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SECONDARY DISPERSION ABOUT THE WATERLOO POLMETALLIC DEPOSIT, MT WINDSOR SUB-PROVINCE, N.E. QUEENSLAND

K.M. Scott

CRC LEME OPEN FILE REPORT 126

April 2002

CRCLEME

(CSIRO Exploration and Mining Report 168R, 1995.
2nd Impression 2002.)

CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, University of Canberra, Geoscience Australia, Bureau of Rural Sciences, Primary Industries and Resources SA, NSW Department of Mineral Resources-Geological Survey and Minerals Council of Australia, established and supported under the Australian Government's Cooperative Research Centres Program.

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CSIRO/CRC LEME/AMIRA PROJECT P417
GEOCHEMICAL EXPLORATION IN REGOLITH-DOMINATED TERRAIN, NORTH QUEENSLAND 1994-1997

In 1994, CSIRO commenced a multi-client research project in regolith geology and geochemistry in North Queensland, supported by 11 mining companies, through the Australian Mineral Industries Research Association Limited (AMIRA). This research project, "Geochemical Exploration in Regolith-Dominated Terrain, North Queensland" had the aim of substantially improving geochemical methods of exploring for base metals and gold deposits under cover or obscured by deep weathering in selected areas within (a) the Mt Isa region and (b) the Charters Towers - North Drummond Basin region.

In July 1995, this project was incorporated into the research programs of CRC LEME, which provided an expanded staffing, not only from CSIRO but also from the Australian Geological Survey Organisation, University of Queensland and the Queensland Department of Minerals and Energy. The project, operated from nodes in Perth, Brisbane, Canberra and Sydney, was led by Dr R.R. Anand. It was commenced on 1st April 1994 and concluded in December 1997. The project involved regional mapping (three areas), district scale mapping (seven areas), local scale mapping (six areas), geochemical dispersion studies (fifteen sites) and geochronological studies (eleven sites). It carried the experience gained from the Yilgarn (see CRC LEME Open File Reports 1-75 and 86-112) across the continent and expanded upon it.

Although the confidentiality period of Project P417 expired in mid 2000, the reports have not been released previously. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authority to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian mineral industry.

This report (CRC LEME Open File Report 126) is a second impression (second printing) of CSIRO, Division of Exploration and Mining Restricted Report 168R, first issued in 1995, which formed part of the CSIRO/AMIRA Project P417.

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PREFACE

The CSIRO-AMIRA Project "Geochemical exploration in regolith-dominated terrain of North Queensland" (P 417) has, as its overall aim, to substantially improve geochemical methods of exploring for base metals and gold deposits under cover or obscured by deep weathering. The Project has two main themes which are *Regolith characterisation* and *Geochemical dispersion for detection of concealed deposits.* This report covers both these aspects at the Waterloo deposit in the Charters Towers area.

A variety of sedimentary materials comprise the transported cover in the Charters Towers-Drummond Basin region. Because of the widespread distribution of these cover sequences, there is considerable interest in the use of transported material as a sampling medium in the region. The Waterloo deposit has a thick cover of Campaspe Formation and a dispersion halo has been reported within this cover. The significance of this halo has been critically investigated by studying the mineralogy and geochemistry of profiles through the Campaspe Formation and into the underlying volcanics.

Mineralogical and geochemical data from regolith profiles suggest that the Campsape Formation is 20-25 m thick rather than up to 50 m, as originally logged in some drilling along the studied section. The Campaspe Formation is characterised by feldspar- and smectite-bearing rocks overlying a 20 m interval where feldspar is absent and kaolinite is the dominant clay. Bands of dolomite and Fe oxides are present immediately beneath the feldspar-bearing Campaspe Formation. It is suggested that the anomalous levels of Pb and Ba occurring immediately beneath the Campaspe Formation represent the occurrence of secondary minerals mechanically transported from secondary mineralisation which cropped out prior to deposition of the Campaspe Formation. Alternatively Pb may be dispersed hydromorphically or residually accumulated during weathering processes and concentrated into the Fe-rich bands below the Campaspe Formation. Zinc and Cu are mobilised during weathering and form a wide dispersion halo about the mineralisation but such an anomaly is restricted to the weathered volcanics.

R.R. Anand, Project Leader
I.D.M. Robertson, Deputy Leader

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SUMMARY

Zinc-rich polymetallic mineralization occurs as steeply dipping lenses at a number of locations within the Cambro-Ordovician Trooper Creek Formation of the Mt Windsor Sub-province, south of Charters Towers. Such mineralization is, however, often obscured by regolith, especially the arenites of the flat-lying Upper Tertiary Campaspe Formation. At the Waterloo deposit a dispersion halo has been reported within the Campaspe Formation. Because of the implications for exploration, the significance of this halo has been critically investigated by studying the mineralogy and geochemistry of profiles through the Campaspe Formation into the underlying volcanics.

Along Line 4 at Waterloo a 20-25 m thick sequence of feldspar- and smectite-bearing sandstone overlies a 20 m interval where feldspar is absent and kaolinite is the dominant clay. Bands of dolomite and Fe oxides are also present immediately beneath the feldspar-bearing rocks. Below ~45 m, relatively fresh volcanics with feldspar, chlorite ± pyrite are present. The presence of a feldspar-bearing unit above an highly weathered feldspar-depleted band suggests a lithological break at that contact. Supplementary geochemical data (Ce, Cl, Zr and Ti/Zr) also suggest that the base of the plagioclase-bearing material represents a major compositional break.

These results suggest that 20-25 m of Campaspe Formation overlies a sequence of weathered volcanics with the Fe-rich horizon representing the near surface Fe enrichment of a lateritic profile. The presence of the dolomite horizon at or above the Fe-rich horizon would thus represent pedogenic or secondary dolomite formation prior to the deposition of the feldspar-bearing Campaspe Formation. It is suggested that the anomalous levels of Pb and Ba occurring immediately beneath the feldspar-bearing Campaspe Formation represent the occurrence of secondary minerals (Pb-bearing alunite type minerals and barite) mechanically transported from secondary mineralization which cropped out prior to deposition of the Campaspe Formation. It is also possible that the Pb could be at least partly residually accumulated or hydromorphically dispersed and concentrated in the Fe-rich horizon. Whatever its genesis, the presence of the Pb halo in a predictable position within the regolith profile makes its use in exploration more viable. Copper and Zn are hydromorphically dispersed within the weathered volcanics but not into the Campase Formation.

1. INTRODUCTION

Polymetallic massive sulfide deposits occur within the Cambro-Ordovician volcanics of the Mt Windsor Sub-province, a 160 km long and 30 km wide belt to the south of Charters Towers in North East Queensland (Berry et al 1992; Figure 1). However, the prospective volcanics are often covered by sandstones of the Pliocene Campaspe Formation (Henderson and Nind, 1994). Sulfide deposits, found prior to 1981, were at least partially outcropping and discovered by either prospectors or by modern, conceptually-based gossan searches and stream geochemistry. However, in 1981, mineralization was found at East Thalanga by geochemical analysis of material derived by RAB drilling. Subsequently, the Waterloo, Reward and Agincourt deposits have been found by drilling through the Campaspe Formation into the underlying volcanic rocks (Berry et al., 1992; Beams and Jenkins, 1995). However, work by Granier et al. (1989) suggests that anomalous levels of Pb, Zn and Cu occur dispersed within the Campaspe Formation directly above and laterally displaced to the south of the Thalanga mineralization. In this case, the anomaly occurs at ~30-40 m depth within a 70 m thick sequence of Campaspe Formation. The work of Govett and Atherden (1987) also suggested that anomalous concentrations of H^+, Zn and Cu occur in anomalous amounts in surficial soils overlying mineralization covered by up to 50 m of transported overburden. These studies offered the potential of utilizing anomalies formed by hydromorphic dispersion from mineralized volcanics into the Tertiary cover rocks. Because of the potential savings over methods involving drilling through often very thick cover, such methods have evoked considerable interest.

At Waterloo work by Hartley and Alston (1995) shows a Pb anomaly occurring at 25-30 m within a 50 m sequence of Campaspe Formation. They argued that this represents mechanical dispersion (from palaeo-outcropping gossan) during deposition of the Campaspe Formation. Because such a dispersion train provides a larger target than that derived by bedrock geochemistry but its position within the Campaspe Formation could be defined *a priori*, Hartley and Alston (1995) recommended systematic sampling of the complete Campaspe Formation profile. This report assesses the significance of that anomaly by considering the mineralogy and geochemistry along a section of profiles through the anomaly.

2. GEOLOGY

The Waterloo deposit occurs within the andesitic and felsic volcaniclastics of the central portion of the Trooper Creek Formation. Such a stratigraphic position is similar to the other volcanogenic deposits of the region, except for Thalanga which occurs within the more acidic Mt Windsor Volcanics at or close to their contact with the overlying Trooper Creek Formation (Gregory et al., 1990). The Waterloo deposit is small but high grade and is sphalerite-pyrite-chalcopyrite rich – 372,000 tonnes at a grade of 19.7% Zn, 3.8% Cu, 2.8% Pb, 94 g/t Ag and 2 g/t Au (Berry et al., 1992). Alteration associated with the mineralization is sericite-pyrite- and quartz-rich and extends for 50 m into the footwall (R. Sainty, pers comm., 1995). The deposit is vertically dipping beneath 30-60 m of flat-lying Campaspe Formation. Mineralization was found in 1985 by drilling through the Campaspe Formation after a small outcrop

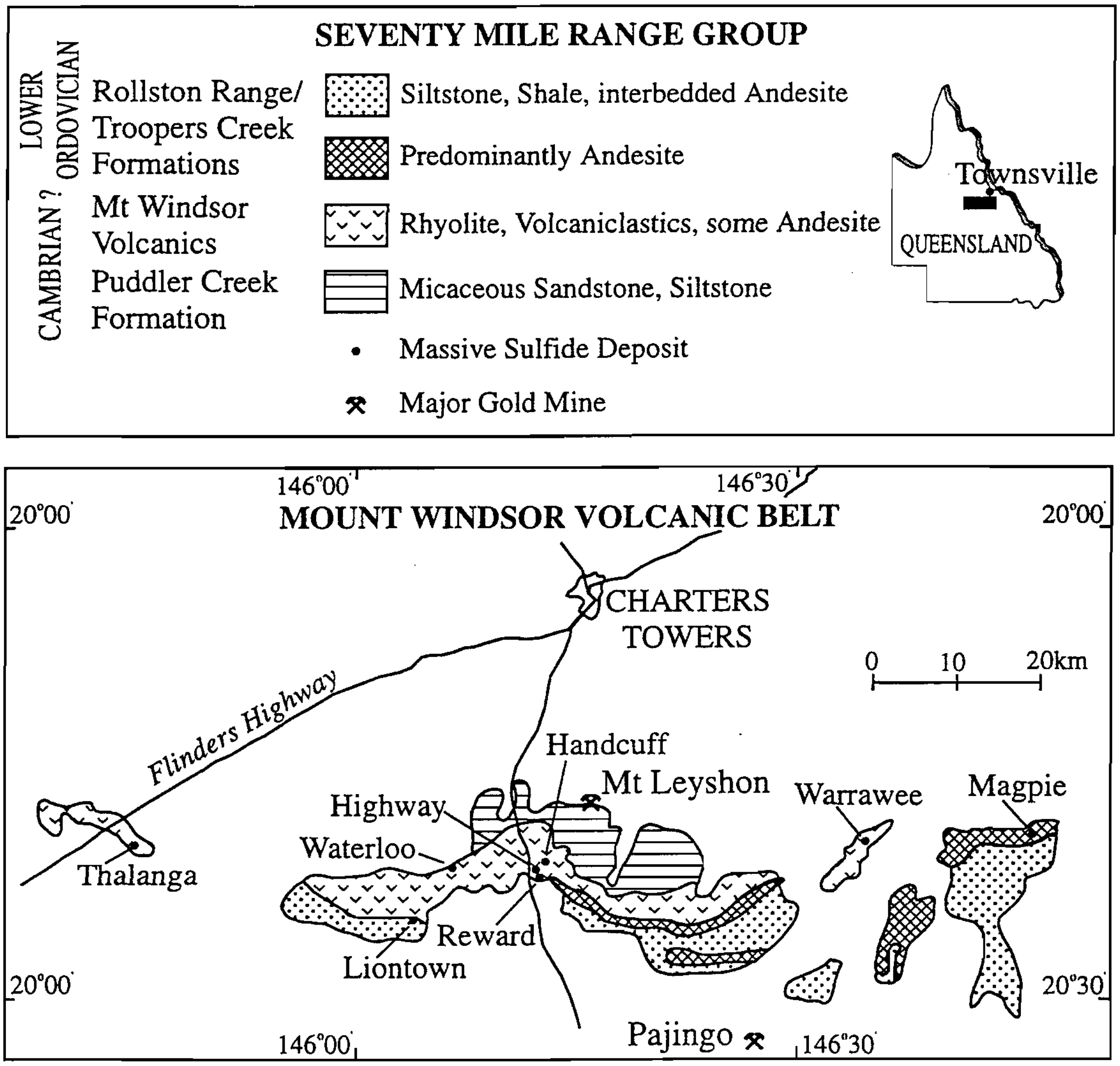


Figure 1 Location map of Mt Windsor Sub-province volcanics and mineral deposits of the region (after Hartley and Alston, 1995).

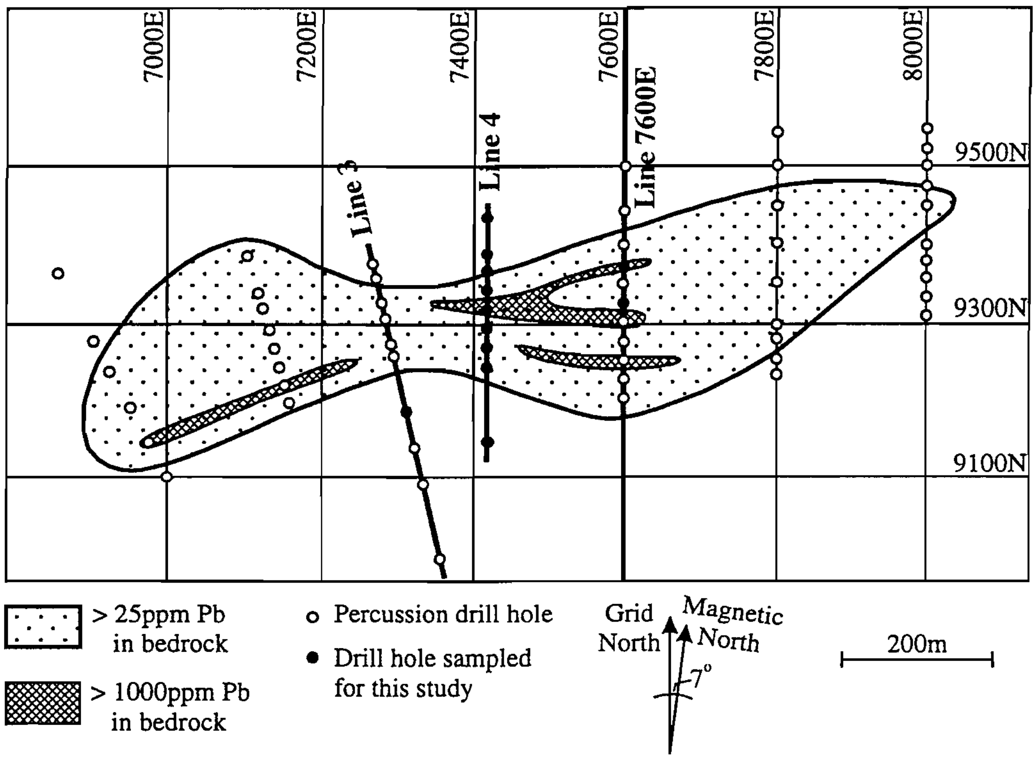


Figure 2 Plan of the Waterloo deposit, showing bedrock Pb contents and location of drill holes (based on the Penarroya (Aust) Pty. Ltd grid).

of altered volcanics was observed in an adjacent creek by Peter Gregory (BHP Minerals). Bedrock geochemistry outlines a zone 700 x 150 m with Pb > 1000 ppm within a 1100 x 250 m zone with Pb > 25 ppm (Figure 2).

3. SAMPLES AND METHODS

A total of of 57 pulps from three drill holes through both thick and thin sequences which were logged as "Campaspe Cover," were collected for an orientation study. Later, 112 pulps from 8 drill holes forming a fence across the deposit were also collected. The pulps were prepared by Pilbara Laboratories (now Analabs), probably using a chrome steel mill, during 1984. Using the drill logs and some company-derived base metal geochemistry as a guide, 82 pulps were analysed by X-ray diffraction using graphite crystal-monochromated Cu Kα radiation to determine the major minerals present. Mineralogical abundances were calculated semi-quantitatively, using six subdivisions of peak heights, to allow comparison of abundances of specific minerals between samples. Using the mineralogical data as a guide, additional geochemical data was determined by X-ray fluorescence spectrometry (XRF) for 46 samples using fused discs. Elements determined were majors (including P and S) and the minors, Ba, Ce, Co, Cl, Cr, Cu, Ga, La, Ni, Nb, Pb, Rb, Sr, V, Y, Zn and Zr. (As indicated above, Cr contents may be subject to some contamination).

4. RESULTS

4.1 Orientation Study

Cuttings from three drill holes, GY218 (Line 3-600N) and GY240, GY241 (Line 7600E-9325N and -9375N respectively), were studied (see Figure 2 for location). Their lithologies, as mapped by Penarroya (Australia) Pty Ltd, are shown in Figure 3.

In the profiles with thin (~15m)sequences of Campaspe Formation, GY240, GY241, X-ray diffraction indicates that the Campaspe Formation consists of quartz, plagioclase, smectite, kaolinite, goethite and muscovite, with dolomite also being found between 6-12 metres in GY241 (Figure 4). The weathered volcanics below 15 m in GY240 consist of assemblages of quartz, kaolinite, muscovite and goethite, (i.e. no plagioclase or smectite) with kaolinite and muscovite tending to be more abundant than in the overlying material (Figure 4).

The Campaspe Formation in GY240 is richer in Na, Ca, Co,? Cr, Sr and V but poorer in Al, Fe, K, S, Cl, Cu, Pb, Rb and Zn than the weathered Trooper Creek Formation (Table 1). Of these elements, the Na, Ca and Sr reflect plagioclase in the cover and Al, K and Rb reflect kaolinite and mica in the volcanics. Sulfur and the base metals, Cu, Pb, and Zn, are at least twice as abundant in the volcanics as in the Campaspe Formation cover rocks. Ti/Zr ratios, which are used to discriminate between various volcanic rock types in the Mount Windsor Sub-province (Berry et al., 1992) are, however, similar for both cover and volcanics, giving the signature of a rhyolite.

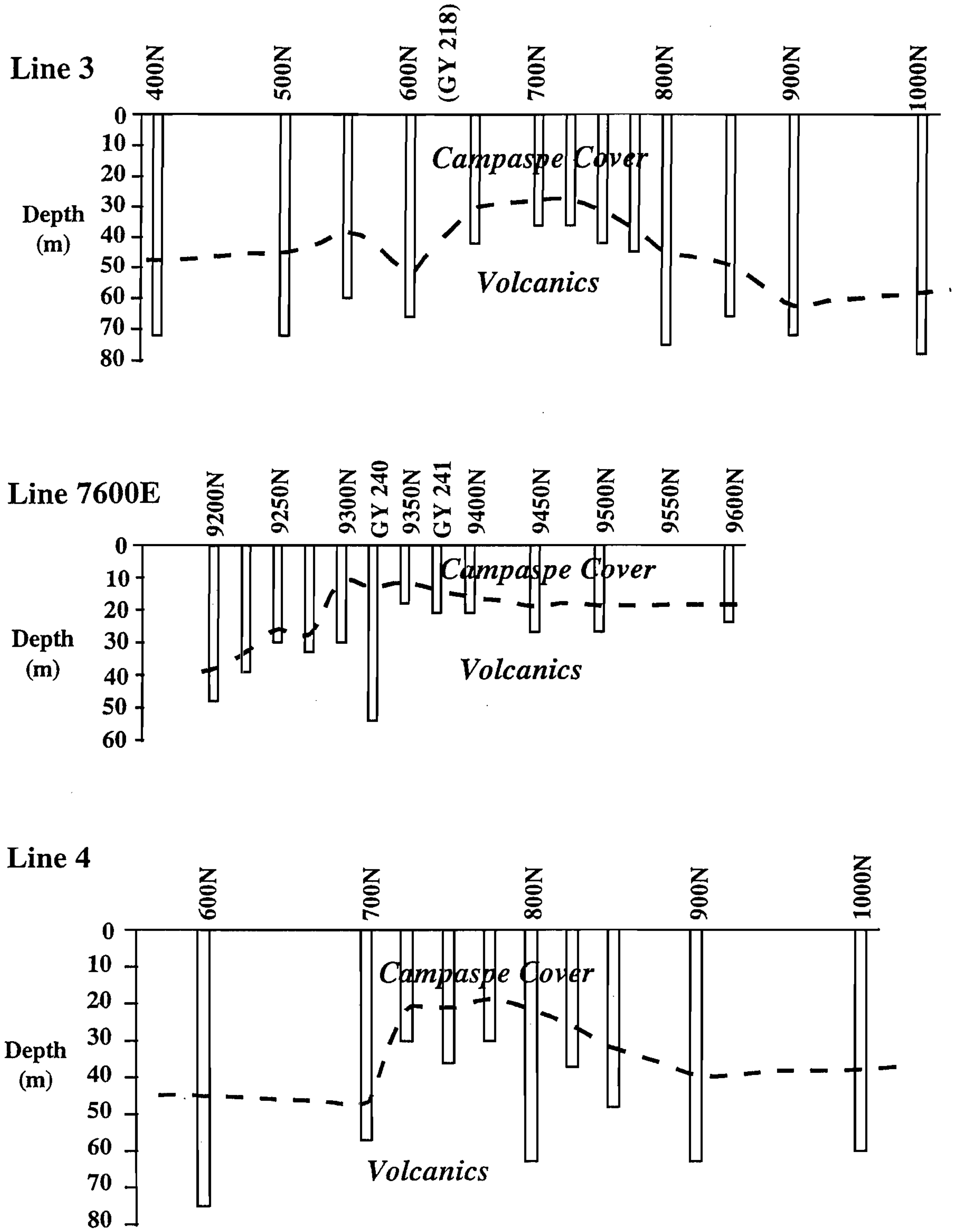
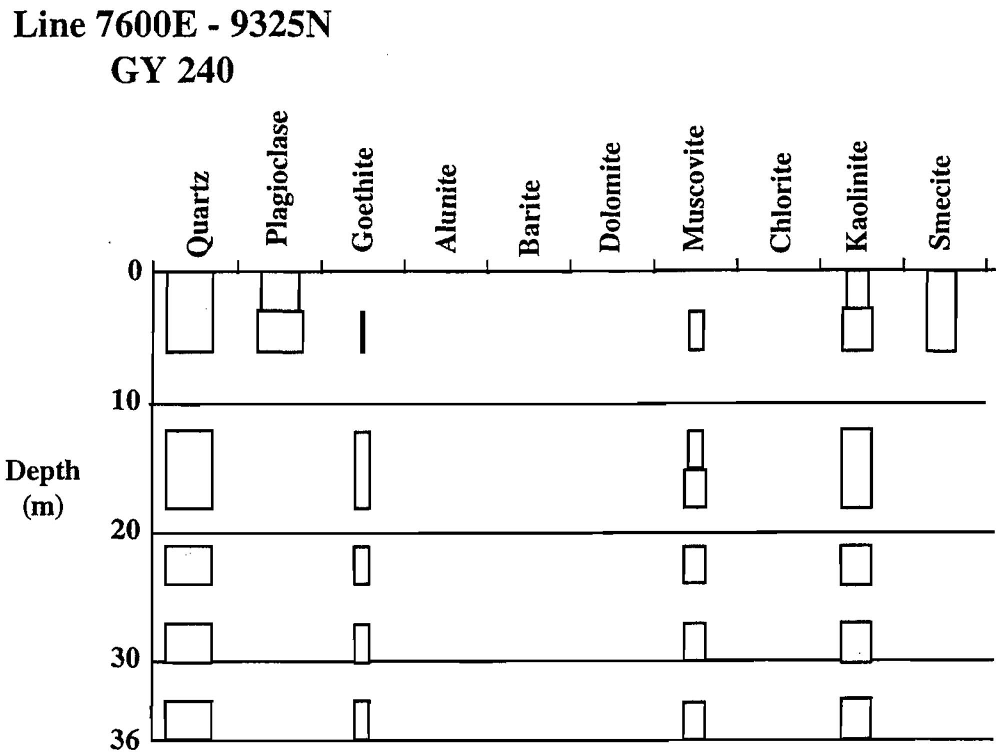


Figure 3 Sections through Line 3 (GY218), Line 7600E (GY240, GY241) and Line 4, Waterloo showing "Campaspe Cover" unconformably overlying volcanics (after Penarroya (Aust.) Pty. Ltd).



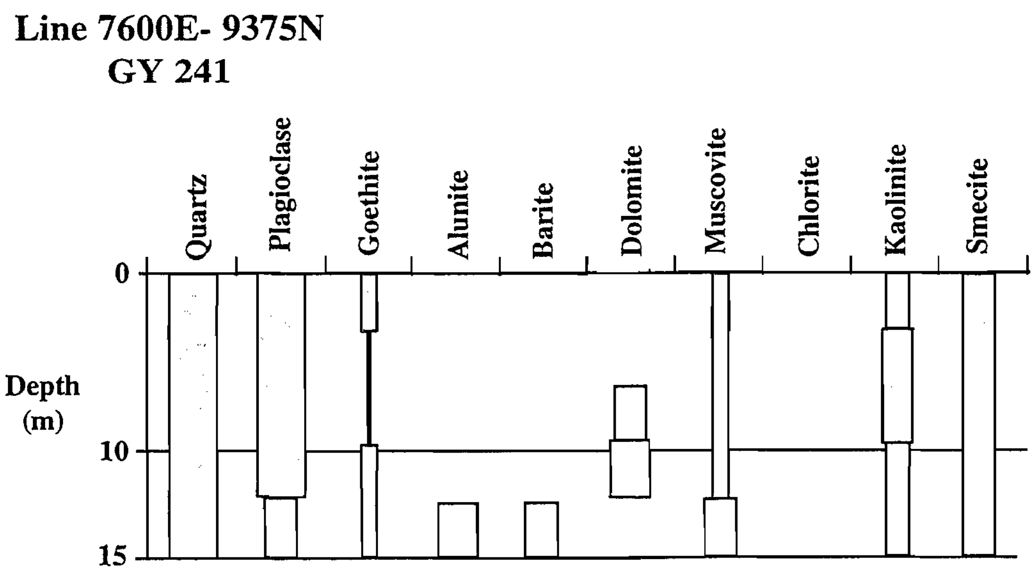


Figure 4 Mineral abundances in drill holes GY240 and GY241 (Upper portions), as determined by X-ray diffraction. (Note: thickness of bars reflects semiquantitative abundance of a mineral. See Key, Figure 5.)

The better sampled portion of Campaspe Formation in GY241 shows that Mg, Ca and Sr are elevated in the dolomite-rich samples, between 6 and 12 m, but otherwise the Campaspe Formation in this hole is similar to that 50 m away in GY240 (Table 1). The 12-15 m sample from this hole has high Al, Fe, K, Cl, Rb and relatively low Cr contents indicative of volcanics but is Na-rich, suggesting Campaspe Formation, i.e. it probably straddles the volcanic/cover boundary. The S, Ba, Ce, Cu, Pb, Sr, V and Zn contents of this sample reflect weathered mineralization now present as barite and a Pb-rich alunite-group mineral. Ti/Zr ratios are similar for each group giving a dacitic signature (Berry et al., 1992).

In the thicker profile through the Campaspe Formation, GY218, plagioclase and smectite (which discriminated between cover and volcanics in GY240) are present throughout the whole profile (Fig. 5.). However their abundance decreases markedly between 27 and 33 m. This interval is also characterized by barite, and marks the upper limit of dolomite and lower limit of muscovite. These major changes suggest that this interval marks a significant compositional break. Deeper in the profile, orthoclase occurs below 45 m and chlorite below 54 m. Such a sequence of stability *viz* plagioclase > orthoclase > chlorite is consistent with weathering of the volcanics and strongly suggests that major weathering changes occur at ~50 m but the transition from weathered volcanics to Campaspe cover occurs within the 27-33 m interval.

The chemical data show a sharp change at 33 m, with more Ce, Cl,? Cr and Zr and lesser Ti/Zr above 33 m than below (Table 2). The Ti/Zr ratio suggests that the volcanics are andesitic here (Ti/Zr > 80) and hence readily distinguished from Campaspe Formation material with a Ti/Zr ratio ~24. Other features of the geochemistry are the low Na but high S, Ba and Pb between 27 and 33 m (reflecting the lower abundance of plagioclase but significant barite and some Pb-rich secondary mineral development). Within the volcanics below 33 m, although Zn and Cu contents increase with depth as weathering becomes less severe, Pb and Ba contents remain relatively constant ~16 and 400 ppm respectively (Table 2). This, and the low Ti/Zr ratios, strongly suggest that the Pb and Ba within the 27-33 m interval are not derived from the underlying rocks.

4.2 Study of Line 4, Waterloo

Because the orientation study suggests that the thickness of the Campaspe Formation has been overestimated in some drill holes, a more complete section across mineralization was studied (Line 4, Figure 3). Using mineralogical data obtained by X-ray diffractometry from 55 samples, the significant changes occurring with depth across the line can be plotted (Figures 6-11). Plagioclase is very abundant in the top 20-25 m, then a zone ~20 m thick where plagioclase is absent occurs before it again becomes abundant below about 40 m depth, where it is associated with chlorite (Figure 6). Pyrite can also be present below 39 m at 1000N. Dolomite occurs in a thin zone at about 20 m, i.e. immediately below the uppermost plagioclase zone and at a much deeper level ≥ 40 m (Figure 7) where it is associated with plagioclase and chlorite (cf. Figure 6). Near-surface calcite is also found in the spoil from several drill holes. Alunite-group minerals occur below the upper plagioclase zone between 700N and 850N, with a vertical interval of 20 m of alunitic minerals at 700N (Figure 8).

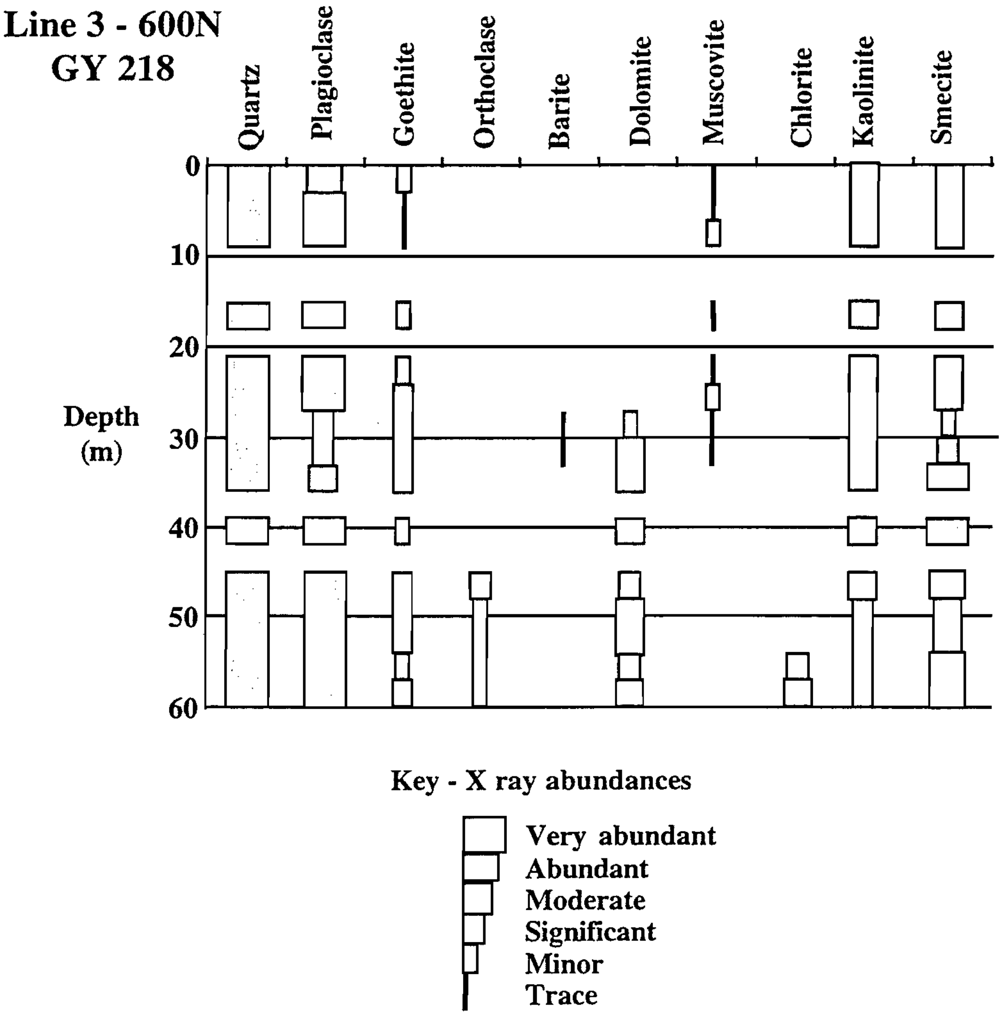


Figure 5 Mineral abundances in drill hole GY218, as determined by X-ray diffraction. (Note: thickness of bars reflects semiquantitative abundance of a mineral).

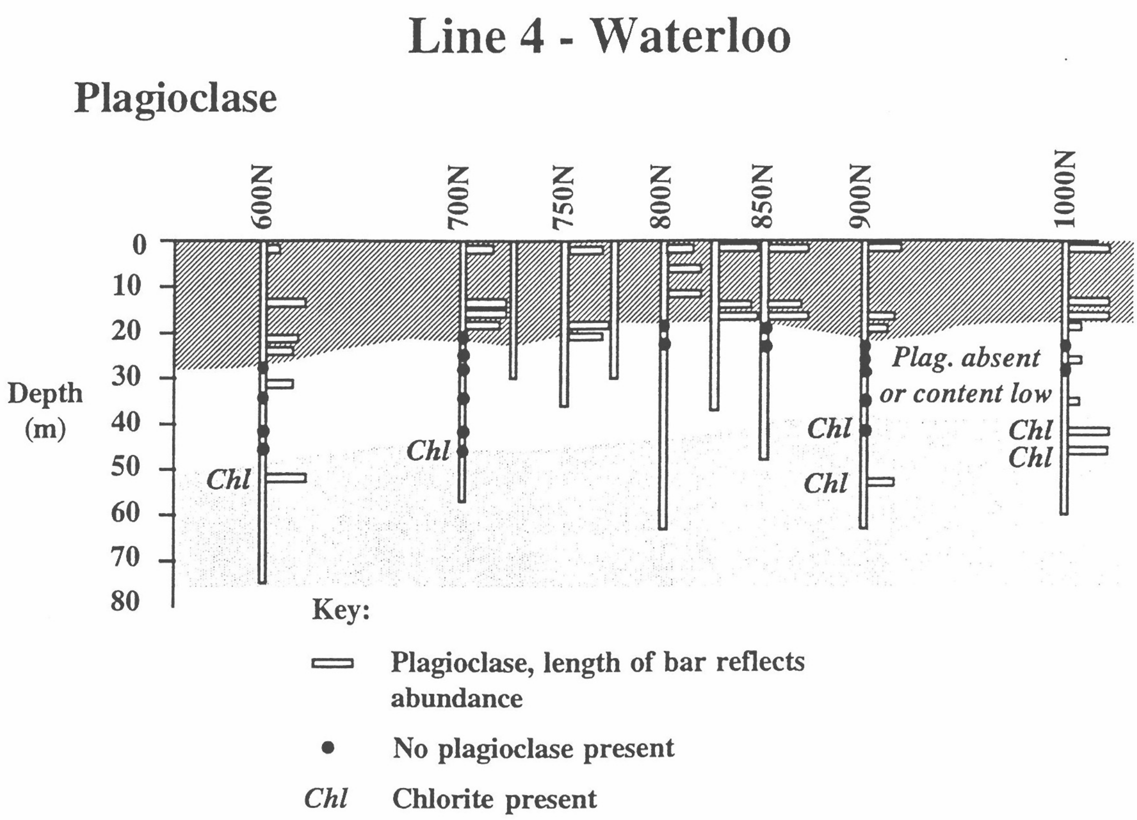


Figure 6 Plagioclase distribution, Line 4, Waterloo, showing upper (regolith) plagioclase zone and lower (fresh rock) plagioclase zones separated by zone with little or no plagioclase.

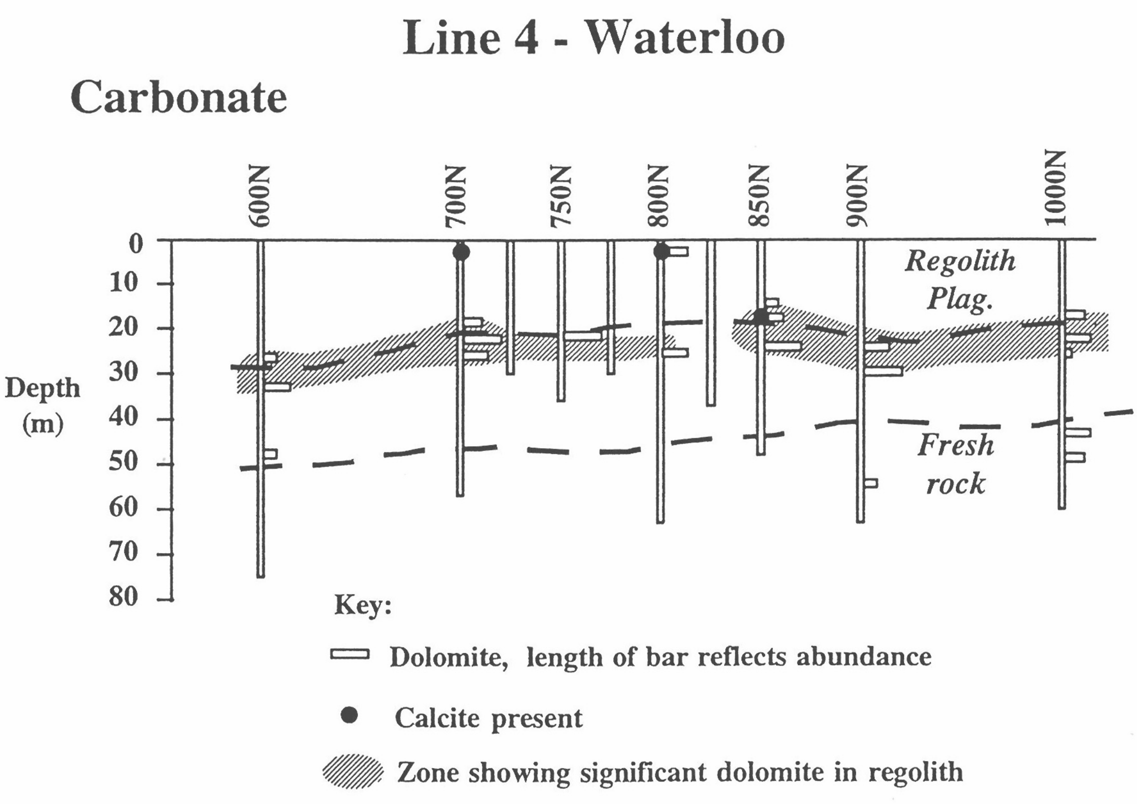


Figure 7 Carbonate distribution, Line 4, Waterloo, relative to plagioclase zones.

Line 4 - Waterloo

Alunite and Barite

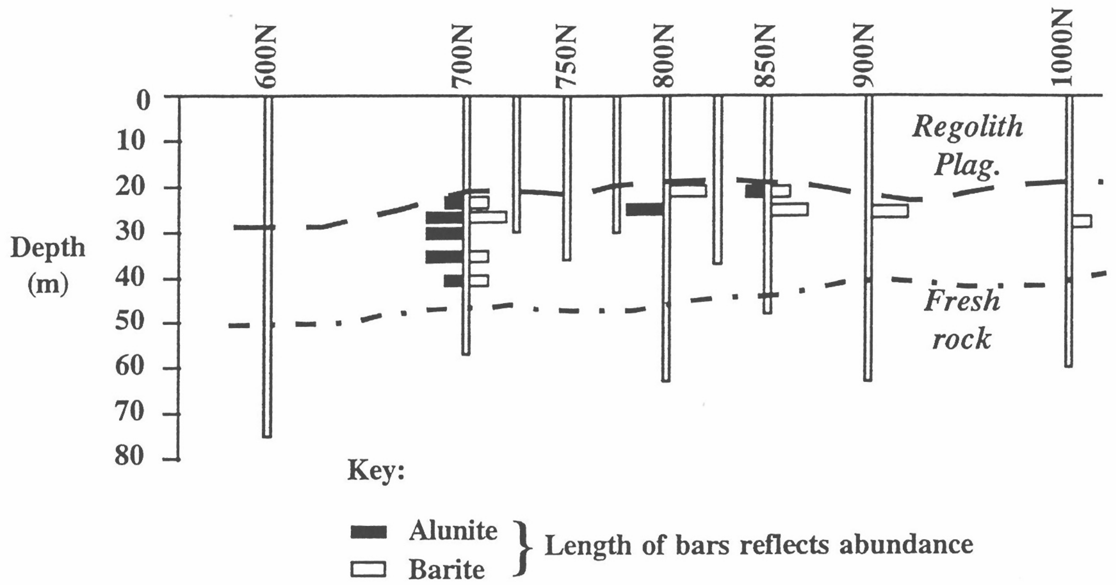


Figure 8 Alunite and barite distributions, Line 4, Waterloo, relative to plagioclase zones.

Line 4 - Waterloo

Goethite and Hematite

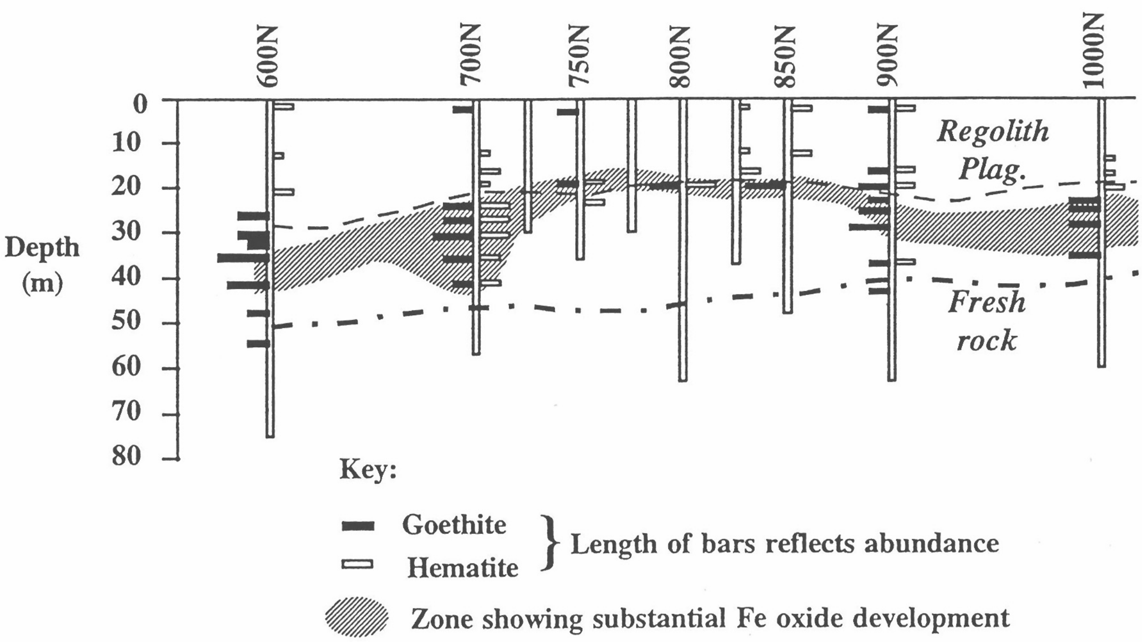


Figure 9 Goethite and hematite distributions, Line 4, Waterloo, relative to plagioclase zones.

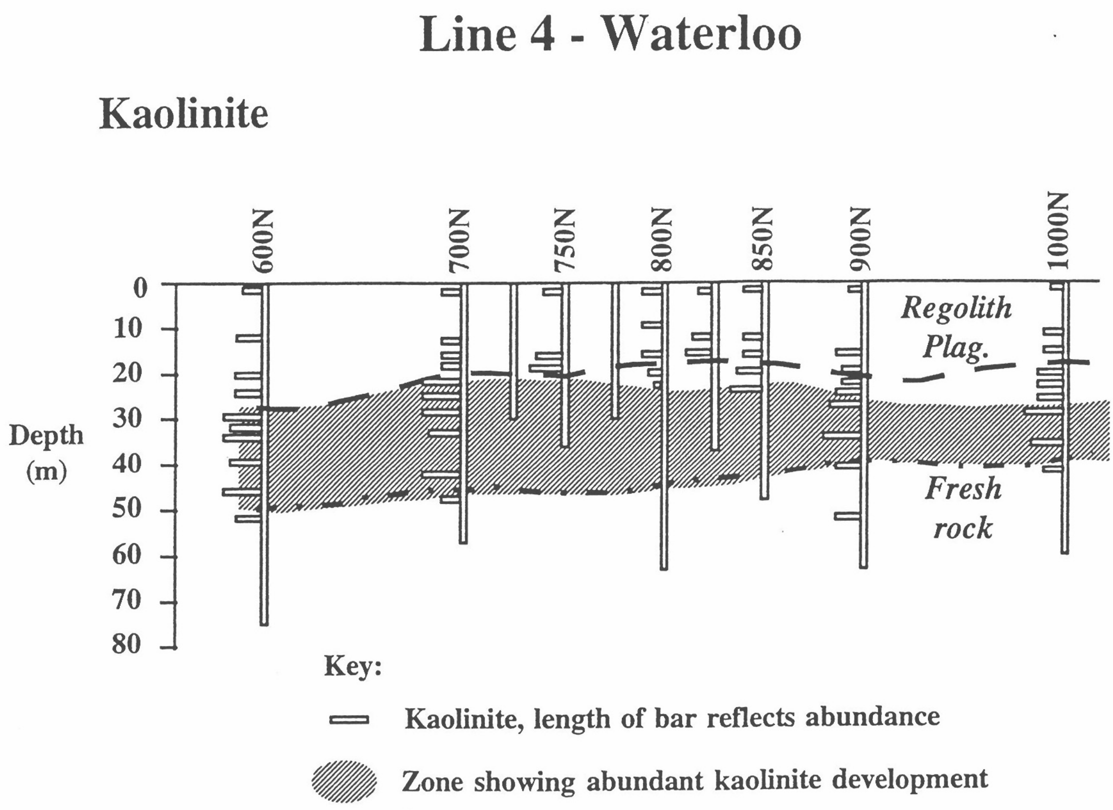


Figure 10 Kaolinite distribution, Line 4, Waterloo, relative to plagioclase zones.

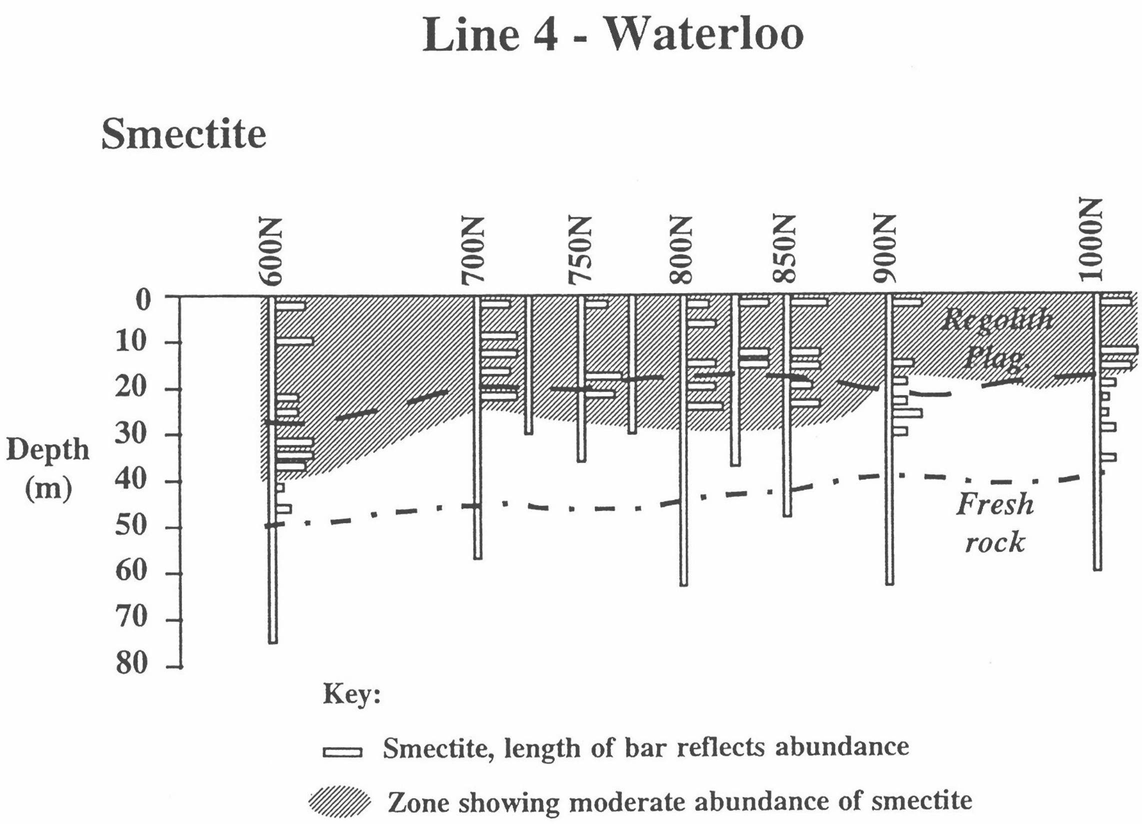


Figure 11 Smectite distribution, Line 4, Waterloo, relative to plagioclase zones.

Barite has essentially the same distribution as the alunite-group minerals with some barite also being found at 900N and 1000N just below the plagioclase zone (Figure 8). Both goethite and hematite are well developed at Waterloo with Fe oxides most abundant at, or below, the base of the upper plagioclase zone (Figure 9). Kaolinite is ubiquitous except in the deepest sample from 1000N (where chlorite is abundant). Kaolinite is particularly abundant in a 20 m interval where plagioclase is absent (Figure 10). Smectites are abundant in the upper parts of the profiles, especially above the base of the upper plagioclase zone (Figure 11).

The base of the upper plagioclase zone thus appears to be a significant boundary which was further investigated chemically by analysing samples from above and below it. Results (Table 3) show that Ce, Cl, Zr and probably Cr generally decrease and Ti/Zr ratios increase (Figure 12) below the base of the plagioclase zone. The geochemistry reveals that at 700N, where alunite group minerals and barite are well developed, Pb and, to a lesser extent, Cu and Zn are more abundant below 24 m (Table 3). Along Line 4 samples with Pb >100 ppm define a thin band at the base of the upper plagioclase zone and in the material below, where it represents oxidized mineralization (Figure 13). However Zn > 100 ppm and Cu >50 ppm occur exclusively below the upper plagioclase zone with abundances > 1000 ppm Zn and >500 ppm Cu representing mineralization at 700N and possible supergene concentration at the base of oxidation between 800 and 900N (Figures 14 and 15).

5. DISCUSSION

5.1 Weathering of sulfides at Waterloo

Although the weathering of the original sphalerite-pyrite-chalcopyrite-rich mineralization has not been studied at Waterloo, similar mineralization at Thalanga and Handcuff has been investigated and this information can be extrapolated to Waterloo. At Thalanga the oxidation of the sulfides proceeds through alunitic and jarositic minerals plus other secondary Zn, Cu and Pb sulfates and carbonates to form gossans composed of Fe oxides, beudantite, barite, quartz, muscovite and kaolinite (Taylor and Horne, 1990; Taylor and Humphrey, 1991). The abundances of Cu, Zn, Pb, As and S have been depleted with Zn being depleted by several orders of magnitude (Taylor and Humphrey, 1991). However, Ba, which was originally present as minor barite in the ore is residually concentrated as more mobile elements (e.g. Zn) are removed by weathering. At Handcuff there are seven distinct alunite-jarosite type minerals in outcrop (Table 4). These range in composition from Al-rich sulfates (plumbian alunite) and Pb-rich sulfate/phosphates/arsenates (hinsdalite, hidalgoite) to Fe-rich sulfates (plumbian jarosite). Despite this mineralogical diversity these minerals generally contain significant Cu and Zn and minor Ba besides their very significant Pb contents. Copper is particularly enriched in the hidalgoites whereas Zn is enriched in hinsdalite and the jarositic minerals (beudantite and plumbian jarosite). Hematite from this outcrop contains 0.28% Cu, 0.43% Zn, 1.52% Pb, 0.54% SO_3 and 3.84% As_20_5 with goethite containing 0.93% Cu, 0.57% Zn, 0.84% Pb, 0.39% SO_3 and 3.95% As_2O_5.

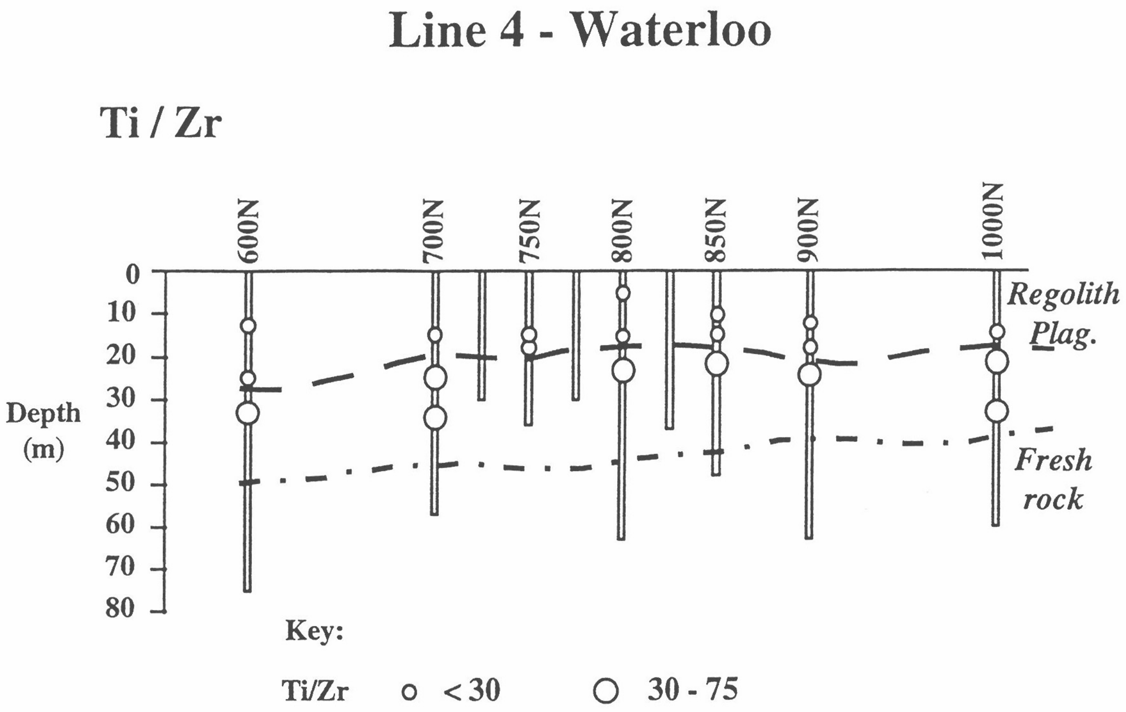


Figure 12 Ti/Zr ratios, Line 4, Waterloo, relative to plagioclase zones.

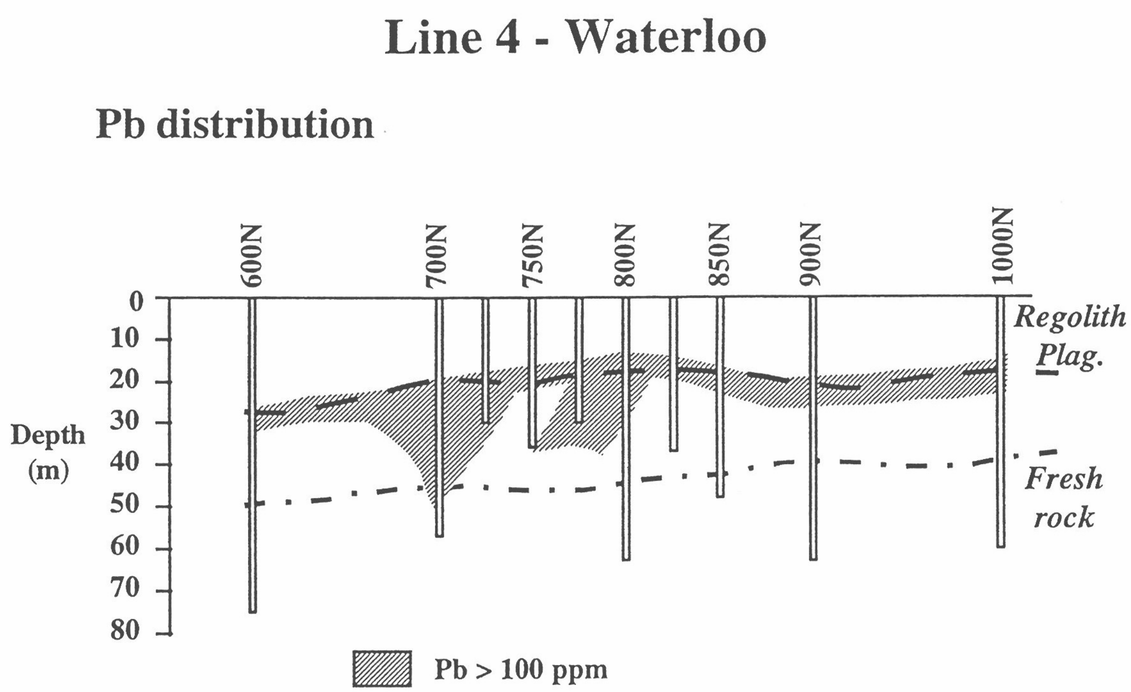


Figure 13 Lead distribution, Line 4, Waterloo, relative to plagioclase zones.

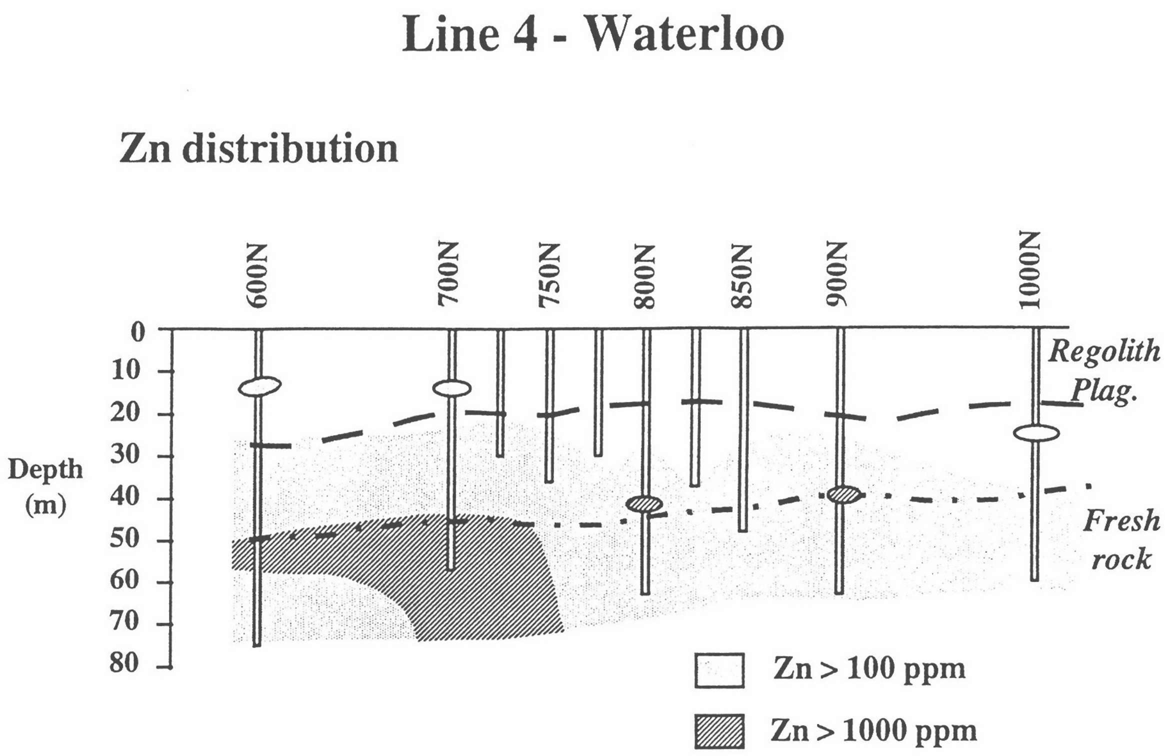


Figure 14 Zinc distribution, Line 4, Waterloo, relative to plagioclase zones.

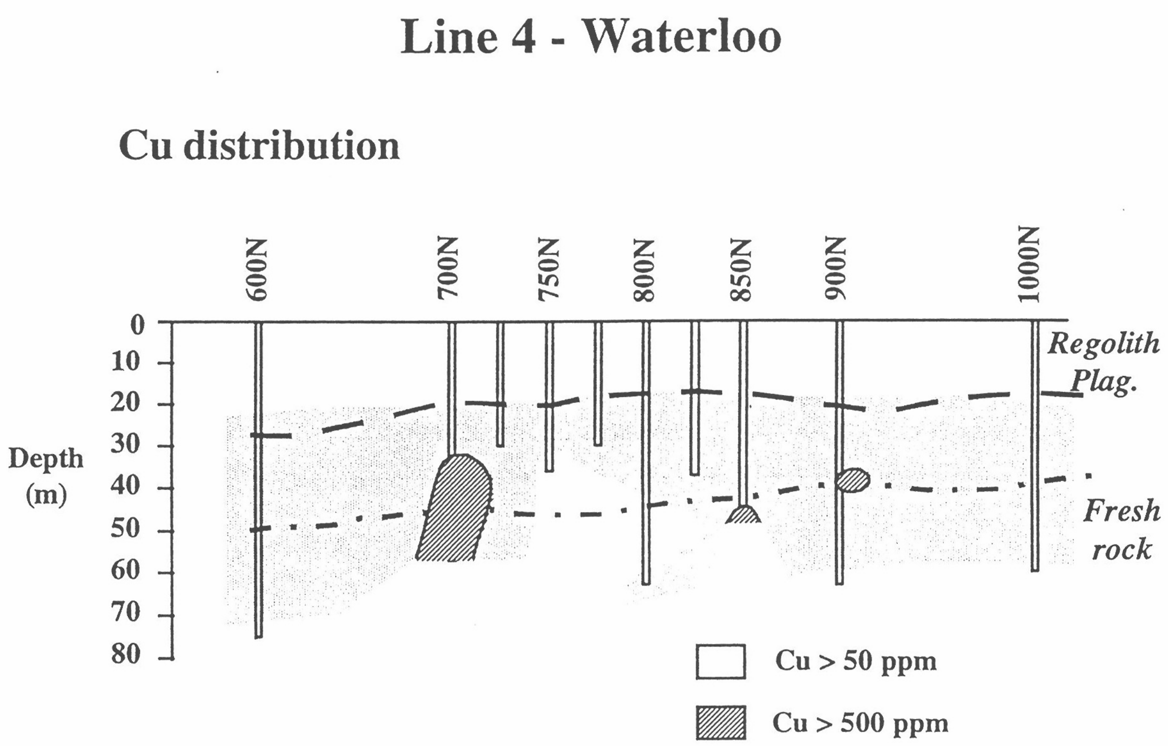


Figure 15 Copper distribution, Line 4, Waterloo, relative to plagioclase zones.

At Waterloo, sample 113521 (Drill hole GY241: 12-15 m) contains, *inter alia,* abundant amounts of an alunitic mineral, goethite and barite, reflecting its high Pb, Ba and SO_3 contents (Table 1). If this sample is derived from average ore-grade material at Waterloo, Cu is depleted by an order of magnitude (3.8 to 0.34%) and Zn by several orders of magnitude (19.7% to 210 ppm). However, Pb is essentially retained and Ba is enhanced by weathering at Waterloo. Thus, these two elements represent the best guides to mineralization at Waterloo. Based on the mineralogical data from Handcuff, it is likely that incorporation of Cu and Zn into alunite-jarosite minerals is a major stabilizing mechanism for these elements.

5.2 Weathered profiles, Waterloo

An idealized mineralogical profile through Campaspe Formation into both unmineralized and mineralized Trooper Creek Formation along Line 4 at Waterloo is presented in Figure 16. This indicates that plagioclase and smectites occur in the top 20-25 m of the section overlying ~20 m of strongly kaolinized material. Plagioclase also occurs with chlorite ± pyrite below 40m. The upper 10 m of the kaolinitic zone generally contains a thin horizon of dolomite directly overlying an Fe oxide-rich horizon in unmineralized profiles. Iron oxides are much more abundant, occurring throughout the whole kaolinitic zone in mineralized profiles (Figure 16). These mineralogical sequences are consistent with plagioclase and smectite representing the Campaspe Formation overlying a weathered profile through the volcanics of the Trooper Creek Formation. The original plagioclase and chlorite are completely weathered to kaolinite above 40 m in the weathered volcanics. Iron oxides toward the top of the kaolinite zone is consistent with near-surface Fe enrichment above a clay-rich zone, typical of a lateritic profile. If this is so, the amount of stripping of the profile before deposition of the Campaspe Formation may not be great. Furthermore the presence of dolomite above the Fe-rich horizon may represent pedogenic dolomite formed prior to the deposition of the Campaspe Formation. Under this scenario, Ba and Pb (within barite and Pb-rich alunitic minerals) would have been mechanically dispersed as components of gossanous fragments derived from outcropping weathered mineralization prior to the deposition of the Campaspe Formation. However in some cases, Ba and Pb occur within a dolomitic zone within the Campaspe Formation (drill hole GY218, Table 2), suggesting local reworking of material into the basal portion of the Campaspe Formation. This feature leads to some difficulty in defining the exact boundary between transported material and *in situ* weathered volcanics. If Ce, Cl, Zr and Ti/Zr contents are used to differentiate between feldspar-bearing Campaspe Formation and highly weathered volcanics (Table 3, Section 4.2), the anomalous Pb contents (above ~100 ppm) which occur at about 20-25 m depth, appear to be within the basal portion of the Campaspe Formation at 600N, 750N, 900N and 1000N. However at 700N, 800N and 850N the anomalous Pb is within the underlying weathered volcanics, and represents *in situ* weathered mineralization (Fig. 13). This suggests that mechanical transport may disperse Pb up to 200 m from its source thereby creating a larger target within the base of the Campaspe Formation than in bedrock. This model is similar to that of Hartley and Alston (1995) except that the Pb anomaly is found to be in a predictable rather than unknown position within the Campaspe Formation. Although highly anomalous concentrations of Zn and Cu are associated with Pb at 700N, where they are probably stabilized in alunite-jarosite

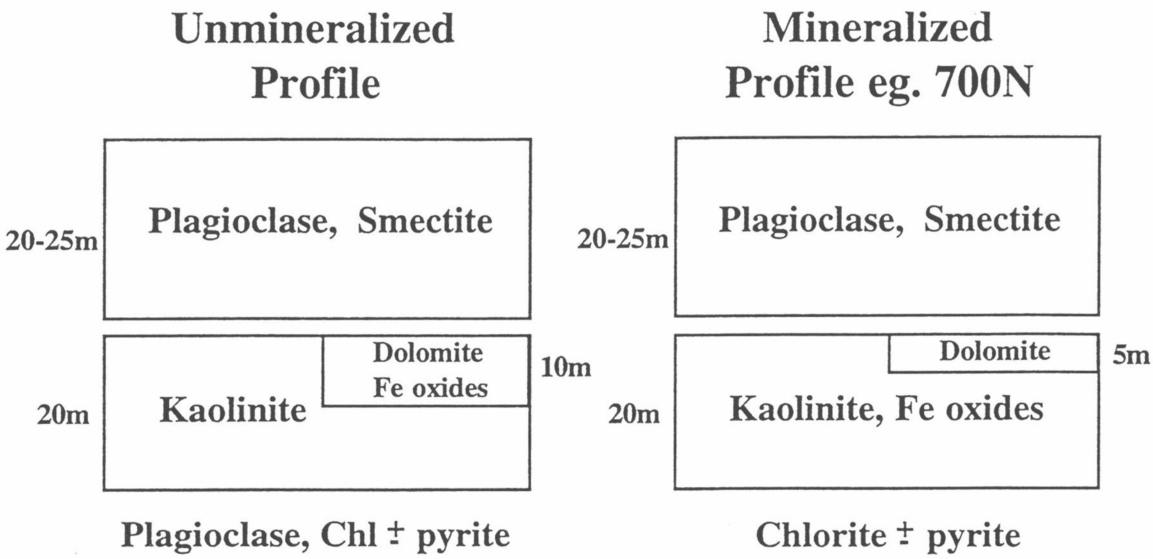


Figure 16 Idealized mineralogical profiles, Line 4, Waterloo.

minerals and Fe oxides (Section 5.1), significant Zn and Cu occur throughout the Line 4 Section within the weathered volcanics but not within the Campaspe Formation (Figures 14 and 15). Thus they appear to have been hydromorphically dispersed probably during weathering prior to deposition of the Campaspe Formation. This scenario implies that Pb has moved mechanically whereas Zn and Cu moved chemically prior to the deposition of the Campaspe Formation. It also indicates that elevated Zn and Cu in highly weathered volcanics just below the Campaspe Formation form a larger target than Pb (Figures 13-15) once bedrock is encountered. The occurrence of isolated areas with anomalous Zn within the Campaspe Formation (Fig. 14) suggests that the use of partial extraction techniques for base metals within Campaspe Formation material may also be worth further investigation.

In the above discussion, Pb has been assumed to be mainly present in alunite-type minerals, but some would undoubtedly be found in Fe oxides (cf. Section 5.1). These Pb-bearing phases have been argued to have been mechanically transported to their current locations. However, it is possible that some of the Pb has moved laterally by chemical means being adsorbed by, or coprecipitated with, Fe oxides in the ferruginous zone at the Campaspe Formation/volcanics boundary. Such a mechanism has been considered likely at Thalanga and Thalanga East (Hartley and Alston, 1995). Pb could have also been residually accumulated in Fe oxides during lateritic processes (e.g. Freyssinet et al., 1989). Determining the Pb contents of alunitic and Fe oxide minerals by electron microprobe and examining Pb-bearing material texturally could help establish the significance of hydromorphic and residual processes relative to mechanical dispersion.

It is also possible that some lower Tertiary Southern Cross Formation (cf. Henderson and Nind, 1994) could occur between the weathered volcanics and the Pliocene Campaspe Formation. Southern Cross Formation sediments were not reported in the initial logging of holes in the Waterloo area because all the overburden was arbitrarily defined as "Campaspe Cover" (R. Sainty, pers. comm., 1995). A more thorough examination of the thicker sequences of overburden at Waterloo and other areas within the Mt Windsor Sub-province may be warranted.

The Pb isotopes in a selection of anomalous Pb samples from both the Campaspe Formation and volcanics of the Trooper Creek Formation have been studied (Dean, 1995). Results indicate that the Pb in both rock types between 700N and 900N has a $^{206}Pb/^{204}Pb$ ratio = 18.06-18.11, typical of volcanic-hosted massive sulfide deposits in the Mt Windsor Sub-province. However, the Campaspe-hosted material from 600N and 1000N has higher ratios ($^{206}Pb/^{204}Pb$ ratio = 18.12-18.21) suggesting incorporation of extraneous Pb. As this material is furthest from the presumed source (~700-800N, Figure 17) a contribution from country rock Pb is quite feasible. Thus Pb isotopic ratios could provide a vector to mineralization at Waterloo. However, because Pb contents are generally low at the extremities of Line 4, uncertainties due to possible contributions of radiogenic Pb developed *in situ* affect these samples more than others (Dean, 1995).

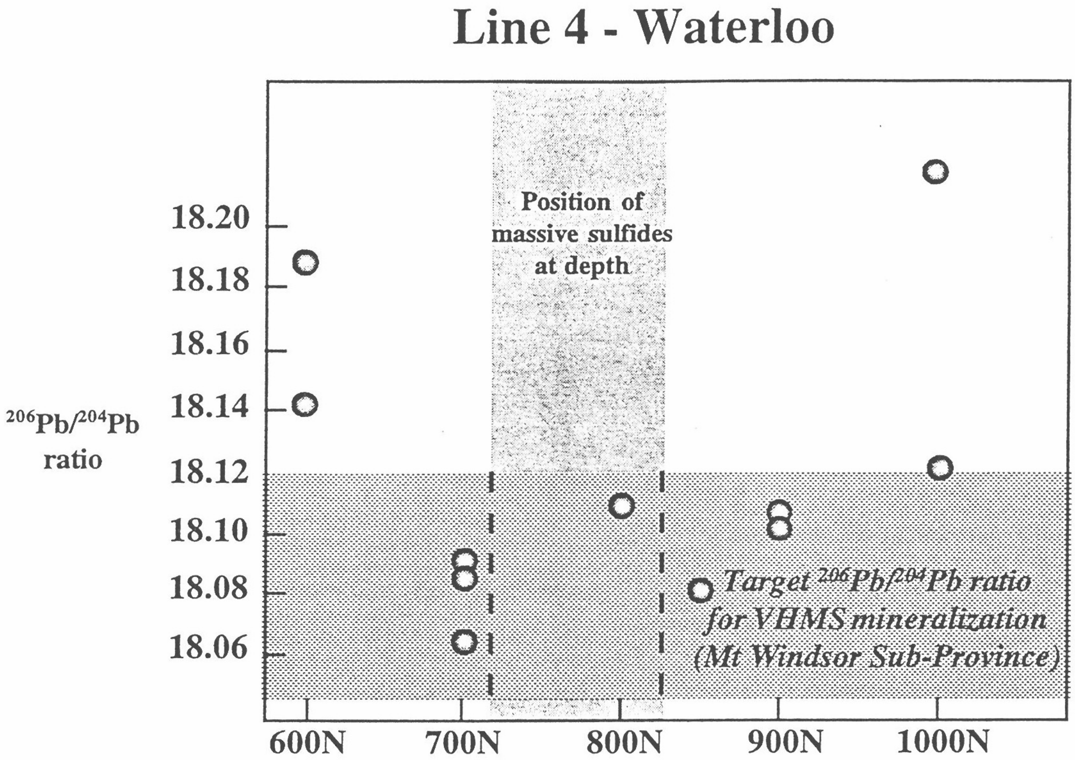


Figure 17 $^{206}Pb/^{204}Pb$ ratios and Pb contents along Line 4, Waterloo (after Dean, 1995).

6. CONCLUSIONS AND IMPLICATIONS FOR EXPLORATION

All the data presented herein are consistent with the Pb anomaly at 20-25 m on Line 4 at Waterloo being present in the base of the feldspar-bearing Campaspe Formation or within highly weathered volcanics of the Trooper Creek Formation. Such volcanics are Fe- and dolomite-rich and appear to represent the near surface portion of a lateritic profile which was subjected to surficial dolocrete formation prior to deposition of the Campaspe Formation. Recognition of the Pb anomaly as being within the basal portion of the feldspar-bearing Campaspe Formation and not in the middle of the unit, as previously thought, suggests that the basal Campaspe material can be systematically sampled rather than having to sample all of it to find any anomaly (cf. Hartley and Alston, 1995). As recognized by Hartley and Alston (1995), Pb anomalies within the basal Campaspe Formation are more extensive than within the underlying bedrock at Waterloo and therefore represent a worthwhile exploration target. Fortunately, in the field, the Campaspe Formation can usually be recognized by the pink colour of plagioclase in drill chips (W. Herman, pers. comm., 1995). Zinc and Cu are mobilized during weathering and form a wide dispersion halo about the mineralization but such an anomaly is restricted to the weathered volcanics (i.e. does not appear to extend into the Campaspe Formation). To recognise the upper portion of the Trooper Creek Formation, use can be made of it dolomite and Fe content. Colour is generally a very poor guide to Fe abundance but dolomite should be easily recognized in drill chips by the use of 6N HCl.

Areas of thick overburden may need to be re-examined to detect any Southern Cross Formation. If present, the recognition of such material would place better constraints upon the likely regolith history of the area.

7. ACKNOWLEDGEMENTS

Pancontinental Mining Limited (especially Mel Jones) is thanked for permission to sample the Waterloo deposit and for providing access to company information. Subsequent continued support by RGC Exploration is also appreciated. Rod Sainty (Pancontinental and now RGC Exploration, Charters Towers) has provided assistance with sampling and very helpful discussions about weathering and exploration in the Mt Windsor Sub-province. Samples were analysed by XRD by Alfredo Martinez (CSIRO, North Ryde) and by XRF by Mike Hart (CSIRO, Floreat Park). Graham Carr, Ravi Anand and Ian Robertson are thanked for comments on an earlier draft of this report.

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Table 1 **Average composition of zones within drill holes GY240 and GY241, Line 7600E, Waterloo (majors, wt%; minors, ppm).**

Drill Hole	GY240		GY241		
Zone	Campaspe Fm	Trooper Ck Fm	Campaspe	Campaspe (Dol)	Mineralized
No.of Samples	2	5	2	2	1
Depth (m)	0-6	12-36	0-6	6-12	12-15
SiO_2	78.2	70.3	72.3	67.6	37.4
Al_2O_3	8.92	13.4	11.4	11.3	14.5
Fe_2O_3	3.96	6.54	5.67	5.52	9.83
MnO	0.07	0.02	0.08	0.08	0.14
MgO	0.75	0.61	0.96	2.27	1.69
CaO	0.31	0.02	0.26	1.64	1.14
Na_2O	1.58	0.12	2.01	2.48	1.28
K_2O	0.78	2.01	0.90	0.85	1.55
TiO_2	0.41	0.45	0.56	0.54	0.57
P_2O_5	0.02	0.04	0.04	0.04	0.13
SO_3	0.03	0.09	0.05	0.02	5.28%
Ba	490	750	920	370	4.12%
Ce	50	46	65	47	450
Cl	140	400	200	280	450
Co	13	<1	9	10	<1
Cr*	76	43	79	64	35
Cu	9	69	12	13	3400
Ga	11	11	13	13	<3
La	38	26	48	26	15
Pb	20	370	27	33	2.96%
Rb	25	81	28	27	56
Sr	64	18	79	130	810
V	58	46	84	90	330
Y	30	21	38	25	<2
Zn	33	220	43	49	210
Zr	160	170	150	140	140
Ti/Zr	16	16	22	23	24

Note: Ni < 10 ppm, Nb < 4 ppm.
*Cr contents may be affected by crushing medium.

Table 2 **Average compositions of zones within drill hole GY218, Line 3, Waterloo (majors, wt%; minors, ppm).**

Zone	Campaspe Fm	Campaspe (Dol)	Trooper Ck Fm (Kaol)	Trooper Ck Fm
No.of Samples	5	2	3	4
Depth (m)	0-27	27-33	33-48	48-60
SiO_2	71.1	61.0	53.4	59.0
Al_2O_3	11.7	14.8	11.4	13.9
Fe_2O_3	6.32	7.71	10.9	9.86
MnO	0.07	0.13	0.23	0.21
MgO	0.74	1.55	2.96	2.10
CaO	0.23	1.27	2.82	2.20
Na_2O	1.80	0.44	2.01	2.21
K_2O	0.67	0.76	0.34	0.88
TiO_2	0.58	0.73	0.67	0.86
P_2O_5	0.03	0.06	0.06	0.18
SO_3	0.02	0.13	0.02	0.01
Ba	380	2200	430	350
Ce	(73)	69	21	26
Cl	130	130	10	<10
Co	13	18	37	21
Cr*	82	62[1]	11	10
Cu	19	65	110	370
Ga	13	16	16	18
La	20	35	8	21
Pb	(43)	280	16	16
Rb	26	48	5	21
Sr	62	110	190	180
V	100	130	260	180
Y	22	23	21	18
Zn	51	110	(330)	5800
Zr	160	180	37	65
Ti/Zr	22	26	110	81

Note: [1]Ni = 13 ppm, Ni < 10 ppm elsewhere; Nb < 4 ppm
Parenthesis indicates average including one anomalously high value.
*Cr contents may be affected by crushing medium.

Table 3 Chemical data for drill holes along Line 4, Waterloo (majors, wt%; minors, ppm).

Drill Hole	4-600			4-700			4-750		4-800			4-850			4-900			4-1000		
Sample No.	128009	128013	128015	128034	128037	128040	128053	128054	128061	128064	128066	128077	128078	128079	128086	128087	128088	128106	128107	128112
Depth (m)	12-15	24-27	30-33	15-18	24-27	33-36	18-21	21-24	6-9	15-18	21-24	12-15	15-18	18-21	15-18	18-21	21-24	15-18	18-21	33-36
SiO_2	70.1	64.7	48.3	66.2	45.7	58.1	67.2	50.3	72.8	73.3	45.8	67.5	72.2	58.6	66.6	66.3	61.4	67.7	63.9	60.4
Al_2O_3	12.0	14.5	16.5	11.8	21.1	20.4	12.5	16.5	11.7	11.4	14.4	13.1	10.9	12.5	9.10	8.98	10.6	12.2	15.9	20.4
Fe_2O_3	5.39	7.44	10.5	5.42	9.77	9.76	7.57	3.43	4.90	4.43	17.9	5.56	4.67	15.6	14.9	14.9	12.0	6.34	7.64	6.27
MnO	0.08	0.09	0.18	0.07	0.06	0.09	0.07	0.10	0.02	0.05	0.05	0.13	0.06	0.03	0.08	0.08	0.02	0.09	0.21	0.01
MgO	1.09	0.93	3.21	1.90	2.75	0.22	1.16	4.42	0.81	1.08	2.17	1.30	1.44	0.65	0.51	0.52	1.75	1.68	0.73	0.44
CaO	0.37	0.61	3.43	1.45	3.80	0.13	0.22	5.49	0.24	0.35	2.24	0.51	0.81	0.27	0.11	0.11	2.11	0.76	0.19	0.13
Na_2O	1.94	0.55	0.17	2.18	0.12	0.13	1.43	0.33	2.46	2.60	1.46	1.79	1.87	0.52	0.45	0.45	0.42	1.93	0.28	0.18
K_2O	0.75	0.85	0.14	0.58	0.16	0.29	0.84	2.25	0.71	0.81	1.16	0.83	1.08	0.48	0.42	0.42	0.38	0.92	0.47	0.30
TiO_2	0.58	0.78	0.68	0.71	1.03	0.73	0.65	0.48	0.54	0.47	1.18	0.69	0.43	0.70	1.20	1.20	0.97	0.54	1.20	0.97
P_2O_5	0.02	0.05	0.03	0.02	0.08	0.17	0.05	0.09	0.02	0.02	0.13	0.03	0.03	0.07	0.06	0.06	0.04	0.04	0.03	0.02
SO_3	0.03	0.05	0.07	0.05	0.29	0.15	0.15	0.78	0.02	0.03	1.30	0.03	0.06	0.19	0.05	0.05	0.04	0.02	0.02	0.02
Ba	560	660	1460	790	1340	340	2360	1730	220	420	7370	410	1130	3330	440	450	400	460	430	150
Ce	58	60	25	42	19	130	42	54	31	37	16	69	46	19	60	60	36	49	73	15
Co	13	<5	11	11	<5	<5	<5	<5	<5	6	<5	11	6	<5	<5	<5	<5	10	10	<5
Cl	430	110	<10	270	110	<10	120	40	510	290	190	440	220	270	210	200	140	90	100	<10
Cr*	57	41	17	59	<10	<10	55	58	59	79	<10	41	49	23	40	44	30	65	35	13
Cu	10	45	70	13	270	710	25	71	12	11	46	16	11	51	83	82	64	23	59	24
Ga	13	17	16	13	14	<3	15	15	14	14	41	15	13	11	7	9	14	15	19	19
La	39	29	16	31	24	49	27	30	14	21	19	34	25	16	28	27	14	27	23	7
Pb	21	190	53	20	1020	3030	98	170	17	18	280	21	33	320	590	600	250	30	130	23
Rb	30	43	7	23	4	9	31	85	27	26	27	36	37	18	23	22	20	34	33	23
Sr	80	62	81	100	140	56	88	340	66	77	520	75	80	150	82	80	110	72	40	26
V	79	120	220	95	190	190	110	72	67	70	370	100	69	230	260	260	200	100	160	160
Y	35	20	21	34	8	<2	25	18	15	25	18	30	22	5	16	16	12	25	22	10
Zn	120	110	170	45	120	430	120	96	58	52	33	66	45	51	82	80	56	54	76	47
Zr	150	200	61	160	83	62	170	110	140	130	150	160	130	100	230	230	150	140	240	98
Ti/Zr	23	24	67	26	75	71	23	25	23	21	48	25	20	42	31	31	38	22	30	59
															Nb 10	Nb 9			Nb 8 Ni 22	Ni 20

Note: Nb < 4 ppm, Ni < 10 ppm except where indicated otherwise.
*Cr may be affected by crushing medium.

Table 4 Compositions of alunite-jarosite group minerals in Handcuff surficial sample, based on the general formula $AB_3(XO_4)_2(OH)_6$

Mineral	No. of analyses	A Site				B Site				XO4 Site			OH Site	
		Pb	K	Na	Ba	Al	Fe	Cu	Zn	SO_4	AsO_4	PO_4	OH	Cl
Plumbian alunite	2	0.28	0.52	0.08	0.03	2.79	0.11	0.06	0.06	1.64	0.36	0.01	5.68	0.05
Hinsdalite	5	0.97	0.01	0.02	0	2.49	0.18	0.03	0.30	1.04	0.11	0.85	5.68	0
Potassian hidalgoite	3	0.81	0.15	0.02	0.02	2.61	0	0.33[(1)]	0.06	1.22	0.77	0.01	5.62	0.04
Potassian hidalgoite	2	0.83	0.15	0.02	0.02	2.30	0.44	0.20	0.06	1.14	0.78	0.42	5.74	0.01
Ferrian hidalgoite	4	0.90	0.07	0.03	0.01	1.39	1.28	0.27	0.06	1.14	0.82	0.04	5.73	0
Aluminian plumbian jarosite	3	0.95	0	0.05	0	0.69	1.68	0.07	0.56[(2)]	1.52	0.19	0.30	5.83	0
Aluminian beudantite	3	0.88	0.06	0.03	0.01	0.91	1.73	0.11	0.25	1.01	0.98	0.01	5.52	0

(1) 0.33 mole Cu = 2.39% Cu
(2) 0.56 mole Zn = 4.98% Zn