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# **FURTHER GEOCHEMICAL STUDIES OF THE SOIL AT THE STEINWAY GOLD PROSPECT, KALGOORLIE, WESTERN AUSTRALIA**

*M.J. Lintern and M.A. Craig*

**CRC LEME OPEN FILE REPORT 100**

**June 2001**

(CRC LEME Restricted Report 27R/  
CSIRO Division of Exploration and Mining Report 252R, 1996.  
2nd Impression 2001.)

CRC LEME is an unincorporated joint venture between The Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining, established and supported under the Australian Government's Cooperative Research Centres Program.





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## RESEARCH ARISING FROM CSIRO/AMIRA YILGARN REGOLITH GEOCHEMISTRY PROJECTS 1987-1996

In 1987, CSIRO commenced a series of multi-client research projects in regolith geology and geochemistry which were sponsored by companies in the Australian mining industry, through the Australian Mineral Industries Research Association Limited (AMIRA). The initial research program, "Exploration for concealed gold deposits, Yilgarn Block, Western Australia" had the aim of developing improved geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, buried or deeply weathered gold deposits. The program commenced with the following projects:

### **P240: Laterite geochemistry for detecting concealed mineral deposits (1987-1991).** Leader: Dr R.E. Smith.

Its scope was development of methods for sampling and interpretation of multi-element laterite geochemistry data and application of multi-element techniques to gold and polymetallic mineral exploration in weathered terrain. The project emphasised viewing laterite geochemical dispersion patterns in their regolith-landform context at local and district scales. It was supported by 30 companies.

### **P241: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1987-1991).** Leader: Dr C.R.M. Butt.

The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

These projects represented 'an opportunity for the mineral industry to participate in a multi-disciplinary program of geoscience research aimed at developing new geological, geochemical and geophysical methods for exploration in deeply weathered Archaean terrains'. This initiative recognised the unique opportunities, created by exploration and open-cut mining, to conduct detailed studies of the weathered zone, with particular emphasis on the near-surface expression of gold mineralisation. The skills of existing and specially recruited research staff from the Floreat Park and North Ryde laboratories (of the then Divisions of Minerals and Geochemistry, and Mineral Physics and Mineralogy, subsequently Exploration Geoscience and later Exploration and Mining) were integrated to form a task force with expertise in geology, mineralogy, geochemistry and geophysics. Several staff participated in more than one project. Following completion of the original projects, two continuation projects were developed.

### **P240A: Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia (1991-1993).** Leaders: Drs R.E. Smith and R.R. Anand.

The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

### **P241A: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1991-1993).** Leader: Dr. C.R.M. Butt.

The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

Most reports related to the above research projects were published as CRC LEME Open File Reports Series (Nos 1-74), with an index (Report 75), by June 1999. Publication now continues with release of reports from further projects.

### **P252: Geochemical exploration for platinum group elements in weathered terrain.** Leader: Dr C.R.M. Butt.

This project was designed to gather information on the geochemical behaviour of the platinum group elements under weathering conditions using both laboratory and field studies, to determine their dispersion in the regolith and to apply this to concepts for use in exploration. The research was commenced in 1988 by CSIRO Exploration Geoscience and the University of Wales (Cardiff). The Final Report was completed in December 1992. It was supported by 9 companies.

### **P409: Geochemical exploration in areas of transported overburden, Yilgarn Craton and environs, WA.**

Leaders: Drs C.R.M. Butt and R.E. Smith.

About 50% or more of prospective terrain in the Yilgarn is obscured by substantial thicknesses of transported overburden that varies in age from Permian to Recent. Some of this cover has undergone substantial weathering. Exploration problems in these covered areas were the focus of Project 409. The research was commenced in June 1993 by CSIRO Exploration and Mining but was subsequently incorporated into the activities of CRC LEME in July 1995 and was concluded in July 1996. It was supported by 22 companies.

Although the confidentiality periods of Projects P252 and P409 expired in 1994 and 1998, respectively, 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 100) is a second impression (second printing) of CSIRO, Division of Exploration and Mining Restricted Report 252R, first issued in 1996, which formed part of the CSIRO/AMIRA Project P409.

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## EXECUTIVE SUMMARY

The CSIRO-AMIRA Project "Exploration in Areas of Transported Overburden, Yilgarn Craton and Environs" (Project 409) has, as its principal objective, development of geochemical methods for mineral exploration in areas with substantial transported overburden, through investigations of the processes of geochemical dispersion from concealed mineralization. The Project has two main themes. One of these, *'Surface and sub-surface expression of concealed mineral deposits'* is addressed by this report, which focuses on the soil geochemistry of the Steinway Au prospect (Kalgoorlie Area).

This study is located in the central and northern part of the prospect where the thickness of transported overburden is variable but greater than 20 m, and the depth to mineralization is about 30 to 40 m. The great thickness of sediments is similar to other sites within the Kalgoorlie area studied in this project, but the presence of the Au at the surface makes it highly unusual. It was considered that a more detailed study of the nature of Au in the surficial material from such an environment will enhance our understanding of the processes whereby Au may (or may not) be enriched in the surficial environment as a result of its proximity to the buried mineralization.

The principal results are summarized as follows:

1. Microscopically-visible Au was present in some ferruginous granules;
2. Gold concentrations of individual ferruginous granules are extremely variable, ranging from <40 to 1500 ppb;
3. Total Au content of coarse material are weakly related to the total Au content of the soil.

Specific targeting of the calcareous horizon has been demonstrated to maximize the probability of sampling the most consistently auriferous sample in all landscape regimes in the Kalgoorlie region. In relict and erosional regimes, such sampling may accurately define drilling targets. However, in depositional regimes, the results for Steinway indicate that there is no direct link with mineralization. Here, although the Au anomaly in the calcareous soil directly overlies buried mineralization, the data suggest that it is derived from detrital Fe granules in the soil, rather than the mineralization itself.

It is concluded that, in depositional areas, sampling of calcareous material at best may indicate the potential of the (sub-)catchment. It is suggested, therefore, that for such landscape regimes, wider sampling intervals should be used, with a follow-up requirement that deep samples be collected including basal sands or ferruginous material in saprolite.

C.R.M. Butt  
R.E. Smith  
Project Leaders  
November 1996



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## 1. INTRODUCTION

Previous CSIRO-AMIRA Projects (240, 240A, 241 and 241A) investigated the geochemical expression of primary and supergene Au mineralization in the regolith. These studies demonstrated that in relict and erosional landform regimes, carefully directed, shallow sampling is generally more cost- and technically-effective than routine drilling to deep saprolite in regional- and prospect-scale exploration. In some locations, it was found that there was a surface expression of mineralization concealed by up to 40 m of barren sediments and/or leached saprolite. In this project (P409), outcomes of the previous projects are being further tested to determine whether similar procedures can be routinely applied in depositional regimes. In an earlier study at Steinway, it was shown that coarse size fractions of soils overlying mineralization, concealed by 25 m of transported overburden, contained up to 450 ppb Au (Lintern and Gray, 1995). This report summarizes further studies undertaken of coarse size fraction material at the Steinway Au prospect (Kalgoorlie Area), and examines the role it may play in the formation of Au anomalies over mineralization.

Two groups of sample media have particular interest for Au exploration in the Yilgarn Craton:

- (i) ferruginous materials, particularly lateritic residuum and lag.
- (ii) calcareous soil horizons, which are widespread in the semi-arid parts of the southern Yilgarn. Gold concentrations are generally much greater in pedogenic carbonate, compared with immediately adjacent horizons. It has been shown in previous studies in relict and erosional areas that failure to sample this horizon consistently in an exploration programme will result in ineffective soil surveys.

In the Kalgoorlie area, the work programme has been to investigate potential sample media in the transported regolith above mineralization. Specifically the study investigated:

- (i) gold at or near the surface;
- (ii) gold in transported overburden;
- (iii) pathfinder elements in transported and residual regolith and bedrock.

Several sites were offered for pilot studies (Table 1). All sites were visited and a preliminary set of samples was taken at most locations. Sites were assessed using various criteria (see Table 1) and the most suitable sites were selected for more detailed investigations of the geochemistry of regolith materials, vegetation and groundwater.



Table 1: Advantages and disadvantages of study sites examined during the P409 pilot study and previous CSIRO-AMIRA projects.

Site	Type of mineralization	Advantages	Disadvantages
<b>Sites chosen</b>			
<i>Argo</i>	<i>At interface and saprolite, beneath 20 m or more of lacustrine sediments.</i>	<i>Extensive drilling available. Strong mineralization. Exposed pit. Distant from upslope Au deposit.</i>	<i>Surficial sampling not completed, due to pit excavation. Poor condition of drill material in top 10 m.</i>
<i>Apollo</i>	<i>In saprolite, beneath 5-10 m of transported sediments and 10 m of saprolite.</i>	<i>Extensive drilling available. Strong mineralization. Distant from upslope Au deposit. Proximity to Argo deposit facilitates comparisons. Reported weak surficial anomaly.</i>	<i>Poor condition of drill material in top 10 m.</i>
<i>Mitchell Challenge Swordsman (Higginsville)</i>	<i>At base of transported material beneath 35 m to 50 m of transported sediments.</i>	<i>Strong mineralization. Distant from upslope Au deposit. Reported surficial anomaly.</i>	<i>Ground partly disturbed before sampling took place.</i>
<i>Kurnalpi</i>	<i>At interface and saprolite, beneath 60 m of transported sediments.</i>	<i>Moderate drilling available. Distant from known Au mineralization.</i>	<i>Not scheduled to be mined. Weak mineralization.</i>
<i>Mt Celia</i>	<i>Beneath 5 to 15 m of transported deposits.</i>	<i>Extensive drilling available. Distant from upslope Au mineralization.</i>	<i>Not scheduled to be mined. Not typical of regolith in Kalgoorlie area.</i>
<i>Panglo (I)</i>	<i>In saprolite, beneath &lt;1 m to 2 m of transported soil and 40 m of saprolite.</i>	<i>Reported strong surficial anomaly overlying strongly leached saprolite above mineralization. Distant from upslope Au deposit. Pit face available to sample.</i>	<i>Not deeply buried.</i>
<i>Runway</i>	<i>In saprolite, beneath 1m of possibly transported soil and 50 m of saprolite.</i>	<i>Reported strong surficial anomaly overlying strongly leached saprolite above mineralization. Distant from upslope Au deposit. Moderate drilling available.</i>	<i>Not scheduled to be mined. Not deeply buried.</i>
<i>Steinway</i>	<i>In saprolite, 5 m beneath 30 m of transported sediments.</i>	<i>Known surficial anomaly. Extensive drilling available. Distant from known Au mineralization.</i>	<i>Not scheduled to be mined. Weak mineralization.</i>
<i>Wollubar (Enigma)</i>	<i>At interface and saprolite, beneath 55 m of transported sediments.</i>	<i>Moderate drilling available. Distant from upslope Au deposit.</i>	<i>Not scheduled to be mined. Weak mineralization.</i>
<b>Sites not chosen</b>			
<i>Gindalbie</i>	<i>With sulphides at interface, beneath 60 m of transported sediments.</i>	<i>Moderate drilling available. Distant from upslope Au deposit.</i>	<i>Poorly mineralized. Not scheduled to be mined</i>
<i>Kat Gap (Forrestania)</i>	<i>Little information available.</i>	<i>Moderate drilling available. Distant from upslope Au mineralization.</i>	<i>Depth of transported material not determined - may be thin.</i>
<i>Kurrawang</i>	<i>Little information available.</i>	<i>Known surficial anomaly. Exposed pit (at a later stage).</i>	<i>Surface regolith mostly residual. Little drill spoil.</i>

Table 1: (continued)

Site	Type of mineralization	Advantages	Disadvantages
<b>Sites not chosen</b>			
<i>Lady Bountiful Extended</i>	<i>At interface beneath 25 m of transported deposits, and also in underlying quartz veins.</i>	<i>Moderate drilling available. Distant from upslope Au deposit. Exposed pits. Strong mineralization.</i>	<i>Severe surficial disturbance.</i>
<i>Lake Cowan</i>	<i>Various deposits associated with palaeochannel and underlying saprolite.</i>	<i>Known surficial anomaly. Extensive drilling available.</i>	<i>Known upslope mineralization.</i>
<i>Samphire</i>	<i>Little information available.</i>	<i>Exposed pit.</i>	<i>Surface regolith mostly residual.</i>
<b>Previous studies</b>			
<i>Baseline</i>	<i>Beneath 20 m of transported sediments.</i>	<i>Exposed pit. Known surficial anomaly.</i>	<i>Samples not available.</i>
<i>Matt Dam</i>	<i>At interface and saprolite, 15 m beneath 10 m of transported sediments.</i>	<i>Extensively studied in earlier project. Known surficial anomaly.</i>	<i>This part of deposit not scheduled to be mined.</i>
<i>Panglo (II)</i>	<i>Located in saprolite 20 m beneath base of 15 m of transported sediments.</i>	<i>Extensively studied in earlier project. Known surficial anomaly.</i>	<i>This part of deposit not scheduled to be mined.</i>
<i>Zuleika</i>	<i>At interface and saprolite, beneath 20 m of transported sediments.</i>	<i>Exposed pit. Extensively investigated in earlier project.</i>	<i>Known upslope mineralization. No further surface samples available.</i>

Anomalous Au concentrations (25-150 ppb) occur in bulk soil directly over mineralization at Steinway and appear to be separated from it by about 30 m of barren transported overburden and leached saprolite (Lintern and Gray, 1995; Gardiner 1993). The great thickness of palaeochannel sediments is typical of the Kalgoorlie area, but high concentrations of Au at the surface makes it highly unusual. It was considered that a more detailed study of the nature of Au in the surficial material from such an environment would enhance the understanding of the nature and origin of Au enriched in surficial material and its relationship to buried mineralization. This study, as with other studies in the Kalgoorlie area, is based on collection and analysis of high quality surficial samples. The data provide further information concerning geochemical relationships between elements and appropriate sampling techniques for exploration in terrain with a deep sedimentary cover.

## 2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

Steinway is one of a series of Au prospects and deposits located within several hundred metres of each other, about 25 km south of Kalgoorlie and 15 km west of the New Celebration Mine (Figure 1). Some of the descriptions that follow have been extracted from Gardiner (1993) and Lintern and Gray (1995). The area encompassing and immediately surrounding the Steinway soil anomaly forms a flat-lying, depositional plain (Figure 2) with higher areas rarely rising more than five metres above it. To the south (1200 m), the Penfold mine is in an erosional area, in mafic saprolite, and to the south west (500 m), the Greenback mine is in a depositional area, with supergene mineralization in the basal units of a palaeochannel sediments and underlying saprolite. Drainage is to a playa, White Lake, about 10 km to the north. Present-day, shallow, ephemeral channels cross the study area and generally flow in a northerly direction; such channels separate the Steinway and Penfold soil anomalies. Vegetation is open salmon gum woodland, with a sparse understorey that includes bluebush.

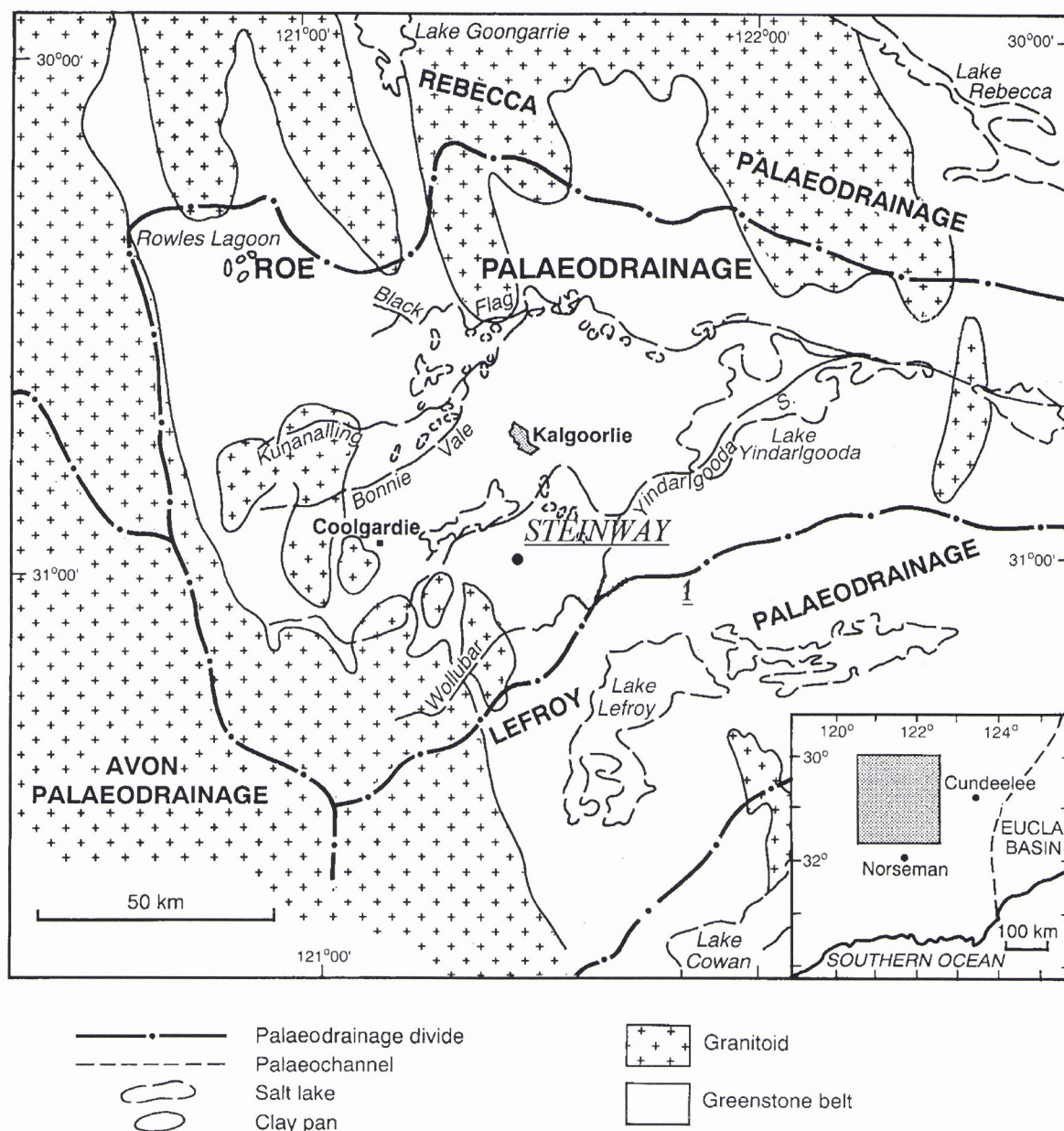


Figure 1: Location map (after Kern and Commander, 1993).

At Steinway, the regolith consists of the following units:

- 0-2 m: calcareous, clay-rich, red soil with abundant ferruginous granules;
- 2-5 m: non-calcareous clay containing large amounts of ferruginous granules;
- 5-25 m: mottled clay;
- 25-30 m: variably sandy to silty clay with lenses of coarser sand-rich material; a sandy unit commonly marks the lowest part of the channel; and mica-rich clays mark the beginning of the saprolite of the residual profile;
- 30-50m: saprolite, clay-rich towards the top;
- 50m+: fresh andesite.



## STEINWAY INTERPRETED LANDSCAPE CLASSES

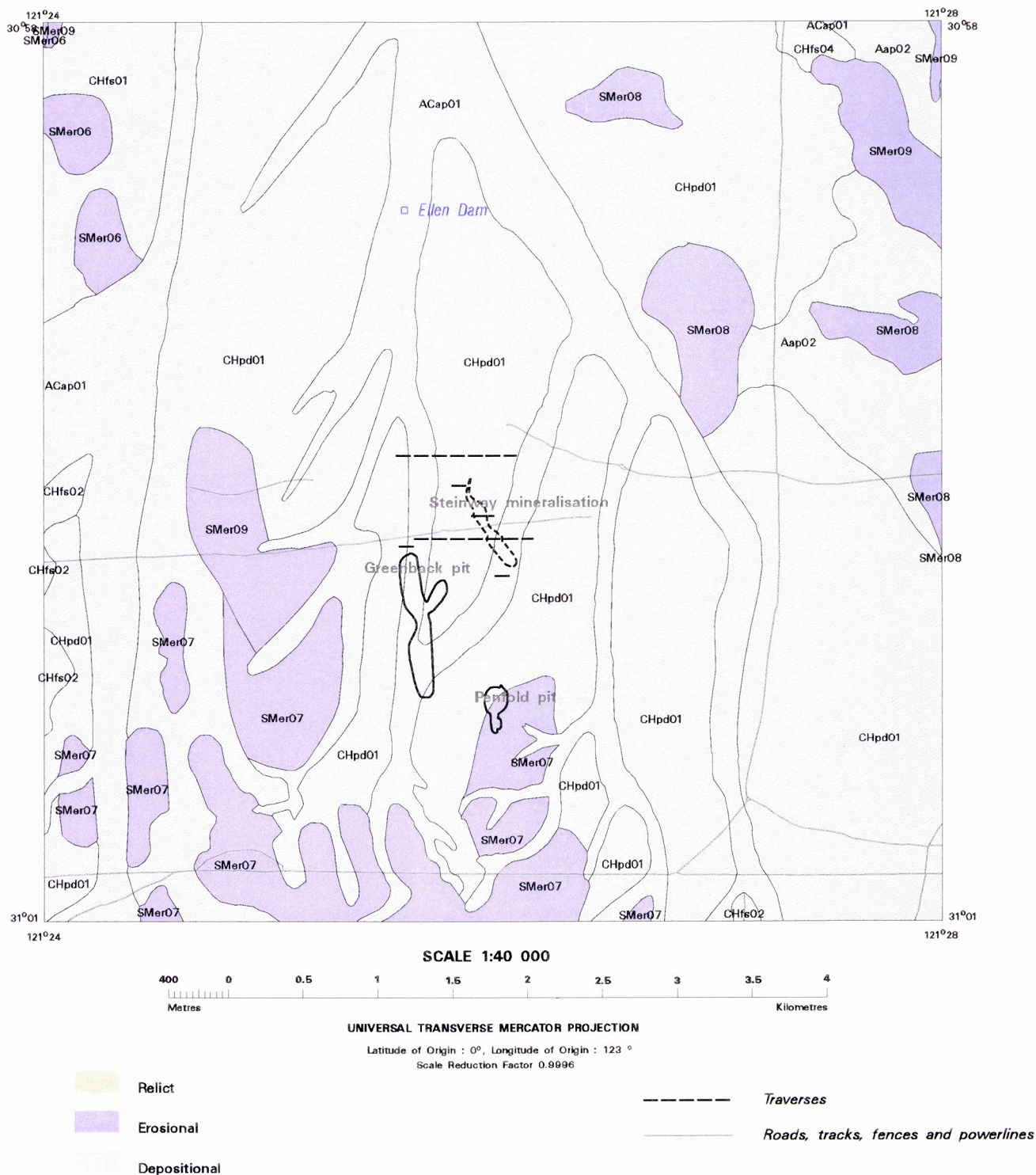


Figure 2: Simplified regolith diagram of the Steinway area. See back of report for full size detailed diagram.

Saprolite of weathered andesitic rocks dominates the upper part of the residual zone. Bedrocks are mafic andesites, trachytes, porphyritic tuffs and black shales.

There are two types of mineralization at Steinway: (i) supergene mineralization below a palaeochannel and (ii) primary mineralization associated with quartz stockwork veining within mafic andesites. The andesites have been metamorphosed to microporphyritic amphibolites dominated by hornblende, biotite, and lesser amounts of feldspar and garnet. Strongly altered areas generally are silicified, carbonate altered, and veined with tourmaline, quartz and disseminated pyrite (M. Spivey and M. Miller, Newcrest Mining Ltd, written communication, 1994).

Earlier studies (Gardiner, 1993; Lintern and Gray, 1995) at Steinway have shown:

1. Mineralization at Steinway is delineated by soils (0-1 m) containing >24 ppb. The highest soil Au content (152 ppb) is located above mineralization;
2. Gold is correlated with Ca only in the top 0.5 m of the soil profile.
3. Concentrations of water- and iodide-soluble Au (partial extractions) are anomalous over mineralization.
4. The 0-1 m sample with the highest total Au content has a relatively low proportion of water extractable Au.
5. High Au concentrations occur in ferruginous granules over mineralization.
6. Biochemical data do not define the location of the mineralization.
7. The groundwater is acid and saline, and in some areas, is sufficiently oxidizing to dissolve gold as a chloride complex.
8. More study is required to assess whether the Steinway soil anomaly is spurious.

These earlier studies recognized the need for a more detailed investigation of the soil geochemistry to determine whether the inter-relationships between Au and Fe, Au and Ca and possibly other elements is similar or variable throughout the entire anomaly. Other soil anomalies in the vicinity also needed to be examined in detail. Specifically, there was a need to:

- (i) examine the relationship between the soil anomalies, underlying mineralization and position of the palaeochannel(s);
- (ii) examine the ferruginous lag containing Au in more detail to try and determine the nature of the Au contained therein, and
- (iii) collect and analyze soil samples from other parts of the Steinway and other anomalies by putting in costeans and/or soil pits, and by more augering.

### **3. REGOLITH LANDFORM MAPPING**

#### **3.1 Methods**

For regolith landform map construction, 1:86000 RC9 black and white aerial photographs were used. Approximately 130 locations were visited and observations recorded to assist with regolith interpretations and map construction. The data were used to construct regolith landform units from calibrated photopatterns and used to modulate data interpreted from satellite imagery. Compilations were performed at photoscale by scanning aerial photographs with overlays attached without the intricate removal of radial distortion. All photographs with overlays were edge-matched then



compiled into one composite sheet. The regolith polygons were scanned and imported into ARC/Info to allow the automatic diagram layout and automatic legend planning.

### 3.2 Interpretation

The dominant regolith landform unit for the Steinway area is depositional which comprises 79% of the total mapped area (TMA) with colluvial sediments providing nearly 43% of the TMA (Table 2). Erosional areas comprise 18% of the TMA; the dominant erosional regolith landform unit is “moderately weathered bedrock” and represents 15% of the TMA. Relict area comprise 3% of the TMA.

Table 2: Principal regolith landform regimes.

REGOLITH LANDFORM UNIT	% OF TOTAL MAPPED AREA (TMA)
RELICT	3.2
EROSIONAL	17.7
Very highly weathered	<0.1
Highly weathered	0.7
Moderately weathered	14.5
Slightly weathered	2.4
DEPOSITIONAL	79.1
Alluvial sediments	18.3
Aeolian sands	3.8
Dunefield	4.9
Colluvial sediments	42.9
Lacustrine	9.4
TOTAL	100

An interpretation was made of the nature of the material expressed directly at the actual land surface (Table 3); this was possible for approximately 50% of the TMA at this level of investigation. These materials represent the source of regolith compositional information as determined by Landsat TM imagery. These surface materials do not indicate the full nature of regolith materials at depth. A complete explanation of the regolith materials and landforms comprising each unit is provided in the legend on the regolith landform map located at the back of this document.

Table 3: Surface material, Steinway area.

	UNIT	% of TOTAL MAPPED AREA
1.	Calcareous earths, soil carbonate, calcareous nodules	1.3
2.	Lag:-variable composition, but dominantly gravel-sized lithic fragments	0.1
3.	Lag gravels: dominantly quartzofeldspathic sand or granules, or mixtures	13.1
4.	Ferruginous fragments - mixed composition: lateritic residuum, duricrust, Fe segregations, Fe saprolite and Fe-stained hardpan	6.2
5.	Fine ferruginous gravel lags	28.3
6.	Black, slightly magnetic, hematite- maghemite-rich ferruginous granules	1.30
7	Unassigned	49.7
	Total map area	100.00



#### 4. SAMPLE COLLECTION, PREPARATION AND ANALYSIS

##### 4.1 Bulk ferruginous granules

Eighty four samples (09-4131 to 09-4214) weighing from 1 to 2 kilos were collected from the surface to 5 m depth using a vehicle-mounted power auger rig; sampling was targeted over known soil anomalies (Figure 3). Samples were dried at 70° C, split, weighed, wet-sieved to retain the >1 mm size fraction, and dried before a sub-sample was either (i) pulverized in a K1045 steel ring mill (Robertson and Crabb, 1988) to nominal <75 µm or (ii) analysed uncrushed, for analysis by INAA (Becquerel Laboratories, Lucas Heights) for Au, Sb, As, Ba, Br, Ce, Cs, Cr, Co, Eu, Hf, Ir, Fe, Au, La, Lu, Mo, K, Rb, Sm, Sc, Se, Ag, Na, Ta, Th, W, U, Yb and Zn.

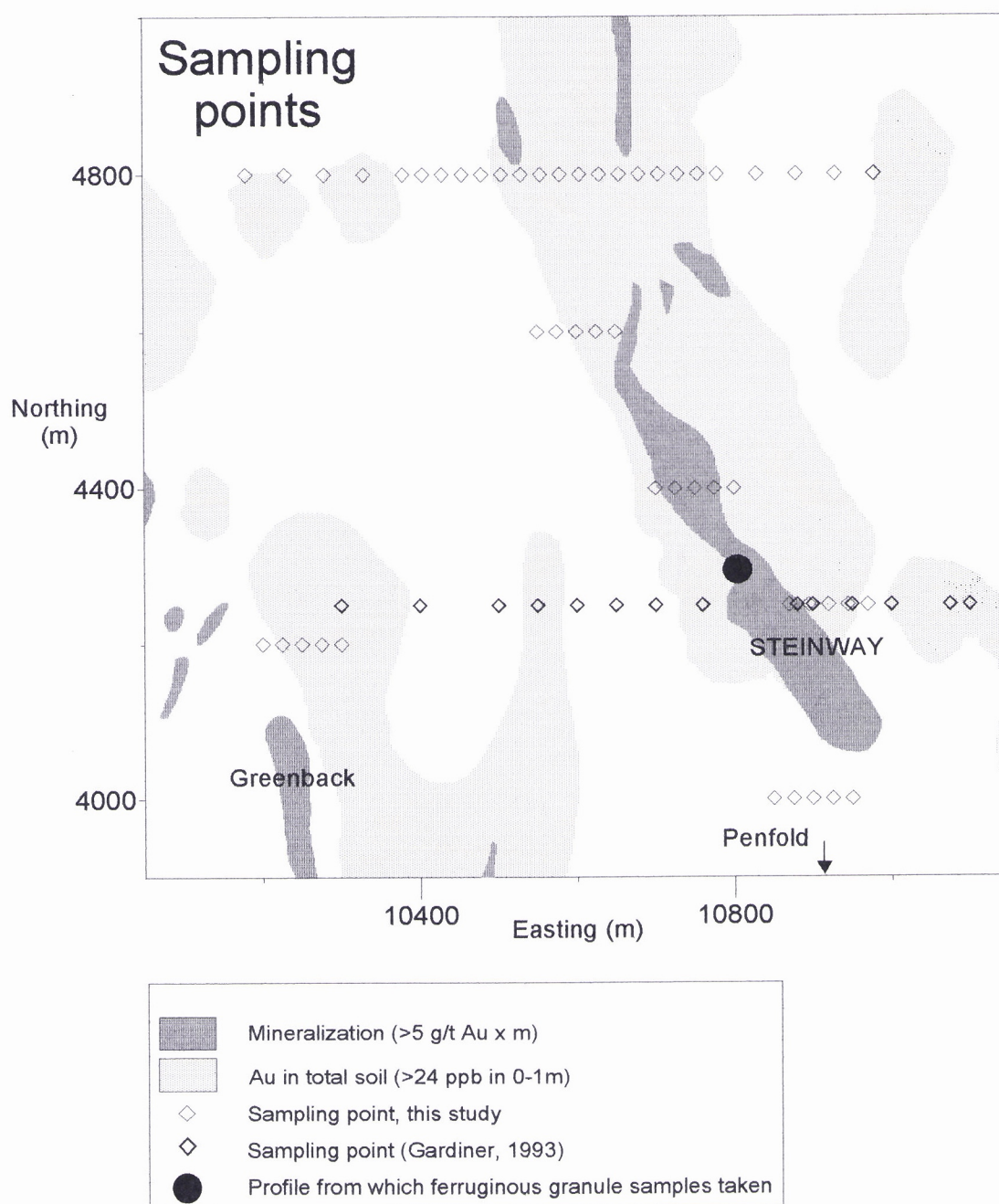


Figure 3: Location of ferruginous granule sample sites investigated in this study. Soil Au geochemistry and mineralization from company data.

## 4.2 Individual ferruginous granules

Sixty ferruginous granules ( $>710\ \mu\text{m}$   $<2\ \text{mm}$ ), randomly picked from two samples investigated in a previous study (Lintern and Gray, 1995), were analysed in more detail. Fifty were taken from sample 09-2046 and 10 from 09-2040. The samples were taken from the soil profile located over mineralization at Steinway (10810E, 4250N, Figure 3 and Figure 4). They were individually sectioned<sup>1</sup>. One half was sent for INAA, and the other half was retained, cemented in epoxy and polished for microscope studies.

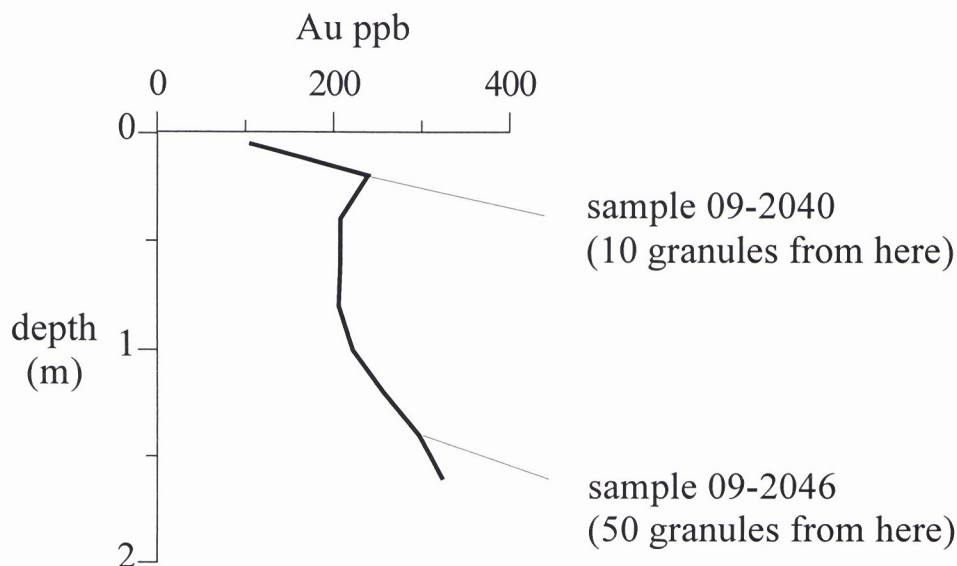


Figure 4: Gold concentration in the soil profile at Panglo (Lintern and Gray, 1995). Samples 09-2040 and 09-2046 used for individual ferruginous granule investigation. Profile located at 10810E 4250N.

## 5. RESULTS

### 5.1 Ferruginous granule survey

The percentage of coarse material ( $>1\text{mm}$ ) sieved from the samples collected by auger varied from  $<1\%$  to  $24\%$  (mean  $8\%$ , standard deviation  $5\%$ ) indicating that the coarse material is a significant but highly variable component of the bulk soil.

Gold concentrations are extremely variable, ranging from  $<5\text{ ppb}$  to  $107\text{ ppb}$  (Figure 5). Not unexpectedly, the highest concentrations in ferruginous granules occur in areas where the total Au in the bulk 0-1 m soil was more concentrated (contoured data in Figure 5). However, only a few anomalous soil samples (4 of 36) have detectable Au within their coarse ( $>1\text{ mm}$ ) fraction. Concentrations of Au in ferruginous granules taken from deeper within the profile are also highly variable (Figure 5), and only 5 of 12 recording detectable Au in anomalous areas.

Arsenic concentrations varied from 41 to 146 ppm (Figure 6). More variability was recorded in the northern section and higher concentrations in the southern section of the study area. No association is

<sup>1</sup> Individual granules were cemented onto microscope slides using Crystalbond 509 thermosetting adhesive. The slide was mounted on a Buehler Isomet 11-1180 slow speed diamond saw using a slide holder and vacuum pump. Granules were individually cut in half with a 10 cm diamond wafering blade (0.03 cm thick), with a 26 g weight. After cutting, the slide was re-heated and the remaining half-sample removed from the thermosetting adhesive.



observed between As concentrations and mineralization, Au in total soil, or Au in ferruginous granules.

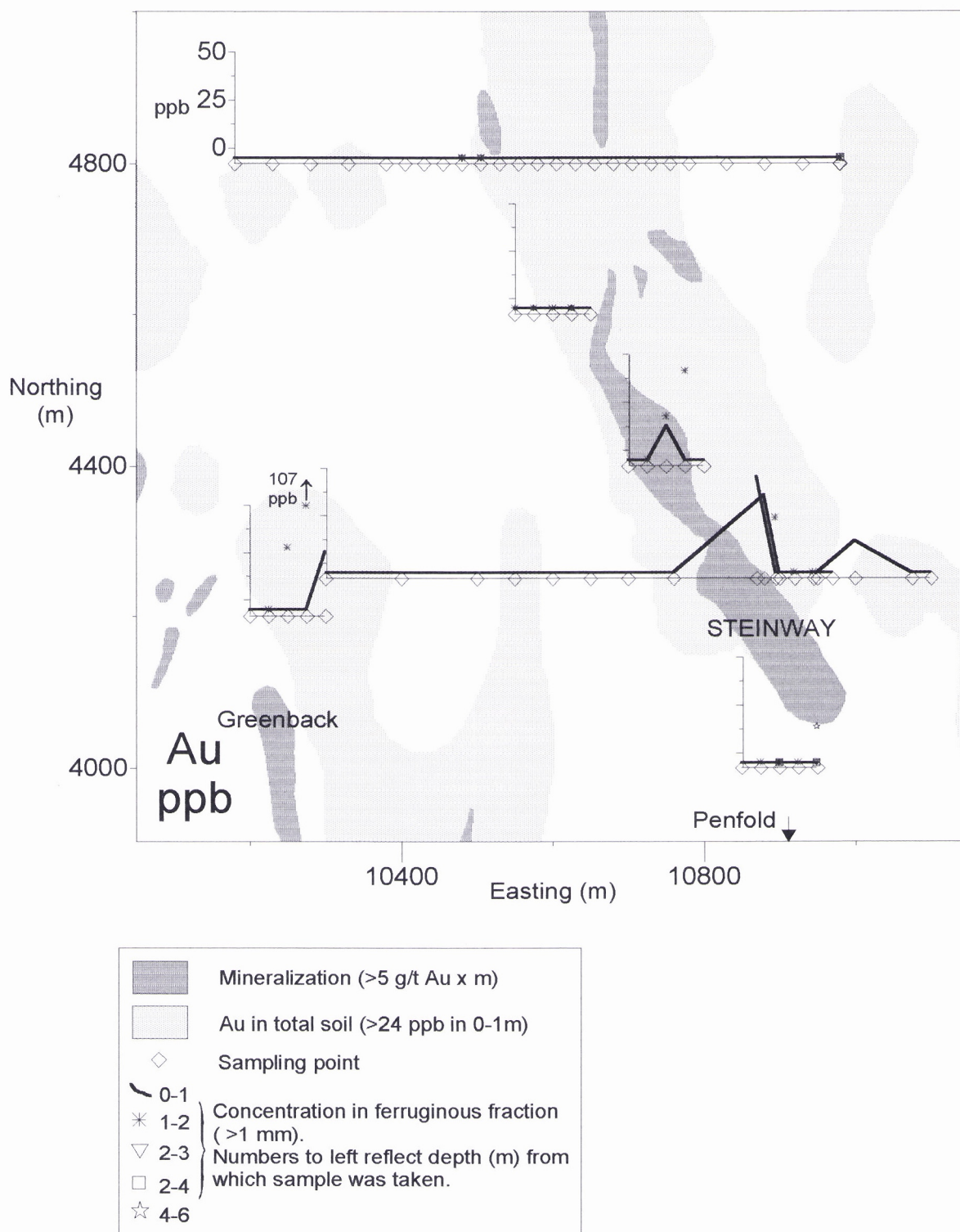


Figure 5: Gold (in ppb) in ferruginous material (>1 mm). Most data are from 0-1 m.

The distribution of other elements in the ferruginous granules are summarized in Appendix A1.1. In particular, it is noted that:



1. concentrations of Yb and Lu are not unusually high above mineralization; Yb and Lu have previously been noted to be enriched in soils overlying Au mineralization at Steinway (Lintern and Gray, 1995; Gardiner, 1993);
2. an easterly trend in Cr distribution, with higher concentrations (>6000 ppm) in the west. This suggests the granules may be derived from the ultramafic rocks that outcrop in the Saddle Hills located about 5 km to the south west of Steinway (Gardiner, 1993).

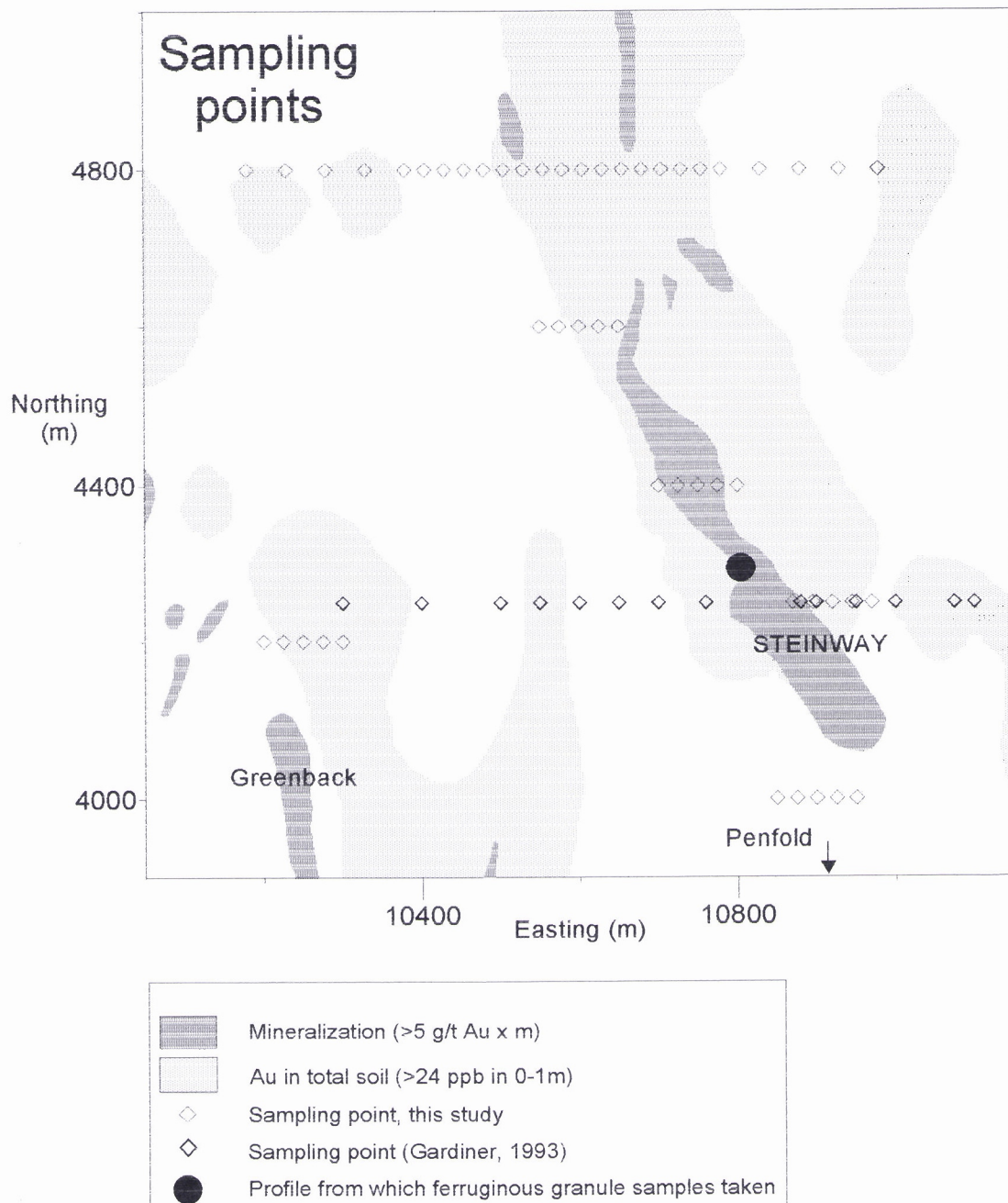


Figure 6: Arsenic (in ppm) in ferruginous material (>1 mm). Most data are from 0-1 m.

## 5.2 Individual ferruginous granules

### 5.2.1 Chemical composition

Analysis of 60 individual granules from samples 09-2040 and 09-2046 indicate a wide variation in Au contents between <40 ppb to 15000 ppb (Figure 7). Nearly half of the samples had Au concentrations of >100 ppb. Samples from the two parts of the profile (0.2 and 1.4 m) did not show any significant differences in Au concentrations (darker histograms in Figure 7).

The pathfinder elements Sb, As and W did not show as wide variations in their concentrations as Au (Figure 7). There is a moderately strong association between Au and W: 8 of the 15 most Au-rich (>200 ppb) granules also have high W concentrations (>15 ppm). No associations were observed between Au and Sb or Au and As. There appears to be a trend of samples with higher Br concentrations to have higher Au contents (Figure 7); the reason for this is unclear.

Geochemical results for other elements are given in Appendix A2.2.

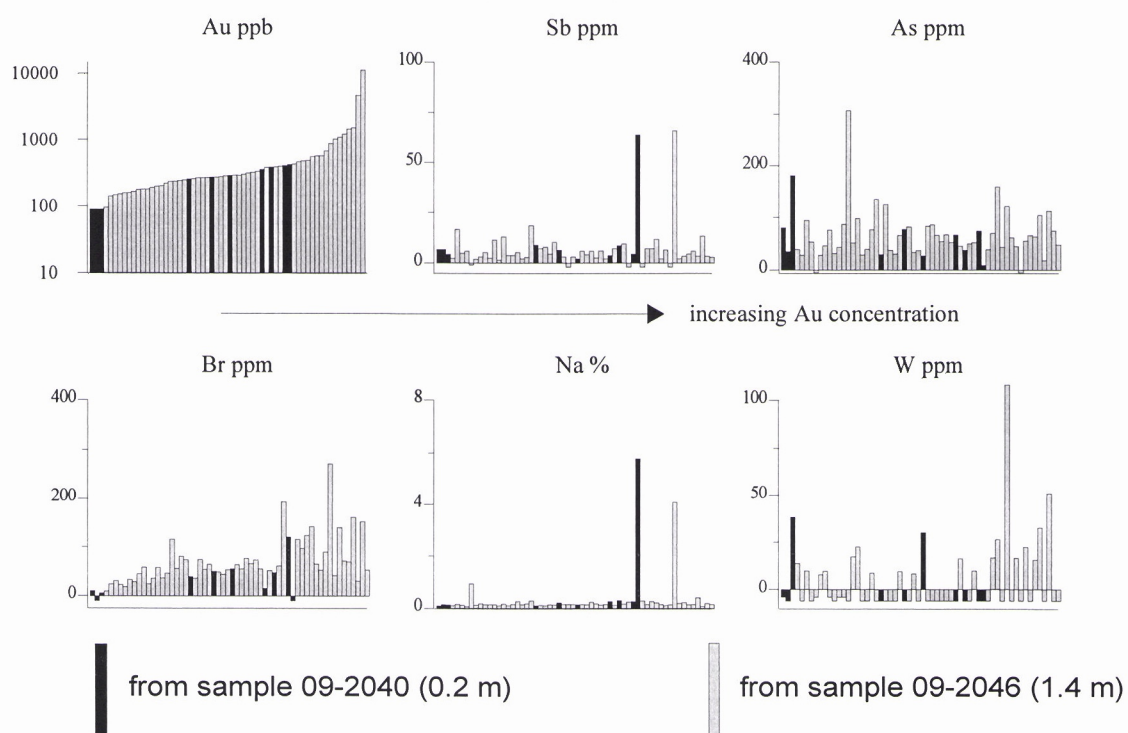


Figure 7: Elemental concentrations for Au, As, Sb, W, Br and Na for individual ferruginous granules from Steinway. All data ranked according to increasing Au concentration from left to right.

### 5.2.2 Microscopic investigations

Petrological investigations were undertaken of 12 individual ferruginous granules with high concentrations of Au (> 250 ppb). Photographs and descriptions are given in Figure 8 and Appendix A2.4, respectively.

The samples are pervasively ferruginized, with some having partly preserved primary lithic fabrics; however, fabrics are not well preserved or readily identifiable. Gold grains up to 10  $\mu\text{m}$  (and possibly up to 30  $\mu\text{m}$ ) in size were observed, but no Ag was detected within them.



Figure 8 (overleaf): Photograph and photomicrographs showing the soil profile and typical ferruginous granules from Steinway. Gold grains indicated by arrows. Red in photomicrographs B-I is ferruginous clay. Grey is goethite.

- A: Calcareous soil profile at Steinway - approximate depth 2 m.
- B: Ferruginous granule (FG34) containing a Au grain; total Au content of granule is 14.9 ppm. Photomicrograph in normally reflected light with oil immersion.
- C: SEM image of Au grain from B; no Ag detected (sample 09-2047 FG34).
- D: Ferruginous granules
- E: Gold grains in ferruginous granule (sample 09-2047 FG34). Photomicrograph in normally reflected light with oil immersion.
- F: Gold grains in ferruginous granule (sample 09-2047 FG34). Photomicrograph in normally reflected light with oil immersion.
- G: Gold grains partly filling a crack in a goethite ferruginous granule (sample 09-2047 FG34). Photomicrograph in normally reflected light with oil immersion.
- H: Gold grain in kaolinite accordion structure pseudomorphed by goethite (sample 09-2047 FG34).
- I: Gold grains in a goethite void filling (sample 09-2047 FG34). Photomicrograph in normally reflected light with oil immersion.
- J: Goethite forming cusate void fill in ferruginous granule (sample 09-2047). Photomicrograph in normally reflected light.
- K: Probable pseudomorphic silicate fabric, possibly after amphibole. Structure across field represents the original cleavage (sample 09-2047). Photomicrograph in normally reflected light.
- L: Similar to K; pseudomorphs after primary silicate fabric and secondary kaolinite accordion structures (sample 09-2047). Photomicrograph in normally reflected light.
- M: Goethite with desiccation cracks; no evidence of primary fabric (sample 09-2047). Photomicrograph in normally reflected light.
- N: Islands of pseudomorphed primary silicate fabric surrounded by, and filled with, secondary goethite. Some poorly-preserved layer silicates present (sample 09-2040). Photomicrograph in normally reflected light.
- O: Goethite cutan surrounding granule with pseudomorphed primary silicate fabrics (sample 09-2040). Photomicrograph in normally reflected light.
- P: Pisoliths, possibly with preserved primary fabrics in cores. Dominantly goethitic (sample 09-2040). Photomicrograph in normally reflected light.
- Q: Desiccation cracks in granules (sample 09-2040). Photomicrograph in normally reflected light.
- R: Layer silicates, preserved in goethitic groundmass (sample 09-2040). Photomicrograph in normally reflected light.
- S: Layer silicates, preserved in goethitic groundmass (sample 09-2040). Photomicrograph in normally reflected light.



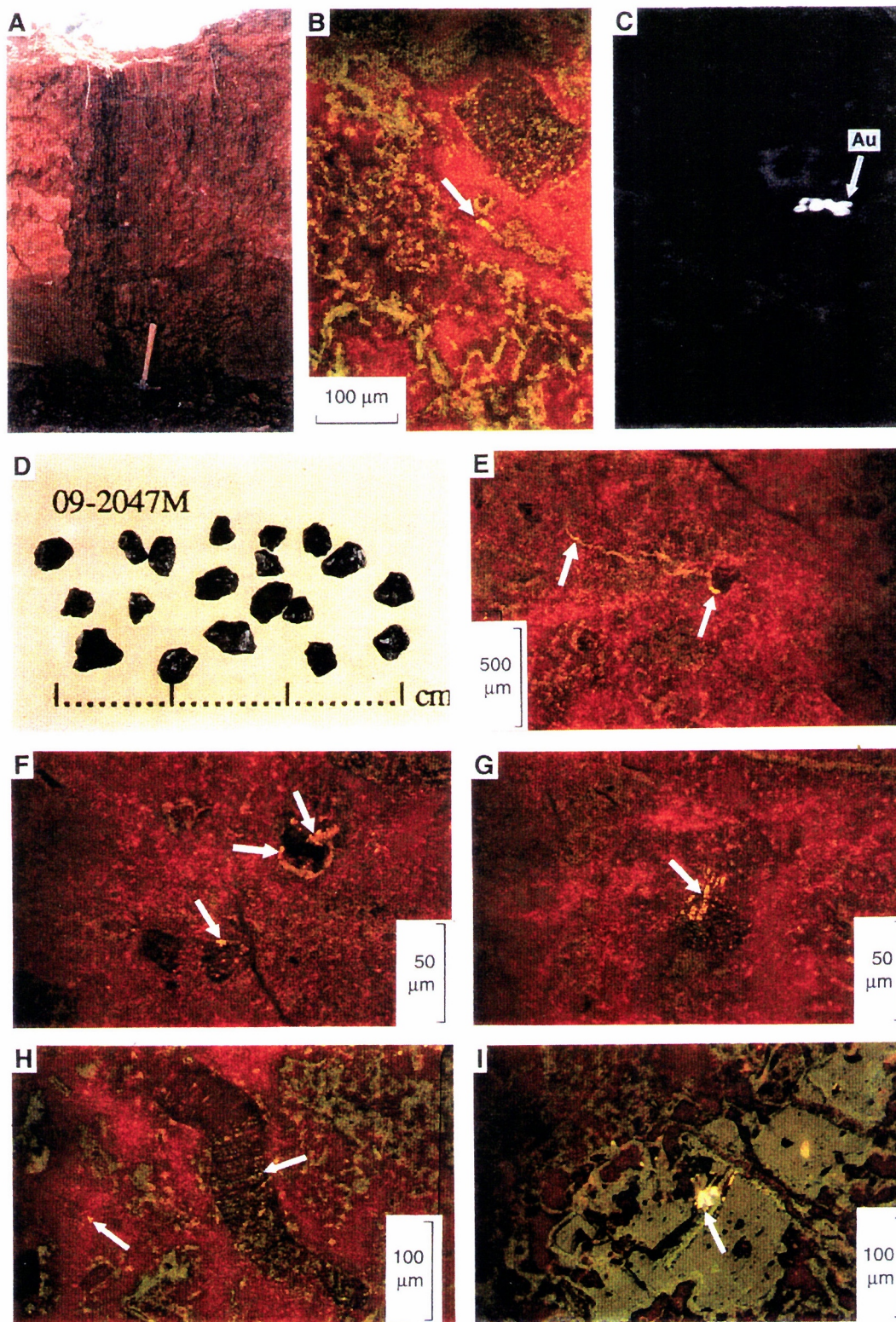


Figure 8: Photograph and photomicrographs showing the soil profile and typical ferruginous granules from Steinway. Gold grains indicated by arrows. Red in photomicrographs B-I is ferruginous clay. Grey is goethite.



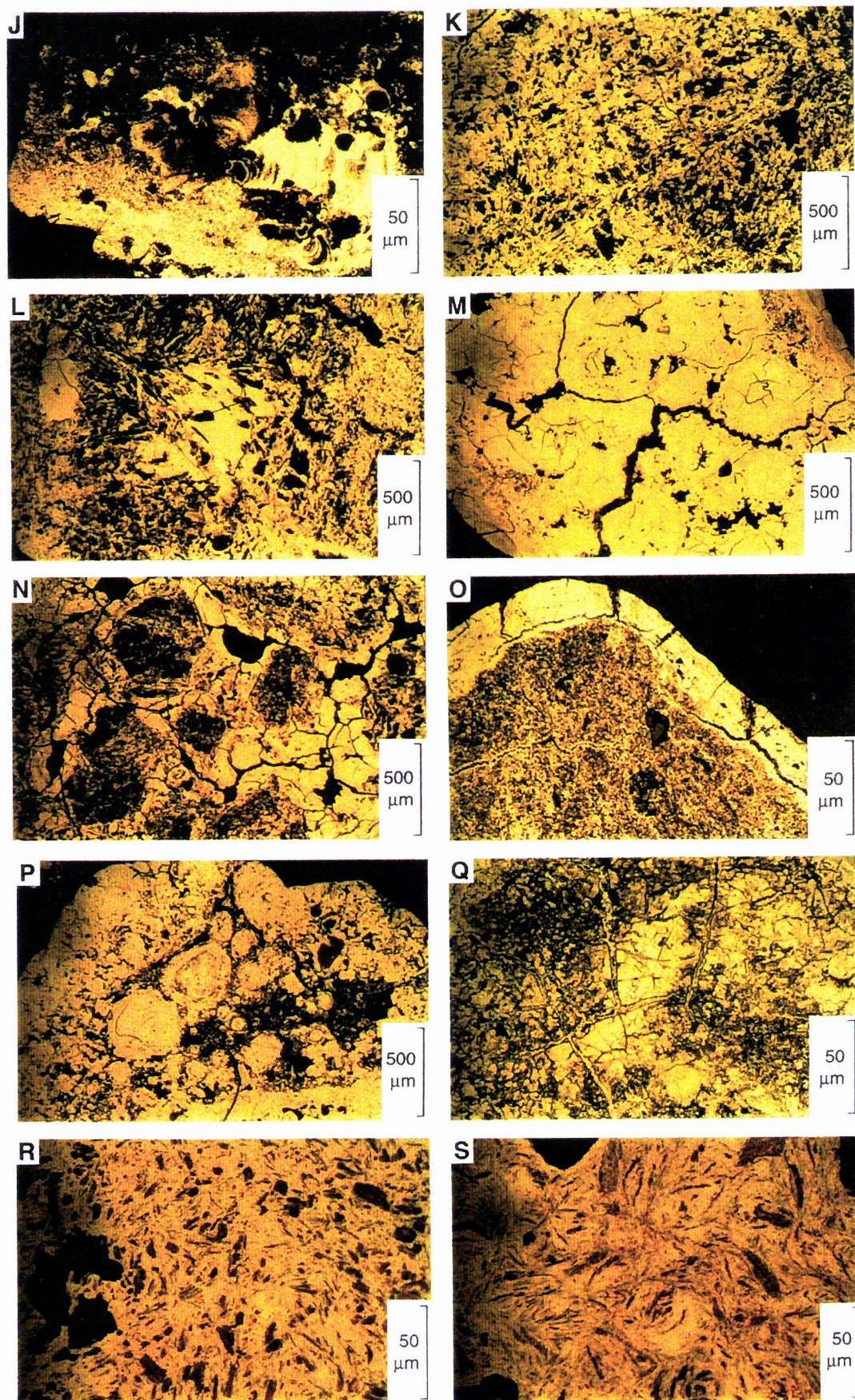


Figure 8 (continued): Photograph and photomicrographs showing the soil profile and typical ferruginous granules from Steinway. Gold grains indicated by arrows. Red in photomicrographs B-I is ferruginous clay. Grey is goethite.



## 6. DISCUSSION

The Steinway gold deposit has minor primary mineralization overlain by a flat-lying zone of supergene mineralization in saprolite at about 30 m depth. This mineralization is itself overlain by a few metres (<5 m) of leached saprolite and up to 25 m of barren sediments in a palaeochannel of presumed Tertiary age. The primary and secondary mineralization trend northward along the axis of the palaeochannel and appear to be delineated by an anomaly (25-150 ppb Au) in calcareous soils. The objective of investigations at Steinway has been to determine whether there is a direct genetic link between the concealed mineralization and the soil anomaly, or whether there is another source for the gold in the soil, giving rise to the anomaly lying coincidentally above the mineralization. It is important to note that there is no soil anomaly overlying the now mined, higher grade Greenback deposit, 500 m to the west, which has similar and, in places, shallower, mineralization.

Erosion of the palaeochannel during the early Tertiary was probably initiated by uplift of the southern part of the Yilgarn Craton, and probably followed a weakness provided by the shear hosting the primary mineralization. The channel was infilled at a time when marine incursions slowed the rate of erosion, giving the sequence of 2-3 m of basal coarse sediments overlain by up to 20 m of fine, lacustrine clays. Subsequently, the region was subjected to deep weathering under humid conditions, affecting both the sediments and the rocks underlying and adjacent to the channel. Lateritic weathering of the sediments is indicated by intense mottling and pisolith formation within the clays. Later erosion, under more humid conditions, caused further infilling of the channels, with the sediments including detritus derived from low hills nearby. These sediments included ferruginous saprolite, nodules and granules, some of which could be derived from outcropping mineralization at Penfold. During the arid phase, continuing to the present, salinization of the groundwater has occurred and has resulted in the mobilization of Au as halide complexes along the shear and the basal horizon of the channel, and its concentration as supergene deposits. The present surface drainage is oblique to the palaeochannel.

The authigenic mottles and pisoliths in the clays do not contain gold. Accordingly, if Au in the soil is directly related to the concealed mineralization, the process must either be active, or must have led to the specific enrichment of the detrital, ferruginous gravels, as a secondary source of Au in the soils. Evidence that weakens the argument for Au being derived from the underlying mineralization includes:

- (i) Apparently "identical" ferruginous granules from the same horizon contain a wide range of Au concentrations from below detection to several ppm. Chemically precipitated Au, derived from underlying mineralization, should be more evenly distributed.
- (ii) If (ground)water is the medium by which Au moves to the surface, complexed Au would have to pass through several metres of sands and silts, which are not favourable media for processes such as capillarity or diffusion because of the large voids.
- (iii) Gold migrating upwards would either have to bypass, or pass through, many chemical traps, such as ferruginous mottles in the transported overburden on its route to the surface. Plant roots are infrequently encountered below the first few metres of the surface, although at Greenback, where there is no soil anomaly, some living roots are present within 2 m of mineralization in the sediments.
- (iv) The presence of Au in ferruginous granules that have lithic fabrics.



Gold in the ferruginous granules was probably emplaced during their formation. Much granular material is released by the breakdown of lateritic duricrust, Fe mottles or Fe-rich saprolite. Gold may be associated with surficial ferruginous material by two main mechanisms:

- (i) Incomplete weathering of primary host rocks, which later become ferruginized, leaving encapsulated Au remaining, e.g. in vein quartz, relatively protected against chemical mobilization;
- (ii) Au chemically-mobilized during humid periods and co-precipitated with Fe oxides.

It is concluded, therefore, that the Au-bearing ferruginous fragments and granules are derived from erosion of exposed weathered mineralization, e.g., Penfold, and were deposited along the then shallow valley marking the old palaeochannel. Following deposition, the ferruginous materials have been further weathered, releasing Au particles, which may themselves have been dissolved (Figure 10).

With the onset of aridity, pedogenically mobilized Au appears to precipitate with carbonates. Detailed study of the soil profile at Steinway (Lintern and Gray, 1995) has shown that Au is associated with both carbonate and Fe oxides. Gold is associated with carbonate in the first metre of the profile and with Fe (in granules) in the second metre of the profile (Figure 9a). Similar results were obtained at Mulline (Figure 9b, Lintern and Butt, 1991) and Zuleika (Lintern and Butt, 1992).

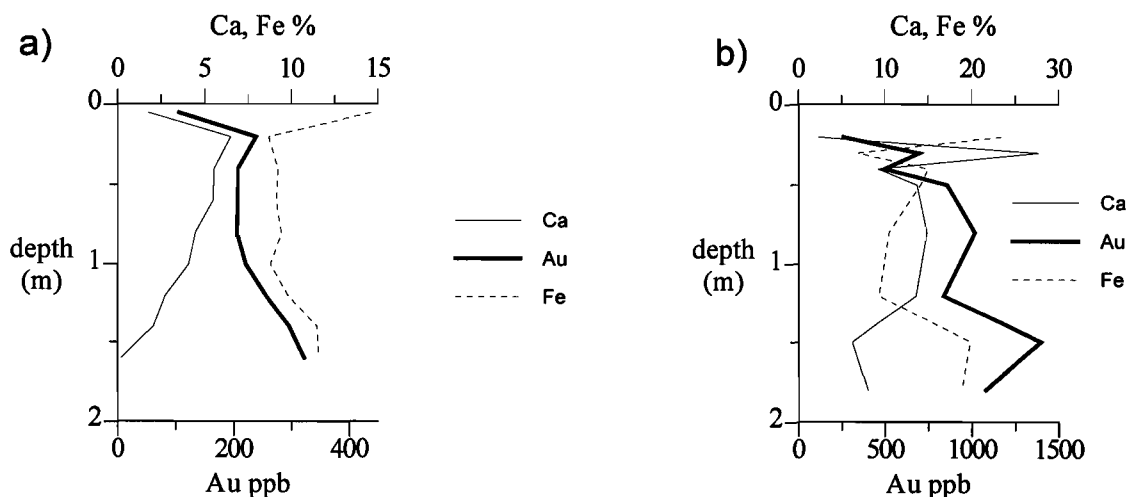


Figure 9: Gold, Ca and Fe distribution for (a) the soil profile at Steinway (after Lintern and Gray, 1995) and (b) a typical soil profile at Mulline (after Lintern and Butt, 1991).

There may be a spatial relationship between the distribution of Au in the granules and the presence of high Au concentrations in carbonate. There is less than a metre separating these horizons and processes such as capillarity, recycling by plants, bioturbation or diffusion may link them. Supporting evidence comes from partial extractions of profile samples which indicate that the Au closest to the surface is nearly ten times more water soluble than Au lower in the profile (Lintern and Gray, 1995) reflecting the association with carbonates and Fe oxides, respectively. A similar relationship was found in a relict site at Mulline (Lintern and Butt, 1991; Figure 9b) where the Fe-rich material is derived from a fragmenting ferruginous duricrust. In such profiles, some Au remains armoured against chemical weathering within ferruginous material such as granules or pisoliths. These act as a reservoir to sustain the Au anomaly over a long period, despite Au in the carbonate being water soluble. The granule is analogous to a slow-release fertiliser pellet. Eventually, however, all the Au in the granules may be released and become widely dispersed, so that the anomaly might eventually weaken and disappear. The strong association between Au in the carbonate and Au-rich Fe

granules may not necessarily be present or apparent, since it depends on several factors including (i) susceptibility of the granules to weathering, (ii) Au solubility (iii) sufficient stability of the soil profile to allow the Au-Ca relationship to develop in carbonate from the ferruginous granules.

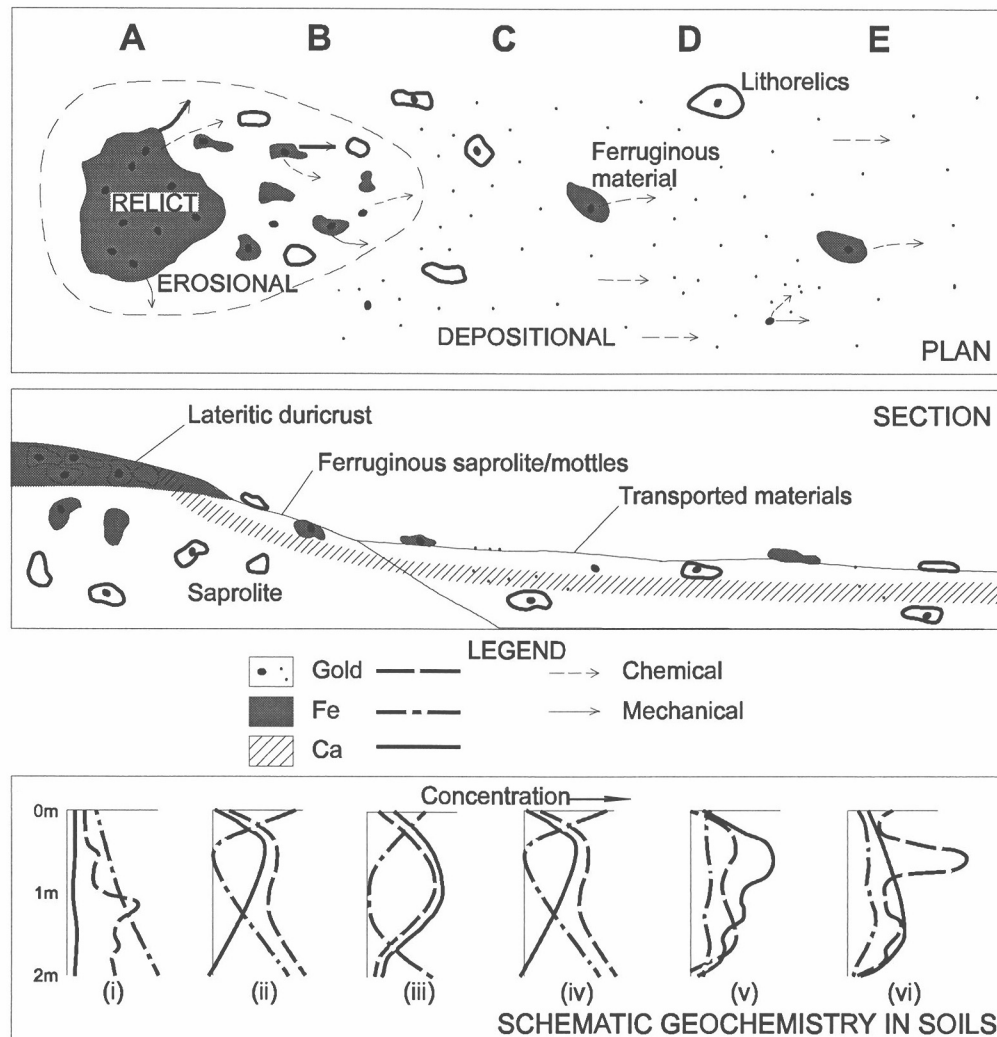


Figure 10: Model for Au dispersion from relict/erosional area into a depositional area:

- A: Relict regime - lateritic residuum containing Fe duricrust containing primary and secondary Au. Gold may be associated with ferruginous material (schematic soil profile (i)) and/or pedogenic carbonates (schematic profile (ii)).
- B: Erosional regime - dismantling of lateritic residuum, ferruginous saprolite and partially weathered lithic fragments leading to physical and some chemical dispersion. Carbonates may promote disintegration by replacement and displacement. Gold within coarse fractions may be armoured against corrosion, but unprotected Au is subject to chemical weathering and associates with secondary minerals such as carbonate (iii).
- C: Depositional regime - polymictic sediments (containing Fe granules, clays, sands, carbonate nodules and lithic fragments) subjected to continuing physical and chemical weathering and dispersion. Much of the Au now is weakly associated with mobile chemical phases such as carbonate (v).
- D and E: Depositional regime - intensification of weathering leading to more dispersion and dilution. Most Au associated with mobile phases such as carbonate, although some still persists within coarse ferruginous material (iv), and as discrete Au particles (vi). Sheetwash disperses Fe granules and Au micro-nuggets throughout the landscape.

The soil anomaly at Steinway is defined by the 24 ppb Au contour (Figure 5). A single Fe granule with a typical mass of 0.1g, and a concentration of 15000 ppb Au (as found in this study) will yield a 60 ppb concentration in a typical 25g sample used for analysis. Soil Au concentrations of similar magnitude can also be produced by several granules having lower Au abundances. This reasoning implies that the whole Steinway Au soil anomaly may be caused by either (i) Au-rich granules dispersing from a single source or (ii) multiple dispersions from pockets of Au-rich granules over a broader area. It is difficult to determine which explanation is correct since surficial processes are highly active and could rapidly change the shape of soil anomalies. Detailed examination of the individual data points that comprise the >24 ppb Au anomaly, and the ferruginous granule survey undertaken in this study, suggest that the soil anomaly is not contiguous but that high Au concentrations sporadically occur within the anomaly area (Figure 11). This explanation is consistent with the origin of the Fe granules being up slope, auriferous and dispersing from a single source (such as Penfold) before being deposited by multiple sheetwash events at a late stage in the evolution of the channel, but when the drainage was still flowing along the same general axis.

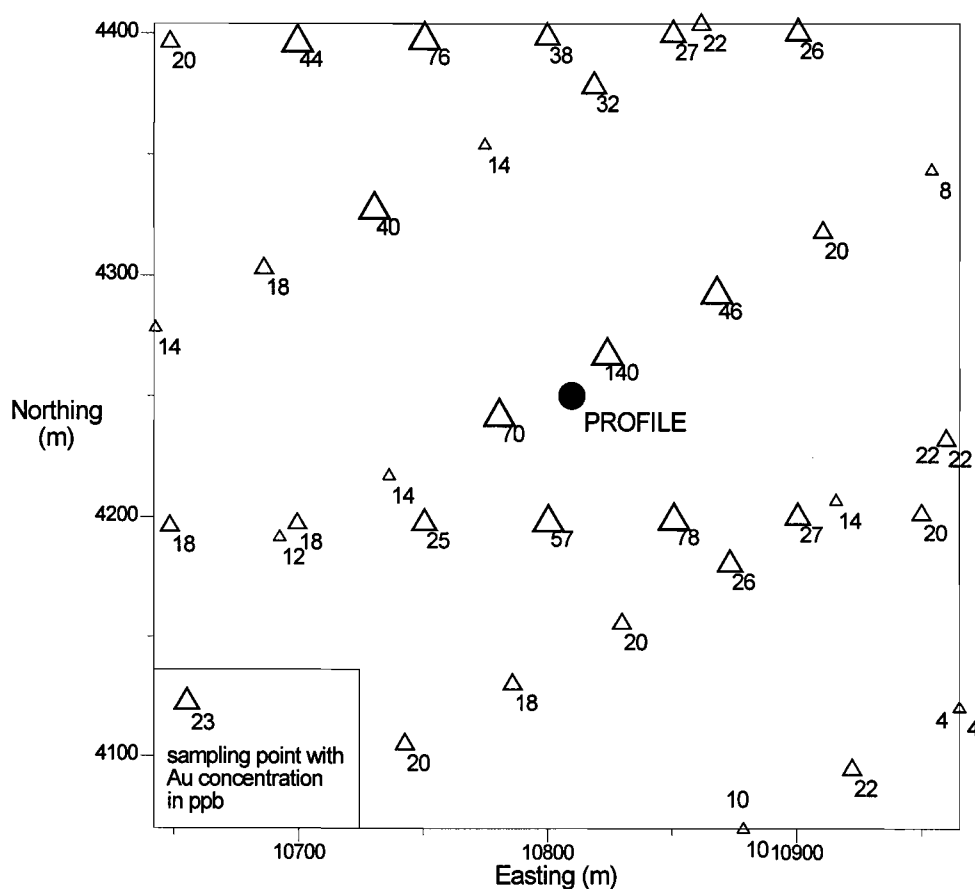


Figure 11: Gold concentrations (ppb) in bulk 0-1 m samples in the vicinity of the soil profile at Steinway (from company data).

## 7. SUMMARY AND IMPLICATIONS FOR EXPLORATION

The principal findings with respect to the Au distribution are:

1. Microscopically-visible Au was present in some ferruginous granules;
2. Gold concentrations of individual ferruginous granules are extremely variable, ranging from <40 to 15000 ppb;



3. Total Au content of coarse material are weakly related to the total Au content of the soil.

Specific targeting of the calcareous horizon has been demonstrated to maximize the probability of sampling the most consistently auriferous sample in all landscape regimes in the Kalgoorlie region. In relict and erosional regimes, such sampling may accurately define drilling targets. However, in depositional regimes, the results from Steinway indicate that there is no direct link with mineralization. Here, although the Au anomaly in the calcareous soil overlies buried mineralization, the data suggest that it is derived from detrital ferruginous granules in the soil, rather than the mineralization itself *i.e.* the apparent association between Au in surficial soils and underlying Au mineralization, buried beneath 30 m of transported overburden, is probably coincidental. This is corroborated by data from the Greenback pit 500 m west of Steinway, where Au has been mined from sediments and underlying saprolite at 15-20 m depth, and yet there is no soil anomaly even though tree roots (a potential medium for vertical Au migration) penetrate to at least 15 m. (Lenses of detrital ferruginous granules are visible in the pit walls, but they have not been analyzed.)

It is concluded that, in depositional terrains, sampling of calcareous material may at best indicate the potential of the (sub-)catchment. It is suggested, therefore, that for such landscape regimes, wider sampling intervals should be used, with a follow-up requirement that deep samples be collected using RC/RAB drill rigs to collect basal lithologies (including sands), and/or ferruginous material from saprolite. Sampling of Fe granules or lag is a possible alternative but their Au distributions are more erratic (Carver *et al.*, 1987). It is improbable that any sampling procedure will be effective in discovering mineralization in depositional regimes with similar lithologies and settings, certainly where the sediments are more than 5-10 m thick.

## 8. ACKNOWLEDGEMENTS

The following people and companies are thanked for their support and expertise in preparation of this report: Newcrest Mining Ltd for allowing access to the site, supplying geological plans, and Au in soil geochemical data. In particular we would like to thank John Viner and Steve Devlin (Newcrest) for their assistance; Ian Robertson for petrological microscope work and descriptions; Bruce Robinson for assistance using the SEM and for taking the photographs; J.F. Crabb and R. Bilz for sample preparation and polished section preparation; F. Obbens for sample preparation; K. Lim for sample preparation and selected analyses; G. Ashton for technical support; C.R.M. Butt and I. D. M. Robertson gave advice in the preparation of this report.

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# APPENDICES

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- 2.2 Tabulated data for individual Fe granules
- 2.3 Graphed elemental abundances for individual Fe granules ranked by Au concentration
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- 2.5 Photographs of high Au content ferruginous granules described in Table A2.4.



## APPENDIX 1: BULK FERRUGINOUS GRANULES

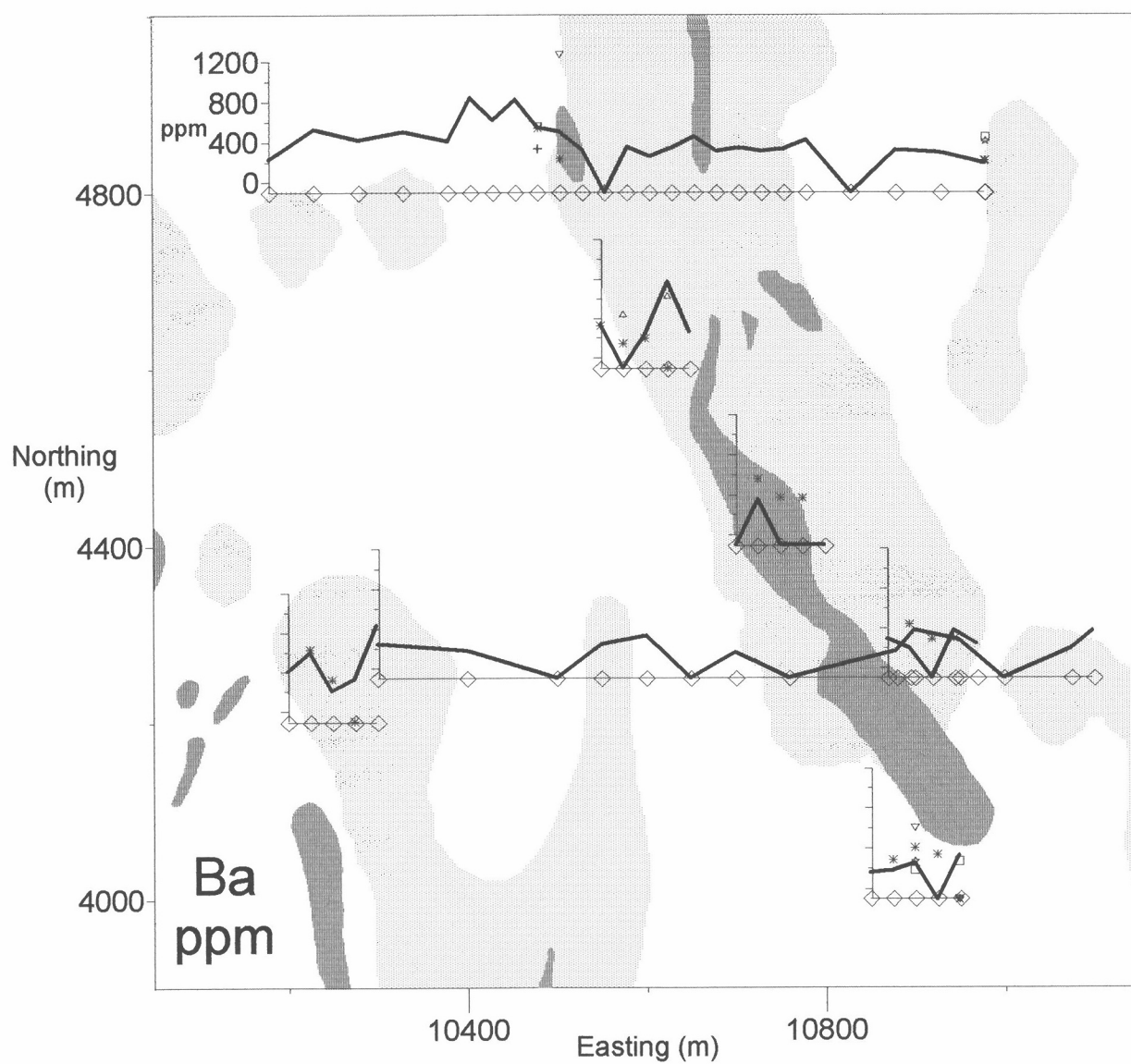


Figure A1.1.1: Concentration of Ba in ferruginous material (>1 mm). Most data are from 0-1 m.

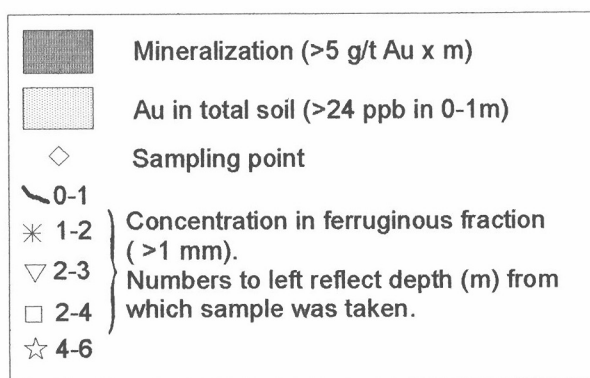
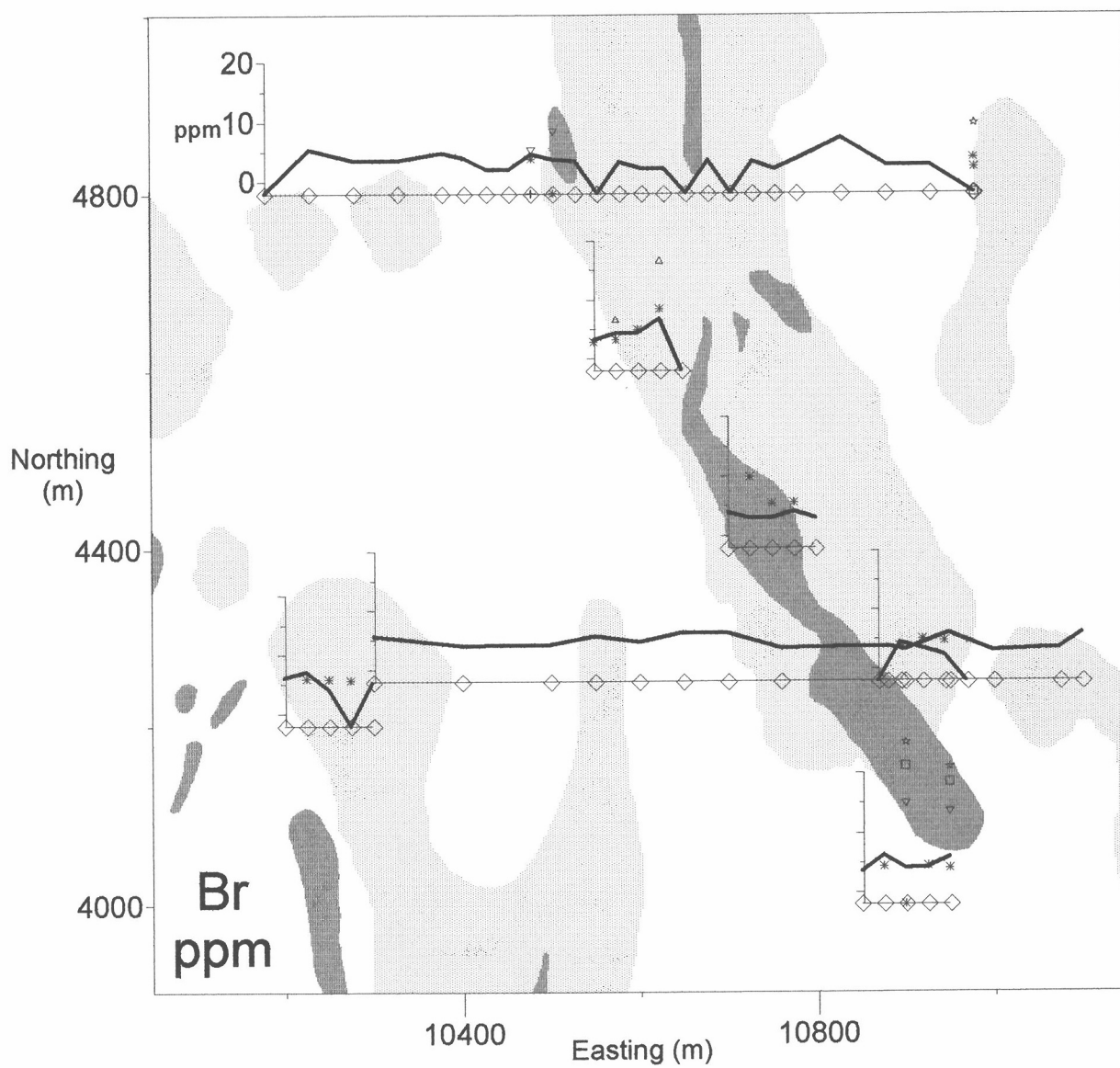


Figure A1.1.2: Concentration of Br in ferruginous material (>1 mm). Most data are from 0-1 m.



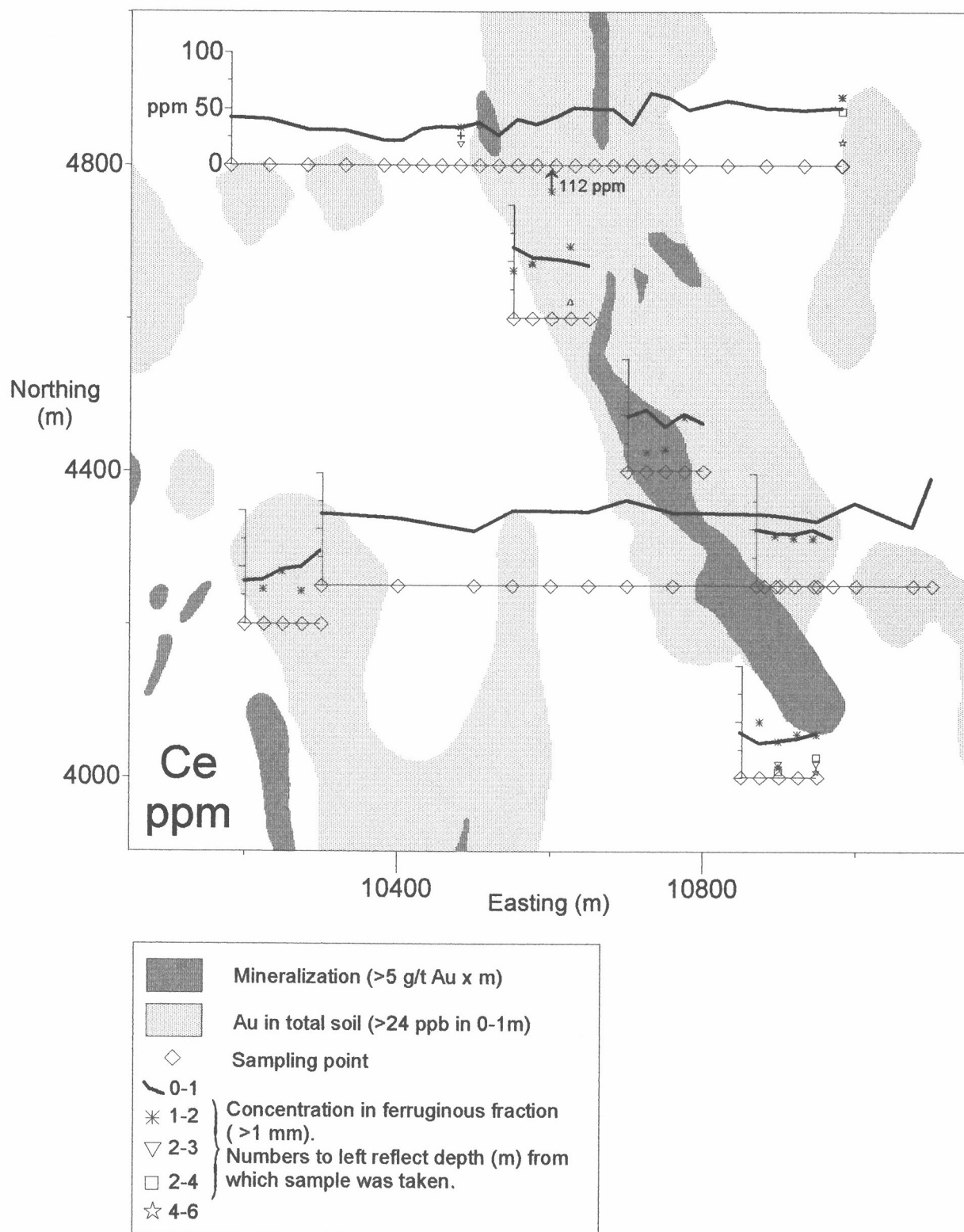


Figure A1.1.3: Concentration of Ce in ferruginous material (>1 mm). Most data are from 0-1 m.

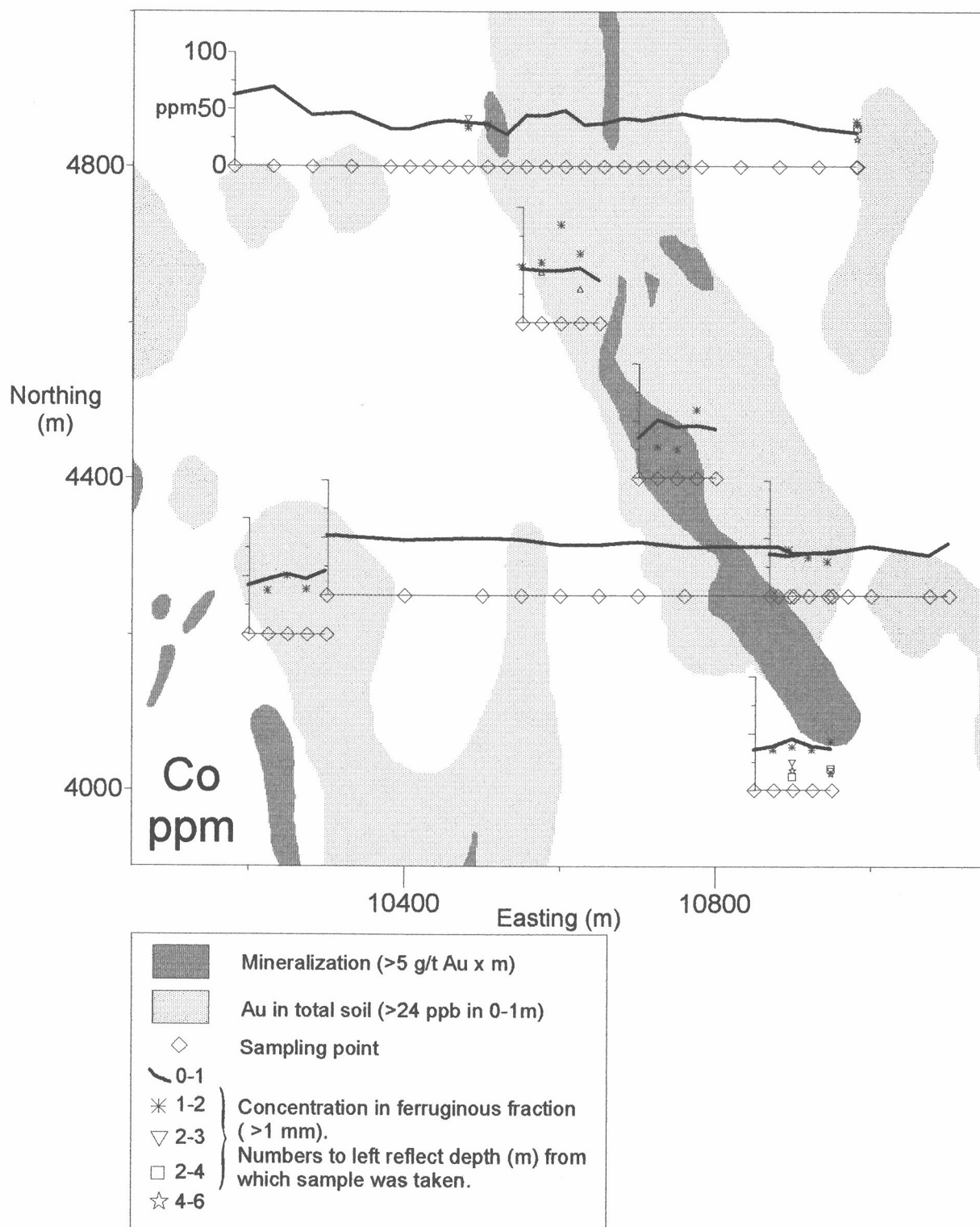


Figure A1.1.4: Concentration of Co in ferruginous material (>1 mm). Most data are from 0-1 m.

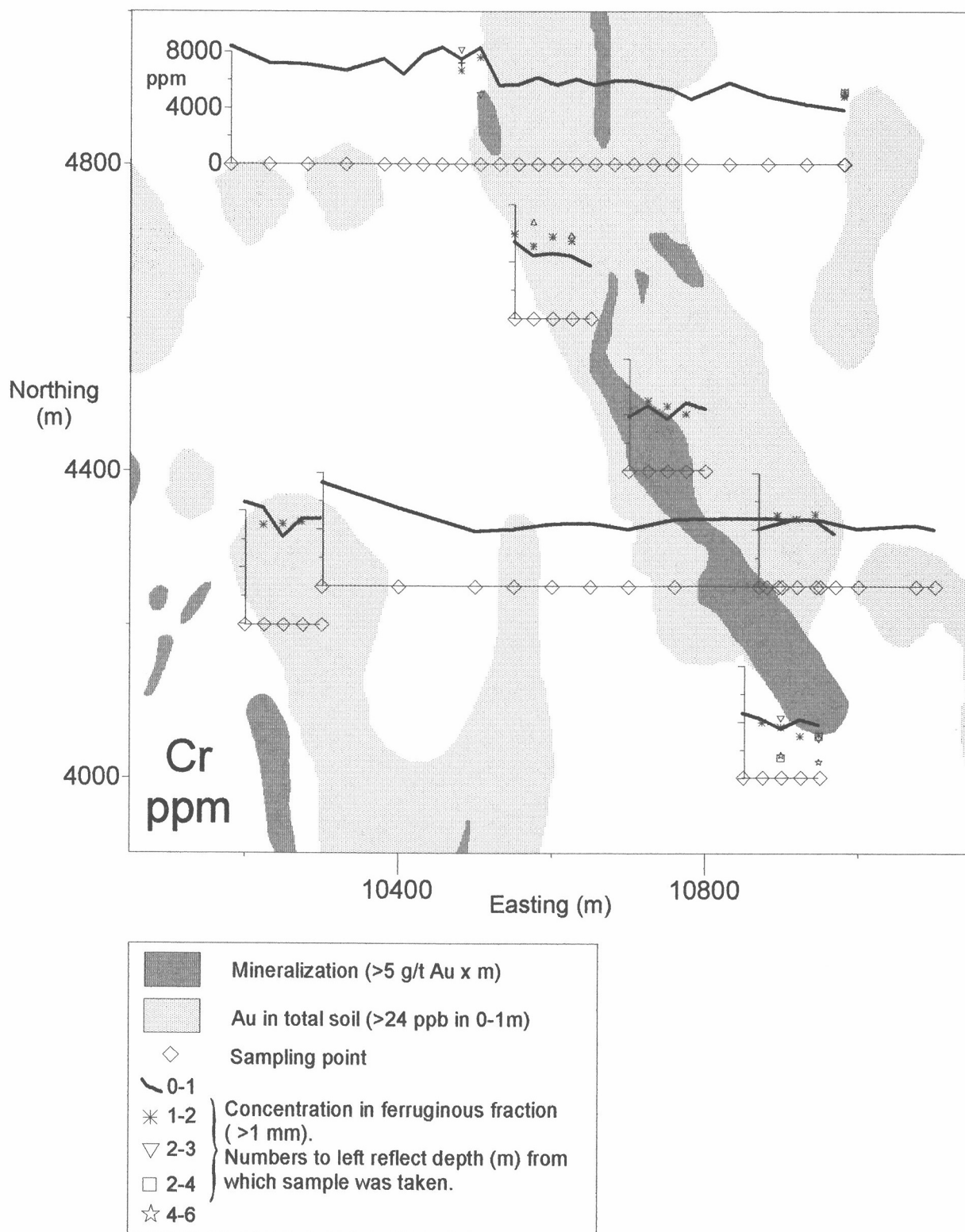


Figure A1.1.5: Concentration of Cr in ferruginous material (>1 mm). Most data are from 0-1 m.



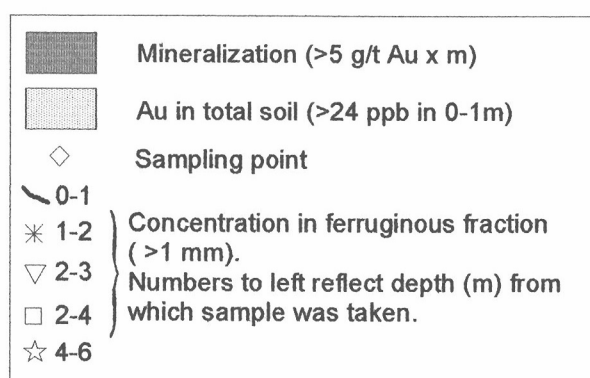
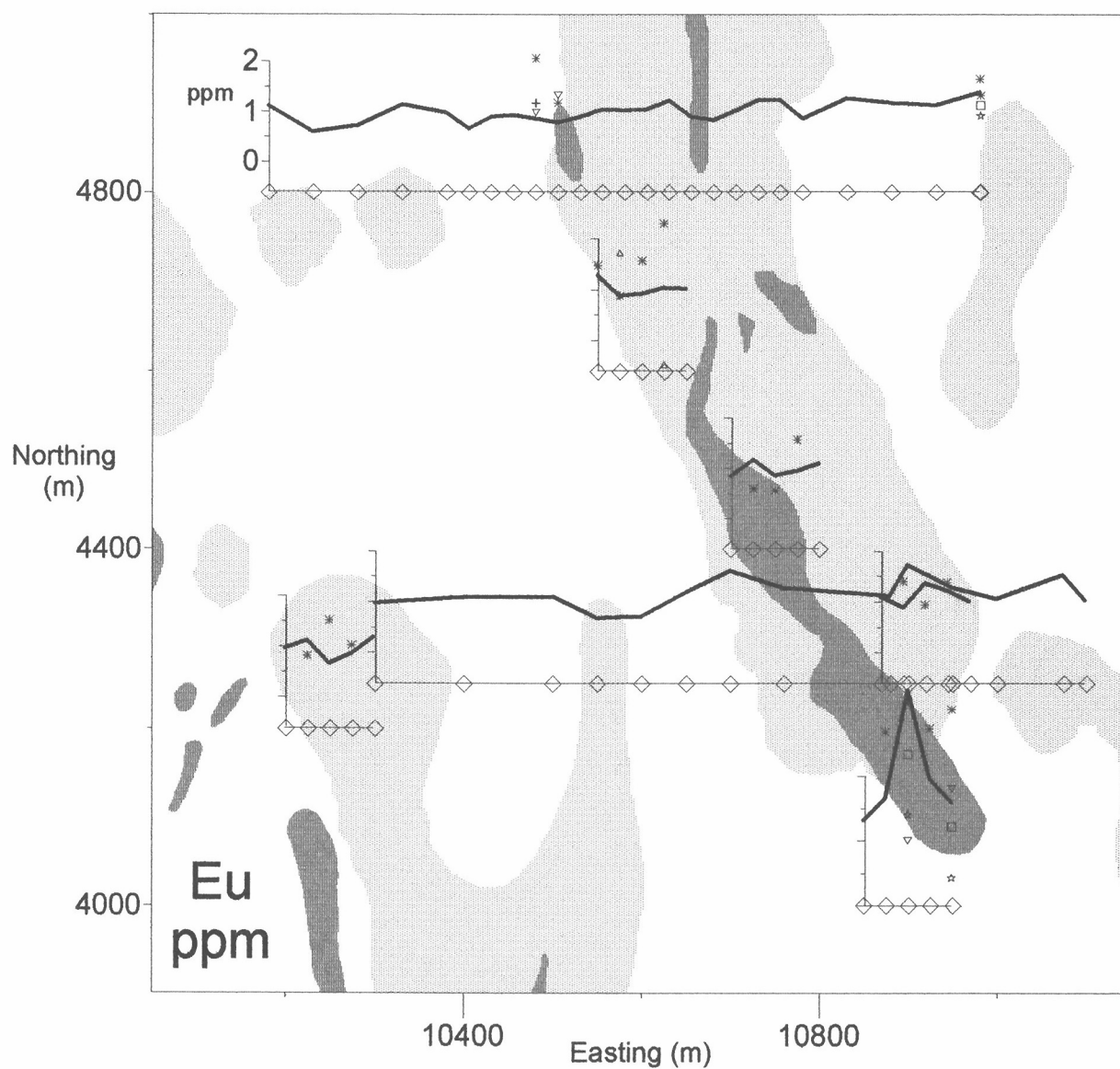


Figure A1.1.6 Concentration of Eu in ferruginous material (>1 mm). Most data are from 0-1 m.

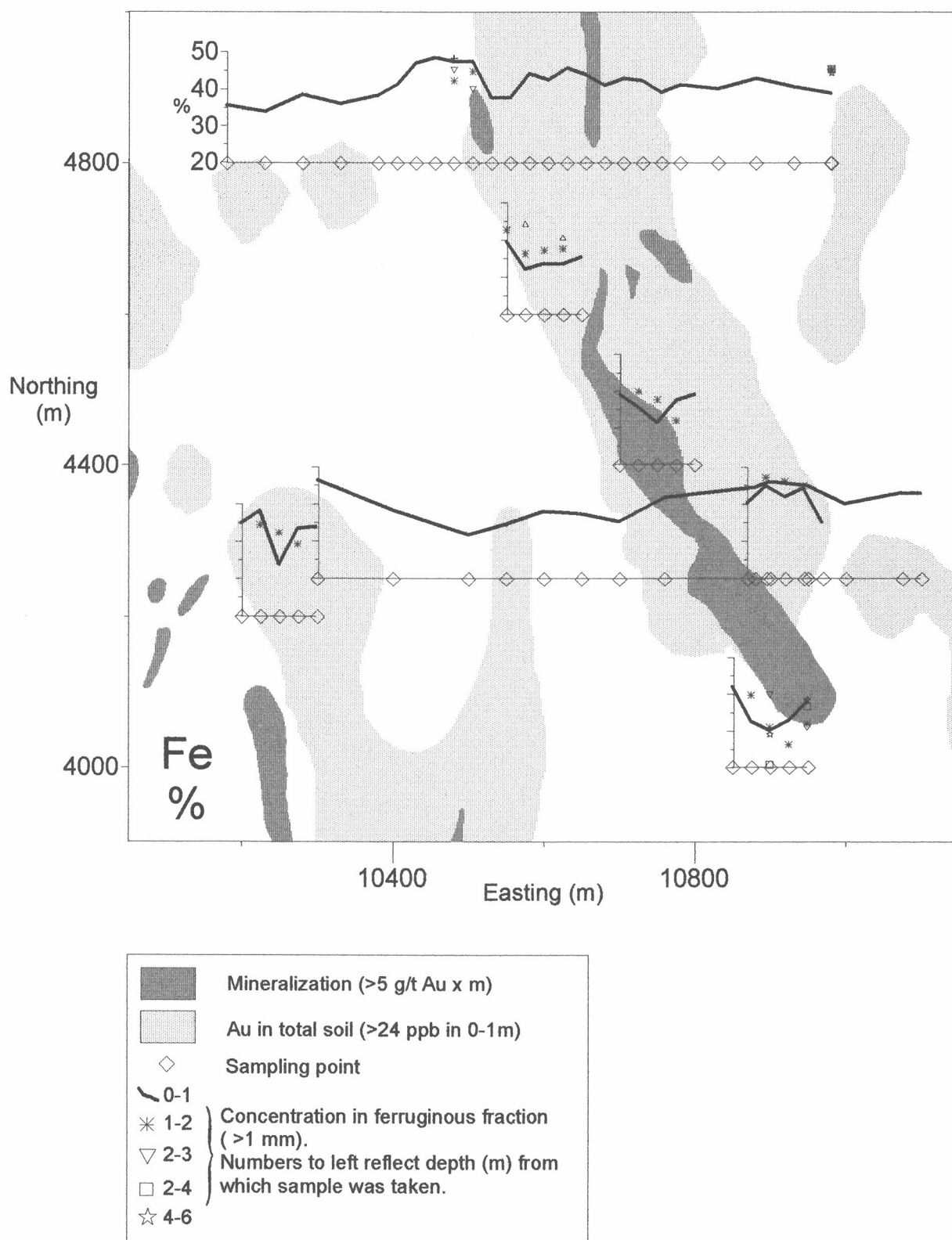


Figure A1.1.7: Concentration of Fe in ferruginous material (>1 mm). Most data are from 0-1 m.

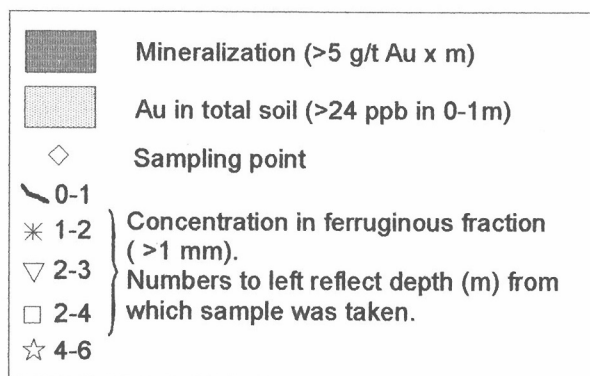
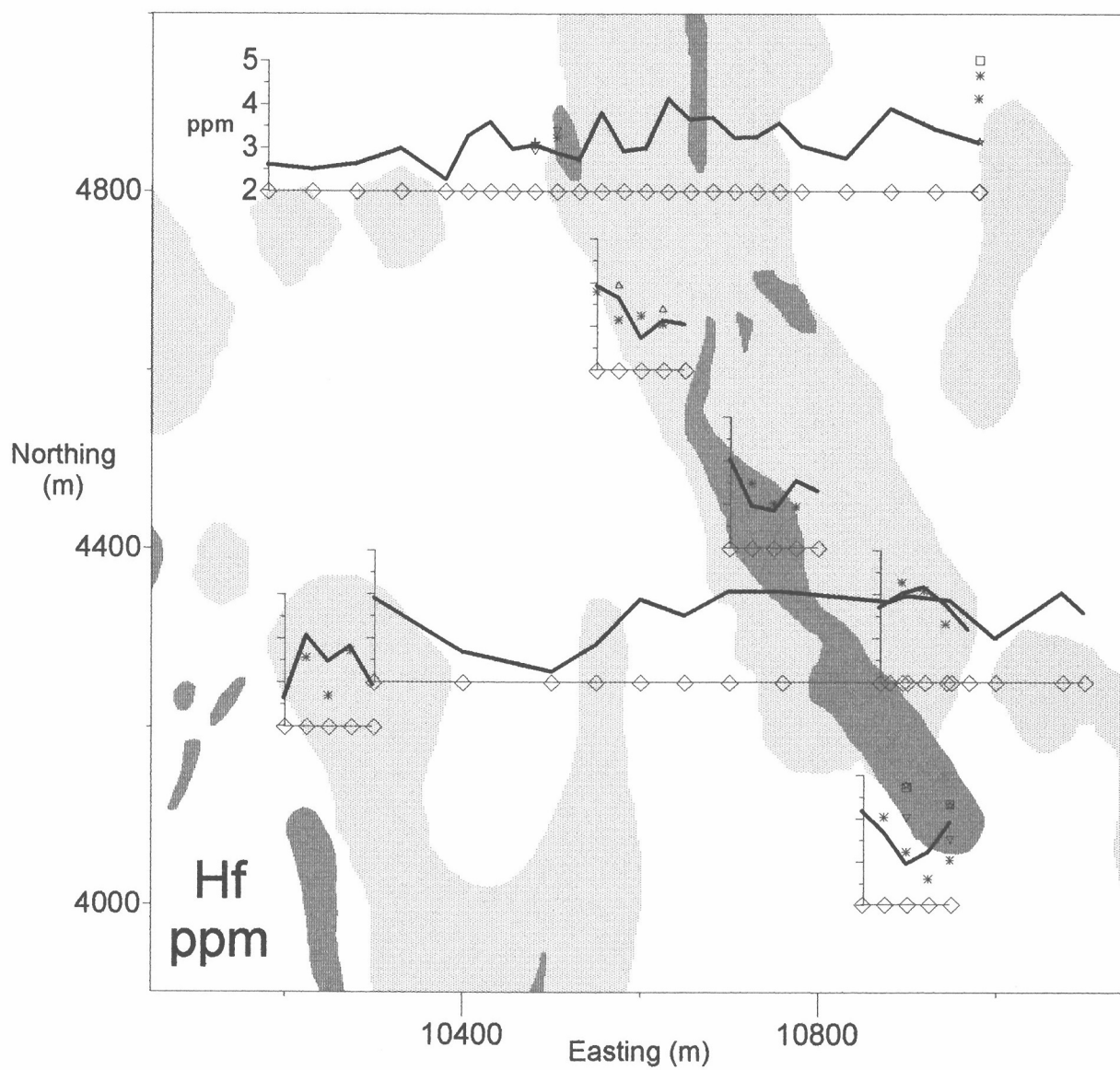


Figure A1.1.8: Concentration of Hf in ferruginous material (>1 mm). Most data are from 0-1 m.



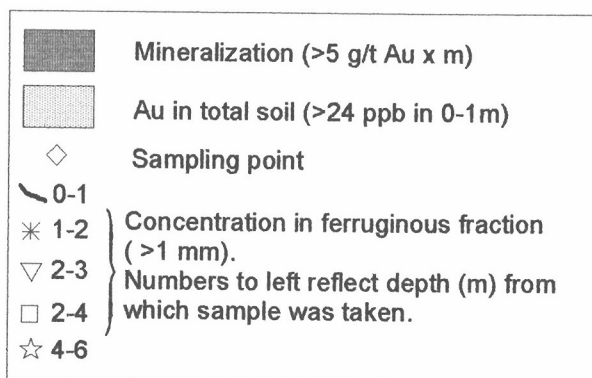
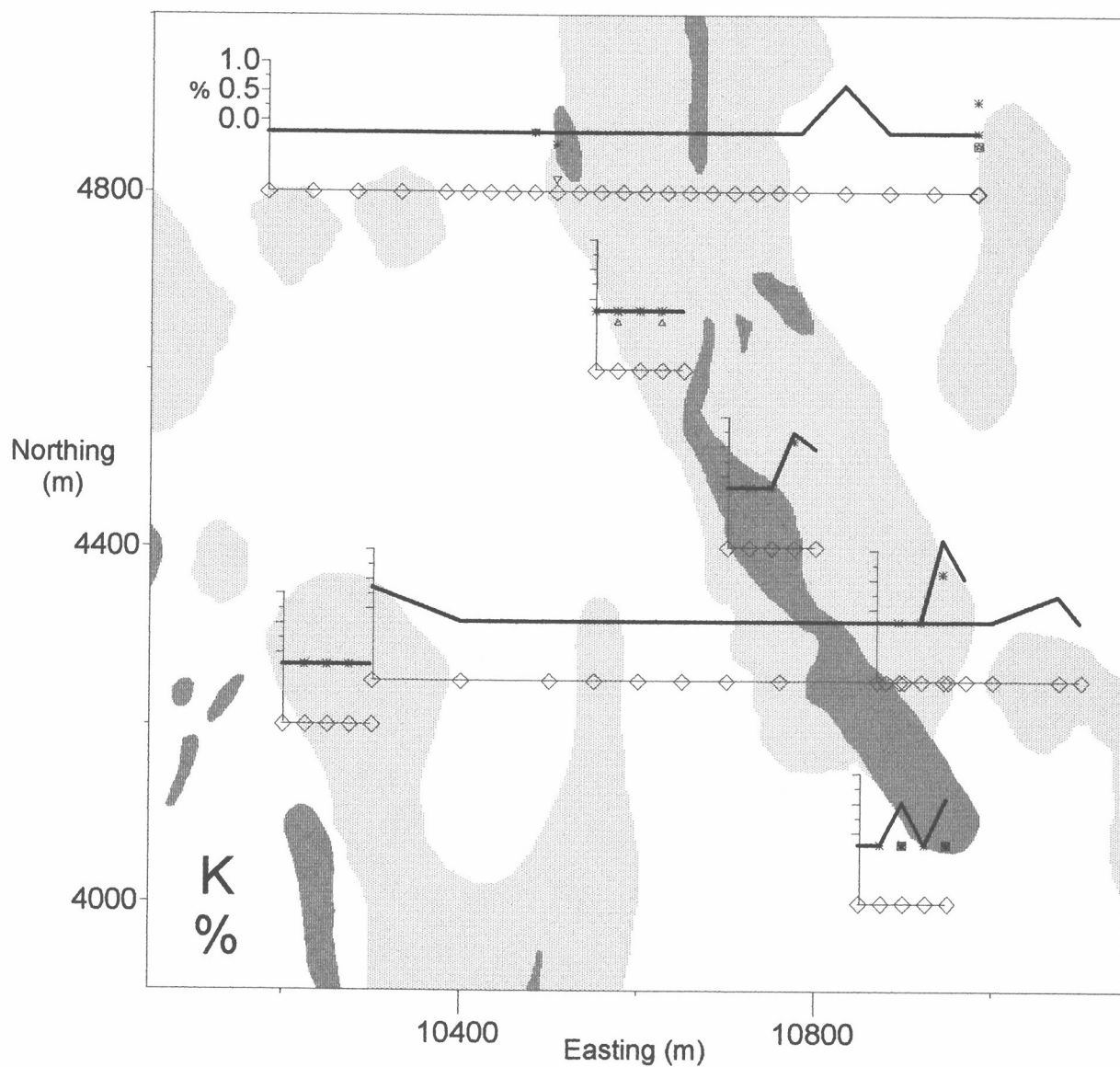


Figure A1.1.9: Concentration of K in ferruginous material (>1 mm). Most data are from 0-1 m.

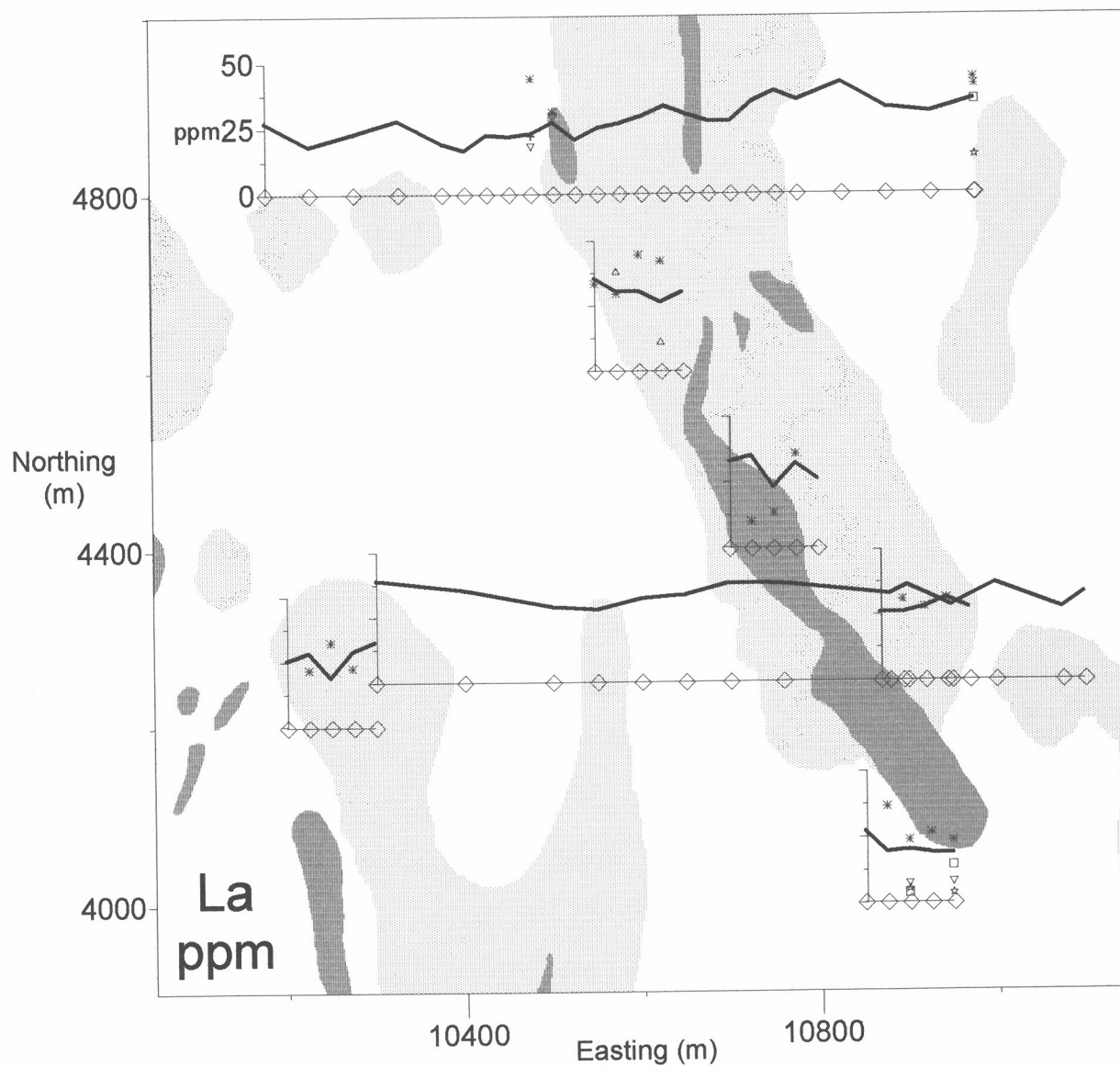


Figure A1.1.10: Concentration of La in ferruginous material (>1 mm). Most data are from 0-1 m.

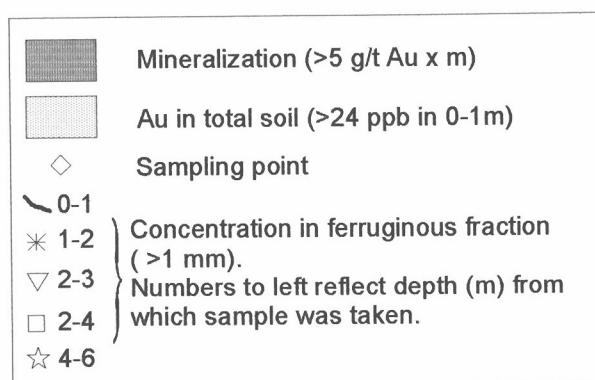
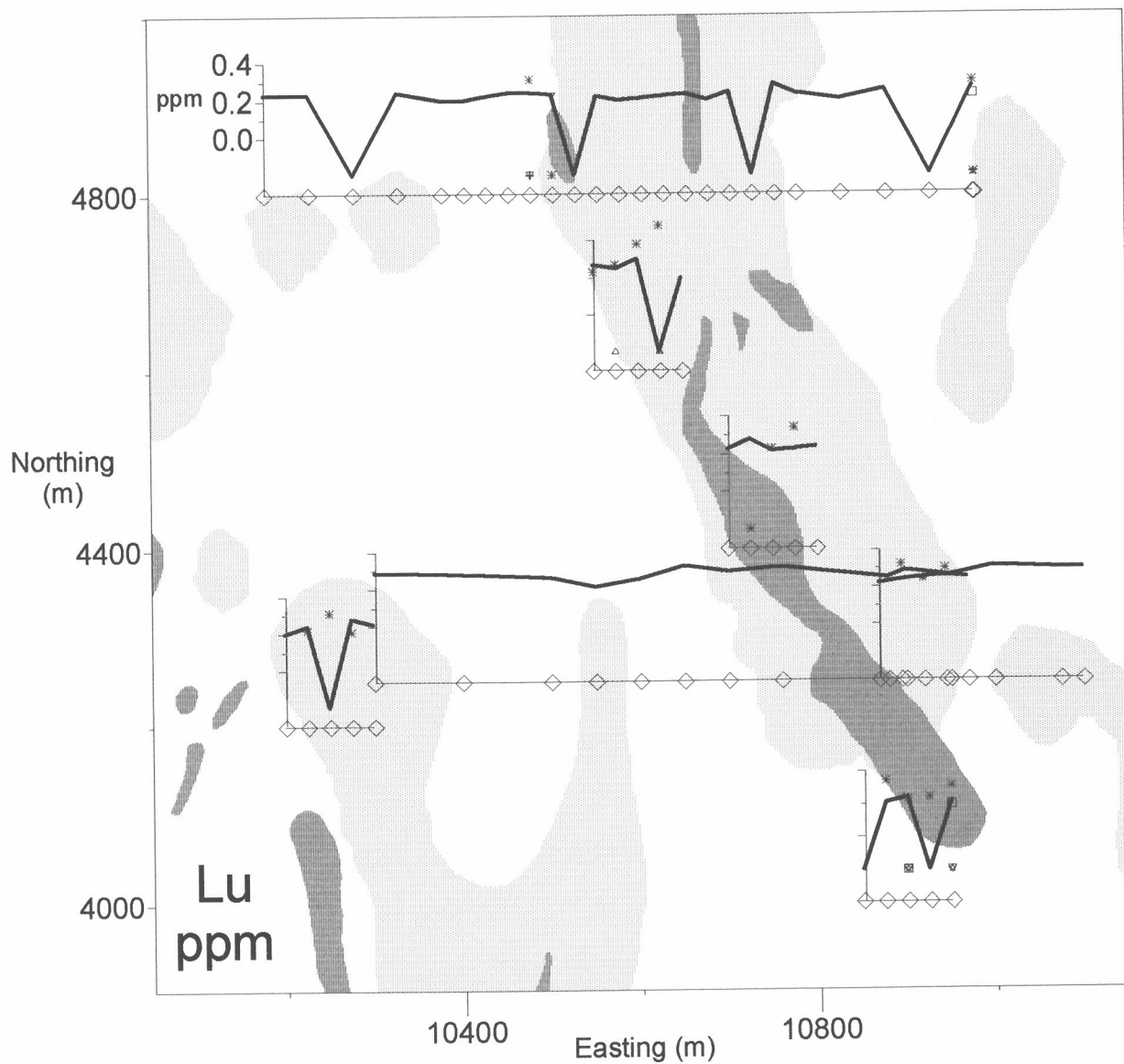


Figure A1.1.11: Concentration of Lu in ferruginous material (>1 mm). Most data are from 0-1 m.



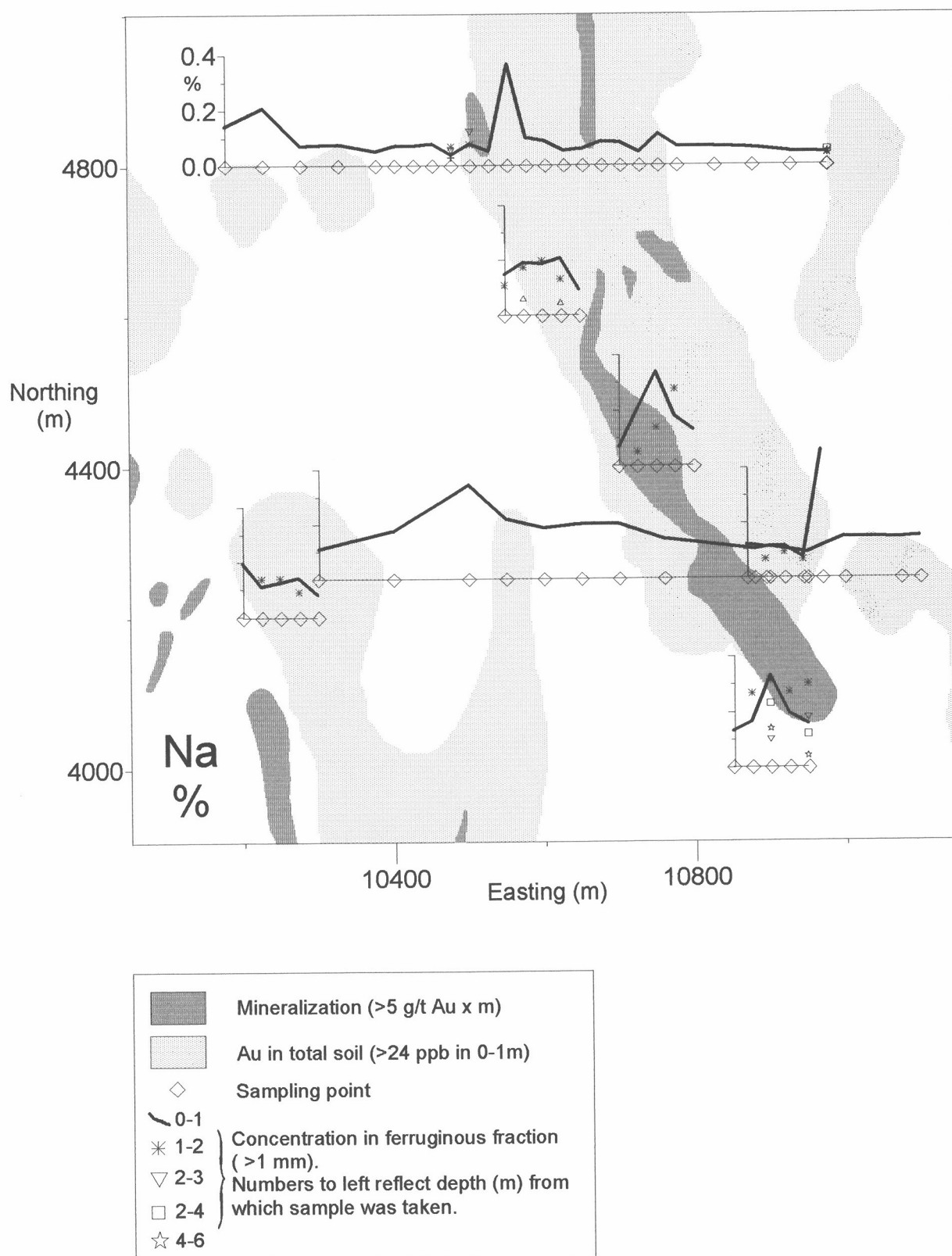


Figure A1.1.12: Concentration of Na in ferruginous material (>1 mm). Most data are from 0-1 m.

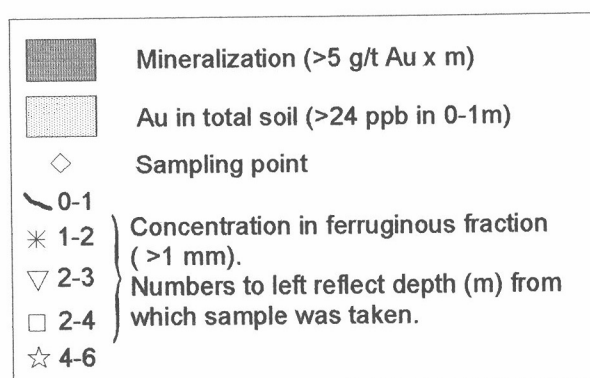
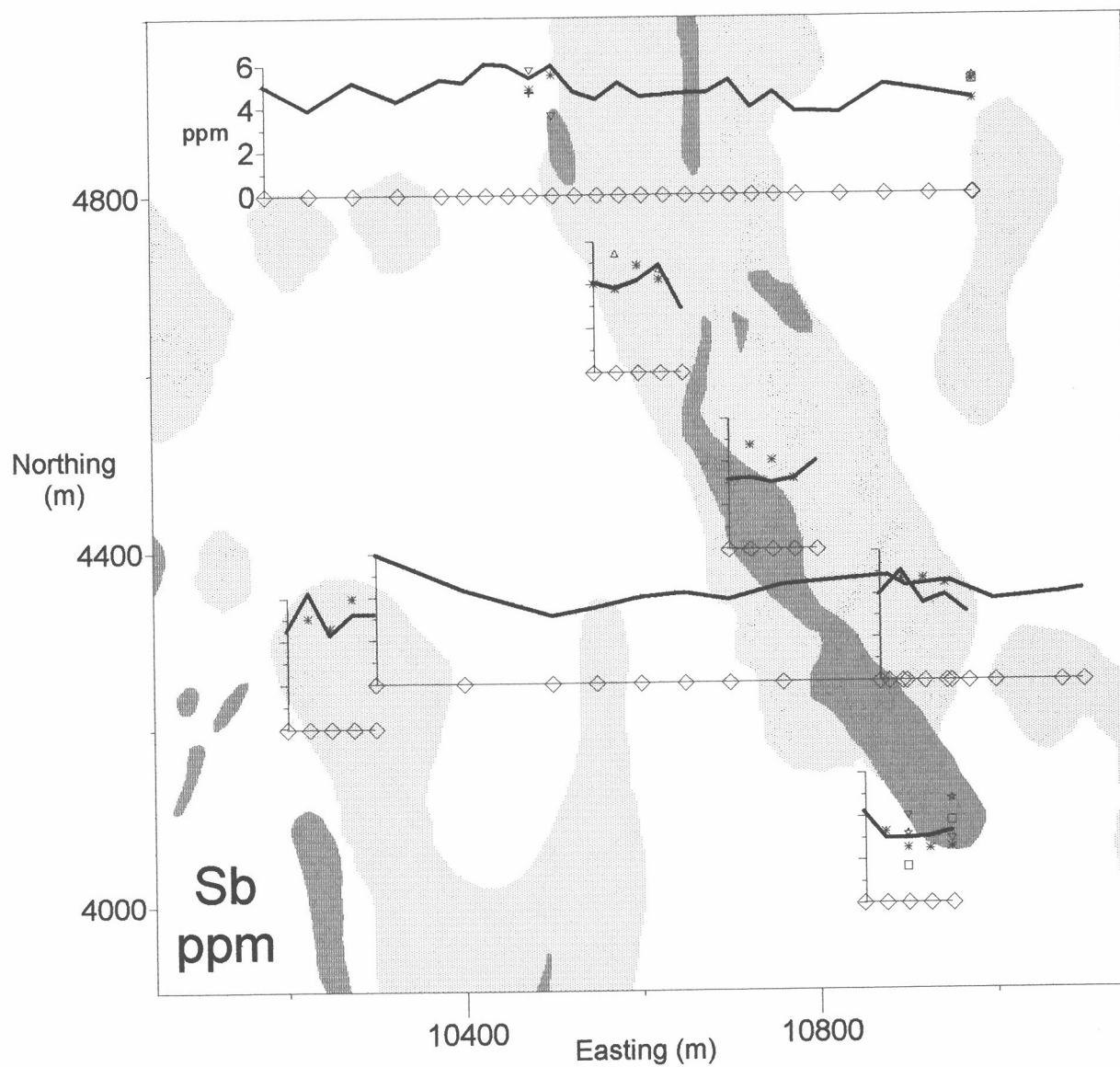


Figure A1.1.13: Concentration of Sb in ferruginous material (>1 mm). Most data are from 0-1 m.

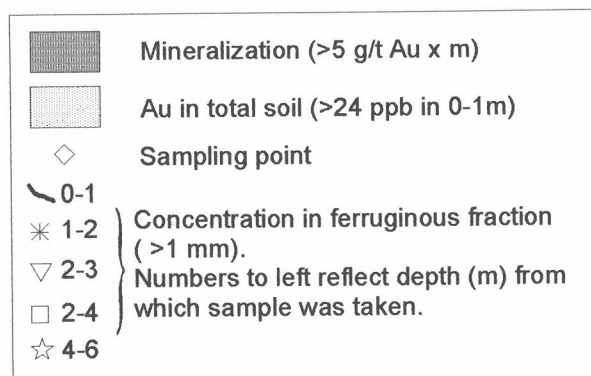
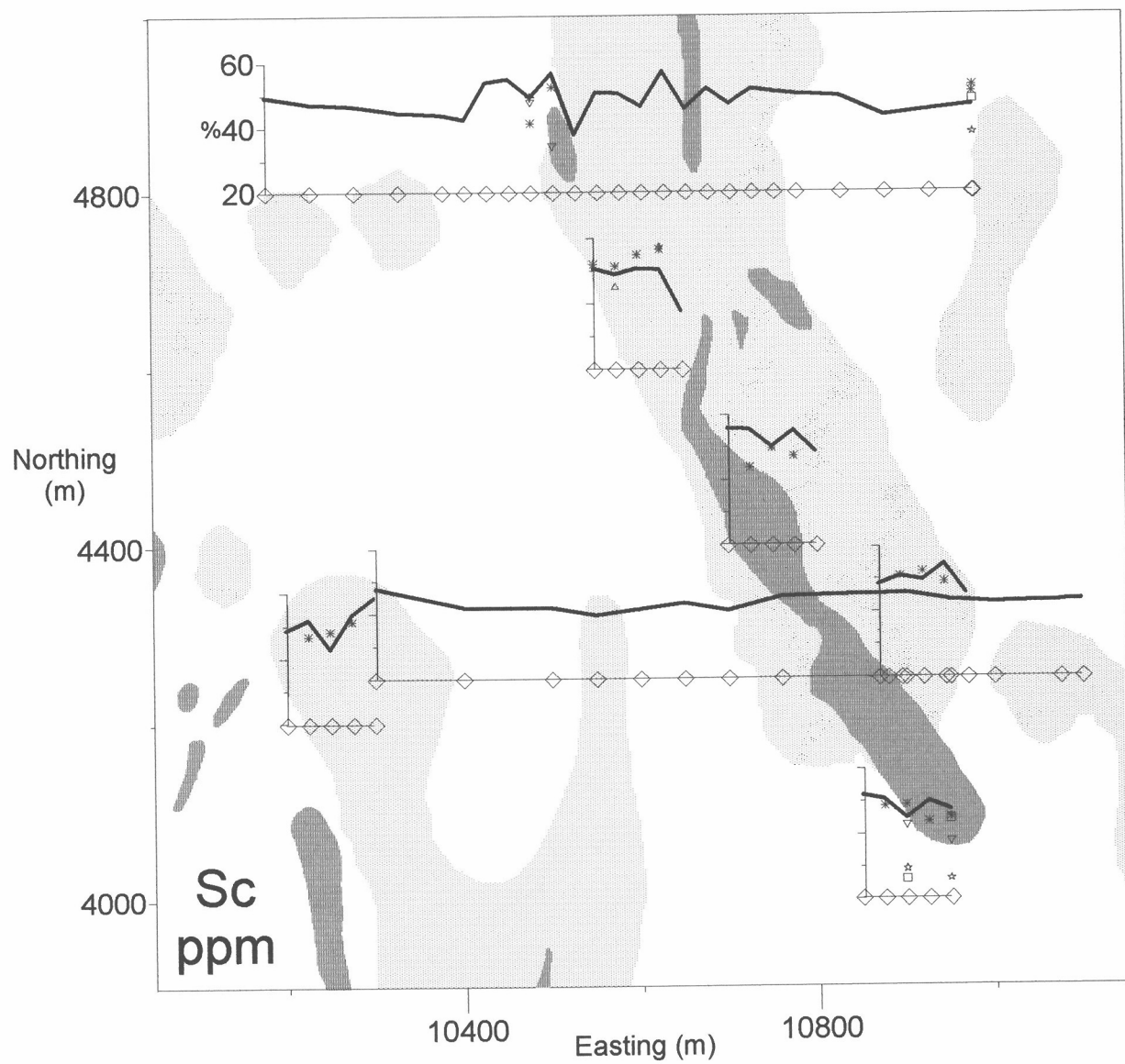


Figure A1.1.14: Concentration of Sc in ferruginous material (>1 mm). Most data are from 0-1 m.



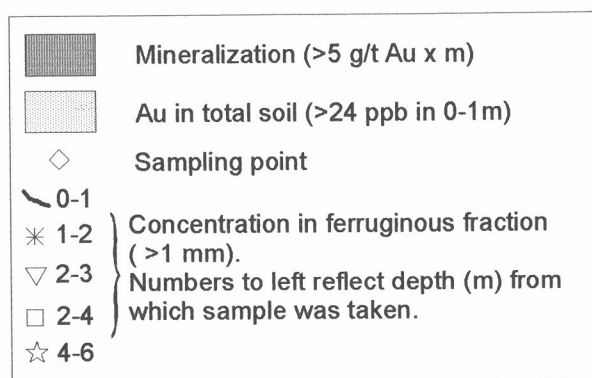
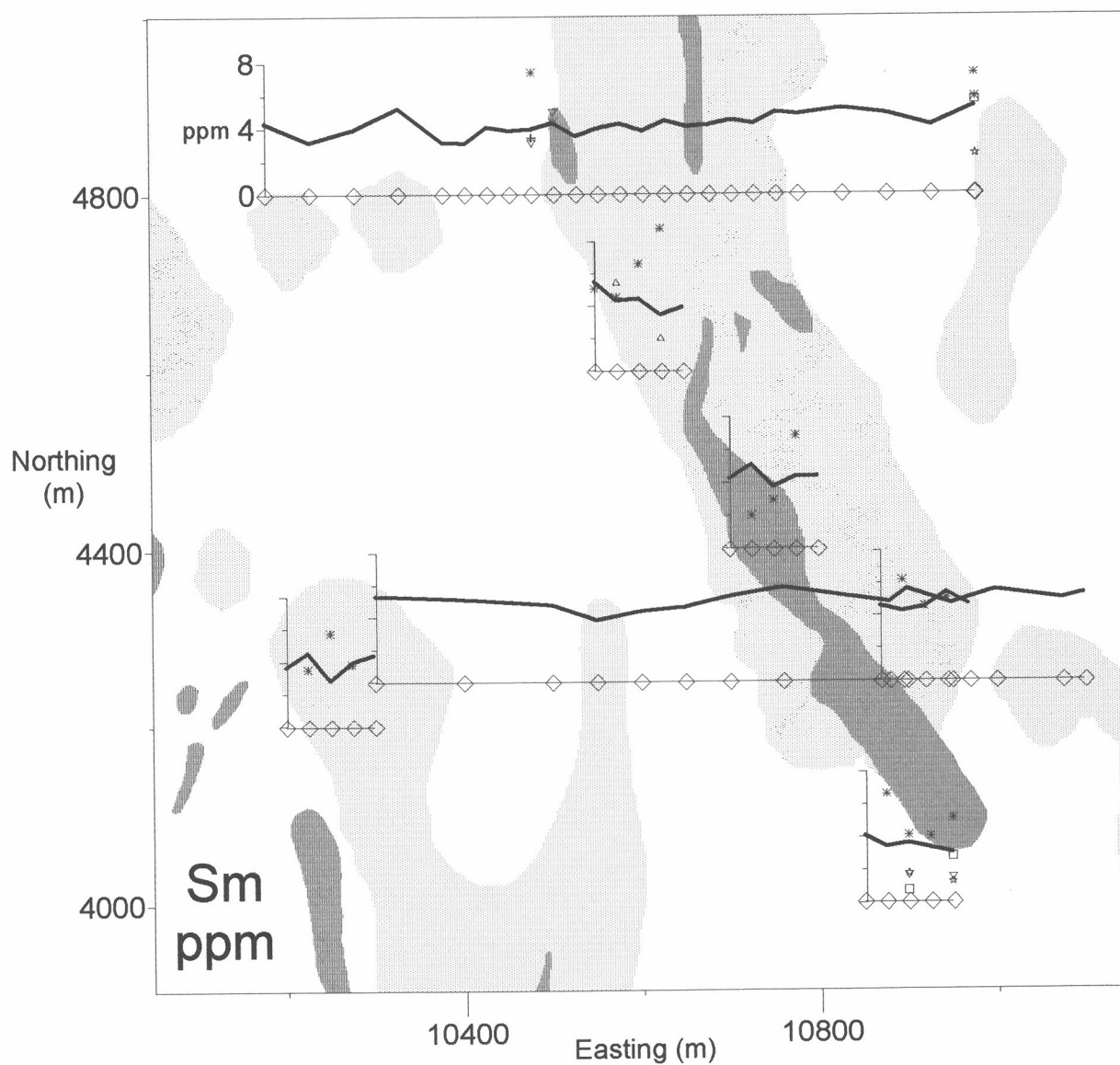


Figure A1.1.15: Concentration of Sm in ferruginous material (>1 mm). Most data are from 0-1 m.

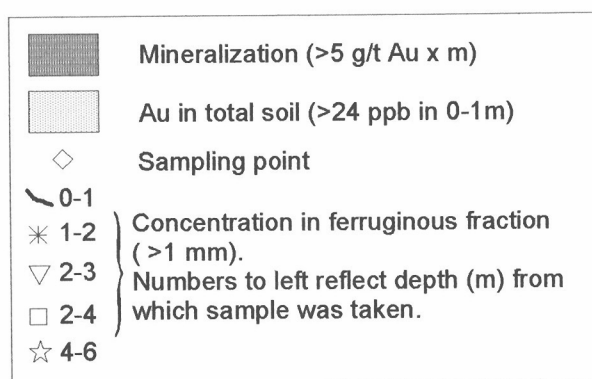
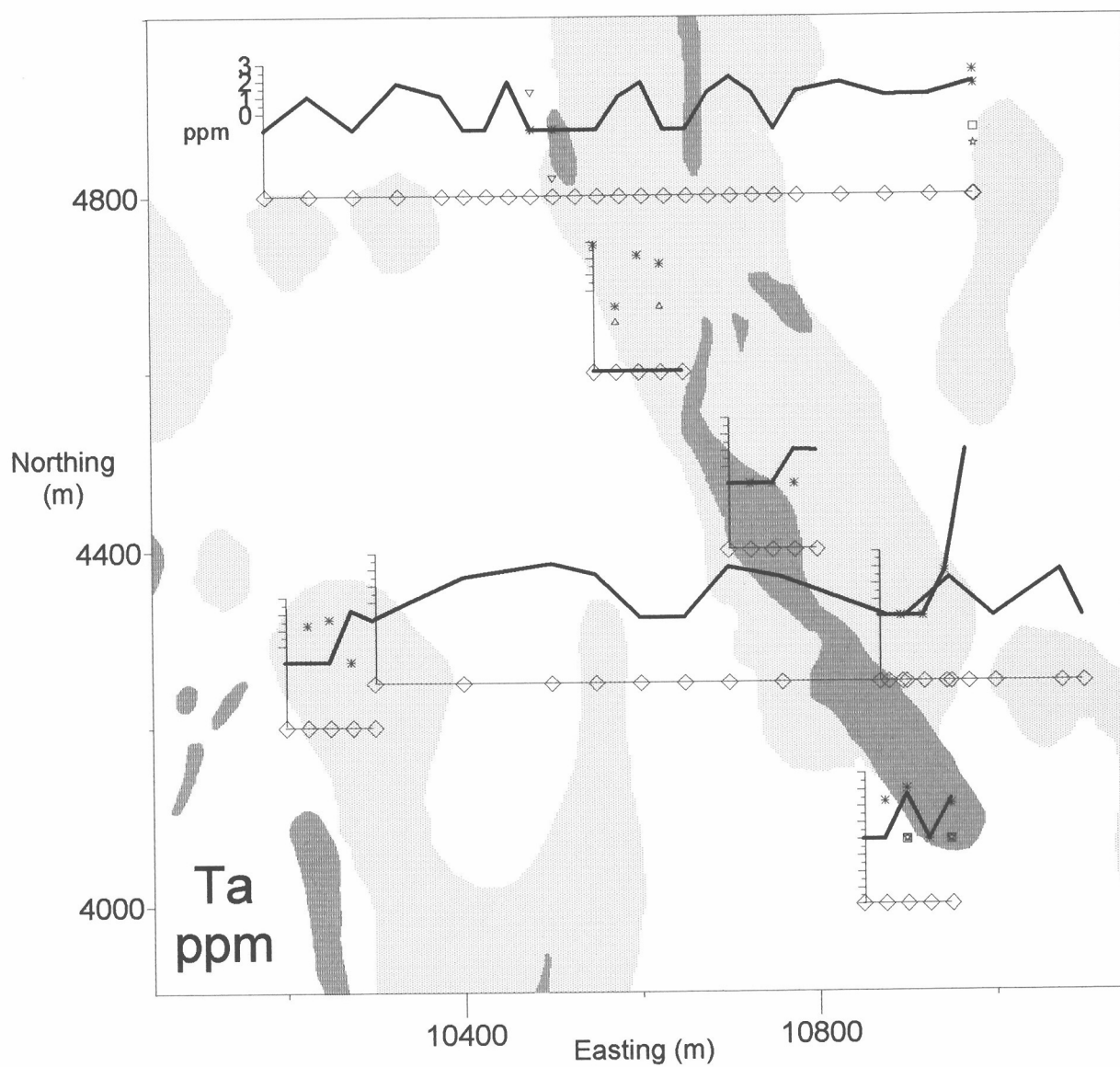


Figure A1.1.16: Concentration of Ta in ferruginous material (>1 mm). Most data are from 0-1 m.

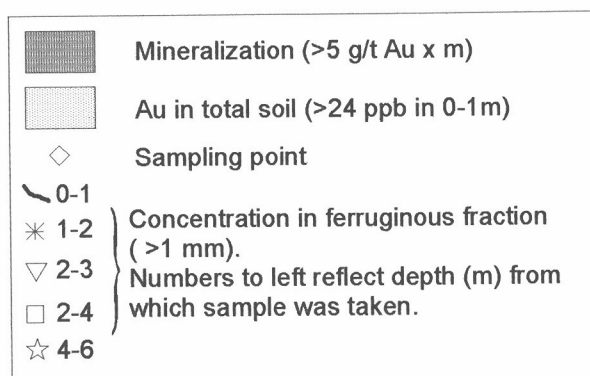
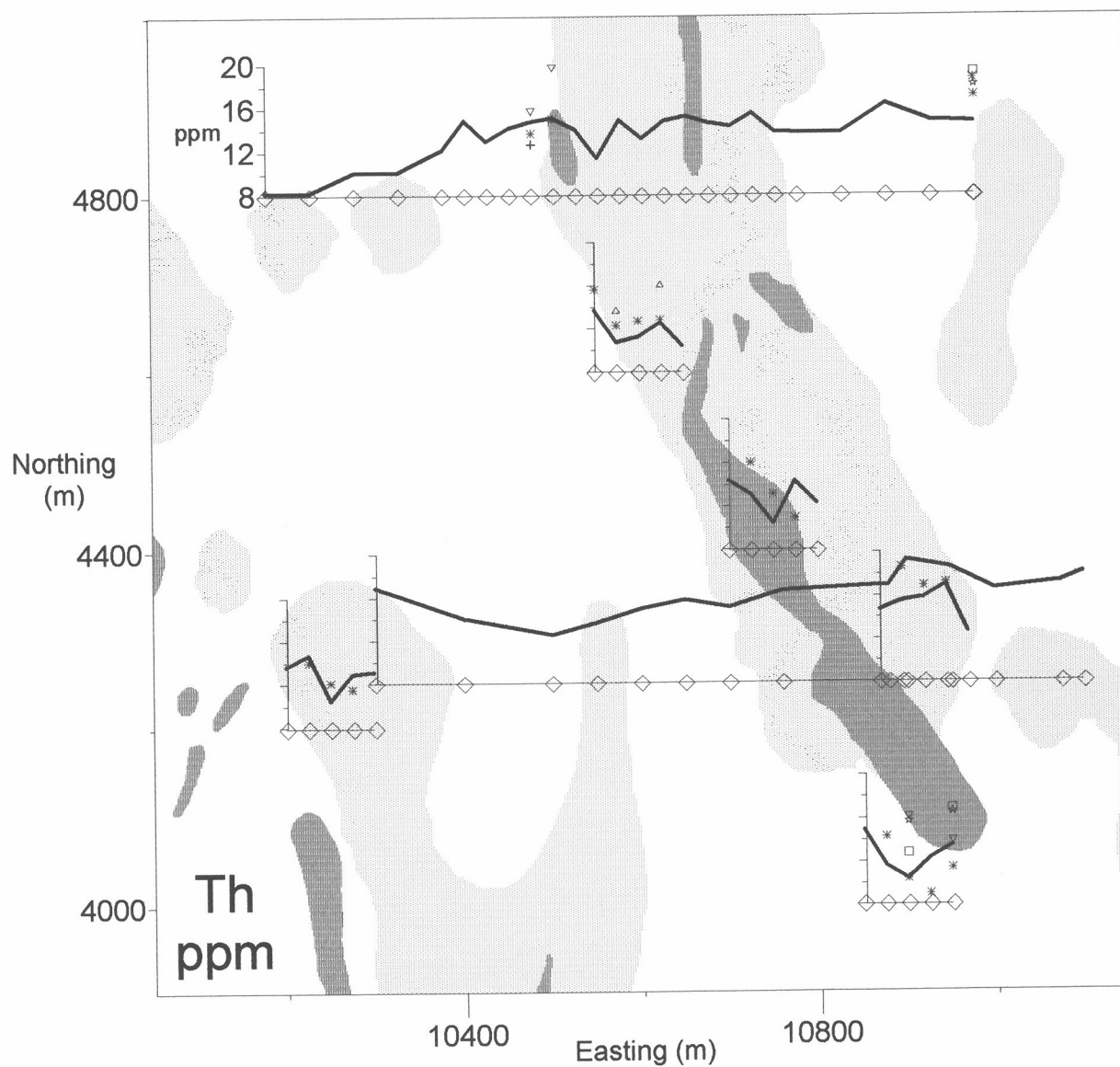


Figure A1.1.17: Concentration of Th in ferruginous material (>1 mm). Most data are from 0-1 m.

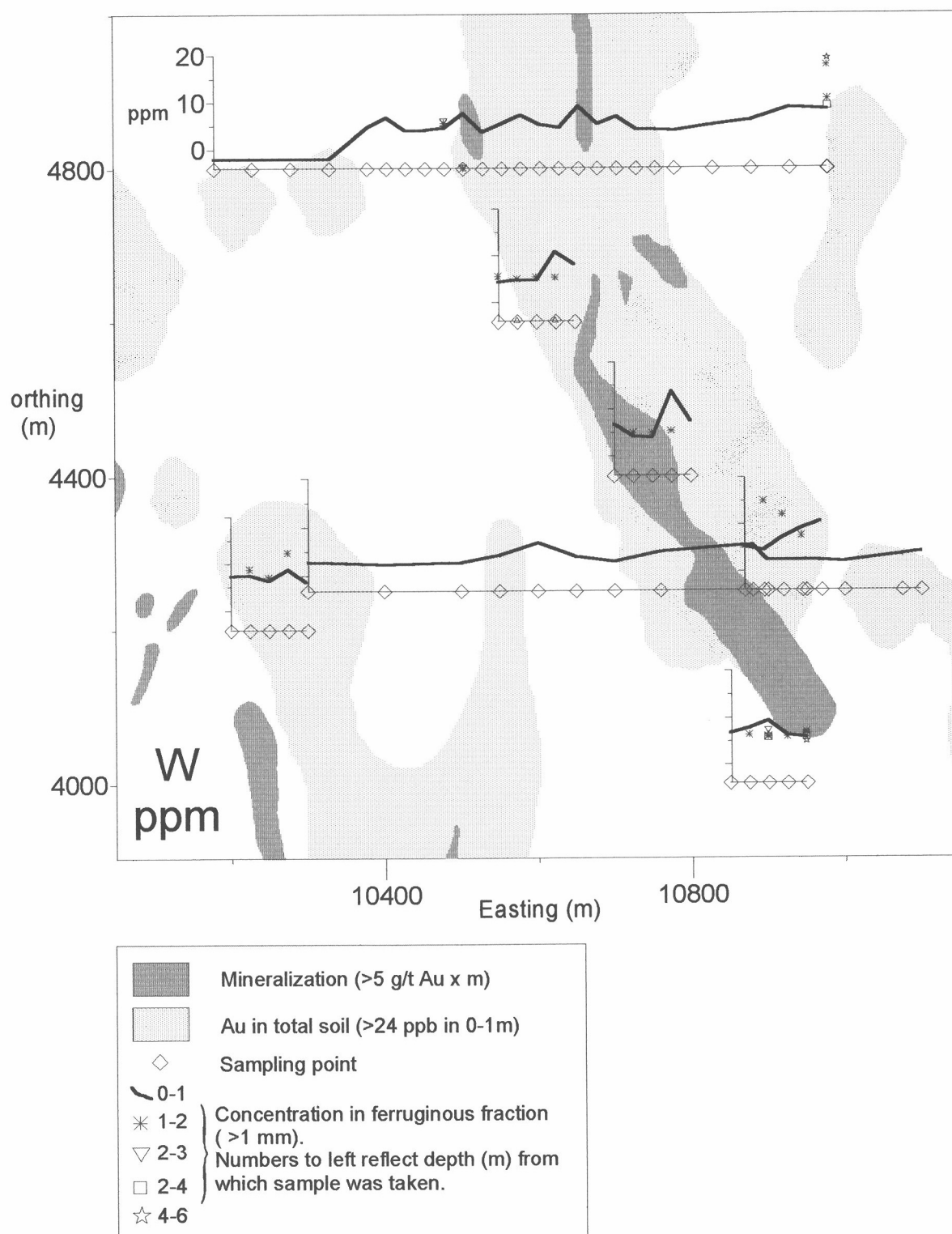


Figure A1.1.18: Concentration of W in ferruginous material (>1 mm). Most data are from 0-1 m.



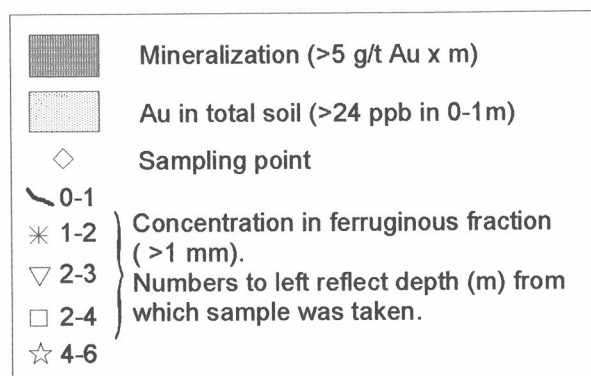
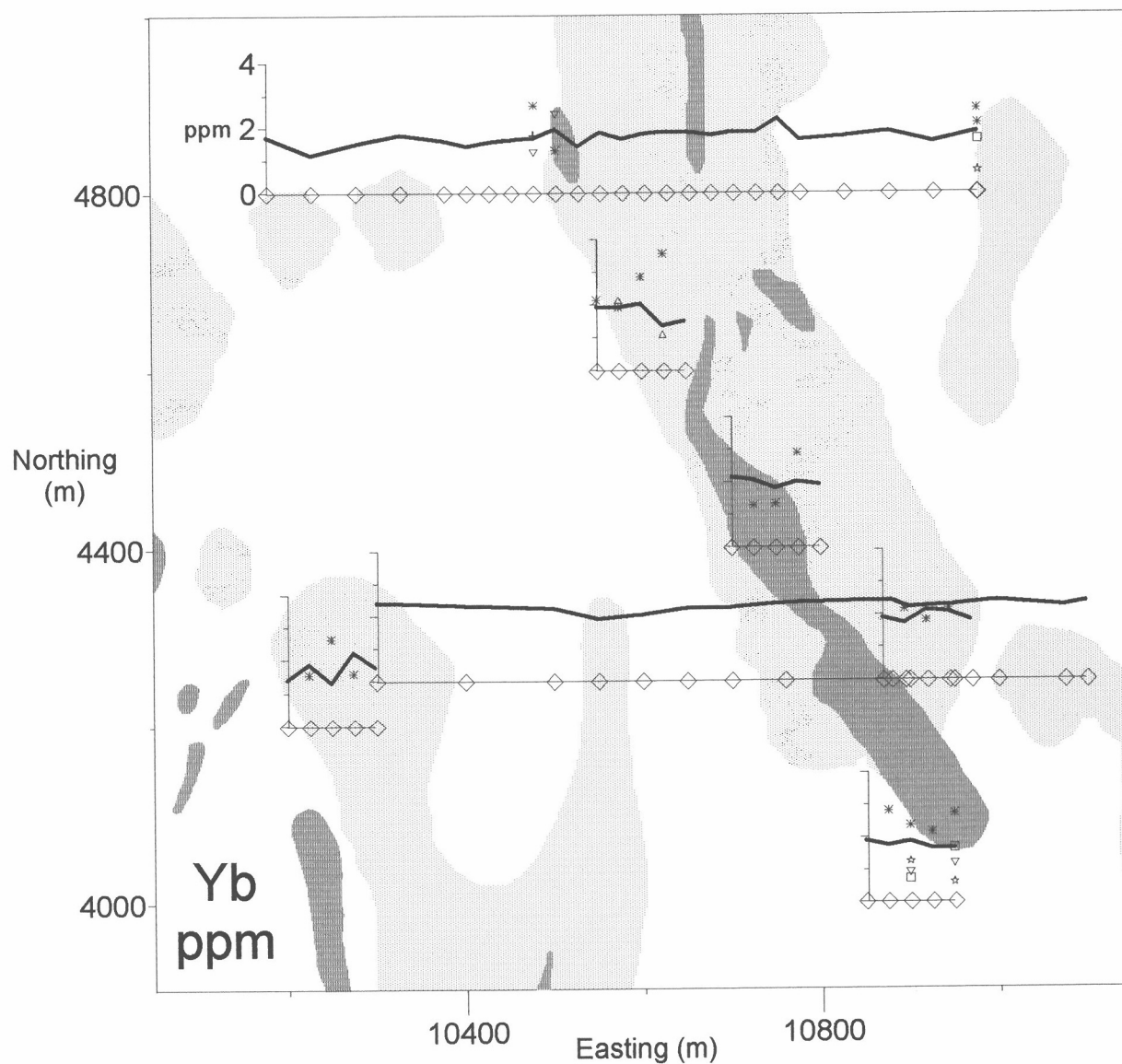


Figure A1.1.19: Concentration of Yb in ferruginous material (>1 mm). Most data are from 0-1 m.

Table A1.2: Elemental abundances at Steinway for ferruginous granule survey.

Sample	E	N	D	+1000µm %	Sb ppm	As ppm	Ba ppm	Br ppm	Ce ppm	Cs ppm	Cr ppm	Co ppm	Eu ppm	Au ppb	Hf ppm	Ir ppb
09-4131L	10980	4800	1.00	3.8	4	63	215	2	60	2	5170	36	1.3	<5	5	<20
09-4132L	10980	4800	3.00	1.9	5	71	447	<2	48	<2	5130	33	1.1	<10	5	<40
09-4133L	10980	4800	5.00	0.8	5	71	407	10	20	<4	4900	24	0.9	<15	3	<40
09-4134L	10979	4800	0.50	4.4	4	61	190	<2	51	2	3860	30	1.4	<5	3	<20
09-4135L	10979	4800	1.50	3.5	5	66	209	4	60	<1	4820	40	1.7	<5	4	<20
09-4136L	10930	4800	0.50	13.2	5	57	292	3	49	<1	4250	33	1.1	<5	3	<20
09-4137L	10880	4800	0.50	6.6	5	62	322	3	51	2	4840	41	1.2	<5	4	<20
09-4138L	10830	4800	0.50	4.2	4	53	<100	7	57	<1	5790	41	1.3	<5	3	<20
09-4139L	10780	4800	0.50	5.5	4	64	422	4	49	<1	4630	43	0.9	<5	3	<20
09-4140L	10755	4800	0.50	8.4	5	62	334	2	60	<1	5340	46	1.2	<5	4	<20
09-4141L	10730	4800	0.50	4.1	4	65	309	3	64	5	5600	44	1.2	<5	3	<20
09-4142L	10705	4800	0.50	9.5	5	77	345	<2	36	<1	5950	40	1.0	<5	3	<20
09-4143L	10680	4800	0.50	10.9	5	73	308	4	50	<1	5930	42	0.8	<5	4	<20
09-4144L	10655	4800	0.50	2.6	5	54	462	<2	50	5	5660	37	0.9	<5	4	<20
09-4145L	10630	4800	0.50	4.2	5	52	347	2	51	<1	6060	36	1.2	<5	4	<20
09-4146L	10605	4800	0.50	3.8	5	68	256	2	43	2	5670	49	1.1	<5	3	<20
09-4147L	10580	4800	0.50	7.2	5	68	356	3	36	4	6160	44	1.0	<5	3	<20
09-4148L	10555	4800	0.50	14.0	4	57	<100	<2	40	2	5690	45	1.1	<5	4	<20
09-4149L	10530	4800	0.50	6.5	5	57	327	3	26	<1	5610	28	0.9	<5	3	<20
09-4150L	10505	4800	0.50	9.4	6	73	507	4	38	<1	8290	37	0.8	<5	3	<20
09-4151L	10505	4800	1.50	1.6	6	68	233	<2	36	<2	7610	37	1.2	<10	3	<40
09-4152L	10505	4800	2.50	0.2	4	55	1270	8	34	<6	4930	33	1.3	<30	3	<80
09-4153L	10480	4800	0.50	7.7	5	61	548	5	33	2	7510	38	0.9	<5	3	<20
09-4154L	10480	4800	1.50	6.8	5	56	539	4	34	2	6650	34	2.1	<5	3	<20
09-4155L	10480	4800	2.50	3.8	6	70	560	5	18	<1	8100	42	1.0	<5	3	<20
09-4156L	10480	4800	0.01	89.6	5	54	336	<2	26	<1	7230	36	1.2	<5	3	<20
09-4157L	10455	4800	0.50	6.8	6	71	823	2	34	3	8340	40	0.9	<5	3	<20
09-4158L	10430	4800	0.50	9.9	6	79	626	2	32	2	7800	38	0.9	<5	4	<20
09-4159L	10405	4800	0.50	5.8	5	67	841	4	22	<1	6400	32	0.7	<5	3	<20
09-4160L	10380	4800	0.50	2.8	5	53	409	5	22	<1	7500	33	1.0	<5	2	<20
09-4161L	10330	4800	0.50	6.2	4	53	509	4	30	2	6670	47	1.2	<5	3	<20
09-4162L	10280	4800	0.50	8.6	5	52	420	4	31	<1	7100	45	0.7	<5	3	<20
09-4163L	10230	4800	0.50	5.0	4	49	532	5	40	2	7210	70	0.6	<5	2	<20
09-4164L	10180	4800	0.50	7.2	5	49	229	<2	42	2	8380	63	1.1	<5	3	<20
09-4165L	10650	4600	0.50	3.1	3	57	269	<2	46	<1	3680	37	1.0	<5	3	<20
09-4166L	10625	4600	0.50	4.5	5	72	780	7	49	3	4390	47	1.1	<5	3	<20
09-4167L	10625	4600	1.50	5.6	4	74	<100	8	63	<1	5420	60	2.3	<5	3	<20
09-4168L	10625	4600	2.50	2.1	5	68	624	17	14	3	5800	28	<0.5	<10	3	<40
09-4169L	10600	4600	0.50	6.8	4	71	239	4	52	2	4550	45	0.9	<5	3	<20
09-4170L	10600	4600	1.50	3.8	5	78	200	5	112	2	5730	85	1.6	<5	3	<20
09-4171L	10575	4600	0.50	20.3	4	67	<100	4	53	2	4410	45	0.9	<5	4	<20
09-4172L	10575	4600	1.50	9.3	4	62	145	3	47	3	5080	52	0.9	<5	3	<20
09-4173L	10575	4600	2.25	1.6	5	80	435	6	47	<4	6720	43	1.7	<15	4	<40
09-4174L	10550	4600	0.50	7.0	4	67	338	3	62	<1	5390	46	1.3	<5	4	<20
09-4175L	10550	4600	1.50	5.2	4	61	329	3	42	2	5930	49	1.5	<5	4	<20
09-4176L	10700	4400	0.50	2.7	3	49	<100	4	48	2	3860	35	0.8	<5	4	<20
09-4177L	10725	4400	0.50	5.5	3	65	359	3	54	1	4630	51	1.2	<5	3	<20
09-4178L	10725	4400	1.50	3.9	5	63	559	10	16	<1	4980	27	0.6	<5	3	<20
09-4179L	10750	4400	0.50	8.1	3	57	<100	3	40	<1	3700	45	0.9	13.0	3	<20
09-4180L	10750	4400	1.50	7.6	4	60	375	5	19	1	4580	25	0.6	17.9	3	<20
09-4181L	10775	4400	0.50	4.6	3	71	<100	4	50	<1	4840	46	1.0	<5	4	<20

Table A1.2: (continued).																
Sample	E	N	D	+1000µm	Sb	As	Ba	Br	Ce	Cs	Cr	Co	Eu	Au	Hf	Ir
				%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppm	ppb
09-4182L	10775	4400	1.50	12.6	3	60	371	6	48	<1	4030	59	1.6	41.5	3	<20
09-4183L	10800	4400	0.50	6.0	4	62	<100	3	42	1	4410	43	1.1	<5	3	<20
09-4184L	10845	4250	0.50	9.5	4	59	298	<2	50	2	4040	37	1.1	45.7	4	<20
09-4185L	10870	4250	0.50	8.0	5	69	198	4	47	2	4420	35	0.9	<5	4	<20
09-4186L	10895	4250	1.50	7.2	5	76	440	4	44	1	5000	40	1.4	24.0	4	<20
09-4187L	10920	4250	0.50	17.2	4	71	<100	4	46	2	4730	37	1.4	<5	4	<20
09-4188L	10945	4250	1.50	6.2	5	73	292	5	42	<1	4730	33	1.0	<5	4	<20
09-4189L	10970	4250	0.50	8.5	4	64	386	2	49	2	4680	38	1.2	<5	4	<20
09-4190L	10995	4250	1.50	3.9	4	67	295	5	42	<1	5070	30	1.4	<5	3	<20
09-4191L	11020	4250	0.50	10.9	3	64	250	<2	42	3	3730	39	1.0	<5	3	<20
09-4192L	10950	4000	0.50	12.9	3	60	326	6	39	2	3780	37	0.9	<5	4	<20
09-4193L	10950	4000	1.50	21.9	3	51	<100	4	38	<1	3100	43	1.5	<5	3	<20
09-4194L	10950	4000	2.50	4.9	3	56	<100	14	12	2	2770	17	<0.5	<5	4	<20
09-4195L	10950	4000	3.50	20.3	4	58	268	19	18	<1	2990	19	0.7	<5	4	<20
09-4196L	10950	4000	4.50	23.8	5	146	<100	21	5	<1	1150	15	<0.5	13.9	4	<20
09-4197L	10925	4000	0.50	5.6	3	53	<100	4	35	<1	4170	39	0.8	<5	3	<20
09-4198L	10925	4000	1.50	6.3	3	70	334	5	39	<1	2990	36	0.9	<5	3	<20
09-4199L	10900	4000	0.50	12.1	3	56	252	4	33	2	3520	45	0.9	<5	3	<20
09-4200L	10900	4000	1.50	22.2	3	49	405	<2	33	<1	3630	38	1.0	<5	3	<20
09-4201L	10900	4000	2.50	3.2	4	62	604	15	12	<1	4240	24	0.6	<5	4	<20
09-4202L	10900	4000	3.50	5.6	2	41	183	21	6	2	1450	12	<0.5	<5	5	<20
09-4203L	10900	4000	4.50	10.4	3	72	266	25	9	<1	1630	17	0.5	<5	5	<20
09-4204L	10875	4000	0.50	5.9	3	58	180	6	31	2	4210	39	1.0	<5	4	<20
09-4205L	10875	4000	1.50	10.2	3	60	281	4	50	<1	3950	36	1.7	<5	4	<20
09-4206L	10850	4000	0.50	8.1	4	68	156	4	41	2	4660	36	0.8	<5	4	<20
09-4207L	10300	4200	0.50	10.8	5	80	875	5	64	2	7480	55	1.2	25.9	3	<20
09-4208L	10275	4200	0.50	11.0	5	80	334	<2	50	<1	7450	47	0.9	<5	4	<20
09-4209L	10275	4200	1.50	11.4	6	83	<100	6	28	<1	7230	38	1.0	107.0	4	<20
09-4210L	10250	4200	0.50	18.5	4	68	206	4	48	<1	6160	52	0.7	<5	3	<20
09-4211L	10250	4200	1.50	9.9	5	76	324	6	46	3	7080	50	1.5	27.8	3	<20
09-4212L	10225	4200	0.50	7.7	6	96	600	7	39	2	8210	47	1.1	<5	4	<20
09-4213L	10225	4200	1.50	2.3	5	76	627	6	30	3	7000	37	0.8	<5	4	<20
09-4214L	10200	4200	0.50	3.2	4	72	411	6	37	4	8610	42	1.0	<5	3	<20

Table A1.2: (continued).																	
Sample	Fe	La	Lu	Mo	K	Rb	Sm	Sc	Se	Ag	Na	Ta	Th	W	U	Yb	Zn
	%	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
09-4182L	32	36	0.3	<5	0.6	33	7	47	<5	<5	0.28	<1	11	5	3	3	207
09-4183L	39	26	0.2	<5	0.5	25	4	49	<5	<5	0.13	1	12	8	<2	2	181
09-4184L	40	26	0.2	<5	<0.2	<20	5	48	<5	<5	0.12	<1	15	5	<2	2	149
09-4185L	45	26	0.2	<5	<0.2	<20	4	51	<5	<5	0.11	<1	16	5	<2	2	146
09-4186L	47	31	0.3	<5	<0.2	<20	6	51	<5	<5	0.07	<1	19	15	<2	2	119
09-4187L	42	28	0.3	<5	<0.2	<20	5	49	<5	<5	0.12	<1	16	7	<2	2	186
09-4188L	46	28	0.2	<5	<0.2	<20	5	52	<5	<5	0.09	<1	17	12	5	2	148
09-4189L	44	32	0.3	<5	1.2	<20	5	55	<5	<5	0.07	2	17	9	<2	2	145
09-4190L	45	31	0.3	<5	0.6	37	5	49	<5	<5	0.06	2	17	8	<2	2	165
09-4191L	35	28	0.3	<5	0.5	47	5	46	<5	<5	0.46	9	13	11	<2	2	149
09-4192L	38	19	0.2	<5	0.6	45	3	48	<5	<5	0.16	1	14	6	<2	2	202
09-4193L	32	24	0.3	<5	<0.2	<20	5	45	<5	<5	0.30	1	11	7	<2	3	183
09-4194L	31	8	<0.2	<5	<0.2	24	2	38	<5	<5	0.18	<1	14	7	3	1	135
09-4195L	37	14	0.2	<5	<0.2	28	3	45	<5	<5	0.12	<1	17	6	<2	2	121
09-4196L	39	4	<0.2	<5	<0.2	<20	1	26	<5	<5	0.04	<1	17	5	<2	1	<100
09-4197L	33	19	<0.2	<5	<0.2	28	3	50	<5	<5	0.20	<1	12	6	<2	2	166
09-4198L	26	27	0.2	<5	<0.2	23	4	44	<5	<5	0.27	<1	9	6	<2	2	210
09-4199L	30	20	0.2	<5	0.5	31	4	45	<5	<5	0.33	2	10	9	<2	2	153
09-4200L	31	24	0.2	<5	<0.2	<20	4	49	<5	<5	0.31	2	10	6	<2	2	212
09-4201L	40	7	<0.2	<5	<0.2	<20	2	43	<5	<5	0.10	<1	16	7	<2	1	156
09-4202L	21	4	<0.2	<5	<0.2	<20	1	26	<5	<5	0.23	<1	13	6	2	1	105
09-4203L	29	5	<0.2	<5	<0.2	<20	2	29	<5	<5	0.14	<1	16	6	<2	1	<100
09-4204L	33	19	0.2	<5	<0.2	36	3	51	<5	<5	0.17	<1	12	8	<2	2	209
09-4205L	40	37	0.3	<5	<0.2	29	7	49	<5	<5	0.27	1	14	6	<2	3	139
09-4206L	42	27	<0.2	<5	<0.2	<20	4	52	<5	<5	0.13	<1	15	7	<2	2	146
09-4207L	44	32	0.3	<5	<0.2	<20	4	58	<5	<5	0.08	2	13	6	<2	2	180
09-4208L	44	29	0.3	<5	<0.2	<20	4	53	<5	<5	0.14	2	13	9	<2	2	197
09-4209L	39	22	0.2	<5	<0.2	31	4	51	<5	<5	0.09	<1	12	12	<2	2	244
09-4210L	34	19	<0.2	<5	<0.2	<20	3	43	<5	<5	0.12	<1	11	6	4	1	164
09-4211L	42	32	0.3	<5	<0.2	<20	6	48	<5	<5	0.14	2	12	7	<2	3	168
09-4212L	48	28	0.2	<5	<0.2	<20	5	52	<5	<5	0.11	<1	15	8	<2	2	166
09-4213L	45	22	0.2	<5	<0.2	<20	4	47	<5	<5	0.14	1	14	9	<2	2	131
09-4214L	45	25	0.2	<5	<0.2	<20	4	49	<5	<5	0.20	<1	14	7	<2	1	169



Table A1.2: (continued).																	
Sample	Fe	La	Lu	Mo	K	Rb	Sm	Sc	Se	Ag	Na	Ta	Th	W	U	Yb	Zn
	%	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
09-4131L	45	41	<0.2	<5	<0.2	38	6	52	<5	<5	0.04	2	17	11	<2	2	192
09-4132L	45	35	0.2	<10	<0.4	<20	6	48	<5	<10	0.05	<1	19	9	<4	2	159
09-4133L	44	14	<0.2	<15	<0.4	<40	2	38	<10	<20	0.05	<2	18	19	<6	1	112
09-4134L	39	35	0.3	<5	<0.2	<20	5	46	<5	<5	0.04	2	15	8	<2	2	137
09-4135L	45	44	0.3	<5	0.3	<20	7	50	<5	<5	0.04	3	19	18	<2	3	174
09-4136L	41	31	<0.2	<5	<0.2	41	4	45	<5	<5	0.05	1	15	9	<2	2	148
09-4137L	43	32	0.3	<5	<0.2	<20	5	43	<5	<5	0.06	1	16	6	<2	2	159
09-4138L	40	42	0.2	<5	0.6	42	5	49	<5	<5	0.07	2	14	5	<2	2	193
09-4139L	41	35	0.2	<5	<0.2	40	5	50	<5	<5	0.07	1	14	4	5	2	201
09-4140L	39	39	0.3	<5	<0.2	34	5	51	<5	<5	0.11	<1	14	4	<2	2	202
09-4141L	42	35	<0.2	<5	<0.2	<20	4	52	<5	<5	0.05	1	16	4	<2	2	213
09-4142L	43	28	0.2	<5	<0.2	32	4	47	<5	<5	0.08	2	14	7	<2	2	132
09-4143L	41	28	0.2	<5	<0.2	<20	4	52	<5	<5	0.09	1	15	5	<2	2	191
09-4144L	44	30	0.2	<5	<0.2	<20	4	46	<5	<5	0.06	<1	15	9	<2	2	163
09-4145L	46	33	0.2	<5	<0.2	<20	4	57	<5	<5	0.05	<1	15	5	<2	2	215
09-4146L	43	29	0.2	<5	<0.2	<20	4	46	<5	<5	0.09	2	13	5	<2	2	216
09-4147L	44	27	0.2	<5	<0.2	30	4	50	<5	<5	0.10	1	15	7	<2	2	134
09-4148L	38	25	0.2	<5	<0.2	<20	4	51	<5	<5	0.37	<1	11	5	<2	2	195
09-4149L	38	21	<0.2	<5	<0.2	<20	4	38	<5	<5	0.05	<1	14	4	4	1	102
09-4150L	48	27	0.2	<5	<0.2	<20	4	57	<5	<5	0.08	<1	15	8	<2	2	144
09-4151L	45	31	<0.2	<10	<0.4	<20	4	52	<5	<10	0.07	<1	15	<4	<4	1	164
09-4152L	40	29	0.2	<40	<1	<100	5	34	38	<40	0.12	<4	20	<16	<12	2	195
09-4153L	47	23	0.2	<5	<0.2	<20	4	49	<5	<5	0.04	<1	15	5	<2	2	142
09-4154L	42	44	0.3	<5	<0.2	29	7	41	<5	<5	0.07	<1	14	6	<2	3	135
09-4155L	45	18	<0.2	<5	<0.2	<20	3	48	<5	<5	0.05	1	16	6	<2	1	158
09-4156L	48	22	<0.2	<5	<0.2	<20	3	49	<5	<5	0.03	<1	13	5	<2	2	175
09-4157L	49	22	0.2	<5	<0.2	<20	4	55	<5	<5	0.08	2	14	4	<2	2	164
09-4158L	47	23	0.2	<5	<0.2	38	4	54	<5	<5	0.07	<1	13	4	<2	2	194
09-4159L	41	17	0.2	<5	<0.2	54	3	42	<5	<5	0.07	<1	15	7	<2	1	142
09-4160L	38	19	0.2	<5	<0.2	<20	3	44	<5	<5	0.05	1	12	5	4	2	159
09-4161L	36	28	0.2	<5	<0.2	<20	5	45	<5	<5	0.08	2	10	<2	<2	2	119
09-4162L	39	23	<0.2	<5	<0.2	<20	4	47	<5	<5	0.07	<1	10	<2	<2	2	141
09-4163L	34	18	0.2	<5	<0.2	<20	3	47	<5	<5	0.21	1	8	<2	<2	1	150
09-4164L	36	27	0.2	<5	<0.2	<20	4	49	<5	<5	0.14	<1	8	<2	<2	2	164
09-4165L	35	30	0.2	<5	<0.2	<20	4	38	<5	<5	0.09	2	10	8	<2	1	196
09-4166L	34	27	<0.2	<5	<0.2	<20	3	50	<5	<5	0.21	<1	13	11	<2	1	193
09-4167L	38	42	0.5	<5	<0.2	21	9	57	<5	<5	0.13	2	13	5	4	4	167
09-4168L	41	11	<0.2	<10	<0.4	<20	2	57	<5	<10	0.04	<1	16	<4	<4	1	145
09-4169L	34	31	0.3	<5	<0.2	22	4	51	<5	<5	0.19	<1	11	5	<2	2	183
09-4170L	37	45	0.4	<5	<0.2	<20	7	55	<5	<5	0.20	2	13	5	4	3	197
09-4171L	32	31	0.3	<5	<0.2	35	4	49	<5	<5	0.19	<1	11	5	<2	2	205
09-4172L	36	30	0.3	<5	<0.2	24	5	51	<5	<5	0.17	<1	12	5	<2	2	153
09-4173L	44	38	<0.2	<15	<0.4	<40	5	45	<10	<20	0.06	<2	14	<10	<6	2	199
09-4174L	40	36	0.3	<5	<0.2	25	5	51	<5	<5	0.15	<1	14	4	<2	2	159
09-4175L	43	34	0.2	<5	<0.2	39	5	52	<5	<5	0.11	3	16	6	<2	2	301
09-4176L	39	33	0.2	<5	<0.2	<20	4	56	<5	<5	0.07	<1	14	7	<2	2	172
09-4177L	36	35	0.3	<5	<0.2	<20	5	56	<5	<5	0.21	<1	13	4	<2	2	197
09-4178L	40	10	<0.2	<5	<0.2	<20	2	44	<5	<5	0.05	<1	16	5	<2	1	141
09-4179L	31	23	0.2	<5	<0.2	<20	4	50	<5	<5	0.34	<1	10	4	<2	2	177
09-4180L	38	13	0.2	<5	<0.2	24	3	50	<5	<5	0.14	<1	13	5	<2	1	140
09-4181L	38	32	0.2	<5	0.7	<20	4	55	<5	<5	0.18	1	14	14	<2	2	199

## APPENDIX 2: INDIVIDUAL GRANULES

Table A2.1: Elemental abundances at Steinway for a) 4 size fractions sieved from 09-2040 (10810E 4250N) and b) 9 whole soil samples taken from the same profile (including 09-2040) (Lintern and Gray, 1995). Analyses in ppm unless otherwise stated. Samples in italics used for individual granule investigation. Ir(20ppb), Mo(5ppm), Se(5ppm) and Ag(5ppm) are below detection (in brackets) for all samples.												
a)	Sample	Sample id	Depth	size fraction	% size	Sb	As	Ba	Br	Ce	Cs	Cr
	09-2040	<i>L40-A</i>	10-30cm	>710um	8.4	5.2	68	330	8.17	58	<2	4820
	09-2040	L40-B	10-30cm	710-250	5.6	0.95	23.6	230	4.5	34.7	<1	1340
	09-2040	L40-C	10-30cm	250-53	26.6	0.56	9.9	214	<2	13.5	1.4	541
	09-2040	L40-D	10-30cm	<53	59.4	0.36	12.7	153	26.1	56.6	6.94	445
	Sample id	Co	Eu	Au ppb	Hf	Fe%	La	Lu	K %	Rb	Sm	Sc
	<i>L40-A</i>	34.9	1.13	56.4	3.42	44	30	0.2	0.28	41	4.72	51.7
	L40-B	26.2	0.9	71.7	3.34	11.6	16.3	<0.2	0.31	33	2.64	16.8
	L40-C	10.4	<0.5	33.9	2.15	4.33	7.03	<0.2	0.39	<20	1.18	7.28
	L40-D	31.6	1.33	304	3.95	4.63	26.4	0.3	0.83	49.7	5.5	22.8
	Sample id	Na%	Ta	Th	W	U	Yb	Zn				
	<i>L40-A</i>	0.125	3.55	17.9	11.7	<4	2.2	247				
	L40-B	0.221	<1	10	5.1	4.92	1.28	241				
	L40-C	0.308	<1	4.78	<2	<2	0.69	<100				
	L40-D	0.531	1.31	10.6	<2	<2	2.15	158				
b)	Sample	Depth	Sb	As	Ba	Br	Ca%	Ce	Cs	Cr	Co	
	09-2039	0-10cm	1.41	23.6	208	5.29	1.8	46.7	2.87	1520	28.6	
	09-2040	10-30cm	1.02	18.2	196	18	6.5	47	3.6	960	28.9	
	09-2041	30-50cm	1.07	17.3	149	20.2	5.6	49.5	3.69	995	29.3	
	09-2042	50-70cm	0.95	17.2	228	22.7	5.5	50.7	4.65	962	31.3	
	09-2043	70-90cm	1.05	16.8	253	16.4	4.5	50.2	5.09	1020	32.6	
	09-2044	90-110cm	0.83	14.9	207	16.7	4.1	52.9	5.08	952	33.3	
	09-2045	110-130cm	0.89	17	296	16.6	2.7	54.8	4.96	1070	35.5	
	09-2046	130-150cm	0.99	22	298	15	2.1	68	5.13	1280	48.9	
	09-2047	150-170cm	1.26	21.2	283	18.5	0.2	105	5.65	1270	67.3	
	Sample	Eu	total Au	Hf	Fe%	K %	La	Lu	Mg%	Rb	Sm	
	09-2039	1.15	106	3.4	14.6	0.33	23.2	0.27	0.38	28.6	4.34	
	09-2040	0.98	239	3.55	8.71	0.7	23	0.3	0.74	49	4.43	
	09-2041	1.17	208	3.97	9.24	0.58	23.3	0.25	0.71	32.5	4.61	
	09-2042	1.12	208	3.62	9.15	0.59	24	0.27	0.72	39.7	4.65	
	09-2043	0.95	206	3.7	9.44	0.43	24.2	0.29	0.65	33.8	4.82	
	09-2044	1.08	222	3.67	8.81	0.1	23.7	0.25	0.58	40.4	4.71	
	09-2045	1.26	257	3.68	9.84	0.48	30	0.29	0.54	32.8	5.7	
	09-2046	1.56	297	3.7	11.5	0.6	34	0.4	0.50	33.6	6.33	
	09-2047	2.01	323	4.14	11.6	0.45	32.7	0.45	0.39	10	7.97	
	Sample	Sc	Na%	Ta	Th	W	U	Yb	Zn			
	09-2039	25.7	0.24	1.24	11	<2	<2	1.87	156			
	09-2040	21.5	0.47	0.5	9.93	<2	<2	1.9	166			
	09-2041	23	0.56	1.04	10.1	<2	<2	1.85	165			
	09-2042	22.9	0.56	1.76	10.6	<2	2.69	2.02	152			
	09-2043	24.2	0.61	1.58	10.8	<2	<2	2.08	154			
	09-2044	24.5	0.65	0.5	11	4.66	2.34	2.11	158			
	09-2045	26.4	0.68	0.5	11.6	<2	<2	2.47	165			
	09-2046	28.4	0.68	1.11	11.9	<2	<2	2.7	159			
	09-2047	28.6	0.73	0.5	12.5	<2	<2	3.57	181			

Table A2.2: Elemental abundances at Steinway for individual granules																
Analyses in ppm unless otherwise stated. Samples in italics used for individual granule investigation.																
Sample	Taken	wgt before	wgt after	Magnetic or	Sb	As	Ba	Br	Ce	Cs	Cr	Co	Eu	Au	Hf	Ir
+710µm	from	section	for INAA	non-magnetic	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppm	ppb
L278-72	09-2040	0.333	0.142	M	6.7	80	1840	10	64	<5	12200	64	1	<40	3	<30
L278-73	09-2040	0.111	0.039	M	6.8	36	<1000	<10	77	<5	4040	86	2	<40	6	<50
L278-75	09-2040	0.164	0.065	M	4.3	181	<1000	6	47	<5	1910	48	1	<40	9	<50
L278-1	09-2046	1.84	1.013	M	2.2	39	<500	9	27	<5	4840	14	2	22	3	<30
L278-12	09-2046	0.206	0.13	M	16.6	28	1250	24	44	25	1380	44	<1	37	3	<50
L278-6	09-2046	0.346	0.191	NM	4.7	95	<500	30	107	<5	4300	95	2	40	4	<30
L278-11	09-2046	0.317	0.147	NM	5.9	54	1700	23	12	<5	5650	21	2	41	2	<50
L278-3	09-2046	0.281	0.169	NM	<1	<5	<500	18	26	5	1600	106	<1	43	2	<30
L278-4	09-2046	0.243	0.123	NM	1.9	28	<500	33	66	<5	1140	27	2	44	2	<30
L278-5	09-2046	0.322	0.124	NM	3.1	46	713	29	114	<5	2210	47	3	47	4	<30
L278-15	09-2046	0.207	0.116	NM	5.2	76	<500	45	40	<5	3600	49	2	52	3	<30
L278-28	09-2046	0.118	0.06	NM	2.3	31	<1000	58	141	<5	735	58	2	52	5	<50
L278-9	09-2046	0.28	0.117	NM	11.4	44	1040	24	140	63	1050	65	1	52	4	<30
L278-7	09-2046	0.404	0.192	NM	1.4	87	<500	36	20	<5	3080	25	<1	56	4	<30
L278-49	09-2046	0.133	0.05	M	13.0	307	<1000	58	26	<5	20600	67	2	60	<1	<50
L278-29	09-2046	0.189	0.095	M	3.9	52	<1000	36	42	<5	2820	47	1	60	8	<50
L278-23	09-2046	0.133	0.062	NM	3.8	98	<1000	46	22	7	3880	42	<1	69	2	<50
L278-47	09-2046	0.077	0.03	NM	5.2	29	<1000	116	42	<5	2840	48	2	76	5	<50
L278-22	09-2046	0.137	0.066	NM	2.1	40	<1000	55	26	<5	2850	27	2	76	<1	<50
L278-41	09-2046	0.123	0.06	NM	2.8	76	<1000	80	44	<5	1330	45	<1	79	5	<50
L278-17	09-2046	0.091	0.037	M	18.5	136	1140	73	26	<5	926	52	2	81	5	<50
L278-71	09-2040	0.24	0.097	M	9.0	29	1510	39	38	<5	2750	20	<1	84	11	<50
L278-14	09-2046	0.204	0.099	M	7.2	126	<1000	36	24	<5	15500	40	1	86	4	<50
L278-44	09-2046	0.119	0.054	M	8.0	38	1700	74	133	<5	5080	161	5	90	7	<50
L278-16	09-2046	0.099	0.071	M	4.5	30	<1000	54	49	<5	858	42	1	90	4	<50
L278-21	09-2046	0.189	0.095	NM	10.4	66	<1000	64	<20	<5	8440	14	<1	92	3	<50
L278-76	09-2040	0.089	0.033	M	6.3	77	<1000	50	66	<5	2300	49	2	92	5	<50
L278-31	09-2046	0.151	0.063	NM	3.1	82	<1000	49	89	<5	3670	42	3	93	3	<50
L278-2	09-2046	0.282	0.09	NM	<2	33	1630	44	37	<5	1810	21	<1	94	8	<50
L278-10	09-2046	0.158	0.061	NM	3.0	37	<1000	53	26	<5	952	42	<1	98	4	<50
L278-74	09-2040	0.169	0.053	NM	2.2	27	<1000	55	25	<5	1980	59	1	100	11	<50
L278-24	09-2046	0.165	0.06	NM	5.9	83	<1000	64	<20	<5	2920	27	1	101	3	<50
L278-8	09-2046	0.233	0.061	M	4.2	87	<1000	55	161	<5	3540	78	3	102	7	<50
L278-25	09-2046	0.088	0.047	NM	5.8	66	1420	76	<20	<5	19200	279	1	106	2	<50
L278-42	09-2046	0.076	0.049	NM	2.6	54	<1000	65	71	<5	2310	64	2	112	6	<50
L278-45	09-2046	0.118	0.053	NM	6.1	67	<1000	73	37	<5	11300	25	2	117	4	<50
L278-35	09-2046	0.122	0.059	NM	2.0	53	<1000	55	<20	<5	6590	50	<1	121	3	<50
L278-78	09-2040	0.073	0.025	NM	3.6	67	<1000	15	94	<5	3790	74	<1	133	11	<50
L278-18	09-2046	0.144	0.062	M	7.2	46	<1000	52	33	<5	4340	18	2	146	11	<50
L278-77	09-2040	0.078	0.027	M	8.7	38	<1000	47	61	13	1220	47	2	148	6	<50
L278-32	09-2046	0.14	0.056	M	9.5	50	<1000	61	51	<5	1400	32	2	150	4	<50
L278-43	09-2046	0.077	0.037	NM	<2	53	<1000	193	254	7	431	70	3	154	8	<50
L278-79	09-2040	0.071	0.026	NM	4.4	74	<1000	121	26	<5	11300	43	<1	161	<1	<50
L278-80	09-2040	0.053	0.022	NM	63.9	9	<1000	<10	25	<5	920	121	<1	167	6	<50
L278-50	09-2046	0.102	0.029	NM	<2	39	<1000	116	78	<5	1510	104	2	172	9	<50
L278-26	09-2046	0.148	0.065	M	7.3	70	<1000	97	<20	<5	3640	23	1	191	7	<50
L278-37	09-2046	0.073	0.037	NM	7.2	160	<1000	124	50	<5	8130	64	4	202	6	<50
L278-48	09-2046	0.107	0.043	M	11.8	44	<1000	143	55	<5	1610	62	2	204	3	<50
L278-46	09-2046	0.124	0.057	NM	2.2	122	<1000	64	27	7	6550	23	<1	245	5	<50
L278-13	09-2046	0.172	0.087	M	6.6	62	<1000	53	21	<5	4240	89	4	256	5	<50
L278-20	09-2046	0.131	0.058	M	<2	45	1140	89	54	<5	3670	45	2	258	5	<50
L278-38	09-2046	0.076	0.029	NM	65.9	<5	<1000	271	55	<5	490	100	<1	321	3	<50
L278-39	09-2046	0.136	0.063	NM	2.2	56	2420	41	33	<5	4220	26	1	451	7	<50
L278-40	09-2046	0.106	0.042	NM	3.3	66	<1000	141	53	<5	1220	50	2	562	4	<50
L278-27	09-2046	0.228	0.1	M	4.4	63	<1000	71	<20	<5	3360	13	1	619	9	<50
L278-19	09-2046	0.145	0.053	NM	5.9	104	1270	69	46	<5	11000	51	1	722	10	<50
L278-33	09-2046	0.083	0.02	NM	3.3	18	<1000	162	310	<5	1760	206	2	918	5	<50
L278-36	09-2046	0.192	0.101	M	13.4	113	522	30	<20	<5	3750	15	<1	970	2	<30
L278-30	09-2046	0.098	0.046	NM	3.4	75	1140	153	<20	<5	8900	67	3	4490	3	<50
L278-34	09-2046	0.118	0.057	NM	2.9	48	<1000	53	<20	<5	2520	28	3	14900	2	<50



Table A2.2: (continued)																			
Sample	Fe	La	Lu	Hg	Mo	K	Rb	Sm	Sc	Se	Ag	Na	Ta	Te	Th	W	U	Yb	
+710µm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
L278-72	63.2	33	0.3	<5	<30	<0.5	70	5	82	<10	<20	0.10	2	<20	18	<4	<5	2	
L278-73	60.4	43	0.3	<5	<50	<0.5	<80	8	15	<15	<30	0.15	<2	<30	32	<6	<10	2	
L278-75	70.3	37	0.3	<5	<50	<0.5	<80	6	33	<15	<30	0.13	3	<30	29	39	<10	2	
L278-1	55.9	16	0.3	<5	<30	<0.5	<40	6	102	<10	<20	0.11	<2	<20	13	14	<5	3	
L278-12	28.8	13	<0.2	<5	<50	2	136	3	42	<15	<30	0.16	<2	<30	11	<6	<10	1	
L278-6	58.2	23	0.6	<5	<30	<0.5	53	8	43	<10	<20	0.12	<2	<20	15	10	<5	5	
L278-11	64.3	38	<0.2	<5	<50	<0.5	<80	5	47	<15	<30	0.08	<2	<30	13	<6	<10	2	
L278-3	8.4	3	<0.2	<5	<30	<0.5	<40	2	39	<10	<20	0.94	<2	<20	1	<4	<5	2	
L278-4	28.8	50	0.2	<5	<30	<0.5	54	6	64	<10	<20	0.13	<2	<20	12	8	<5	2	
L278-5	62.6	177	0.3	<5	<30	<0.5	<40	11	48	<10	<20	0.18	<2	<20	23	10	<5	3	
L278-15	52.9	37	0.4	<5	<30	<0.5	<40	8	51	<10	<30	0.14	<2	<30	10	<4	<5	3	
L278-28	40.1	53	0.3	<5	<50	<0.5	<80	6	33	<15	<30	0.15	<2	<30	17	<6	<10	2	
L278-9	48.8	30	0.4	<5	<30	1	164	6	71	<10	<20	0.15	<2	<20	18	<4	<5	3	
L278-7	49.7	17	0.2	<5	<30	<0.5	63	3	83	<10	<20	0.12	<2	<20	23	<4	8	2	
L278-49	55.1	22	0.6	<5	<50	<0.5	<80	8	63	<15	<30	0.17	<2	<30	11	<6	<10	4	
L278-29	66.6	33	0.3	<5	<50	<0.5	122	6	19	<15	<30	0.11	2	<30	11	17	<10	3	
L278-23	50.8	18	<0.2	<5	<50	<0.5	<80	4	68	<15	<30	0.16	<2	<30	10	23	<10	1	
L278-47	26.2	40	0.2	<5	<50	<0.5	117	6	39	<15	<30	0.27	3	<30	11	<6	<10	2	
L278-22	37.6	42	0.2	<5	<50	<0.5	<80	6	100	<15	<30	0.14	<2	<30	11	<6	<10	4	
L278-41	36.3	21	<0.2	<5	<50	<0.5	<80	3	35	<15	<30	0.19	<2	<30	9	9	<10	2	
L278-17	24.1	19	0.5	<5	<50	1	<80	5	25	<15	<30	0.29	<2	<30	16	<6	<10	4	
L278-71	57.4	22	<0.2	<5	<50	<0.5	<80	4	115	<15	<30	0.11	2	<30	33	<6	<10	1	
L278-14	57.8	19	<0.2	<5	<50	<0.5	<80	4	35	<15	<30	0.12	<2	<30	7	<6	<10	2	
L278-44	70.3	168	0.7	<5	<50	<0.5	<80	22	48	<15	<30	0.11	<2	<30	36	<6	<10	6	
L278-16	25.6	28	0.3	<5	<50	1	<80	4	50	<15	<30	0.14	<2	<30	17	<6	<10	3	
L278-21	62.2	15	<0.2	<5	<50	<0.5	108	2	95	<15	<30	0.13	<2	<30	8	10	<10	<1	
L278-76	50.9	36	<0.2	<5	<50	<0.5	<80	6	22	<15	<30	0.22	4	<30	28	<6	<10	<1	
L278-31	43.5	101	0.4	<5	<50	<0.5	<80	12	132	<15	<30	0.16	<2	<30	10	<6	<10	3	
L278-2	42.6	19	<0.2	<5	<50	<0.5	<80	5	196	<15	<30	0.17	<2	<30	38	8	<10	2	
L278-10	29.2	52	<0.2	<5	<50	<0.5	<80	6	50	<15	<30	0.16	<2	<30	28	<6	<10	2	
L278-74	69.2	18	<0.2	<5	<50	<0.5	<80	3	10	<15	<30	0.15	5	<30	12	30	<10	1	
L278-24	48.0	30	<0.2	<5	<50	<0.5	<80	3	61	<15	<30	0.17	<2	<30	23	<6	<10	2	
L278-8	61.9	80	0.6	<5	<50	<0.5	<80	11	43	<15	<30	0.15	<2	<30	34	<6	<10	5	
L278-25	55.9	15	0.8	<5	<50	<0.5	<80	4	175	<15	<30	0.25	<2	<30	8	<6	<10	3	
L278-42	28.4	49	0.3	<5	<50	<0.5	92	7	17	<15	<30	0.18	<2	<30	14	<6	<10	2	
L278-45	61.0	29	0.3	<5	<50	<0.5	<80	7	77	<15	<30	0.13	<2	<30	13	<6	<10	3	
L278-35	24.5	9	0.2	<5	<50	<0.5	<80	3	99	<15	<30	0.16	<2	<30	5	<6	<10	3	
L278-78	43.9	53	<0.2	<5	<50	<0.5	<80	7	76	<31	<30	0.27	<2	<30	41	<6	<10	4	
L278-18	68.8	42	0.2	<5	<50	<0.5	<80	6	28	<15	<30	0.12	<2	<30	37	16	<10	2	
L278-77	34.7	16	<0.2	<5	<50	<0.5	<80	5	22	<15	<30	0.31	<2	<30	16	<6	<10	5	
L278-32	37.4	75	<0.2	<5	<50	<0.5	<80	7	72	<15	<30	0.17	<2	<30	13	<6	<10	2	
L278-43	24.5	66	0.6	<5	<50	<0.5	<80	13	93	<15	<30	0.24	<2	<30	32	10	<10	5	
L278-79	64.1	16	0.2	<5	<50	<0.5	299	4	38	<31	<30	0.27	<2	<30	9	<6	<10	2	
L278-80	8.6	9	0.4	<5	<50	<0.5	<80	3	57	<15	<30	5.78	<2	<30	3	<6	<10	3	
L278-50	43.8	45	0.3	<5	<50	<0.5	<80	6	147	<15	<30	0.28	<2	<30	32	<6	<10	2	
L278-26	66.2	8	<0.2	<5	<50	<0.5	<80	3	62	<15	<30	0.17	<2	<30	26	17	<10	<1	
L278-37	44.7	66	1.1	<5	<50	1	<80	15	30	<15	<30	0.26	<2	<30	23	27	17	9	
L278-48	70.3	32	0.5	<5	<50	<0.5	<80	7	31	<15	<30	0.21	<2	<30	18	<6	<10	4	
L278-46	52.9	17	0.2	<5	<50	<0.5	<80	3	44	<15	<30	0.16	3	<30	24	108	<10	2	
L278-13	60.6	46	1.0	<5	<50	<0.5	<80	14	21	<15	<30	0.11	4	<30	18	<6	<10	7	
L278-20	70.8	33	0.3	<5	<50	<0.5	99	14	39	<15	<30	0.15	9	<30	16	17	<10	3	
L278-38	5.1	8	<0.2	<5	<50	<0.5	<80	2	19	<15	<30	4.09	<2	<30	4	<6	<10	2	
L278-39	53.5	13	0.4	<5	<50	<0.5	<80	4	113	<15	<30	0.19	3	<30	25	22	<10	3	
L278-40	24.3	55	0.5	<5	<50	<0.5	<80	9	54	<15	<30	0.23	<2	<30	13	<6	<10	4	
L278-27	65.4	15	0.4	<5	<50	<0.5	<80	5	14	<15	<30	0.15	<2	<30	22	16	<10	3	
L278-19	57.4	29	<0.2	<5	<50	<0.5	<80	5	34	<15	<30	0.17	5	<30	19	33	<10	<1	
L278-33	22.5	60	0.3	<5	<50	<0.5	<80	9	22	<15	<30	0.41	<2	<30	16	<6	<10	3	
L278-36	67.3	7	<0.2	<5	<30	<0.5	92	2	18	<10	<20	0.09	<2	<20	5	51	11	1	
L278-30	34.3	80	0.6	<5	<50	<0.5	<80	13	77	<15	<30	0.20	3	<30	9	<6	14	5	
L278-34	43.9	33	0.4	<5	<50	<0.5	97	10	61	<15	<30	0.16	<2	<30	19	<6	<10	5	

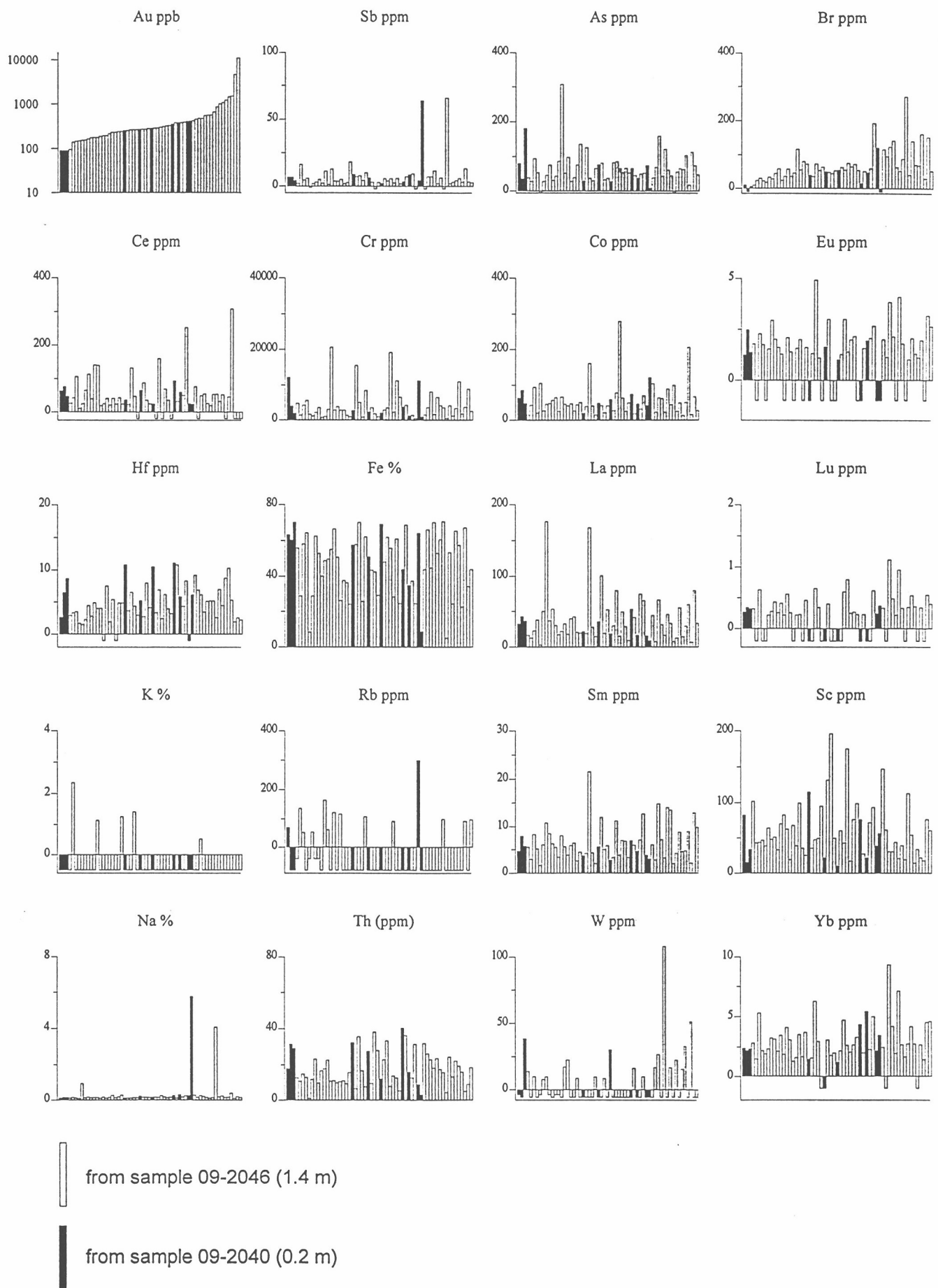


Figure A2.3: Elemental abundances for individual ferruginous granule samples from the soil profile at Steinway. Samples are ranked according to Au concentration. For most samples Ag (30), Ba (1000), Hg (5), Ir (0.05), Mo (50), Se (15), Ta (2) and U (10) data were close to or below detection indicated in parentheses (ppm). Negative data below detection.

Table A2.4: Descriptions of Au-rich Fe granules at Steinway.

Granule number	Descriptive notes	Magnetic or non-magnetic	Au ppb
13	Goethite. Inclusions in the centre of the specimen. Cutan present about 5% of total thickness. Goethite in centre is red-brown; goethite in cutan honey-brown.	M	256
20	Irregular dark brown porous goethite.	M	258
27	Centre massive goethite going to hematite with ?dehydration cracks. Appears to be zoned on the outside. Growth rings present Very dark brown.	M	619
30	Rich in red clays. Low reflectance. Goethite stained clays. Goethite on outside. ? part of lateritic duricrust. Large (120 $\mu$ m) barite grains detected on SEM.	NM	4490
33	Similar to 38. Partial cutan of goethite and clay. ?lateritic duricrust origin. Within core, vermiform structures and massive red clay present.	NM	918
34	Goethite stained clays. Partial cutan of goethite. Irregular patches of goethite within core. Generally, clay-rich with vermiform structures. Many Au grains present ranging from 1 $\mu$ m to several tens of microns. (see Figure 8)	NM	14900
36	Massive goethite with dehydration cracks. No cutan present. Extremely dark brown.	M	970
38	Clays with irregular patches of goethite or ?quartz Low reflectance. Sutured structure present. Quartz present. Red. Much silicates.	NM	321
39	Structures unknown. Goethite present. ?possibly primary. Many barite grains.	NM	451
40	Clays. ?micas. Sheer structure present. Many Zr grains.	NM	562
46	Porous, goethite-rich with dehydration cracks. Partial cutan present.	NM	245
19	Complex grain matrix composed of: (i) massive goethite; and (ii) goethite with clay structures. Structures after kaolinite or smectite. Matrix also consists of goethite with low reflectance. ?possibly irregular quartz.	NM	722



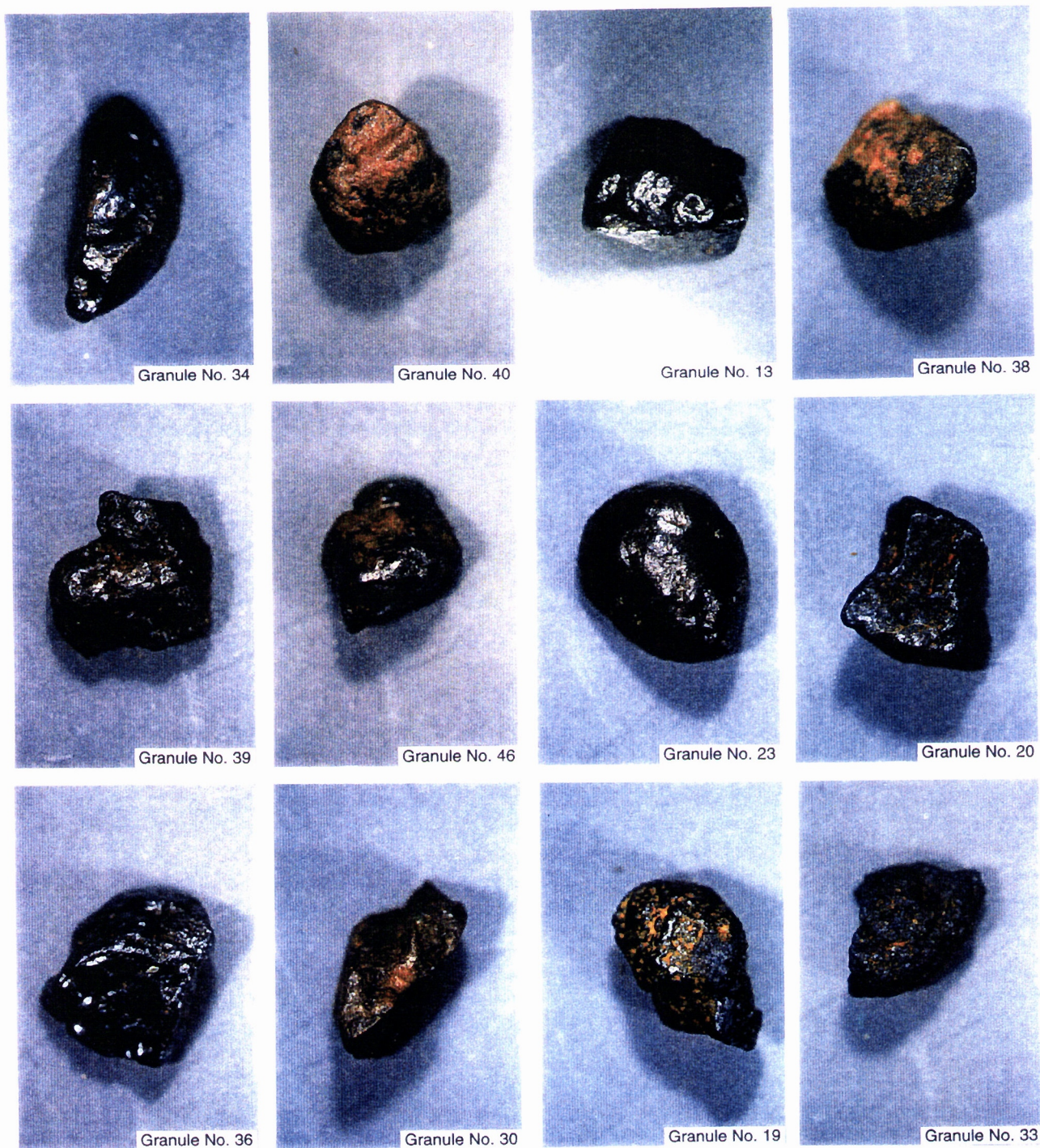


Figure A2.5: Photographs of high Au content ferruginous granules described in Table A2.4.



