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Mobile Forms of Elements: Their Use in Geochemical Mapping and Exploration

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ABSTRACT

This short paper summarises some empirical aspects of mobile ion geochemical surveys; in particular, it highlights the significance of enrichment and depletion anomalies, which occur at all scales.

A new group of methods have been developed in various countries for exploring covered areas: MPF, CHIM, MDE, MMI, enzyme leaches, Fe and Mn oxide phase leaches (extraction) and others. All are based on the principle of selective extraction of the mobile and weakly bonded elements (MWBE). MWBE anomalies have their own specific qualities, the main one being a vertically-flowing migration of material from ore bodies. As a result, and MWBE anomaly is formed over an area broadly coinciding with the ore body's projected surface area (Antropova, 1992).

Information for the exploration of the geological situation at depth is, as a rule, limited to the registration of the MWBE anomaly.

On a larger scale, complex structures of geochemical fields of various metals can often be observed in covered areas. Regional surveys of large areas frequently reveal major linear structures, with significant sections containing increased or decreased concentrations of metals.

Figure 1 (a, b, c, d) contains part of a map (scale 1:500 000) showing geochemical fields of Ni, Mn, Zn and Ga. The area surveyed is in the northern part of the Bendigo-Ballarat Zone of Victoria, within the Lachlan Fold Belt of Eastern Australia. Overlying Murray Basin sediments are 20–50 m thick, and cover the gold-prospective Ordovician sedimentary rocks. The maps of the geochemical fields (one sample point per 5–6 km^2) show the distribution of metals (fulvate and humate) as found by the MPF method (Antropova *et al.*, 1992). Apparent is a complex linear structure of increased concentrations of Ni/C % up to 0.55 and Mn/C% up to 4.2 A strong direct correlation between these elements can be observed. The correlation coefficient is +0.74. In this zone Zn/C% and Ga/C% show a linear structure with a dramatically decreased concentration. The correlation Zn/C% with Mn/C% and Ni/C% is characterised by an inverse relationship. The correlation coefficient is –0.5 for Ni/C% and -0.46 for Mn/C%. The width of the linear submeridional structure of these three elements is approximately 7.5–10 km. It was monitored for 45 km in a meridional direction. Spatially, this structure is a continuation of the Ballarat-Wedderburn line (O'Shea *et al.*, 1992).

Another example shows the distribution of elements in the Sunshine area; the diagram covers some 1000 m^2 (one sample point per 5–6 km^2) within the Melbourne Zone, immediately to the east of the Bendigo-Ballarat Zone. Here the turbidite host rocks of Silurian-Ordovician age are covered by a Tertiary sand and clay overburden approximately 50–100 m in thickness, which in turn is covered by basalt flows 20–60 m in thickness. Here is a series of Ni/C% and V/C% local anomalies, grouped in linear mutually perpendicular zones, 5–7 km wide, northwest and northeast in direction, the former being more clearly defined. A strong, direct relationship can be noted between these elements. Their correlation coefficient is +0.71.

Another structure detected in the geochemical field is that of gold. The distribution of Au/C% has a cell structure, and is manifested as a combination of areas (cells) that contain positive concentrations, with other areas that contain decreased concentrations of Au/C%.

These combinations create areas that are polar in form, and can be connected into systems according to this principle. The size of such systems is approximately 100–150 km^2 (for a survey of this scale). In this region such systems are grouped into a zone which is approximately 15–20 km wide, has a north-northwest direction, and extends further.

It must be noted that such a cell structure can be observed when mapping geochemical fields of MWBE at all scales from regional (shown in Figures 2 a–c) to local (shown in Figure 2d). Figure 2d shows that this cell structure is repeated, and has a similar form to that for the larger system described above. Each system is composed of smaller cells / systems.

Several exploration holes (each about 200 m in length) have been drilled through basalt and Tertiary sand, clay and coal within the area of the detected positive anomalies at the Sunshine site, detecting significant gold mineralisation in the host rock.

The observed patterns within the geochemical fields of ore-forming elements, at various scales, are similar to each other. Such a pattern is connected to the manifestation of the characteristics of the fractal nature of the geochemical fields (Feder, 1991). The fractal nature of the

In "Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration" *edited by* A.G. Gubins, 1997, p. 365–370

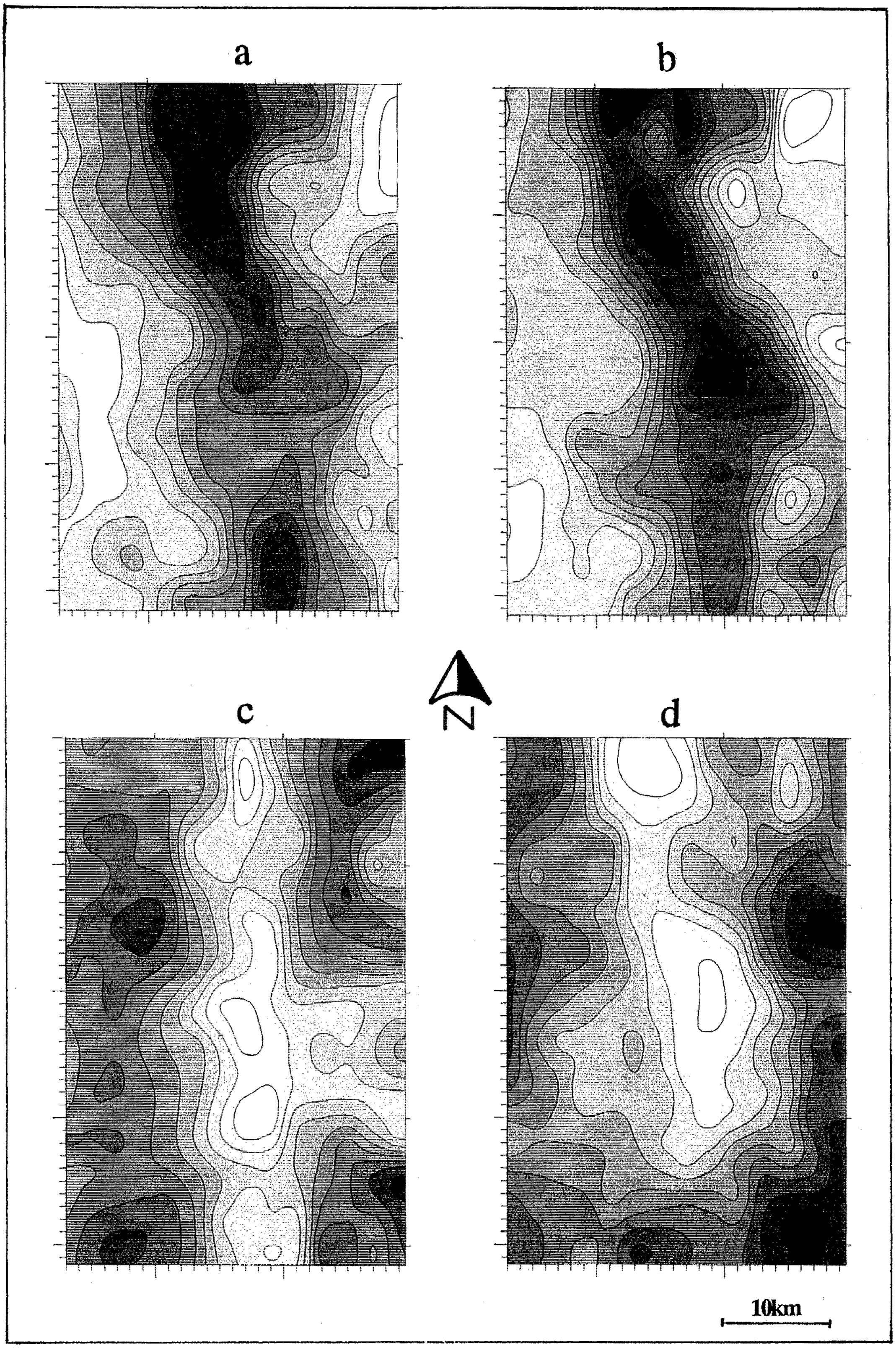

Figure 1: *A large linear geochemical structure (MPF data). Bendigo-Ballarat Zone, Victoria. Sedimentary cover (over 20 m). Scale: 1:500 000 Distribution of: (**a**) Ni/C%, (**b**) Mn/C%, (**c**) Zn/C% (**d**) Ga/C%.*

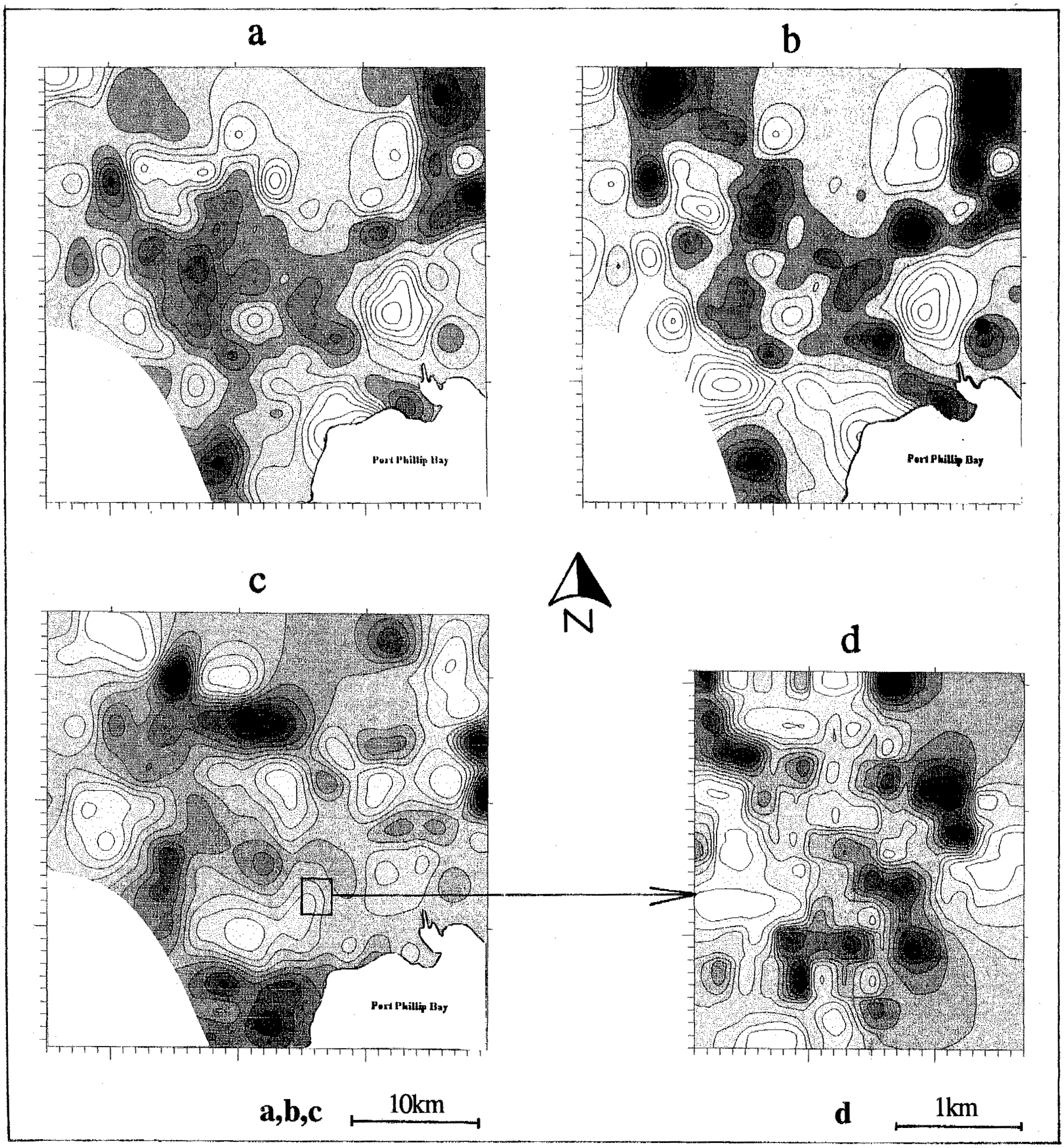

Figure 2: *The structure of a geochemical field (MPF data). Sunshine, Melbourne Zone, Victoria. Basalt and sedimentary cover (over 100 m) Scale 1:500 000. Distribution of: (**a**) Ni/C%, (**b**) V/C%, (**c**)Au/C% Scale 1: 50 000. Distribution of (**d**) Au/C%.*

geochemical fields supposes a very high level of variation of concentration in the space, and an absence of, among other things, broad low-amplitude positively anomalous areas.

The presence of such fields has been detected in the host rocks of ore regions. They are ubiquitous at all scales, and are distinguished by their size and various combinations of positive and negative anomalies. Most typical are dipolar structures, which can unify into bidipolar and polydipolar systems. The polar form of their manifestation, and the polar position in space of various groups of elements, suggest that the mechanism of their formation is electrochemical. Such systems are referred to as "geoelectrochemical systems" (Goldberg, 1993, 1995).

Experience on many mining fields has shown that the nature of a geoelectrochemical anomaly at surface largely reflects, the distribution of ore metals in the underlying host rocks. This is so even when the apparent source is deeply buried, or concealed under very thick overburden or volcanic cover. Several examples from published works are given below.

Figure 3 shows a traverse made with the CHIM method over a copper-nickel deposit in Montcalm Township, Ontario, Canada. Here the ore bodies are located in medium to coarse grained gabbro, and are covered by 20 m of till (Alekseyev *et al.*, 1996).

Figure 4 shows a traverse made with the MPF method over a lead-zinc deposit in Orlovskoye, Kazakhstan. Here the ore bodies are located in sedimentary and effusive rocks, and are covered by unconsolidated clay and sand (Antropova, 1972).

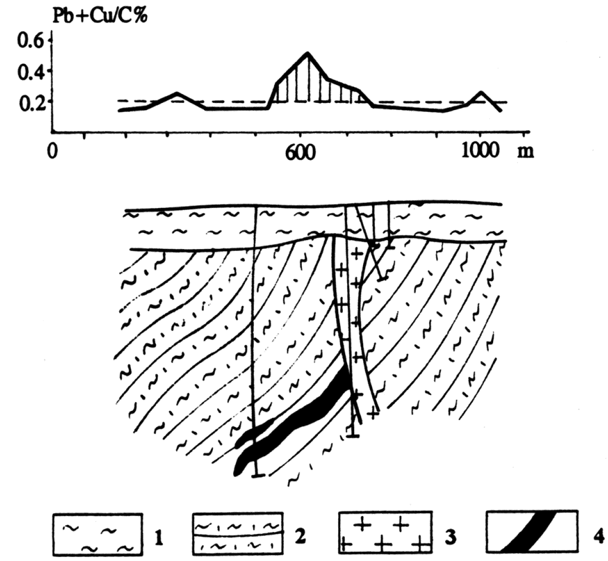

Figure 4: *MPF. Pb-Zn ore deposit, Orlovskoye, Kazakhstan. 1. Overburden. 2. Sedimentary-effusive rocks 3. Granitic dyke 4. Pb-Zn deposit.*

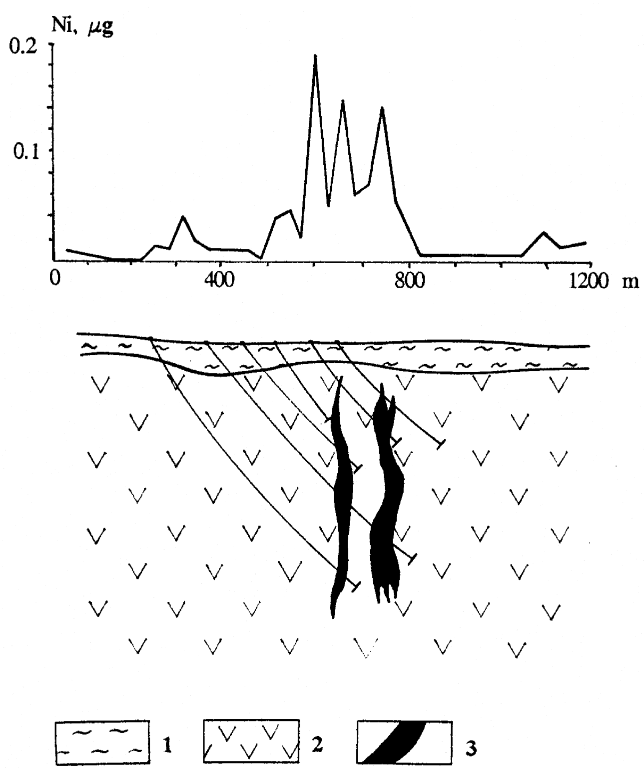

Figure 3: *Results obtained employing CHIM. Ni-Cu deposit, Montcalm Township, Ontario, Canada. 1. Overburden. 2. Gabbro 3. Ni-Cu deposit.*

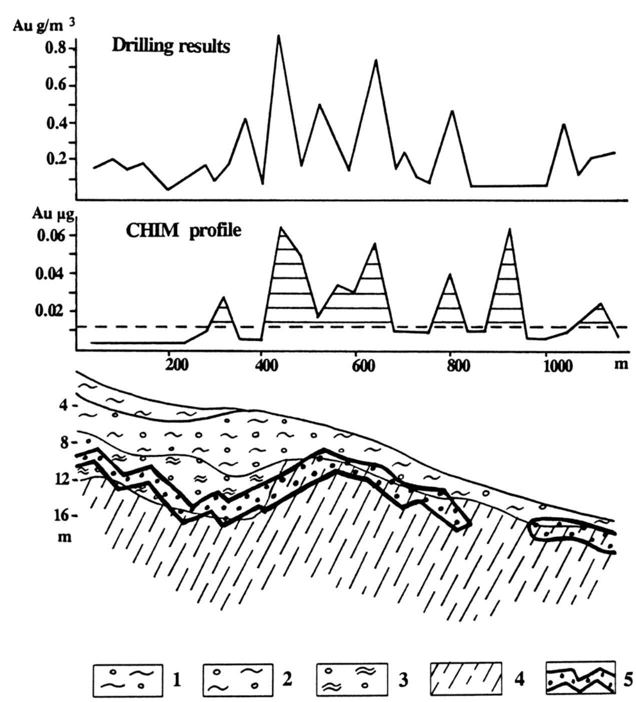

Figure 5: *Results obtained employing the geoelectrochemical CHIM method over an alluvial gold deposit. East Partisan, Siberia. 1. Alluvium (recent). 2-3. Alluvium (ancient). 2. Sand-rich. 3. Clay-rich. 4. Alluvial gold zone.*

Ore bodies containing extremely low metal concentrations can also be detected by the mobile ion methods; this includes primary and alluvial gold deposits. It is not uncommon for gold in these deposits to be localized in the form of separate, unconnected fine particles. For example, Figure 5 shows a survey done over buried alluvial gold in East Partisan, Siberia, where the gold content does not exceed 1 g / m^3.

On both regional and detailed maps positive geochemical gold anomalies have been detected, in which the concentration in rocks is still lower. Negative anomalies are also detected, and are believed to represent extremely low concentrations at depth.

The statistical distribution of mobile forms of elements is heterogenous, and reflects the presence of various levels of concentration (Los and Norseev, 1984). Figure 6 shows a fairly typical histogram of gold distribution for the sites with thick overburden in the Murray Basin area, Victoria, Australia. It clearly shows the groups of samples with depleted, normal and anomalously increased concentration.

This gives the impression of a flow of mobile forms of the elements through the overburden, forming a complex structure of MWBE on the surface, to some degree reflecting the geochemical structure of the underlying rocks.

We have reached the point at which there are numerous questions that are yet to be answered. The key questions are:

- the dynamics of the transition of elements into a mobile state, and their relationship with the macro-components;
- the mechanism of the migration to the surface of elements in low and extremely low levels of concentration, and their transformation in the surface deposits;
- the influence of the overburden on the movement of mobile forms of elements.

The accumulation of experience in the use of geoelectrochemical methods such as MPF, CHIM, TMGM and MDE, as well as other broadly similar methods, makes their wider implementation more possible. The methods can be used for:

- mineral exploration,
- geochemical mapping in covered areas for the detection of regional geological features,
- detecting geoelectrochemical systems of different scales,
- Multipurpose environmental research, including the choice of locations for construction, or the burial of toxic, radioactive and other forms of waste,
- earthquake prediction.

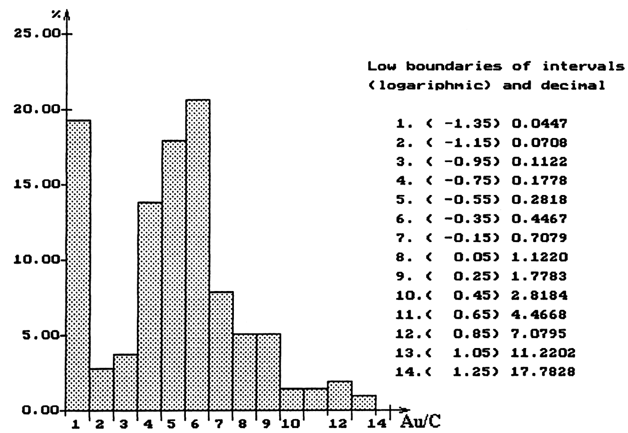

Figure 6: *Histogram. Distribution of Au/C% in soil (MPF data. 231 samples). Bendigo-Ballarat Zone, Victoria.*

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