Structural Analysis, Alteration Mapping and Remote Sensing Services

Services Document

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prepared by:

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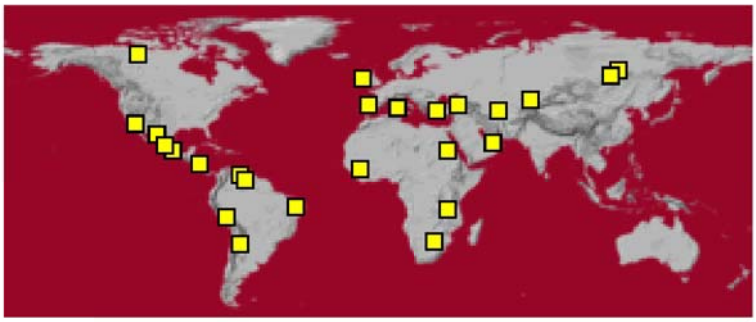
Introduction

Telluris Consulting Ltd is a geological consultancy established in 1993 that specialises in the application of structural and alteration studies with bespoke image processing. We have a broad range of clients from small companies to major corporations and we provide a high quality of service that has resulted in several significant exploration successes. Although most of the work currently undertaken is in the mineral exploration sector, oil and gas, environmental, forestry, planning and other related sectors are catered for. We have over 18 years experience in the interpretation of remote sensing data from arctic and desert to tropical terrain that cover a very broad range of structural environments from the Archean to the Tertiary and neotectonic conditions.



Map showing the location of project work undertaken by Telluris Consulting Ltd

This document briefly outlines some of the main techniques and work elements that have been used successfully by Telluris Consulting Ltd in mineral exploration projects. These have been applied in a variety of structural regimes in differing environments and for a wide range of deposit types in North and South America, Asia, Europe and Africa.

Mineralisation styles studied include porphyry copper/gold, low-sulphidation and high-sulphidation epithermal deposits, skarn and carbonate-replacement (CRD and MVT), sedex, iron oxide-copper-gold (IOCG), diamonds, orogenic gold, and volcanogenic massive sulphide deposits (VMS). Studies have ranged from detailed mine-scale fault-reserve problems, detailed structural and alteration mapping, and mine district projects up to regional and country-wide interpretations.

An important element of each study, where possible, is the application of detailed field observations to define structural and hydrothermal fluid models and apply them to the processing and interpretation of remote sensing imagery. The ability to re-process and re-interpret data and imagery in the field means that each study obtains the best results and is of maximum benefit to the client. Each study tends to require a different combination of techniques to solve the complexities of a given deposit and provide a set of criteria for further local or regional exploration.

The main components of services offered cover the following:

- Acquisition and processing of satellite data including Landsat TM, SPOT, Aster, Ikonos and radar products including the development of in-house processing techniques.
- Bespoke processing that is always undertaken by an exploration geologist with considerable experience in structural geology and the recognition of different hydrothermal systems.
- A flexible methodology of working is adopted where data can be re-processed in the field by applying interactively the results of on-going field studies and anomaly checking.
- The interpretation of remotely sensed images and stereo/air photo data for structural, lithological, alteration data to produce integrated exploration plots.
- Detailed mine-scale and/or regional field studies and field mapping to ground-truth interpreted data, produce high-quality synthesis maps, and to develop structural, fluid evolution and alteration models for exploration.
- The collation and synthesis of interpreted data with published and/or company data such as geochemistry, geophysics etc. to define and prioritise exploration targets.
- Considerable experience in the interpretation of structural features and alteration from remotely sensed imagery and its application to detailed field mapping.

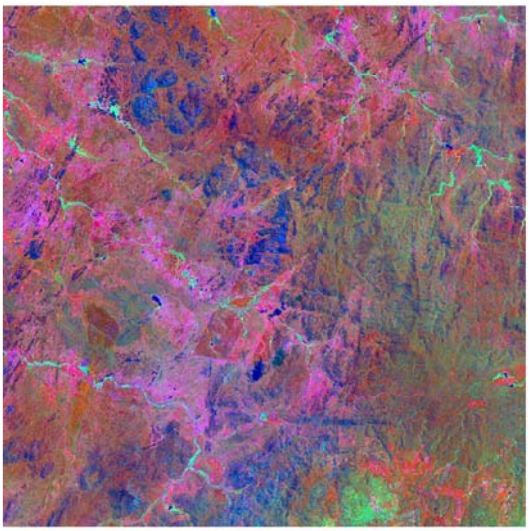
Our aim is avoid using a “black box” approach to processing and interpretation. At Telluris Consulting Ltd we prefer to employ and test a wide range of techniques to each study to produce imagery, anomalies, structures and targets that are geologically meaningful and that have the greatest probability of exploration success. Many of the example figures included herein are taken from previous studies of porphyry copper, skarn/CRD, IOCG, orogenic gold and epithermal deposits/districts, nonetheless examples are available of other deposit types studied.

(Detailed location information has been removed to maintain client confidentiality and some of the data included here has been presented previously.)

Image Processing

The aim of selecting satellite data is to choose the optimum image available. This involves finding a scene that is as near cloud-free as available, with a minimum of haze and a moderate sun angle (depending on topographic relief). It is usually acquired with a date when maximum contrasts can be identified or when vegetation is at a minimum (often in the driest part of the year).

The principal objective of the processing of satellite data for mineral exploration is to provide a single or group of images containing as much information as possible. This includes structural detail, lithological discrimination, and mineral anomalies that may reflect hydrothermal alteration.

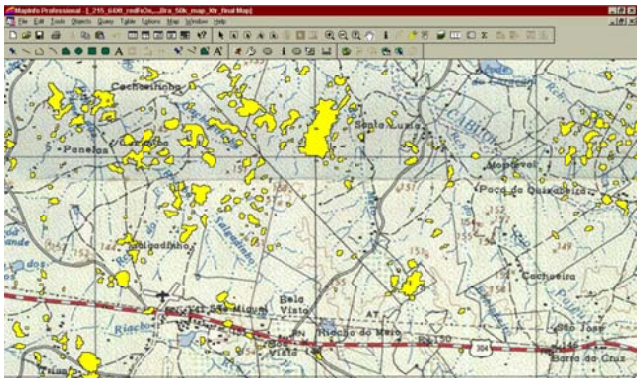


principal component image high-lighting lithology and structural trends

The main advantages of using imagery for exploration are as follows:

- A large area can be initially prospected very quickly at a variety of scales in order to define potential target zones;
- Mineral anomalies such as clay and iron oxide species that are commonly found in alteration haloes of mineralised structures (e.g. in high/low sulphidation epithermal and porphyry environments) can be detected and often mapped accurately;
- Regional structures that often play a fundamental role in controlling mining districts (such as poorly exposed major terrane boundaries or structures developed during early deformation phases) can be defined and mapped;
- Subtle structural elements that are not obvious in the field but may control mineralisation can be delineated and their extensions traced;
- In areas of poor background information or where field access is restricted, high quality geological and logistical orientation maps can be produced, and refined with the aid of selected field data;
- Satellite data can be geometrically corrected using ground control points, to a client specific coordinate system to provide a base to overlay other databases such geophysical and geochemistry data or to be used as part of an analysis in a GIS environment.

In each study, the available imagery is processed to provide the optimum information on structure, lithology, and defining surface alteration patterns. Often the data can initially be processed at a regional scale and then re-processed in more detail for specific areas of interest. All imagery and results can be provided as full colour raster and vector plots in digital formats for incorporation into a GIS system such as ArcView or MapInfo.



Alteration vector polygons overlying a georeferenced topographic map scan

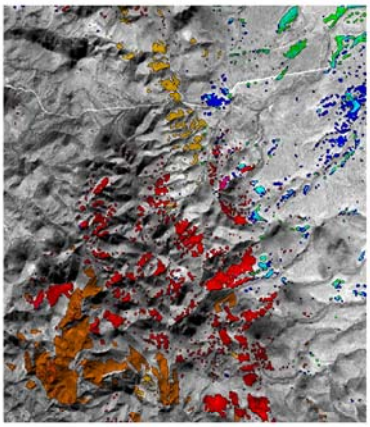
Alteration Mapping

Lithology and hydrothermal alteration can be inferred and mapped from imagery in a variety of ways:

Hydrothermal alteration products (broadly speaking clays and limonites) can be mapped using Landsat TM data. More traditional processing methods involve band ratios but unfortunately, these products suffer greatly from atmospheric effects and decrease in signal to noise as a side effect of the ratio. They also suffer from low dynamic range in the resulting data and most importantly the influence in the clay ratio make it impracticable in all but true dessert environments. These problems can be overcome using Crosta PC and LSF Residual statistical methods that have been proved in remote sensing studies in a wide range of geological environments and climates.

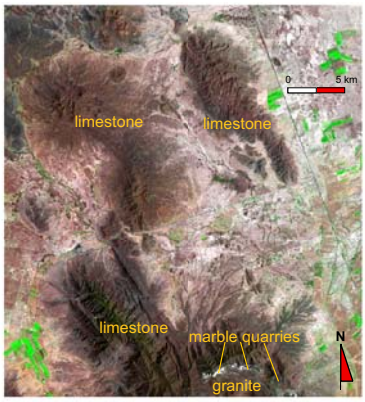
The resultant hematite, jarosite, and clay anomaly images can be digitally combined with a 1,4,7 composite (or greyscale for clarity) to produce an all-round product which is economic to produce, easy to use in the field and avoids the inaccuracies that can occur in overlaying data sets. These anomalies are also provided as separate files for GIS databases in both raster and vector formats.

Ideally the initial processing should be field checked and where pertinent secondary processing may be applied in order to get the best results. As the imagery is processed by an exploration geologist, the aim is to produce geologically significant anomalies, avoiding a “black box” approach. In most cases, especially when applying field experience to processing the imagery, the majority will reflect true hydrothermal alteration.

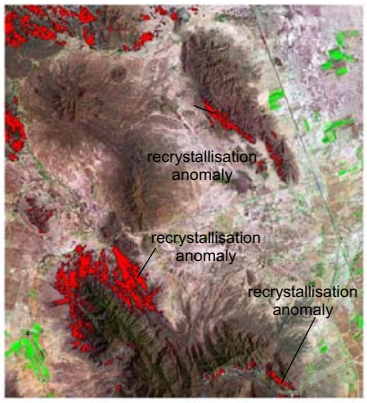


calc-silicate, iron-oxide and clay anomalies

In-house processing techniques have resulted in a method for mapping limestone recrystallisation associated with CRD and skarn deposits. In some cases the distribution of recrystallisation has extended the limit of field mapped skarn/skarnoid alteration and contributed significantly to re-focussing the exploration program.

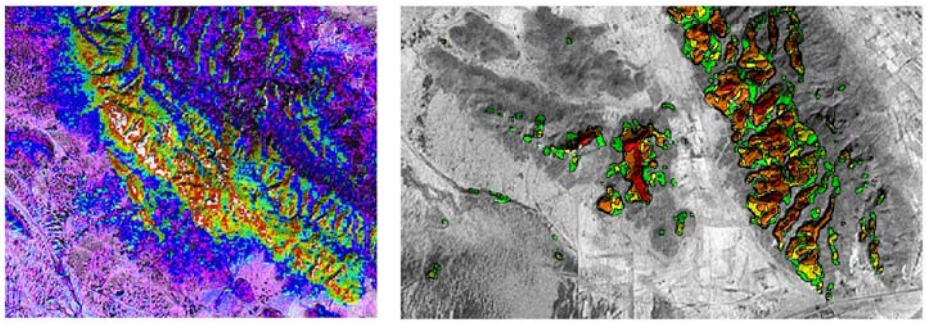


147 base image



147 base image with recrystallisation anomalies

The anomaly data can be sliced to show the zones of potentially the strongest alteration and also to define areas of lower intensity anomalies that may be geologically very significant and highly prospective.

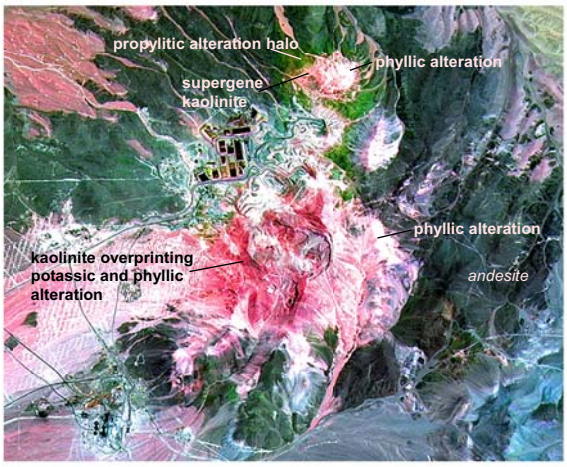


density sliced and contoured anomaly maps defining areas of strongest limestone recrystallisation / skarn alteration

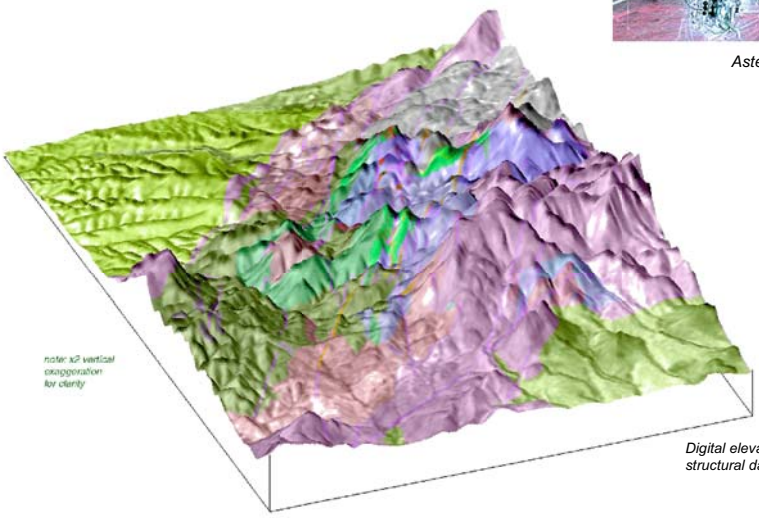
Aster data can allow also the discrimination of sulphates (e.g. alunite, anhydrite and jarosite), carbonates (e.g. calcite, dolomite, ankerite), montmorillonite and kaolinite clays, feldspar and garnet group minerals and quartz/silicification.

This enhanced capability with the same visible band resolution as Landsat TM 7 can be applied for alteration mapping to a wider range of mineral deposit types such as orogenic gold, iron-oxide-copper-gold systems and in diamond exploration.

The availability of Aster imagery at present is limited in some areas but it is constantly improving. We can process both 1A and 1B data.



Aster image of the El Salvador mine, Chile



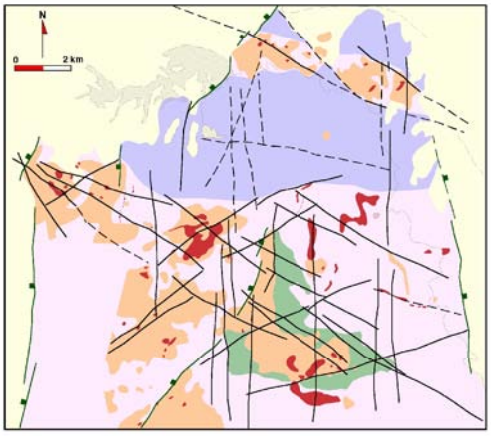
Another advantage of the Aster system, apart from its low cost, is the stereo capability from which digital elevation models (DEM / DTM) can be produced. Satellite data or lithological mapping can be merged with the DEM to help visualise the three-dimensional relationships of the structure, alteration and lithology.

Digital elevation model overlain by field-mapped lithology, alteration and structural data.

Colour air photographs (and to a lesser extent black and white photos) can be useful in more detailed mapping of hydrothermal alteration. In areas of moderate to good exposure they can be used to differentiate argillic or advanced argillic alteration, propylitisation and areas of iron-oxides common with many porphyry copper deposits.

The stereo capability of air photo data is very useful in the interpretation of lower angle structures such as thrusts and detachment faults which are often difficult to trace using non-stereo imagery.

In some established exploration districts air photo data is readily available and, when ortho-corrected, is very useful to provide a high-resolution base to other remote sensing data (e.g. Landsat or Aster).

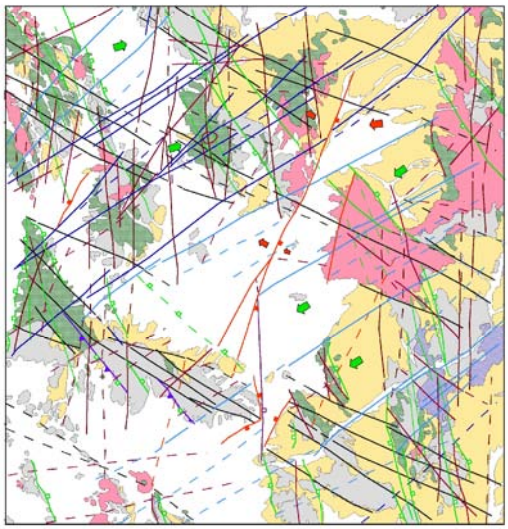


Structural interpretation and alteration mapping of a porphyry copper exploration play derived from colour air photo data

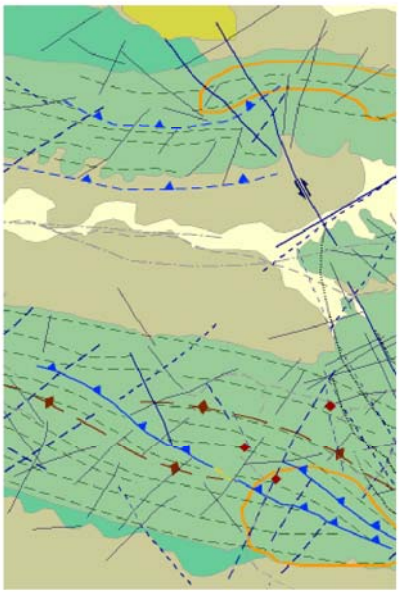
In order to prioritise mineralisation anomalies derived from imagery, even a rapid first pass structural interpretation performed in the field can help to define the best initial targets for field checking.

Structural Interpretation

The integration of field data to a structural interpretation helps to differentiate large-scale, structural features and prioritise favourable structural zones. A good example of this is the identification of tilt domains when looking for potential blind porphyry copper mineralisation in the Basin and Range province of North America.



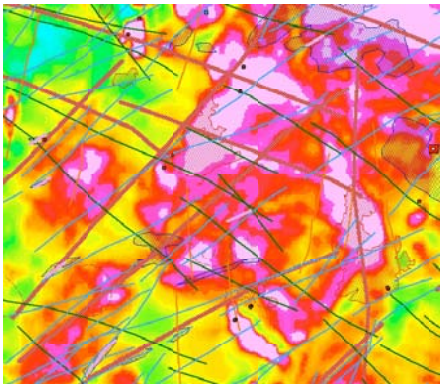
Structural interpretation of an area of the Basin and Range province showing the subdivision of structures into different ages and tilt domains of detachment fault blocks.



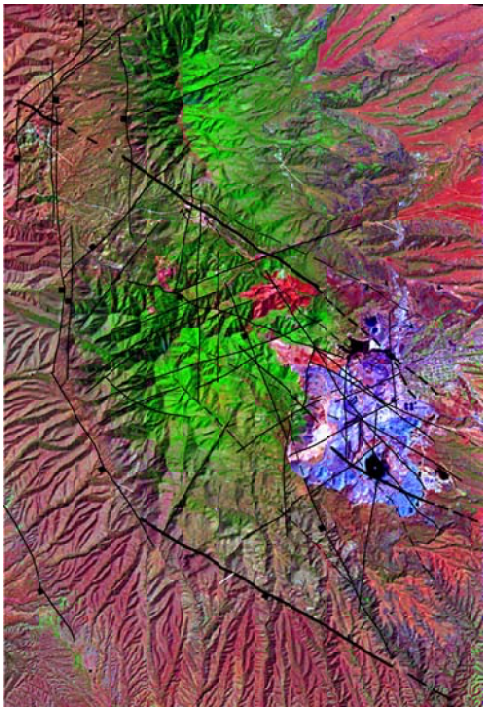
Structural-alteration map of an exploration district in a fold-thrust belt based on Aster data and DEM 3D surface images.

The interpretation of data at different scales also helps to subdivide structures into different categories such as regional, major, minor, local etc. helping in target selection. The use of all available geological data incorporated with field checking of specific areas allow high-quality structural alteration maps to be rapidly produced.

The interpretation of satellite data is not only concerned with lineament recognition but also should aim to resolve structural and spatial relationships that are relevant to exploration. In most mineral districts, the tectonic event associated with mineralisation is often one of several phases in a protracted history that may also include pre-mineralisation and post-mineralisation deformation.



Structural-alteration interpretation combined with geophysical data.



Simplified interpretation of a mine area showing the main structural trends

Field Structural Analysis

In most studies it is strongly recommended that, where possible, some days fieldwork are undertaken, especially if there is little data on structural regimes and controls of the mineralisation. The main reasons for incorporating fieldwork into a study comprise the following:

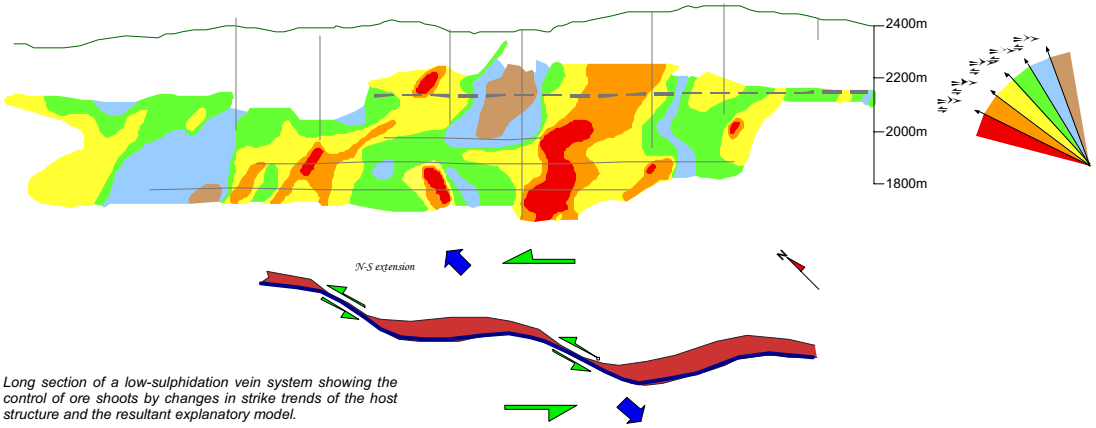
• To ground-truth the structures interpreted from the remotely sensed data, which is of prime importance in evaluating subsequent potential target areas. The detailed analysis of smaller scale structures and their relationship to the major faults provides invaluable information on their kinematic history.

• It allows the determination of fault kinematics/stress systems associated with one or more mineralising events to develop structural models and define the controls on mineralisation. This also enables previously mapped areas to be reinterpreted.

Outcrop data used to develop a structural model for mineralisation.

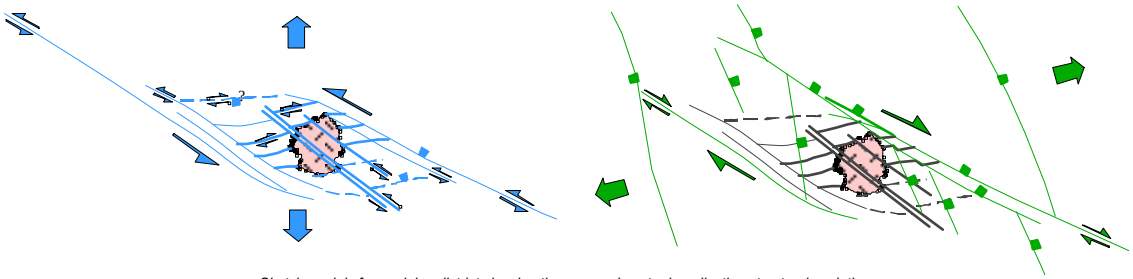
• The structural analysis should cover the full range of deposits in a given study area. One or more structural models can then be applied to the interpretation for target generation. The data can then be synthesised to produce summary exploration maps with targets at the scale of interpretation and showing the main structures of importance and potentially mineralised dilational zones.

• In mines, a model of the structural evolution is used to define favourable exploration zones, the plunges of orebodies, constrain drilling targets and help find extensions displaced by post-mineral faulting. This has been achieved in several mines by Telluris Consulting resulting in the discovery of new orebodies and significant increases in proven reserves.



Long section of a low-sulphidation vein system showing the control of ore shoots by changes in strike trends of the host structure and the resultant explanatory model.

Telluris Consulting has considerable experience in terrains where a wide range of deposit types display different controls with age and a varying degree of influence of pre-existing structural elements. Post-mineralisation deformation is often common where up to three or four phases of post-mineralisation deformation have been identified as an important factor to consider during exploration. With field analysis of the area under study, the definition of the tectonic evolution helps to effectively focus exploration.



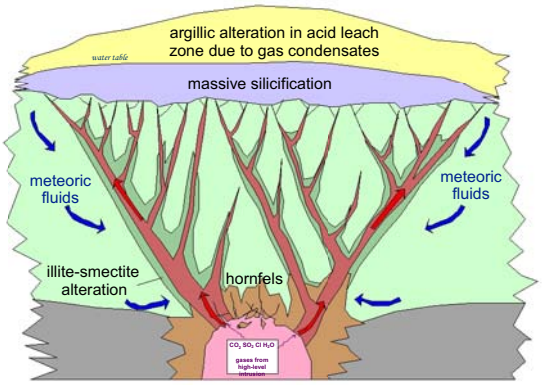
Sketch models for a mining district showing the syn- and post-mineralisation structural evolution.

A period of fieldwork also provides an opportunity to present and discuss the preliminary and/or final results. Training in English or Spanish can be provided in certain aspects employed in the study.

Field Alteration Studies

Another important factor in the field analysis of areas of potential mineralisation is the recognition of alteration signatures. This involves field checking of alteration signatures produced from Landsat TM/Aster image processing and includes definition of alteration styles related to known deposits. An understanding of alteration types is essential for elucidating the hydrothermal system and determining the location of the outcrop in both lateral and vertical alteration profiles relative to fluid sources.

As Dr Tony Starling is also a Visiting Research Fellow at the University of Leeds, UK, detailed petrography, mineralogy and fluid inclusion studies also can be employed to support field observations and better constrain deposit models.



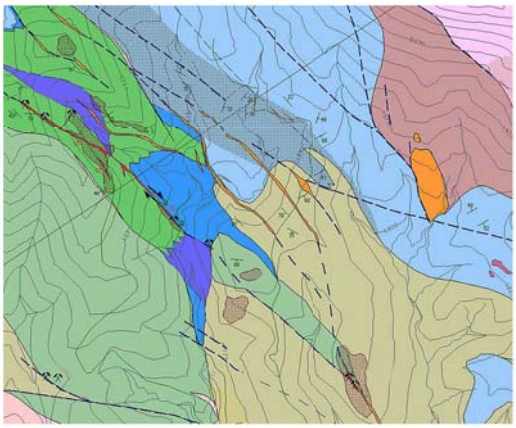
Sketch model for a low-sulphidation vein system as a guide to exploration

Field Mapping

The integration of structural, lithological and alteration mapping combined with iterative secondary processing and interpretation of imagery results in rapid high-quality exploration target maps.

One of the main advantages of using such an approach is that deposits can be assessed at both the regional and local scales. Field alteration mapping combined with detailed field-based image processing means that the best results can be obtained from the data and other areas rapidly identified that may be prospective.

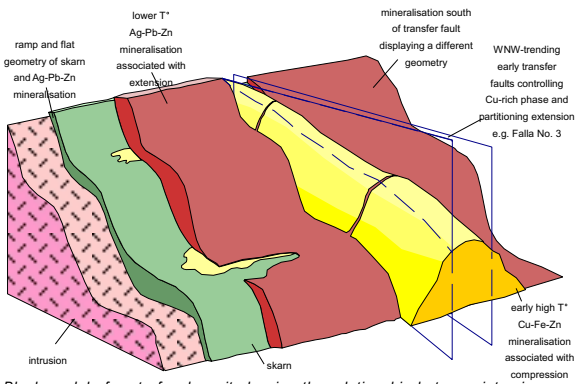
In areas where access is poor or where there are significant constraints on field time, this integrated approach can help to efficiently focus exploration. The application of digital elevation models can help visualise mapped geology and provide topographic base maps in regions that are not well mapped or where data is restricted.



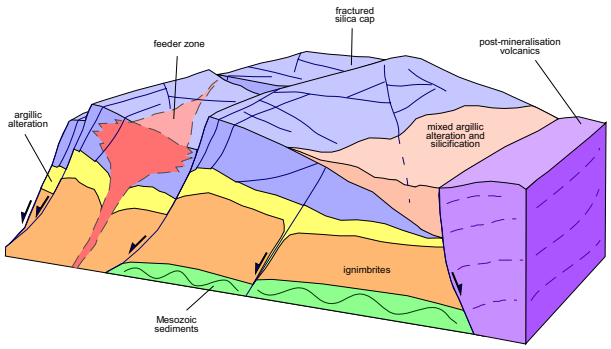
Extract of structural, lithological and alteration mapping at prospect scale.

Deposit Models

During field studies, where applicable, a model is produced for the mineralisation and the evolution of the hydrothermal fluids. This also includes alteration zonation and targets for higher-grade reserves incorporating any available additional data such as drilling, geophysics and/or geochemistry results and fluid inclusion data. The deposit modelling is intrinsically linked to the structural model and both are used in conjunction to derive a single unifying model for the mineralisation. Understanding the structural controls and the hydrothermal evolution is fundamental to the planning of geochemical and geophysics studies and an intrinsic part of defining the best drilling targets.



Block model of part of a deposit showing the relationship between intrusion, alteration and different phases of mineralisation.



Block model showing the effects of post-mineralisation deformation on high-level alteration patterns

Project Components

The style of final report varies depending on client needs. This can range from a comprehensive report with detailed descriptions of field observations, synthesis, and modelling to a report covering brief summaries of the observations and the main conclusions and recommendations. Where applicable, as for example during large or multi-component studies, update reports are provided on a regular basis along with digital figures or plots of work in progress.

The type and style of each project is highly variable and depends on the area of interest, local geology, and budget constraints of the client. Projects may vary from short field visits with a brief report on structural controls, alteration systems etc. to a large-scale remote sensing project covering regional and local imagery and/or air photos, field mapping, and several weeks field work. The aim is to tailor each study to address the specific requirements for the clients exploration program.

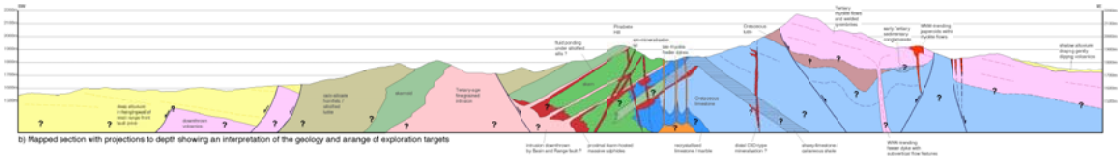
Results

Major exploration successes have been achieved in a significant number of studies ranging from working mines to grass roots exploration projects. For example, in Mexico new orebodies have been discovered at Taxco, San Martín, Velardeña and Charcas mines. These discoveries, found as the result of detailed structural, alteration and remote sensing studies, have realised several hundreds of millions of dollars (US$) of new reserves.

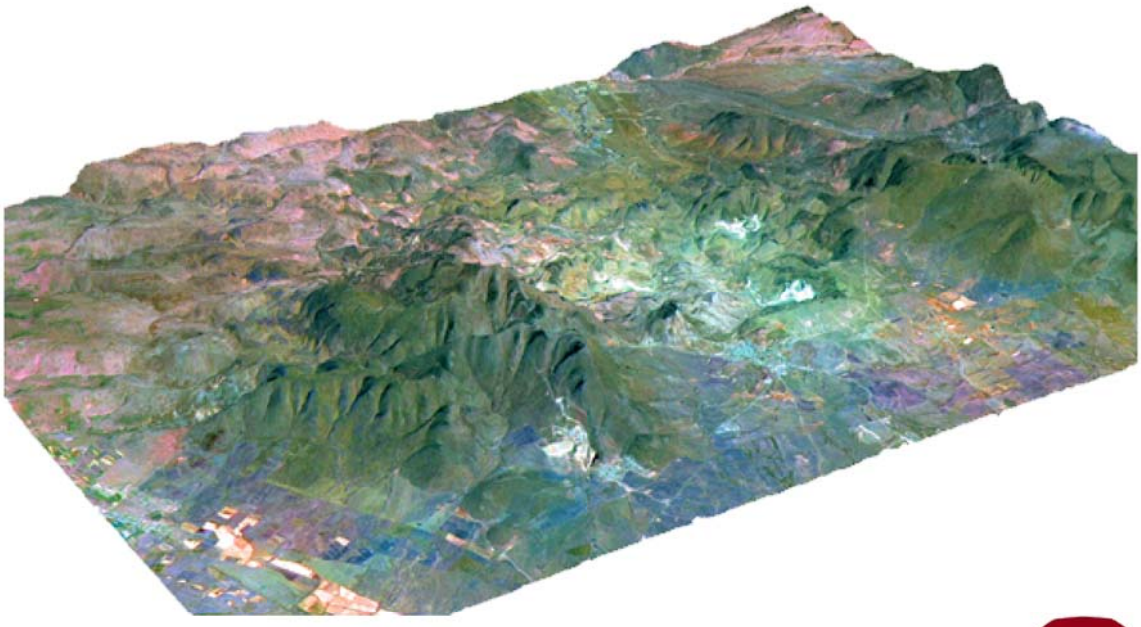
Targets identified through regional studies and followed through to the deposit scale have been successfully carried through to the drilling stage.

Re-processing of client Landsat TM data in Eastern Europe, in an area where all previous attempts had failed, achieved a greater than 80% success rate in positively identifying hydrothermal alteration anomalies and directly resulted in the discovery of a new porphyry system.

Client confidentially at present does not allow disclosure of the results of some exploration programs.



Cross-section with interpretation to depth based on field mapping augmented by satellite and air photo interpretation



Three-dimensional fly-through of a mining district generated from Aster DEM and SWIR-VNIR composites as an aid to structural interpretation

Clients

some of our clients include:

TECK CORPORATION
CentralAsian Gold Corp.

Anglo American Exploration (Canada) Ltd.

bhpbilliton

eldoradogold

PLACER DOME INC.

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Peñoles

FRANCISCO GOLD CORP.
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COMPAÑIA SAN FELIPE, S.A. DE C.V.

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Structural and Remote Sensing Exploration Analysis