SYNTHESIS REPORT

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TITLE : INNOVATIVE ANALYTICAL AND GEOPHYSICAL TECHNOLOGIES FOR DETECTING BLIND POLYMETALLIC OREBODIES IN SOUTHERN SPAIN

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ABSTRACT

The work undertaken for the project was carried out from October 1992 to April 1995 in the framework of a European Community contract involving several partners, with BRGM as coordinator.

Today, the depletion of near-surface mineral resources in the Iberian Pyrite Belt (IPB) means looking for deeper orebodies. Present exploration techniques are generally capable of revealing anomalies, but are not capable of determining the best potential targets from these anomalies. Improved performance in this area requires the development of an updated exploration methodology by which it is possible to identify the signatures in the zone of influence of a polymetallic deposit through new field and laboratory methods and technology.

The first objective of the project, and probably the most problematical, was to discover an economic polymetallic sulphide deposit in the Spanish part of the IPB, through - the second objective - developing an effective low-cost exploration methodology; this was based on improved reasoned geological deduction, and on the development testing and application of new and powerful exploration and analytical tools in the fields of geophysics and geochemistry:

The project hinged around several closely linked poles of interest with the immediate aim of discovering a base- and precious-metal sulphide deposit. Beginning with the results of standard exploration methods (geological, geophysical and geochemical surveys), it was necessary to develop:

- new exploration tools (gas sampler, 3-axis electromagnetic system) for use in the field or for resolving exploration-related geological problems;
- more powerful synergic systems of data processing (3D geophysical and geological modelling, multidataset processing, regional database);
- an analytical tool capable of providing varied geochemical data rapidly and cheaply (ICP-MS laser ablation probe) for use in the laboratory;
- a methodology based on the new tools and on improved geological deduction.

To solve these problems, the project was structured into eight main tasks in which the partners were variously involved.

BRGM (French Geological National Research Centre) was responsible of "Task 1- Develop 3D geophysical softwares" and "Task 2- Develop a selective gas sampler for geochemical exploration".

VG Elemental (Fisons, UK) and the ***University of Southampton*** were involved in "Task 3- Develop an ICP-MS microprobe as a laboratory tools"; VG developed the new generation ICP-MS laser ablation microprobe, and delivered its prototype to the University which was responsible for the geological application of the ICP-MS, using geological materials supplied by the other partners.

SEIEMSA, (Spanish Mining Company of the BRGM group) formed a joint venture with ***RTM***, (Spanish Mining Company); both were responsible of "Task 4- Systematic data acquisition, for a given prospection area", "Task 7- Carry out a sectorial multidataset study, for the prospection area", and "Task 8- Drill the selected anomalies".

APIRSA (Spanish mining company) and the ***University of Huelva*** were responsible for **"Task 5-** Study a known blind deposit (Los Frailes) in order to construct a model of this deposit",

ITGE (Spanish Geological National Research Centre) was responsible of **"Task 6-** Construct a regional database (geological, geophysical, geochemical and satellite data)".

The main results that come out of this project are:

1. Instrumental:
   a. interactive 3 D modelling software MODGM-5D for integrated geological and geophysical data (gravimetry, magnetism);
   b. software package for a downhole 3-axis EM system ARLETT (acquisition, representation and interpretation of data); the 3-axis EM system was developed to both recognise and locate conductive bodies within a radius of about 150 m of a barren borehole
   c. development of a selective gas sampler based on the use of charcoal (activated carbon fibre tissue TCA) as sorbant, capable of trapping volatile organo-metallic compounds derived from underlying mineralization
   d. development of a powerful laser ablation mass spectrometer (ICP-MS) to provide multi-elemental and multi-isotopic analyses in solid geological sample (laboratory support).

2. Methodological:
   a. better geological knowledge of the Pyrite Belt, with a new regional structural sketch, and characterization of discriminant criteria for sulphide orebodies, such as hydrothermal alteration factors (Ni/Co ratio in rocks), metallic enrichment factors (Au correlations and Sri-Co grades);
   b. constitution of a regional database for the Spanish part of the Pyrite Belt, assembling a wide variety of spatial data collected from diverse geoscience sources and, using a GIS based on a geo-relational data model.;
   c. block-modelling of the Los Frailes orebody;
   d. simultaneous use of tools and synergic data interpretation under operational conditions (exploration methodology).

The new tools that have been developed and the new geological data that have been acquired can be integrated into a mineral exploration methodology. The gas sampler and the 3-axis EM probe are direct prospecting tools that find their place in the investigation of preselected anomalies. The gravimetric modelling software is a data interpretation tool which can be used for modelling the possible shapes and sizes of known orebodies and for interpreting "virgin" anomalies. The ICP-MS laser ablation probe is a laboratory tool used in the detailed studies required for defining and controlling geological selection criteria.

The criteria that have been defined as a result of this project are relevant to all stages of mineral exploration, from the selection of a potential mineralized province or geological series to the evaluation of an orebody. The proposed exploration methodology is based on mainly the results of the project work and has not involved an exhaustive evaluation of existing methods; nevertheless the suitability of each tool and criterion must be considered in the light of the local conditions under which it is to be used.

In conclusion, one of the aims of the project, that of developing new exploration techniques based both on new technological tools and on an improved methodological approach, was fulfilled, with geophysical and analytical tools being developed as planned. The other aim of the project, that of discovering a polymetallic deposit in a traditional mining province in decline - Andalusia, was not successful This was due in part to the inherent risk in all mineral exploration, which is high despite the great improvement in exploration methodology. Nevertheless, the results of this work could reduce the delays and costs of future mineral exploration and remove some of the risks of ending up with a non-economic deposit.

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1.1. PROBLEMS AND OBJECTIVES

The mineral industry in the Iberian Pyrite Belt, previously based on the extraction of pyrite, is today in decline and must orientate itself towards extracting polymetallic ores in order to survive. However, the depletion of near-surface mineral resources means looking for deeper orebodies. Present exploration techniques are generally capable of revealing anomalies, but are not capable of determining the best potential targets from these anomalies. Only through a long and very expensive follow-up procedure is it possible to know whether an anomaly is related to a 'barren' sulphide deposit or to a polymetallic orebody. Improved performance in this area requires the development of an updated exploration methodology by which it is possible to identify the signatures in the zone of influence of a polymetallic deposit through new field and laboratory methods and technology.

The first objective of the project, and probably the most problematical, was to discover an economic polymetallic sulphide deposit (> 10 Mt with Cu+Pb+Zn grades of > 15°/0, including Ag-Au equivalents) in the Spanish part of the Iberian Pyrite Belt, through developing an effective low-cost exploration methodology. The second objective of the project was to develop this methodology for improving performance in the exploration of deep massive sulphides; this was based on the development, testing and application of new and powerful exploration and analytical tools in the fields of geophysics and geochemistry, and on improved reasoned geological deduction.

1.2. PROJECT METHODOLOGY

The project hinged around several closely linked poles of interest with the immediate aim of discovering a base- and precious-metal sulphide deposit. Beginning with the results of standard exploration methods (geological, geophysical and geochemical surveys), it was necessary to develop:

- new exploration tools (gas sampler, 3-axis electromagnetic system) for use in the field or for resolving exploration-related geological problems;

- more powerful synergic systems of data processing (3D geophysical and geological modelling, multidataset processing, regional database);

- an analytical tool capable of providing varied geochemical data rapidly and cheaply (ICP-MS laser ablation probe) for use in the laboratory;

- a methodology based on the new tools and on improved geological deduction,

1.2.1. New exploration tools

a) Selective gas sampler

The selective gas sampler, developed as a low-cost exploration tool, contains a material or materials (resin, activated charcoal, etc.) capable of fixing volatile organo-metallic compounds present in the soil where it is placed for up to 1 month. Subsequent analysis determines the quantities of fixed metals (Cu-Pb-Zn-Hg-As-Sn-Se) and reveals the presence of any anomalies that could indicate the presence of ore.

b) 3-axis EM system

The 3-axis EM system was developed to both recognise and locate conductive bodies within a radius of about 150 m of a barren borehole. The primary EM field is created by a large transmitter loop laid out on the surface and fed with an alternating current. This field generates eddy-currents within the conductive bodies, which in return form a secondary field. The 3-axis EM system then measures the three components of the total magnetic field (primary and secondary) in the borehole.

1.2.2. Synergic systems of data processing

a) 3D gravimetric modelling software

The 3D gravimetric modelling software was developed to be able to incorporate geological data into the geophysical model. The software thus provides integrated 3D geometrical modelling of geophysical data (gravimetric, magnetic) related to local geological constraints (mapping, drilling, etc.).

b) Multidataset processing system

The process of superposing very diverse data derived from geophysical and geochemical exploration methods and geological mapping during the mineral exploration phase, is a feature of the BRGM Geographic Information System (SynerGIS). This software enables rapid analysis and combination of data and an output of predictive maps,

c) Regional database

The Regional Database of the Spanish Pyrite Belt can be defined as an organized collection of multidisciplinary spatial data covering one of the most important metallogenic regions in Europe. In this era of reliable computerized modelling it provides a powerful tool *in* the mineral exploration field.

1.2.3. Analytical tool

ICP-MS laser ablation microprobe

The newly developed ICP-MS microprobe uses an ablation laser to analyse small spots (1 0 pm) in solid samples for a wide range of elements and isotope ratios with standard deviations no greater than 2% and 0.5% respectively. It is much more precise than any existing equipment.

1.2.4. Geological deduction

Geology of the Pyrite Belt and the massive sulphide deposits

The usefulness of reasoned geological deduction in exploration (interpretation concerning mineral-bearing horizons, paleostructures, zones of h ydrothermal alteration, Hercynian structures, etc.) is incontestable and perfectly illustrated by recent discoveries (Neves-Corvo in Portugal), but the rarity of such discoveries also illustrates the progress still required in the field of gitological prediction. Recent work has revealed the signatures to be expected in the zone of influence of a massive sulphide type mineralization, and which could be applicable to the exploration phase: i.e. the mineralogical and geochemical signatures of the mineralization, the host rock series and the hydrothermal alteration halos, and the structural lineaments controlling the emplacement of the mineralization.

1.3. PROJECT STRUCTURE AND ROLE OF THE PARTNERS

The work undertaken for the project was carried out from October 1992 to April 1995 in the framework of a European Community contract involving several partners, with BRGM as coordinator, The project was structured into eight main tasks in which the partners were variously involved (see Project Flow Diagram - Table 1):

Task 1. Develop 3D geophysical software for (a) interactive modelling of gravimetric and geological data, and (b) for a new 3-axis EM system capable of locating and characterizing an off-hole conductive body.

Task 2. Develop a selective gas. sampler capable of trapping volatile organo-metallic compounds derived from underlying mineralization.

Task 3. Develop an ICP-MS microprobe (hardware - software - analytical methodologies) to provide element and isotope analysis in solid samples.

Task 4. Systematic data acquisition, for a given area, involving the systematic collection of all available geological, geophysical, geochemical and satellite data so that these can be digitized for constructing a database.

Task 5. Study a known blind deposit in order to construct a model of this type of deposit and test the innovative tools developed by the project.

Task 6. Construct a regional database to be used for regional modelling from the available field-controlled geological, geophysical, geochemical and satellite data of Task 4.

Task 7. Carry out a sectorial multidataset study, using the constructed databases and interpretations from the regional and blind-deposit studies, to develop models and select and classify anomalous areas.

Task 8. Drill the selected anomalies in order to check them and thus indirectly valorize (or revise) the model.

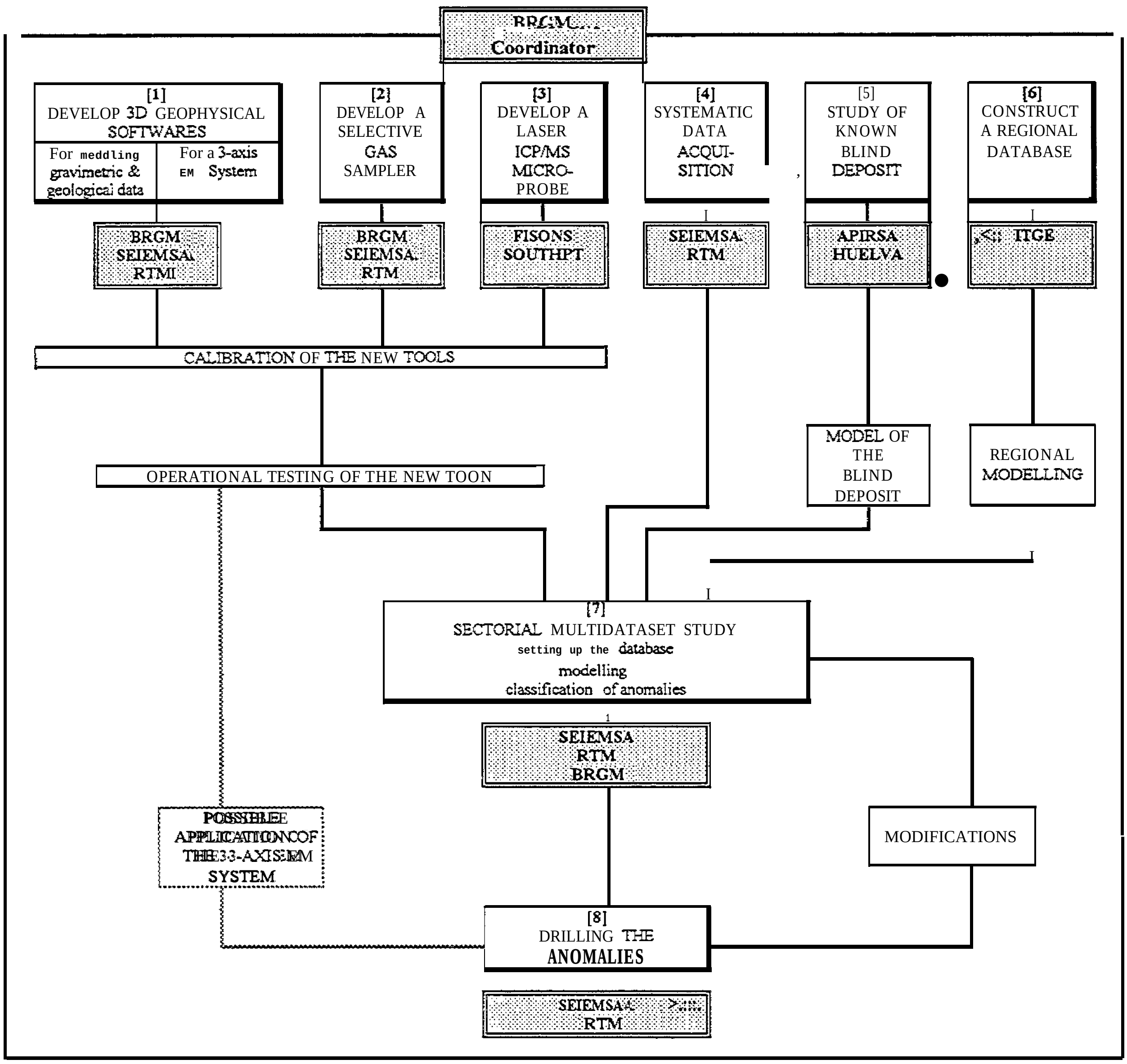


Table 1- Project flow diagram showing the major tasks [1] to [8] of the project, their interrelationships, and the partners involved in each task.

BRGM: Bureau de Recherches Géologiques et Minières (France); SEIEMSA: Sociedad de Exploraciones, Investigaciones y Explotaciones Mineras S.A. (Spain); RTM: Rio Tinto Minera S.A. (Spain); FISONS: Fisons p.l.c. (United Kingdom); ITGE: Instituto Tecnológico GeoMinero de España (Spain); HUELVA: University of Huelva (previously belonging to the University of Sevilla, Spain); SOUTHPT: University of Southampton (United Kingdom); APIRSA: Andaluzas de Piritas S.A. (Spain).

2. TECHNICAL DESCRIPTION

As scheduled at the beginning of the project, several tasks were devoted to the technical development of new tools, whereas others were aimed at acquiring exploration and geological data. The purpose of both approaches was the integration of all the practical results to provide an “idealized” exploration methodology.

2.1. WORK PERFORMED FOR THE TECHNICAL DEVELOPMENT OF NEW TOOLS

2.1.1. The 3D-Gravimetric Modelling Software

Gravimetry and magnetism are very effective methods of geophysical exploration, because they provide the geologist with synthetic documents (anomaly maps and profiles). Both 2D and 2.5D (pseudo 3D) modelling software are today available on the market (e.g. BRGM's GMI-PACK software), but the problem of correlating a large volume of geophysical data with the surface and subsurface geological constraints still exists. Gravimetric modelling of mining targets requires precise geological data (maps, sections, boreholes) and density measurements of the formations (obtained from surface and core samples or from logging). These data must be integrated with each phase of the gravimetric interpretation - from construction of the initial geometric model, through the introduction of contains into the reversals, up to the reconstruction of the modelling results.

To resolve these problems, a 3D-gravimetric modelling software (MODGM-5D) has been developed to enable interactive 3D modelling of integrated gravimetric and geological data, mainly along geological sections.

The initial software prototype was developed on a VAX workstation after testing the algorithms on both theoretical and experimental data. The program is able to both store (in a database) and manage combined geophysical (gravity or magnetic measurements as grids or profiles) and geological (tables of geological units, locations, geological sections, boreholes) data, as well as the computational results of 3D modelling; this is called the ***B5D database.*** A ***3D geometric modelling*** module enables an automatic construction of the 3D surfaces from the initial geological data. The gravity effects of the resulting 31) model are then computed using a specific algorithm (Gotze and Lahmeyer, 1988) in a module of ***model effect computation.***

The final version of the software has been developed to run on a PC, so as to favour its industrial applications. The PC version enhances the graphic user interface and interactive capabilities and offers field availability. The development of the user interface was performed using Microsoft VISUAL C++ so as to be able to integrate the algorithms achieved during the initial step, and previous algorithms from GMI-PACK (a BRGM 2D-gravimetric modelling software). The user interface window offers several menus to facilitate: input of initial geophysical and geological data; display of anomaly maps and profiles; drawing and correction of geological sections; printing of graphic screens; and export of modelling results to external 3D visualization tools. The ability to compare experimental and theoretical fields on profiles and maps means that one can effectively carry out interactive modifications to improve the initial geometric model.

2.1.2. The 3-Axis Electromagnetic System

The detection of a conductive body close (<150 m) to a barren borehole is already possible with an electromagnetic axial probe, such as the BRGM REMI probe (Bourgeois *et* al., 1992). This enables cost-effective exploration from barren boreholes, as it expands their effective investigation radius. However, the diagnosis requires at least two series of measurements; moreover, the precise location of such a conductive body cannot be determined with a 1-axis system. The objective therefore was to build a 3-axis EM system that can provide quick and reliable information (detection and position of a conductive body) from a single measurement.

The starting point was the ARLETT probe (Fig. 1), a prototype receiving-probe measuring the three components of the magnetic field in boreholes within the 50-2000 Hz frequency range. The probe also contains an orientation module and a temperature sensor. A surface instrument is used to transmit the surface magnetic field to the probe as a phase reference and for amplitude normalization. This surface instrument also manages the downhole information through an optic coder on the cable pulley. The signals of the four magnetic paths (Hx, Hy, Hz and Href) are digitized and analysed spectrally in the probe and the spectra are sent to the surface in digital form, thus avoiding the differential distortions that can occur on three paths if the time signals were sent to the surface in analog form. The whole of the ARLETT system is designed to be driven by a Hewlett-Packard microcomputer; the surface instrument only ensures the dialogue between the computer and the probe.

The acquisition takes place as follows. Once the probe is at the required depth, the operator takes orientation measurements until the probe is steady, and verifies that the temperature is also relatively steady. He then chooses the working frequency among those available to the TX 1000 transmitter. Once the frequency has been chosen and the operator has keyed in the current intensity value circulating in the transmitter loop, the measurement can begin. An acquisition lasts from 5 to 15 minutes per depth, depending on the number of frequencies used, on the background noise and on the required quality of the measurements. Once the acquisition is terminated, the data are recorded in magnetic memory. Each line in the storage file represents an acquisition at a given depth and frequency, with 28 variables stored.

The possibility of instant graphic display of the 3D polarization ellipse in the geographic reference system has been added. This enables immediate materialization of the measurements in the horizontal plane, and also in the vertical plane of the long axis of the ellipse. In the absence of a conductive body near the borehole, the ellipse is very elongate and points towards the centre of the transmitting source <quasi-rectilinear polarization). In the presence of nearby conductive bodies, the ellipse becomes deformed because these bodies act as secondary sources having different directions and different phases from those of the transmitting loop. The ellipse generally becomes more rounded, in other words more elliptical.

During the field calibration and application tests (Bourgeois, 1994, Bourgeois and Hendrickson, 1995), some unexpected mechanical and electronic problems arose with the probe. First, part of a horizontal sensor became loose, causing for problems in signal repetitivity. The second incident was that the system broke down completely; a breakdown caused by the communications card in the surface box. These problems have been successfully resolved and the measurement repetitivity and the general running of the probe are now almost perfect.

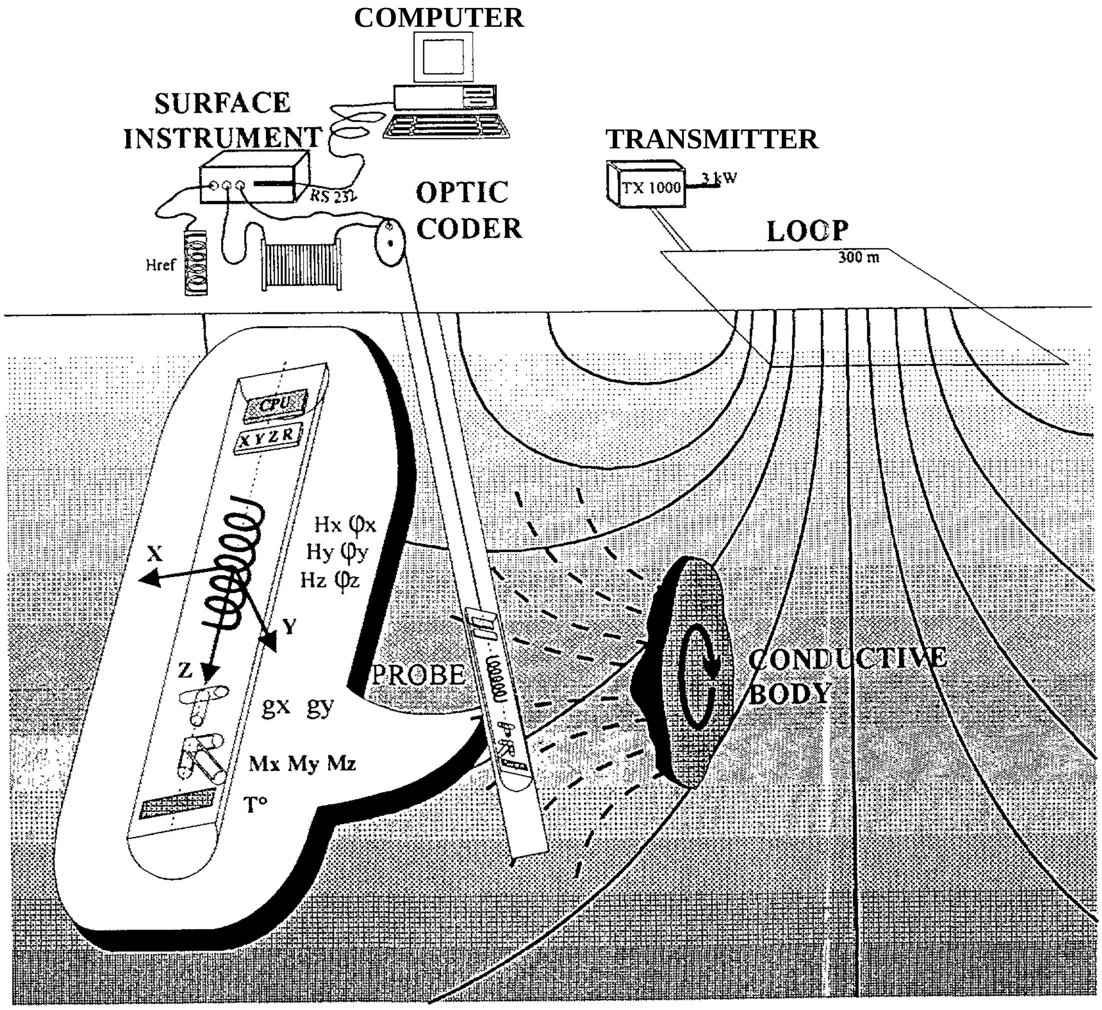


Fig. 1- ARLETT system. Sketch of the three-axis probe and of the surface to borehole EM system.
Href: reference sensor; CPU: Digital stage (AD conversion, filtering, FFT); Hx,φx/Hy,φy/Hy,φy: EM analog stage (sensors, amplifiers); gx,gy,Mx,My,Mz: orientation module (2 gravity components, earth magnetic field)

The developments programmed for the project consisted mainly in writing the associated software programs for the ARLETT system: i.e.:

- an acquisition software (***ARL US***) which drives the probe so as to obtain a log in a borehole. The variables are stored directly in a file and the log of certain variables can be displayed in real time on the screen;
- a data-processing software (***ARLETUS***) the main functions of which are: reading a backup and print file (eliminating erroneous or repeated data); consolidating several files dealing with the same log; sorting and storing the final backup file; calculating a result file; graphic representation as logs or polarization ellipses;
- a ***3D modelling software,*** the creation of which was advantageous y resolved by the purchase of an existing software (EM3D from the University of Utah); only interactive user interfaces needed to be written for this software;

- a ***data interpretation software***: faced with data as numerous and as complex as those provided by the ARLETT probe, it was essential for the development of the method to establish a processing and interpretation procedure (how to approach the data, which to calculate, what procedures to apply, in what order, etc.). The main objectives were (a) to define the most useful measured field parameters (the most informative, universal, sensitive) for detecting conductive targets, (b) to see whether it was possible to locate the detected bodies directly from the measured field, using the azimuth information contained in the horizontal paths, (c) to evaluate the reduction procedures, or any other procedure aimed at improving the detection and localization capacities of the measured data.

2.1.3. The Gas Sampler

BRGM has already carried out extensive research into the use of gas geochemistry for exploration and some of the experiments have been relatively positive in that they enable the detection of anomalous Hg, CO_2, CH_4, COS and mercaptans associated with mineralization. However, this early work remained at a relatively upstream stage of research without developing into operational procedures. A review of the scientific Literature on this subject for the past 15 years (Pauwels, 1991} came to identical conclusions in spite of the encouraging scientific results.

The absence of gas geochemistry as an exploration tool is due to the low reliability of the geochemical signal and the complexity and cost of the analytical techniques. Apart from mercury detection, the methodologies used for characterizing and analysing gases have relied on very sophisticated field techniques (mass spectrography, gas phase chromatography, etc.). The reliability of these techniques is not in doubt, but their complexity and, above all, the cost of the analyses remain prohibitive at an operational scale. The development of passive samplers enabling a geochemical signal to be collected over a long period of time, accompanied by the. development of suitable laboratory analysis techniques has launched atmogeochemical research. The gases are trapped in the samplers and then analysed in the laboratory, making this a relatively low-cost tool. The use of new materials with a high adsorption capacity and a high selectivity vis a vis certain gaseous or aqueous complexes has advanced these techniques to the stage that it is now used for various applications such as checking air quality.

The development of a selective soil-gas sampler required first a characterization of soil gas flows so as to be able to correctly locate the samplers in the field, and secondly the conception and testing of the gas sampler itself.

In situ measurement of soil gases: geochemical maps and profiles of the soil gases were compiled from simultaneous in situ analyses of He, CO_2 and Rn over several known blind deposits (Los Frailes, Vallejin-Herrerias, Sierrecilla). In general, it was found that the He and CO_2 anomalies are well marked on faults cutting the orebodies, and that Rn anomalies over these faults are only detected where the mineralization is fairly shallow. Based on these results, soil gas mapping was tested under semi-operational conditions in the La Torerera exploration area (Block XVIII). Although the resulting maps display several anomalies, these are mainly related to volcanic facies - no specific anomaly could be linked to faults or blind mineralization.

Gas sampler: the first phase of the study consisted in testing different products likely to trap very small quantities of metallic compounds, The five products used were: (1) an activated wood charcoal, (2) an activated coconut charcoal, (3) a membrane impregnated with silver nitrate, (4) an ion-exchange resin (Amberlite XAD-2 resin), and (5) a crown polyether compound (Dibenzo 18C6). Several types of selection test were carried out at Los Frailes. The two products that gave the most conclusive results are the crown polyether compound and the activated coconut charcoal, since both products show anomalies in the greatest number of elements (Ni, Pb, Zn, Cu, As). The results also indicated the optimal burial times and the correct quantities of the product for the samplers.

The next phase of on-site experiments consisted in running passive sampler profiles perpendicularly across three known VMS (Los Frailes, Vallejin-Herrerias and Sierrecilla), using charcoal (activated carbon fibre tissue [TCA], activated coconut charcoal [NC], activated wood *coal* [FXL]) and polyether compound [PEC] samplers. The tests at Los Frailes and Sierrecilla showed that orebodies effectively do emit volatile metallic compounds, and that it is possible to trap these metals with the aim of determining the presence of ore; the metals, in a form that has yet to be determined, are apparently transported through fracture zones in the subsurface. The quantities of metals that can be trapped then desorbed from carbonaceous products left for several weeks in the ground can be as high as several tens of micrograms. However, the use of passive samplers at the Herrerias site did not reveal the presence of the ore. Here it should be mentioned that of the three orebodies that were tested, the Herrerias ore is the least rich in base metals and is also the most deeply buried. The three carbonaceous products can be classified in terms of cleanness of the initial product and sorption capacity; the TCA therefore seems to be a suitable product for detecting buried ore. The PEC is also a product that gives very good results, but it is at present too expensive; this product is not manufactured industrially,

2.1.4. The ICP-MS Laser Ablation Microprobe

The most popular micro-analytical system at present used in laboratories is the electron microprobe (developed in the late 1960's) which allows selected spots of about 10 or more microns to be analysed for major elements, but which is severely limited in terms of quantitative estimation of trace elements, Another technique, Inductively Coupled Plasma Mass Spectrometry (ICP-MS; developed in the UK in the early 1980's), is an outcome of developments in ICP/OES (Optical Emission Spectrometry). The ICP-MS system is based on the fundamental principle that when a compound is introduced into a high temperature environment it emits energy. This energy is characteristic of the material being heated and it can be resolved both in terms of what elements are present and in what quantities. The principle has been used in a wide range of analytical instruments developed for geological research.

VG Elemental has recently patented design improvements in the ICP-MS interface. To transform these preliminary improvements into a useful analytical tool, the project task was broken down into three parts. Firstly, the production of small sampling spots (with a diameter of less than 10 pm); secondly, improving the performance of the ICP-MS such that its sensitivity is augmented by a factor of at least 102 over that which was current at the start of the project so that statistically meaningful, multi-element data can be acquired from a sample whose total weight does not exceed 0.1 mg; and thirdly, the development of analytical and display software so that the technique becomes routine.

The microprobe developed for the project (Fig. 2) is based on a solid state neodymium-doped yttrium-aluminium garnet (Nd:YAG) laser of the pulsed type. The fundamental frequency (1024 nm) was quadruped to produce a monochromatic beam of wavelength 266 nm. The delivery optics were of the specially-coated type to handle this very short wavelength; viewing of the sample was via a CCD camera. A prototype microprobe was delivered to the University of Southampton within seven months of the formal commencement of the project which enabled the applications development to get under way quickly.

Improvement of the MS sensitivity transpired to be the most challenging of the three broad areas of endeavour. The work was subdivided into the following parts: improvement in transmission of ions across the ICP to MS interface; the use of mixed-gas plasmas to enhance the process of ionisation in the plasma; development of mathematically rigorous interference corrections and use of Faraday screen to reduce polyatomic contributions; and enhancement of quadruple stability and transmission characteristics.

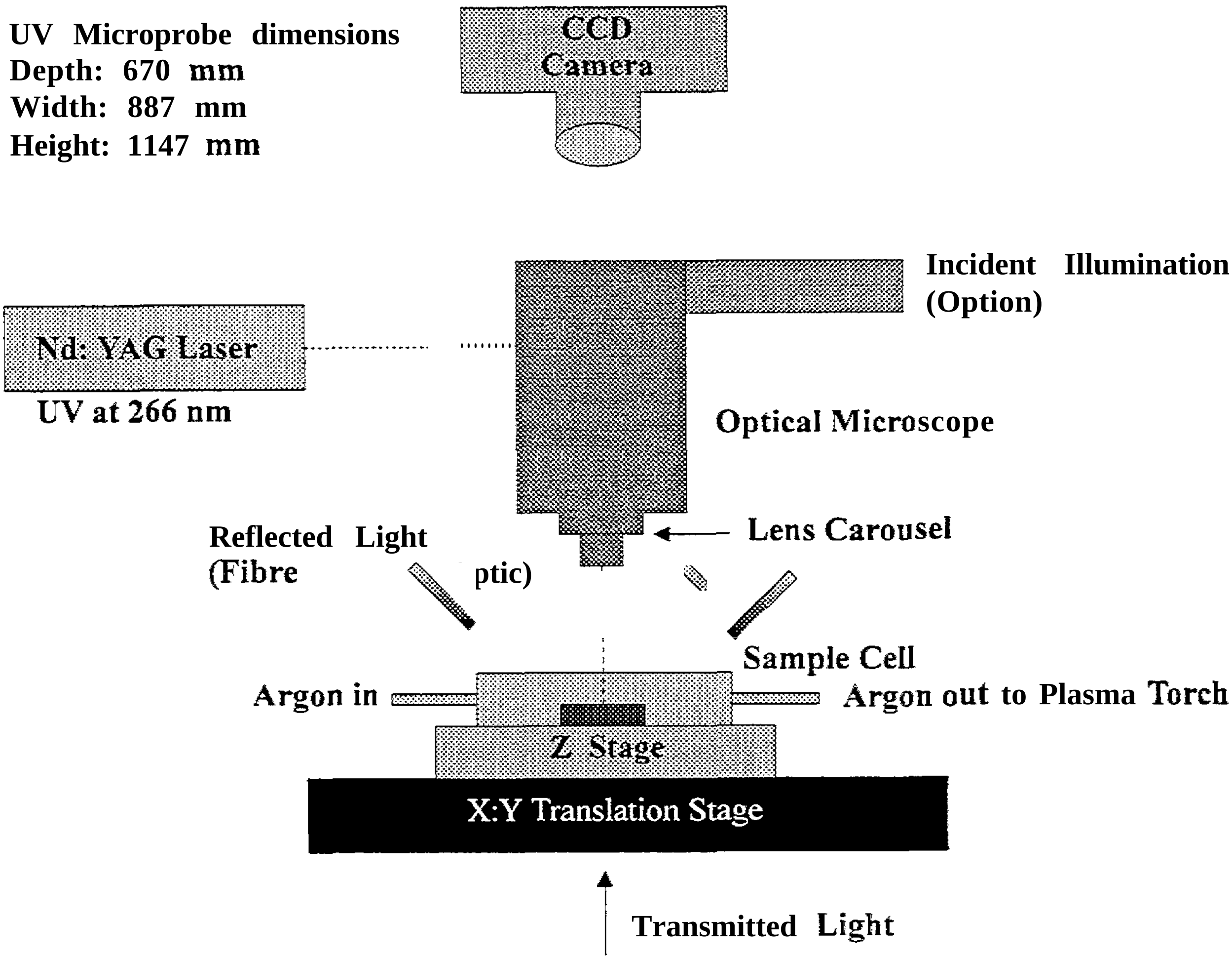


Fig. 2- Schematic of UV Microprobe.

Analytical and display software. The capacity to monitor and display the concentration of many isotopes as a function of position on a solid sample in real time was a requirement of the project. Sophisticated software has been developed which can map isotopic (and hence elemental) concentrations *as* a function of position on the surface of the sample or as a function of depth. The data can be exported to third party software for further manipulation.

Finally, several tests have proven the suitability of the probe for geological applications: e.g. Au analysis of pyrites; U-Pb isotopic data on zircons (Hirata and Nesbitt, submitted) and REE measurements on zircons and monazites; platinum group analysis; measurement of trace element composition and isotopic ratios in fluid inclusions; Sr isotopic ratio measurements (Raith *et al,* submitted); low-level trace element values in silicate minerals and inclusions.

2.2. DATA ACQUISITION AND MODELLING

Two types of data were acquired during the project: basic exploration data and "scientific" geological data. The exploration data acquisition provided *a* huge amount of information essential for testing the new tools and for improved reasoned geological deduction. This task involved the application of classical exploration techniques: geological mapping, geophysics and geochemistry, drilling. It is not the purpose of this report to give the details of the exploration prograrnme, but an idea of the quantity and type of information that was collected throughout the project is given by Table 2, whereas Figure 3 shows the various areas investigated in the field.

Data acquisition was performed at several scales: 1) at the regional scale of the Spanish part of the Pyrite Belt; 2) at the scale of delimited blocks of the Huelva Reserve and concessions; 3) at orebody scale (Los Frailes, La Zarza, Tharsis). The regionally acquired data was used to create a Regional Database. The block- and orebody-scale data acquisitions revealed a series of discriminant criteria which can be applied for VMS exploration.

2.2.1. Regional Database

The Regional Database of the Spanish Pyrite Belt is the consequence of a previous infrastructural project developed by the ITGE, the General Directorate of Mines (Ministry of Industry and Energy of Spain) and the Mining Service of the Junta de Andalusia (Regional Government). A large amount of information has been compiled from the geological and mineral exploration work developed over the last 20 years (Fig. 4). The process of defining and organizing real data into a consistent digital dataset that is useful and informative is essential in this type of project (Ortiz Figueroa, 1995; Ortiz Figueroa *et al.*, 1993).

The intrinsic nature of the data to be stored and analysed in a region such as the Spanish Pyrite Belt, expressed in terms of spatial data obtained through visual observation, description or measurement of the surface and subsurface properties of the terrain, led us to adopt the so-called georelational data model, which can be considered as an adaptation for spatial databases of the entity-relation concept.

TASK	TYPE OF INFORMATION AND DATA COLLECTED	
4.	DATA ACQUISITION	
	Gravimetry	12277 stations
	Geochemistry	10196 samples
	Mapping at 1:10,000 and digitization	130 km' geological map -57 km of structural cross-sections 26 digitized maps at scale 1:10,000
	Electrical and magnetic testing of gravimetric anomalies	57 profiles= 169.76 km
	Soil geochemistry	5757 sifted samples. 5117 ICP analyses
5	STUDY OF A BLIND DEPOSIT AND OF ITS RELATIONSHIPS WITH A NEARBY OUTCROPPING AND MINED DEPOSIT	
	Geological mapping	40 km² at 1:10,000 scale
	Modelling of the deposit (Los Frailes)	Production of a 3D model using the following data: - Cu, Pb, Zn and Ag analyses on 2165 samples from 5000m of drill cores: 18 NS profiles for Cu,Pb,Zn; 35 level distributions for Zn - minor/trace elements analyses on 793 samples from 2202m of drill cores: 18 NS profiles for Ag, 3 NS profiles for Tl,Sb, As,Bi, based on 793 samples -20 NS and 5 EW geological profiles -11 geological level interpretations
8	SECTORIAL MULTIDATASET STUDY	
	Drilling	6 boreholes on Block XVIII, 1993.10 m 1 borehole on Block XVII, 290. 10 m

Table 2- Exploration data - Quantity and type of infornations collected during the "classical" mining exploration phases of project.

Such a model establishes the correspondences between the entities given by the thematic maps, the elements of geometric representation and the observed or measured attributes. This spatial data model is computed by a GIS (Arc-Info) that supports both vector and raster data structures for locational data, using a relational database management system for handling the attribute tables. A graphic user interface has been developed in AML, the specific macro-language of Arc-Info. The database is stored in a Unix-based workstation server such as HP9000/735 running Arc-Info 6.1.

This database is a powerful mineral exploration tool for companies developing projects in the Iberian Pyrite Belt (IPB). Some of the data could be considered as confidential for a specific period of time. The advantages obtained from using this database will be available to the companies currently working in the area or those intending to do so; only the costs involved in accessing the system will be charged. A CD ROM catalog containing the whole regional database is currently available from the Mining Service of the Junta de Andalucía.

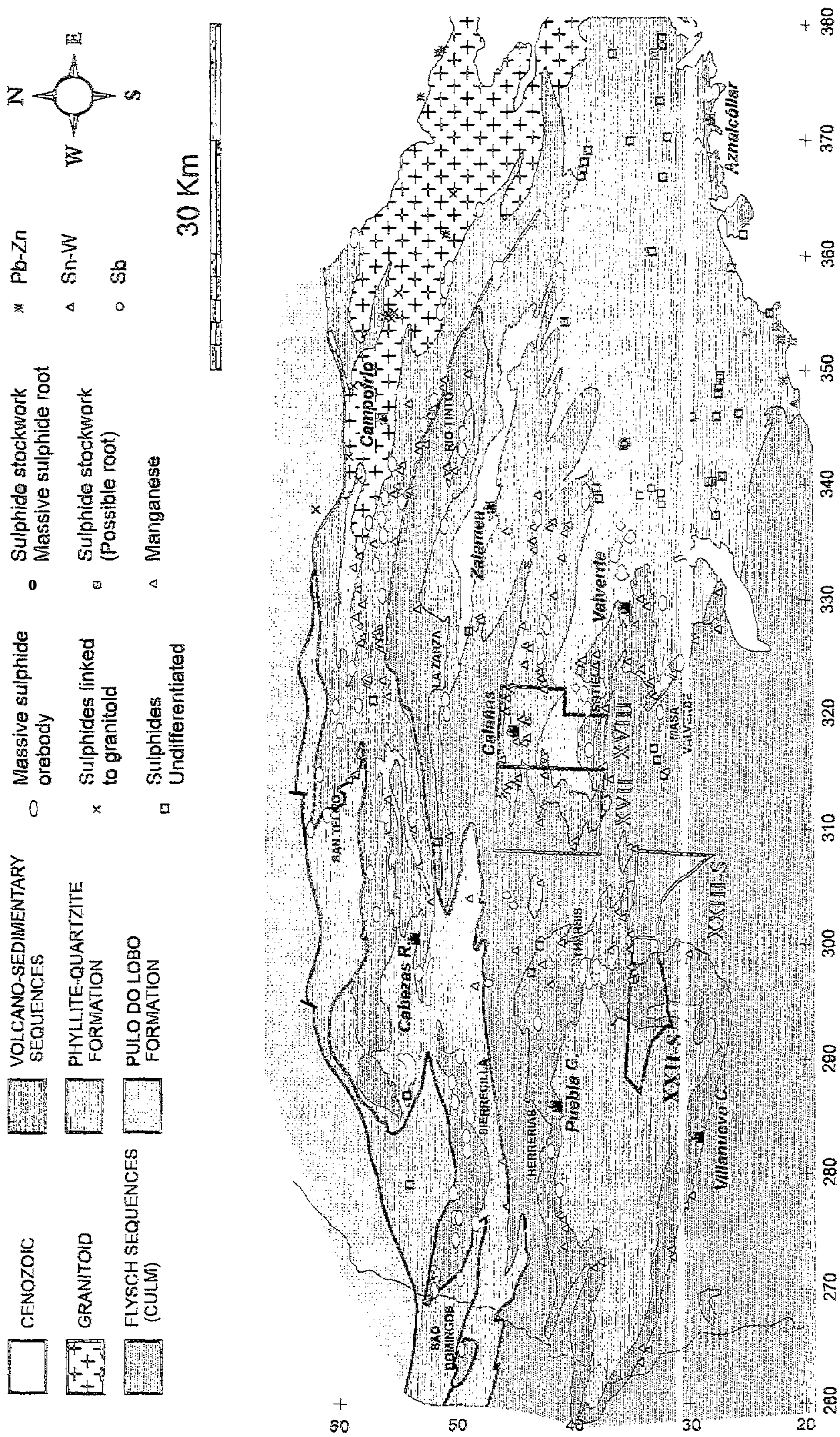


Fig. 3 - Schematic geological map of the Spanish part of the Iberian Pyrite Belt, with the location of the blocks and main deposits studied in the frame of the project.

GEOLOGICAL MAPPING 1:100,000 GENERALIZED MAP 1:50,000 MAP SHEETS (12)	**MINERAL OCCURRENCES** 353 DATA RECORDS CLASSIFIED BY SIZE, MORPHOLOGY, ETC.
GRAVIMETRIC DATA 27,335 STATIONS (4.5 s/km)	**AEROMAGNETIC DATA** 215,925 RECORDS FROM AIRBORNE SURVEY
SATELLITE IMAGERY LANDSAT TM (7 BANDS) SPOT STEREO ERS-1 RADAR	**DRILL HOLE DATA** 123 RECORDS
PLANIMETRIC DATA ROADS, RIVERS, RAILWAYS, ETC. AT 1/100,000 SCALE	**GEOCHEMICAL DATA** SOILS AND ROCK SURVEYS ON TEST OREBODIES

Fig. 4- Contents of the regional database.

2.2.2. Characterization of Discriminant Criteria for Sulphide Orebodies

Improving performance in the exploration for blind massive sulphide deposits requires that a maximum number of significant geological signatures are characterized during the regional exploration stage. The work that was carried out in this area can contribute to such an improvement.

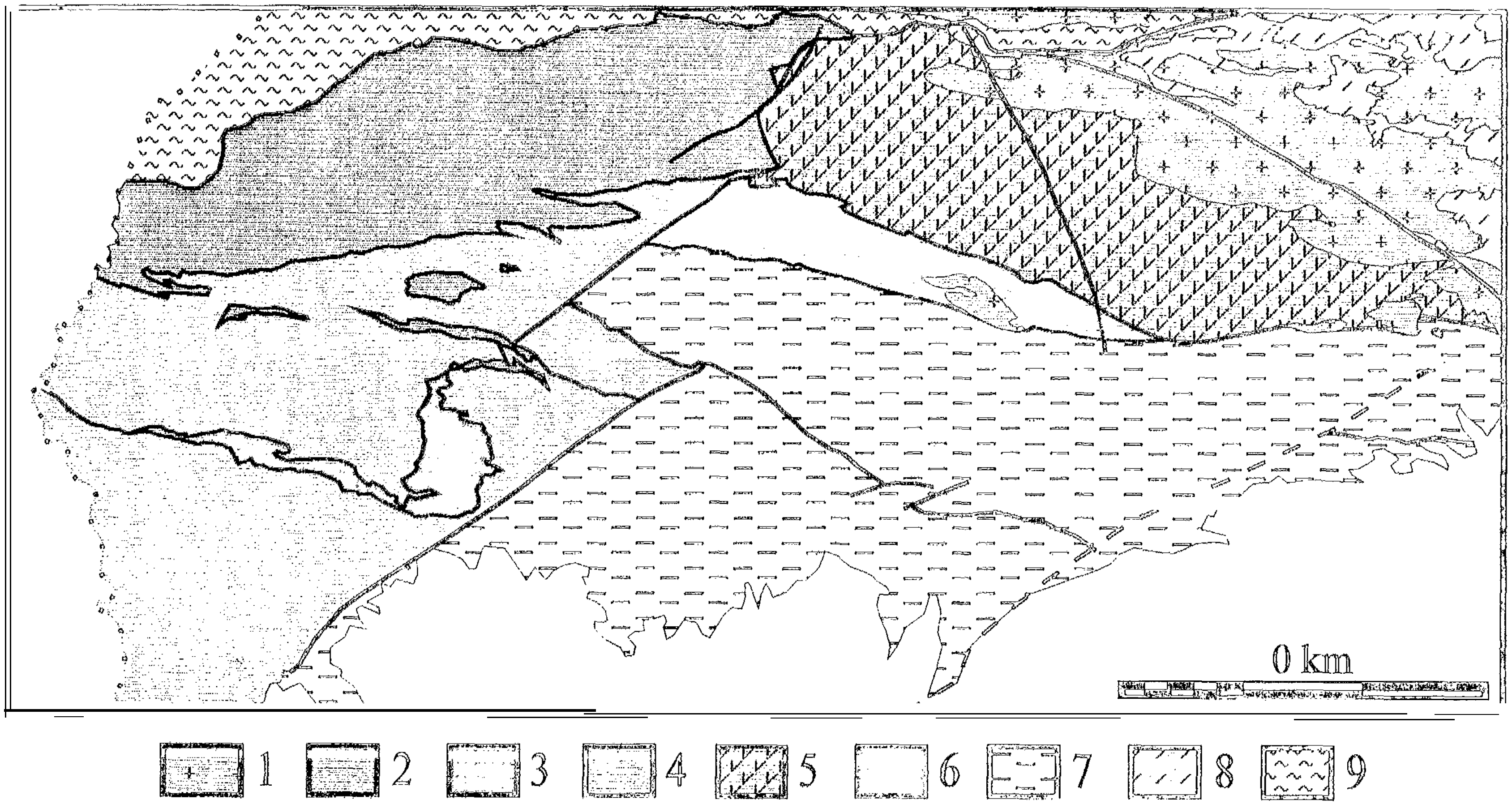
a) Regional structures and structural modelling to interpret exploration areas

• ***A new structural interpretation of the IPB***

Recent developments in the structural geology of the Iberian Pyrite Belt (IPB) have brought to light the significant role played by thin-skinned thrust tectonism during the Hercynian inversion of the South Portuguese terrane (Silva *et al.*, 1990). This has been recognized locally within the IPB, but no evaluation of its importance at regional scale has yet been attempted. Due to the large size of the IPB, a central test area was selected for this study, after which the area was extended to the rest of the Belt. The reinterpreted structural maps have been produced from detailed fieldwork.

The analysis of geological structures of the I PB, together with the available knowledge on its stratigraphy, petrology and metallogeny, has led to a subdivision of this metal logenic province into three blocks (Fig. 5): Western, Central and Eastern. Their boundaries are delineated in every case, not by simple structural discontinuities but by complex several-kilometre-wide fault zones which are oblique to the regional structural trend (E-W). From a structural point of view these boundary fault zones represent lateral ramps to the thrust faults which constitute the main structural features in the Pyrite Belt.

Three domains corresponding to three subbasins have been deduced to occur within both the Western and Central blocks (Fig. 5):
- a Northern Domain, where the VSC was mainly submarine and isolated from a terrigenous continental source;
- an Intermediate Domain with subaerial to very shallow marine VSC;
- a Southern Domain of a predominantly sedimentary nature.



1: Intrusives:

	Western Block	Central Block	Eastern Block
Northern Domain	2	5	8
Intermediate Domain	3	6	
Southern Domain	4	7	

9: Pulo do Lobo

Fig. 5 - Schematic structural map of the Spanish part of the Iberian Pyrite Belt.

Most of the sulphide deposits are located within the Northern Domain or in the northernmost units of the Southern Domain. The exceptions are al [related to the existence of volcanic areas within the VSC of the Southern Domain.

This proposed subdivision of the Iberian Pyrite Belt could be useful as a geologic reference tool for defining future m ineral exploration strategies. A good knowledge of the thrusts and nappes is essential for defining new exploration areas in sectors that have so far been considered as having no mineral potential (e.g. below the PQ basement, as is well illustrated by the discovery of the Migollas deposit - see later).

• ***Structural Modelling***

Large structural sections were mapped within blocks XVII and XVIII which, in this area, correspond to the eastern closure of the large Valverde anticl ine (Fig. 3). A major fault marking the southern boundary of the Devonian formations has thrust the whole of the northern 1 imb and the core of the anticline onto the southern limb, creating a nappe with a vergence of several ki lometres. This nappe locally brings the thrust Devonian formations into overlying contact with the mineralized Culm facies; the Sotiel-Migollas deposits are located below the thrust Devonian rocks. In view of this, consideration should be given to prospecting anomalies apparently located within the Devonian.

A regional gravimetric modelling, using BRGM GMI-PACK modelling software, was performed along a cross-section through the Valverde anticline (Calañas area). This type of model ling is a very useful tool for structural interpretation, especially for a correct interpretation of thrust areas, as it helps to constrain the thicknesses of the different formations. In this way, the depth of the ore-bearing horizon below the thrust Devonian formation can be estimated much more real istically.

At orebody scale, a knowledge of al l the structures is vital for the mining phase because the orebody geometry is largely controlled by late deformation events. In the Aznalcól lar-Los Frailes area, the deformation and structure are similar to those in other areas in the I PB (Sáez *et d.*, 1993). The general tectonic style is thin-skinned with south-verging asymmetric folds, thrusts and a penetrative foliation in most cases parallel to the axial plane of the major folds. Large thrust structures are the most striking feature. Several major thrust sheets were mapped, each separated by large thrusts. In turn, minor similar structures can be distinguished within each of the sheets.

In the La Zarza mine, most of the contacts between the 1 ithologic units are thrusts showing a ramp and flat geometry. The deposit is made up of an antiformal sheet stack bounded by a folded thrust to the north and an out of sequence" thrust to the south. Specific ore types associated with these bands are of tectonic origin and are enriched in base metals (banded polymetallic ores) and gold (hanging wall gangue-ore alternations]. In addition to its remobilizing role, the tectonic evolution was also responsible for increasing the width of the orebody through stacking several ore sheets (up to five}.

b) Indirect markers of massive sulphide mineralization

•Hydrothermal alteration halos

Due to its size, the hydrothermal alteration halo is easier to detect in the field than the mineralization with which it is associated. Therefore a good definition of its characteristics and chemico-mineralogical gradients could provide a useful tool in the search for blind deposits. Several general characteristics of hydrothermal alteration halos have been found for the Iberian deposits: they classically show an inner chlorite zone and an outer sericite zone (Salgadinho: Plimer and Carvalho, 1982; Rio Tinto: Garcia Palomero, 1990, Piantone *et al.*, 1993; Aljustrel: Barriga, 1983); Na and Ca are highly leached and Mg and, in places, K show clear enrichment. Although such geochemical anomalies are described along profiles across certain well-known giant deposits, this pattern does not so far seem to have been applied in exploration within the IPB.

In the multicriteria methodology applied by Seiemsa (Bonnemaison *et al.*, 1993) for exploring blocks XVII, XVIII, XXII-S and XXIII-S, the results of soil geochemistry were used to establish hydrothermal alteration maps *using* element ratios (Mg/TiO_2 and Ba/K_2O) rather than single elements to amplify the commonly discreet signals. These alteration maps were integrated into the multidataset study and the ranked anomaly maps produced by SynerGIS take this “alteration index” into account.

A study performed at orebody scale on the Aznalcóllar-Los Frailes deposits provides new data for this area (Almodóvar ***et al, 1995).*** The hydrothermal alteration related to the stockwork mineralization consists mainly in an early silicification, followed by chloritization + silicification in the inner halo of the system, and sericitization + silicification in the outer halo. The following specific features were also noted: the chloritic alteration is marked by Co enrichment and REE, Zr, Y and Hf mobility (development of tiny zircon crystals in chloritic facies and Zr enrichment in massive polymetallic sulphides); the Fe content (Fe/(Fe+Mg) = 0.35 to 0.7) and Al/Si ratio of the chlorite increase towards the inner zone within the chlorite halo, whereas no specific trend is seen in the sericite halo. Both the Co/Ni ratio and the geochemistry of REE and Zr are therefore new potential geochemical indicators for prospecting massive sulphides in the IPB.

Footwall alteration of the volcanic rocks in the La Zarza mine also displays classical trends, with a diffuse and weak sericitization heavily overprinted by stronger silicification and, overall, chloritization processes. The geochemical signature shows anomalous high contents in Mg and Fe, and more erratic As-Sb anomalies.

•Petrography and geochemistry of chert and associated facies

Chert and jasper are classically considered as lateral equivalents of volcanogenic massive sulphide mineralization, and are very useful in exploration (Scott *et al.*, ***1983).*** Chert, however, is so abundant in the volcano-sedimentary rocks hosting the massive sulphide deposits of the IPB, that it cannot be used as an exploration guide (Barriga, 1990). Field studies, and petrographic and geochemical analyses, were performed to establish whether some chert facies might display a specific signature that could be linked to sulphide mineralization (Leistel *et* al., 1995). Chert in the IPB occurs at two main lithostratigraphic levels, both hosting massive sulphides, but any lateral chert/sulphide equivalence is apparent. Petrographic analysis shows the presence of three main facies corresponding to three successive phases of formation: (1] jasper {red hematitic chert ± magnetite); (2) pale pyritic chert; and (3) rhodonite-carbonate facies (rhodonite and/or Mn carbonate ± magnetite + quartz ± chlorite and sulphides). Geochemical analysis revealed no discriminating characteristic by which to distinguish chert that could be considered as a lateral ore marker. The chert is all of hydrothermal origin, with a weak positive Ce anomaly indicating a shallow marine origin; an absence of positive Eu anomaly distinguishes it from present-day hydrothermal fluids and sediments. The lead isotopic signature is appreciably more radiogenic than that of the massive ore. The hypothesis of a hydrothermal 'chert' event occurring independently of that responsible for the massive sulphides is to be considered.

• ***Characterisation of doubtful mineral occurrences***

Most of the mineralized showings found during exploration can easily be classified as being either of the massive sulphide type or of the late-vein type. In the case of doubtful occurrences, metallographic study and lead isotope analysis have proven to be very determinant techniques. The feeder stockworks of the massive sulphide deposits include a discriminating mineral association with Bi and Co minerals (Marcoux *et* cd., in press), and all the massive sulphide type mineralization shows a very constant and characteristic Pb- isotopic signature ($^{206}Pb/^{204}Pb$ = 18.187 ± 0.050, $^{207}Pb/^{204}Pb$ = 15.620 ± 0.025; Marcoux *et al.*, 1992). Metallographic and geochemical studies were performed for many mineral showings, and especially for chalcopyrite occurrences hosted by the Culm facies and marking certain structural and metallogenic alignments (Fig. 3). These chalcopyrite veins, which have been locally mined, display a very monotonous chalcopyrite+quartz paragenesis and have Pb-isotopic signatures ($^{206}Pb/^{204}Pb$ = 18.45 to 18.80, $^{207}Pb/^{204}Pb$ = 15.61 to 15.68) very different from those of the massive sulphide type. Therefore, this type of occurrence cannot be directly Iinked to a massive sulphide orebody.

•***Petrography and geochemistry of volcanic rocks hosting massive sulphide deposits***

New data obtained from the Spanish part of the IPB show the close relationship between the massive sulphide-bearing bimodal volcanic series and the gabbroic to granitic rocks exposed in the NE part of the belt (Campofrío area; Thiéblemont *et al.*, 1995). In Spain, as in Portugal, the basic and acidic lavas appear to have distinct origins, with the latter probably resulting from the melting of a basic protolith at low pressure. Marked E-W metrological variations of both the basic and acidic rocks may be explained by the involvement of increasingly enriched sources (crustal and mantle) toward the west. The genesis of the acidic magmas through the remelting of recently accreted basic rocks is envisaged, which requires a high geothermal gradient. Overall, the geochemical data suggest an emplacement over a juvenile crust under extensional tectonic conditions. Earlier Canadian studies have shown that rare earth element patterns may, in some instances, serve to discriminate between ore-bearing and barren felsic rocks: most of the sulphide-bearing lavas show mild LREE enrichment, no FREE fractionation and a marked negative Eu-anomaly (Galley, 1995). Clearly, the felsic rocks from the Pyrite Belt meet all these criteria. Nevertheless, the large variation in Nb content and Nb/Zr ratio suggests that the original magmas were derived from distinct sources; thus, the similar REE patterns may reflect similar conditions of melting rather than similar sources. Finally, it is worth noting that the

Neves Corvo deposit, the major deposit of the Pyrite Belt, is located within the "alkaline sub-province", although whether this particular situation is responsible for the very high potential of this deposit is not at present clear.

c) The VMS mineralization: enrichment criteria

The stringer zones and, commonly, the interaction zone at the base of the massive sulphide mounds in the Iberian Pyrite Belt contain bismuth and cobalt minerals that are not found in the overlying massive sulphides (Marcoux *et al.,* in press). These are fairly rare cobalt sulphoarsenides (cobaltite, alloclasite, glaucodot) that were formed at the beginning of the massive sulphide genesis, and fairly common bismuth sulphides (bismuthinite, hammarite, wittichenite, cosalite, kobellite, joseite, etc.), including species rare at world scale (nuffieldite, giessenite, jaskolskiite), that were deposited from last-stage high-temperature (>300°C) copper-bearing fluids containing Bi (Te, Se). The last-stage fluids precipitated chalcopyrite containing Cu, Bi, Te, (Se) sulphosalts at the base of the sulphide mound to form a high cupriferous zone. Their interaction with the massive sulphides is reflected by the formation of an exchange zone, a few metres thick and showing chalcopyrite disease textures, at the *base* of the mound; this zone forms the upper limit of potentially economic copper enrichment and of bismuth minerals.

Multi-element geochemical analyses of the massive sulphide ores have revealed specific Au and Sri-Co signatures (Leistel and Marcoux, 1995; Marcoux and Leistel, 1995). From the observed correlations between the tenors of Au and those of the other metals, two generalized ore types can be distinguished: (a) the Aznalcollar-Rio Tinto type which shows gold enrichment in facies having a polymetallic signature (Zn+Ag±As±Tl±Hg), and (b) the Tharsis-Sotiel-Migollas type which shows gold enrichment in facies having a (Co±Cu±Bi) signature; moreover, the mineralogical expression of gold should be different in the two cases. It is also noted that, on average, all the larger deposits (>20 Mt), and some small deposits located close to large deposits, show an enrichment in Sn and/or Co with respect to the bulk of the small deposits (<5 Mt).

A certain number of criteria likely to be an aid in mineral exploration can be deduced:

- Bismuth minerals and cobalt minerals are specific to the stringer zones and interaction zones underlying the massive sulphide ores in Iberia. The mineralogical studies that were carried out have nowhere recorded these same species in the overlying massive sulphide orebodies, nor in the numerous mineralized Post-Hercynian veins of the region. The discovery of bismuth or cobalt minerals in sulphide veinlets of ambiguous nature, therefore, enables one to assign them with a high probability of success to the stringer zone **of** a massive sulphide ore deposit, This criterion could be of major interest in mineral exploration, when trying to identify sulphide veinlets discovered in the field or intersected by drilling.
- In addition to the presence of Bi-Co minerals, the presence of a zone with abundant chalcopyrite disease textures is a good criterion of the proximity of underlying cupriferous enrichment; conversely, its absence is an unfavorable criterion for the existence of copper-enriched zones.
- In the search for gold-enriched facies within known orebodies, a knowledge of their "gold type" is essential.
- Sn enrichment of VMS mineralization is an encouraging factor for the presence of large deposit,

2.2.3. Block Modelling of a Deposit: example of the Los Frailes orebody

Based on geological interpretation (structure, petrography, metallography, geochemistry) and geometric modelling, a tridimensional model of metal distribution in the Los Frailes orebody has been constructed using geologic and geochemical databases and the BolGeo and Microstation software packages; the block model is valid for large open pit mining with a block size 10*20*15 metres. The model for the Los Frailes orebody indicates a total of 70Mt of massive sulphides with average grades of 3.92 % Zn, 2.25 % Pb, 0.34 % Cu and 62 g/t Ag.

2.2.4. Multidataset processing

The process of superposing geological, geophysical and geochemical data is done using a Geographic Information System (BRGM SynerGIS software) to enable a rapid and objective computer processing of multi-source data. Applying this processing to the exploration area provide ranked-anomaly maps that can be used directly for detailed follow-up investigation.

The approach used consisted of: a) Establishing a database (mapping, geophysics, soil-geochemistry); b} Determining a target model and translating its attributes into signatures; c) Area scanning. The data are crossed and a map of ranked anomalies produced by the SynerGIS program.

The main characteristics of the target model are:

- a positive gravimetric anomaly of 0.3 to 0.6 mGal above the background gravimetric signal of the country rock;
- a geochemical Pb, Zn and Cu signatures. Other elements may be present (Sri, Sb, etc.) but, due to their weak values, their detection is haphazard and so they cannot be used as discriminatory factors.
- a geochemical signature of hydrothermal phenomena: the Mg/TiO_2 and Ba/K_2O ratios were selected after several tests and then, since the ratios vary according to the lithology, the resultant signals were filtered formation by formation so as to obtain only the peaks clearly higher than the average value characteristic of each formation.
- finally, the geological data are used to place the geochemical data in their geological context.

Following this methodology, the ranked anomaly maps produced for block XXII-S display the existence of 13 anomalies, and for blocks XVII and XVIII display the existence of 15 anomalies. For block XXIII-S, owing to the almost only presence of Culm facies at the surface, soil geochemistry has not been performed and geological mapping is very restricted; so the SynerGIS methodology was not applied.

2.2.5. Drilling the anomalies

After a selection of the anomalies to be drilled, six boreholes (1993.10 m) have been realized on block XVIII and one (290.10 m) on block XVII; but only disseminated sulphide mineralization has been found, without any economic massive sulphide occurrence.

2.3. EXPLORATION METHODOLOGY

The work that was carried out within the context of the project has provided new exploration tools and new geological data which can be integrated into an "idealized" exploration methodology ("idealized" in that each expiration programme is specific and calls for several economic-related choices at each stage, therefore an exploration methodology can be only indicative). Figure 6 gives an overview of such a methodology, with special emphasis on the results of the project (but it is not an exhaustive review of al l the explorat ion methods).

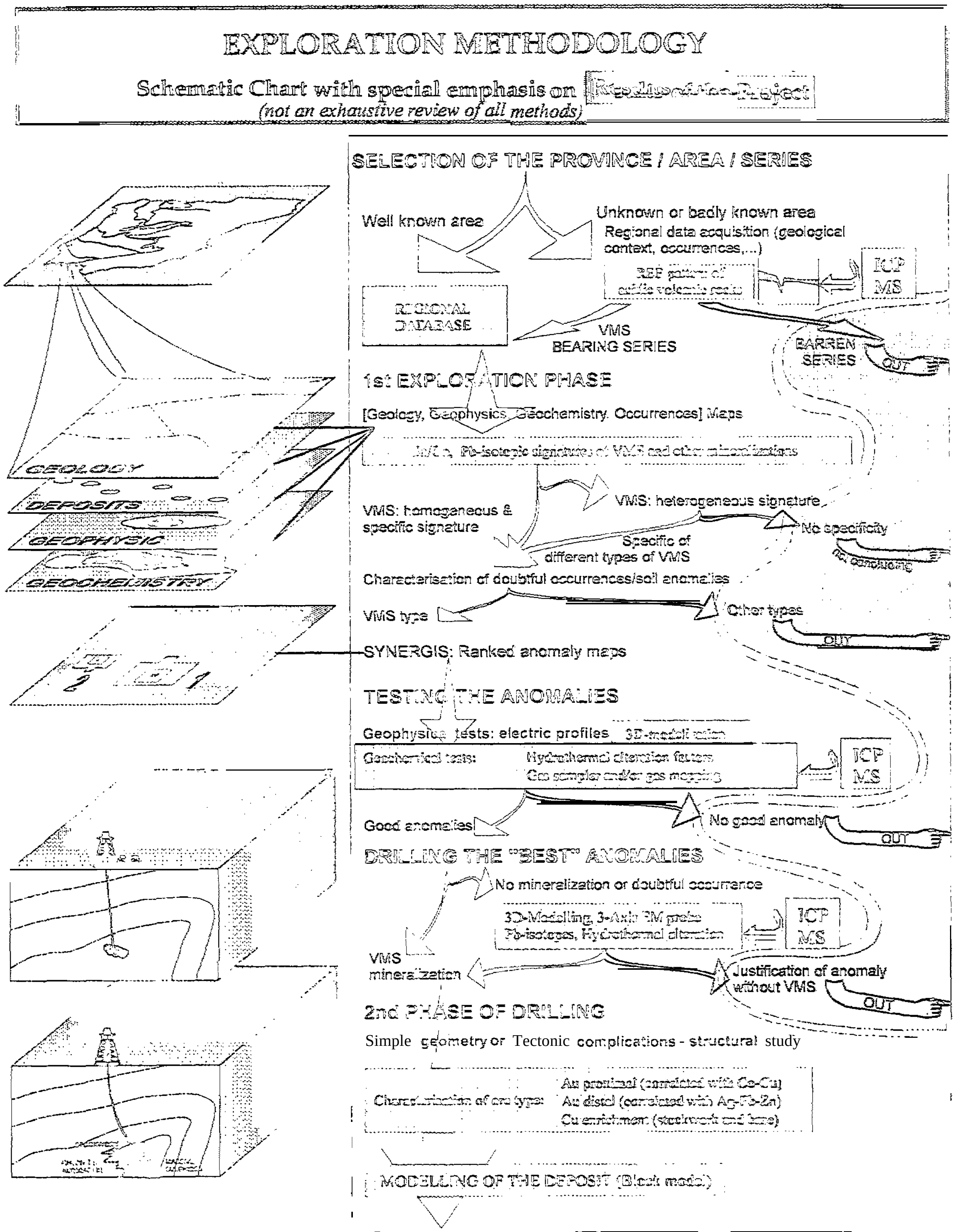


Fig. 6 - Exploration methodology, Schematic chart with special emphasis on results of the project.

3. RESULTS

The main innovations that have come out of the project are:

1. Instrumental:

   a. an interactive 3D modelling software (MODGM-5D) for integrated geological rind geophysical data (gravimetry, magnetism);
   b. a software package system (data acquisition, representation and interpretation) for the ARLETT downhole 3-axis EM;
   c. development of a selective gas sampler based on the use of charcoal (activated carbon fibre tissue [TCA]) as sorbant;
   d. development of a powerful laser ablation mass spectrometer (ICP-MS).

2. Methodological:

   a. a better geological knowledge of the Pyrite Belt, with a new regional structural interpretation and a characterization of discriminant criteria for sulphide orebodies, such as hydrothermal alteration factors (Ni/Co ratio in rocks), metallic enrichment factors (Au correlations and Sri-Co grades);
   b. the development of a Regional Database for the Spanish part of the Pyrite Belt, assembling a wide variety of spatial data collected from diverse geoscience sources and using a GIS based on a gee-relational data model; a CD ROM catalog containing the whole regional database is currently available from the Mining Service of the Junta de Andalucía;
   c. block-modelling of the Los Frailes orebody;
   d. a simultaneous use of tools and synergic data interpretation under operational conditions (exploration methodology).

4. CONCLUSIONS

The aims of the project were (a) to develop new exploration techniques for VMS type deposits, based both on new technological tools and on an improved methodological approach, and (b) to find a polymetallic deposit in a traditional mining province in decline - Andalusia.

The second aim, that of discovering a polymetallic deposit, was not successful. This was due in part to the inherent risk in all mineral exploration, which is high despite the great improvement in exploration methodology. Nevertheless, the results of this work could reduce the delays and costs of future mineral exploration and remove some of the risks of ending up with a non-economic deposit.

The first aim, that of technological and methodological development, was fulfilled, with geophysical and analytical tools being developed as planned.

The 3D geophysical (gravimetric and magnetic) modelling software MODGM-5D has been developed to run in a Windows environment on PC. The data acquisition and processing software for the ARLETT 3-axis EM probe are operational and enable the detection and location of conductive bodies in the vicinity (about 150 m) of a barren borehole; field trials on known VMS deposits were highly successful The operational procedure developed for a new activated-charcoal gas sampler makes it possible to trap organo-metallic compounds derived from a sulphide (ore)body. Finally, the ICP-MS ablation laser microprobe will analyse trace elements, REE and isotopes in situ on minerals and fluid inclusions in an ablation pit with a diameter as small as 10 pm.

These tools are all marketable products. The geophysical tools and the gas sampler are still at the prototype stage and require further development; their market potential is being studied with a view to taking out patents. The products developed from the design of the ICP-MS laser ablation microprobe, however, will be put on the market in 1995.

The Regional Database for the IPB is an unique system that is of interest to all the partners involved in mineral exploration in this region.

The detailed mapping and geological investigation work, which was undertaken at both regional and deposit scale during the mineral exploration programmed, has significantly improved our understanding on the emplacement of the sulphide mineralization in the Iberian Pyrite Province. This has led to a new regional structural interpretation and a definition of selection criteria relative to massive sulphide deposits and their host volcanics.

The new tools that have been developed and the new geological data that has been acquired can be integrated into a mineral exploration methodology. The gas sampler and the 3-axis EM probe are direct prospecting tools that find their place in the investigation of preselected anomalies. The gravimetric modelling software is a data interpretation tool which can be used for modelling the possible shapes and sizes of known orebodies and for interpreting “virgin” anomalies. The ICP-MS laser ablation probe is a laboratory tool used in the detailed studies required for defining and controlling geological selection criteria.

The criteria that have been defined as a result of this project are relevant to all stages of mineral exploration, from the selection of a potential mineralized province or geological series to the evaluation of an orebody. The proposed exploration methodology is based on mainly the results of the project work and has not invoked an exhaustive evaluation of existing methods; nevertheless the suitability of each tool and criterion must be considered in the light of the local conditions under which it is to be used.

Acknowledgements

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