissance sampling should be considered, even when the principal objective is the actual location of discrete orebodies rather than the delineation of broad mineralized districts.

Regional trends of fundamental significance were also outlined by the confirmation of the presence of a distinct belt of mainly cupriferous deposits in the Western Cordilleran polymetallic province of northernmost Peru – it perhaps continues into southern central Ecuador as far as Chaucha (Fig. 10).[13] That successful exploration of such a region was achieved through the collection of comparatively few, selected, stream-sediment samples again underlines the value of low-density geochemical reconnaissance, especially in areas of active erosion where geochemical mobility from large orebodies is likely to be at a maximum. Rapid drainage surveys, relying on an initial, but uniform, sample density of about one per 25 km^2, may therefore constitute a viable method of exploration for specific deposits, particularly of the copper porphyry type.

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