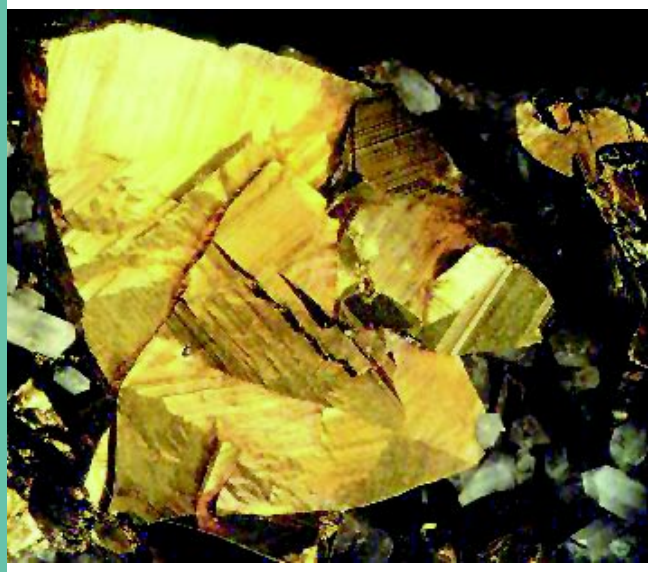
Geodynamics and Ore Deposit Evolution (GEODE)

An ESF scientific programme



The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

From the Renaissance to the present day Europe's prosperity has depended on the mining and extraction of metals and other raw materials from beneath the Earth's surface. Even though some European countries are significant mineral producers and the recycling of metals and other materials is on the increase, the region continues to rely on imports of raw materials to sustain economic growth. For this reason, Europe cannot afford to play a passive role and allow nations elsewhere to dictate the exploration and exploitation of mineral resources.

It is thus imperative for Europe to conduct fundamental research into the nature and formation of mineral deposits. This will underpin resource assessment, the exploration for minerals and mining operations in order to improve their cost effectiveness and environmental sustainability. As major users of minerals extracted from many countries, with a huge financial interest at stake, European countries need a strong technological basis for making decisions over when and where to take an active role through investment or direct exploitation both in Europe and globally.

The ESF's five-year GEODE programme, launched in April 1998, aims to meet these objectives, and build a quantitative understanding on all scales of the geological processes that lead to the formation of world-class ore deposits suitable for exploitation. It is particularly important to understand the geodynamic processes that determine when and where such deposits form.

Introduction

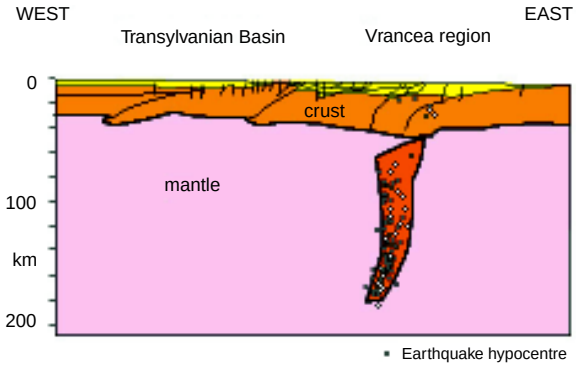
There are good reasons for expecting the five-year GEODE programme to achieve its objective of developing greater understanding of metallogenesis associated with both deep and shallow geodynamic processes, especially those involving continental convergence and break up. The geology of Europe is particularly diverse, incorporating a number of tectonic and mineral provinces that span the full range of geological time. Furthermore many aspects of this geology are better known and understood than anywhere else in the world. This understanding stems from the detailed mapping of surface geology over the last two centuries, culminating in two major ESF programmes, the European Geotraverse, and EUROPROBE. The GEODE programme is particularly timely because it can take advantage of significant findings obtained by these earlier programmes. EUROPROBE is especially relevant because it has obtained major new findings about geodynamic processes in all of the five mineral provinces that form the basis of separate projects within GEODE. These include the Alpine-Carpathian Chain, the southwestern Variscides, the Urals, the Fennoscandian Shield Precambrian Province and sedimentary basins that host mineral deposits. Supporting projects in South America and the SW Pacific provide a global perspective and comparison.

GEODE is taking the holistic approach, for which the ESF is now renowned, and will extend links between disciplines established in EUROPROBE and earlier initiatives. A multidisciplinary approach is necessary to make optimum use of the existing base of expertise and to establish a sufficient base of knowledge for understanding the nature and genesis of world class ore deposits. Accordingly GEODE is establishing closer collaboration between scientists across a wide range of disciplines from research institutions, geological surveys, and the mining industry.

Research aims

The critical physical and chemical processes that determine how mineral deposits will develop and whether they are potentially viable for extraction operate over a range of scales in both space and time. The GEODE programme has identified four critical scales, each of which will be tackled as distinct but closely interacting themes.

First it will address the large-scale thermo-tectonic settings of each of the five mineral provinces being studied, and how they have evolved in time. Although a strong relationship between the timing and location of mineral deposits and their tectonic setting is well known, not enough is understood about how and why mineralisation forms at a specific time and place in an orogen to make the predictions needed for mineral resource exploration. It is



Top: Cross section through a lithospheric model of the eastern Carpathians indicating slab detachment and associated earthquake activity (after illustration compiled by H-G Linzer in Gee, D.G. and Zeyen, H.J. (eds). EUROPROBE 1996 – Lithosphere dynamics: origin and evolution of continents. Publ. Europrobe Secretariat, Uppsala University, 1996).

this that GEODE aims to address. An analysis will be conducted of the fundamental dynamic processes that create the major body forces and control the principal thermal regimes within the lithosphere. These create the conditions for melting, directly giving rise to magmatic mineralisation, but also producing a major source of mineralising hydrothermal fluids. Heat flow may also drive non-magmatic crustal fluid flows which are important for a variety of styles of mineralisation. Tectonic forces create pathways for magma emplacement, control the location and timing of fluid flow, and may help the concentration and accumulation of ore bodies. Changing stress and temperature regimes lead to metamorphism in crustal rocks, as well as controlling basin formation.

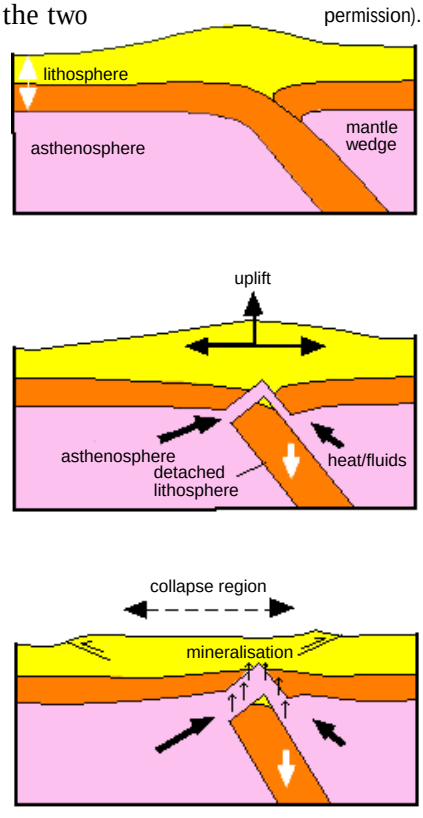
Secondly, it will examine the chemical and isotopic evolution of magmas and fluids on the scale of mineralising systems (from metal source to deposition site) which govern the locations of individual ore bodies within a mineral province, their size and their ore grade and characteristics. Mobile fluids interact both physically and chemically with their surroundings in complex ways that modify their character. Within sedimentary basins, evolving porosity and permeability control the generation and mobility of mineralising fluids. Surface processes further modify the mineralogy and economics of ore deposits.

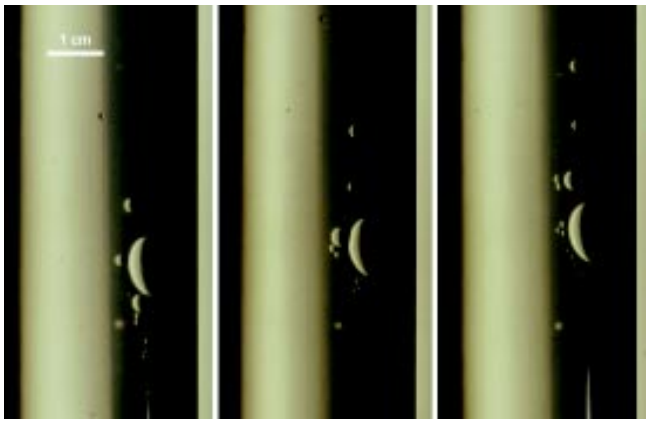
The third level focuses on smaller scale localised events within the mineralisation process that influence the precise composition of the final deposit. As minerals concentrate, microscale interactions between fluid and host rocks over time play a fundamental role in the development of the ores. The composition of wall rocks that have been changed by such interactions, along with the properties of fluid and solid inclusions within them, provide important clues to the physical and chemical environment in which metal scouring occurred in the source region and ore mineral precipitation resulted at the deposition site.

Understanding these fluid-mineral interactions requires thermodynamic and kinetic data derived from experiments. The GEODE programme is conducting experiments to obtain such data spanning all five of its projects. Europe is well placed for this part of the programme, having some of the world's leading laboratories in experimental geochemistry, petrology, rock deformation, and mineral physics. For example the two most important qualitative techniques for fluid inclusion analysis – microthermometry and the Raman microprobe – in current use worldwide were first developed and put to commercial use in Europe.

The fourth dimension is concerned with the geochronology of the various processes involved in mineral ore deposit evolution. To gain a full understanding of mineral deposit evolution, it is necessary to know more about the sequence of events and how long each lasts. This in turn requires accurate, high resolution dating of ore-mineral

Bottom: Schematic diagram of how slab detachment and orogenic collapse can result in elevated temperatures in the lower crust and upper mantle, leading to melting and ascent of fluids and magmas to produce mineralisation in the upper crust (after de Boorder, H., Spakman, W., White, S.H. and Wortel, M.J.R. Late Cenozoic mineralization, orogenic collapse and slab detachment in the European Alpine Belt. Earth planet. Sci. Lett. v. 164, p 569-575, 1998, reproduced with permission).





Experiments simulating the transport of sulphides in magmatic liquids carried out by J. de Bremond d'Ars at the University of Rennes. An aqueous fluid (representing silicate liquid) and suspended oil droplets (representing sulphide) are pumped upward through the vertical tube shown in the photos. The smaller drops are transported faster and overtake the larger drop, without coalescing. The results show that sulphides can be transported efficiently in normal magmatic systems.

precipitation. Such techniques are now available, but have yet to be applied systematically to date events within the evolutionary history of mineral deposits.

The ESF scientific programme

GEODE has an excellent base to build on, both of expertise and of geological maps and research results obtained by earlier studies. The European Geotraverse and EUROPROBE programmes have established knowledge of the deep geology of the lithosphere and mantle beneath Europe without precedent anywhere in the world.

The GEODE scientific programme is built upon five projects, each relating to mineral provinces in Europe which contain world class ore deposits. At the same time it is essential to compare and contrast mineral deposits in Europe with those elsewhere in the world in cases where this may provide better opportunities to resolve specific scientific questions. Therefore the programme includes two supportive projects, in South America and the SW Pacific region, specifically aimed at providing insights that can be applied to give a better understanding of ore deposit types in Europe. The programme divides into studies of mineral provinces in orogenic systems active at the present day and studies of mineral provinces from the geological past. With modern systems the mineralising processes can be related to the present day large scale structure and properties of the lithosphere. With most ancient systems their original lithospheric structure has been greatly modified or lost, although the structure of the Urals orogen does appear to have been preserved since the time it was active.

Project Working Groups have been set up to define the scientific problems on which to focus in each of the five projects and to initiate the scientific activities needed to address them. The five projects focus on:

1. The Alpine-Carpathian Chain

Co-ordinators Professor Franz Neubauer (University of Salzburg, Austria) and Professor Christoph Heinrich (University of Zürich, Switzerland)

This province includes a number of specific tectonic environments, chiefly convergence, collapse and rifting, reflecting the underlying known geodynamic behaviour of the subduction zone. The prime mineralising system is the Carpatho-Balkans region of convergence and collapse, characterised by porphyry and epithermal styles of mineralisation. Here, during the late stages of continental collision and orogenic collapse, asthenospheric melts generated by slab break-off may have played a prominent role in generating additional heat and chemical components essential for mineralisation. This province provides a natural laboratory to study the world's major style of copper mineralisation (porphyry), and the second or third most important style of gold mineralisation (epithermal). Extensive tomographic and seismic studies by EUROPROBE researchers have produced a comprehensive database related to deep structures and thermal anomalies. In addition, tectonophysical modelling has characterised the evolution of these structures and anomalies particularly

well. GEODE is taking full advantage of all this knowledge about the thermo-tectonic and structural evolution of the region to focus on the mineralisation processes of specific deposits.

2. Ore Deposits and Geodynamics of the Southwestern Variscides

Co-ordinator Professor Fernando Barriga (University of Lisbon, Portugal)

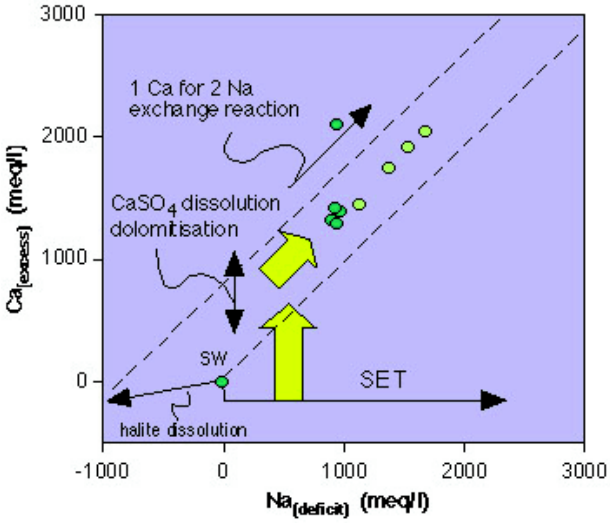
The Iberian Pyrite Belt contains some of the world's largest concentrations of volcanic-hosted base metal deposits, and is already the subject of a EUROPROBE project focused on the transgressional orogeny in this part of the Variscides specifically in order to place the massive sulphide ore deposits within their tectonic setting. Here GEODE will collaborate with the existing EUROPROBE team, increasing both the geographical and inter-disciplinary reach of the research through its co-ordinated approach. Research will also include studies of the mineralisation of the Massif Central and NW Iberia, particularly on the geochronology, fluid chemistry and modelling of the palaeo-hydrology of subaqueous hydrothermal systems that form giant VHMS deposits.

3. Basin-Hosted Deposits

Professor Willy Viaene (University of Leuven, Belgium)

Europe has two areas particularly well suited to metallogenic research, the classic carbonate hosted lead-zinc Navan ore deposit in Ireland, and the major Kupferschiefer copper deposits of Poland. Unlike their giant counterparts in the Precambrian of Canada, central Africa and Australia, these deposits have been undisturbed by subsequent deformation. As a result, clues pointing to the formative processes are easier to obtain.

The Kupferschiefer is one of the best examples of the world's second most significant type of copper mineralisation, and can provide important insights which could be relevant in copperbelts elsewhere in the world. The Irish Carboniferous lead-zinc deposits are of excellent quality, making them a potentially lucrative target for which a well defined model would help with future exploration. Success in exploration for new deposits of both types depends on sophisticated exploration concepts because they are generally buried under shallow cover and are difficult to find with conventional methods that are currently available.

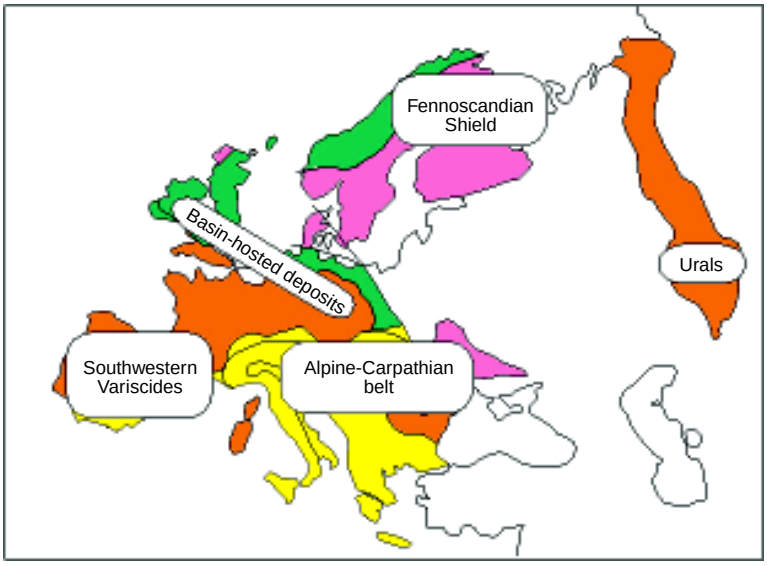


Research on basin-hosted deposits: Crush leach analysis of fluid inclusions in carbonates associated with Mississippi-type lead–zinc mineralisation (dark green circles) and with a non-mineralised strike-slip fault (light green circles) demonstrate that dolomitisation and subsequent Na-Ca exchange reactions can explain the final chemistry of the mineralising fluids. The fluids expelled along the strike-slip fault underwent a greater Na-Ca exchange: sw = seawater, SET = Seawater Evaporation Trajectory

4. The Urals Mineral Province

Co-ordinator Dr Richard Herrington (Natural History Museum, London UK)

This province remains a frontier area for mineral exploration, containing major volcanic-hosted VHMS deposits such as Degtiarskoe, Uchalinskoe, Sibay and Gai, the Magnitogorskoe skarn-hosted magnetite deposits and the ophiolite-hosted chrome deposit at Kempirsai. These deposits are at least an order of magnitude larger than average deposits in the same geological settings elsewhere in the world. Deeper mantle processes may hold the clue to the striking productivity of this collision belt. A well advanced EUROPROBE project has produced superb structural and tectonic information about the orogen, which has retained its crustal and lithospheric roots, and is marked



The five main GEODE projects all relate to mineral provinces which contain world class ore deposits. Tectonic provinces: Precambrian (pink), Caledonian (green), Variscides and Uralides (orange) and Alpides (yellow)

by an anomalously low geothermal gradient which has resulted in excellent preservation of original deposit features. The region is thus an ideal area to study ore-forming processes because the ore deposits have suffered less overprint by post-formation events. GEODE will build on EUROPROBE by focusing on the mineralisation.

5. The Fennoscandian Shield Precambrian Province

Co-ordinator Dr Pär Weihed (Swedish Geological Survey, Uppsala, Sweden)

In common with many other early Precambrian provinces, the Fennoscandian Shield is metal rich, and has for a long time been a major source of metals in Europe. It includes a major diamond deposit on the White Sea coast near Archangel and gold deposits in the Proterozoic and Archean greenstone belts of Eastern Finland, the iron ore deposits of Kiruna, and significant base metal deposits at Aitik, Skellefte-field, Bergslagen, Pyhasalmi, Outokumpu and Pechenga. In these areas complex deformation processes and metamorphism of host sequences have hindered interpretation of tectonic observations and so made it difficult to study the ore formation processes. The shield has been well studied geologically and geophysically, but many of the major deposits remain enigmatic, at least in part because complex deformation and metamorphism of host sequences has hindered interpretation of tectonic settings. The application of new techniques in geochronology and geochemistry will further our understanding of the ore deposits of this province. The project will include the Precambrian of Greenland and the Ukraine along with Fennoscandia.

European Minerals Information System – EMIS

It was recognised early on that a database of the major ore deposits in Europe would be vital to underpin GEODE research. The objective is to have a database system that is easily accessible to non-specialists using standard portable computers, providing details of deposit type, tectonic setting, economic significance etc., of the major mineral deposits of Europe. Following help from Rio Tinto and BHP to produce a prototype, the Minerals Industry Research Organisation MIRO has agreed to set up, manage and maintain this resource for GEODE. The European Minerals Information System EMIS will serve both as an information source and a communications platform. It will deliver two services, a structured ACCESS97 database service for a minimum of 50 major mineral deposits in Europe, and a research bibliography and information service based on MIRO's EGAMI electronic documentation system. The database will be compliant with the EuroGeoSurvey's Geological Electronic Information EXchange System GEIXS. The communica-

tions platform will include an APEX meta-datafile system with information on researchers and their facilities, hyperlinks to relevant sites and a users' memo-board for interactive inquiries.

Programme activities

The ESF is managing GEODE through a Scientific Steering Committee whose membership is drawn partly from the mining community and partly from scientists working in those countries that have agreed to provide financial support for the programme (Austria, Belgium, Denmark, Finland, France, Norway, Portugal, Sweden, Switzerland, and the UK). The five year GEODE programme started in April 1998 when the Scientific Steering Committee set up working groups to develop each of the main projects. A workshop was held in Lisbon in November 1998 to formulate the research plans and establish the structure of the projects. To get these off to a flying start the Steering Committee set up a "Grants for Visits" scheme to encourage scientists in the field to visit a research institute in another European country in order to develop new collaborative research and prepare research grant proposals. The programme is complementing and collaborating closely with EUROPROBE and associated projects while also developing its own unique research ethos based on cross fertilisation between all relevant disciplines.

A key part of the GEODE initiative is the establishment of a database of the major ore deposits of Europe (see above), which will underpin the scientific research. The Scientific Steering Committee has set up a database steering committee to work together with MIRO to develop and populate the database, the strategy for which was developed early in 1999.

A GEODE Website (http://www.gl.rhbnc.ac.uk/geode/) has been set up to publicise its activities, including there an open invitation for interested scientists to become involved. An e-mail address list is forming the basis for a database of relevant researchers and research facilities.

GEODE Symposia will be held during the European Union of Geosciences Assembly in Strasbourg 28 March–1 April 1999, and at the SGA–IAGOD meeting in London 22–25 August 1999, details of which are shown on the GEODE website. Other workshops relating to specific GEODE projects are also being planned during 1999 and 2000.

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For the latest information on this programme consult the GEODE home page (http://www.esf.org/lp/GEODEa.htm)

Cover picture:
Chalcopyrite – a major ore mineral for copper. Annual world production of copper is 12 million tonnes, worth some $35 billion. Europe produces some 900,000 tonnes of copper per year from the Kupferschiefer of Poland, the Carpatho-Balkans belt, the Iberian Pyrite Belt and Scandinavia. World demand for copper is growing, particularly from countries with emerging economies such as the Peoples Republic of China, and may increase by 2.4 million tonnes, more than twice current European mine production, in the next decade.

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