Chapter 6

Calcrete sampling for mineral exploration

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6.1 Introduction

6.1.1 Background

Terminologies aside, there are basically two types of calcrete that have been used in mineral exploration: pedogenic and groundwater. In most of the case studies that follow, it is the pedogenic form, found in the top one or two meters of the soil profile, that is being discussed. In many of the case studies, the detailed morphology of the calcrete is not known and is, therefore, not described; however, where such information is available it is included in the site description. The calcrete types that have been sampled vary between powdery and nodular to more indurated forms such as laminar and boulder (massive) and this distinction is made where possible.

According to McGillis (1967), the use of calcrete as a geochemical guide to metal deposits may have begun in Russia during the late 1950s. However, its potential may have been recognised earlier by Cuyler (1930) who suggested Ca-rich (and other metals?) waters, rising under hydrostatic pressure, deposit calcrete in faulted areas. Outside of Russia, the value of calcrete as a specific geochemical sampling medium was not fully recognised until the early 1970s. One of the early records of calcrete as a geochemical sampling medium appears to have been in the Yilgarn Craton, WA (Western Australia) when it was investigated as a means to explore for Ni deposits. Initially, it was considered as a geochemical diluent (Mazzuchelli 1972) and other media such as the residual soils themselves were sampled instead or efforts were made to upgrade the metal content of samples by dissolving the calcrete away and analysing the residue, e.g. Garnett *et al.* (1982). However, Cox (1975) gave further consideration to its specific use when looking for Ni in the Kambalda area (Yilgarn Craton, WA). Other base metal studies in South Africa and Australia followed during the next decade, some of which are documented in the case studies that follow. Exploration companies, however, never systematically used calcrete as a sample medium of choice during these early years. As with many other geochemical techniques such as the collection of soil, rock chip or stream sediments, calcrete sampling has recently benefited from analytical laboratories providing low-cost, rapid chemical analyses with low detection limits.

Mineral deposits have been discovered directly as a result of their association with calcrete for centuries. Early mineral discoveries were often made by untrained people such as shepherds or farmers tending their herds and crops and finding evidence of mineralisation at the surface or in animal burrows and scrapes. Copper was one of the first metals found in this manner. Bright green Cu carbonate minerals, which visually contrast with the paler colours of the calcrete, were often the first indications of Cu mineralisation. For Au, the colour contrast with calcrete is not so marked but, nevertheless, according to anecdotal evidence from early mining documents, the lustre was conspicuous enough for the discovery of Au in "limestone cement", road base material and in the calcareous "soil" of the Eastern Goldfields of WA. Most of these early discoveries relate to the fortuitous presence of Cu or Au within calcrete rather than any specific or systematic exploration technique. If the soil in which the Au nuggets were found happened to contain calcrete then an association was documented in historical records irrespective of it being accidental. Furthermore, there are no known geological, chemical or physical reasons why Au nuggets should be found in calcrete, except that both Au and calcrete are found in the same surficial environment. Prospectors using metal detectors are just as likely to detect Au nuggets at the surface whether there is calcrete present or not. Conversely, calcrete does not always contain Au. Bright yellow and pale green U minerals in groundwater calcretes are another example of visually contrasting secondary mineralisation occurring in calcrete.

Calcrete had a major impact as a specific sample medium for Au exploration in Australia in the late 1980s until the present as a result of CSIRO and later CRC LEME research. In 1987, the CSIRO commenced a research project with a consortium of exploration companies through AMIRA (Australian Mineral Industries Research Association Ltd) to improve geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, concealed or deeply weathered Au deposits. In late 1987, the first detailed research on calcrete above a Au deposit commenced at Bounty (120 km S of Southern Cross, WA; Lintern 1989) with spectacular results! For the first time an economically important metal was demonstrated to be highly correlated (not merely associated) with Ca (calcrete); this was strong evidence indeed for the soluble and mobile nature of Au in the soil. The results showed not unexpectedly that Fe and many other elements had been diluted by the calcrete, consistent with the earlier base metal studies, and so were not correlated with Ca or Au. The correlation was widespread at the Bounty Deposit in soils which were typical of those found throughout the auriferous greenstones of the Eastern Goldfields of WA. Thus the potential for the widespread use of calcareous soil (calcrete) for exploration was enormous. In fact, results from further research and company exploration at several other deposits between 1988 and 1993 confirmed the relationship to be common in the southern Yilgarn and indicated that calcrete was a robust geochemical sample medium that could be used with confidence, pending certain important provisos.

Calcrete sampling reached a significant milestone as an exploration technique when its use was publicly acknowledged to have found the Challenger Gold Deposit (Gawler Craton, South Australia) in 1995. Subsequently, in a series of conference proceedings, company reports, magazine reviews and newspaper articles describing Au exploration on the Gawler Craton, calcrete was highlighted and recommended by many as the principal sampling technique to be used. Indeed, "calcrete" became a household word for mineral explorers in South Australia (SA). So why was it so vigourously acclaimed in SA rather than WA where it was first recognised? There appear to be several reasons for this:

1) Calcrete appears to be ubiquitous throughout much of the Gawler Craton, whereas it is mostly restricted to the SE portion of the Yilgarn.
2) In WA, other technologies and sampling media had been successful including ferruginous lag and lateritic residuum.
3) Calcrete is more prominent in SA (greater thicknesses, more indurated, and commonly highly visible on the surface) compared with WA where it is generally present in powdery forms and sub-surface; calcrete has been used as a housing, fencing and road-making material in SA. Blocks of calcrete have been piled up in many farm paddocks in SA as it is a hindrance to agriculture.
4) Calcrete found the first significant gold deposit (Challenger) in a new exploration province.
5) The confidential, industry-sponsored nature of CSIRO research on calcrete sampling initially stifled the dissemination of the technique beyond the borders of WA. In fact Mr K. Wills, then with Metana Metals (an AMIRA sponsor), is credited with applying the WA calcrete research to SA.

Interestingly, by the end of the 1990s, calcrete was being acclaimed as the sampling medium of choice in the Yilgarn Craton by a much wider audience of exploration companies than in the early 1990s, many of whom were not familiar with the earlier WA research, but had been convinced by the successes in SA. Clearly the technique has taken several years to filter through to the junior explorers even in the area where it was first recognised! As with many other geochemical sampling media, such as soil, rock chip or stream sediments, the popularity of calcrete has benefited from analytical laboratories providing low-cost, rapid chemical analyses with low detection limits. Calcrete has now gained a foothold in many other parts of the world for mineral exploration including North and South America, southern and northern Africa, and parts of the former USSR, and no doubt will increase in popularity as new discoveries are made with it.

6.1.2 Advantages and disadvantages of calcrete as a sampling medium

Calcrete has both advantages and disadvantages for mineral exploration as described by Butt (1992). The presence of calcrete may be advantageous to exploration in the following circumstances:

1) Calcrete may represent a pH contrast to underlying neutral to acid regolith and may cause the precipitation and concentration of mobilised metals, hence forming epigenetic anomalies.

2) The re-location of some of the Au to the calcareous horizons of soils appears to be primarily governed by the processes of meteoric water infiltration and evapotranspiration. This may give rise to or enhance a near-surface expression to concealed primary or secondary mineralisation.
3) Groundwater calcrete in particular may be the aquifer and host rock for the transport and precipitation of potentially economic U concentrations.
4) Calcrete represents a consistent, easily identified, sampling medium (generally corresponding to a B or illuvial horizon) for exploration purposes.

The principal disadvantages are:

1) Many pedogenic calcretes represent absolute additions to soils developed on pre-existing deep weathering profiles, which, in many instances, have been partly or almost fully truncated prior to soil and calcrete formation. The concentrations of many mobile elements associated with economic mineralisation may have been already reduced by leaching during the initial deep weathering and later pedogenesis, so that the addition of calcrete causes dilution and depresses anomaly contrasts still further. The replacement of primary and secondary minerals by carbonates may lead to the mobilisation and loss of some elements, including Pb and Zn.
2) The high pH prevailing in calcrete reduces chemical mobility of many elements (but, significantly, not complexed Au in the soil) and hence restricts the development of epigenetic anomalies.
3) The addition of calcrete acts as a diluent to other well-established sample media, e.g. laterite or skeletal soils developed on bedrock.
4) Calcrete may occur in different forms and/or positions in the soil profile representing different ages, stages of development or climatic episodes that may have different levels of metal concentration or dilution. For example, calcrete many metres thick might not be particularly useful as a sample medium nor would calcrete developed high in the profile of an aeolian dune.
5) The presence of non-pedogenic carbonates e.g. groundwater, that may be difficult to distinguish from pedogenic varieties, and do not have the Au association.

6.1.3 Regolith classification

With any geochemical sampling technique, knowledge of the regolith, geomorphology, style of mineralisation, geology, and present climate is crucial to the process of finding mineral deposits. This knowledge, in turn, guides us towards the most appropriate sample media to use, the grid size for sampling, the elements to be analysed and the choice of analytical technique. To assist the process, several sets of regolith classification models have been suggested to help provide a framework for stratigraphy, relief, climate and understanding landscape evolution. This approach has enabled particular exploration case histories to be "pigeon-holed" according to criteria determined for a particular model to facilitate our understanding and to make valid comparisons between case histories. One of the more useful models for (sub-) tropical terrains has been proposed by Butt and Zeegers (1992) who broadly divided the regolith into three Types (A, B and C) based on the degree of preservation of the "complete" weathering profile. A complete weathering profile is one that has saprock, saprolite, mottled zone, soil and a lateritic duricrust. These types were further divided according to modifications of the pre-existing profile, e.g. alteration, or the presence of calcrete, gypsum, silica and/or transported material. Type A models are those in which the profile is complete i.e. fully preserved. The uppermost residual horizon is commonly lateritic duricrust, or soils developed over or from it. Type B models are those in which the profile is partially truncated by erosion (lateritic duricrust absent), so saprolite with quite different geochemical characteristics from the ferruginous horizon forms the uppermost horizon and the parent material of residual soils. Type C models are those in which the earlier regolith has been entirely eroded and bedrock is either buried by transported overburden, outcrops at surface or has thin or skeletal residual soils forming directly from it. A simplified and modified version of this approach is used for the case histories presented below.

Although it has been widely recognised by mineral explorers that in deeply weathered terrains, the degree of regolith truncation (if any) and the presence of lateritic duricrust are important, insufficient emphasis has been placed on the importance of transported overburden. This is an important consideration that has ramifications for the type, interpretation and cost of a geochemical sampling programme, including those involving calcrete. Ideally, the depth and type of transported material should be known since this may have a bearing on the ability of metals to migrate vertically to the surface, but this is not always possible, particularly for regional soil surveys where drilling is limited. The presence of even a thin layer of transported material can have enormous effects on the use of calcrete as a sampling medium. Exploration companies have used two basic strategies to explore in regolith dominated by transported overburden.

The first approach has been to drill through the overburden and into the underlying bedrock (itself usually weathered and leached of elements of interest). This approach is expensive but low-risk and is commonly used on the prospect scale when there has already been one or more areas of mineralisation identified, and the odds are in favour of finding more of the same.

The second approach involves the collection of materials (including calcrete) at or near the surface, and is high risk, poorly understood and relies on the premise:
(i) that because the sediments are old and have undergone either diagenesis or post-depositional weathering, there has been time for pathfinder or target elements to migrate towards the surface;
(ii) that there is active dispersion of such elements (e.g., vapour phase), thereby revealing the presence of any buried mineralisation; and/or
(iii) that in cases where there is thin transported overburden, bioturbation can mix sediments and physically re-locate particles to the near-surface.

For Au, the surface expression of mineralisation through many tens of metres of transported overburden is the subject of much controversy. It has been apparently demonstrated by some explorers, doubted by many geochemists and believed by many others. The initial research undertaken by CSIRO and others suggested that calcrete developed in transported overburden appeared to accumulate Au (or reflect the geochemistry) of underlying mineralisation even where the combined overburden (both the transported component and leached saprolite) was up to 40 m thick. However, recent follow up work by CSIRO and CRC LEME shows that only in certain cases does surficial calcrete appear to be able to accumulate metal ions vertically transported, and only if the transported overburden is less than 10 m (Butt *et al.* 1997). However, more comprehensive case studies are required in this area.

To reflect the emphasis on the substantial effect transported overburden has on the exploration geochemistry of weathering mineral deposits, it is proposed to introduce a "T" Type model to the system suggested by Butt and Zeegers (Figure 6.1). Thus, the simplified and modified models of Butt and Zeegers (incorporating the lower pedolith and mottled zone in Type B, and ignoring the alteration and genetic themes) and the new Type T model can be summarised below:

Type T: transported overburden present.
Type A: weathered bedrock host with lateritic profile.
Type B: weathered bedrock host with no lateritic profile.
Type C: saprock-bedrock host with thin mainly residual soil.

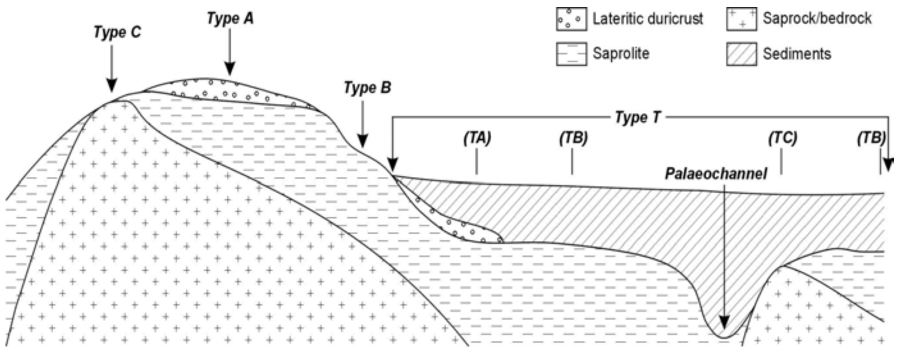

Figure 6.1: Schematic diagram showing regolith models. Type T: transported overburden present. Type A: weathered bedrock host with lateritic profile. Type B: weathered bedrock host with no lateritic horizon. Type C: saprock-bedrock host with thin mainly residual soil. Type TA, TB or TC refers to transported overburden lying over laterite, weathered bedrock or saprock-bedrock, respectively (if known).

This model system can be further modified. If transported overburden is overlying residual regolith then the annotation Type TA, TB or TC may be used; however, while this degree of detail may be important for general exploration, it does not appear necessary when discussing the use of calcrete as an exploration medium. The approximate depth of overburden, if known, is important and may be incorporated in the annotation such as Type T5 or T5-10, signifying the presence of 5 m or 5 to 10 m of overburden, respectively. This detailed nomenclature has not been included in the case studies below because of insufficient data.

6.1.4 Paleochannels

A special case of transported overburden is the palaeochannel, which is a feature of the Australian continent, particularly in the cratons, the Tasmanian Fold Belt and their margins. They have formed partly as a result of deep weathering, tectonic stability and long periods of humid followed by dry climatic conditions. In Australia, many of the palaeochannels are probably of mid-Eocene age and have been filled with fluvial and lacustrine sediments of Cainozoic age. Their presence is not easily detected and the course they follow is commonly poorly defined, even after drilling. They are of particular importance in the southern Yilgarn Craton (WA) where they have been shown to host, or be related to, significant Au mineralisation, commonly within the basal sands or in underlying saprolite. They present a special problem for exploration because barren sedimentary units, 15 to over 50 m thick, usually conceal them. Nevertheless, surficial anomalies have been reported by exploration companies directly above buried mineralisation in some locations, often associated with calcrete. In many cases, the immediate origin of the mineralisation in the palaeochannel has not been determined. Locally, sub-economic mineralisation occurs within the palaeochannel sediments but the highest grades seem to occur at the unconformity between the basal sands and the underlying weathered units. In addition, high-grade mineralisation has been identified below the unconformity, but even this appears to follow the course of the palaeochannel probably following structural features in the bedrock.

6.1.5 Regolith history

Calcrete is an overprint or secondary accumulation on an existing profile. The particular geochemical signature of calcrete may therefore be largely dependent on the original geochemical signature of the host material (i.e. transported overburden, weathered or fresh bedrock). A basic understanding of the geochemical processes and elemental distributions within the soil (pre-calcrete formation) is therefore desirable. Thin residual soils developed directly on partially weathered mineralised bedrock would be expected to produce strong geochemical anomalies in the surrounding soil. Residual soils developed on deeply weathered and leached rocks are more complex. For Au in a Type A weathering profile, a pre-existing enrichment of Au in the lateritic duricrust would be expected. If there is no duricrust present (Type B), then the geochemistry may be more complex and may require information on, for example, the degree of stripping and/or leaching, development of supergene deposits at relict water tables or redox fronts, presence of relict auriferous quartz veins or other partially-weathered rock clasts; the reader is referred to Butt and Zeegers (1992) for a full discussion of these points. Gold is unusual, as the case histories will demonstrate, in that there is usually a strong relative accumulation of the metal, derived from the original host material, in the calcrete.

In its weakest or youngest expression, calcrete occurs as fine powdery accumulations or coatings of pedogenic carbonate that maybe indistinguishable from the host regolith except with the aid of acid. In these situations, the tenor of the host regolith geochemistry imposed on the calcrete appears to be strongest. Progressively, calcrete will replace and displace host materials until the original regolith host or even bedrock becomes unrecognisable. Ultimately, as the calcrete develops into a separate component of the regolith, the influence of the host regolith geochemistry becomes gradually diminished or lost entirely, so that the uppermost calcrete in a profile will mostly reflect the geochemical signatures of underlying calcrete layers rather than the original host. For example, the Bridgewater Formation is a sequence of Quaternary aeolian sediments (calcarenites) found on the coastlines of Southern Australia. It unconformably overlies rocks of Proterozoic and Archaean age and can reach up to 200 m in thickness; in such circumstances, it is extremely unlikely to reflect at its surface the characteristics of these older rocks.

6.1.6 Landforms

The type of landform, relief or topography can have a series of complex effects on the dispersion of geochemical anomalies in the soil whether they be chemically (hydromorphic) or clastically (mechanically) controlled (Figure 6.2). In this respect, calcrete behaves no differently from other soil components. Calcrete, however, is an unusual sample medium as it can be either readily dissolved and/or mechanically transported as dust, nodules, pisoliths or fragments. For Au, it appears that calcrete provides a host for both (i) hydromorphically-mobilised forms probably occurring as organic ligands, and (ii) mechanically-mobilised Au particles of various size ranges ((m to cm) that become re-located within the re-mobilised Ca. Thus Au anomalies in calcrete may be found in a variety of landscape positions relative to the ore body source.

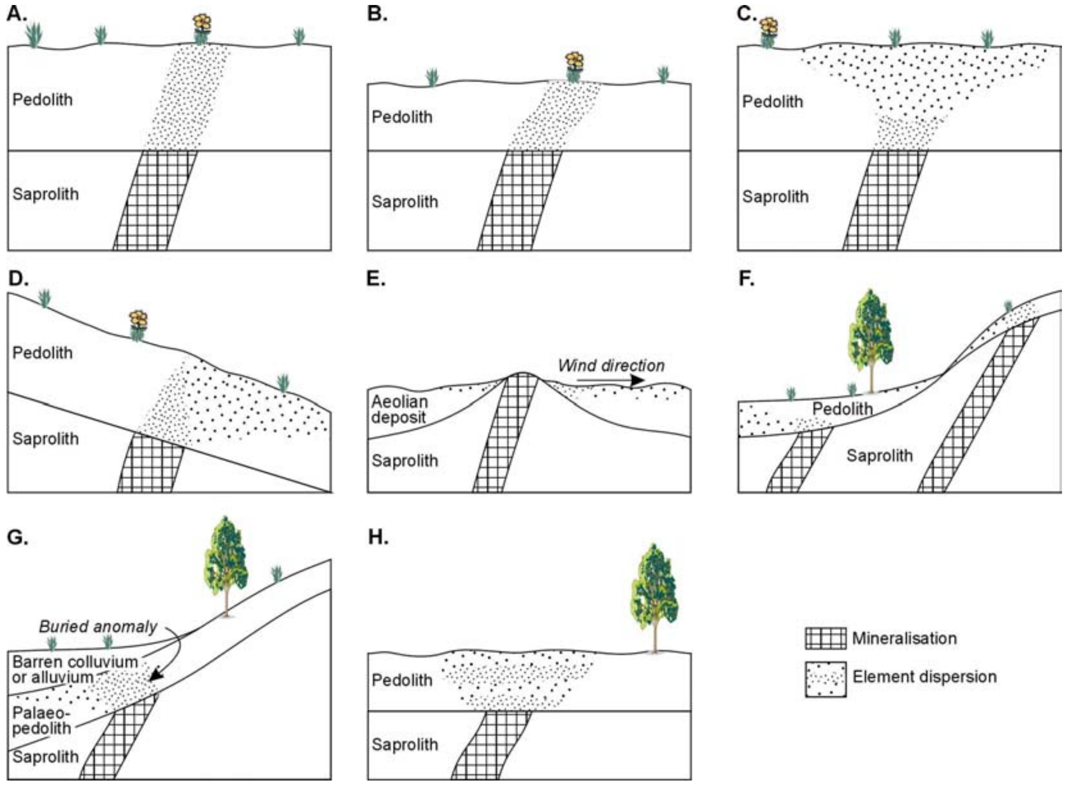

Figure 6.2: Schematic diagrams showing mechanisms for chemical and mechanical dispersion into calcrete (modified from Joyce 1984, pp 48-51). A) Residual clastic dispersion. B) Residual clastic dispersion pattern displaced by eluviation. C) Residual clastic dispersion enlarged by physical/biological mixing. D) As for C but displaced by soil creep. E) Aeolian clastic dispersion. F) Clastic and chemical dispersion down slope. G) As for F but further complicated by presence of transported overburden. H) Chemical dispersion due to upward movement of soil moisture during dry periods.

Sand dunes present some of the most difficult environments for the application of geochemistry. The presence of calcrete within sand dunes and aeolian sand sheets is evidence of the mobile nature of carbonate within the landscape during the Quaternary. In simplistic terms, the calcrete forms and, with vegetation, serves to partly-stabilise the dunes during wetter climatic periods, but becomes exposed and begins to fragment (physically weather) during drier periods. Importantly, the exhumed calcrete may then be re-located down slope to swale areas. However, in either the dune or swale, surficial calcrete is likely to be of limited use as a geochemical indicator of underlying rocks as it has relatively little time to acquire any possible signature (including mineralisation) from the underlying rock. However, the calcrete found *at depth* within the swale soil sequence is a more effective sample since it is more likely to reflect the geochemistry of the underlying rocks, e.g., through capillarity and bioturbation. Obviously, other techniques such as sieving to remove aeolian sand are beneficial in "upgrading" the calcrete sample. A related problem is that caused by relief inversion (Figure 6.3). Differential erosion of calcareous material and overlying soil and alluvial layers exposes harder calcrete layers (laminar, massive and breccia forms) that are more resistant. These in turn become topographic highs and their eventual dismantling leads to mechanical movement of calcrete down slope from breakaways.

6.1.7 Biota

The role of biota in the re-cycling of elements such as Cu, Au and Ca at the surface is confirmed by the presence of these elements in plant tissues, although the magnitude of the role in the Au-calcrete association is possibly only minor. Elements are absorbed via roots, enter the plant tissue, and are ultimately returned to the soil surface as plant litter. In the solum, biological processes take place

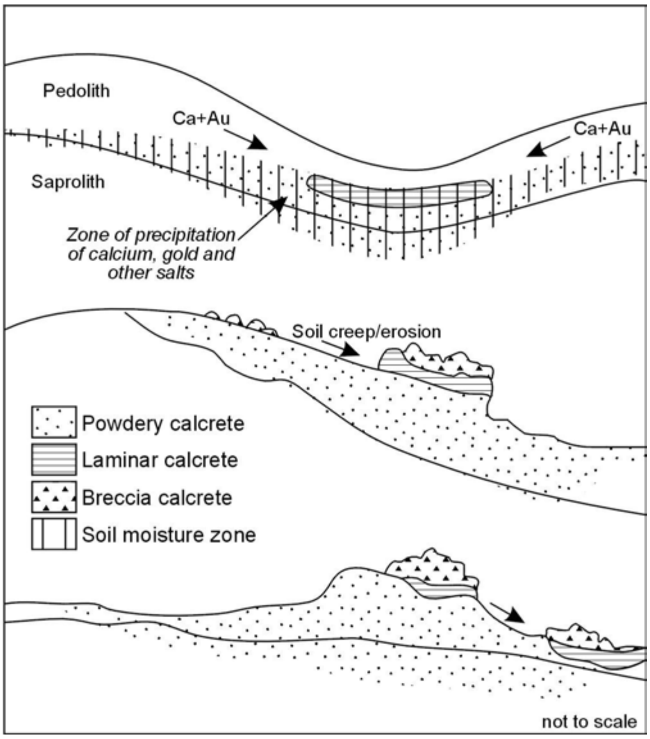

Figure 6.3: Relief inversion through calcrete formation (after Arakel 1995).

involving the conversion of plant litter into an enormous variety of organic and inorganic compounds through the action of soil invertebrates, fungi, bacteria and other microorganisms. The biochemical processes involved in the conversion of metallic organic and inorganic complexes from plant litter into those that reside in the soil is poorly understood mainly due to the low concentrations involved.

Gold is possibly mobilised in soil solution as an organic complex and deposited as an evaporite in this complexed form, with the calcrete. It has been speculated that Au and other elements of economic interest have been brought to the surface from great depths by root systems, thereby providing a mechanism by which anomalies can form in soils developed in transported material. There is no doubt that plants, particularly trees, have extensive root systems particularly in dry areas. However, at least for Au in the Eastern Goldfields (WA), strong evidence for the role of plants translocating material from depth to the surface is lacking: (i) the absence of long (greater than 15 m) vertical roots within open cut mines, (ii) the presence of highly saline ground water unsuitable for plant growth, and (iii) the generally poor correlation between concentrations of Au found in vegetation, soil and underlying mineralisation.

6.2 Case studies

6.2.1 Introduction

The case studies that follow have been derived from research conducted by CSIRO Exploration and Mining, CRC LEME, industry and universities, and were reported in academic journals (particularly the Journal of Geochemical Exploration), reviews in published texts, books and company reports. As can be seen from Figure 6.4, many of the case studies originate from WA, an area dominated by deeply weathered terrains, and most familiar to the author. The emphasis is primarily on Au but other commodities have been included where information is available. Only brief descriptions of the case studies are provided and the reader is referred to the original reference for complete description and discussions. The regolith profiles have been described as Type A, Type B (based on Butt and Zeegers, 1992) and the new Type T in accordance with the arguments presented above; Type T case studies are described in order of increasing depth of transported overburden. No Type C (fully truncated profile or bedrock) case study samples involving calcrete has been described in the literature. In reality, regolith profiles are usually complex and many of the deposits and prospects described in the case studies have examples of more than one type of regolith. Many gold and base metal anomalies in calcrete are now being found throughout Australia forming the basis for further case studies. This will help further refine the models and improve understanding of the processes of formation of geochemical anomalies.

6.2.2 The Menzies Line

The Menzies Line is an important environmenal and geological boundary relating to the distribution of calcrete and hence exploration techniques in the Yilgarn Craton, WA. It is a narrow (~5-100 km) EW transitional zone, stretching across the southern Yilgarn Craton where there are marked changes in soil types, vegetation associations and groundwater quality (Butt *et al.* 1977; Figure 6.4). The changes are

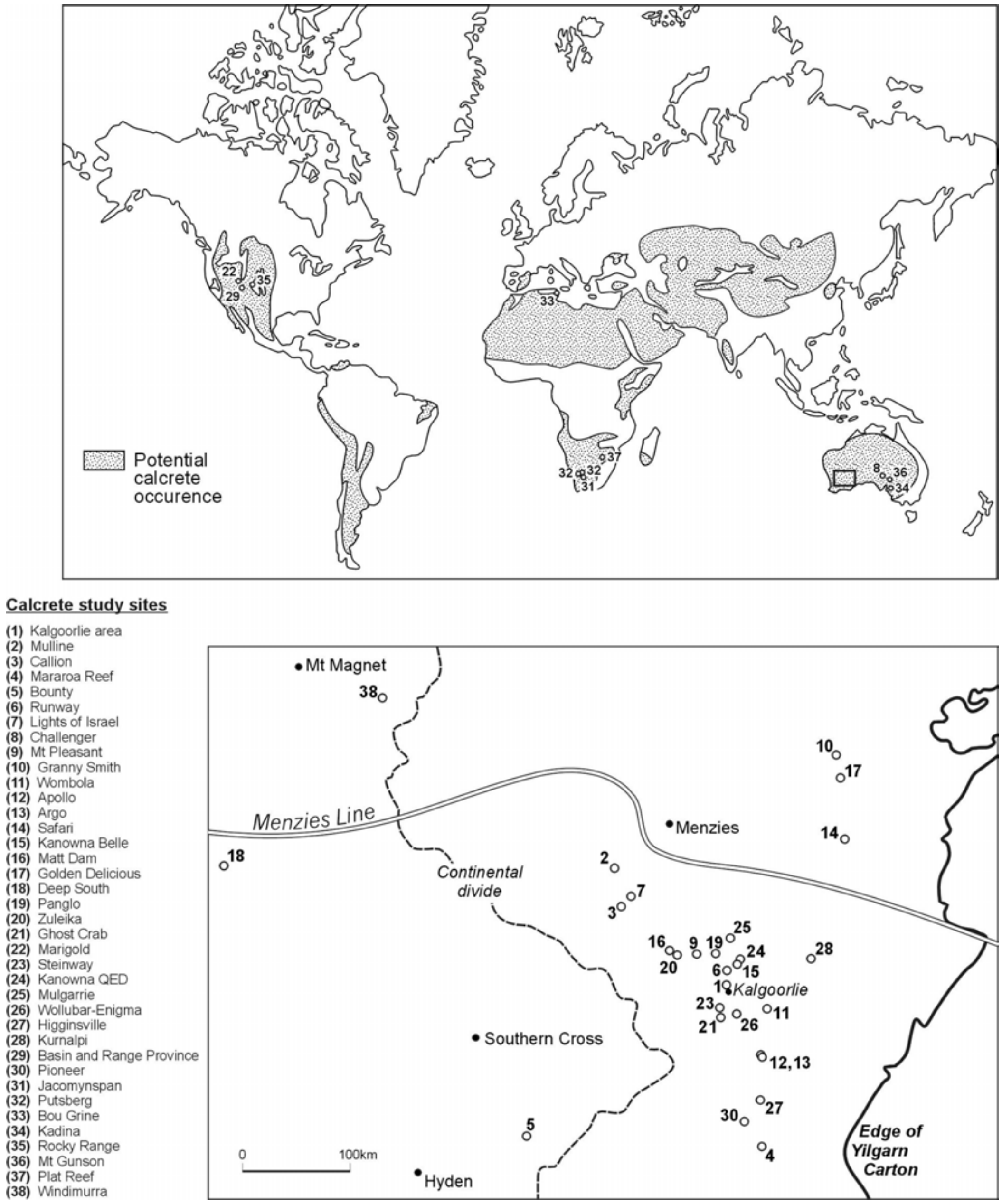

Figure 6.4: Location of case studies and the Western Australian Menzies Line. Australian calcrete distribution map from D.J. Gray (CSIRO, July 2001, written communication) derived from Northcote *et al.* (1975). South Africa calcrete distribution after Netterburg (1971). World distribution of arid and semi-arid terrains after Dregne (1983).

probably a response to climatic factors, although the sharpness with which the changes occur is more abrupt than any climatic gradient. South of the Menzies Line, soils are predominantly neutral to alkaline, orange to red loams, with extensive development of pedogenic calcrete. Non-calcareous earthy sand soils occupy high landscape positions, principally over granitic rocks. Groundwaters tend to be saline, neutral to acid. Average annual rainfall generally exceeds 225 mm, mainly in winter; annual evaporation is less than 2500 mm and the annual mean temperature is less than 19^{o}C. Vegetation immediately S of the Line is typical of that within the Coolgardie Botanical District, comprising woodlands of mixed eucalypts, especially salmon and gimlet gums (*Eucalyptus salmonophloia* and *E. salubris*) and shrublands of mulga (*Acacia*), *Grevillea*, mallee (*Eucalyptus*) and sheoak (*Casuarina*). North of the Menzies Line, soils are predominantly neutral to acid, red, non-calcareous earths, sands and lithosols, with extensive development of red-brown siliceous hardpans. Groundwater (or valley) calcretes are common in major drainages. Groundwaters are less saline than in the S, and are neutral to alkaline. Annual rainfall is generally less than 225 mm, falling mainly in the summer, with annual evaporation exceeding 2500 mm and annual mean temperatures exceeding 19^{o}C. The vegetation is typical of that found within the Austin Botanical District, comprising shrublands dominated by mulga, with eucalypts, such as the river red gum (*E. camaldulensis*) common only along water courses and some valley calcretes.

6.2.3 Gold case studies

6.2.3.1 Lateritic residuum host (Type A)

The presence of calcrete in lateritic residuum-capped weathering profiles has not often been described. It occurs in Mauritania (Nahon *et al.* 1977) and southern Australia (Anand *et al.* 1989, Anand *et al.* 1997), and is probably present in equivalent regions elsewhere. The paucity of data may be due to lateritic residuum, formed during humid climates, being already modified or destroyed by calcrete during an arid phase. Continued calcrete accumulation is a strong factor involved in the destruction of indurated lateritic horizons both physically, by growth of carbonate segregations, and chemically, by replacement of existing minerals. The calcrete, containing lateritic residuum, forms a fragmentary surface horizon or calcareous soil subject to erosion and mechanical dispersion. Lateritic residuum and calcrete can co-exist but there are many instances where its presence and associated soil appear to restrict the accumulation of the alkaline earths, possibly due to the acidic nature of the ferruginous material. Thus, we may have a landscape where lateritic residuum is present in a soil devoid of calcrete adjacent to a soil containing calcrete but no lateritic residuum. This can present particular problems for interpretation of geochemical sampling data. In such terrains, it is recommended that Fe and Ca are routinely analysed as part of the analytical suite.

(1) Kalgoorlie area, WA. (Mazzucchelli and James 1966, Butt and Zeegers 1992)

Carbonate dilutes the concentration of many elements in the soil profile especially those retained or concentrated in Fe oxides, including certain pathfinders (chalcophiles, siderophiles) for Au mineralisation, and, consequently, it has been avoided during sampling programs. In the Kalgoorlie region (WA), Mazzucchelli and James (1966), exploring for Au mineralisation, found that As is concentrated in lateritic fragments (220 ppm) compared to calcrete (40 ppm). Arsenic anomalies can be enhanced by preferentially sampling either the surface ironstone fragments (lag), mostly free of carbonate coatings, or the coarse (>840µm) soil fraction, in which these fragments are most concentrated; whole samples or the <175µm fraction are diluted by calcrete (Figure 6.5).

The surface fragments also give a wider anomaly, due to dispersion by sheetwash, as is the case for pisoliths and lags.

(2) Mulline, WA. (Lintern and Butt 1991)

The Peach Tree Gold Prospect is situated in the Mulline area, approximately 50 km W of Menzies and about 140 km NW of Kalgoorlie (WA). The Mulline township (now abandoned) is located near Peach Tree and close to the site of an underground Au deposit mined earlier in the century. The deposit occurs in basalt and hornblende-schist zones with mineralisation controlled by quartz veining and shears. Alteration of the primary deposit includes silicification and the formation of hydromica. Minerals associated with Au include pyrite, galena, sphalerite and chalcopyrite. Production figures reported were 4.2 tonnes of Au, mined from a grade of 25.3 g/t (Geological Survey 1990). The region is characterised by the local preservation of complete lateritic regolith profiles, especially over mafic rocks. Gold and Fe are enriched in lateritic gravels and duricrusts, and along sub-surface redox boundaries, over primary mineralisation and form small Au deposits. One such deposit (Peach Tree)

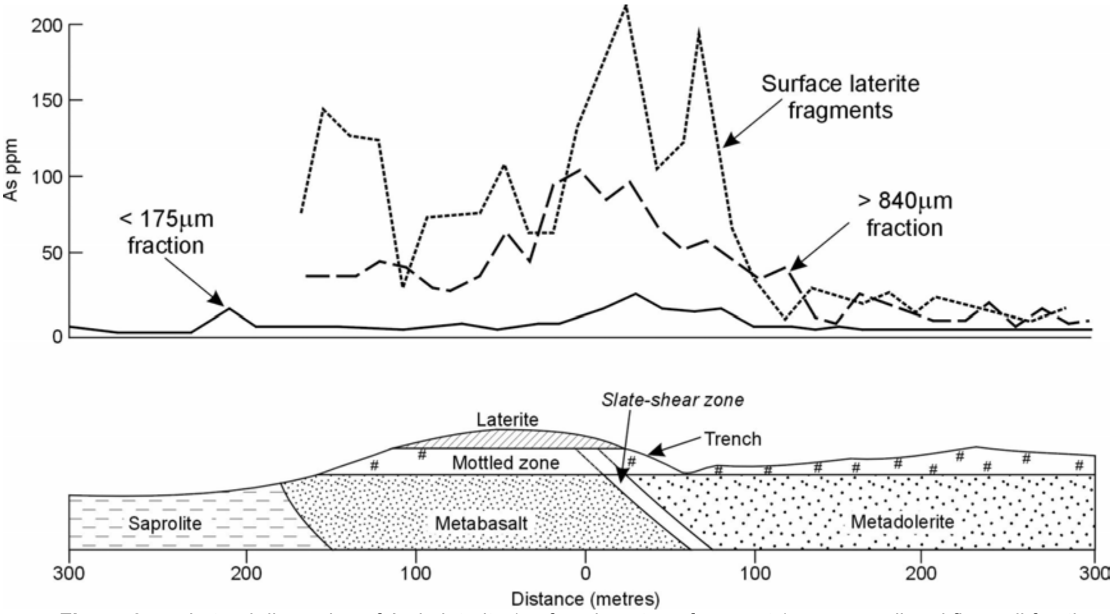

Figure 6.5: Lateral dispersion of As in laterite (surface ironstone fragments), coarse soil and fine soil fractions (modified after Butt 1992, Mazzucchelli and James 1966).

was investigated (Lintern and Butt 1991). The thickness of the deposit (with grades >0.5 ppm Au), and the locations of drill traverses and trench profiles are illustrated in Figure 6.6A.

Mulline is situated just S of the Menzies Line. The soils are alkaline, with strong development of pedogenic carbonates invading the pre-existing lateritic gravels; the vegetation is an open eucalypt woodland (predominantly *E. salmonophloia*) with a sparse shrubby understorey of *Acacia* and *Melaleuca*. The area is thus fairly typical of conditions S of the Menzies Line. Locally, however, the soils and vegetation relate closely to the geological setting; eucalypt woodlands are present mainly on the mafic rocks of the greenstone belts and pedogenic calcretes only appear to be abundant close to specific source units. Indeed, the Menzies Line here extends unusually far N, following the Davyhurst-Mt. Ida greenstone belt to beyond Bottle Creek, 65 km to the N.

Sampling sites were selected from data supplied by Pancontinental Mining Ltd. A trench exposed the top 1 to 2 m of the regolith, and several profiles were sampled (Figure 6.6B). Profiles were sampled by vertical channel sampling from the surface to the base of the trench. Deeper samples were collected by sub-sampling drill cuttings from two grid lines on traverses that extended from mineralisation to background zones low in Au. Adjacent traverses were selected (25 m apart) to examine differences due to sub-sample or spatial inhomogeneities. Samples were taken from bagged RC cuttings for depths of 0-1 m and 3-4 m.

A typical soil profile at Mulline is described below:

0-0.4 m	Red calcareous clay-rich loam with Fe oxide and calcrete pisoliths and nodules
0.4-0.6 m	Orange loam with Fe oxide pisoliths and calcrete nodules. Some calcrete nodules enclose Fe oxide-rich pisoliths
0.6-0.95 m	Similar to 0.4-0.6 m; Fe oxide-rich pisoliths more abundant
0.95-1.2 m	Pseudo-bedded calcretes enclosing Fe oxide-rich pisoliths
1.2-1.5 m	Fe oxide-rich pisoliths with some calcrete layers

Lateritic gravels and duricrusts host the Au mineralisation at Peach Tree prospect and contain pedogenic carbonate in their upper 2 m. The zone of Au enrichment (as shown by the isopachs in Figure 6.6A) trends approximately EW and has well-defined southern and western boundaries that parallel the occurrence of the lateritic materials. Thus, to the S, soils are developed directly from saprolite, with little or no lateritic gravel, and to the W there are outcrops of fresh rock. From the S in particular, the lateritic materials are seen to form a low mound with an EW trend. The shallow N-S trench cut in the centre of the anomaly shows that carbonates are abundant in the near-surface horizons. A massive "bar" of calcrete cross-cuts the trench, striking approximately EW along the axis of the Au

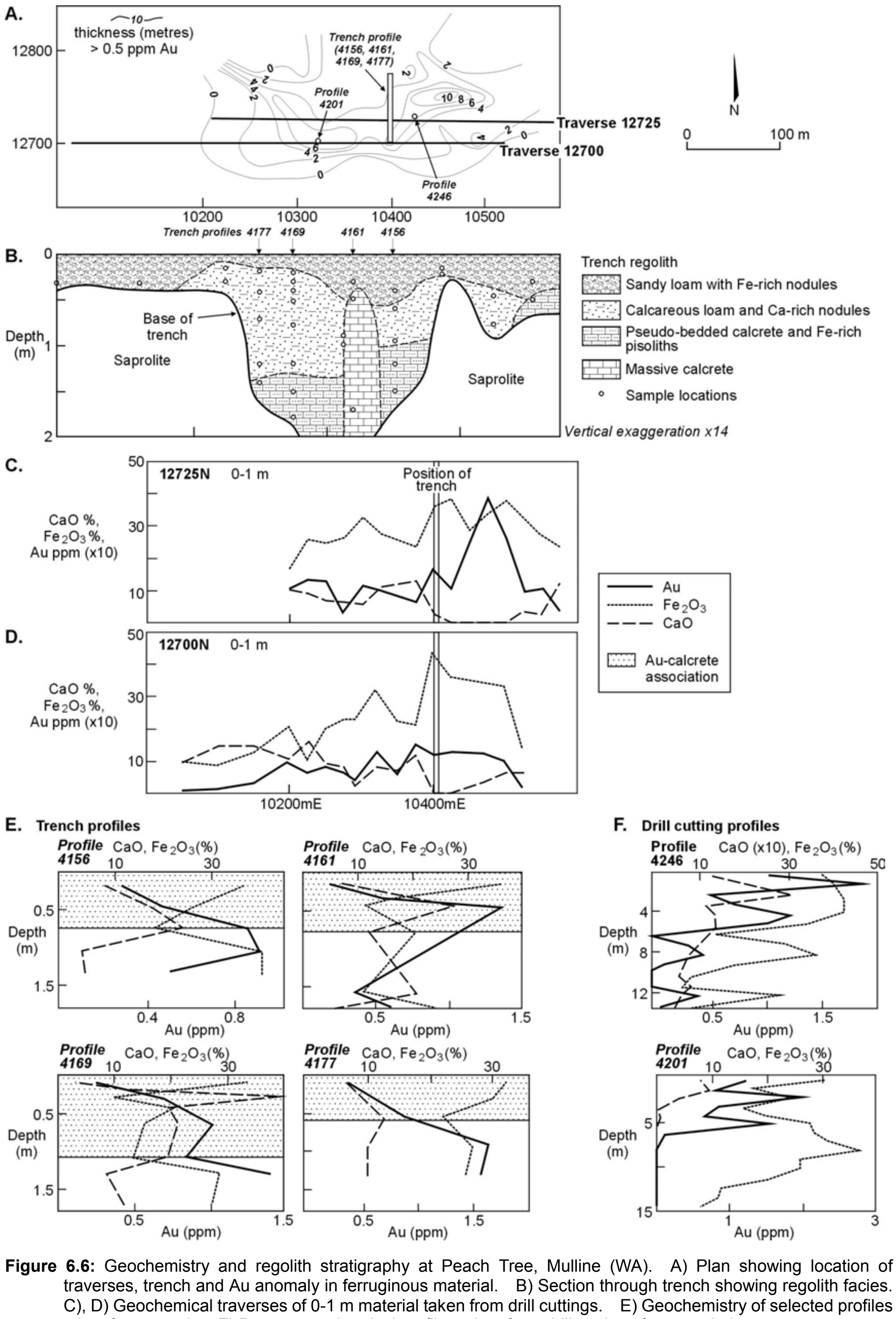

Figure 6.6: Geochemistry and regolith stratigraphy at Peach Tree, Mulline (WA). A) Plan showing location of traverses, trench and Au anomaly in ferruginous material. B) Section through trench showing regolith facies. C), D) Geochemical traverses of 0-1 m material taken from drill cuttings. E) Geochemistry of selected profiles taken from trench. F) Deeper geochemical profiles taken from drill cuttings from two holes.

anomaly. The amount of carbonate enrichment appears to decrease away from this bar and the lateritic gravels, exposed at the S end of the trench and nearby drill holes, are carbonate-free. It appears that the primary source of the Au has an EW strike, parallel to lineaments interpreted from aerial photography. This source may be related to the carbonate bar exposed in the trench. Indeed, the bar may also reflect a Ca-rich rock (e.g. carbonate alteration) and hence represent the local source unit for much of the pedogenic carbonate. Similar massive calcrete about mineralisation is found at Callion (see below; Glasson *et al.* 1988) and other prospects. Gold is present in both carbonate-rich and Fe oxide-rich soils and gravels and there are no simple correlations between Au concentrations and their abundances (Figure 6.6C-E). Thus, in some samples, the ferruginous pisoliths contain 1.5-3.0 ppm Au whereas the associated calcrete contains 0.7-1.5 ppm Au. The carbonates possibly dilute the initial Au content of the lateritic materials but have themselves been Au-enriched. The association between Au and Ca is strongest in the top 0.5-1.0 m, where carbonates are more abundant and occur as coatings and within the soil matrix. Deeper in the profile, where carbonate does not occur, there is a clear association of Au with Fe peaking at a series of old redox boundaries (Figure 6.6F).

(3) Callion, WA. (Glasson *et al.* 1988; Butt 1992)
Callion is a now abandoned mining centre 100 km NNW of Kalgoorlie (WA) which was worked intermittently between 1899 and 1956. Gold occurs in quartz-filled shear zones within a sequence of metamorphosed (amphibolite facies) basalts, interflow sedimentary rocks and acid tuffs within the Archaean Wiluna-Norseman greenstone belt (Glasson *et al.* 1988). The area has a subdued relief with low laterite-covered hills rising to a maximum of 20 m above colluvial-alluvial plains. Weathering commonly extends to depths of 40-60 m and, where it has not been eroded on the hills of metabasaltic rocks, the profile consists of:

1) red brown clay loam soil, up to 0.3 m thick;
2) coarse pisolitic laterite, 1.0-3.0 m thick, with pisoliths to 50 mm diameter, commonly including a pedogenic calcrete horizon;
3) mottled zone, with ferruginous nodules and fragments in a kaolinitic and commonly silicified matrix;
4) saprolite, bleached and kaolinitic in the upper 10-20 m and passing downwards to yellow to red-brown and pale green clays, probably smectitic in part.

A soil sampling survey on parallel traverses across each of the thirteen laterite-covered hills on the tenements was undertaken (Figure 6.7A). One kg samples of soil and pisoliths were collected at 50 m intervals. Two adjacent samples on the first traverse were highly anomalous (530 and 350 ppb Au) compared to the background of 60 ppb Au. A detailed soil survey on a 25 x 50 m grid outlined a 200 x 600 m anomaly, defined by the 100 ppb contour, and parallel to the N-S structural trend. The 1000 ppb contour of the anomaly, 70 x 340 m in size, defines the lower cut-off grade of the small lateritic Au deposit. This deposit was outlined by drilling to the base of the mottled zone (5 to 10 m) on a 25 x 25 m grid, locally infilled at 12.5 m intervals (Figure 6.7B). Reserves were estimated to be 71000 t at 2.0 g/t, with an average thickness of 3 m. Gold occurs as the free metal, associated mostly with Fe oxides, and includes some clearly secondary forms. The highest concentration of Au (16.1 ppm) was associated with the inferred position of Au-rich quartz veining and massive pedogenic calcrete, (exposed in a trench) near the centre of the anomaly (Figure 6.7C). In general, the Au contents of the soils were about 50% of those of the underlying laterite deposit, probably due to dilution (e.g. by transported clays and sand). The coincident distributions of Au, As and, to a lesser extent, Pb in soils reflects the occurrence of arsenopyrite and galena in the primary mineralisation.

Subsequent drilling resulted in the discovery of the primary mineralisation underlying the soil anomaly and lateritic deposit. A quartz-veined shear was located by deep diamond drilling after initial drilling to 30 m depth had been unsuccessful. Thereafter, drilling on 25 m centres proved a saprolite resource of 104,000 t at 7.9 g/t Au using a 2 g/t lower cut-off. The 3 m wide ore zone was found to occur over a strike length of 300 m and to extend to the base of weathering at 60-70 m. According to Butt (1992), although the deposit is very small, the Au distribution illustrates many of the features typical of supergene Au deposits in semiarid lateritic terrains:

1) There is a "mushroom-like" dispersion of Au into the mottled and pisolitic horizons of the profile.
2) Gold is largely depleted between 3 and 9 m in the upper saprolite.
3) Gold in the saprolite is more or less confined to the shear, with some very high values (e.g. up to 54 g/t) suggesting enrichment, possibly at an old water-table level. However, as the primary mineralisation is vertically zoned and is poorly developed in the unweathered zone despite the continuation of the shear, the degree of enrichment cannot be estimated.
4) There is an increase in Au fineness towards the surface, from 81% below 40 m to 92% above.
5) Secondary forms of Au, including crystals, are present in the lateritic horizon.

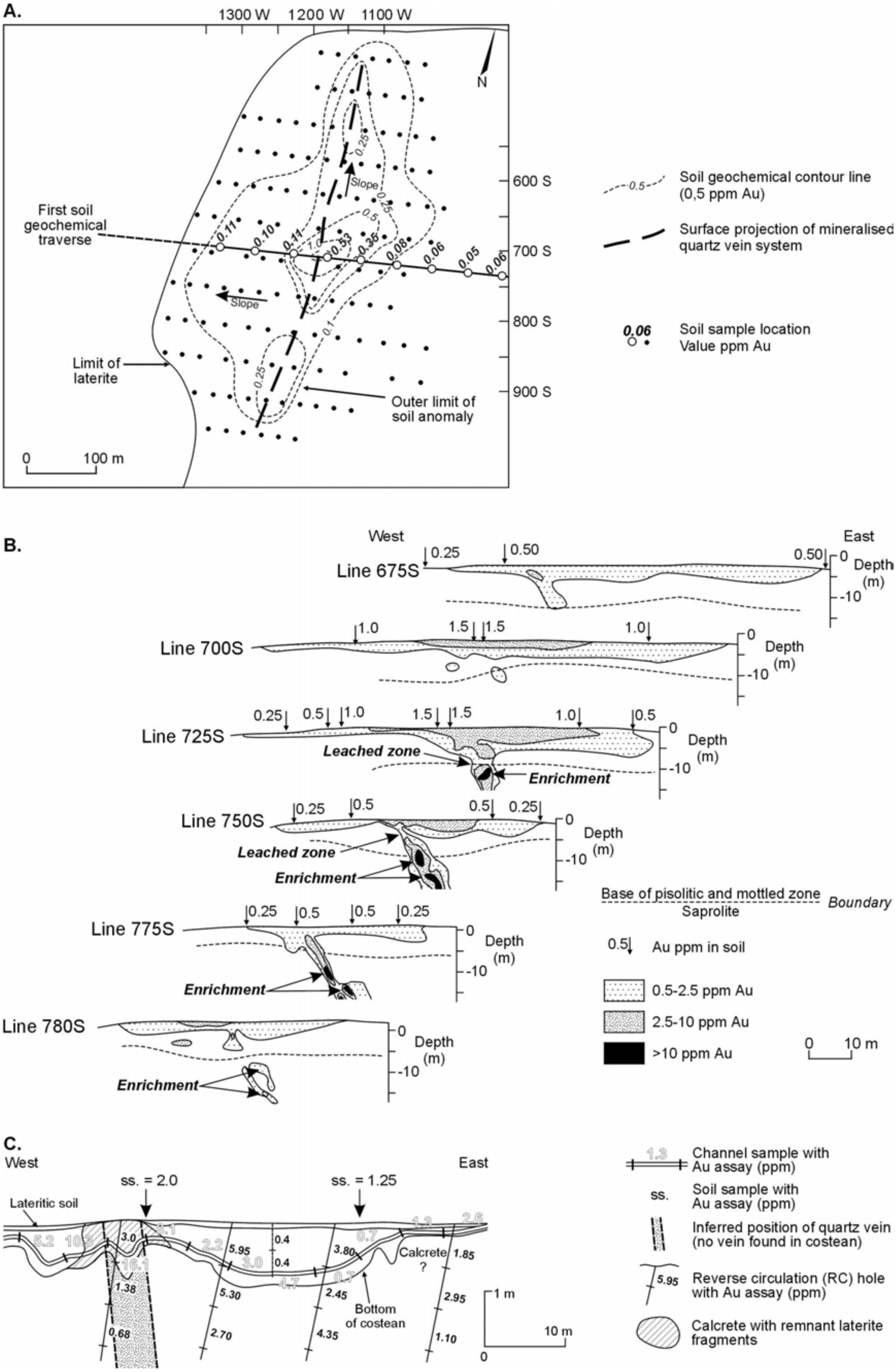

Figure 6.7: Geochemistry of the Callion Gold Deposit (after Butt 1992, Glasson *et al.* 1988). A) Plan of Au anomaly and location of soil traverses. B) Sections through the main ore body showing dispersion of Au to form an anomaly in the calcrete. C) Section through trench over main ore shoot.

Although dispersion processes generally dilute the tenor of anomalies, Au concentrations in calcrete associated with lateritic residuum at Callion are still high enough to assist exploration by providing a larger target.

6.2.3.2 Pedolith or saprolith host (Type B)

These examples include sites where there are thin (<2 m thick) predominantly residual soils developed directly on mottled zone, saprolite or above saprock where lateritic residuum (if ever developed) is not present.

(4) Mararoa Reef, Norseman, WA. (Smith and Keele 1984, Butt 1992)
The effects of dilution by calcrete, sand or clastic material (aeolian or colluvial) may be reduced by data manipulation. For example, analytical data for As may be adjusted according to variations in Fe content because As is generally concentrated in ferruginous material. At Norseman, WA, As- and Au-bearing quartz reefs occur in shear zones cross-cutting an Archaean greenstone belt. Smith and Keele (1984) showed that the geochemical expression of known mineralisation could be distinguished in the calcrete-rich surface (0-1 m) horizon by normalising As data with respect to Fe (Figure 6.8A). However, such normalisation may be neither applicable nor necessary if As dispersion is still active, for in calcareous soils, it may be trapped by carbonates rather than Fe oxides (Frick 1985). At Mararoa, Au is concentrated in surficial material (probably calcareous, see Figure 6.8B), with maximum values (>30 ppb) directly over the mineralisation itself, rather than over the barren subcrop of the shear, so there is actually no need to sample the ferruginous material for As (Figure 6.8A). Smith and Keele (1984) recommend that samples should be taken from a common horizon of in situ material below the highly calcareous horizon; this may be appropriate for collecting Fe-rich material for As determination but is in contrast to other work from this area (e.g Higginsville case study) that indicates it is the carbonate horizon that should be sampled and analysed for Au.

(5) Bounty, Southern Cross, WA. (Lintern 1989, Lintern *et al.* 1990)
The first study ever to demonstrate the strong correlation between Au and carbonate was commenced at the Bounty Gold Mine area in 1988, prior to mining activity. The Bounty Gold Mine is located about 440 km E of Perth (WA). The major landform of the area is a series of undulating plains averaging about 440 m ASL with about 50 m of relief. The principal mineralised zone (Bounty Zone) is situated on the eastern flank of a broad gently sloping hill. Drainage is poor but generally E from the Bounty Zone to a broad valley about 400 m away, where it drains gently N and E for approximately 10 km into a salt lake system. The climate is semi-arid with an estimated annual average rainfall (falling mostly in the winter) of 400 mm.

The nature and density of the vegetation is largely controlled by the two main soil types (see below) and topographic location, and consists of a mosaic of distinctive plant communities. Over the calcareous clay soils, sclerophyll woodland is dominant consisting of a eucalypt canopy (up to 10 m in height) with locally larger salmon gum (*Eucalyptus salmonophloia*), and a lower and semi-continuous shrubby horizon up to 1-2 m in height where tea-tree (*Melaleuca*) is prominent. In lower-lying areas to the N of the Bounty Zone, eucalypts are mainly of a mallee form (up to 4 m in height) with a sparse understorey. Vegetation controlled by lateritic soils is also of two forms, namely scrub heath consisting of vegetation no more than a metre in height characterising an area to the NW of the Bounty Zone, and broombush thicket consisting of a mixture of very dense *Acacia*, *Casuarina*, *Hakea* and minor mallee *Eucalyptus* up to 4 m in height growing over the southern portion of the Bounty Zone.

The Bounty Gold Deposit is situated in the Forrestania Greenstone Belt, the southern extension of the Southern Cross Greenstone Belt (Chin *et al.* 1982). According to Smith (1987), Au mineralisation at Bounty is hosted by a steeply dipping, semi-conformable shear system near the contact of a mafic intrusive and a komatiitic flow sequence. Mineralisation cropped out with no obvious leached zone. The main area of interest, the Bounty Zone, has an ore reserve of 5.6 Mt grading 4.6 g/t (Maxey 1997). Mining of the site commenced in late 1988 and is continuing.

Soils in the vicinity of the Bounty Zone fall into two broad types:

1) Calcareous clay soils are developed within a heavy red clay loam consisting of an almost homogeneous material (both in colour and texture) with gravelly ironstones (ferruginous granules a few mm in diameter). Additional features include a veneer of organic litter and the presence of

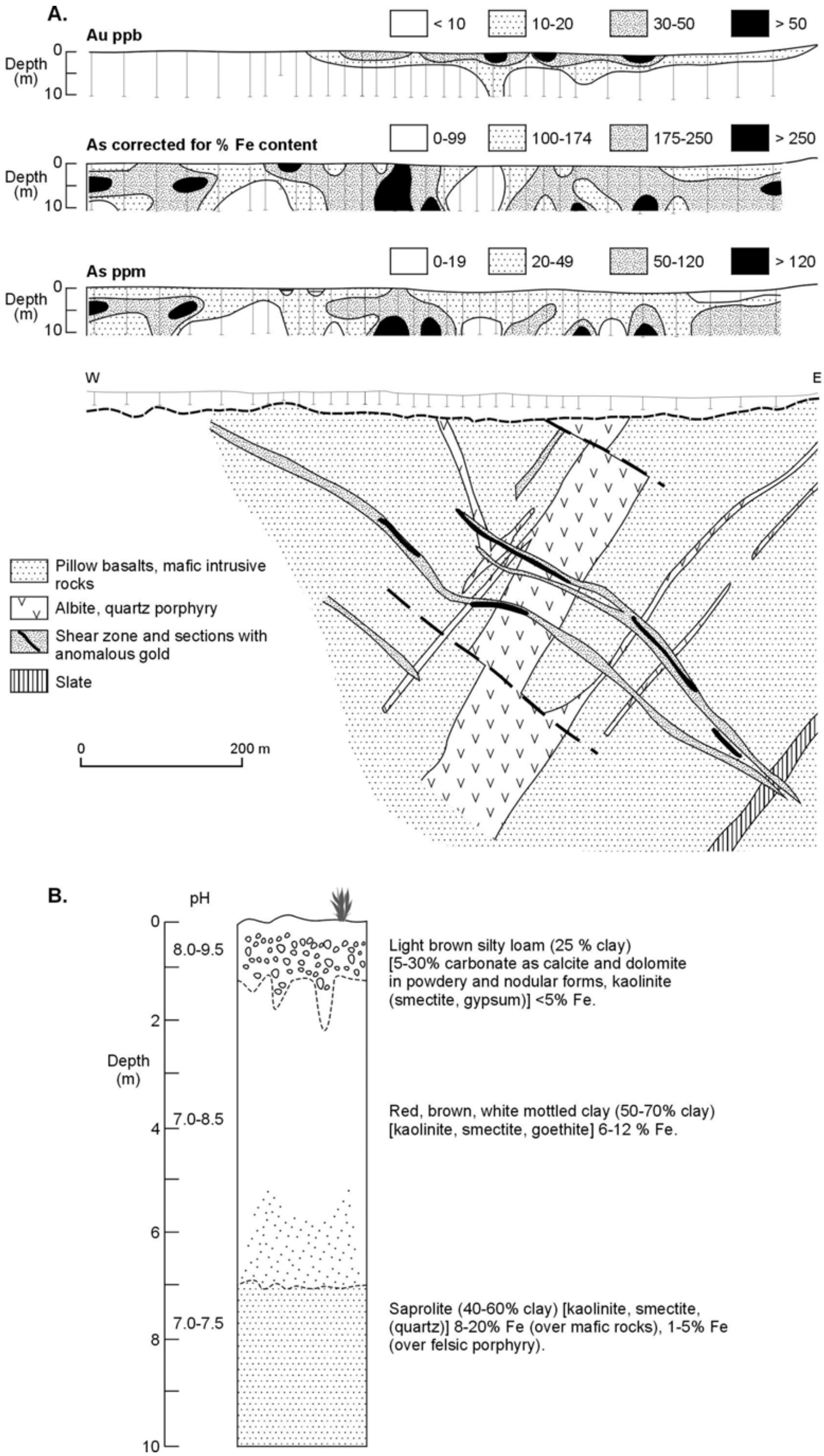

Figure 6.8: A) Distributions of Au and As above mineralisation in section at the Mararoa Reef. B) A regolith profile over the Mararoa Reef showing location of calcareous material above mottled clays. (After Smith and Keele 1984).

sheetwash containing sand and minor rock fragments mainly of quartz. Near the surface, and contained usually within the top 2 m, is a prominent horizon of frequently lighter coloured, friable to nodular clay-rich material composed of kaolinite, calcite and dolomite. Invariably the calcite occurs above the dolomite to form a continuous carbonate horizon.

2) Gravelly, lateritic soil profiles consist of yellow mottled (goethitic) nodular ferruginous material with zones of induration and loosely agglomerated material. Ferruginous nodules vary in size but are generally less than 30 mm in diameter. Decaying vegetation litter overlying sandy material (as for calcareous clay soils) occurs at the surface. There is little carbonate in the lateritic soils, although they are often located adjacent to calcareous clay soils.

The study consisted of (i) the multi-element analysis of 1060 augered samples from ~0-1 m, (ii) the excavation, description and geochemistry of 7 soil pits and (iii) the construction of a regolith-landform map of the area. The northern part of the study area is shown in Figure 6.9A. The highest Au concentration in the augered samples (1020 ppb) occurs directly over the main Bounty Zone. Gold and carbonate are highly correlated vertically within the soil profile. There is an anomalous plume of Au from the Bounty Zone downslope (Figure 6.9C). Where there are thin transported sands (<0.2 m) overlying the red clays (duplex soils), the calcrete and Au are located slightly deeper in the soil profile (Figure 6.9B, profiles 6 and 7). Whereas there is excellent vertical agreement between Au and the alkaline earth metals as demonstrated by the soil profile data, the correlation is not apparent in a lateral sense when the augered sample geochemistry is plotted along a traverse (Figure 6.9D); obviously not all the calcrete is equally rich in Ca and Au. (Profile 4 was collected on the edge of remnant calcrete-poor lateritic residuum, which would explain the low Ca and Mg contents reported for the corresponding augered samples).

The studies conclusively demonstrated that Au has being mobilised hydromorphically, since the alkaline earth metals and Au are highly correlated (Figure 6.9B). In conclusion, auger sampling is clearly successful in collecting the Au-rich calcrete horizon.

(6) Runway, Kalgoorlie, WA. (Lintern 1996a)

The Runway prospect is located ~10 km N of Kalgoorlie in the Archaean Wiluna-Norseman greenstone belt. The deposit is hosted by sedimentary rocks of the Black Flag Group that dip steeply to the W, and trend N-S. The lithology is comprised of four EW orientated units: volcanic sandstone, interbedded conglomerate-sandstone, black shales and siltstones, and massive sandstone. Runway is situated on a flat plain with areas of sub-cropping saprolite. The climate is semi-arid with average annual rainfall of 280 mm. Vegetation consists of open eucalypt woodland over residual terrain, and small shrubs including bluebush dominate depositional areas.

Mineralisation at Runway occurs as a thin, sub-horizontal zone of supergene Au enrichment close to the weathering front, beneath 50 m of leached or barren saprolite (Figure 6.10A). Primary mineralisation occurs as sporadic, narrow quartz veins. Minor sulphides, including pyrite, arsenopyrite, sphalerite and galena, are present and As, Ag, Cu, Zn and Pb are associated with Au mineralisation. The veins appear to be generally restricted to the interbedded conglomerate-sandstone unit, which exhibits pervasive carbonate-sericite alteration and disseminated pyrite and arsenopyrite.

The saprolite at Runway is thinly covered by semi-residual, calcareous, red, sandy clay soils. The saprolite is within 1 m of the surface in places. Reddish-brown sandy clay extends from the surface to about 0.25 m depth, and contains small (to 10 mm) carbonate nodules. Orange silty sandy clays are present between 0.25-1 m and contain carbonate nodules of varying size, but becoming smaller (<1 cm) with depth. Calcareous, orange and yellow, clayey silt, at 1-2 m depth has friable lithic nodules derived from underlying saprolite.

A geochemical study of the near surface (0-1 m) was undertaken at the Runway prospect (Lintern 1996a; Figure 6.10A). The study was concentrated adjacent to a geochemically anomalous area in Au (maximum of 270 ppb) outlined by an earlier survey of the 0.3-1.3 m interval. In both studies, regolith material (principally calcareous soil) was sampled by augering on an EW traverse over the thinly covered mineralised basement. In the follow-up study, Au (maximum of 0.094 ppm), As (405 ppm), Sb (8 ppm) and W (11 ppm) were anomalous compared to backgrounds of <0.01, <20, <1 and <2 ppm respectively (Figure 6.10C). Over mineralisation, samples below 0.5 m were moderately more concentrated in Au and carbonate compared with samples above 0.5 m. A soil profile directly over mineralisation was analysed to a depth of 2 m. Here, there is a weak association between Au, Ca and

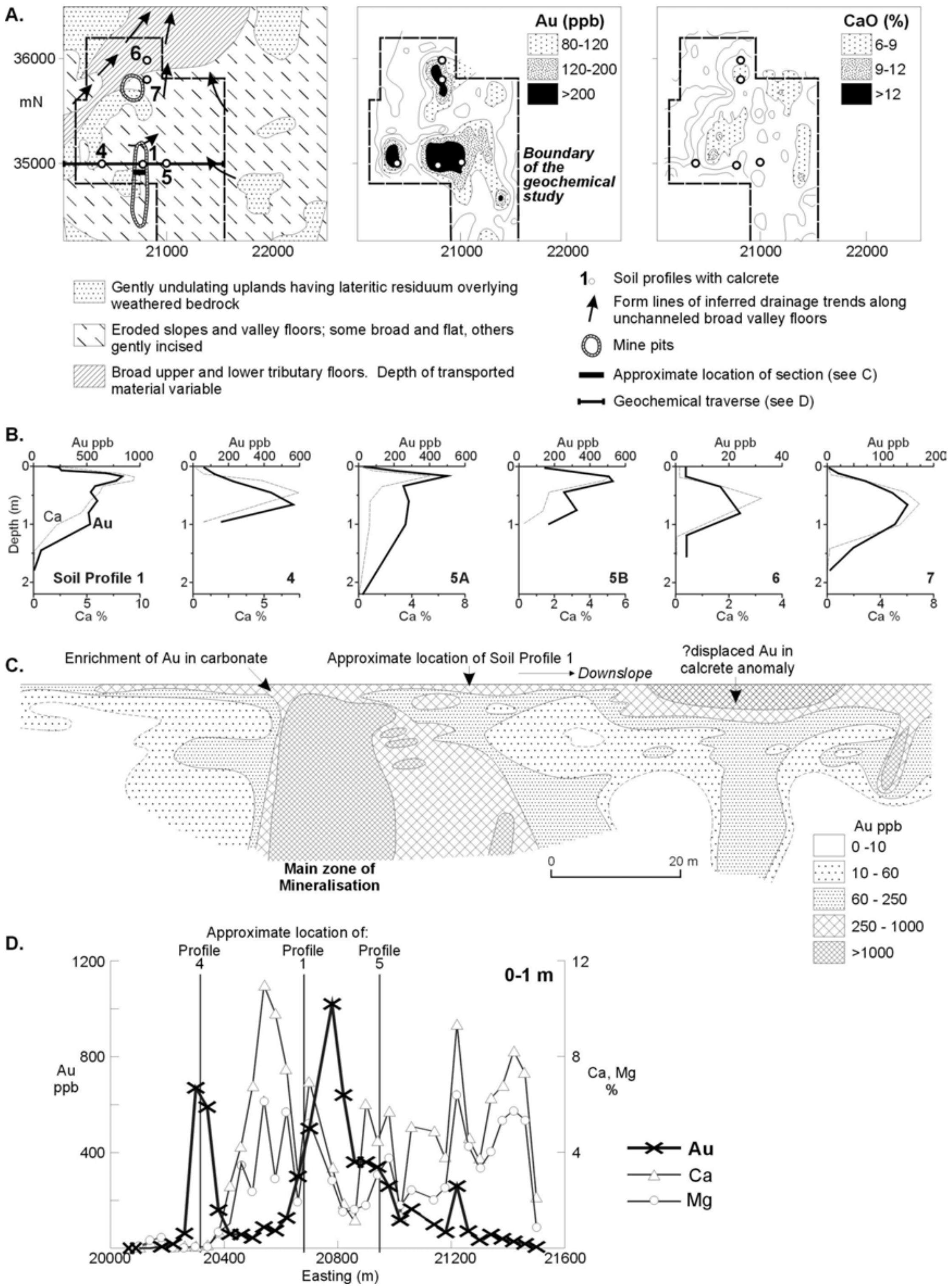

Figure 6.9: Geochemistry and regolith-landforms at Bounty. A) Regolith landform map and geochemical distributions around the Bounty mine pits. B) Geochemical profiles from several soil pits. C) Distribution of Au in the top 20-30 m across the Bounty mineralisation (after Smith 1987). D) Geochemical traverse from drill cuttings prior to the excavation of the Bounty Pit.

Mg in the top 1.3 m, but the highest Au concentrations (80 ppb) and the least Ca and Mg are found below 1.5 m (Figure 6.10B). Highly anomalous concentrations of As (2700 ppm), Sb (42 ppm) and W (45 ppm) are present between 1.75-2.00 m.

The coarse fraction (>1 mm) from three soil samples taken from over mineralisation was sub-divided into five components: calcareous nodules, green lithic fragments, assorted saprolite / mottled zone

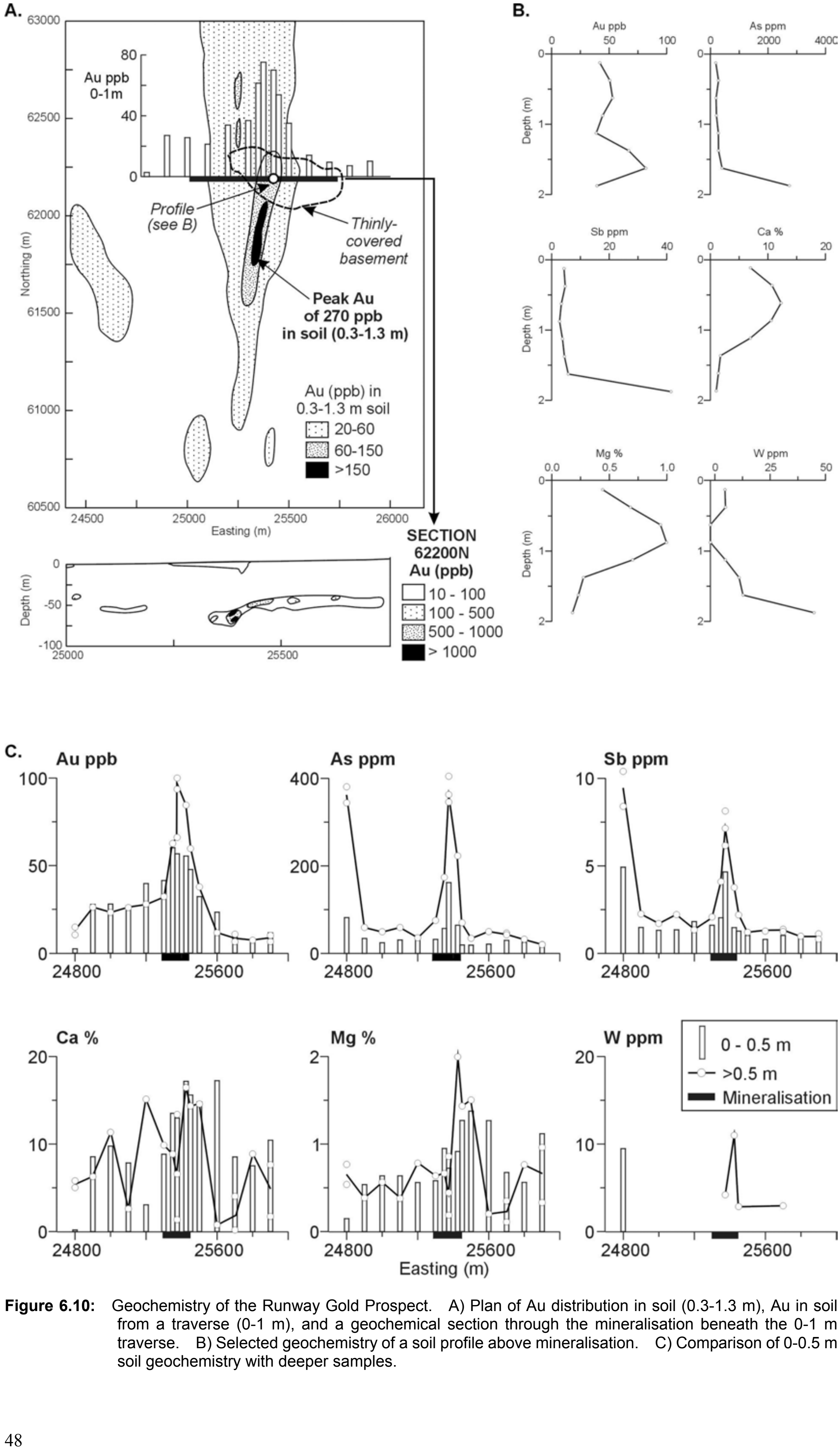

Figure 6.10: Geochemistry of the Runway Gold Prospect. A) Plan of Au distribution in soil (0.3-1.3 m), Au in soil from a traverse (0-1 m), and a geochemical section through the mineralisation beneath the 0-1 m traverse. B) Selected geochemistry of a soil profile above mineralisation. C) Comparison of 0-0.5 m soil geochemistry with deeper samples.

fragments, ferruginous saprolite, and magnetic ferruginous granules. Gold occurs in each, with the highest concentrations in the calcareous fraction (>500 ppb) and in the ferruginous granules (295 ppb).

The study demonstrates that although Au appears to be associated with carbonate in the soil, and would be effective to sample to delineate mineralisation, the probable immediate source of the Au in calcrete anomaly is relict grains of Au occurring in the saprolite. In addition, it study demonstrates that Au can still be found above mineralisation in soils developed over significant thicknesses (>40 m) of Au-poor saprolite.

(7) Lights of Israel, Davyhurst, WA. (Robertson and Tenhaeff 1992)
The Lights of Israel Gold Deposit is located about 100 km NE of Kalgoorlie (near Davyhurst). Biotite schist within metabasalt hosts mineralisation. Pre-production ore reserves of 415000 tonnes at 4.2 g/t were outlined (Hellsten *et al.* 1990). Full-scale underground production began in 1996 and was forecast to initially produce 40000 oz from 400000 tpa. The deposit is located beneath eucalypt woodland S of the Menzies Line. The weathering profile has been truncated to the mottled zone or lower. Carbonate skins cover blocks of saprolite in places. The stratigraphy of the top 2 m of the regolith showing the position of the carbonate is shown in Figure 6.11D. A limited geochemical study was undertaken at Lights of Israel mainly restricted to a traverse across mineralisation (Figure 6.11A). Gold showed the best indications of mineralisation in soils with significant anomalies (400-700 ppb) developed in a regional background of 5-7 ppb and a local background of 33-120 ppb (Figure 6.11B). The <4 (m fraction has the highest Au concentrations (750 ppb) but lesser, similar anomalies (peaking at 400 ppb) from the <75 (m fraction and the complete soil (Figure 6.11C) were found. Gold was strongly correlated with Ca in the <4 (m fraction demonstrating that much of the Au was finely dispersed. Normalising with respect to Ca content removed some of the apparently spurious anomalies to the W of mineralisation (Figure 6.11B).

(8) Challenger, Gawler Craton, SA. (Lintern and Sheard 1998)
The Challenger Gold Deposit is located in the northern Gawler Craton 750 km NW of Adelaide (SA). It was discovered in 1995 as a direct result of calcrete sampling. Calcrete is almost ubiquitous in southern SA as a variably indurated horizon up to 1 or 2 m thick just beneath the surface. It is easily sampled by digging a shallow hole and using a crowbar or a pick to remove the preferred nodular-laminar material.

The climate of the Challenger area is semi-arid with an annual rainfall of <200 mm. Vegetation consists of chenopod-dominated shrublands, with scattered open woodland groves of *Acacia*. The landscape is very subdued and consists of low rises, sand spreads and dunes, gibber plains, silcrete outcrops and ephemeral drainages. The palaeolandscape of the northern and western parts of the Gawler Craton appears to be similar to the Yilgarn Craton, as investigations have revealed a series of palaeochannel drainages in-filled with Cainozoic and earlier sediments that drain into the Eucla Basin.

The bedrock is a garnet-rich paragneiss consisting of plagioclase, perthitic K-feldspar, quartz, cordierite, garnet and biotite. Mineralisation is associated with silica and arsenopyrite alteration. Mineralisation occurs over a strike length >250 m and to a vertical depth >450 m. The high-grade ore shoots plunge 30^{o} at 030^{o}. Structural studies indicate that the plunge is defined by a megascopic fold closure in the gneissic foliation.

The near-surface regolith consists of variably silicified and calcreted units with underlying clays. The calcrete occurs as in several forms including coatings on sand grains (soil), laminar, massive and nodular. In adjacent areas, up to several tens of metres of variably silicified clays comprise a transported overburden which themselves overlie a deeply weathered basement profile truncated to the saprolith (Figure 6.12C). The regolith in the mineralised zone consists of a deeply-weathered profile truncated in the saprolith.

A broad Au anomaly (>5 ppb, >4 sq km) is present in the calcrete overlying the Challenger mineralisation (Figure 6.12A). This was outlined from a regional survey based on a 1.6 km square grid with a peak Au concentration of 180 ppb. Importantly, if calcrete had been sampled a few metres E or W the Au concentration would have been an order of magnitude smaller and the anomaly downgraded in importance. A later, detailed geochemical survey of calcrete revealed the full extent of the anomaly, which included a maximum concentration of 620 ppb Au. The recent investigation by Lintern and Sheard (1998) of the geochemistry of calcretes and other regolith materials along a NW-SE

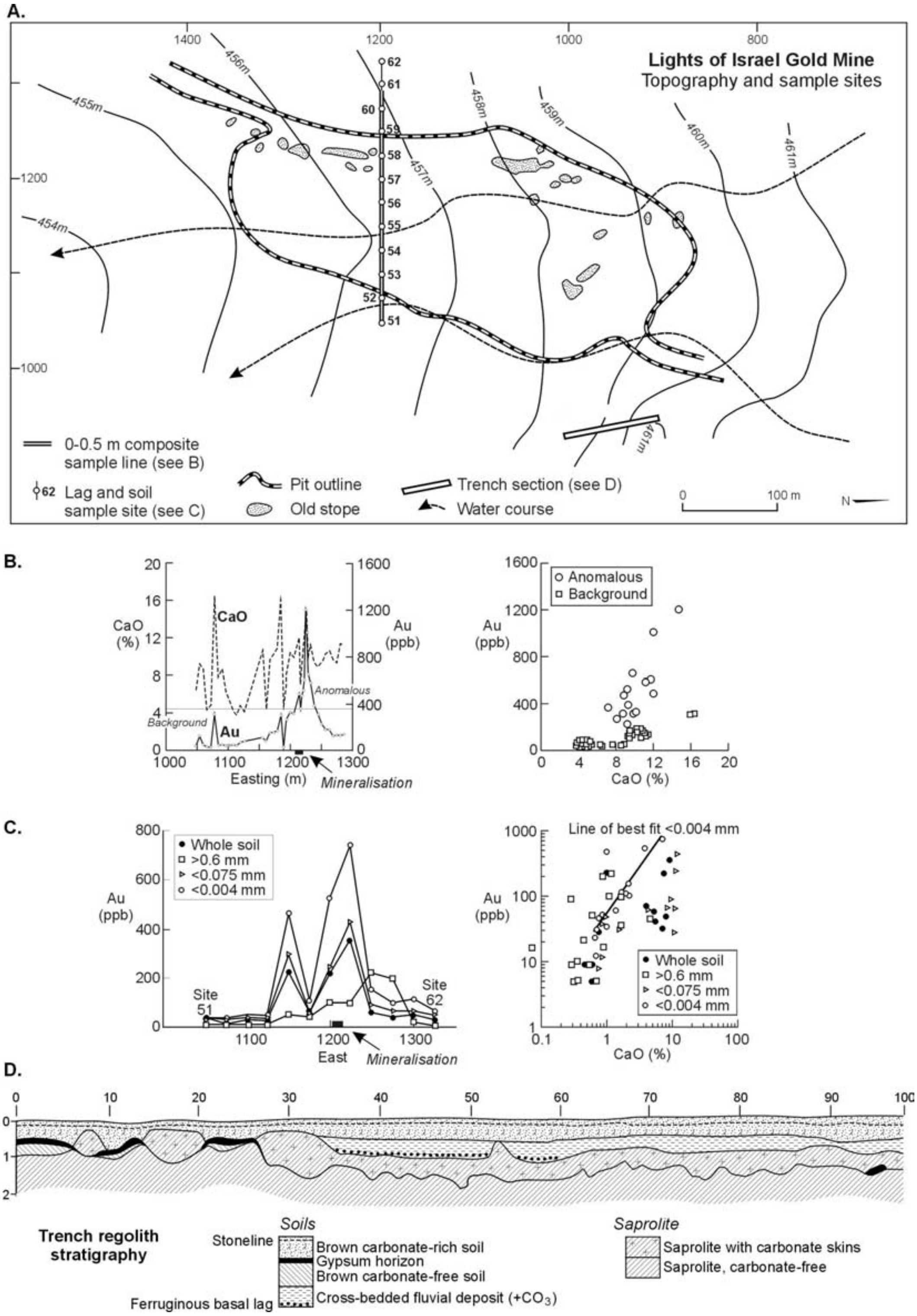

Figure 6.11: Geochemistry and regolith at the Lights of Israel Gold Deposit (after Roberston and Tenhaeff 1992). A) Plan showing topography and location of sampling points. B) Gold and Ca concentrations of 0-0.5 m composite soils across mineralisation and scatter plot showing broad association between the two elements. C) Soil size fractionation geochemical study and scatter plot of Ca and Au data.

traverse across mineralisation, reported a concentration of 2370 ppb Au in calcrete directly overlying the main mineralised Zone 1 (Figure 6.12C). Such high concentrations of Au are indicative of mineralised saprolite or native Au within the calcrete sample. The process of calcrete replacement and displacement has all but destroyed the host saprolite minerals and fabrics. However, in soil pits above mineralisation (GCP121-123) quartz veining extending within a few cms of the surface was observed. Gold concentrations as high as 100 ppm were recorded in material from 2 m in pit GCP122. East of the main lode, the presence of 20 m thick transported overburden appears to prevent any significant Au appearing in the surficial calcrete. However, the soil pit above mineralisation here (Zone 3, GCP106) indicates anomalous Au (>15 ppb) associated with sub-surface calcrete and requires further investigation (Figure 6.12B). There is a broad association between Au and Ca in the soil pits but this disappears where high Au grades associated with quartz veins occur.

The Challenger Deposit is the largest deposit found specifically using calcrete as a sampling medium although many more prospects have been located in the vicinity including ET, Tunkillia, South Hilga, Golf Bore, Birthday, Myall, Sheoak and Campfire Bore. South Australia was the scene of frenzied activity in the mid to late 1990s by exploration companies using calcrete.

6.2.3.3 Transported overburden host (Type T)

Exploration in areas of transported cover using surficial materials has been investigated at many sites. The advent of calcrete as a sampling medium provided another avenue to investigate the possibility of using surficial materials as a cheap and effective technique to explore in this type of terrain. In this context, transported overburden includes locations where the depth of transported material is in excess of a nominal 2 m and commonly considerably more; calcrete developed in thin cover often contains material derived from underlying saprolite or other residual units from pedological processes such as bioturbation. Type T also includes deposits concealed or hosted by palaeochannels which characterise ancient landscapes including many regions of Australia, e.g. the Gawler and Yilgarn Cratons. Typically the cover is Cainozoic in age for most of the case studies discussed. As more data has become available, it has become apparent that with many Type T case studies (including many of those that follow), a simple transect is normally insufficient to validate whether an anomaly developed in soil or calcrete is derived from the underlying buried mineralisation or from downslope dispersion from outcrop (Type A, B or C). Ideally, case studies require detailed four-dimensional information-encompassing factors such as regolith characterisation, landscape evolution, topography, and a study of the soils themselves.

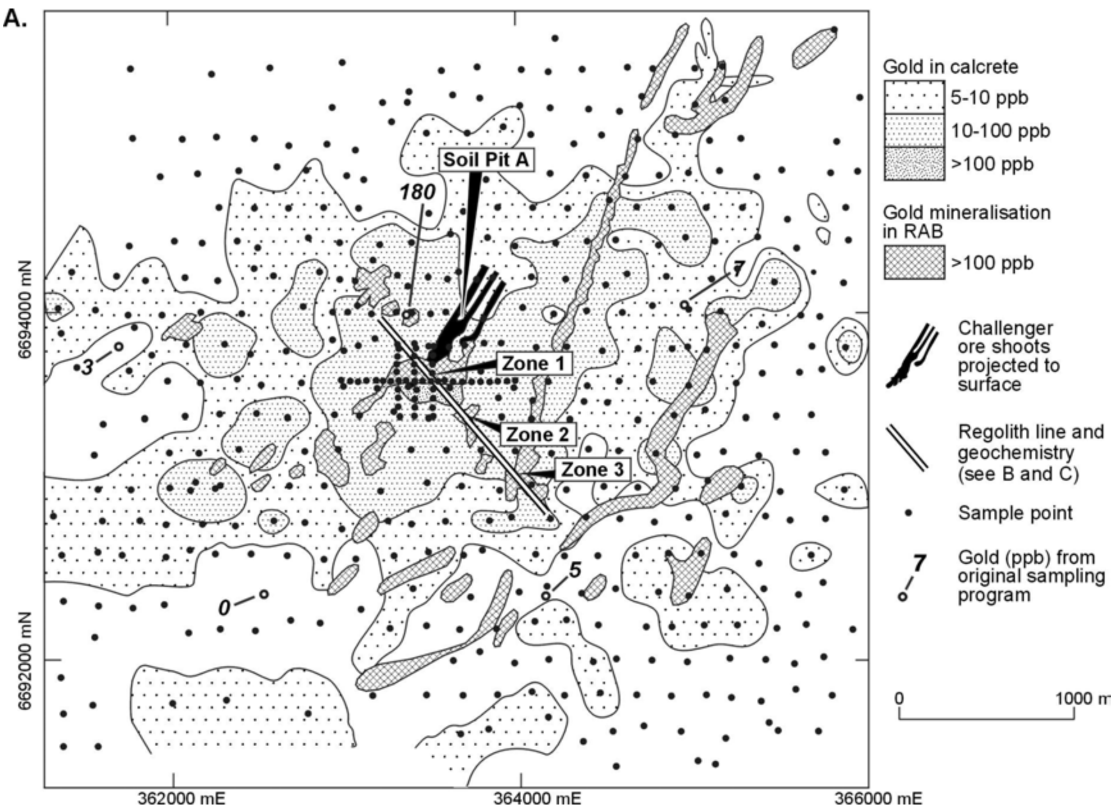

Figure 6.12: Geochemistry and regolith at the Challenger Gold Deposit. A) Plan showing Au in relation to calcrete distribution, mineralisation and the sampling line.

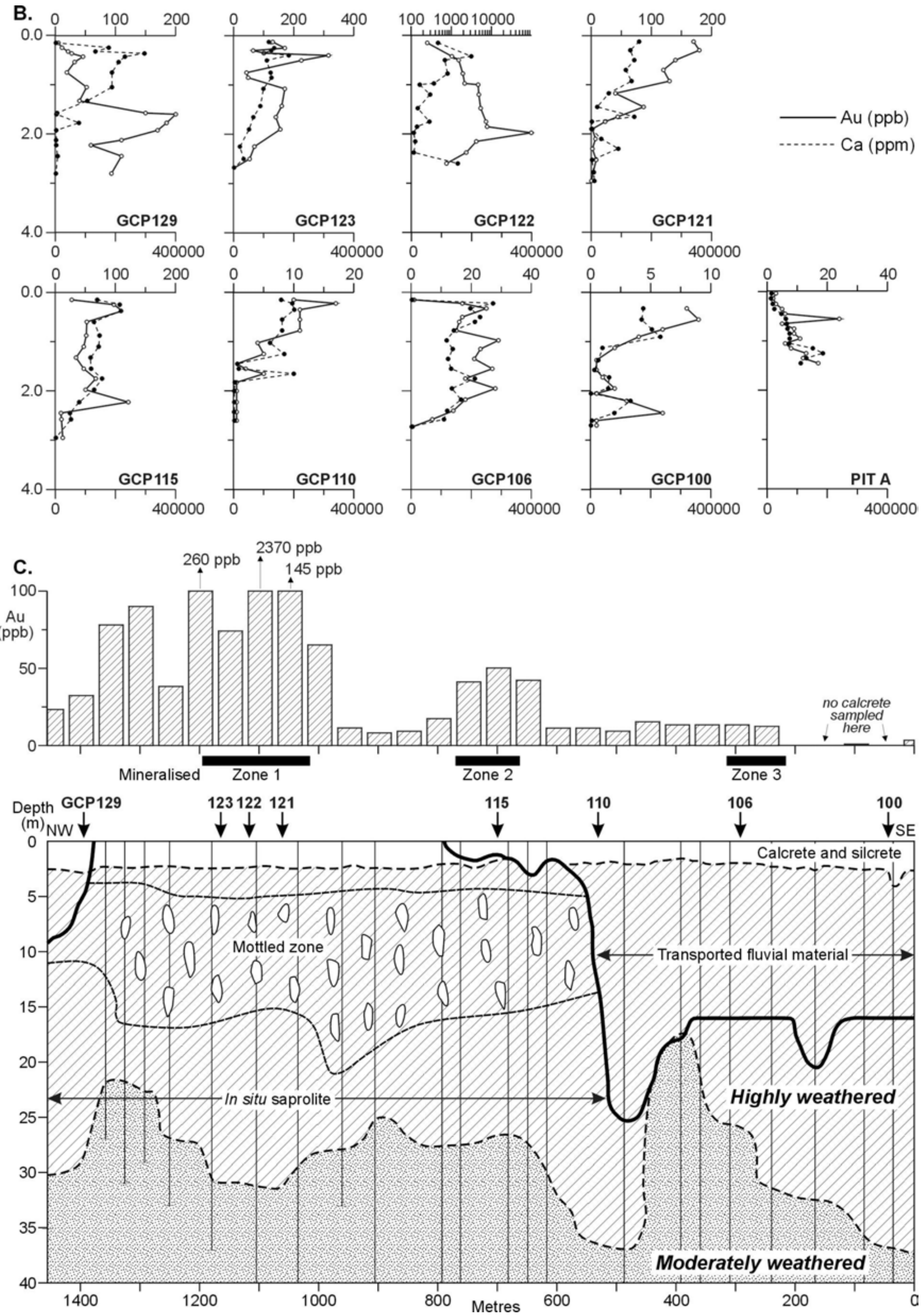

Figure 6.12 (continued): Geochemistry and regolith at the Challenger Gold Deposit. B) Soil profiles (position indicated in C) from along the sampling line. C) Gold in calcrete from the sampling line with a section through the regolith beneath.

(9) Mt Pleasant, Kalgoorlie, WA (Lawrance 1988, Lawrance and Butt 1992).
The Golden Kilometre Gold Mine at Mt Pleasant is situated in relatively flat terrain in the Norseman-Wiluna Greenstone Belt, about 35 km NW of Kalgoorlie (Figure 6.13A). Climate is semi-arid with mean annual rainfall of 280 mm. Vegetation is typical of the Kalgoorlie area and consists of open eucalypt woodland with a sparse under-storey.

Gold mineralisation occurs in a quartz vein system and surrounding pyrite-rich calcite-muscovite alteration zones hosted by a differentiated layered gabbro (Figure 6.13C). The mineralised zone is 1.2 km long, 5.5 m thick and extends to at least 80 m depth. The estimated total reserve is 3 Mt averaging 3.2 g/t.

The presumed original lateritic profile over the deposit has been largely eroded and is overlain by 0.5 to 5 m of alluvial and colluvial sediments. The remaining residual profile extends to 30 m depth around the lode and, away from the mineralisation, fresh gabbro occurs at the unconformity. The surface slopes very gently towards the creek to the SE. The transported overburden consists of four units:

1) Soil (0.5-1.5 m thick). Composed of ferruginous clay-rich loam. Soil is commonly weakly cemented by carbonate minerals just below the surface.
2) Sandy lateritic gravels (0-1 m thick). A layered, unconsolidated horizon of lateritic gravels and quartz sand overlies the ferruginous clays. Gravels partly comprise sub-rounded ironstone pebbles and pisoliths, some weakly cemented by carbonate minerals. This horizon also contains rare rock fragments similar to those in the basal horizon, and quartz fragments, which become more common closer to the quartz veins of the lode.
3) Ferruginous clays (0-1 m thick). Lenses of red-brown ferruginous clay, containing lateritic pebbles.
4) Basal gravels and conglomerates (0-0.5 m thick). Clast-supported horizon composed of fluvial gravels and cobbles containing rounded to angular, coarse, polymictic lithofragments, quartz and ferruginous nodular and pisolitic material in a matrix of coarse quartz sand and red-brown clay.

Gold concentrations in the transported material at Mt Pleasant vary. Up to 420 ppb Au was found in samples collected at the unconformity with concentrations reaching only 10 ppb in the soil immediately above (Figure 6.13B). Coarse Au nuggets (2-6 mm in diameter), some with quartz, suggest there has been a net concentration of Au at the old land surface (now the unconformity) by deflation, although their low Ag contents compared with the lode Au suggest some chemical re-working.

Lawrance (1988) did not document the vertical distribution of Au or Ca in the soil profile in detail (Figure 6.13C). The broad association of Au within the soil may either be interpreted as hydromorphic dispersion directly from the unconformity or chemical re-working of coarse Au from the unconformity after being displaced either from upslope or vertically by bioturbation processes. In plan, the Au anomaly more or less directly overlies the mineralisation. The strike of the mineralisation is perpendicular to the presumed flow direction of the palaeo- and present drainages.

(10) Granny Smith, Laverton, WA (Lintern and Butt 1993)
The Granny Smith Gold Deposit is 25 km S of Laverton (about 250 km NW of Kalgoorlie, WA) and N of the Menzies Line. The land surface is essentially flat and consists of thin colluvium and alluvium (about 1-3 m thick) at 410 m above sea level, with two hills of BIF rising above the surrounding plain. Deep gullies drain the flanks of the higher hill (Figure 6.14B). Vegetation is open scrub (dense along creek lines) consisting primarily of mulga (*Acacia aneura*) with a sparse understorey of shrubs including *Cassia*, *Eromophila* and *Maireana*.

The deposit lies in a major structural corridor in which several other Au deposits are also located (Figure 6.14A). The depth to mineralisation varies but is generally about 5-20 m. The regional and local geology have been described by Hallberg (1983) and Hall and Holyland (1990) (Figure 6.14A). The measured, indicated and inferred resource are estimated to total 39.4 Mt at 1.6 ppm. Mineralisation comprises three ore zones, two of which are shown in section (Figure 6.14B):
1) Goanna. Mineralisation occurs in a shear zone trending NNW and dipping 50o E with a strike length of at least 1 km and thickness that varies between 5 and 20 m. The host rocks are sedimentary (including BIF), which are weathered to depths of up to 80 m.
2) Grannys. Located 1.5 km S of Goanna, mineralisation occurs as a shallow sub-horizontal blanket along the contact between a granodiorite intrusion and overlying sediments and rocks. The

contact is sheared and brecciated. The shear has a strike length of 600 m, is up to 500 m wide, 15 to 40 m thick and dips 25^{o} E. The depth of oxidation is highly variable, ranging from 10 to 80m. A higher-grade zone exists in the upper part of mineralisation.

3) Windich. Located 0.8 km S of Grannys, Windich is buried beneath at least 5 m of colluvium/alluvium. No investigations were undertaken here.

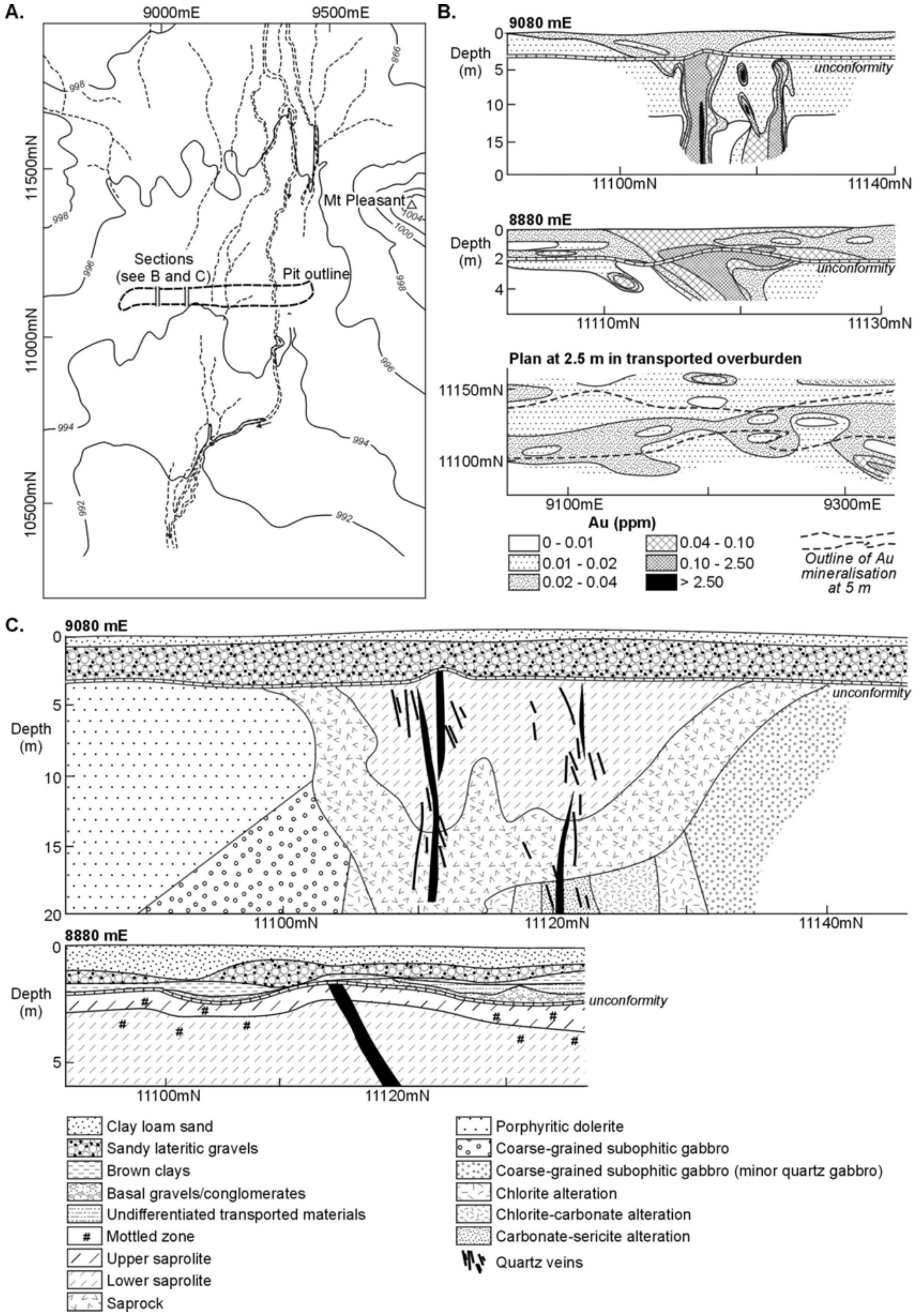

Figure 6.13: Geochemistry and regolith of the Mt Pleasant Gold Deposit (after Lawrance 1988). A) Plan showing drainage, location of open cut mine and sampling lines. B) Section showing distribution of Au in sampling lines. C) Section showing detailed geology for sampling lines.

Five upper regolith profiles were sampled from existing vehicle ramps into the Goanna and Grannys pits. They consist of three horizons, unconsolidated soil or topsoil, hardpan and brecciated saprolite:

1) Soil. Gravelly, unconsolidated, shallow, sandy, acidic (pH 4.6) colluvium varying in thickness from a few centimetres to nearly one metre. The gravels consist of coarse polymictic clasts, including BIF, ferruginous nodules and quartz.
2) Hardpan. Red-brown, indurated colluvium and residual clays several metres thick having a variable sub-texture consisting of laminated and blocky units with occasional friable silty-clay segregations. In the upper portion, manganiferous nodules and Mn staining are common. Calcareous segregations occur towards the base of the hardpan. The hardpan commonly grades into brecciated saprolite with depth.
3) Upper saprolite. This consists of sub-angular clasts of weathered bedrock in a groundmass of red-brown clays, locally mottled ochre, red and/or orange. The upper saprolite, to a depth of at least 9 m, is commonly calcareous. Carbonates (calcite) are dispersed through the clay-rich matrix as clasts and also form veins and segregations. The abundance of carbonate in the lower regolith is surprising, since usually it is found within the upper two metres of the surface, particularly S of the Menzies Line. The saprolite below 10 m was expected to be poor in secondary carbonate, as reported for other saprolites in the region.

Gold concentrations for each unit are described below and illustrated in Figure 6.14C:

1) Soil. The Au content of the soil varies from 3 to 18 ppb. The highest concentrations occur in profiles 5 and 6, and may be due to the inclusion of hardpan that is richer in Au, since the soil is very shallow in both these profiles. The unusually high Au contents in profile 3 (12 ppb) may be due to particulate Au from sub-cropping mineralisation shed from upslope, where visible Au was found (Figure 6.2). The strength of the anomaly in the soil is very weak considering that profile 6 was located only 20 m from sub-cropping mineralisation.
2) Hardpan. The highest Au concentrations occur in profile 6 (190 ppb at 1.25 m), which is close to sub-cropping mineralisation. In profiles 3, 4 and 6, the Au maxima are close to the base of the hardpan, whereas in profiles 1 and 5, the highest Au is in the upper part of the hardpan, with minor peaks lower down close to the saprolite.
3) Upper saprolite. The interface between the saprolite and the hardpan is not distinct, since the former becomes brecciated and is composed of sub-angular clasts (lithorelics) supported by a siliceous hardpan matrix. The highest Au contents of the saprolite occur closest to the contact with the hardpan and may be due to the presence of this material. The highest Au content of the saprolite occurs in profile 1 (80 ppb at 3.75 m).

The highest concentrations of Au in the upper horizons of the regolith at Granny Smith appear to be primarily related to the contact between transported and residual components of the soil profile; this commonly occurs towards the base of the hardpan and is coincident with a trend towards increasing pH. Soils have become acid as a result of leaching of cations from the upper part to the lower part of the profile. The soil and hardpan are acid, (minimum pH 4.6), whereas the upper saprolite is alkaline due to the precipitation of carbonate and other cations. Segregations of hardpan from the contact zone indicate that Au is present in lithorelics and the matrix of the hardpan, although most is found in the latter.

Most Ca (and calcite) occurs at the top of, or within, the saprolite horizon, dispersed throughout the clay-rich matrix and as veins and concretions. The above results indicate that the Au-Ca association is only weakly present, if at all, at Granny Smith, even though evidence for the association was specifically and critically investigated. Generally, Au and Ca do not follow the same pattern of mobilisation and precipitation as noted in the southern Yilgarn case studies and, therefore, the carbonates should not specifically be sought as an exploration sample medium. Pedogenic carbonate is, in general, uncommon N of the Menzies Line and it is uncertain whether its presence at Granny Smith is atypical for the region or different in origin to that in the S. The reasons for the differing behaviour of Au and Ca N and S of the Menzies Line may be due to the soil hydrology. The carbonate may well represent a transitional stage between pedogenic and groundwater forms present in the regolith.

This study indicates that prescriptions for geochemical exploration for Au in areas dominated by hardpan are more difficult than for areas S of the Menzies Line. The behaviour of Au in soils at Granny Smith should not be extrapolated to other sites that have hardpan development, since only five profiles were sampled. Nevertheless, sampling of hardpan at the contact between transported and

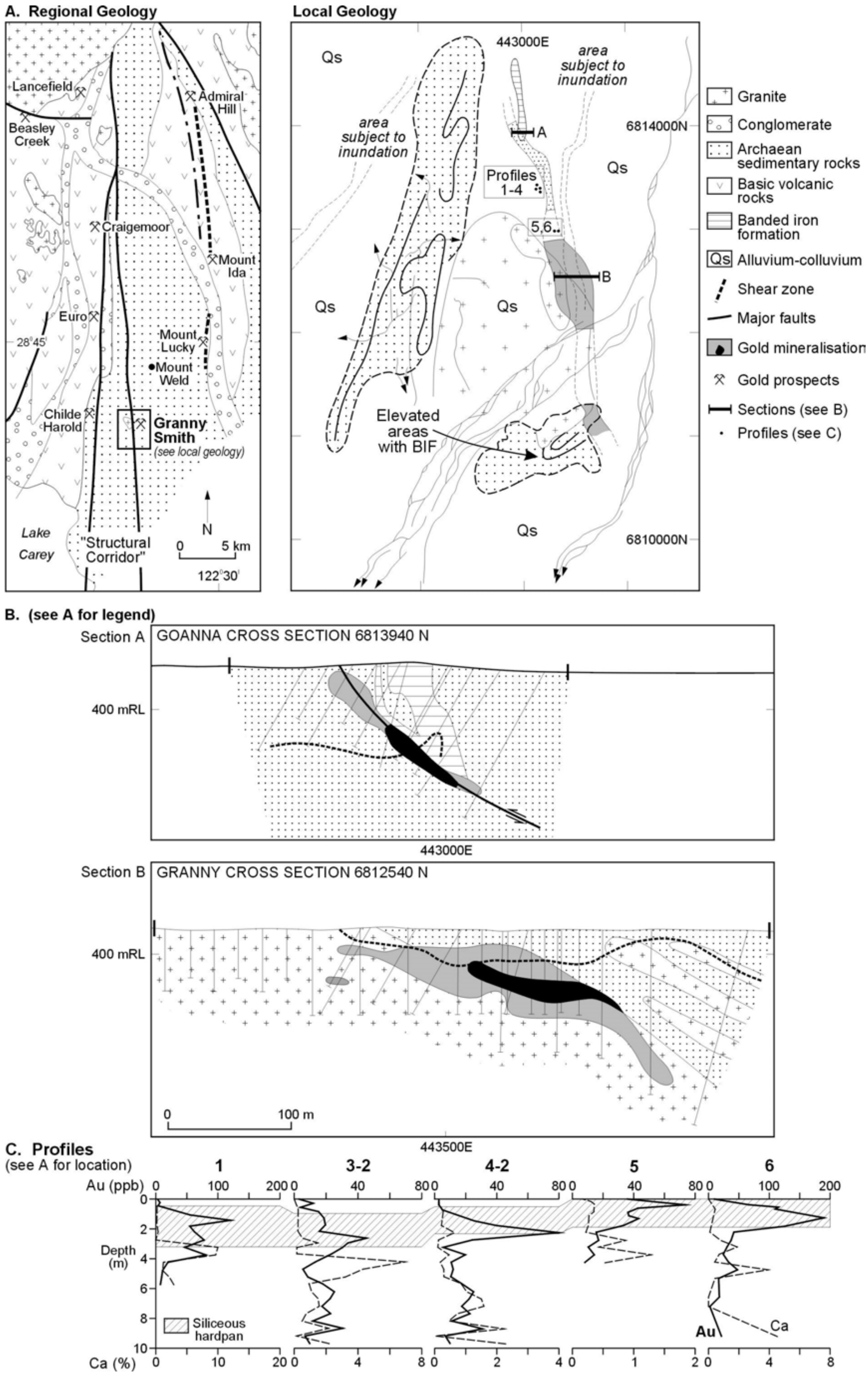

Figure 6.14: Gold distribution and regolith at the Granny Smith Gold Deposit. A) Regional and local geology (after Hallberg (1983) and Hall and Holyland (1990)). B) Sections A and B through mineralisation (see A for location). C) Geochemical profiles (see A for location).

residual components may have some general application. Furthermore, different Au-Ca characteristics may be exhibited where the hardpan is developed entirely within transported overburden, which itself may be 5-10 m thick and overlie leached saprolite.

(11) Wombola Gold Prospect, Kalgoorlie, WA (Anand *et al.* 1993)
The Wombola district is located in Archaean granite-greenstone terrain of the East Coolgardie Goldfield, about 50 km SE of Kalgoorlie. It consists of a lower unit of felsic volcanic rocks (rhyodacite, and minor basalt-andesite) overlain by a strongly deformed ultramafic-mafic sequence consisting predominantly serpentinised peridotite with subordinate gabbro, pyroxenite, felsic volcanic-volcaniclastic rocks and high Mg basalt (Ahmat *et al.* 1993). The local geology at the Wombola Gold Prospect consists of a thin belt of amphibolite, dolerite, shale, black shale and porphyry intrusions.

The Wombola district is characterised by low, rounded hills that grade gently into broad alluvial floors and salt lakes. The prospect is located in a colluvial outwash plain. The regolith stratigraphy consists of a mantle of fine to coarse polymictic lag comprising ferruginous granules and pebbles, quartz and carbonate, which overlies about 1 m of calcareous red soil with gravels and carbonate nodules. This, in turn, overlies 2 to 4 m of transported red clay with gravel. Below this is a truncated mottled zone 8 to 10 m deep with lenses of transported, loose pisoliths at the unconformity. Bleached saprolite lies beneath the mottled zone. Mineralisation occurs at 40 m depth.

A variety of near-surface regolith materials was sampled, including ferruginous pebbles, calcareous soil, loose pisoliths from the red soil, and hardened mottles from the saprolith. The highest concentration of Au is 440 ppb and occurs in one sample over mineralisation in the calcareous soil (0-1 m, Figure 6.15) there are no other data available to assist with the interpretation of the origin of the Au in the soil.

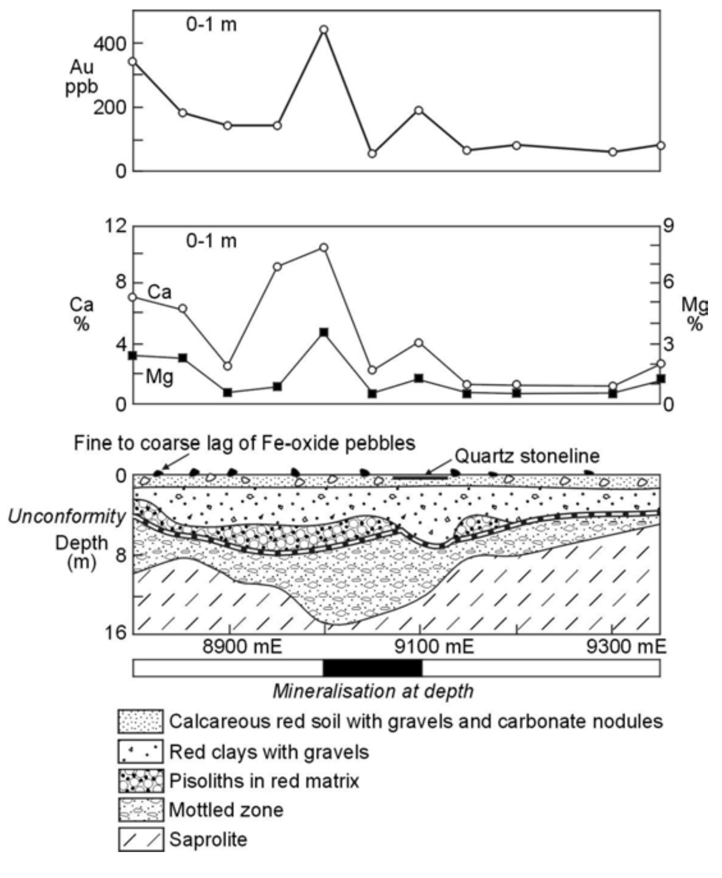

Figure 6.15: Regolith and Au distribution at the Wombola Gold Prospect (after Anand *et al.* 1993). The 0-1 m samples are drill cutting composites.

(12) Apollo, Kambalda, WA. (Lintern *et al.* 1997).
The Apollo Gold Prospect is located about 25 km SE of Kambalda, and about 500 m NE of the Argo

Gold Deposit. The two case studies illustrate the role played by thickness of overburden and depth to mineralisation, which are both greater at Argo. The climate is semi-arid with average annual rainfall of 280 mm. Vegetation is sparse and composed of open mixed woodland of *Eucalyptus*, rare *Casuarina* (she-oak), and small shrubs including *Eremophila* (poverty bush) and false bluebush (*Cratostylis conocephala*). The landscape is typical of the floodplains bordering the salt lake landscape regimes of the region. A broad colluvial plain with scarce clay pans drains the study area to the SW towards the salty and usually dry Lake Lefroy, where dunes cover large areas.

Apollo is located in the western limb of the St Ives Antiform, part of the Archaean Norseman-Wiluna belt of the Yilgarn Craton. The bedrock consists of the Paringa Basalt, the Black Flag Group and the Condenser Dolerite, all of which strike NE, dip 70-80^{o} SW and are weakly metamorphosed. The deposit is hosted within the Condenser Dolerite, a sill up to 400 m thick, which fractionated in situ to several zones. Gold mineralisation tends to have an affinity with a highly siliceous and Fe-rich zone. Mineralisation is encountered at about 15 m depth and can be traced down dip in excess of 760 m to the W. It is confined to bedrock and saprolite, and is associated with albite alteration products within two NNE-trending mylonitic shear zones.

The regolith is complex. Three principal sedimentary units cover the residual regolith and palaeochannel sediments in the Apollo area (Figure 6.16A). A sandy aeolian drift, generally 10 to 20 cm thick (but up to 2 m thick locally), covers a calcareous soil. It covers a calcareous clay-rich red clayey sand from 0.2-2.0 m depth, which contains a dark manganiferous horizon at ~1.5 m depth. The soil is characterised by locally abundant calcareous nodules 1-2 cm in diameter, some of which are coated rock fragments, (derived from outcrop located 1-2 km away). This covers an upper, partly calcareous red-brown sandy clay which can be further sub-divided. A unit of hard red and grey clays with variable ferruginous mottling covers the saprolite. This unit contains zones of indurated ferruginous and siliceous material, forming a cement (probably a palaeosol) of variable thickness, generally between 2-7 m depth. The residual regolith profile consists of variably coloured, dark, clay-rich saprolite. The saprolite is generally between 20-30 m thick, but is thinner beneath palaeochannel sediments which are incised into the residual regolith 250 m to the S of the Apollo prospect, cuts across the nearby Argo deposit in an approximate EW orientation. The palaeochannel has a maximum depth of 60 m and average width of 400 m.

The results from a variety of samples are variable:

(i) The mean Au content of the calcareous sandy clay (0-1 m and 1.3-1.8 m composite samples) from mineralised areas (9 ppb) and background areas (11 ppb) is similar.

(ii) Gold and carbonate appear to be weakly associated in 0-1 m composite samples (Figure 6.16D). Limited data from two soil profiles near Apollo, one from over mineralisation (L) and one from background (M) (Figure 6.16C), suggest marginally higher Au contents over the former.

(iii) For both profiles, the highest Au concentrations occur between 0.5-0.8 m and there is only a weak association between Au and Ca; profile samples from 0.0-0.1 m (Figure 6.16C) are below detection (<5 ppb).

(iv) Beneath the top 2 m of sediments and upper (ferruginous) saprolite there is a zone poor in Au (<10 ppb). However, Au contents of mineralised deeper saprolite exceed 500 ppb.

(v) For 0.05-0.15 m soils, Au was anomalous (>10 ppb) but not related to carbonate above mineralisation (Figure 6.16B).

(vi) Deeper grab samples (up to 0.8 m depth) taken from shallow soil pits over mineralisation were richer in Au compared to the surface soils (up to 37 ppb) but were not related to carbonate.

Interpretation of the geochemical results for Au is equivocal. Although there is some suggestion that higher Au concentrations in the soil may be related to shallowly buried mineralisation, on a broader local scale (including Argo), these results do not appear to be significant. Augering the top 1-2 m is the best practical sampling technique for collection of the calcrete, although this, in itself, is not effective in detecting mineralisation in this environment. The presence of recently deposited and variably thick sandy material in the Apollo area makes it difficult to locate the calcrete.

(13) Argo, Kambalda, WA (Lintern and Gray 1995b)

General information on the location, climate, vegetation and mineralisation of the Argo Gold Deposit is given in the Apollo case study. Argo is located about 500 m SW of the Apollo prospect and has thicker overburden and greater depth to mineralisation than the latter. The Argo deposit is situated on the side of an EW palaeochannel, which has a maximum depth of 60 m and average width of 400 m. The channel has been incised into a residual regolith profile of variably coloured, clay-rich saprolite. The saprolite is generally 20-30 m thick, but is thinner beneath the palaeochannel. As with Apollo, the Archaean stratigraphy has been blanketed by transported material. Primary and secondary mineralisation is confined to bedrock, saprolite and the unconformity between these and the transported material, where it appears to follow the palaeotopography downslope and along the base of the palaeochannel (Figure 6.16A). Hence, the depth to mineralisation is variable but generally commences at the Archaean-Tertiary unconformity (20-30 m depth), deepens laterally and is continuous to the base of the adjacent palaeochannel.

Seven sedimentary units infill the palaeochannel, the upper three of which appear to blanket the entire region and are as at Apollo: a red and grey clay, a clayey sand and a sandy drift, with the latter two units being variably calcareous. The four units confined to the palaeochannel consist of mottled lacustrine clays (10 m thick), consisting of kaolinite and quartz, with secondary accumulations of goethite and hematite. These overlay approximately 15 m of spongolite, consisting of pale silts and siliceous sponge spicules, about 30 m of grey clays containing carbonaceous woody fragments and lignite and, finally, a basal unit of fluvial gravels, sand and lignitic silts, up to 16 m thick.

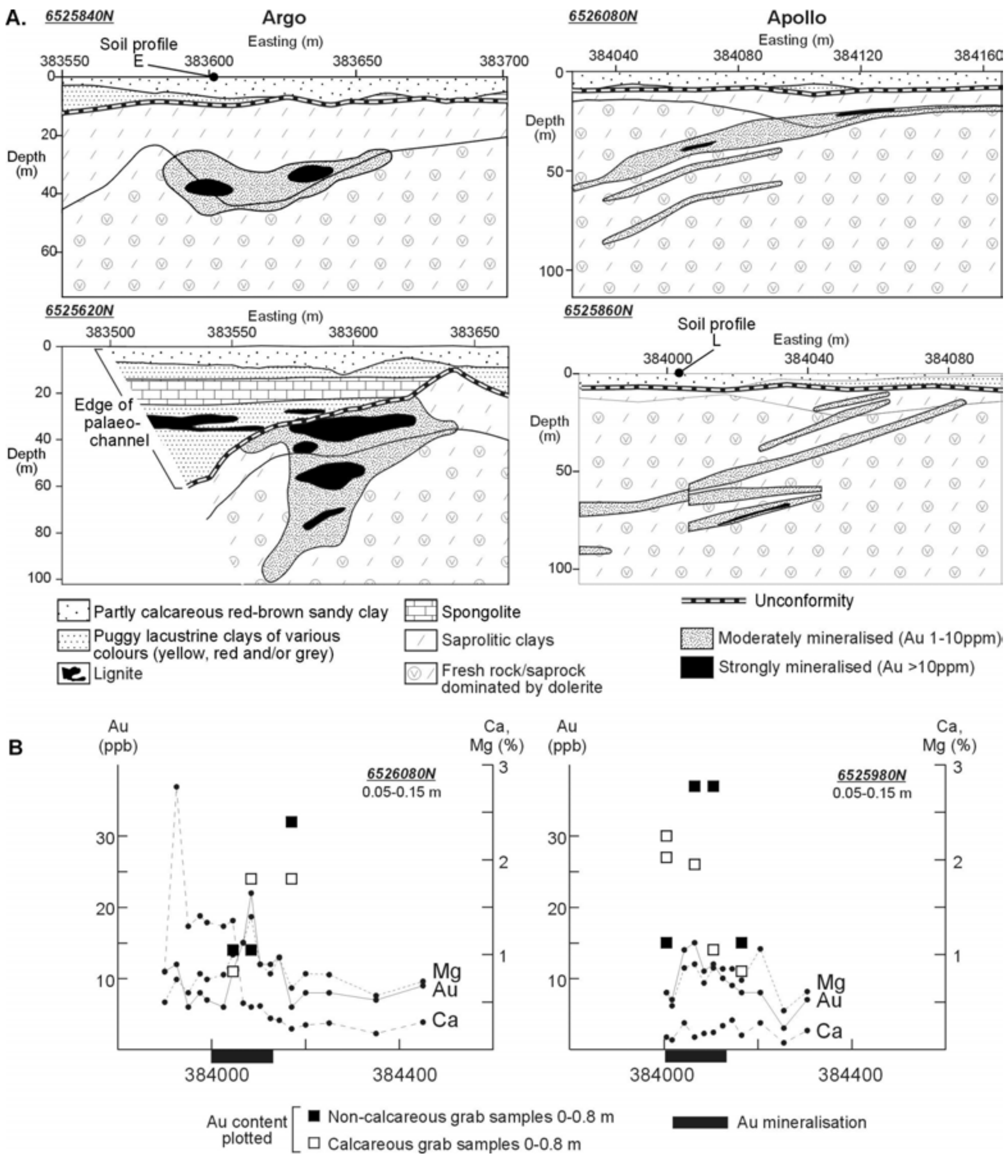

Figure 6.16: Geochemistry and regolith stratigraphy at Argo and Apollo (WA). A) Geological sections showing distribution of Au mineralisation. B) Geochemical traverses for soil (0-0.15m) and deeper grab samples.

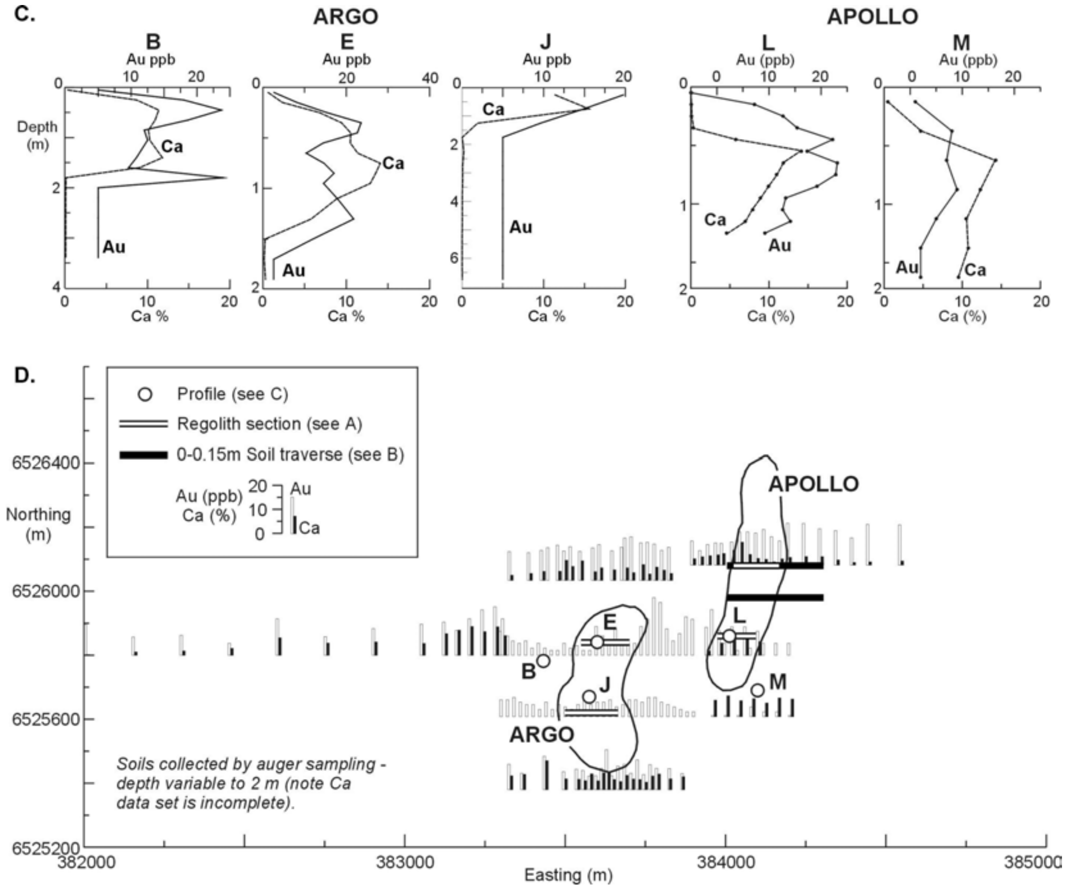

Figure 6.16 (continued): Geochemistry and regolith stratigraphy at Argo and Apollo. C) Geochemical profiles for soil. D) Plan showing location of traverses with geochemistry, mineralisation and sections.

The distribution of Au in the soil at Argo does not appear to be related to underlying mineralisation. There are no significant differences in the distribution characteristics, or total Au content, between mineralised and background areas. The Au concentrations in the soil profiles are generally less than 10 ppb, with maxima occurring between 0.3-0.5 m (carbonate, max 23 ppb), and 1.2-1.8 m depth (Mn-rich horizon, max 24 ppb) (Figure 6.16C). The latter horizon has also scavenged As, Co, Mo, Sb, W and REE (Lintern and Gray 1995b). The Au in the top 2 m of the soil at Argo is generally associated with Ca-Mg carbonates (Figure 6.16D).

Augering the top 1-2 m remains the best regional sampling technique for collection of material containing the highest Au concentrations, although its use for detecting underlying mineralisation is not effective. The greater depth to mineralisation and the complex sediments that overlie it may prevent any Au from migrating to the surface at Argo unlike at Apollo. However, as at Apollo, the interpretation is equivocal and more samples need to be analysed.

(14) Safari (Mt Celia), Lake Raeside, WA (Bristow *et al.* 1996b)

The Safari Gold Prospect is located 200 km NNE of Kalgoorlie and 9 km NE of the margin of Lake Raeside, close to the Menzies Line. The climate is semi-arid with mean annual rainfall of 225 mm. Rain falls variably throughout the year, resulting from frontal systems in winter, or convectional storms and cyclone-related depressions in summer. The vegetation is medium to dense woodland of *Acacia* with minor *Eucalyptus*. Safari is situated on a broad, sandy, colluvial valley that slopes gently to the SW. As for Golden Delicious, three regional surface regolith units can be delineated by Landsat TM imagery. These consist of dominantly post-Archaean sediments covering over 85% of the region, residual Archaean units, and ferruginous materials developed in both the Archaean units and the post-Archaean sediments.

The Safari Prospect lies within the southern extension of the Laverton Tectonic Zone, part of the Archaean Wiluna-Norseman belt. The bedrock geology consists of a greenstone assemblage composed of a wide variety of volcanic and volcaniclastic rocks. These rocks are heterogeneously deformed and generally strike NNW. Regionally, the greenstone sequence has been metamorphosed to lower greenschist facies, but alongside large plutons of intrusive porphyritic syenite, coarse granodiorite and adamellite, the greenstone sequence has been metamorphosed to amphibolite facies. Drilling to date indicates a resource of 1.08Mt at 3.3g/t Au. The mineralisation is hosted by andesite to dacite metavolcanic rocks, now largely represented by quartz-chlorite-sericite$\pm$carbonate schists. They are bound to the W and E by serpentinised komatiite and talcose schists. Gold is primarily associated with quartz veins within an anastomosing shear. Anomalous Au occurs in the saprolite just below the unconformity, especially where it directly overlies primary mineralisation (e.g. 1200 ppb in a quartz vein from the top two metres of the saprolite). The top metres of saprolite give is strongly anomalous over mineralisation (1000 ppb), compared to an elevated and noisy local background of 10-50 ppb Au (Figure 6.17A).

The palaeosurface is much steeper and more variable than the present land surface (Figure 6.17C). The most prominent features of the palaeosurface are a palaeohigh that meets the present land surface, and a valley draining W in the northern part of the area. The study area is completely blanketed by transported overburden, except for the small area coinciding with the palaeohigh where Archaean rocks outcrop. There is a uniform distribution of sheetwash and aeolian sand up to 1 m thick at the surface. The composition and thickness of the sediments, including the sheetwash, varies. Generally, the sediments are 5-10 m thick, reaching 20 m in the northern palaeovalley. The sediments below the sheetwash are a polymictic assemblage containing 2-10% coarse material in a matrix of sand, silt and, locally, clay. The coarse fraction commonly occurs towards the base and is comprised of angular, weakly weathered rock fragments over most of the area, including near the mineralisation. However, in the northern palaeovalley, there is a mixture of ferruginous pisoliths, nodules and lithorelics. Locally, drilling has intersected narrow lenses of coarse alluvial sand and gravel. Post-depositional modification of the sediments is widespread; most significant is the widespread calcification from about 0.5-5.0 m below the surface. Mottles of carbonate, a few tens of millimetres in diameter, occur only 0.2 m below the surface, but the carbonate morphology below 1 m depth is uncertain (probably as coatings) because the only samples are drill cuttings. Beneath the zone of intense calcification, silica and Fe oxides commonly indurate the sediments, moderately to strongly. Most of the residual regolith consists of saprolite with variable clay content, although in isolated areas in the N of the prospect, there are deep profiles with highly ferruginous upper horizons. Incipient mottling is present throughout the saprolite and the upper few metres are commonly indurated by silica and/or carbonate. Fresh rock is generally encountered 10-20 m below the unconformity. The bedrock is reasonably fresh where it subcrops, but it is subject to the same calcification as that of the upper few metres of the sediments. Calcium carbonate causes the brecciation of the subcrop and the upper few metres contain large (to tens of cm) nodular structures.

Anomalous Au (22-60 ppb) is present in the carbonate horizon, with enrichment strongest from 0.5-2.5m depth directly over mineralisation (Figure 6.17B). Concentrations of Au (over 7 ppb) above background occur in the calcareous horizon for 800 m across strike of the mineralisation. Using a cyanide leach for Au with a low detection limit (0.04 ppb), an anomaly in the top half metre, with excellent contrast, peaks directly over the primary mineralisation with concentrations exceeding 5 ppb for over 600 m across strike. Despite higher absolute Au contents within the calcrete horizon, preferentially sampled highly calcareous fragments do not increase anomaly contrast, and the Au/Ca ratio in these is consistently lower than a bulk sample from the same interval. The Au anomaly associated with carbonate at Safari accurately reflects mineralisation, with optimum sampling between 0.5 and 2.5 m depth.

The Safari case study is a convincing example of anomalous Au in calcrete within transported overburden above mineralisation. The continuous nature of the anomaly from mineralisation through about 5 m of transported units and into the calcrete has not been recorded elsewhere. Further examination of the anomaly with analyses of samples from adjacent sections is recommended to examine the shape of the anomaly in three dimensions. The anomaly has probably been formed from a combination of bioturbation, capillarity and possibly re-cycling through vegetation.

(15) Kanowna Belle, Kalgoorlie, WA (Anand *et al.* 1993)
The Kanowna Belle Gold Deposit is located about 18 km NE of Kalgoorlie. The Kanowna district forms part of a belt of NNW-trending metamorphosed ultramafic, mafic, sedimentary and felsic volcanic, and intrusive rocks of the Norseman-Wiluna Belt. The deposit is contained within a package

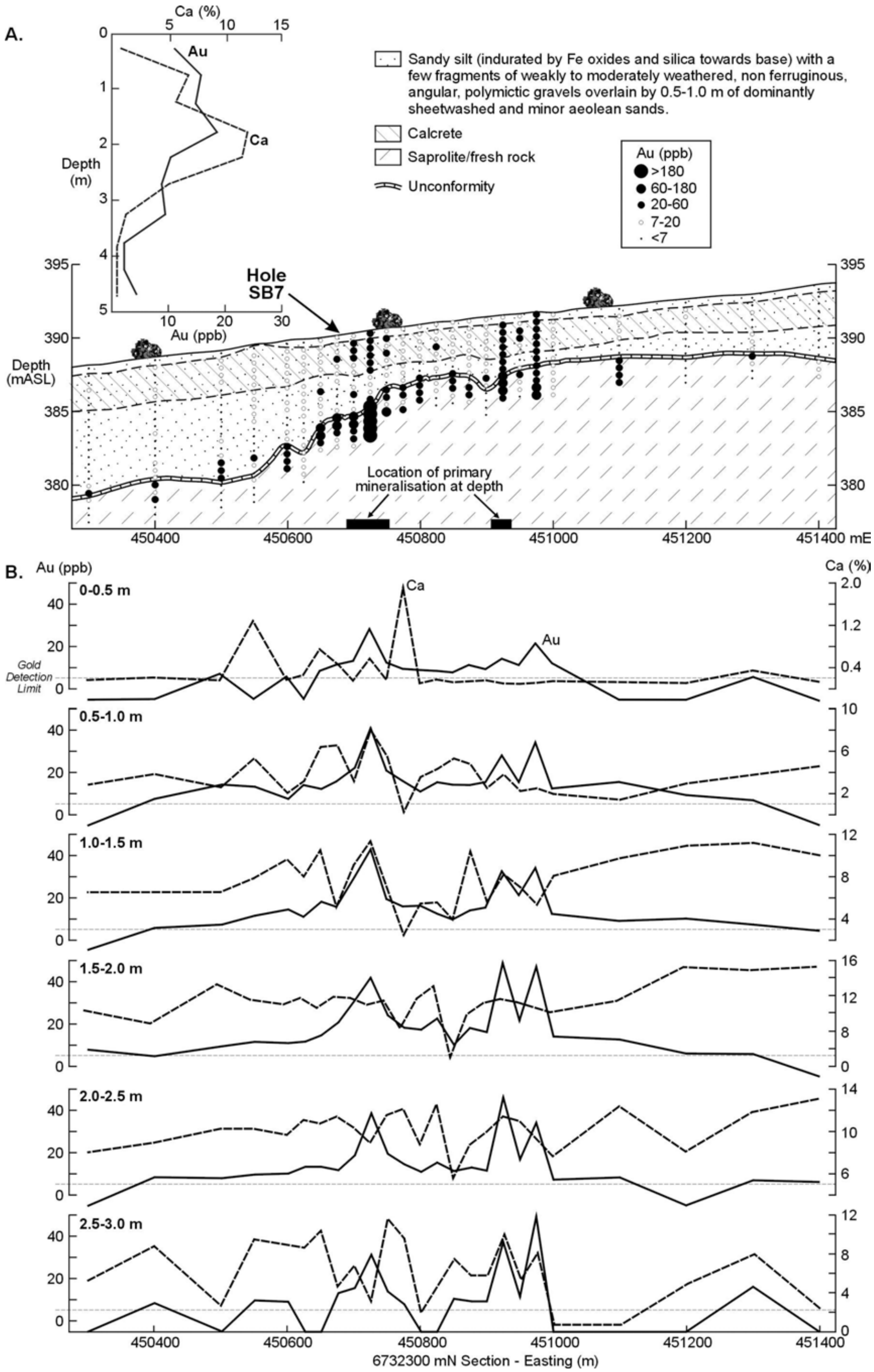

Figure 6.17: Geochemistry and regolith stratigraphy at Safari Bore, Mt Celia (after Bristow *et al*. 1996b).
A) Section showing distribution of regolith materials and Au; inset shows a geochemical profile generated from the data displayed in the section.
B) Geochemical profiles for different depths.

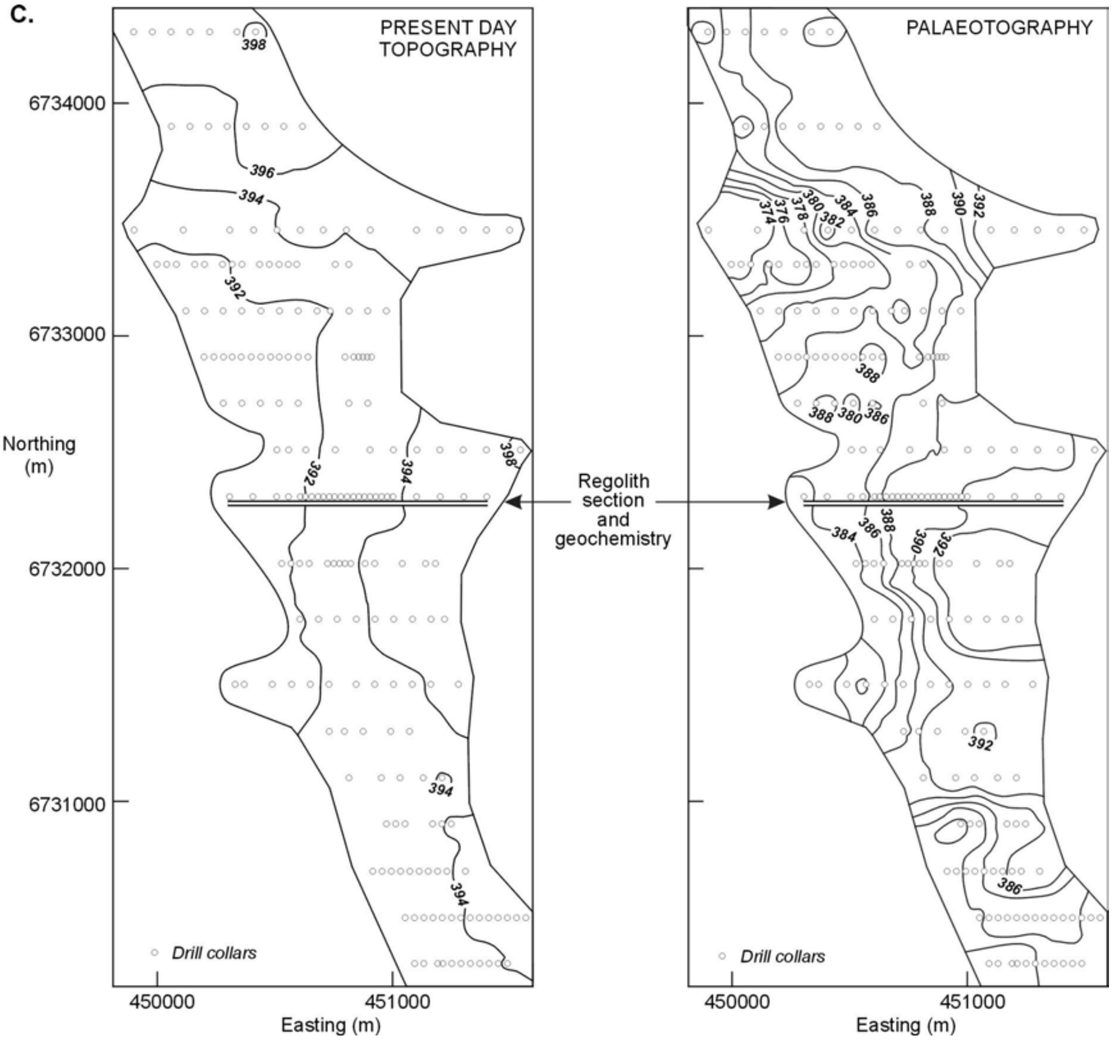

Figure 6.17 (continued): Geochemistry and regolith stratigraphy at Safari Bore, Mt Celia.
C) Section showing distribution of regolith materials and Au; inset shows a geochemical profile generated from the data displayed in the section.
D) Geochemical profiles for different depths.
E) Plan showing topography, palaeotopography and regolith section.

of NE trending, S dipping, predominantly intermediate to felsic, volcanic-derived tuffaceous mass flow units and breccias. The total resource at Kanowna Belle is 15 Mt at 5.3 g/t to a depth of 650 m (Thomson and Peachey 1993).

Kanowna Belle lies on the edge and beneath a depositional plain within a major N flowing drainage basin (Figure 6.27A). Pale orange, calcareous clay soils containing abundant black ferruginous granules form a 0.2-1 m thick mantle. Calcrete, 2 to 5 m thick, occurs as coatings on, and as soft aggregates within, the clay. Acid red clay, largely devoid of carbonate, underlies the calcareous soils and also contains abundant ferruginous granules. A mottled zone occurs at depths generally greater than 2 m. A zone of silcrete, 1 to 8 m thick and preferentially developed from the weathering of grits and feldspar porphyry, marks the base of the mottled zone above bleached saprolite; it is anomalous in Au. The silcrete is strongly silicified, commonly with a conchoidal fracture and a vitreous lustre; the transported-in situ boundary is located immediately above or within the silcrete. Beneath this zone, leached or barren saprolitic clays 20 to 50 m thick occur above mineralised bedrock. Supergene Au mineralisation is significant, with a well-developed horizon (>0.1 ppm Au) 1-4 m thick and up to 200 m wide at the base of the saprolite (35-45 m below surface); smaller (<20 m wide) pods of supergene mineralisation (<0.1 ppm) occur closer (5-12 m) to the surface.

Two traverses across mineralisation were investigated (Figure 6.18B). Ferruginous granules (highly ferruginous, hematite-rich, vitreous, hard pellets up to 5 mm in diameter) and the soil above mineralisation are anomalous in Au, Sb, As and Ce. Gold concentrations in soil (mean 90 ppb), are

10-20 ppb higher than those in the ferruginous granules extracted from the same soil (Figure 18A). Gold concentrations in the top metre range from 17 to 230 ppb and are normally in excess of 60 ppb. There is a considerable decrease in Au concentrations in samples collected from 2-3 m. The observed peak Au concentration within the calcrete conforms well to the sub-surface position of the major ore shoots (Figure 6.18C).

The appearance of anomalous Au in calcareous soils above mineralisation concealed by relatively thin sediments is not surprising. However, the strength of the anomaly (maximum >200 ppb Au) is unusual. The source of the Au may be the underlying ore body (located at 50 m depth) or more possibly from the Au enrichment in the silcrete and/or relict Au in the upper saprolite. However, the limited scope of the study does not preclude the possibility of the Au being laterally derived from upslope.

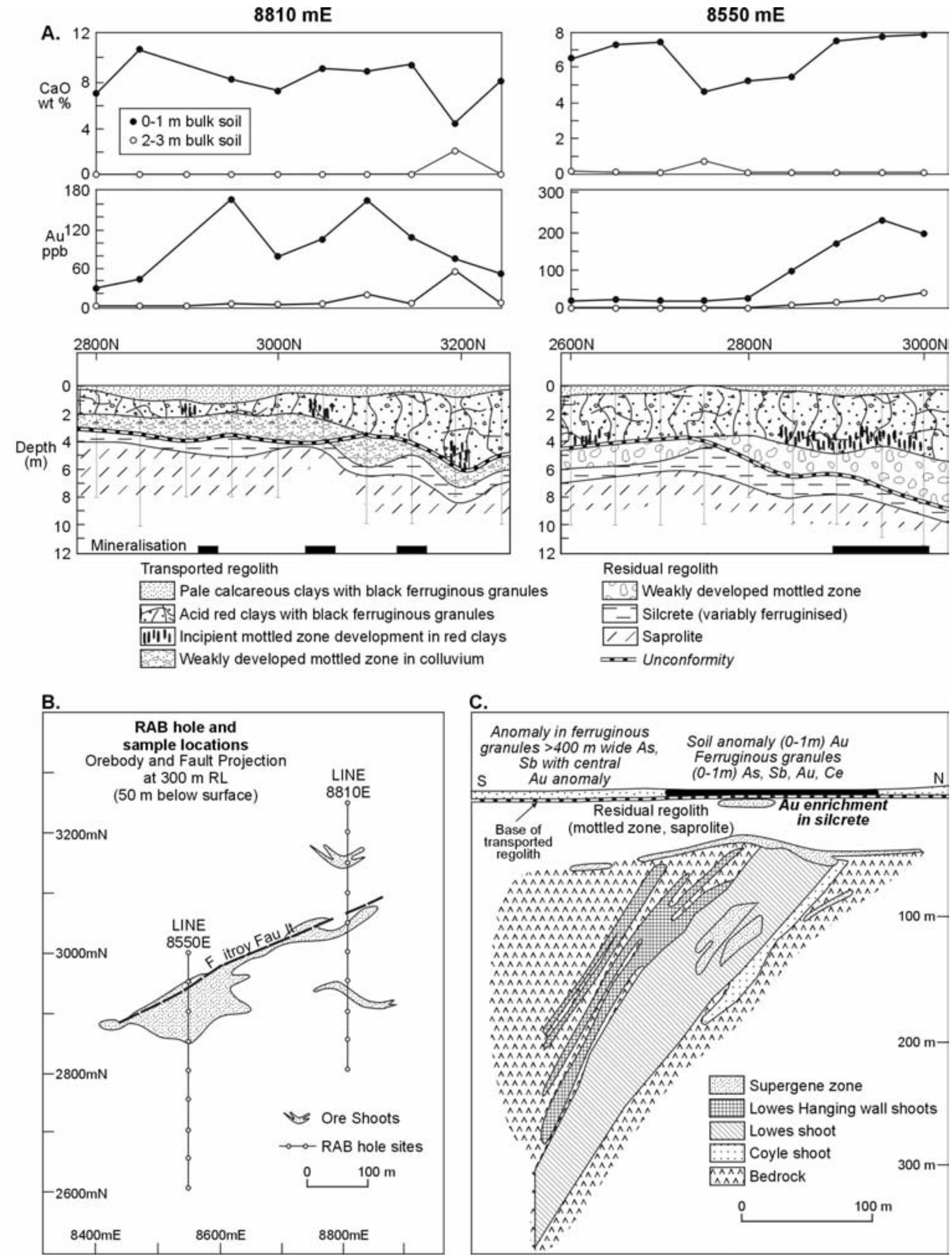

Figure 6.18: Gold distribution and stratigraphy of the Kanowna Belle Gold Deposit (after Anand *et al.* 1993).

A) Geochemistry and regolith section for the two sampling traverses.

B) Location of sampling traverses with respect to mineralisation.

C) Cartoon showing geochemical halo above mineralised shoots.

(16) Matt Dam, Kalgoorlie, WA (Anand *et al.* 1993)
The Matt Dam Gold Prospect is located about 55 km NW of Kalgoorlie and 4 km from the Zuleika Sands Deposit. Primary mineralisation is hosted by NW trending high-Mg basalts and komatiites with bands of intermediate to felsic tuffs and sedimentary rocks (Harrison *et al.* 1990). A 0-1 m soil survey over the area on a 200 by 50 m grid outlined a 3 km wide NW-trending 30 ppb contoured Au anomaly. Two lines, 7400N and 7700N, were investigated.

Matt Dam is located partly in erosional (Type B) and partly in depositional (Type T) regolith regimes. In the erosional areas, the surface is mantled by a coarse, irregular, yellowish-brown to reddish-brown, residual lag derived from ferruginous saprolite. The top 0.5 m consists of pale, orange, calcareous, sandy, clay soil containing saprolite fragments. Carbonates occur as coatings, and as nodules within the clay. The calcrete nodules are composed of irregular, pinkish material, varying from 1 to 5 cm in diameter, enclosing partially to completely replaced ferruginous saprolite fragments and hardened mottles. Saprolite occurs at depths generally >0.5 m. In depositional regimes, a black lag of ferruginous granules mantles the regolith. Fragments in this lag are generally <0.1 m in diameter and range from sub-rounded to irregular. Calcareous soils are up to 1 m thick and contain varying amounts of carbonate nodules and ferruginous granules. On 7400N, a 16 m deep palaeochannel was identified with a white, kaolinite-rich, bleached clay zone extending to 25 m under the channel (Figure 6.19). The stratigraphy of the channel consists (from the surface) of (i) calcareous clays, (ii) acid, kaolinitic, red clays with mottles, and (iii) smectite-rich puggy grey clays containing hardened mottles and fine ferruginous granules. The stratigraphy along 7700N is more complex (Figure 6.19). It has several zones of transported clays with mottling crossing the unconformity into the saprolite. Underlying interbedded tuffs, dolerites, ultramafic rocks and shales dip near-vertically to the E. Zones of white, bleached clays are evident under transported clays containing hardened mottles.

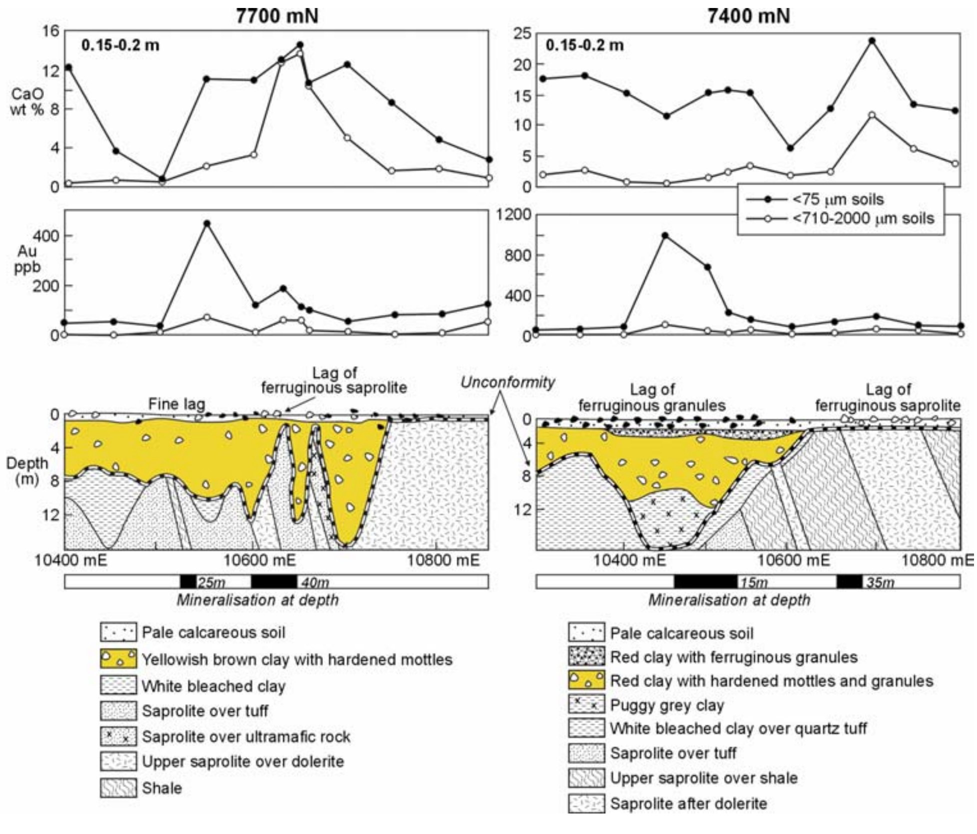

Figure 6.19: Matt Dam Gold Prospect showing Au distribution and regolith (after Anand *et al.* 1993).

High concentrations of Au in surficial materials occur on both traverses. In the palaeochannel area, where mineralisation occurs at 15 m depth on 7400 N, Au concentrations peak at 1010 ppb in the calcareous fine (<75 (m) fraction (Figure 6.19). Calcareous nodules themselves have a maximum of 160 ppb Au. Gold is also present in ferruginous granules over the palaeochannel and the saprolite, but in much lower concentrations. Gold concentrations are much weaker over the saprolite where mineralisation occurs at 35 m depth. For the fine calcareous soil on 7700N, Au concentrations appear to be higher (450 ppb) over the weakly mineralised area (740 ppb at 20 m) compared with the stronger mineralised area (150 ppb over a maximum 8 ppm at 40 m). Gold was not detected in ferruginous granules. More data on adjacent sections would assist with the interpretation of the origin of the Au in the soil.

(17) Golden Delicious, Lake Carey, WA (Bristow *et al.* 1996a)
The Golden Delicious Deposit is located 50 km S of Laverton and north of the Menzies Line. The climate is semi-arid with an annual rainfall averaging 200-250 mm. Vegetation in the area consists of sparse to dense woodland of *Acacia*, with an understorey of smaller shrubs of *Acacia*, *Cassia* and *Eremophila* (poverty bush). Golden Delicious is situated on a broad colluvial plain, and the present land surface slopes very gently towards the NW (Figure 6.20A). Three regional surface regolith units were delineated by Landsat TM imagery. These consist of dominantly post-Archaean sediments covering over 85% of the region, residual units derived from Archaean bedrock, and ferruginous materials developed in both the Archaean units and the post-Archaean sediments.

The Golden Delicious Deposit is in the Archaean Norseman-Wiluna greenstone belt, in the southern part of the Laverton Tectonic Zone. The region comprises variously faulted, folded and metamorphosed greenstone sequences intruded by granites. Gold mineralisation is hosted by volcaniclastic "greenschist" rocks on the western margin of a suite of granitoids that intrude intermediate to mafic volcanic rocks. The resource is estimated at 6.1Mt @ 1.3g/t Au. The main mineralised unit begins at about 20 m depth, about 5 to 10 m below the unconformity between the Archaean and the Cainozoic sediments, where there is also minor enrichment in Au.

The sediments are poorly-sorted, polymictic colluvium-alluvium consisting of clay, silt and gravels that generally become coarser with depth. The colluvium-alluvium can be divided into three units:

1) T1: Calcareous, hardpanised silty clays, 3-5 m thick, that are strongly indurated with silica, carbonates and Fe oxides. Secondary carbonate occurs as thin sub-horizontal laminar material and Mn oxides are present as dendritic coatings.
2) T2: A variable unit, 3-6 m thick, dominated by fine-grained sediments. Ferruginous gravels are more common than in the upper unit, and it is less strongly indurated by silica and Fe oxides. Carbonate is present, mostly as irregular masses up to 40 mm in diameter.
3) T3: The lowermost unit, up to 10 m thick, is below the watertable. It contains 25% coarse material consisting of: abundant ferruginous gravels; pisoliths and nodules which are mostly broken and abraded; and minor quartz and lithorelics, some of the later being almost fresh. Maghemite is common in the pisoliths and the upper few metres of this unit, particularly in the NE, have minor amounts of concretionary goethite, apparently formed in situ.

The sediments (transported overburden), ranging from 9-16 m in thickness, lies over a mottled zone (Figure 6.20B) and, locally, directly over saprolite. A clay-rich saprolite merges into less clay-rich saprolite between 30-50 m depth, and fresh rock is usually encountered at about 70 m depth. The weathered Archaean bedrock has a mottled zone, characterised by large (up to 200 mm diameter) hematite-rich mottles overprinting clay-rich saprolite.

The palaeotopography at the Golden Delicious Deposit, like the modern day topography, slopes to the NW but at a much steeper and more variable gradient (Figure 6.20A). Much of the transported overburden is probably derived from the greenstone uplands 5-10 km ESE. It is possible that widespread lateritic profiles once existed there, as the sediments at Golden Delicious resemble, in reverse order, the materials of such profiles.

The results of a geochemical study of the drill cuttings indicate that the basal ferruginous gravels of the lowermost sedimentary unit provide the greatest target enlargement of any sample medium at the Golden Delicious Deposit. Gold concentrations up to 107 ppb occur 400 m across strike, offset slightly downslope (Figure 6.20). Shallower sediments have much lower Au contents (less than 5-12 ppb). Gold concentrations of 12-81 ppb in the upper few metres of residual regolith occur 300 m across strike but are not offset. The Au content of the weathered Archaean increases with depth, due to either depletion from the upper part of the zone, or to the original primary distribution. The solubility of Au and the presence of dissolved Au in the groundwater (Bristow *et al.*, 1996a), suggest depletion may have occurred. Although calcrete occurs throughout the top 6 m of the transported overburden, there is no consistent association with Au, however, in some holes (002, 004, 008, 009, and 011), there is a weak carbonate-Au association in the top 2-3 metres.

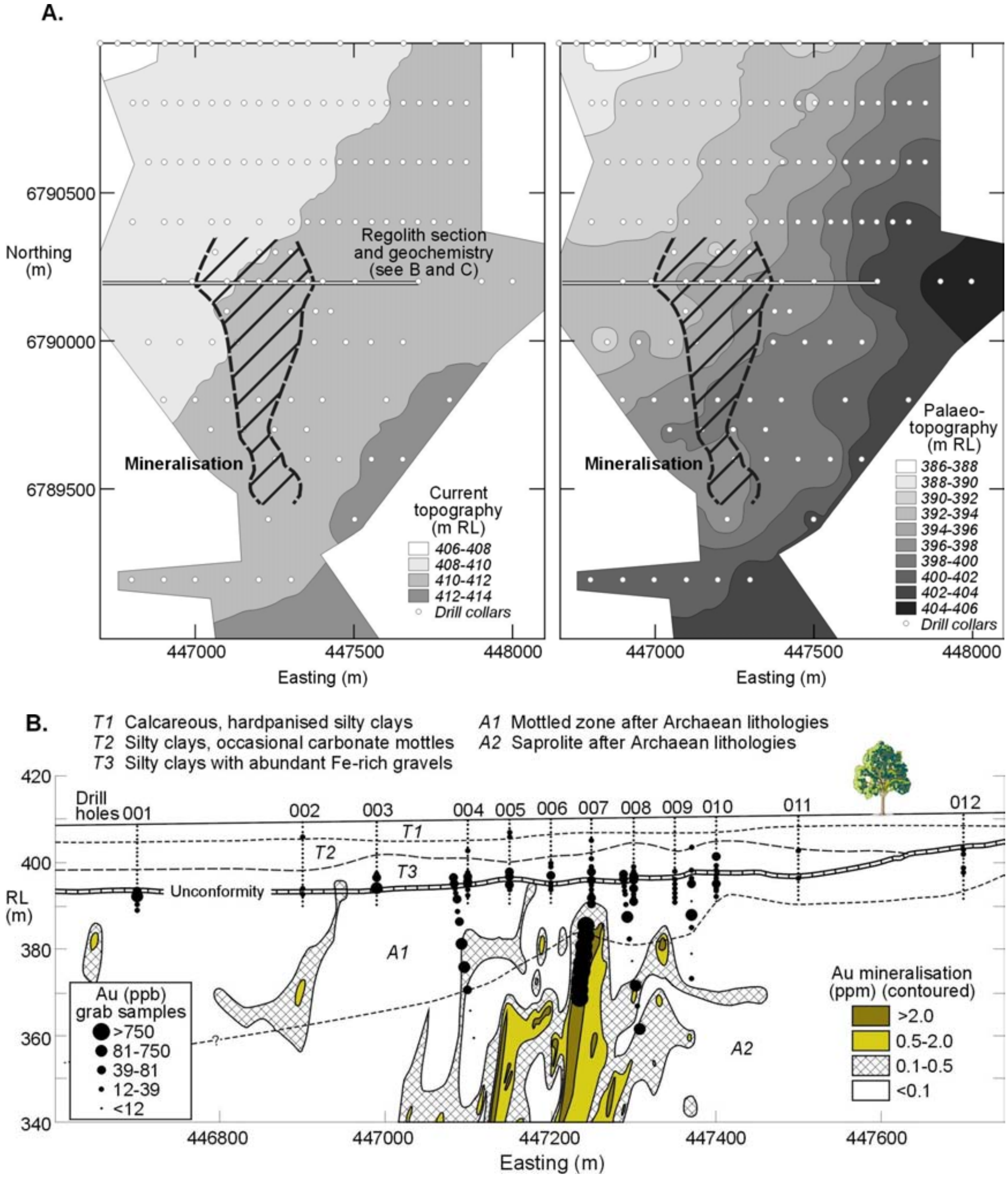

Figure 6.20: Regolith and geochemistry of the Golden Delicious Gold Deposit (after Bristow *et al.* 1996a).
A) Topography, palaeotopography and location of the sampling and regolith section.
B) Regolith section.

(18) Deep South Gold Deposit, Mount Gibson, WA (Madden 1996)

The Mount Gibson gold deposits are approximately 300 km NE of Perth, WA, in the Retaliation Greenstone Belt, Murchison Province. They lie at an elevation of 300 to 360 m on a regional divide between the Lake Moore and Lake Monger saline playa systems. The climate is semi-arid with an average rainfall of about 250 mm, most of which falls in winter. Vegetation is dominantly thickets of *Acacia* over areas of granitoid rocks and sandplain, with *Eucalyptus* woodland communities over finer-textured soils of the greenstone rocks (Anand *et al.* 1989). Deeply weathered profiles capped with laterite are widespread throughout the region with partial erosion and stripping leading to widely distributed lateritic detritus, and exposure of bedrock on hillslopes. Primary mineralisation at Deep

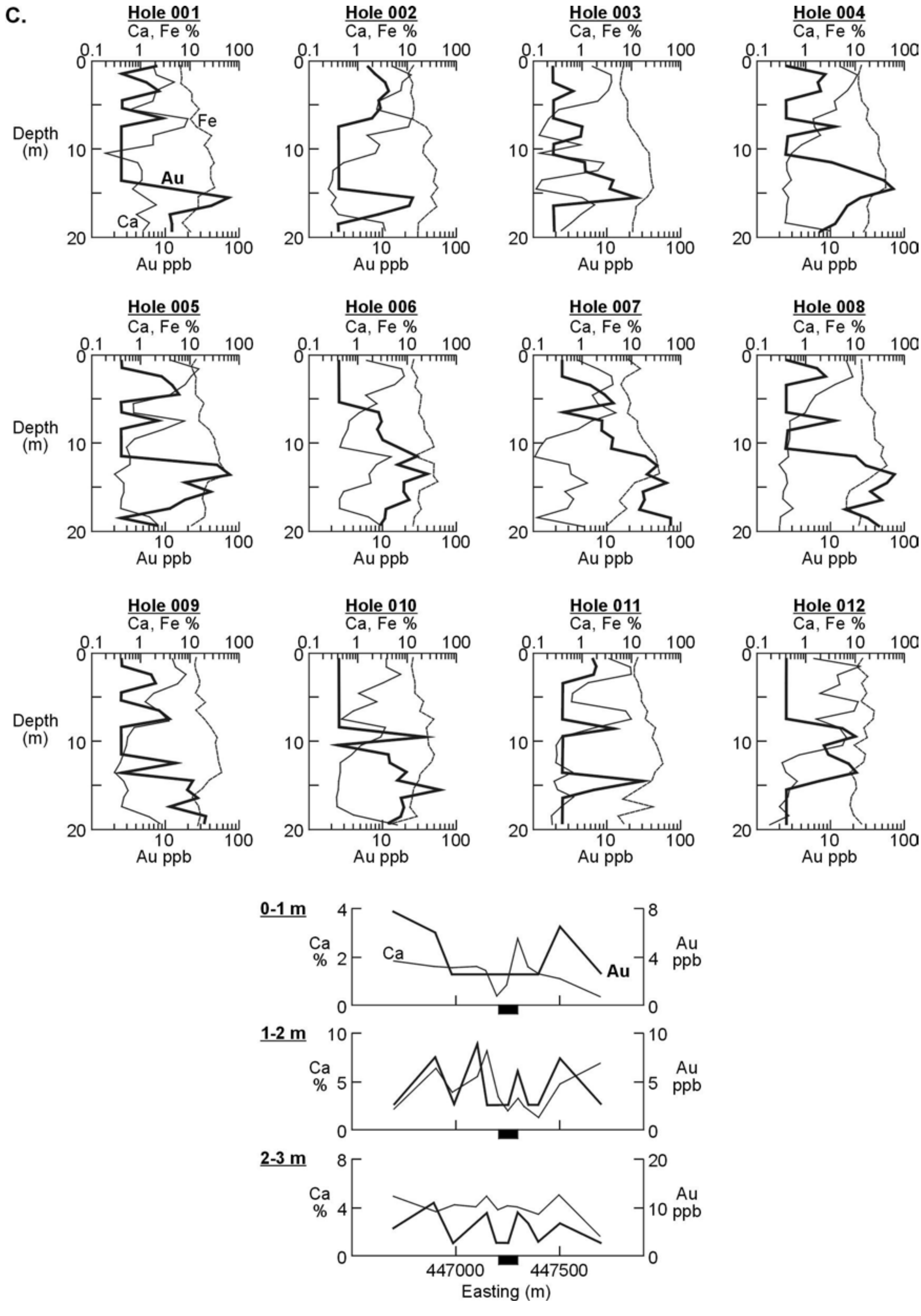

Figure 6.20 (continued): Regolith and geochemistry of the Golden Delicious Gold Deposit.
C) Selected geochemistry of drill holes.

South is hosted in felsic schists with some associated base metals probably associated with an earlier volcanogenic massive sulphide-mineralising event. Secondary Au mineralisation is present as a result of deep weathering and re-mobilisation of Au into the saprolite and during the formation of the laterite.

The Deep South regolith stratigraphy is comprised of two units (Figure 6.21A and B):

1) Sediments 10 to 15 m in thickness consisting of quartzo-feldspathic colluvium set in a kaolinite matrix becoming mottled with depth. They are capped with a siliceous and partly-calcareous red-brown hardpan a few metres thick. The sediments thin towards low hills of outcropping granitoid saprolite from which they are probably derived.
2) Saprolite, partly silicified and/or mottled in its upper portion, overlying variable lithologies including schistose mafic and felsic types and pegmatitic granitoids.

Despite the presence of 10-15 m of transported material, exploration data indicate that Au concentrations up to 360 ppb are present in near-surface materials (Madden 1996). Two profiles had Au concentrations over 250 ppb in calcareous hardpan. Separations of material from the hardpan indicated that the highest concentrations of Au were found in the carbonate but were not restricted to it (Figure 6.21).

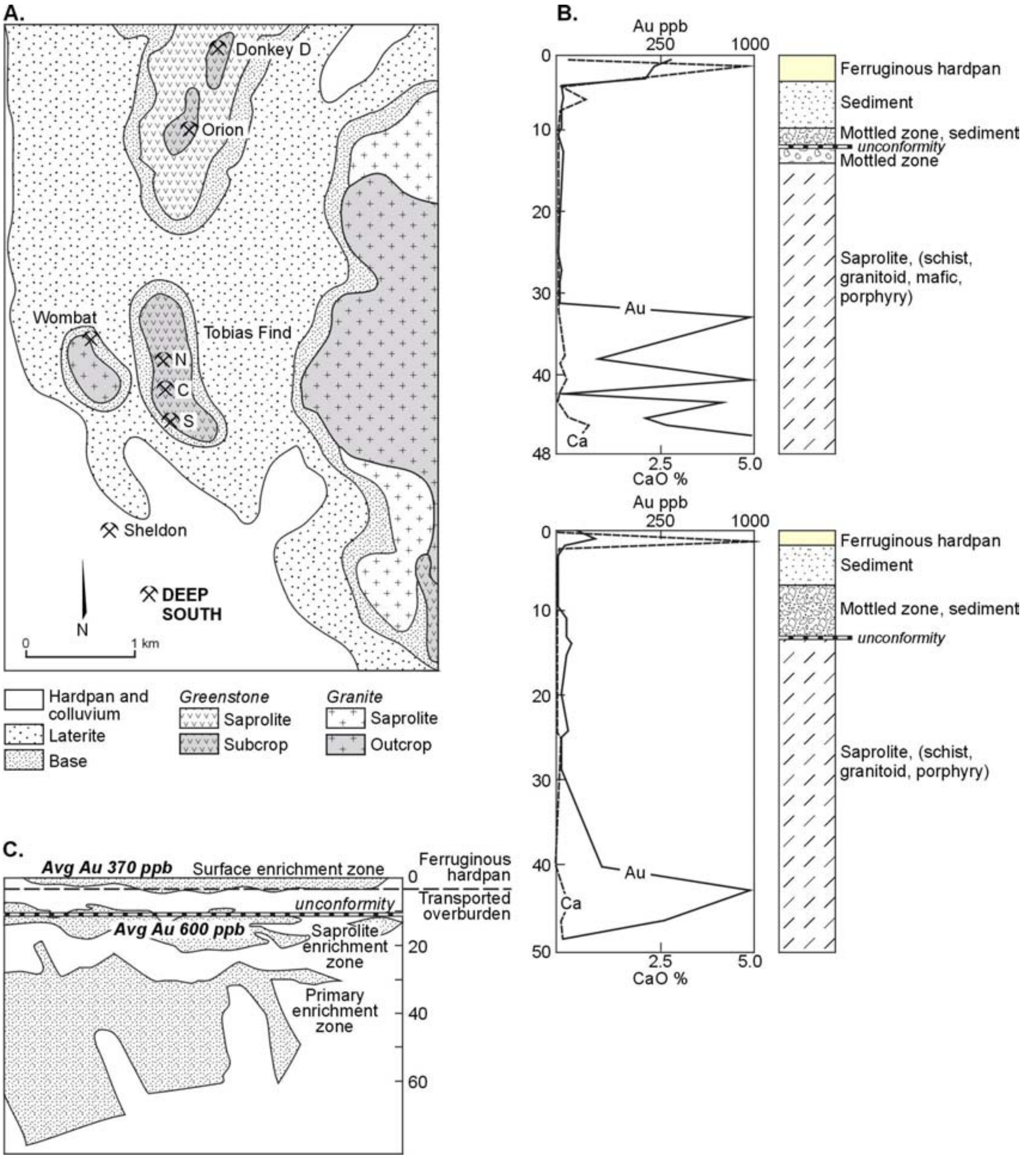

Figure 6.21: Regolith and distribution of Au at the Deep South Gold Deposit (after Madden 1996). A) Regolith map of the Deep South area. B) Regolith and geochemistry for two sets of drill hole samples from over mineralisation. C) Cartoon showing Au distribution.

The study was limited in terms of the number of samples taken and the absence of a systematic survey of the geochemistry of the hardpan over the area. However, the granitic nature of the overburden sediments, deriving from the NE rather than the auriferous laterite found directly along strike to the N, suggests the Au in the overlying calcareous hardpan may be derived from the underlying mineralisation. Madden (1996) suggested that the Au was derived from the underlying mineralisation (Figure 6.21C) via a mechanism that involved higher water tables and re-mobilisation and re-precipitation of the Au. While this may be a plausible explanation, more data on adjacent sections would assist with the interpretation of the origin of the Au and whether it, in anyway, may have originated from upslope.

Table 6.1: Element concentrations in a variety of regolith materials.

Element	Hardpan	Manganese oxide	Nodular carbonate	Laminar carbonate
Au (ppb)	137	52	200	40
Cu (ppm)	24	22	2	13
Ni (ppm)	46	53	5	39
Pb (ppm)	27	42	9	22
Zn (ppm)	18	18	8	18

(19) Panglo, Kalgoorlie, WA (Lintern and Scott 1990, Lintern 1996b)
The Panglo Gold Mine is located 30 km N of Kalgoorlie (WA). The climate is semi-arid with mean annual rainfall of 280 mm. The diversity and abundance of the vegetation are largely determined by the characteristics of the soil. Salt- and drought-tolerant species, e.g. *Maeriana* and *Atriplex*. (<0.5 m in height) with minor *Eremophila* (up to 2 m) dominate the clay-rich soils of the broad valley floor to form an open shrubland. Where soils are thin, the vegetation is sporadic and the total biomass is low. Tall *Eucalyptus* trees (up to 20 m) with an understorey of *Eremophila* (1-2 m) form open woodland over gravelly soils but are absent in the broad valley floor. There is a sharp transition between these two vegetation communities reflecting the different soil types, although individual examples of plant species occur sporadically in both communities.

The Panglo Gold Deposit is located within a 200 m wide sequence of steeply W-dipping carbonaceous shales and mafic to ultramafic volcanic rocks, within a major shear zone (Figure 6.22A). Mineralisation occurs as a relatively flat-lying, supergene deposit, up to 16 m thick between 30 and 55 m depth, over a 1 km long, N-trending zone. Underlying primary mineralisation is associated with disseminated pyrite and arsenopyrite within strongly sheared and carbonated shales and mafic volcanic rocks. Panglo was discovered in 1987, but mining did not commence until late 1994. The mineable reserves are 1.5 Mt at 2.7 g/t Au.

Most of the Panglo deposit has a covering thin (<1 m), weakly ferruginous-calcareous soil, commonly with a transported component, overlying a mottled clay and 35-40 m of leached kaolinitic saprolite, locally containing alunite. In bedrock, potassic (muscovite-rich) rocks occur with primary mineralisation. Laterally, the wall-rocks have paragonite and muscovite, instead of muscovite alone. At the southern end of the deposit, the saprolite has been eroded and is partly overlain by a palaeochannel containing up to 10 m of sediments. The soils over the Panglo deposit may be divided into two main groups:

1) Gravelly soils. These occur in high areas of the landscape (relief of 10 to 20 m) including those overlying the known southern limits of mineralisation, and are developed on sediments in a palaeochannel of presumed Tertiary age. The soils consist of an organic surface horizon containing Fe-rich gravels in a sandy matrix. Beneath this, the regolith is characterised by unconsolidated, locally-derived, Fe-rich, rounded to sub-rounded ferruginous nodules (mottled clay), varying in size from a few mm to several cm in diameter, in a sandy to loamy matrix to 2 m overlying silty clays. In certain areas, saprolite limits soil depth to a few centimetres.
2) Clay-rich soils. These are dominant in the axis of the present broad drainage that covers the northern and central sections of the deposit. They consist of a veneer of sandy loam overlying pale grey to yellow, homogeneous clays and clay-rich saprolite; saprolite is visible in shallow trenches (<1 m depth) over the deposit. Blocks of weathered rock are common within the soil profile and are either pale (clay-rich) or red (Fe-rich). Towards the S, the soils become increasingly saline as the drainage nears a playa.

Pedogenic carbonates are present in both soil types to 1 to 1.5 m depth. They are disseminated through clay-rich soils, as friable fragments and veneers on the ferruginous nodules in unconsolidated Fe-rich material, and as coatings, up to several mm thick, on indurated, shallow subcrops of saprolite.

Gold and Ca are highly correlated in soils developed over the palaeochannel (now partly a topographic high) suggesting Au has been hydromorphically mobilised (Figure 6.22D). The peak Au concentration in the soil (0-1 m, 160 ppb) appears to be accurately located above the supergene mineralisation found beneath 10 m of barren transported sediments and 30 m of poorly mineralised saprolite. However, there are also enrichments of Au (i) at the unconformity between the transported

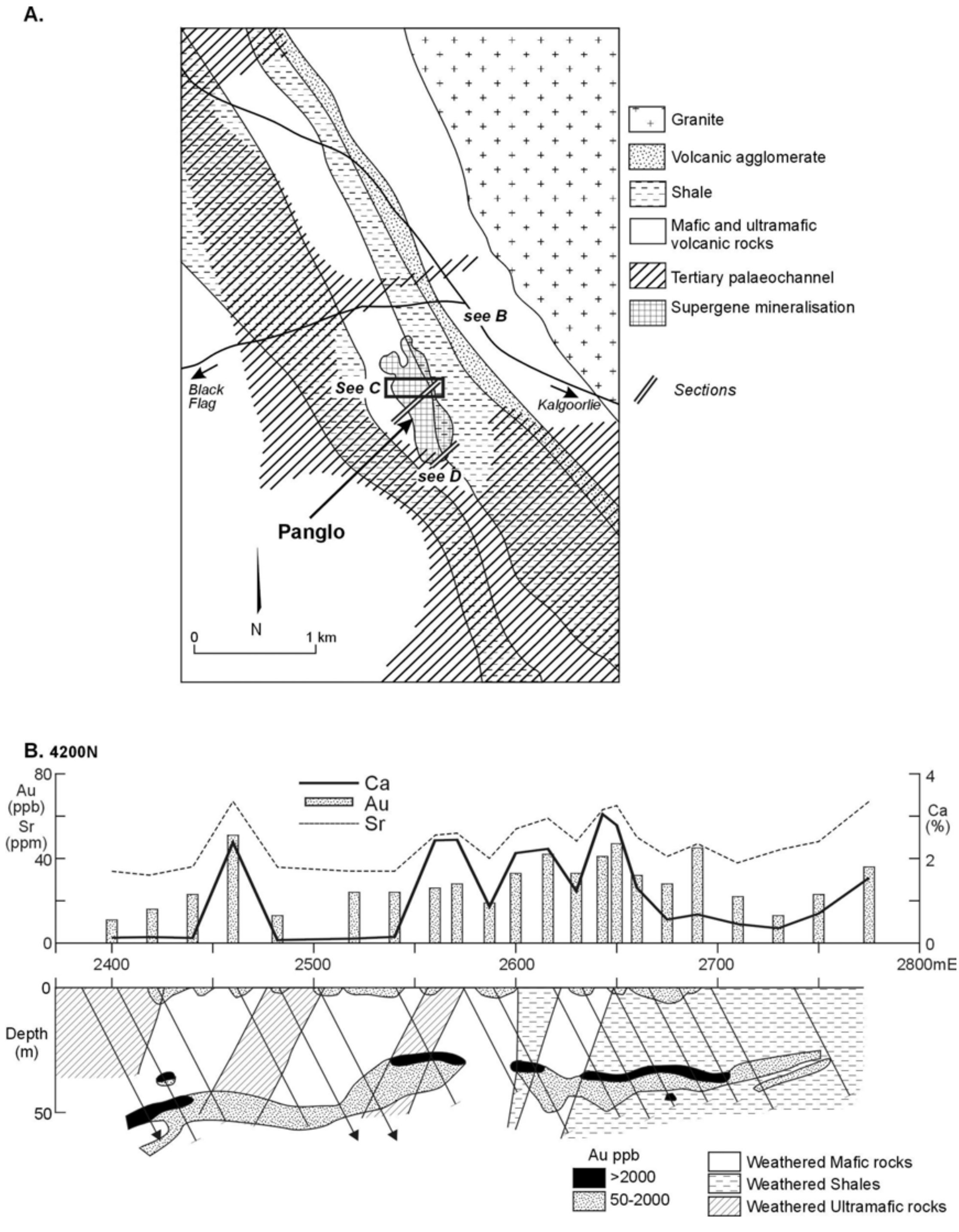

Figure 6.22: Geochemistry and geology at Panglo. A) Section 4200N showing geochemistry of soil (0-0.2 m), geology and Au distribution across mineralisation. B) Plan showing location of the study areas.

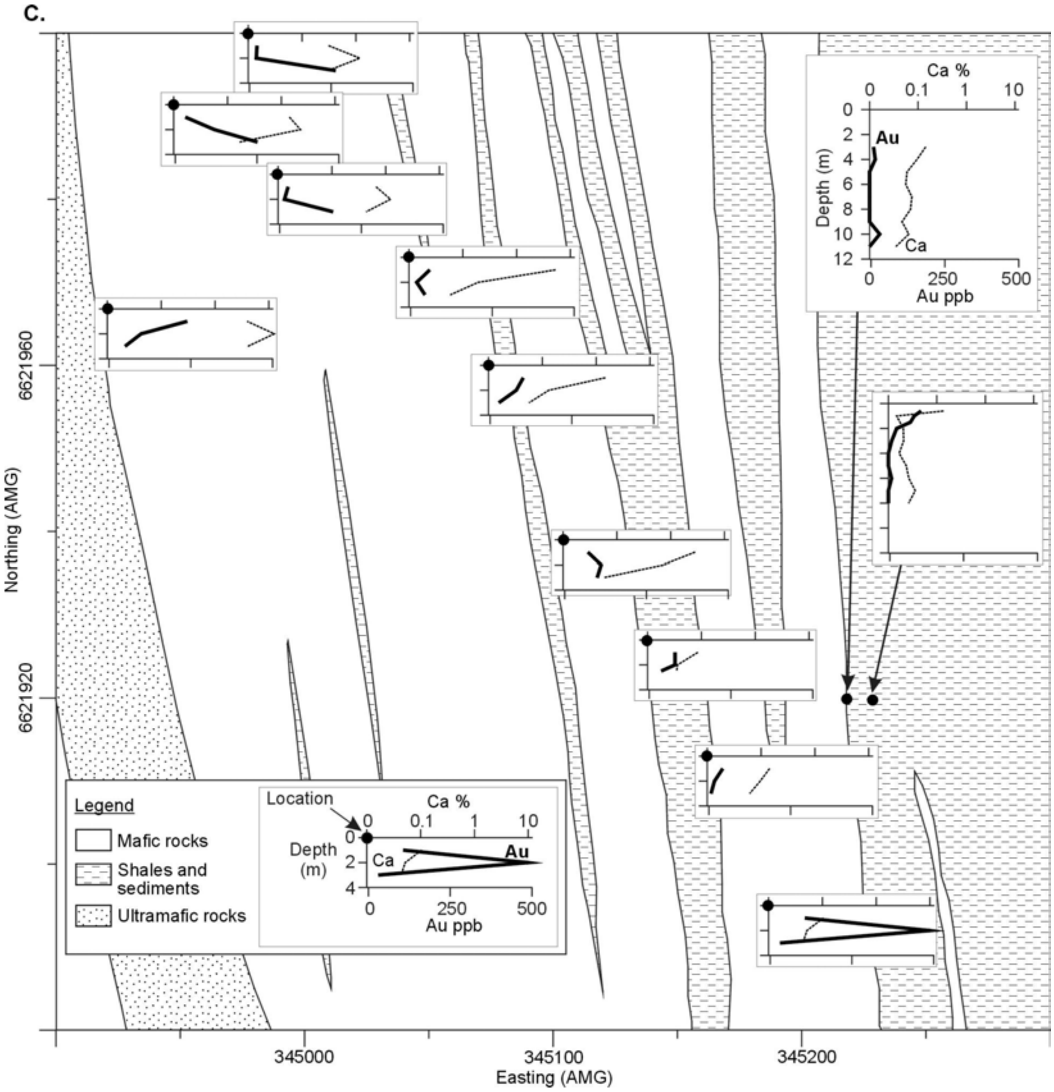

Figure 6.22 (contiuned): Geochemistry and geology at Panglo. C) Geochemical profiles of Ca and Au in relation to the geology.

material and weathered bedrock, and (ii) in nearby outcropping saprolite where Au peaks at 910 ppb (grab sample from trench). The interpretation for the source of the Au in the calcrete is equivocal, since it might be sourced from any of three locations: (i) the underlying mineralisation, (ii) the adjacent saprolite material, or (iii) the unconformity. The argument against hypothesis (ii) is that, because the saprolite in this area is mostly physically-located downslope, it cannot be the source of the Au in the soils above the palaeochannel; besides, soils directly over the saprolite are lower in Au. However, further detailed work investigating the geochemistry, three dimensional regolith structure and detailed topography of this area is required.

In other studies at Panglo (Lintern and Scott 1990, Lintern 1996b), the composition of soils and the upper regolith was examined in a Type B (saprolite) area where truncation to the mottled zone had taken place (boxed area on Figure 6.22A, and C). The strong relationship between Au and alkaline earths, noted in 0-0.01 m soils (Figure 6.22B), was examined in more detail in drill cuttings and grab samples from trenches. Data indicate that the relationship between Au and the alkaline earths is weak and is probably influenced by particulate Au present within nodular mottles or weathered rock of the saprolith, some of which has been affected by calcrete and some of which has not (Figure 6.22C). Thus samples of regolith material containing high Au concentrations (>100 ppb) when sub-sampled did not show any particular affinity for Ca or Fe (Table 6.2). The presence of Au in the upper saprolite is a relic from deep weathering that has survived leaching by being partly armoured by secondary mobilisation and precipitation by Fe and Si (c.f Runway case history). The nodular mottles and weathered rock may be an important source of Au found in the soil and calcrete.

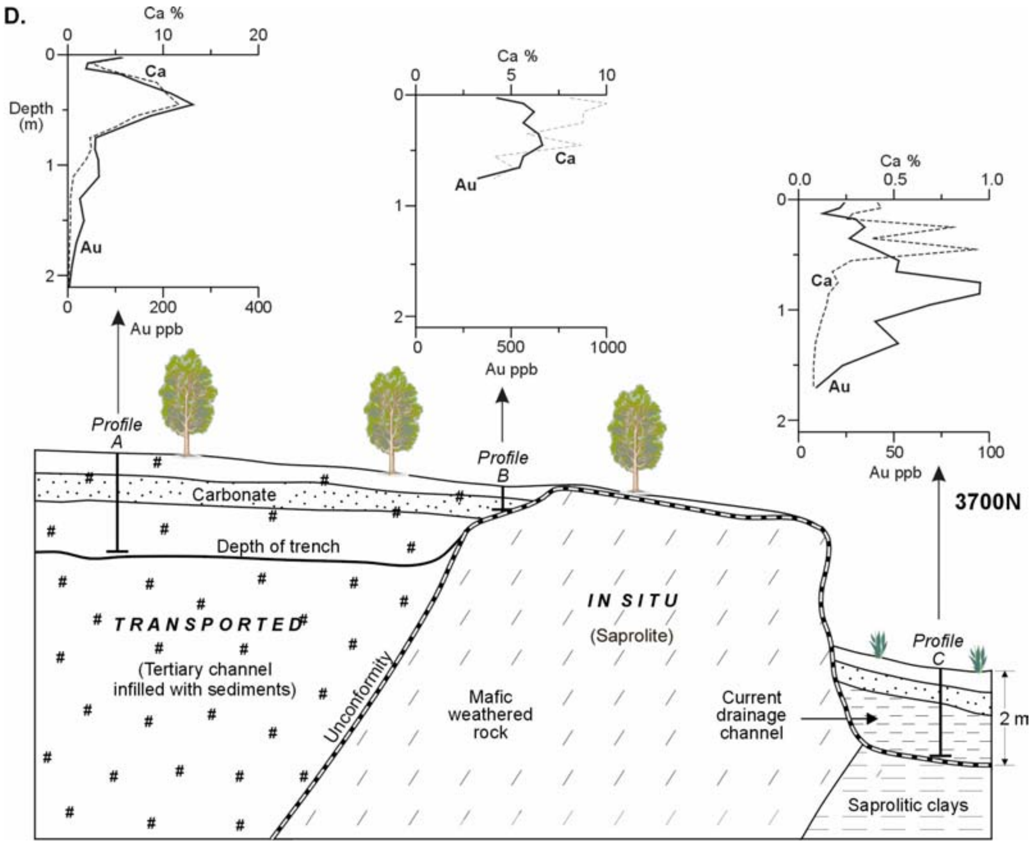

Figure 6.22 (contiuned): Geochemistry and geology at Panglo. D) Trench section showing regolith and geochemistry of profiles.

Table 6.2: Gold, Ca and Fe concentrations in the coarse fraction (>1000 (m) of selected near-surface samples collected near 4200N over mineralisation. Note the poor correlation between Au and Ca or Fe.

Sample	Number	N	E	Depth (m)	Fe (%)	Ca (%)	Au (ppb) bulk	Au (ppb) +1000 µm
09-3679	1	6621967	344920	1.5	11.4	12.58	102	75
09-3662	***2***	***6621939***	***345104***	***2.5***	***9.47***	***0.06***	***103***	***309***
09-3663	3	6621960	345074	0.5	9	1.47	105	96
09-3681	4	6621920	345228	0.3	12.6	0.14	106	14
09-3651	5	6621895	345187	0.5	10.7	0.11	110	113
09-3661	6	6621939	345104	1.5	14.5	0.72	115	260
09-3676	7	6621992	344947	1.5	13.7	2.25	123	42
09-3671	***8***	***6621983***	***344989***	***2.5***	***11.4***	***0.43***	***166***	***349***
09-3680	9	6621967	344920	2.5	3.72	3.96	241	93
09-3677	***10***	***6621992***	***344947***	***2.5***	***14.2***	***0.17***	***253***	***376***
09-3674	***11***	***6622000***	***344977***	***2.5***	***11.6***	***0.30***	***264***	***369***
09-3652	***12***	***6621895***	***345187***	***1.5***	***6.73***	***0.05***	***485***	***742***

(20) Zuleika, Kalgoorlie, WA (Lintern and Butt 1992)

The Zuleika Sands Gold Mine is located about 50 km WNW of Kalgoorlie and approximately 18 km due S of Ora Banda. The climate is semi-arid. Ora Banda has short cool winters and long hot dry summers. January is the hottest month (average maximum of 35°C) and July the coldest (average maximum of 16°C). Mean evaporation is about 3000 mm, and monthly evaporation exceeds rainfall for 10 or 11 months of the year. The annual rainfall is 275 mm but may vary from 100 mm to 500 mm, with more than half falling during winter.

Vegetation is mainly comprised of open woodland. The floodplain has patchily distributed *Eucalyptus salmonophloia* (salmon gum), with some specimens over 15 m in height, and other eucalypts less than 15 m. The groundcover is comprised mainly of chenopod shrubs, e.g. *Maireana* (bluebush) of less than 0.5 m height. A thickly vegetated area of closed woodland of *E. salmonophloia, E. salubris* (gimlet), *Acacia* (mulga), and *Casuarina* (sheoak) occurs on 4200N (Figure 6.23A). It is several hundred metres in length and breadth and comprises a topographic low where run-off probably collects and remains for longer periods than on the surrounding floodplain. The inferred abundance of soil water enables the development of a larger vegetative biomass. The ground is covered by considerable quantities of mull ranging from decaying leaves and branches to whole trees.

Primary mineralisation in the Zuleika Mining Centre about 1 km to the N of the Zuleika Sands Gold Deposit is hosted by high-magnesian basalts and commonly associated with shear zones, e.g., at the Zuleika South Pit. Strong soil Au geochemical anomalies occur in clay- and/or carbonate-rich soil developed on at least ten metres of poorly mineralised and depleted saprolite overlying primary mineralisation. The regional geology has been described by Harrison *et al.* 1990. Investigations were undertaken at the Zuleika Sands palaeochannel deposits to the S of the Zuleika South Pit. The source of the supergene mineralisation in the palaeochannel has not been determined, although the mineralisation at Zuleika South is an obvious candidate (Figure 6.23A). Some sub-economic mineralised zones exist within the palaeochannel sediments, but the highest grades seem to occur at the unconformity between the basal sands and the underlying weathered units. In addition, some high grades of mineralisation have been identified well below the unconformity.

The palaeochannel at Zuleika Sands runs approximately parallel to the regional strike. The base of the palaeochannel at the study location is between 15 and 20 m below the present land surface, which is in an active floodplain. A subdued spur of saprolite marks the western limit of the residual regolith, and a simple projection to the axis of the channel indicates that the palaeochannel has a very steep eastern "bank". The palaeochannel is infilled by sands and clays that have been weathered since deposition (Figure 6.23B).

The total study at Zuleika involved the description and collection of drill cuttings, soils, vegetation and lags from four traverses 500-600 m in length and spaced 170-290 m apart, and soils from a series of soil pits. All four traverses crossed W to E from transported overburden in the floodplain (Type T) and underlying palaeochannel to saprolite-dominated regolith (Type B) on the margins. Only results for the traverse on 4200N are reported here.

The soils of the floodplain have been studied in the most detail. They are predominantly red to red-brown clay, ranging in texture from sandy-silty in the top-soil (0 - 10 cm) to uniform platy-blocky clay in the sub-soils. Within the top two metres, there are one or more distinct sedimentary lenses, each a few centimetres in thickness, consisting of rounded (transported) ferruginous gravels and other material (e.g., quartz, basalt). Modification of the top metre (at least) of the sub-soils has taken place to varying degrees by recently-deposited carbonate. The carbonate takes on the form of powdery coatings (<1 mm thick) on soil particles and, where the sub-soil is indurated, as precipitates on partings (>1 mm thick). Denser pockets of carbonate do occur and can be spatially related to the sedimentary, ferruginous gravel horizons. In addition, within the first five metres of the profile, there are indurated (lateritized) horizons consisting of hard, homogenous clay and ferruginous segregations. A prominent feature of the sub-surface clays (2 - 5 m) is the presence of dark grey-green and some paler mottling. This suggests the clay is partially reduced and indicates that percolating rainwater has been de-oxygenated, possibly by respiration of micro-organisms. The soils of the subdued spur are comprised of a heterogeneous mix of residual sands, silt and gravels that grade into saprolite within the top two metres. Soils are pale coloured and have been highly modified by carbonate which commonly occurs as large indurated nodules often containing a core of saprolite. There is a considerable segregation of the sub-soil which is comprised of ferruginous and siliceous nodules and fragments. Further east of the spur, residual soils consist of sandy topsoil and a brown clay-rich loam sub-soil. The top metre has been modified by introduced carbonate that occurs as coatings on, and soft segregations within, the clay. The soil grades into ferruginous segregations similar to those in the sub-soils of subdued spur, which suggest the two soils have similar origins and have developed on a similar substrate.

Sampling of drill cuttings indicates that there is no clear or discrete Au anomaly over the mineralisation in the palaeochannel, and the highest concentrations (90 ppb) are present in residual soils developed in saprolite E of the channel, probably over minor mineralised zones (Figure 6.23C). Detailed investigations of these soils, (e.g. profile K), indicate that Au concentrations (200 to 300 ppb) are directly related to those of Ca and Mg in calcrete. However, such correlations between Au and the alkaline earth metals are not apparent in soils developed on the floodplain sediments (profiles G, H, I and J). In the floodplain, where there is less calcrete and generally much lower Au, some of the Au appears to be associated either with other soil components, or be randomly distributed. In profile H, for example, a highly anomalous concentration of 910 ppb Au is probably due to particulate Au.

For soils in the floodplain, directly overlying mineralisation, the origin of Au is uncertain but could realistically come from two possible sources: (i) the relatively high Au contents in residual soils to the E (e.g. profile K), and (ii) the Au mine approximately 1 km upslope to the N. Both represent sources

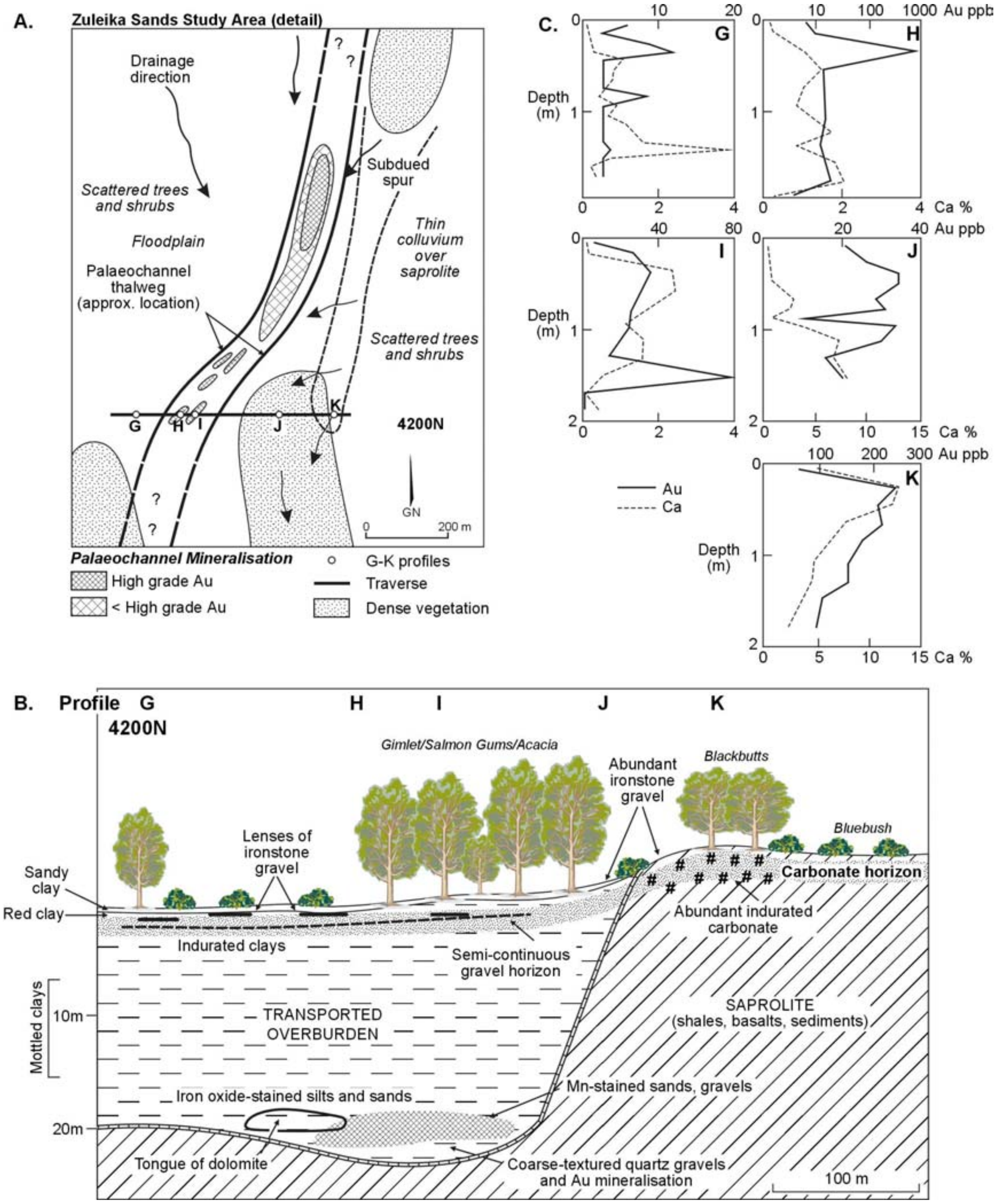

Figure 6.23: Gold distribution and regolith stratigraphy of the Zuleika Sands Gold Deposit. A) Plan showing location of sampling traverse. B) Section through palaeochannel showing mineralisation, regolith and profile location.

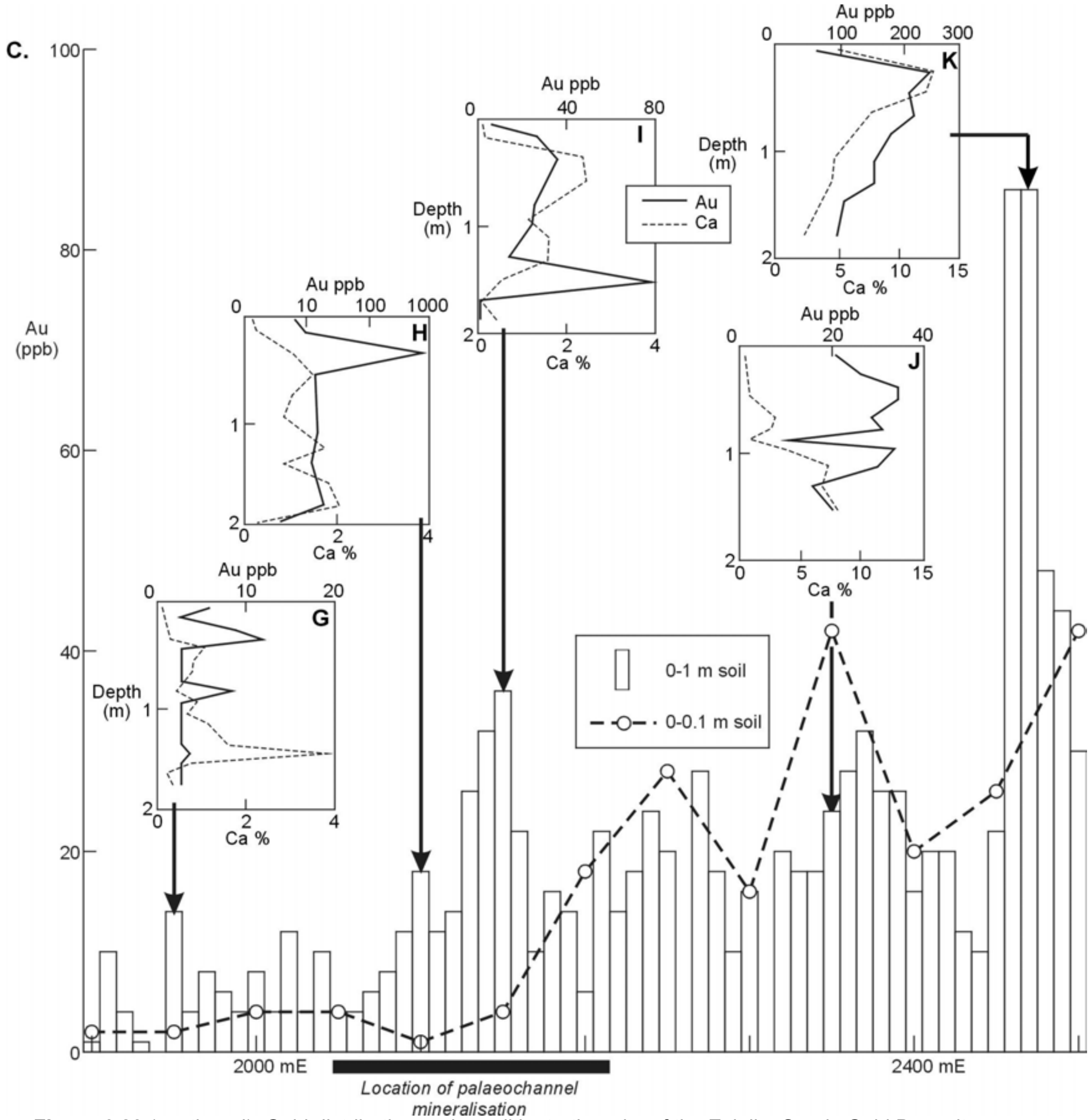

Figure 6.23 (continued): Gold distribution and regolith stratigraphy of the Zuleika Sands Gold Deposit. C) Geochemistry of soil profiles, soils and 0-1 m drill cuttings.

for detrital Au-rich materials that may have been deposited in the floodplain. The poor correlation between Au and Ca in the soils may be partly explained by the recent deposition of these materials, so that chemical re-working of the Au dispersed in the soil to the calcrete has not yet occurred. The case study is similar to Steinway and Higginsville in that the origin of the Au is probably from upslope. At Zuleika, much weaker "Au in calcrete" anomalies are developed despite the shallow depth to mineralisation.

(21) Ghost Crab Gold Deposit, Kalgoorlie, WA (Miller *et al.* 1999).
The Ghost Crab Gold Deposit is located about 15 km SW of the Steinway Gold Prospect. Transported material reaches thicknesses of about 25 m. Initially, a Au anomaly (defined by the >20 ppb contour) in the soil associated with mineralisation peaked at 57 ppb with a N-S strike length of 1.1 km (Figure 6.24). More detailed sampling of the soil was undertaken using a power auger and targeted the calcrete horizon. The maximum Au concentration in calcrete was 550 ppb Au about 200 m to the NE of the current pit boundary (Miller *et al.* 1999). The contoured soil anomalies changed their shape and direction as the density of sampling is increased, and the mineralised trend (N-W) became known from the aeromagnetic data. The final maximum concentration of Au over mineralisation was 134 ppb and was located in residual soils in what is now the SE of the open cut (Figure 6.24).

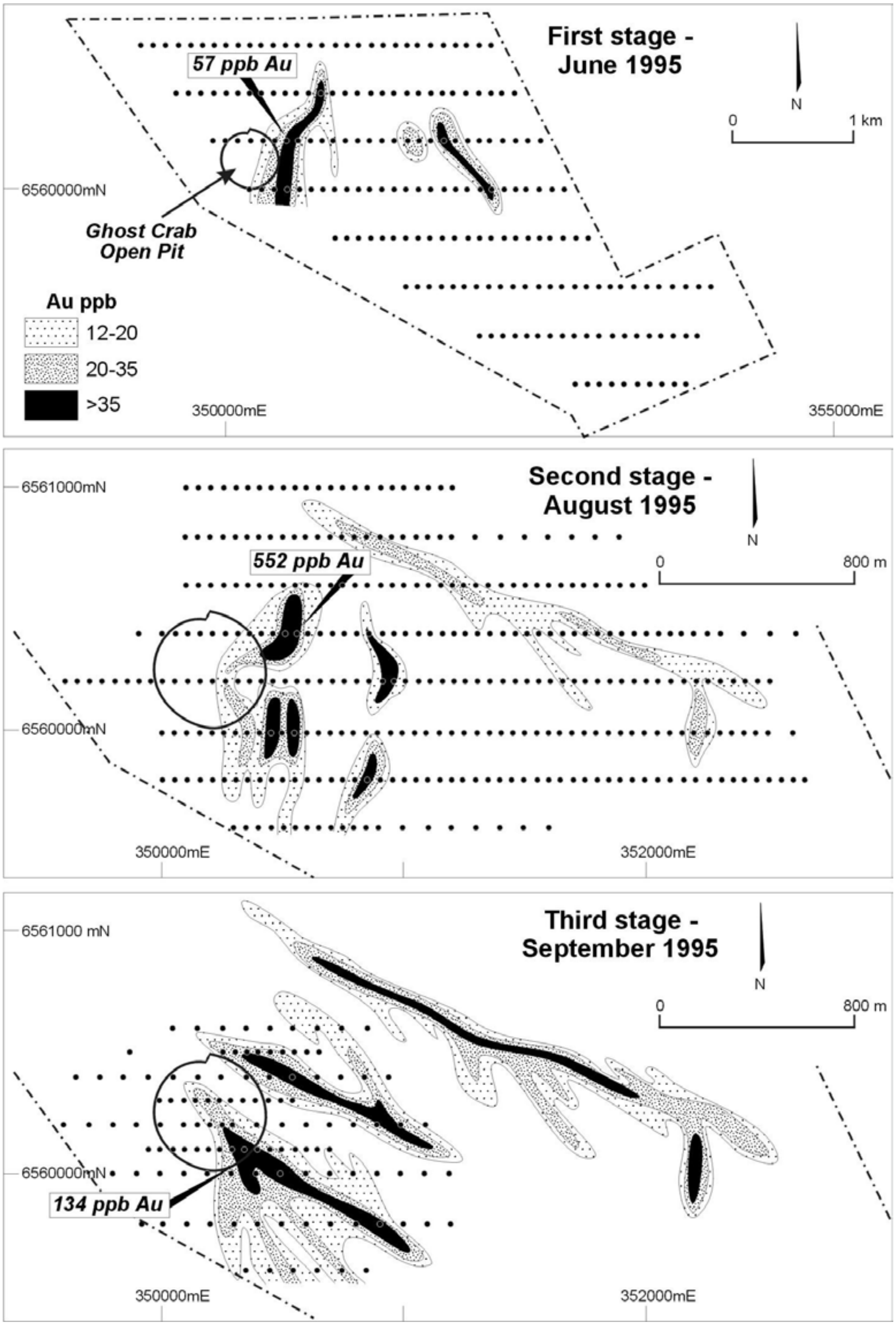

Figure 6.24: Series of plans showing the evolving location, shape and orientation of the Au anomalies as sample density increases at Ghost Crab Gold Deposit (after Miller *et al.* 1999).

No detailed research into the nature of the anomaly has been undertaken, but it is understood that Miller and colleagues have interpreted the surface expression as due to mechanical/chemical dispersion from upslope residual soils that lie on the same mineralised trend as the Ghost Crab Deposit itself. Part of the anomaly extends over the deposit buried beneath in excess of 25 m of Cainozoic sediments. The terrain is very similar to that found around Steinway, where results suggest the anomaly is due to detrital Au and not produced from the underlying mineralisation. In addition, as with the Steinway area, not all the anomalies drill-tested have mineralisation beneath them.

(22) Marigold Gold Deposit, Nevada (Smee 1998).

The Marigold Mine is located in Nevada, 30 km NW of Battle Mountain (Figure 6.25A). The Marigold deposits lie within the Basin and Range physiographic province of NW USA, a region of generally N-trending mountain ranges separated by broad alluvium-filled valleys. The area is semi-arid with an annual rainfall of 150 mm. Smee (1998) reported that the tan to grey silty sandy matrix shows little horizon development, with the exception of a poorly developed pedogenic carbonate layer. The valleys are sparsely vegetated with mesquite, greasewood, bunchgrass and shadscale.

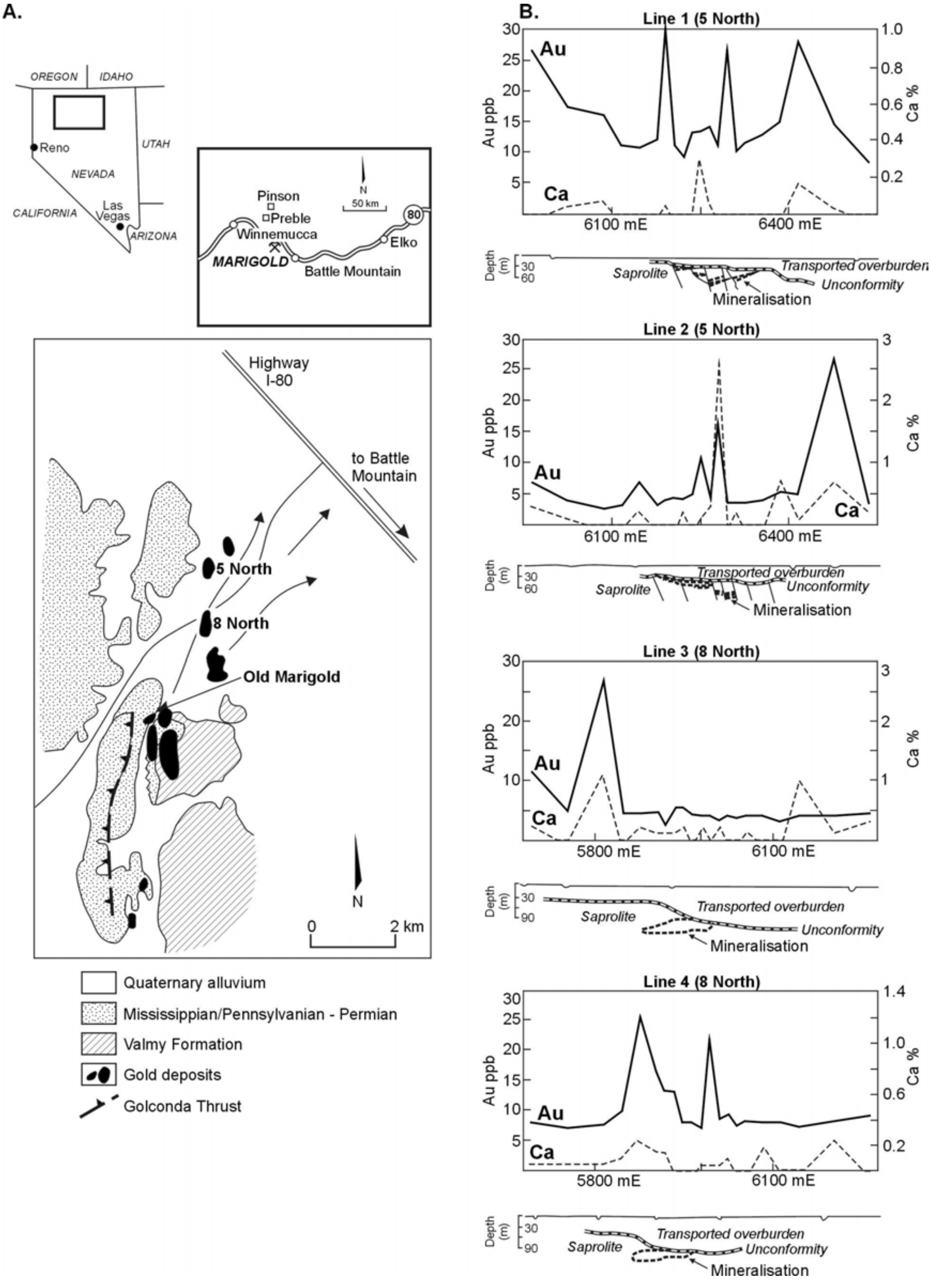

Figure 6.25: Gold distribution and stratigraphy at the Marigold Gold Deposits (after Smee 1998).

Clastic rocks of the Valmy and Antler sequences host the Marigold deposits, which are orientated approximately N-S. The Antler sequence is of Permian age, hosts the 8 North and 5 North deposits, and is composed of coarse conglomerates and sandstone that grade upward into limey mudstone, shales, siltstone and sandstones. Mineralisation is controlled by N-trending faulting and NW striking zones of fracturing. The 8 North mineralised body is approximately 300 m by 170 m in plan view. Overburden, consisting of alluvial and fluvial outwash of Tertiary age and inter-layered lacustrine clay, covers the 8 North deposit to a depth of about 100 m. The 5 North body is covered by 20-50 m of alluvium and is hosted by debris flows and siltstones, with minor limestone.

A geochemical survey involving four traverses (two over each deposit) was conducted at 8 and 5 North. A variety of partial extraction, "total" element digestion and other chemical techniques was used to identify whether there is a surface expression to mineralisation. Calcium and Sr are correlated with total soil Au and produce positive one-sample anomalies, in some cases over mineralisation (Figure 6.25B). Double peak or "rabbit ear" anomalies for total Sr and acetate-extractable Ca occur over mineralisation (Smee 1998). Smee proposes that the alkaline earth distributions may be attributable to an element migration involving the release of H^+ ions (during sulphide oxidation) and migration of H^+ or CO_2 (after reaction of the acid with carbonate wall rock) to the surface. At the surface, these components react with carbonate and Fe/Mn oxides causing disequilibrium and subsequent migration of elements away from the stimuli and towards ambient pH. At the margins of the stimuli the mobilised elements are re-precipitated forming the "rabbit ears".

Smee (1998) concluded that the analysis of Ca, Au, As and Sr in closely spaced soil samples in alkaline environments is recommended for these types of buried deposits. In a follow-up article Smee (1999) provided data suggesting that the pH of hydroxylamine extracts of soils could be used as an indicator of buried mineralisation. The data indicated that higher pHs are recorded for the "rabbit ear" samples. The author visited the site in 1999 and was of the opinion that further testing should be undertaken,e.g., to test sample site variability, carry out detailed regolith landform mapping and sample further traverses to form a grid. This would help to exclude other plausible explanations for the observed variation in the data, for example drainage from the ranges and mine areas.

(23) Steinway, Kalgoorlie, WA (Lintern and Gray 1995a, Lintern and Craig 1996)

Steinway is located about 27 km SSW of Kalgoorlie. The climate is semi-arid with mean annual rainfall of about 280 mm. Vegetation consists of open woodland of *Eucalyptus* and a sparse understorey that includes *Maireana* (bluebush). The Steinway Au prospect is located beneath a depositional plain, with few areas rising 5 m above it. To the S, an erosional area composed of mafic saprolite hosts the nearby Penfold Gold Mine, and to the SE a palaeochannel hosts the Greenback Gold Deposit. Present day ephemeral channels cross the depositional plain, generally flowing N to White Lake, a playa about 10 km distant. Ephemeral channels split the Steinway-Penfold Au anomaly found in soil (Figure 6.26A).

The Steinway prospect is located adjacent to the regional contact between mafic-ultramafic rocks of the Saddle Hills Greenstone Belt, and the overlying intermediate to felsic volcanic and sedimentary rocks of the Black Flag Group. Mineralisation at Steinway is buried beneath at least 25 m of Cainozoic sediments and is of two types: supergene mineralisation located below a palaeochannel, and deeper primary mineralisation associated with quartz stockwork veining within mafic andesites/amphibolites (Figure 6.26B).

The regolith consists of an uppermost unit of calcareous, clay-rich red soil with abundant ferruginous granules overlying a non-calcareous red clay containing large amounts of ferruginous granules between 2-5 m depth (Figure 6.26B). Beneath this, massive clays between 5-25 m depth containing strongly mottled zones of Fe-rich material occur. These in turn overlay a basal sand and silty-clay unit, between 25-30 m depth. The residual regolith profile consists of saprolite, becoming more clay-rich towards the top, and is about 20 m thick. Fresh rock is encountered at about 50 m depth.

Analysis of a soil profile located above mineralisation shows that Au concentration gradually increases with depth, whereas Ca and Mg concentrations sharply increase and then decrease (Figure 6.26E). Gold and Ca are probably associated in the upper horizons. Iron concentrations gradually increase with depth and, below 0.5 m, Au and Fe appear correlated. The Au anomaly (>24 ppb) in the 0-1 m composite samples from Steinway reaches 150 ppb against a background of less than 20 ppb (Figure 6.26C). The anomaly is over 150 m wide in an EW direction and stretches over 1 km to the NW,

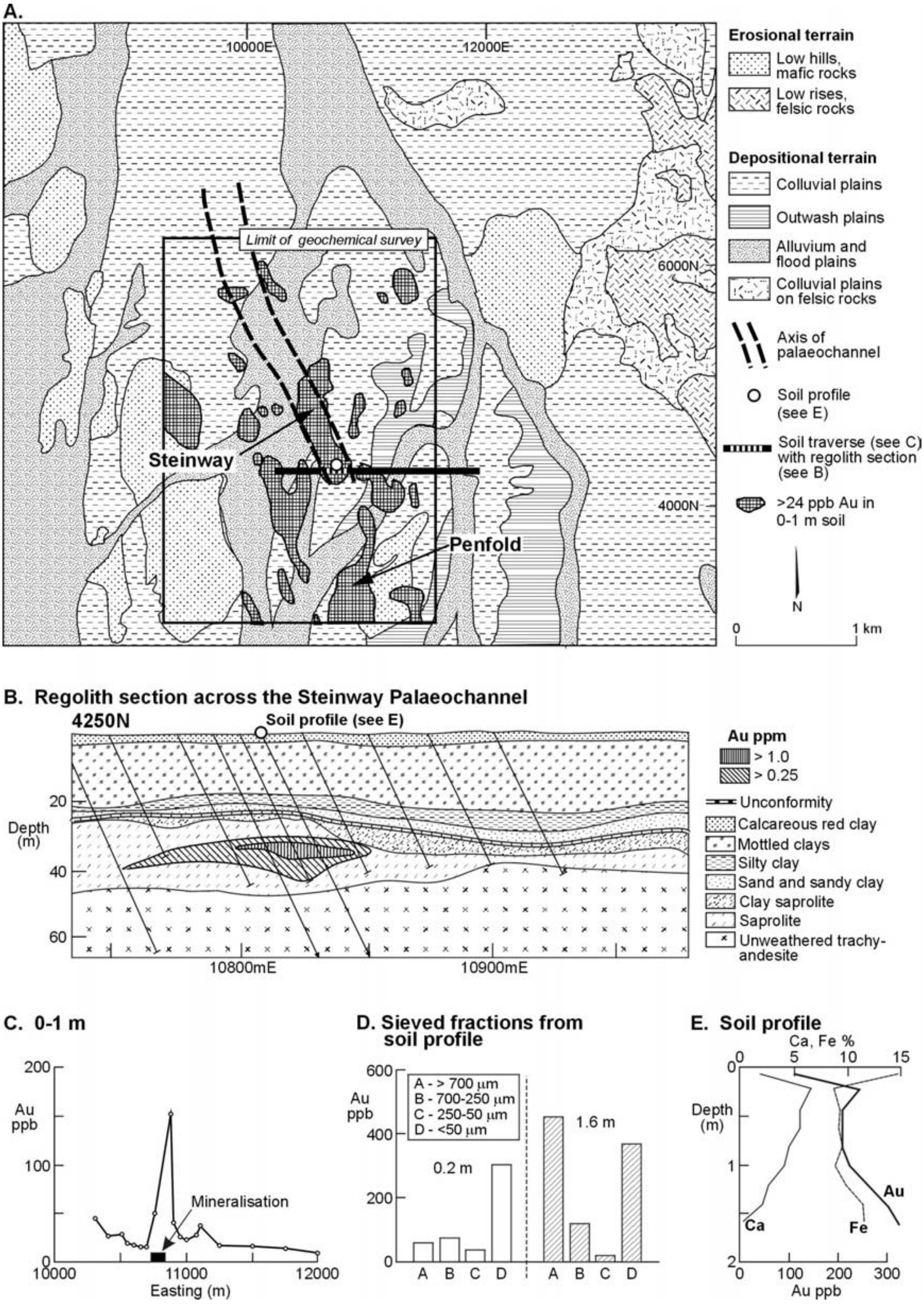

Figure 6.26: Geochemistry and regolith at Steinway. A) Plan of regolith landforms. B) Regolith section across the Steinway Palaeochannel. C) Distribution of Au across Steinway mineralised zone. D) Gold concentration in different size fractions for two samples taken from the soil profile. E) Soil profile geochemistry.

following the direction of the palaeochannel. There are also high concentrations of Au (maximum 107 ppb) in the coarse, ferruginous fractions of the soil in the same area. The distribution of Au in 0-1 m composite soil samples appears, at first, to be related to underlying mineralisation. However, broken pisoliths and other transported fragments from upslope, and the random concentration of Au in the ferruginous granules, suggest that the apparent association may be coincidental. This was investigated further. Ferruginous granules from 1.6 m depth were wet-sieved into four size fractions: > 710 µm, 710-250 µm, 250-53 µm and < 53 µm. The coarse fraction (> 710 µm) representing 10.6% of the total weight of the sample had the highest Au concentration at 450 ppb, 17% of the total mass of Au. Most of the Au (80%) is found in the fine fraction (> 53 µm) (Figure 6.26D). The ferruginous granules had lithic fabrics (related to basement rocks) suggesting a transported origin. Individual ferruginous granules had visible Au and concentrations up to 15 ppm. Paradoxically, at Greenback Gold mine about 400 m to the W, containing about 50000 ozs of Au, Au is located higher in the profile (in the sediments themselves, and with a palaeochannel stratigraphy similar to Steinway), but there is no Au anomaly in the soil above it.

The Steinway case study is similar to that at Higginsville. At both sites, the results suggest that the ferruginous granules are the immediate source of Au in the soil, and that the Au and the granules are sourced via mechanical dispersion from laterally upslope, rather than vertically from underlying buried mineralisation. The Au in the calcareous unit of the soil is probably derived from either (i) the ferruginous granules, which have weathered and released Au that has migrated by capillary action over 1 or 2 metres vertically, or (ii) direct chemical dispersion from a similar upslope source as the ferruginous granules themselves. In regolith dominated by thick palaeochannel sediments, such as Steinway, results indicate that there is probably no causal link with underlying mineralisation and that sampling of soil including calcareous material, at best, may indicate the exploration potential of the (sub)catchment. It is suggested, therefore, that for such landscape regimes, wider auger sampling intervals should be used (to indicate the potential of mineralisation in the catchment). Deeper samples, including basal sediments and/or ferruginous saprolite, should be collected when exploring for palaeochannel-related mineralisation.

(24) Kanowna QED, Kalgoorlie, WA (Dell 1992, Anand *et al.* 1993)
To the N of the Kanowna Belle Gold Deposit is an area known as QED (Figure 6.27A). This is the locality of many of the famous "deep leads" palaeochannel deposits that were mined by individual and small groups of miners in the late 19th and early 20th centuries. The ore they were chasing was located in the quartz boulders, gravels and sands found at the base of the palaeochannels. Recently, these deposits have been mined in open cuts to supplement the reserves from nearby underground operations mining primary Au.

A regolith profile from the NLP9 pit located in the palaeochannel system was studied. The regolith consists of 0.2 to 0.4 m of red to brown calcareous soil overlain by a medium to fine polymictic lag of abundant ferruginous gravels, vein quartz and lithic fragments. The soils lie above a 1 to 4 m thick horizon of pale orange calcareous clay. The unit contains multiple lenses of bedded and graded alluvium from streams that have cut channels in an underlying clay unit (2 to 5 m thick), also containing polymictic gravels. Bleaching and incipient mottles are developed within the Fe-rich clays and mark the transition into the (mini-)mottled zone (Figure 6.27B). A zone containing larger mottles 10 to 25 cm long with black ferruginous granules in turn underlies this (mega-mottled zone). The mottled zone becomes completely bleached with depth. A pisolitic greenish-grey clay, coarse quartz-rich basal gravels (unconformity) and weathered Archaean saprolite occur beneath the bleached zone (Figure 6.27B).

Gold is concentrated in the calcareous clays (up to about 200 ppb) and in the mottled zone (about 300 ppb) (Figure 6.27B). No further work was performed on the soils to identify which fraction hosted the Au. The concentrations are similar to those found at Kanowna Belle to the S but the depth to mineralisation is only 30 m in the sediments at NLP9 (the deep lead) compared with 50 m for the former. The thickness of transported material is also much greater at NLP9. Unlike Kanowna Belle, there is no shallow source of Au (such as the silcrete at 8 m depth at Kanowna Belle). It is unlikely that the soil Au enrichment is derived from the mottled zone as concentrations are similar. A lateral source of Au is more probable.

(25) Mulgarrie, Kalgoorlie, WA. (Gray 1992).
The Mulgarrie Gold Deposit is located 40 km N of Kalgoorlie. The climate is semi-arid with average rainfall of about 250 mm predominantly occurring in winter. Pan-evaporation at 2700 mm is well in excess of rainfall. Vegetation is open woodland of eucalypts with a sparse understorey including *Acacia*, *Eremophila* and *Casuarina*. The landscape relief is subdued with ephemeral drainage.

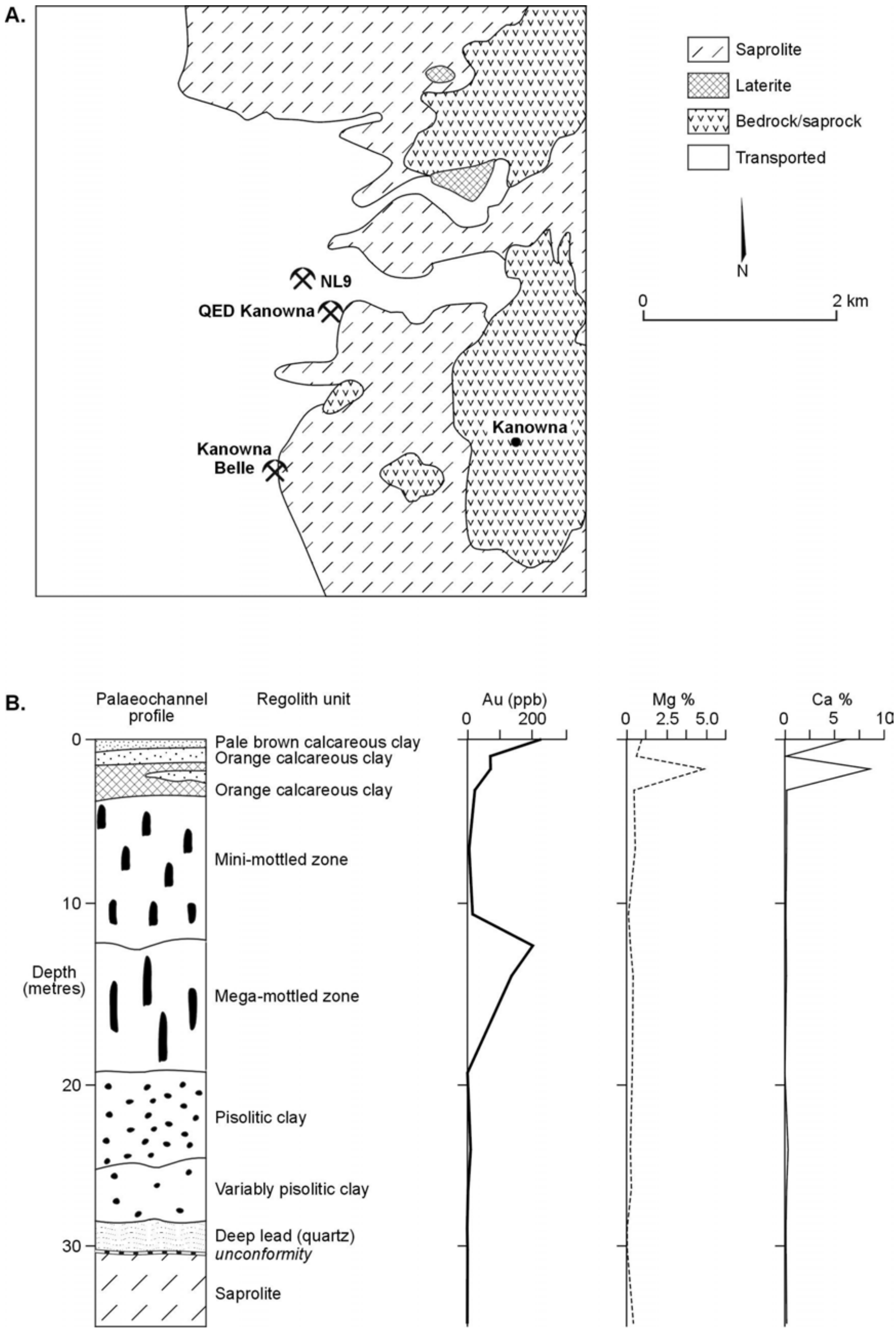

Figure 6.27: Gold distribution and regolith at the NL9 pit, Kanowna QED Gold Deposits (after Dell 1992). A) Regolith map showing location of QED an NL9 Au deposits. B) Regolith profile showing Au, Mg and Ca concentrations.

The main deposit occurs within mafic and ultramafic rocks of the Mulgarrie-Gordons greenstone belt on the eastern side of a granitic batholith. The regional strike is NW, dips are steeply E and metamorphic grade is lower greenstone facies. Locally, the stratigraphy consists of massive blocky tholeiitic basalts, overlain by a thinner pile of komatiites that show a highly variable mineralogy both laterally and vertically. Two open pits access the mineralisation. South of the Palm Pit, strong serpentinisation of the komatiites has occurred, whereas the upper, komatiitic basalts have been intensely carbonated. In the Palm Pit, high-grade Au mineralisation (5-100 ppm) is associated with quartz vein sets trending NE and dipping between 40-70^o NW. The quartz sets consist of a high density network of narrow, 1-10 cm sub-parallel quartz veins and stringers, hosted by an intensely carbonated talcose ultramafic rock. The host rock is also weakly mineralised, but Au concentrations rarely exceed 1 ppm in one metre samples. In the Trial Pit (located 200 m NW and downslope ofPalm), weathered ultramafic rocks are covered by a palaeochannel with 35 m of transported overburden. The transported overburden is typical of palaeochannels in the Kalgoorlie area, consisting of a sequence of a calcareous red-clay soil, variably mottled zone of clay-rich alluvium/colluvium, quartz sands and quartz-rich basal conglomerates.

Three holes were drilled between the two open pits. RAB cuttings were sampled and analysed for Au and alkali earth metals. Gold concentrations exceed 400 ppb in hole MC500. In the upper 5 m, there is a strong correlation between Au, Ca and, to a lesser extent, Mg (Figure 6.28). Varying proportions of carbonate occur as calcite, dolomite and magnesite in the upper regolith. The top metre is dominated by calcite whereas dolomite is more prevalent in the next 2-3 metres. Below this, magnesite is present particularly in hole MC 529 where Au is present in minor amounts.

The origin of the Au present in the upper regolith is equivocal since the study was limited to just three drill holes. The surficial Au is probably laterally sourced from the upslope Palm Pit area. However, vertical mobilisation from the underlying basement mineralisation at 25-40 m depth (including the interface between the transported and the basement) though unlikely cannot be discounted.

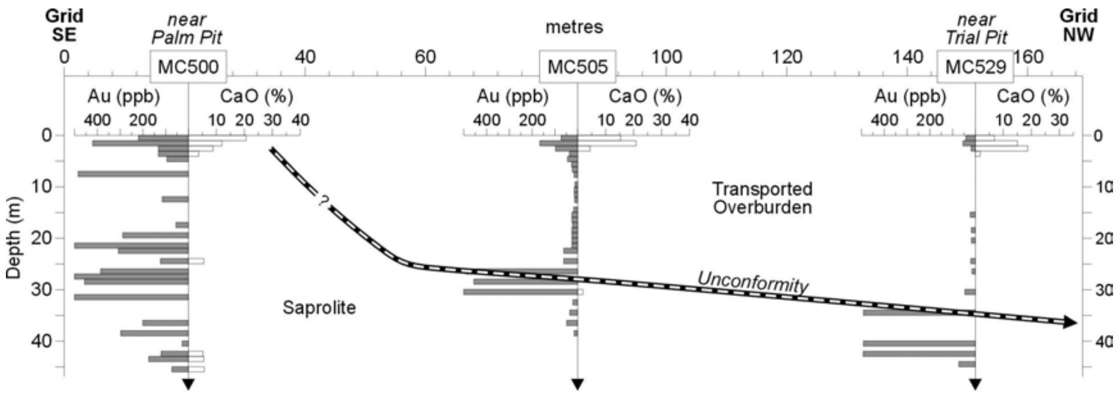

Figure 6.28: Gold and alkaline earth concentrations of 3 drill holes from the regolith at Mulgarrie (after Gray 1992).

(26) Wollubar-Enigma, Kalgoorlie, WA (Lintern and Gray 1995d)
Wollubar-Enigma is located about 35 km SSE of Kalgoorlie. The climate is semi-arid with an average annual rainfall of about 280 mm. Vegetation is sparse and consists of open woodland of *Eucalyptus* with *Eremophila* (poverty bush), bluebush and other small shrubs. The area has been extensively de-forested in the past, and there is a considerable groundcover of grasses. The site is on a flat, depositional plain with some development of ephemeral drainage in the W of the study area.

The deposit is located within part of the Archaean Wiluna-Norseman Greenstone Belt. Bedrock consists of high Mg basalts, some with pillows and variolitic textures, and sedimentary, felsic volcanic and volcaniclastic rocks of the Black Flag Group. Bedrock has been regionally metamorphosed to upper greenschist - lower amphibolite facies. The N-S trending Mt Hunt fault runs though the prospect, and the Au-bearing Boulder-Lefroy Shear occurs 4 km to the W. Primary Au mineralisation at the Wollubar-Enigma prospect is associated with sericitic schist. Supergene mineralisation is present in sub-horizontal enrichment zones in sands at the unconformity between the transported overburden and residual materials.

The study area is located in the large Wollubar Palaeochannel, which is infilled by clays and sands. Within the channel, the largely stripped residual weathering profile is covered by some 55 m of sediment. From the top of the regolith profile, reddish clays occur between 0-15 m depth. The soil consists of a sand-rich upper horizon (0.1 m thick) containing abundant ferruginous granules. Carbonate infuses the top 1-2 m of the red clays. The clay-rich horizon contains Fe-rich granules and pisoliths. Pale (cream, yellow and pink) clays occur from 15 m depth to the base of the palaeochannel, with some grey-coloured reduced clay present below 35 m depth. Rounded to sub-rounded sand grains may be sieved from the clays from 20-55 m depth. The saprolite is clay-rich beneath the unconformity, and is increasingly indurated with depth, with saprock at about 90 m depth.

A limited geochemical study was undertaken at Wollubar-Enigma, targeting soil, vegetation, ferruginous components in the transported cover, and material from saprolite and saprock. Soil was sampled by augering to a depth of 1 m on an EW traverse over mineralisation. Sediment, saprolite and saprock samples were collected from RC drill cuttings. Only soil data are reported here.

There is no evidence of anomalous Au at the surface across mineralisation. In general, Au concentrations are low for the region, averaging about 12 ppb (Figure 6.29). The maximum Au concentration is 25 ppb and several samples, some directly over mineralisation, are below detection (less than 5 ppb). Calcium and Mg are evenly distributed over most of the traverse, with the highest concentrations of Ca towards the W. Normalising Au with respect to Mg or Ca does not produce any significant trends. The results of this case study provide further evidence for the masking of buried mineralisation beneath thick overburden.

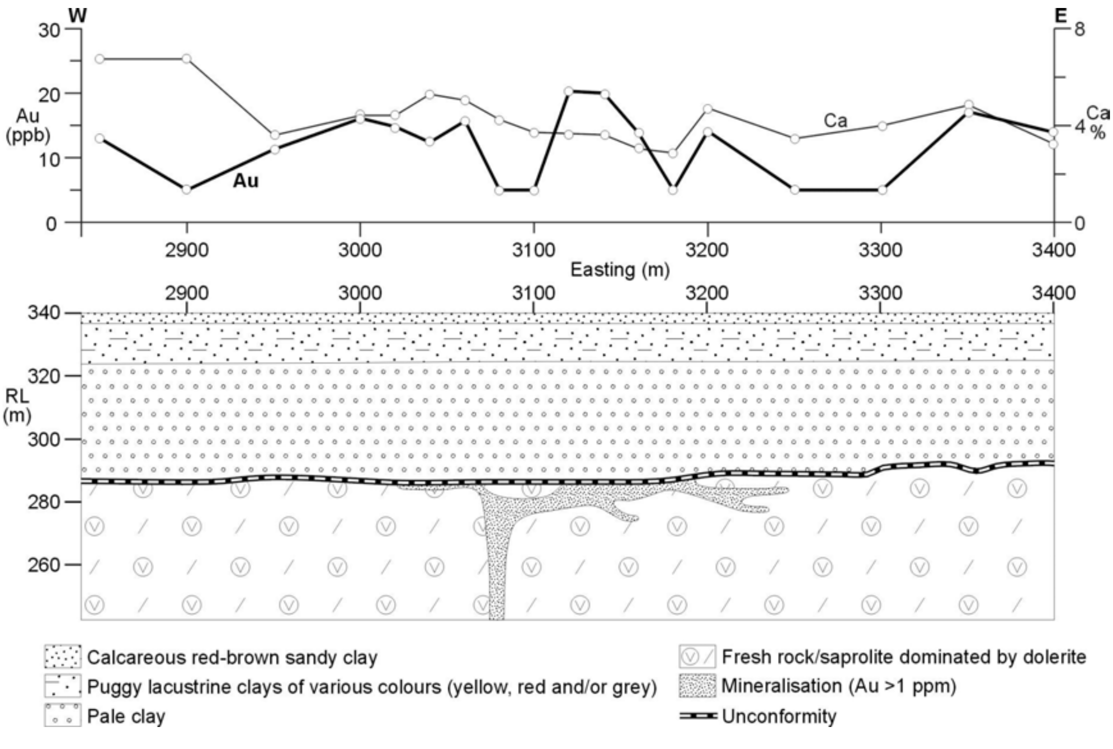

Figure 6.29: Geochemistry and regolith stratigraphy of the Wollubar-Enigma Prospect.

(27) Higginsville, Kambalda-Norseman, WA (Lintern *et al.* 1996).
The Higginsville Gold Deposits are located 120 km S of Kalgoorlie. The climate is semi-arid with an average annual rainfall of 270 mm. The vegetation at Higginsville consists of open woodland dominated by Eucalyptus and Melaleuca. Small shrubs including *Maireana* (bluebush), *Cratystylis conocephala* (false bluebush), *Atriplex* (saltbush) and *Eremophila* (poverty bush) comprise the understorey. The study area is situated within mostly depositional terrain, and outcrop is generally poor.

The study area is located within the Archaean Norseman-Wiluna greenstone belt. The Zuleika Shear runs through the area and mineralisation is associated with second order splays. Two of these structures, the Poseidon South Fault and the Mission Fault, bound steeply dipping, NNW trending, sedimentary rocks of the Black Flag Group. To the E and W of the sedimentary units, high Mg basalts and ultramafics with minor interflow sedimentary rocks, intruded by gabbros, dolerites and acid porphyries, represent the limbs of a regional syncline.

The Mitchell Palaeochannel drains the old Higginsville mine area. To the east and running parallel is the Challenge-Swordsman Palaeochannel (Figure 6.30B). Estuarine, marine and lake sediments filled these during marine incursions in the Eocene. Gold mineralisation is present in basal sands, grits and conglomerates (Figure 6.30A). The palaeochannels overlie major shears and significant alteration zones in the Archaean and intersect patchy primary mineralisation. This indicates that the Au deposits in the palaeochannels are probably a chemical supergene deposit remobilised from a proximal Archaean source. However, it is also possible that the Au was washed into the rivers from an unknown source(s), or that Au-bearing fluids were injected up underlying basement faults into the sandy sediments. Extensive ferruginised, calcareous soils, aeolian sands, and remnant Tertiary sediments overlie deeply weathered Archaean basement. The resulting regolith is complex, with fresh rock occurring below 80 m depth. A typical section over the palaeochannel mineralisation consists of:

0-2 m	Dense red calcareous clays with abundant ferruginous gravels. The calcrete occurs as powdery segregations in clay and coatings on, and replacement of, ferruginous granular material.
2-6 m	Red, non-calcareous clays with some grey mottling.
6-10 m	Multi-coloured clays with abundant ferruginous nodules and some pisoliths.
10-18 m	Red and khaki puggy clays with some Fe-rich nodules, becoming paler with depth.
18-34 m	Cream to white silty sandy clays
34-40 m	Sandy clays with carbonaceous (including fossil wood) and sulphidic material.
40-80 m	Clay saprolite consisting of variably coloured clays, quartz and rock fragments.

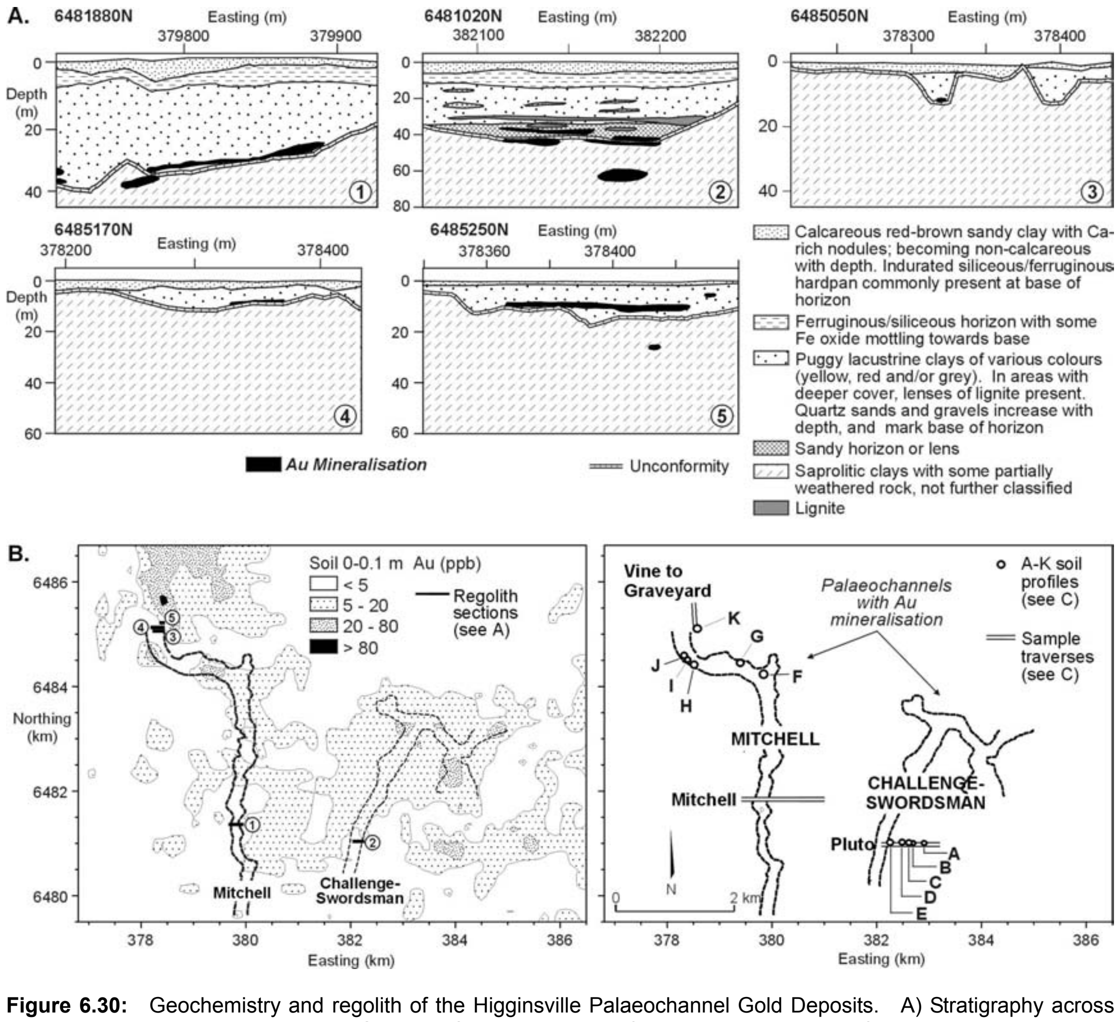

Figure 6.30: Geochemistry and regolith of the Higginsville Palaeochannel Gold Deposits. A) Stratigraphy across palaeochannels. B) Gold and Ca concentrations for soil traverses and profiles.

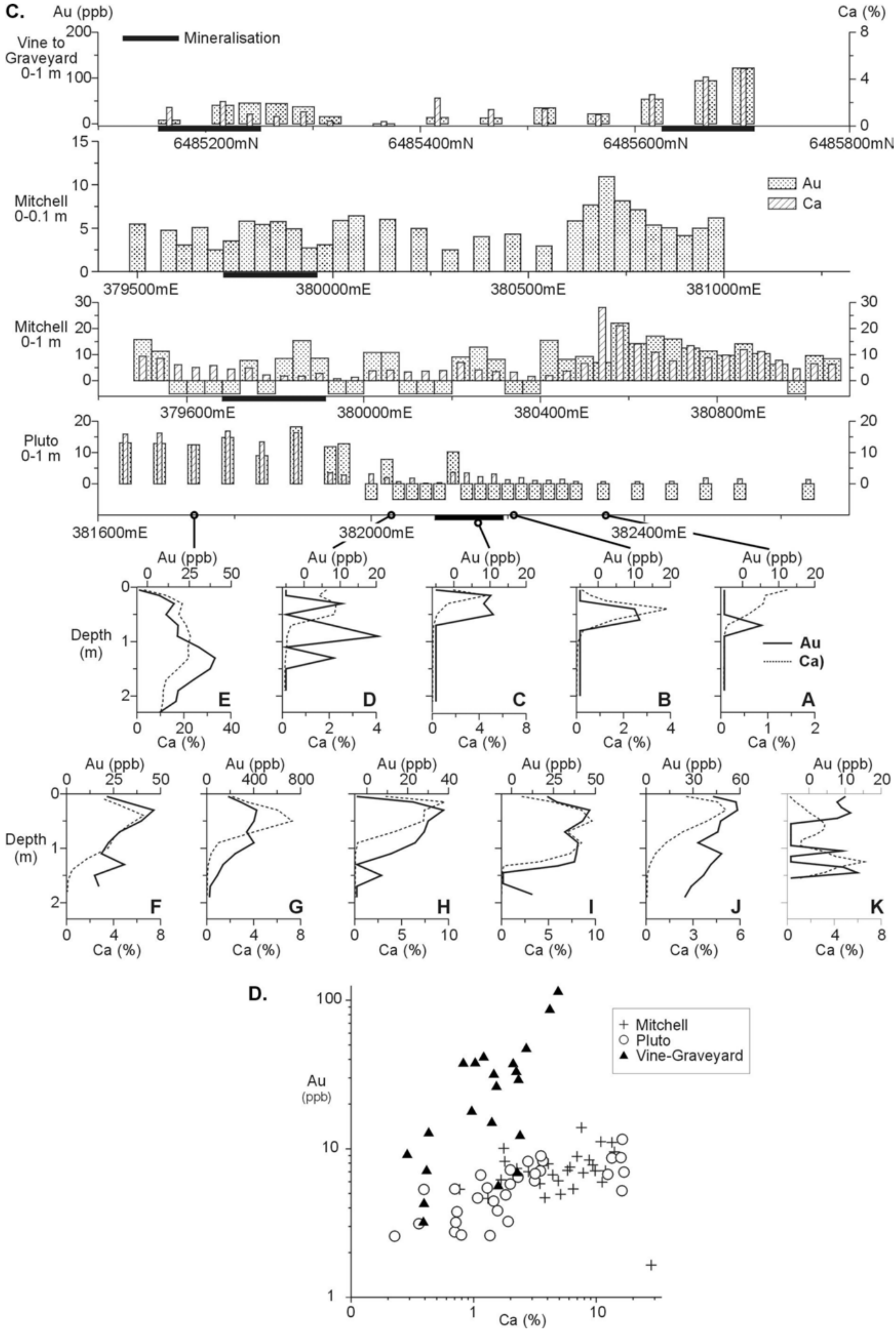

Figure 6.30 (continued): Geochemistry and regolith of the Higginsville Palaeochannel Gold Deposits. C) Plan showing regional Au anomaly, location of palaeochannels and stratigraphic sections. D) Scatter plot showing Au and Ca relationship in soil (0-1 m).

Soil samples were collected from three auger traverses (0-1 m): (i) across the Pluto deposit (Challenge-Swordsman Palaeochannel), (ii) across the Mitchell-4 deposit (Mitchell Palaeochannel), and (iii) downslope from the outcropping Vine deposit to the buried North Graveyard deposit (upper reaches of the Mitchell Palaeochannel). In addition, near-surface soils (0-0.1 m), eleven soil profiles, and ferruginous materials from selected soils and drill cuttings were collected (Figure 6.30B); the latter two sampling media are not reported here.

For the 0-1 m samples, there is a strong anomaly and an association between Au, pedogenic carbonate and mineralisation in residual soils at the Vine deposit (Type B) (Figure 6.30C). The anomaly possibly extends to the shallowly-buried (<10 m) North Graveyard deposit (Type T), although the latter anomaly is possibly related to higher carbonate contents. Importantly, however, the Au content of the soils from over the Mitchell-4 and Pluto deposits (Type T) is not related to underlying mineralisation. In fact, no Au (<5 ppb) was detected in any samples directly overlying the mineralisation at Mitchell and Pluto. Of all the soils collected, the highest Au concentration (425 ppb) was found within a soil profile located downstream of the Aphrodites pit (profile G, Figure 6.30C). Soils from 0-0.01 m have lower Au concentrations (<5-11 ppb) than the 0-1 m soils (<5-20 ppb), with neither sample type reflecting the occurrence of mineralisation at Mitchell. Gold and Ca concentrations in 0-1 m soils are correlated (Figure 6.30D).

In order to examine the associations of Au with other components of the soil in more detail, fifty individual ferruginous granules were randomly selected from a soil profile adjacent to the Graveyard-Aphrodites pit located in the Mitchell palaeochannel. The results show ferruginous granules have highly variable Au contents. One granule contained 51 ppm Au, while other granules had Au contents below detection (100 ppb). Petrological investigations of Au-rich granules (over 250 ppb) confirm they are pervasively ferruginised, with some partly-preserved primary lithic fabrics. Silver-free Au grains up to 10 µm size were found in sectioned granules.

It is probable that Au released from the detrital ferruginous granules is the immediate source of much of the Au in the calcrete. As the granules weather they release Au and this becomes associated with the carbonate under soil conditions. The ferruginous granules containing high concentrations of Au are presumably derived from upslope auriferous ferruginous saprolite (Type B regolith) or lateritic duricrust (Type A). The study demonstrates how significant amounts of Au found in calcrete can be displaced from mineralisation by many tens or hundreds of metres.

(28) Kurnalpi Palaeochannel, Kalgoorlie, WA (Lintern and Gray 1995c)
The Kurnalpi Palaeochannel Gold Prospect is located about 70 km NE of Kalgoorlie. The climate is semi-arid with an annual rainfall of 280 mm. Vegetation is dominated by *Acacia*, some *Casuarina*, and on higher ground, stunted *Eucalyptus*. Small shrubs are scarce due to the impact of grazing sheep. The Kurnalpi Prospect is located on the edge of a broad floodplain. There is a range of hills to the E and NE, and Mt Parkin rises 100m above the floodplain 2.5 km to the SE. Present day ephemeral streams, some choked with ferruginous lag, generally flow in a SW direction, draining to a side branch of Lake Yindarlgooda about 4 km to the S. The landscape is typical of floodplains E of Kalgoorlie.

The Kurnalpi Prospect is situated in the Archaean Norseman-Wiluna greenstone belt. Komatiite and variolitic basalts, mafic schists and (minor?) intrusions of gabbro, dolerite and felsic porphyry of the Mulgabbie Formation form the bedrock (Figure 6.31A). The rocks are strongly deformed and metamorphosed to greenschist facies. Two main shears cross the study area, one trending approximately NW and the other NE. Mineralisation is associated with quartz veining hosted by weathered meta-basalts. The Kurnalpi Prospect occurs beneath a deep palaeochannel, which appears to be influenced by the two shears that cross the study area. The northern part of the palaeochannel follows the NE trending shear, but where the shears cross, the southern section follows the NW trending shear. Four sedimentary units infill the palaeochannel (Figure 6.31B):

1) 0-5 m: clay-rich red soil containing abundant ferruginous granules, with pedogenic carbonate, principally as calcite, in the top 2 m.
2) 5-20 m: mottled pale and pink clays, with abundant ferruginous granules.
3) 20-30 m: variably coloured puggy clays with occasional pisoliths, which are most abundant in the grey reduced zones of the puggy clay.
4) 30-60 m: clayey sand, with some coarser gravel.

Beneath the transported cover, the thickness of the saprolite is variable. Fresh rock is generally present by 80 m depth, although the depth to fresh rock is shallower on the margins of the palaeochannel. Buried lateritic residuum is locally present, on the channel margins.

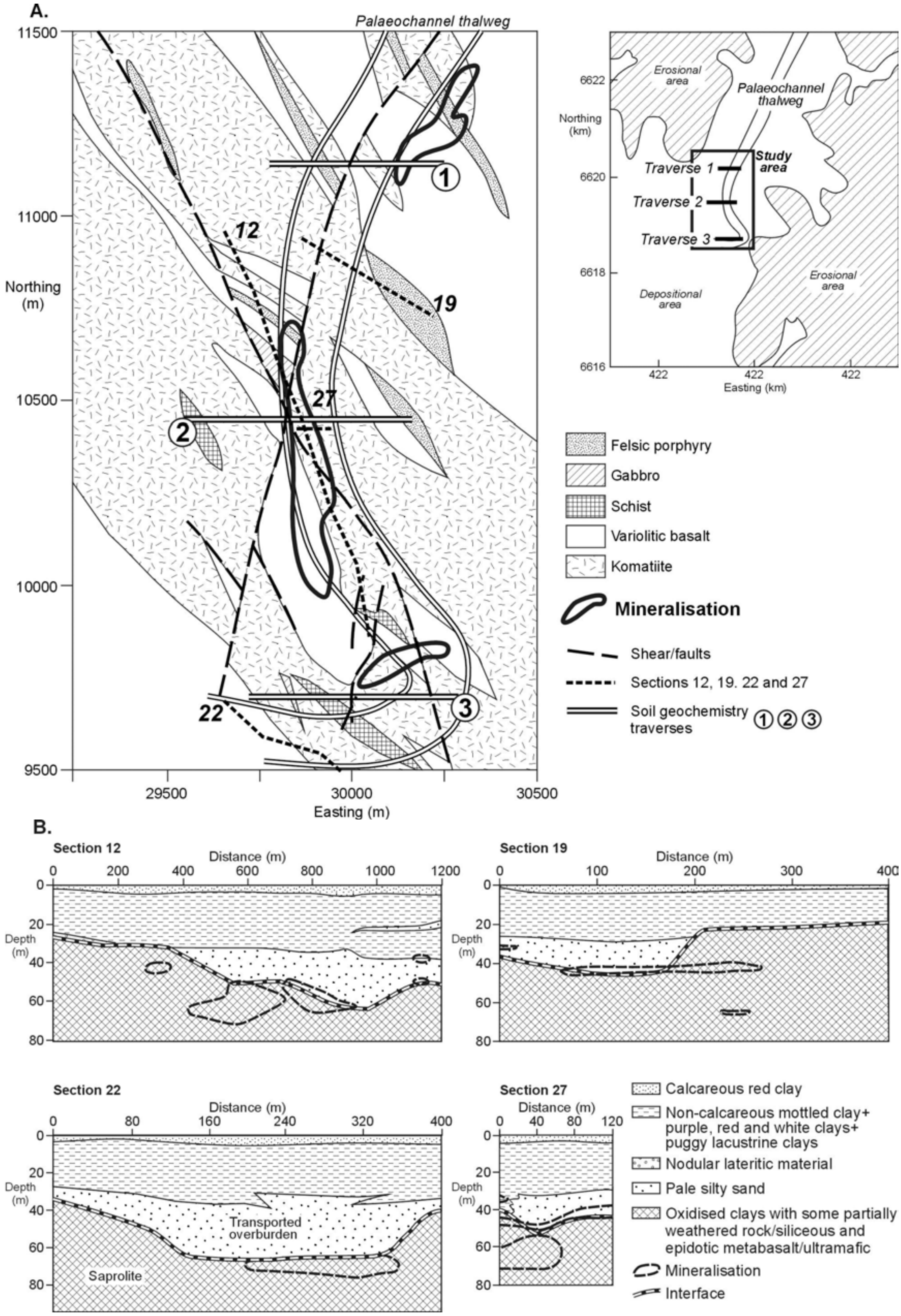

Figure 6.31: Geochemistry and regolith at the Kurnalpi Palaeochannel Gold Prospect. A) Plan showing geology, location of regolith sections and sampling lines. B) Regolith sections

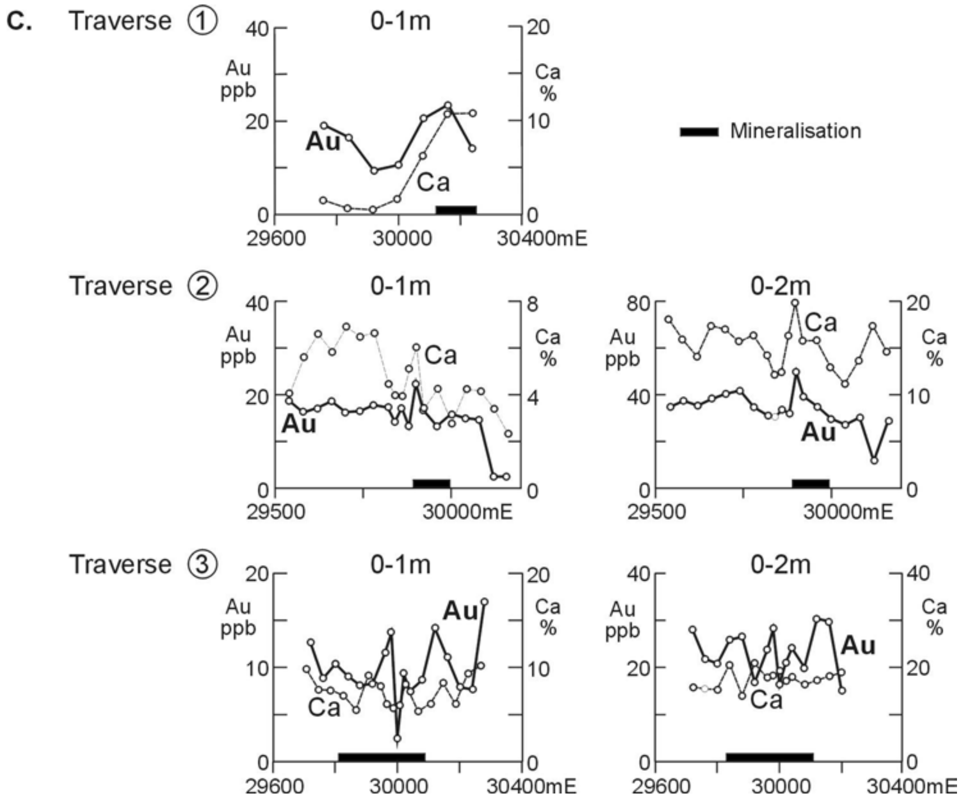

Figure 6.31 (continued): Geochemistry and regolith at the Kurnalpi Palaeochannel Gold Prospect. C) Geochemistry of soils (0-1 m and 0-2 m).

A limited geochemical study was undertaken at Kurnalpi, targeting soil, ferruginous components in the transported cover, and material from saprolite and bedrock. Soil was sampled by augering to a depth of 2 m over three traverses sited over the palaeochannel, downstream, over and upstream of mineralisation. Sediment, saprolite and bedrock samples were collected from RC drill cuttings. Only the soil traverse data are reported here.

Gold in the soil at Kurnalpi is largely confined to the calcareous horizon, which drill cuttings tend to indicate generally occurs within 2 m of the surface. There appears to be no correlation between Au distribution in the soil and the position of the palaeochannel mineralisation (Figure 6.31C). The mean Au concentration is 10 ppb for the 0-1 m depth material, with Ca concentrations (6-12%) relatively constant across the traverse. Soils in the traverse directly overlying the mineralisation have marginally higher Au concentrations (mean 19 ppb) than those downstream. Although soils located "upstream" of the mineralisation are considered background, Au concentrations (mean 16 ppb) are similar to those over mineralisation.

At Kurnalpi, augering appears to be effective in sampling the calcrete but the great depth to mineralisation and generally elevated background concentrations of Au mask any possible vertical movement of Au from buried mineralisation. The most probable source of elevated background Au concentrations in the calcrete is from the old Kurnalpi mine site 5 km to the NNE. The study demonstrates the importance of collecting sufficient samples, both from background and mineralised areas, to determine the source of the Au adequately.

(29) Basin and Range Province, Nevada (McGillis 1967).
Secondary dispersion haloes of Ag in calcrete on alluvial fans around eighteen Ag and Au mining districts were studied by McGillis (1967) as a possible guide to precious metal deposits in the Basin and Range Province of Nevada. He noted that Erickson *et al.* (1964) had previously found Ag in calcrete near the Getchell Mine, Humboldt County, Nevada. For these studies, the detection limit for Au was presumably too high and so only Ag was determined. McGillis (1967) found anomalous concentrations (mean of 3.1 ppm) of Ag downslope of all the districts sampled. The range of 0.1-4.8 ppm was recorded against backgrounds and thresholds of 1.3 ppm and 2.5 ppm, respectively.

McGillis assumed that the calcrete would act as a chemical pH barrier to any mobilised Ag with precipitation of Ag carbonate on contact with the calcrete. Samples were taken from the underside of rock fragments and their interstices from locations in intermittent stream channels that cut into the alluvial fans exposing the calcrete.

The study found that there was no significant difference in Ag content immediately above or below zones of mineralisation but that concentrations were lower in background areas. This suggests that Ag in calcrete alone cannot specifically locate mineralisation but that it may be useful as a regional tool. In contrast, the Ag content of stream sediments appeared to decrease with increasing distance from mineralisation; however, poor precision and large concentration ranges suggested contamination from mining activity. The Ag content of buried calcrete layers appeared to be no different from surface calcrete layers, indicating either there was no anthropogenic contamination from mine sites or that all the samples were similarly affected by mining activity, the former probably being the case. The study suffers from lack of data on Ag concentrations in other regolith materials or outcrop. It is possible that Ag concentrations are higher, or provide a better vector to mineralisation, in soils or weathered bedrock rather than calcrete or stream sediments.

6.2.4 Base metals case studies

6.2.4.1 Pedolith or saprolith host (Type B)

(30) Pioneer Nickel deposits, WA (Cox 1975, Butt 1992)

The Ni-Cu sulphide deposits at Pioneer, 85 km SSW of Kambalda (WA), are small bodies of massive pentlandite, pyrrhotite and chalcopyrite situated at the base of serpentinised ultramafic rocks in the Archaean Kalgoorlie-Norseman greenstone belt (Figure 6.32B). Soils are mainly residual, 0.1-1.0 m deep and developed over partly truncated profiles 25-100 m deep (Cox 1975). A calcrete horizon, 0.5-1.5 m thick, is developed below about 0.2 m depth, across the soil-saprolite transition, and consists of calcrete-coated lithorelics in a white matrix of calcareous smectitic clays. The mineralisation subcrops as a gossan, also overlain by calcrete and soil. Traverses across it showed that metal concentrations in sieved soil ($<180\mu m$) and the calcrete horizon were greatly reduced compared to those in saprolite and gossan (Figure 6.32A). Nevertheless, the maximum Ni, Cu, Co and Zn contents and Ni/Cr ratios in soils were found to be coincident with those in saprolite but had a greater lateral spread, particularly downslope. Metal concentrations were higher in the calcrete horizon than the soil but lateral dispersion was less. Dispersion in the weathered bedrock was minimal. The $<180\mu m$ fraction was appropriate since Ni and Co were incorporated in Mn oxides, Zn and Cu in smectites (which comprise the fine fraction), and the coarse fraction contained clastic diluents such as quartz.

This contrasts with the finding in other case studies described in this chapter, where gossanous and/or ferruginous fragments (granules) present in the soil as a lag component increase the metal contents of coarse soil fractions. Soil profile samples indicated a gradual change in concentration with depth in Ni, Cu, Zn, Co and Cr; this suggests that metal concentrations in the saprolite are being diluted by the calcrete and soil components (Figure 6.32C).

(31) Jacomynspan Farm Copper and Nickel deposit, South Africa. (Danchin (1972), Vermaak (1984) and Tordiffe *et al.* (1989))

As with southern Australia, vast areas of the semi-arid and arid regions of southern Africa are covered with thick calcrete that often masks the underlying geology. At Jacomynspan Farm, calcrete covers migmatitic, porphyroblastic, biotite-garnet gneiss hosting Cu-Ni sulphide mineralisation occurring in a sill-like, pre-tectonic mafic intrusion. The ore body is zoned with the main horizon consisting of chlorite-biotite-tremolite schist containing disseminated chalcopyrite, pyrrhotite and pentlandite with 1-3% total sulphides. The area is located on a flat to gentle rolling pediplain with a weakly developed drainage to the N. The calcrete layer is <3 m thick and consists of various types including massive, nodular, powdery and laminar. A thin layer of sand that is rarely more than 10 cm thick generally covers it.

About 90 samples of mainly soil and calcrete were collected for a geochemical study. Results indicate that anomalies of Cu, Ni and Co in the calcrete are strong but limited in size, reaching background concentrations within 30 m of sub-cropping mineralisation (Figure 6.33B). However, as at Pioneer Ni deposits (see above), Tordiffe *et al.* (1989) found that soil and calcrete both defined the subcrop of mineralisation and retained the elemental association that reflects the host rocks (in this case mafic rocks rich in Fe-Mn-Co-Cu-Ni) and the association with secondary Fe oxides (Figure 6. 33A).

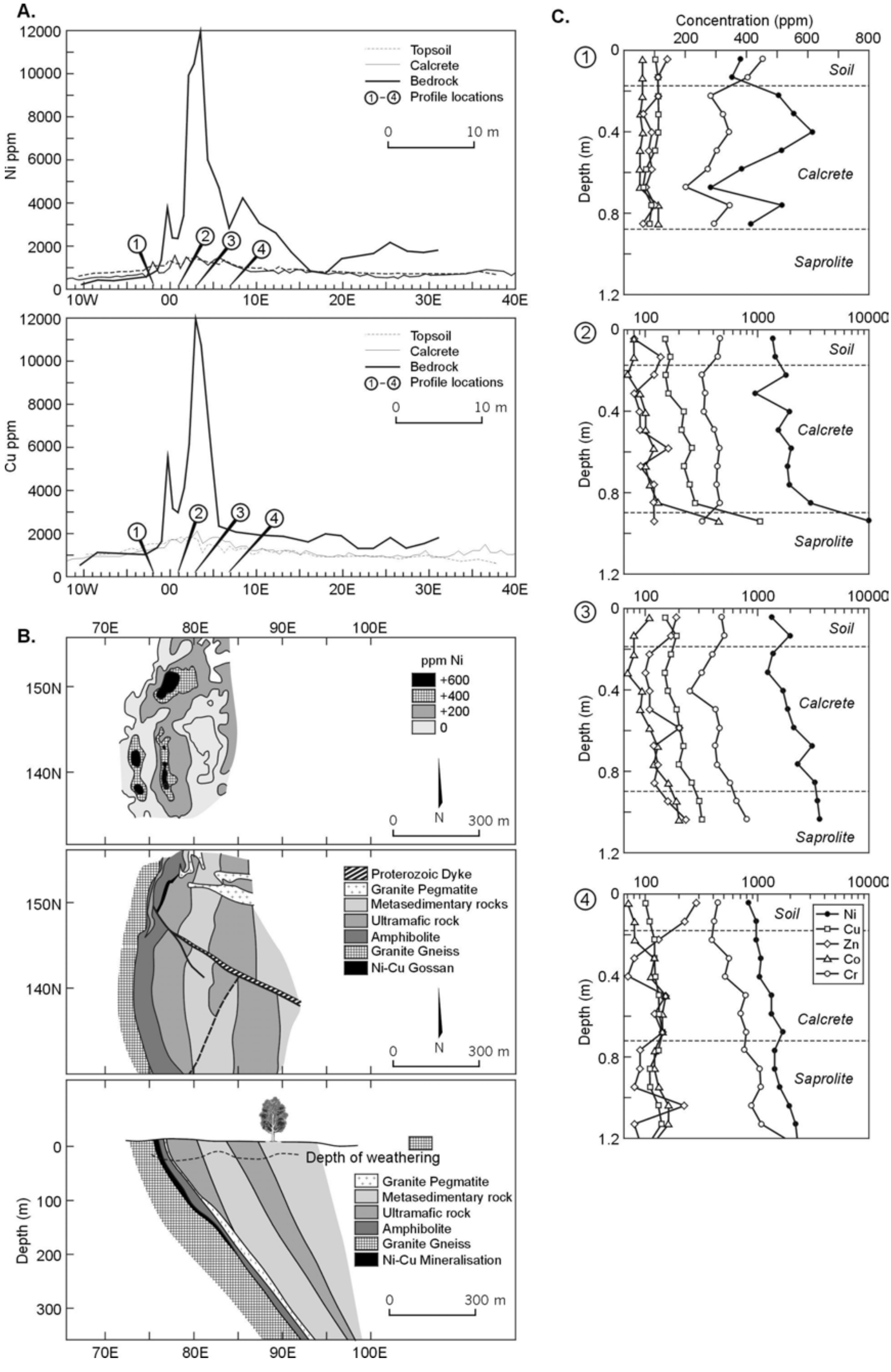

Figure 6.32: Copper distribution in various sample media at Pioneer (after Cox 1975). A) Traverse across mineralisation comparing Ni and Cu response in topsoil, calcrete and bedrock. B) Plan and section of Ni distribution and local geology. C) Profiles through the calcrete showing concentrations of various elements.

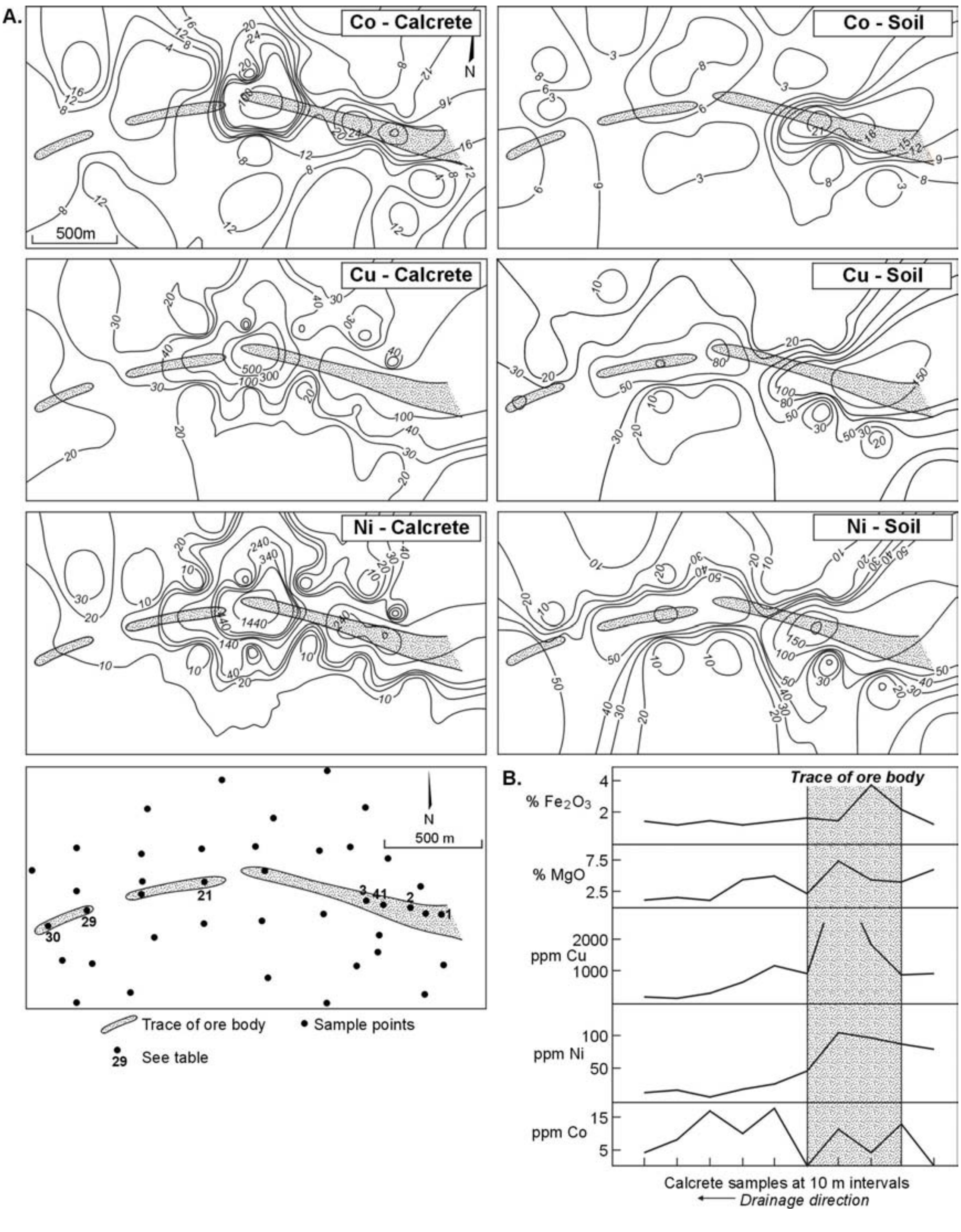

Figure 6.33: Copper, Ni and Co distributions at Jacomynspan (after Tordiffe *et al.* 1989).
A) Element distributions about the ore body.
B) Selected element concentrations in calcrete across mineralisation.

The latter are presumed to have formed by earlier weathering event(s) under more humid conditions prior to calcrete formation. In an earlier study, Vermaak (1984) found that metal concentrations in soil (30-200 ppm Cu, 45-205 ppm Ni) and calcrete (40-1730 ppm Cu, 45-2330 ppm Ni) were greatly reduced relative to mineralised schist (0.10-0.49% Cu, 0.15-2.30% Ni) (Table 6.3).

The results suggest that both soil and calcrete can be used to determine the location of the ore body. Copper, Ni and Co concentrations are nearly always higher in the calcrete than in the soil. Tordiffe and colleagues interpreted this as an indication that the elements are relatively immobile and precipitate readily in the carbonate under high pH conditions. Another possibility is that metals are greatly diluted in the soil by the presence of the aeolian sand.

Table 6.3: Element concentrations in different regolith materials from profiles (written communication Tordiffe 2000; background data from Vermaak 1984).

Sample No.	Sample No.	Cu	Ni	Co	Pb	Zn
41	C	131	194	19	26	9
	C	1731	2331	220	29	40
	C+MS	2745	4356	155	35	58
	MS+C	4898	23082	1285	22	126
1	S	191	131	15	53	60
	C	249	217	22	38	19
	MS	1546	1543	151	40	45
2	S	199	133	20	50	58
	C	241	349	29	35	32
	MS	496	450	99	39	129
3	S	135	206	23	62	36
	C	219	271	27	37	10
	MS	361	642	81	54	74
21	S	81	109	9	59	89
	C	121	192	10	47	16
	MS	1045	1972	111	48	49
29	S	32	43	8	54	36
	C+S	30	50	5	47	25
	MS	1360	2236	113	29	44
30	S	51	71	11	54	35
	C	39	36	19	32	6
	MS	1586	1815	141	52	62
Background	C	80	114	7	34	11

S Soil
C Calcrete
MS Mineralised schist

(32) Putsberg Copper Deposit, South Africa (Garnett *et al.* 1982)
The Putsberg Copper Deposit is located within the high-grade metamorphic terrain of the Namaqualand Metamorphic Complex. It is found in supracrustal rocks of the Bushmanland sequence (quartzites, ferruginous quartzites, aluminous schists, pink gneiss, amphibolite and calc-silicate rocks). Trenches across the area revealed the stratigraphy and provided access for sampling the soils and underlying material.At Putsberg, calcrete is commonly 2 to 7 m thick, but locally can extend to as much as 15 m depth, and is developed on and within bedrock. The upper contact of the calcrete is well defined in most cases, but the base is gradational. The ore zone itself is concealed by calcrete only 0.4 m thick. Immediately upslope of the ore body, the calcrete consists mostly of boulders and nodules (up to 0.5 m diameter), having calcareous silty cores and laminated carbonate skins, in a silty calcareous groundmass, but this changes to both nodular and finer calcrete further upslope and downslope (Figure 6.34D). The calcrete horizon is abruptly overlain by a sandy soil that has residual, aeolian and colluvial components. Over mineralisation, gossan fragments are present within calcrete nodules, soil and surface lag. Both coarse (1-2 mm) and fine (75-180µm) soil and calcrete samples gave a response over mineralisation (Figure 6.34A). The background values for Cu in the soil were considered to be of the order of 25 ppm or less, with the upper part of the calcrete having slightly higher concentrations, at about 60 ppm (coarse fraction) and 80 ppm (fine fraction). Near the ore zone, the strength of the geochemical response was found to be significantly greater in the calcrete than in the soil, particularly in the samples overlying the downslope section of the mineralisation (compare soil and calcrete graphs in Figure 6.34A). However, the overall width of the anomaly was probably greatest in the fine fraction of the soil. Thus, the mineralised zone was anomalous at 40 ppm, with scattered maxima greater than 200 ppm. Nevertheless, Cu, Zn and Pb contents were still greatly depleted relative to bedrock, and Cd and Ag were anomalous only in the coarse fraction.

Most of the decrease in base metal contents from saprolite to calcrete and calcrete to soil can be explained by dilution of mineralised saprolite and derived gossanous fragments by carbonates and quartz float, although some leaching may have occurred during calcrete formation. The association of Cu and Zn with heavy minerals and ferruginous fragments at Putsberg and nearby Kantienpan was also clearly demonstrated (Figure 6.34B and C). Garnett *et al.* (1982) and Vermaak (1984) both recommended the upper part of the calcrete horizon for regional sampling, because of (i) the higher metal content of the calcrete, and (ii) locally, the soil may either be absent or composed entirely of transported material. Garnett *et al.* (1982) demonstrated that the Zn anomaly could be enhanced by removal of the carbonate diluent using an acidic ammonium acetate leach and analysing the residue (Figure 6.34A). This wet chemical technique may not, however, be practical for routine exploration.

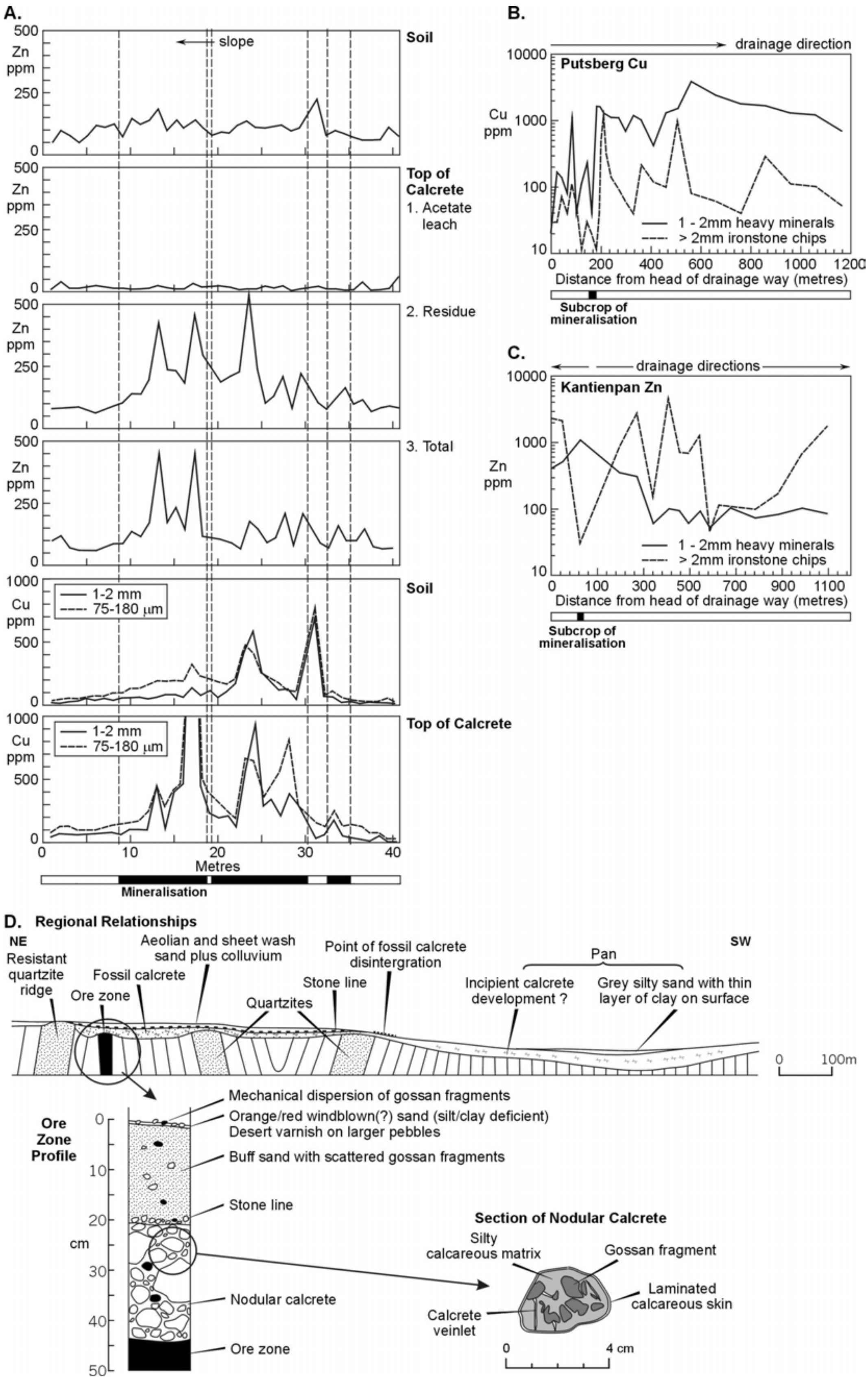

Figure 6.34: Copper and Zn distribution and regolith stratigraphy at Putsberg and Kantienpan (after Garnett *et al.* 1982). A) Concentrations of Zn and Cu in different sampling media across mineralisation. B) Concentration of Cu in heavy minerals and ironstone chips (ferruginous granules) at Putsberg. C) Concentration of Zn in heavy minerals and ironstone chips (ferruginous granules) at Kantienpan. D) Regolith section and profile at Putsberg.

(33) Bou Grine Lead-Zinc Deposit, Tunisia. (Leduc 1986, Guedria *et al.* 1989)
The Bou Grine Lead-Zinc Mine is located at the edge of the Lorbeus diapir about 150 km SW of Tunis, Tunisia. The stratigraphy consists of Triassic claystone, gypsum and sandstone rocks overlain by Cretaceous marls and limestones (Figure 6.35A). Three styles of mineralisation occur: (i) lenticular sulphides (sphalerite, galena and pyrite) associated with celestite and barite at the contact between the Triassic and Cretaceous rocks; (ii) disseminated sulphide mineralisation in Cretaceous limestones; and (iii) a semi-massive sulphide body that cross-cuts the Cretaceous sediments and is characterised by high Zn contents (> 20%). The reserves at 4% cut-off grade were estimated at 7.3 Mt @ 2.4% Pb and 9.7% Zn, and represent one of the largest base metal deposits in North Africa. Regional geomorphology is characterised by gentle slopes descending from the diapirs. Mean altitude is 500 m, the climate is semi-arid with an annual rainfall of 500 mm, and the natural vegetation consists of small trees and shrubs that have been heavily grazed.

The regolith stratigraphy consists of five units (Figure 6.35B):
1) surficial horizon containing colluvial material composed of parent rock, disseminated quartz and re-worked fragments of calcrete. Thickness increases downslope to 1 m. There is commonly asharp contact between this unit and underlying units;
2) two 0.1-0.4 m thick calcrete sub-horizons consisting of thinly-bedded lamellae separated by friable material resembling saprolite. The lower lamellar sub-horizon is of white to pinkish sub-horizontal sheets that are about 2 cm thick, slightly indurated with carbonate, and alternating with thin beds of saprolite. The upper indurated sub-horizon consists of calcareous material, is micro-grained (micrite) and hard, and displays light and dark bands;
3) nodular calcrete 0.5-1 m thick consisting of calcareous nodules about 0.5 cm in diameter, weak to medium hardness, white to pink, and a fine-grained texture. The nodules generally have a hard core of saprolite;
4) thin saprolite (0.25 m) developed directly on Triassic or Cretaceous parent rocks.

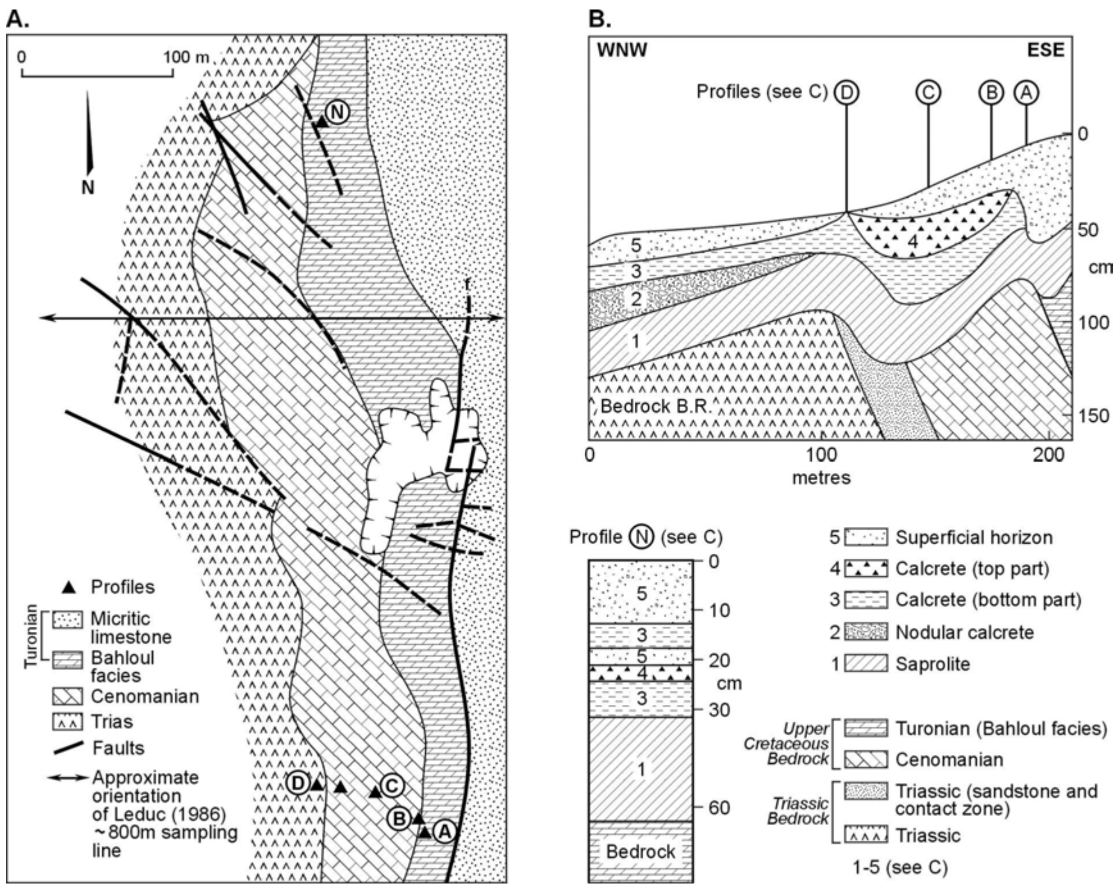

Figure 6.35: Geochemistry and stratigraphy of the Bou Grine Lead Zinc Mine, Tunisia (after Goudria *et al.* 1989).
A) Local geology of the Bou Grine area showing profile and traverse locations.
B) Regolith detail and profile locations.

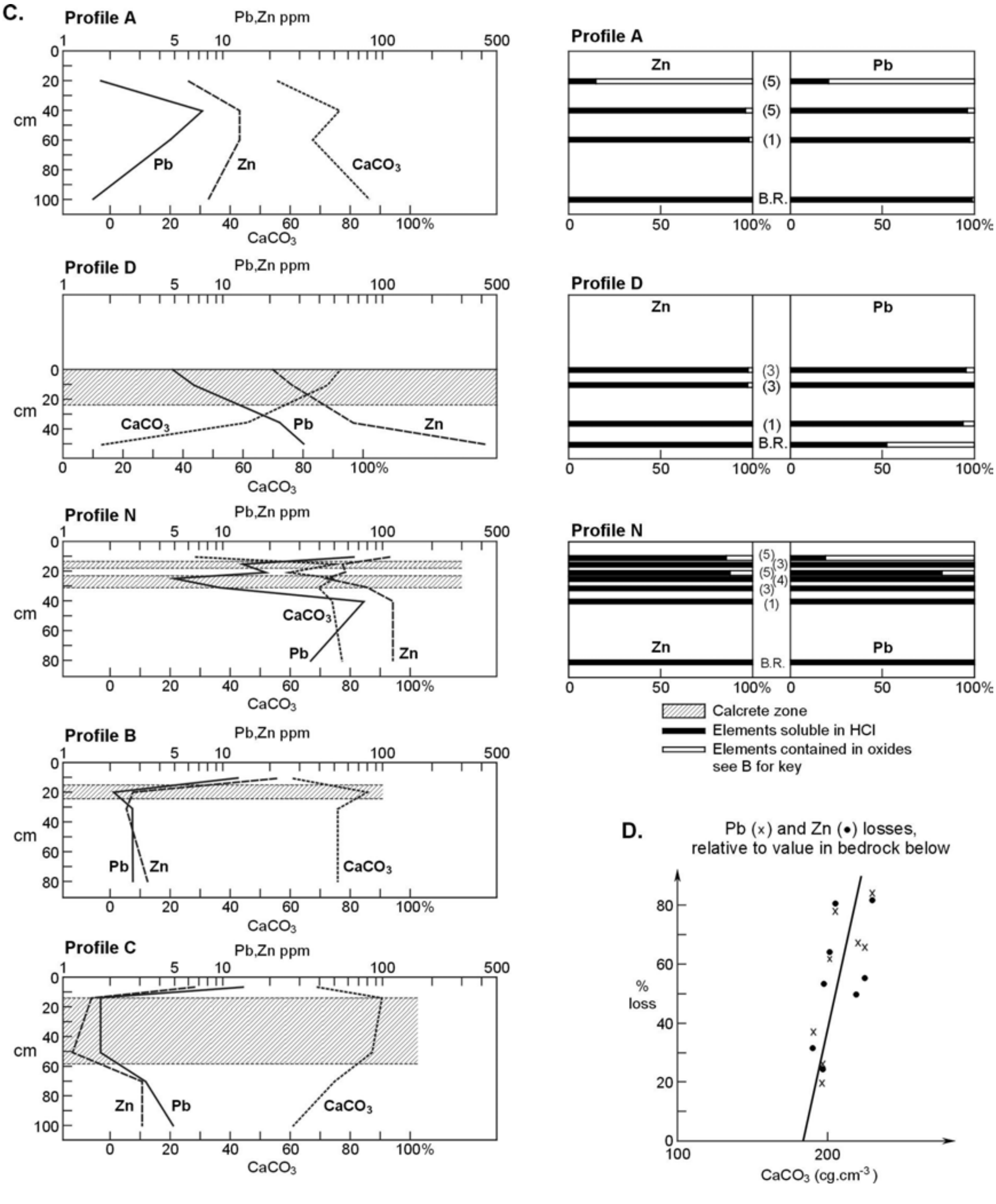

Figure 6.35 (continued): Geochemistry and stratigraphy of the Bou Grine Lead Zinc Mine, Tunisia (after Goudria *et al.* 1989).
C) Geochemical profiles and selective extraction studies.
D) Pb and Zn losses relative to bedrock as a function of carbonate content.

A petrological study indicated a progressive replacement and in-filling of cracks of the original parent rock material by micrite (fine-grained carbonate). The replacement conserves structural and geometrical features and volume, even though its constituents disappear. The geochemical and petrological data suggest that during hard calcrete layer formation, assumed to have been derived from re-working of the parent rock, absolute concentrations of metals such as Pb and Zn have decreased compared with the parent rock (Figure 6.35D). Of the Pb and Zn in the calcrete, >95% is soluble in dilute HCl. In samples that have lower carbonate contents, most Pb and Zn are not soluble but are associated with Fe oxides (Figure 6.35C).

In conclusion, Guedria and colleagues suggest that hard calcretes are not an ideal sample medium to use in base metal exploration but recommend that material beneath the calcrete is probably better even though this may still be partly calcareous. They suggest that anomaly contrasts decrease with increasing age of the calcrete and repetition of periods of calcrete formation.

Leduc (1986) performed an orientation study over the Bou Grine Lead Zinc deposit comparing "humic" soil with calcrete. In contrast to Guedria *et al.* (1989), Leduc found that there was little difference between Pb and Zn contents of the soil compared with the calcrete, although metal contents in the calcrete were slightly lower (Figure 6.36). Both sample media appeared to be capable of locating mineralisation. A subsequent geochemical survey carried out on a 25x50 m grid established anomalies that were later successfully drilled.

The different conclusions from the two studies are not easily explained from the given data. The study of Leduc (1986) suggests that it is not necessary to avoid calcrete during sampling, whereas the more detailed study by Guedria *et al.* (1989) clearly indicates that metal concentrations have been reduced by absolute amounts during the process of calcrete formation presumably by a leaching process.

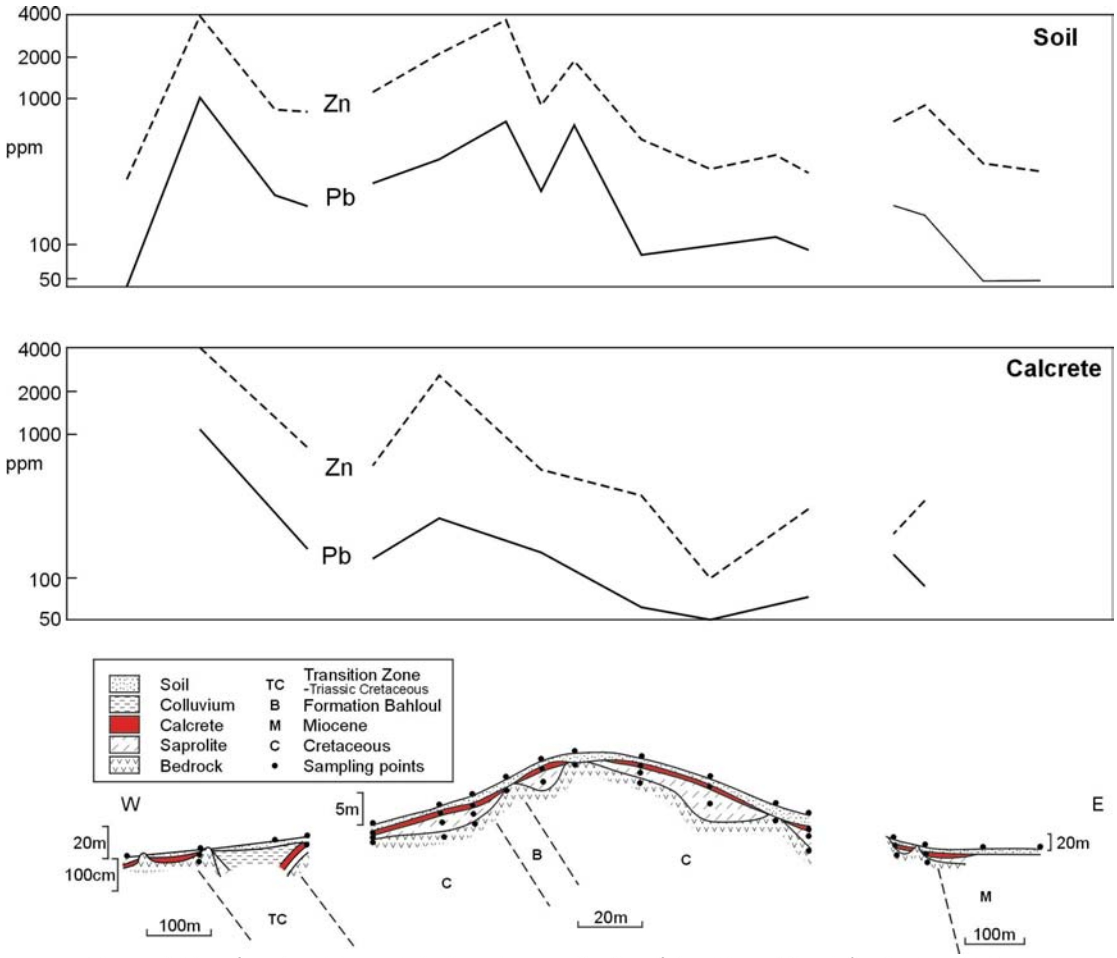

Figure 6.36: Geochemistry and stratigraphy over the Bou Grine Pb-Zn Mine (after Leduc 1986).

6.2.4.2 Transported overburden host (Type T)

(34) Kadina, Yorke Peninsula, SA. (Mazzucchelli *et al.* 1980, Butt 1992)

Proterozoic sulphide mineralisation (2% Cu) at Kadina, SA, is obscured by up to 70 m of Cainozoic transported and residual overburden (Mazzucchelli *et al.* 1980). Nodular, powdery and massive calcretes (0.6-2.0 m thick) developed within shallow clay loam soils overlie up to 40 m of transported clays deposited on saprolite. A study of Cu distribution was conducted over an area with relatively shallow overburden (5-10 m). The calcretes are alkaline (up to pH 9.5), whereas underlying units are acid (pH 4.5-6.0). Copper is distributed in narrow zones (to 15 m wide) in saprolite with >1000 ppm Cu surrounded by ~90 m wide dispersion haloes defined by the 250 ppm contour (Figure 6.37). Analysis for cold-extractable (acid ammonium acetate) Cu gave a 'mushroom-shaped' anomaly, with the strongest part immediately beneath the calcrete-clay interface. Low-order anomalies extended through the calcrete and were evident in the topmost samples at 1.5 m depth. The extractable-Cu response at the calcrete-clay contact was similar in location and dimensions to that obtained by saprolite sampling, but was more evenly distributed. Accordingly, shallower, more widely-spaced drilling could have been used in the initial stages of exploration without appreciable risk of missing significant anomalies. The extractable Cu pattern is considered to be due to continuing upward migration of Cu in highly saline acidic groundwaters, with some lateral dispersion occurring prior to fixation in the zone of high pH, represented by the calcrete.

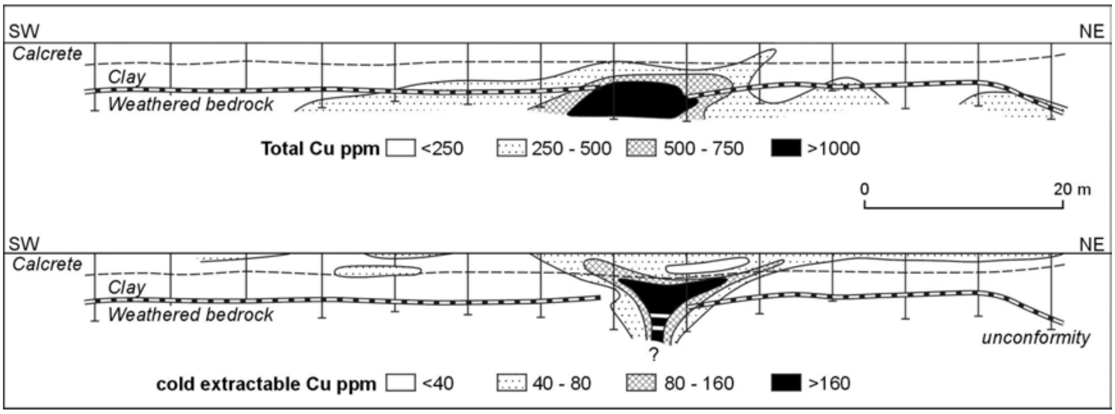

Figure 6.37: Regolith stratigraphy and Cu distribution at Kadina (after Mazzucchelli *et al.* 1980).

The distribution of Cu and Au was also examined in regolith profiles from the Poona pit at Moonta and similar results were found. A peak of total Cu (up to 200 ppm) occurring at the base of a 2-3 m thick calcrete horizon was found to be coincident with the occurrence of alunite in 6-10 m of transported overburden (Hartley 2000); Au concentrations were commonly higher (>4 ppb), however, in the calcrete horizon.

(35) Rocky Range Copper Deposit, Utah, USA. (Erickson and Marranzino 1960, Butt 1992)
A similar hydromorphic mechanism to that at Kadina is considered to have formed an epigenetic Cu anomaly in calcrete coatings on pebbles in alluvium downslope from mineralisation at Rocky Range Copper Deposit, Utah, (USA), although the dispersion is governed principally by gravity rather than upwards migration of groundwater. A chalcopyrite-bearing skarn is overlain by 6-70 m of alluvium, on a gently sloping (7o) pediment footslope in the Rocky Range mountains (Erickson and Marranzino 1960). The Cu distribution and anomalies (>300 ppm), shown by the <180µm fraction of the alluvial soil, probably indicate detrital Cu minerals derived from old workings upslope, although a few isolated high values were present above the buried mineralisation (Figure 6.38). In contrast, the Cu contents of calcareous crusts scraped from pebbles were highest (200->400 ppm) close to mineralisation, and the ratio Cu in calcrete/alluvium exceeded 1.5 at sites overlying or downslope from it. Thus, Cu appears to have been liberated from the sulphide mineralisation under acid conditions and precipitated preferentially in the neutral to alkaline environment of the calcrete. Dispersion is presumably further augmented due to mechanical dispersion downslope.

(36) Mt Gunson, Stuart Shelf, SA. (Lintern *et al.* 1998)
The Mt Gunson Copper deposits occur in the Neoproterozoic Stuart Shelf, overlying the eastern edge of the Gawler Craton (Figure 6.39A). They lie 60 km W of the Torrens Hinge Zone, which separates the Shelf from the Adelaide Geosyncline and coincide with a NNW-trending transcontinental gravity lineament (the G2 corridor), which continues through the Olympic Dam Deposit (O'Driscoll 1986, Preiss 1993). Mineralisation occurs in several units of the Adelaidian and pre-Adelaidian sequence, but principally in the Pandurra Formation, Cattle Grid Breccia, Tapley Hill Formation and Whyalla Sandstone. Two major styles of mineralisation are recognised at Mt Gunson and exemplified by the two areas studied by Lintern *et al.* (1998) (Figure 6.39B). Firstly, in the Cattle Grid open cut mine, mineralisation generally occurs at the interface between the Pandurra Formation and the Whyalla Sandstone. According to Van Herk *et al.* (1975), the ore is flat-lying, stratiform and epigenetic, lying beneath 15 to 35 m of Whyalla Sandstone and up to 10 m of Quaternary sand. The mineralised unit (termed Cattle Grid Breccia) consists of a blanket of brecciated, silicified, red-bed Pandurra Formation

sandstone, averaging 4.5 m in thickness (Williams and Tonkin 1985, Preiss 1987). Secondly, at the Windabout Prospect, Cu mineralisation is much deeper and is largely confined to black calcareous shales of the Tapley Hill Formation, which, in the area studied, occurs at depths between 65 m and 97 m depth, with a general thickness of 15 to 25 m. It is separated from the Quaternary units by Tregolana Shale and Whyalla Sandstone. The richest Cu grades (average 1-3 % Cu) occur at the base of the Tapley Hill Formation at about 70 m depth, and the indicated mineral resource is 18.7 Mt of Cu at 1% and Co at 0.05%. No Cu data are available for the lower regolith above the Tapley Hill Formation, although Cu concentrations in the Whyalla Sandstone immediately above the Tapley Hill Formation are generally of 10 to 100 ppm (data derived from Pacminex Pty Ltd).

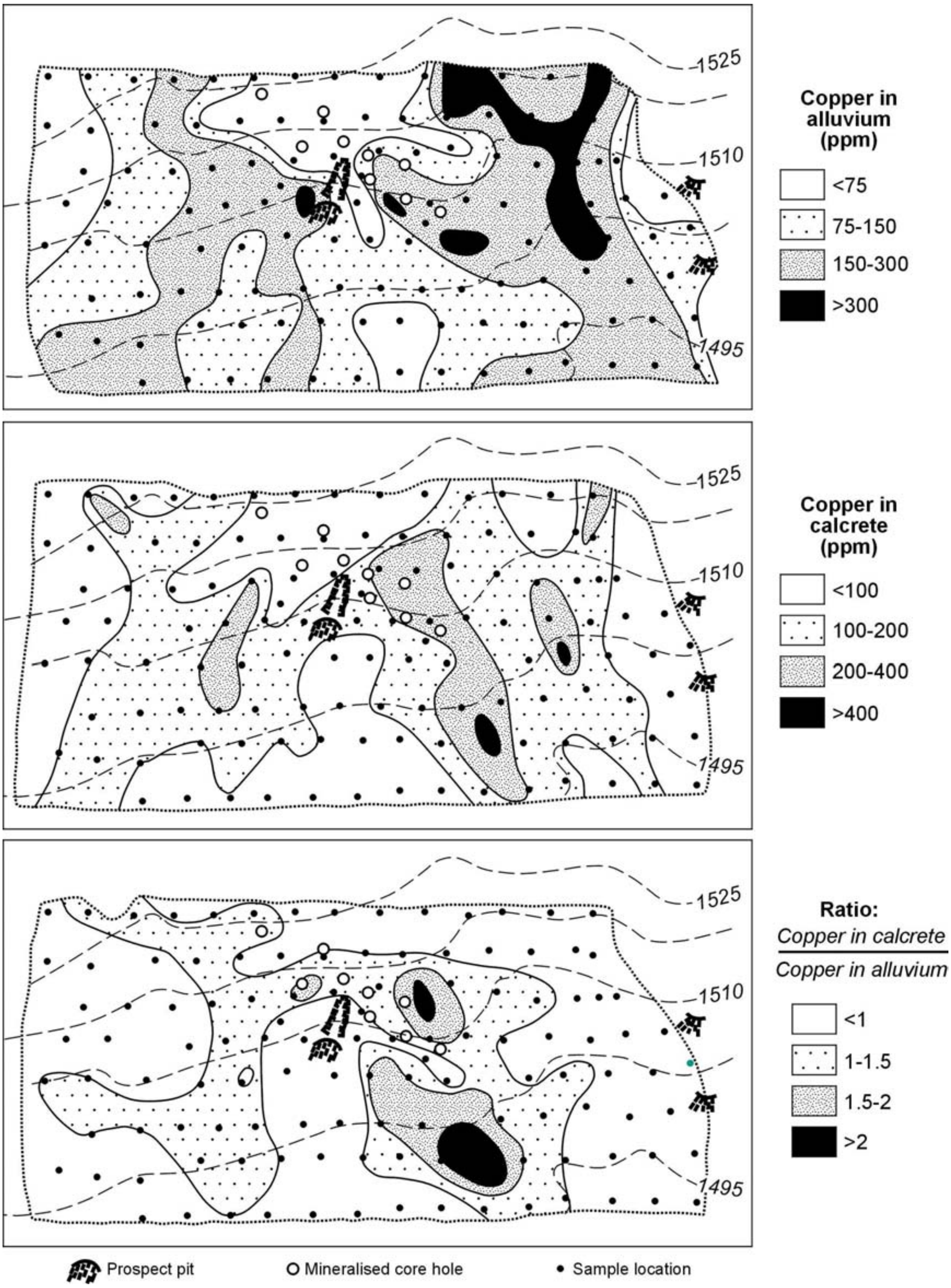

Figure 6.38: Copper distribution at Rocky Range (after Erickson and Marranzino 1960).

The area surrounding the local high point of Mt Gunson (259 m AHD, about 100 m above the surrounding terrain) has relatively low topographic relief and is dominated by low rises related to Proterozoic outcrop (Figure 6.39A). The Cu deposits are located just W of Pernatty Lagoon, which is one of a number of large, rectilinear, and approximately N-S oriented dry salinas in this region. Cainozoic sediments, in particular the Quaternary orange sand dunes and related sand spreads, mantle the pre-Cainozoic land surface and impose a local and regional topographic pattern (about EW). Aeolian dust as clay, silt, carbonate and gypsum, has been incorporated by illuviation and solution into the otherwise sandy (also aeolian) Cainozoic sedimentary landforms.

The available mine pits provide an excellent window into the regolith, which is otherwise poorly exposed in this area. Tertiary and Quaternary weathering and concomitant cementing processes have modified the regolith. Crystalline gypsum veining is common within the Quaternary sand spreads and appears to pre-date the calcrete influx and normally underlies it. Large (cm scale) individual euhedral gypsum crystals are also found in the red-mottled gley clays that overlie the Stuart Shelf sediments at Windabout. These gley clays are probably either mid to late Tertiary or early to mid-Quaternary in age and may represent slow deposition under water-logged conditions. Carbonate occurs as silt, sand, earthy coatings and segregations, or as more indurated forms of calcrete-grain cement/coatings, pisoliths and nodules. Calcrete is generally present throughout the Quaternary sands in the Cattle Grid area but, at Windabout, it is restricted to near the surface and to the base of the sands (16-17 m

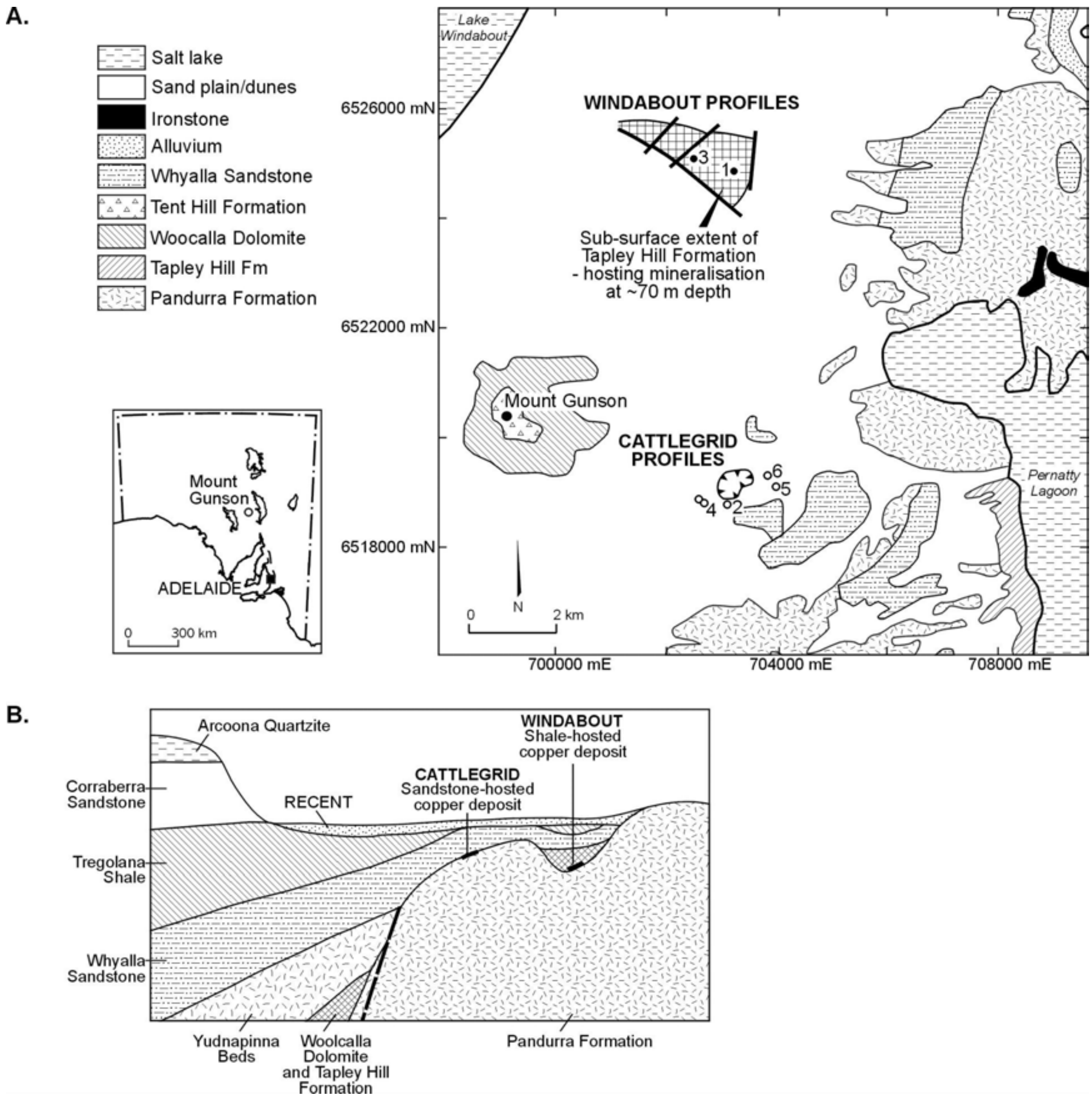

Figure 6.39: Element distribution and regolith at the Mt Gunson Copper Deposits. A) Local geology showing location of regolith profiles. B) Cartoon of geological section showing two styles of mineralisation.

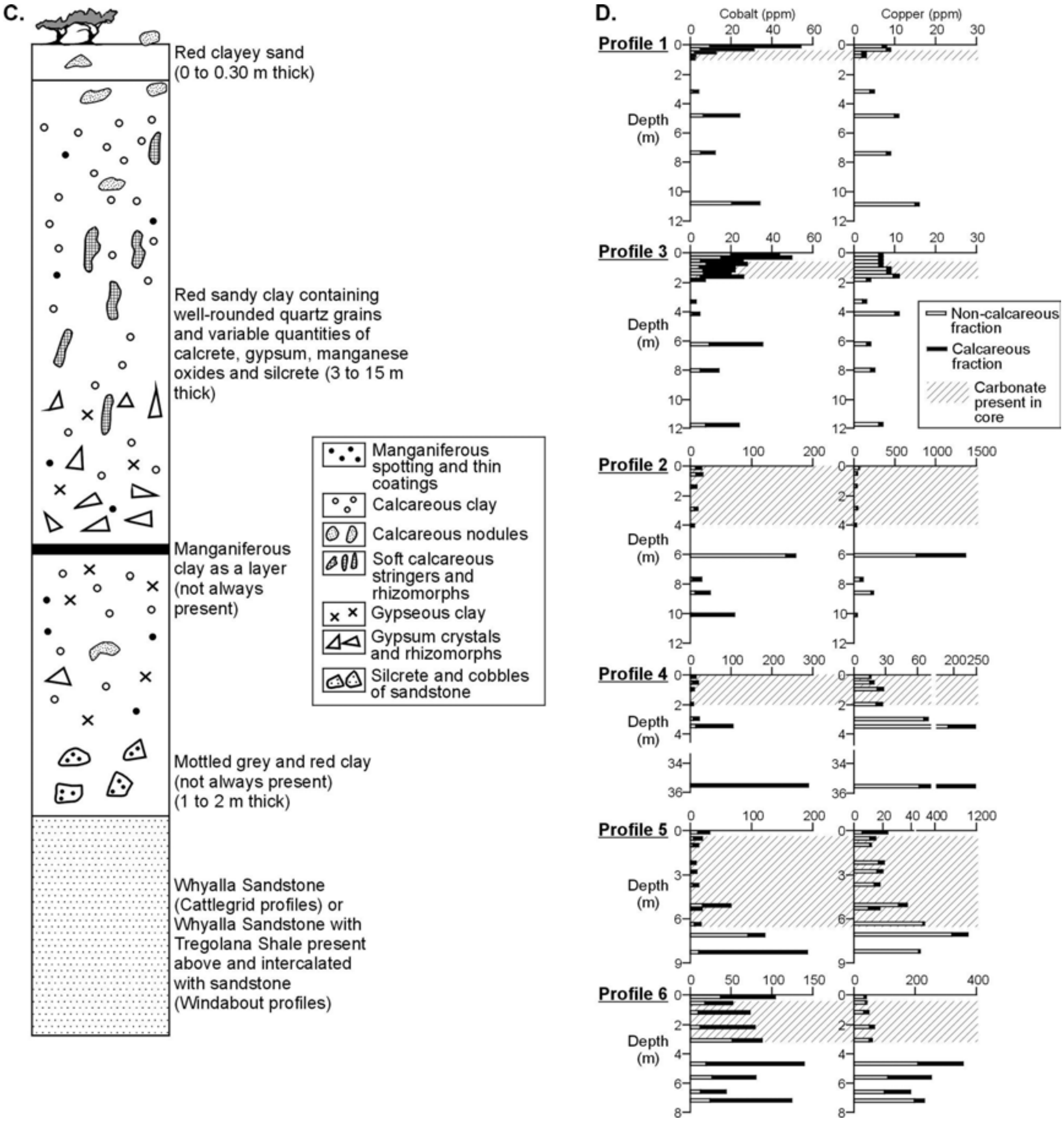

Figure 6.39 (continued): Element distribution and regolith at the Mt Gunson Copper Deposits.
C) Cartoon of regolith profile. D) Distribution of Co and Cu in regolith profiles.

depth), just 2 m above the gley clays. Manganese-rich materials are present as cutans, gypcrete coatings or inclusions, and occur low in the Cainozoic sand profile (>6 m). A distinct narrow zone of dark Mn-rich material was observed in two profiles at Cattle Grid (Figure 6.39C).

Three reagents were sequentially used on an aliquot of pulverised sample to examine the solubility of selected metals (Ca, Mg, Fe, Ag, As, Au, Bi, Co, Cr, Cu, Ni, Pb, Th, U and Zn) in three different phases in the regolith (Chao, 1984): (i) pH 5 acetate solution (for the carbonate and surface adsorbed metals phase), (ii) 0.1 M hydroxylamine (Mn oxides-oxyhydroxides phase) and (iii) 0.25 M hydroxylamine (amorphous Fe oxides phase). A separate aliquot of sample was dissolved using a triple acid digest to enable calculation of a fourth "insoluble" phase.

At Cattle Grid, anomalous total concentrations of Co, Cu, Ni and Zn were found sporadically, but not consistently, in the soils (Figure 6.39D). Manganese oxide staining is common throughout the soils, but only in three profiles (2, 5 and 6) is Mn sufficiently concentrated to be clearly visible on the pit face. Here, it was found that highly anomalous concentrations of Cu (and other metals) were associated with Mn oxides, which occur as grains, flakes, fragments and coatings on sand grains and larger sandstone clasts.

The Windabout profiles showed generally poorer surface soil responses for most base metals and chalcophiles (Cu, Ni, Pb and Zn) compared to Cattle Grid, perhaps reflecting the greater depth of sediment (70 m compared with 30 m) or the different style of mineralisation. In contrast, Co appears to be anomalous at Windabout in the top 20 cm and appears to be associated with Mn in theacetate-extractable (calcareous) fraction. The gypseous horizon immediately beneath has generally lower concentrations of Co and Cu.

The reagents dissolved only minor proportions of the total Fe, with the greatest dissolution for 0.25 M hydroxylamine. In general, extractable Mn is 50% or more of the total Mn, with most dissolved Mn in the pH 5 acetate solution, possibly representing trace Mn substitution in the calcrete either in calcite or, as the separate phase, rhodochrosite. At Windabout, the limited data suggests that for Cu, Zn and Pb, at least, no significant concentrations can be found in the upper regolith, even though these elements are associated with the Tapley Hill-style of mineralisation (Johns 1974, Rattigan *et al.* 1977). However, there are clear enrichments of these and other elements with Mn-rich materials, although additional sampling is required to test the exploration utility of such materials. The situation for Co is less clear, with significantly high concentrations found in surficial materials and apparent associations of Co with higher Mn in the calcareous horizon.

6.2.5 Platinum case studies

(37) Plat Reef, Bushveld Complex, South Africa (Frick 1985)
A study of the regolith in the Plat Reef area of the central Transvaal indicated that in most areas a thick colluvium is present. The colluvium is derived from material that has been moved considerable distances. As a result, a study of volatile elements such as Hg, As and S as geochemical indicators of underlying mineralisation was undertaken. The behaviour of these elements was compared with elements such as Ni, Co, Cu and Fe that were considered to be non-volatile and have moved laterally with the soil. Ferruginous material is common in the area, whereas calcrete is present in only limited amounts.

The Plat Reef consists of a stratified horizon in the Bushveld Complex with appreciable amounts of sulphides, copper sulphides and PGEs (Figure 6.40A). Four traverses crossing mineralisation were investigated and results suggested to Frick (1985) that, where colluvium is thin (1-2 m), all the elements used could locate mineralisation (Figure 6.40B). Where colluvium is thicker (>4 m), only Hg yields anomalies (directly above mineralisation), whereas other elements gave erratic results. Mercury concentrations also appeared to be higher above faults that intersect the ore body and were related to the depth of the ore body. Arsenic gave erratic results probably because it can become adsorbed on other components in the soil such as Fe oxides. Frick (1985) considers this to be the result of the reaction between arsenious acid and calcite to form minerals of the weilite group ($CaH(AsO_4).nH_2O$) (Figure 6.40C). It also appears that As and Hg may be flushed from the soil by rain; subsequent replenishment seems to confirm the active nature of the dispersion.

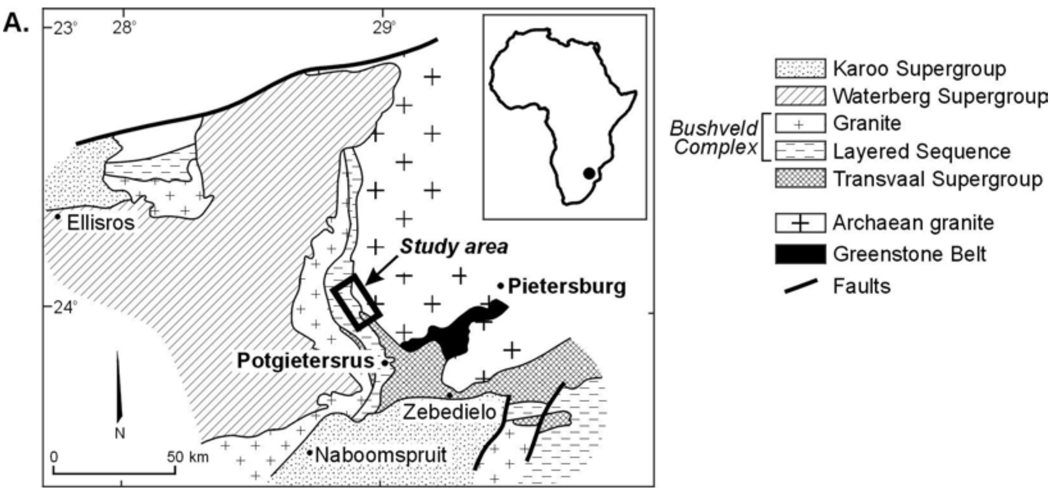

Figure 6.40: Arsenic distribution at Plat Reef (after Frick 1985). A) Regional geology.

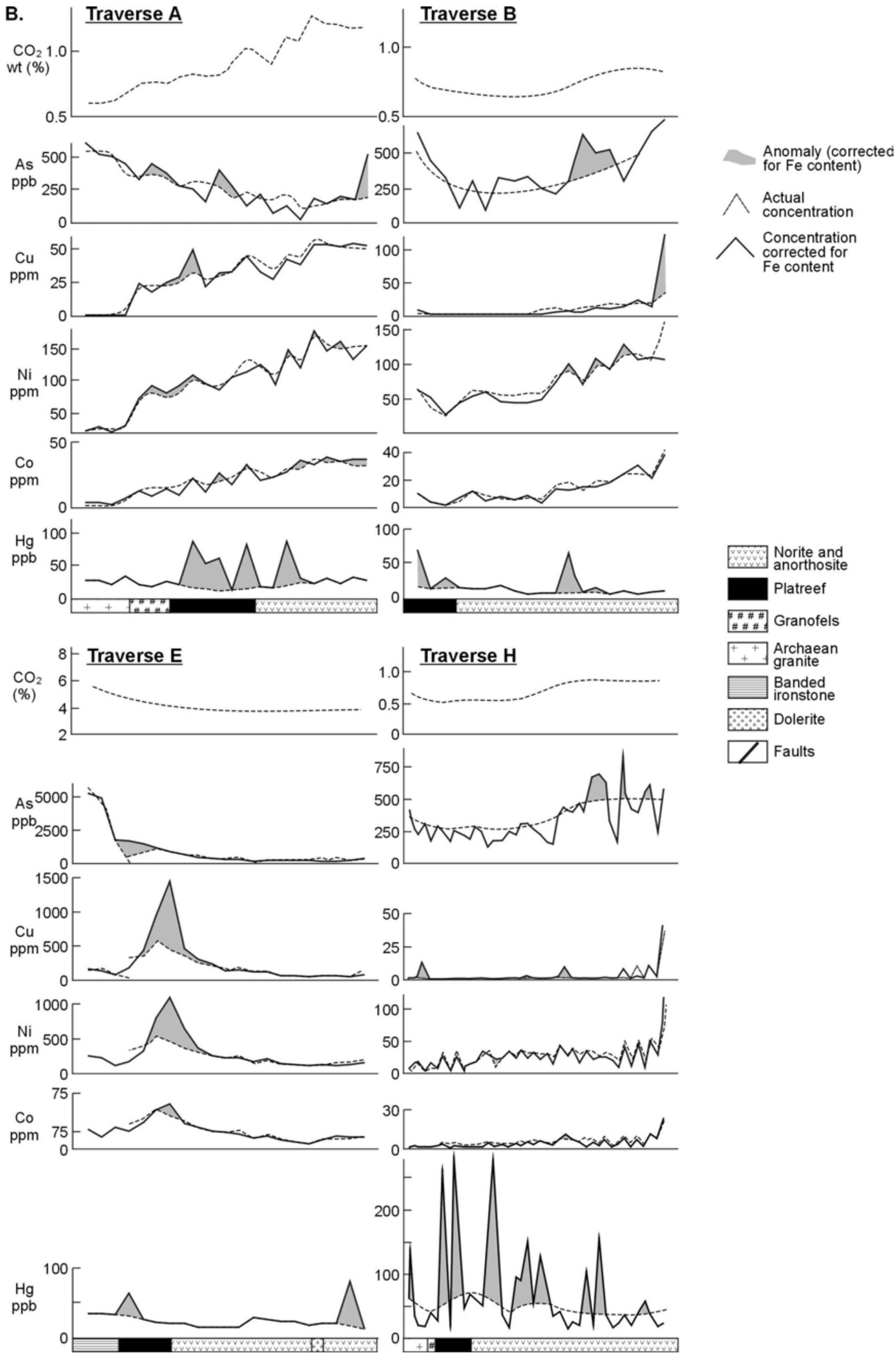

Figure 6.40 (continued): Arsenic distribution at Plat Reef (after Frick 1985). B) Geochemical traverses A, B, E and H.

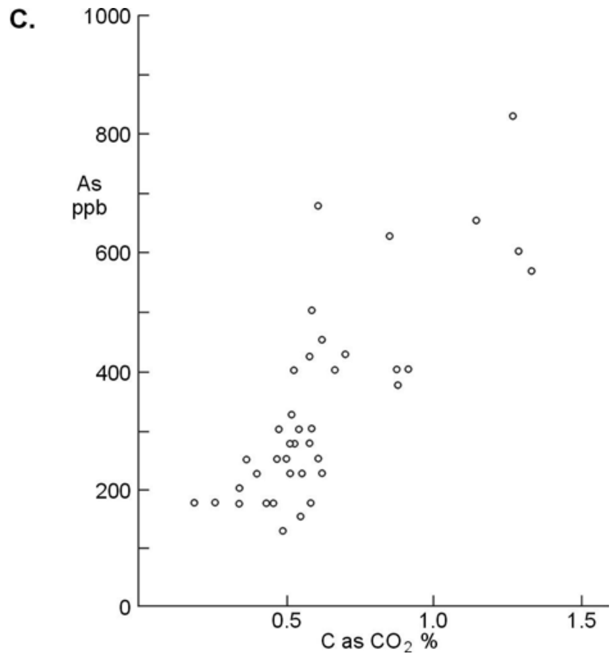

Figure 6.40 (continued): Arsenic distribution at Plat Reef (after Frick 1985).
C) Arsenic versus CO_2 (calcrete) for traverse H samples.

(38) Windimurra Complex, WA. (Harrison 1990, Butt 1992)
The Windimurra Complex is a weakly layered mafic-ultramafic complex located about 400 km NE of Perth, WA. Mineralisation containing >2 ppm PGE is associated with narrow (0.8-2.0 m) bands of disseminated and massive chromite, about 50 m apart. The mineralised sequence is covered by shallow residual lithosols containing coarse fragments coated by calcrete (R.J. Perring, verb. comm. to C.R.M. Butt 1990). The <180µm fractions of these soils, collected at 5-30 cm depth at 10 m intervals across strike, were analysed by fire assay fusion followed by ICP-MS. On the traverse illustrated by Harrison (1990), mineralisation was indicated by an anomaly 130 m wide (maxima 43 ppb Pt, 37 ppb Pd), defined by a threshold of 8 ppb compared to a background of 2 ppb, for both Pt and Pd. In comparison, Cu and Ni gave apical anomalies of 230 ppm and 300 ppm respectively. Inspection of the data suggested that soil anomaly was accurately reflecting mineralisation and a zone with high-background PGE contents; the extent of the anomaly is such that a wider sample spacing (e.g. 20m) may have been adequate. The specific role, if any, of the soil carbonates in PGE dispersion was not assessed. Mineralisation was also detectable in stream sediment samples (<180µm fraction), using the same threshold values.

6.2.6 Uranium case studies (summarised from Butt 1992)

6.2.6.1 Introduction
Epigenetic U enrichment in groundwater calcretes, carbonate-cemented sediments and overburden during the late Cainozoic has resulted in potentially economic surficial deposits. Such deposits are known in arid terrains in Africa, the Americas and Australia (IAEA 1984). They have formed by the solution and transport of U from a dispersed source (usually weathering granitic rocks) followed by concentration and precipitation in a relatively confined site, commonly as carnotite ($K_2(UO_2)_2V_2O_8.3H_2O$). The deposits are classified as follows (Toens and Hambleton-Jones 1984):

1) Fluviatile: in palaeovalleys and drainages containing sediments with aeolian, colluvial, alluvial, lacustrine or evaporitic components.
2) Lacustrine/playa: in dry or ephemeral lakes with evaporitic and fine-grained clastic sediments.
3) Pedogenic: in residual or transported regolith, associated with calcrete, dolocrete or gypcrete.

The only known deposits with economic significance are of the fluviatile type, with the carnotite associated with non-pedogenic, groundwater calcretes (Australia and Somalia), and calcareous and/or gypsiferous sands and gravels (Namibia and South Africa). Exploration for these deposits has depended upon radiometric surveys of favourable geological and geomorphological environments, followed by reconnaissance drilling of the anomalies, which themselves constitute the deposits. Soil or regolith sampling to search for a dispersion halo has been unnecessary. Future exploration may focus on concealed deposits that have formed as precipitates within undisturbed sediments, and those that have no radiometric expression because either they are very recent (and have not reached radiometric equilibrium) or differences in mobility have separated the daughter products from the parent U. Conversely, strong anomalies may be due to the concentration and deposition of Ra either distant from the U deposit, or where no U deposition has occurred at all. Consequently, understanding the genesis of these deposits, which involves weathering and dispersion in the regolith, is important for the interpretation of hydrogeochemical data in the exploration for buried and radiometrically blind deposits.

6.2.6.2 Fluviatile, lacustrine and pedogenic deposits of uranium

A number of factors may be involved in the genesis of fluviatile and lacustrine deposits (Mann and Deutscher 1978) but the most important, especially for those in Australia, are the evaporative concentration of U, V and K in groundwaters and the redox control of V mobility; a lesser role is ascribed to changes in pH and in CO_2 partial pressures that cause dissociation of uranyl carbonate complexes. The cations (U, V, K) are all derived from weathered granitoids and transported in groundwaters to the valley axis (Figure 6.41). Uranium is soluble as uranyl carbonate complexes and V as a tetravalent cation. Precipitation of carnotite occurs where concentrations of U and K have been elevated by evaporation and where V is oxidised to the pentavalent state. This may be where V has diffused upwards from depth under a redox gradient or where a subsurface bar has caused upwelling of groundwaters to relatively oxidising conditions, accompanying effects being mounding and spread of calcrete. However, calcrete is not the only host to mineralisation and in many deposits carnotite is precipitated in other sediments.

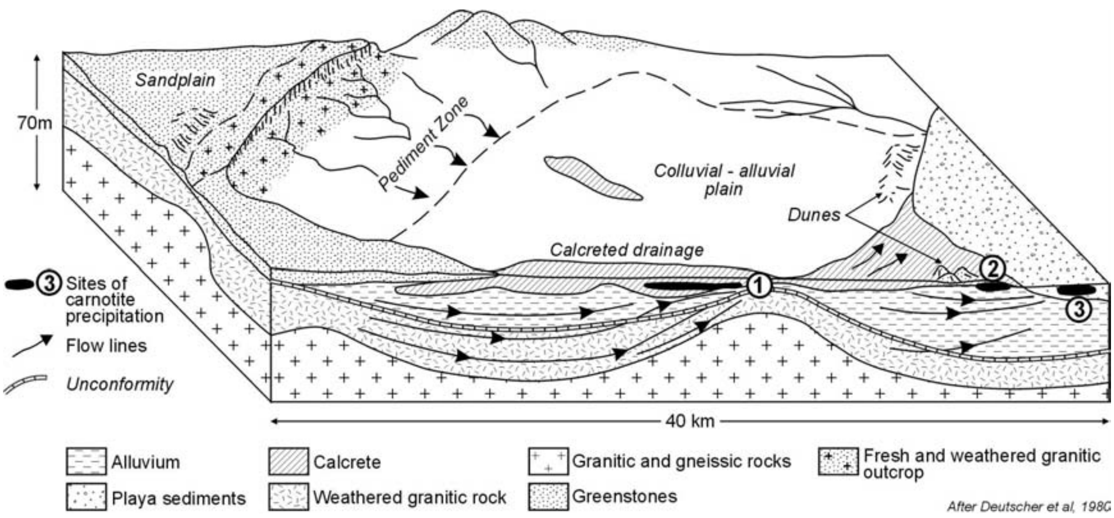

Figure 6.41: Cartoon of U mineralisation in fluviatile and lacustrine carbonate deposits (after Deutscher *et al.* 1980).

Enrichment of U may occur in pedogenic calcrete and underlying carbonated weathered bedrock in the upper 1 to 5 m of the profile. Such enrichment tends to overlie specific source rocks or occur a short distance downslope from them. It is formed by the capillary rise or evaporative pumping of groundwater above the water-table, so that activities of K+, V5+ and U6+ exceed the solubility product of carnotite. Total U contents exceeding 1000 ppm have been recorded (e.g. Minindi Creek, Butt 1988) but, because the volume ratios of source to enrichment site are small, mineable tonnages are low and the deposits are unlikely to be economic. Pedogenic concentration over source rocks having high abundances (>5-10 ppm) of labile U may constitute false anomalies in exploration for concealed primary deposits, the surface expression of which may arise by analogous processes. However, anomalies derived from primary mineralisation would be expected to contain trace element signatures in addition to K and V.

6.3 Discussion

The case studies (summarised in Table 6.4) illustrate the importance of regolith classification in determining the effectiveness of calcrete sampling when exploring for Au and other metals. For Type A and Type B regolith regimes, the beneficial use of calcrete, as an exploration medium, is clear.

Target elements appear to be present in other materials at the surface, e.g. lateritic residuum, mottles, saprolite and quartz, prior to the accumulation of calcrete. Initially, the interaction of pre-existing material with the gradual introduction of calcrete is one of dilution. Later, the carbonate serves to displace, disrupt and replace pre-existing materials during the process of calcrete formation. Clasts of the original host from the micro- to the macro-scale can become incorporated in the calcrete and these may or may not contain target elements. Thus, the metal contents of calcrete may contain spuriously high values (particularly Au), which are due to clastic materials incorporated within the material. In situations where there have been recent additions to the soil profile of calcrete or other aeolian material, metal concentrations may be diluted; aeolian sand can be removed from calcrete by sieving. One method by which "nugget effects" and diluents (e.g., aeolian material) may be averaged for calcareous soils to give less erratic data, is to take a composite sample of soil using an auger, as is commonly done in the Eastern Goldfields, WA. This, of course, adds to the costs of sampling, but will provide more reliable data than soil sampling alone in many circumstances. If aeolian material is particularly prevalent, e.g. sand then selection of sieved coarse calcrete material should be considered, as has been successfully used in parts of the Gawler Craton, SA.

Gold occurs in two different forms in the calcrete and, as a result, the selection of calcrete as a "consistent" sample medium requires some caution:

1) Au may occur in clasts and become physically incorporated into the calcrete, either as a discrete grain or incorporated within a host, e.g. ferruginous granule.
2) Au appears to have undergone a chemical transformation to a chemical species that allows it to become concentrated within, rather than diluted by, the calcrete.

This is most clearly shown in profiles where only powdery, newly-formed, calcrete occurs (e.g. Bounty and Panglo case studies) but it has undoubtedly occurred elsewhere where there is now great thicknesses of older calcrete and the strong correlations have been lost by other pedogenic processes. A theoretical physico-chemical process has been proposed for the manner in which Au and Ca become closely associated in calcrete, but clearly more chemical speciation studies need to be undertaken (Lintern 1989). Briefly, the process requires Au and Ca to be in the soil environment, i.e. particulate, colloidal or chemical Au dispersed from host material such as laterite or saprolite and Ca as wind-blown carbonate. It is proposed that Au is complexed with organic ligands produced by soil flora and fauna, e.g. fungi, bacteria, algae, plant root exudates. After rain and soil moisture build-up, the Au and Ca become relatively mobile and are re-distributed independently, albeit over distances of a few microns, within the soil profile. Some Au and Ca will be adsorbed by plants and re-cycled to the surface. As the soil moisture dries due to evaporation and transpiration processes, the solubility limits of the Ca and Au complexes are reached and they are precipitated. Their close correlation in the soil implies that the solubilities appear to be very similar. The cycle is repeated the next rainfall event, and so on. Numerous (possibly hundreds or thousands) rainfall events will gradually cause some of the Ca and Au to become normally (Gaussian) distributed (with respect to distance from the land surface) in the soil. The distribution is likely to develop a skew to the surface if soil is eroded, or skewed deeper if rainfall increases over a period of time and/or new material becomes deposited e.g. sand.

Evidence in support of the process includes:

1) the strong association between Au and calcrete as shown by soil profiles in the case studies;
2) the strong relationship between Au and soil moisture in soil profiles from Argo and Zuleika (Lintern and Gray 1995b, Lintern and Butt 1992);
3) the soluble nature of Au in laboratory studies (Gray *et al.* 1990);
4) the hypothetical presence of Au complexes in the near-surface environment (Gray 1998); and
5) the presence of Au in plants (e.g. Lintern 1989).

One of the factors that may influence calcrete as a sample medium is the depth at which it is found. The depth at which it appears to be accumulating does not appear to be wholly related to, or predictable from, the annual rainfall, as suggested by Jenny (1941) or Yaalon (1983). For example, the rainfall at

Table 6.4: Case study summary. Locations are in WA unless stated. Mineralisation abbreviated to "min" and maybe secondary in some cases.

No.	Location	Type	Target	Depth to mineralisation	Transported overburden thickness	Other information
1	Kalgoorlie	A	Au	Not known		As (pathfinder) is diluted in calcrete
2	Mulline	A	Au	<5	<1	Gold in both laterite and calcrete
3	Callion	A	Au	<2	<1	Highest Au in calcrete
4	Mararoa	B	Au	20	<1	Arsenic normalised from Fe oxides, Au over min.
5	Bounty	B, T	Au	<5->10	<1-10	Strong evidence for hydromorphic Au
6	Runway	B	Au	50 m	<1	Anomalous Au in calcrete
7	Lights of Israel	B	Au	<2	<1	Gold in calcrete developed in mottled zone
8	Challenger	B, T	Au	<2-20	<1-20	Au in calcrete – calcrete cementing quartz veins
9	Mt Pleasant	T	Au	<5	<1-5	Probable anomalous Au in calcrete. Particulate Au
10	Granny Smith	T	Au	5-20	1-3	Mostly background Au in calcrete. Calcrete not in surface material
11	Wombola	T	Au	40	3-7	Anomalous Au in calcrete. Inconclusive.
12	Apollo	T	Au	15	7	Background Au in calcrete
13	Argo	T	Au	20-30	7-60	Background Au in calcrete
14	Safari	T	Au	8	5-10	Anomalous Au in calcrete
15	Kanowna Belle	T	Au	50	5-10	Anomalous Au in calcrete, Fe granules
16	Matt Dam	T	Au	35	1-16	Anomalous Au in calcrete, Fe granules
17	Golden Delicious	T	Au	20	9-16	Background Au in calcrete
18	Deep South	T	Au	15	10-15	Anomalous Au in calcareous hardpan.
19	Panglo	T, B	Au	30	10	Anomalous Au in calcrete and in adjacent saprolite. Inconclusive study
20	Zuleika	T, B	Au	20	20	Anomalous Au in calcrete possibly unrelated to min.
21	Ghost Crab	T	Au	40	1-25	Anomalous Au in calcrete
22	Marigold, USA	T	Au	30-100	20-100	?Mobile metals above sulphides due to migration of acid (as H^+ or CO_2 gas)
23	Steinway	T	Au	35	30	Anomalous Au in calcrete, Fe granules
24	Kanowna QED	T	Au	30	30	Anomalous Au in calcrete. Inconclusive study
25	Mulgarrie	T, B	Au	35	35	Inconclusive study
26	Wollubar-Enigma	T	Au	55	55	Background Au in calcrete
27	Higginsville	T, B	Au	<1-50	<1-50	Anomalous Au in calcrete, Fe granules
28	Kurnalpi	T	Au	60	60	Background Au in calcrete
29	Nevada, USA	T	Au/Ag	Not known	Not known	Ag in calcrete used as regional tool for Au deposits
30	Pioneer	B	Ni-Cu	<2	<2	Metals occur attached to Mn oxides within the calcrete.
31	Jacomynspan, SA	B	Cu-Ni	<3	<3	Metals occur attached to Fe oxides within the calcrete.
32	Putsberg SA	B	Cu	2-15	2-15	Anomalous Cu in ferruginous granules within the calcrete.
33	Bou Grine, Tun.	B	Pb-Zn	2	<2	Lead and Zn associated with carbonate in the calcrete and not Fe oxides.
34	Kadina	T	Cu	Up to 70	Up to 40	Copper precipitated on calcrete by upward migration of groundwater
35	Rocky R., USA	T	Cu	6-70	6-70	Copper precipitated on calcrete coatings by downslope water percolation
36	Mt Gunson	T	Cu	70	70 m	Copper and Co associated with Mn oxides in/about calcrete horizons
37	Plat Reef, SA	A B T	PGE	Not known	1->4	Arsenic anomalous in calcrete
38	Windimurra	B	PGE	Not known	<2	Inconclusive study (insufficient detail)
39	U Case Studies	T	U	1->10	1-10 m	Valley calcretes anomalous in U to form deposits in their own right

Laverton (about 220 mm) is slightly less than at Kalgoorlie (about 280 mm), yet the zone of carbonate accumulation is variable occurring below 3 m and at least to 9 m. Clearly, other factors are important for the depth at which carbonate (but not Au) accumulates, and may include the following inter-related characteristics of the region:

1) Type (frequency and duration) of rainfall; rainfall is mostly cyclonic and commonly occurs in large quantities over a short period during summer months. The high evaporation rates imply that soils dry more rapidly than in the winter-rainfall areas. This, in turn, results in a shorter growing season.
2) Hydrology; most rainfall does not percolate down through the soil profile but probably either flows over the surface, or channels preferentially through macropores that occur in the hardpan; the clay-rich calcareous soils that occur S of the Menzies Line, on the other hand, allow more general permeation of water through micropores.
3) Type of vegetation; *Acacia* dominate the landscape rather than *Eucalyptus* which predominantly occur S of the Menzies Line.
4) Low organic content and, presumably, biological activity in soils N of the Menzies Line.
5) Soils are acid becoming alkaline with depth, whereas in the southern Yilgarn, many soil types are alkaline becoming acid with depth.

The depth of transported overburden is the most important factor in determining whether sampling surficial calcrete is likely to be effective or not. For Au, there are no comprehensive case studies demonstrating that calcrete sampling would convincingly lead to the discovery of buried mineralisation where the depth of transported overburden exceeds 10 m. At some sites e.g. Wombola and Matt Dam, Au appears to be unusually highly concentrated in the calcrete when compared with other sites e.g. Zuleika, to be explained by simple upward movement of Au from a buried source. Even where the depth of transported overburden is less than 10 m, there are many cases where calcrete sampling does not locate mineralisation and/or where calcrete does not occur in significant quantities e.g Granny Smith (N of the Menzies Line). Although a fairly detailed study was undertaken, Safari requires further investigation to prove conclusively that calcrete sampling can be effective through overburden thicknesses as great as 5-10 m. Here, a mechanism(s) for the accumulation has not been established but progressive bioturbation, capillarity, soil gas, and vegetation may be involved. The reason for the accumulation of Au in calcrete at Safari and not in other areas, such as Argo and Apollo where the depth of transported material is less, is not easily explained but may be due to the possible differences in age or type of sediments. Superficially, there are sites where anomalous Au in calcrete overlies deeply buried mineralisation. However, there is strong evidence for the derivation of Au being from upslope rather than vertically from underlying mineralisation, particularly when detailed studies have been undertaken e.g., Higginsville and Steinway; these last two sites contrast with Zuleika where shallowly buried mineralisation barely produces an anomaly at all. In cases where calcrete has been acclaimed as a sample medium capable of discovering deeply buried mineralisation, unusually high concentrations of Au in the calcrete e.g. greater than 100 ppb, should arouse suspicion and suggest other causes. Although many studies may provide good examples of the use of calcrete in transported overburden, they are often coupled with a paucity of data (e.g. regolith-landform maps, topography, stratigraphy, detailed soil analysis) for a rigorous scientific appraisal to be made. Unfortunately, many studies have helped to promote an overly optimistic outlook for the use of calcrete in transported regolith: this may not be justified.

For Cu and other metals, case studies have been insufficiently detailed or numerous to demonstrate convincingly that the calcrete horizon, or material just beneath it, are effective sample media in areas of transported overburden. Only where the overburden is relatively shallow (<10 m), does there appear to be evidence of concentration of metal in calcrete as with Au, e.g. Kadina and Moonta, but whether this is due to upwards movement of metal-enriched groundwater or down gradient groundwater flows e.g. Rocky Range is not clear.

6.4 Recommendations for exploration

(1) The case studies indicate the importance of regolith characterisation before deciding on an exploration programme for a particular area. At present, this can only be achieved with drilling and regolith-landform mapping, but recent remote sensing techniques such as airborne EM,

Landsat TM and radar altimetry may give some hope in being able to map large areas with relative ease. Ideally, the regolith should be classified in terms of Type A, B or T. In terms of using calcrete for exploration, regolith Types A and B (regolith developed within variably weathered bedrock) appear to present fewer problems than Type T (regolith developed in transported material over Types A or B). The deeper the transported overburden, the less effective is calcrete as an exploration sample medium. The case studies suggest that where Type T regolith has transported material exceeding 10 m in thickness, it is unlikely that any response in the calcrete can be directly attributable to underlying mineralisation.

(2) Calcrete appears to both replace and displace host material, whether it be laterite, saprolite or sediment, and has a variable effect on the subsequent distribution of elements of interest within the original material. Calcrete commonly acts as a diluent in soils for base metal exploration, whereas Au appears to accumulate, or at least reside preferentially, within the calcareous horizons. The presence of parent material containing high concentrations of metal within the calcrete, e.g., in ferruginous granules, which may be a by-product of lateritic duricrust disintegration, may tend to distort the apparent effectiveness of the calcrete itself.

(3) The sampling procedure for calcrete depends on the type, depth and presence of other material. Nodular or laminar calcretes can be beneficiated by sieving away the fine fraction (particularly aeolian sand). These may be found at depth and can be sampled by digging small pits and breaking indurated surface with, for example, a crowbar or a robust auger. Powdery calcretes are best sampled by taking soil composites (e.g. 0-1 m) with an auger. This is particularly important on a prospect scale where large variations in the metal content of the calcrete may be expected due to inclusions. Loose nodular calcretes found on the surface should be avoided since (i) their origin is unknown, and (ii) they may have been preferentially leached of metals of interest. A sample size of 1 kg is sufficient for most samples.

(4) The identification of calcrete is most important. Calcrete samples may artificially enhance (for gold) or dilute (for base metals) the expected geochemical response and so it is important to be able to compare (in a sampling batch) similar materials or at least be aware of potential complications. The nature of the calcrete has already been mentioned in (2) above and so "calcrete" samples could include anything from, for example, a pure calcite deposit consisting of 40% Ca to fresh rock coated with a carbonate skin with a Ca concentration of less than 1%; both extremes will effervesce when acid is applied. Analysing the sample for, at least, Ca, Fe and ore-associated elements is recommended for an exploration programme. The analysis of Ca and field observation of effervescence will assist in estimating the amount of carbonate, although the presence of gypsum and other Ca-bearing minerals can give falsely high Ca concentrations. Iron concentrations will provide information on elements known to be scavenged, including pathfinders for Au, such as As and base metals.

(5) The use of partial or selective leaching techniques appears to be useful in some cases but the cost of such a procedure may be prohibitive in routine exploration. Leaching is used to enhance a geochemical response either by (i) removal of a perceived dilution effect caused by the carbonate, or (ii) specifically analysing for the mobile phase of the metal occurring in the carbonate itself.

(6) Sample spacing depends on many factors. As a guide, sample spacing that should be similar to a normal soil sampling programme recommended for that area. Obviously, sample spacing may be quite broadly spaced for initial regional work (1.6 km grid) but may be narrowly spaced for defining drilling targets (10 m).

(7) Sample preparation and analysis, data handling and interpretation rules apply to calcrete sampling as they would for any other geochemical programme. Appropriate standards must be included in submissions to analytical companies and preferably be of calcrete or similar material. Acid digests of calcretes must be of sufficient strength to digest the carbonate and take up the analyte of interest. Cyanide digests are recommended for Au dissolution when carbonate is present. Appropriate detection limits must be used; as a guide, if there is a detection limit of 0.1 ppb (recommended) then the minimum contoured gridded value should be not lower than 1 ppb, i.e 10 times the detection limit. Do not expect high correlations between Ca and Au from soil samples (e.g. 0-0.1 m, 0-1 m) collected during a routine sampling programme; high correlations are only observed in samples collected vertically down a soil profile.

(8) The results indicate that whilst pedogenic calcrete is important for mineral exploration, the role of groundwater calcretes has not been determined. Uranium is the exception since it may form mineral deposits within groundwater calcretes in its own right. At Granny Smith, north of the Menzies Line, calcretes possibly representing an intermediate form were investigated and shown to be of little value when compared with other regolith materials.