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Resource issues -
towards sustainable use

Earth sciences for society

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Prospectus for a key theme of the International Year of Planet Earth

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Earth Sciences for Society

What is this brochure for?

This brochure is a prospectus for one of the main scientific themes of the International Year of Planet Earth.

It describes, in terms accessible to the informed layperson, why the research that the Year hopes to support under this theme is of such vital importance to our understanding of the Earth System, and to society at large.

It was written by a panel of world experts, assembled by the Science Programme Committee for the International Year.

To find out more…

Every science theme will have a prospectus like this one. To find out about the other research themes being pursued under the International Year, please consult www.yearofplanetearth.org (where all our publications can be found).

What to do next…

If you are a scientist wishing to register initial interest in possibly making a research proposal under this theme, please go to www.yearofplanetearth.org, download the Expression of Interest form, and follow the instructions on submitting this to the International Year.

The Earth is not running out of critical mineral resources - at least for the near future

Resources - energy and raw materials

Nearly everything we make or build, and nearly all the energy we use, comes out of the Earth. Modern society is increasingly dependent on mineral and fossil energy sources. They are non-renewable, they differ in their availability, in the cost of production, and in their geographical distribution.

The last century saw the industries that find and produce non-renewable resources evolve from being dominated by metals, to those increasingly concerned with industrial minerals, oil, and gas. This has made the resources industry a major player in influencing national economies in both developed and developing countries.

Mineral deposits are diverse in nature and composition, reflecting their origins. Processes that form these deposits range from magmatic intrusions from Earth's mantle, to sedimentary processes at the Earth's surface and even (in the case of some nickel deposits) meteorite impacts. Assessing mineral prospectivity requires that geologists understand these processes and the interactions that underlie the differences between an ordinary rock formation and an economic mineral deposit.

Growing demand requires continued exploration for and development of mineral deposits yet to be discovered. Even if finding a world-class deposit is a rare event, no global shortages of non-fuel mineral resources are expected in the near future, according to the USGS Global Mineral Resource Assessment Project. However, a growing number and variety of (real and perceived) obstacles have begun to restrict the availability of these resources. The Earth is not running out of critical mineral resources - at least for the near future - but the ability to explore for, and produce, those resources is being restricted in many regions by competing land use, as well as political, and environmental issues.

The "mineral resource problem" is mainly a product of the economics of developing mineral resources in a socially and environmentally responsible way. Informed planning and decisions concerning sustainable resource development require a long-term global perspective and an integrated approach to land-use, resources, and environmental management. This approach, in turn, requires that unbiased information be available on the global distribution of identified (and especially undiscovered) mineral resources, the economic factors influencing their development, and the environmental consequences of their exploitation.

Sustainable mining relates to the potential disruption to society from the mine life-cycle of exploration, discovery, mining, commodity use, and site rehabilitation. The extractive industry is well aware that environmental and social challenges must be taken seriously if companies are to retain their social legitimacy.

Construction materials include rock, cut and crushed, sand, gravel and clay, worldwide demand for which continues to grow. Global annual extraction totals about 25 billion tonnes, about 13 billion of which are aggregates (crushed rock, sand and gravel). Assessing the best ways to preserve and extract these resources so as to avoid current and future land-use conflicts demands careful planning.

Who is behind the International Year?

Initiated by the International Union of Geological Sciences (IUGS) in 2001, the proposed International Year of Planet Earth was immediately endorsed by UNESCO's Earth Science Division, and later by the joint UNESCO-IUGS International Geoscience Programme (IGCP). The Year also boasts a large number of Founding Partner institutions, which are listed on the inside back cover.

The main aim of the International Year - to demonstrate the great potential of the Earth sciences to lay the foundations of a safer, healthier and wealthier society - explains the Year's subtitle: Earth sciences for society.

Many prominent scientists have observed that at
some future time, the world will run out of oil ...
such observations may be irrelevant

"Sustainable development"

The term 'sustainable development' came from opposition between those who supported policies preserving the 'sustainability' of the Earth's environment and those who advocated economic development. Environmentalists acknowledged that economic development was necessary (in part to avoid imposing the costs of environmental protection on those least able to afford them) but also because economic stagnation often reduces support for environmental protection efforts.

(continued...)

Rock and aggregate

The aggregates industry supplies materials for a wide range of construction, including roads, railways, airfields, buildings, harbours and other civil engineering work, as well as the raw materials of concrete. Aggregates are obtained by quarrying and gravel pit extraction on land, from the sea floor, recycling of industrial waste, and from thermal power plants. The industry also supplies substantial amounts of clays and natural rock.

Many countries attempt to minimise the volume of material excavated from quarries, pits and the sea-floor so as to protect the environment and to conserve water resources and quality. Re-landscaping former quarries often gives rise to novel possibilities for future land use. Qualitative evaluation of construction materials is essential for optimal matching of the material with the job in hand; enhanced research and development will open new opportunities in the growing trade in ornamental stone from developing countries. Improved exploration methods, the production of less hazardous waste, the development of new technologies and tools, and improved products with better functionality will all benefit society.

Hydrocarbons

The oil industry has shown that environmental challenges are manageable. Natural gas is becoming an increasingly attractive fuel for many purposes. It provides a clean flame, relatively non-polluting exhaust gases, easily controlled rates of heating, and, where required, high heat intensity. In special situations it may also be used as an efficient automotive fuel in compressed or liquefied form.

Petroleum is a non-renewable resource that comes from organic materials derived from ancient plants and micro-organisms. In 2004, the potentially recoverable reserves of conventional crude oil and natural gas were estimated to be about 158 gigatonnes of "oil equivalent", both for oil and gas. Natural gas hydrates, as well as unconventional resources (e.g. extra-heavy oils, tar sands, gas in tight sands, coal bed methane, methane in shallow reservoirs, and methane dissolved in water) are not part of these estimates but are present collectively in very large quantities. Experts expect that unconventional resources, including hydrates, will become major components of world energy consumption in about 30 to 50 years' time, but their development must be followed carefully in view of utility, macroeconomic changes, and political preferences.

The world gas trade is being integrated, and nations are steadily opening their economies to competition and deregulation. A truly international gas market can be envisaged in the foreseeable future, driven by the same forces spurring globalisation. New technologies such as fuel cells, distributed generation networks, hydrogen storage systems, gas-to-liquids technology, and microgenerators could radically change the world's energy systems. An economy based on hydrogen as the 'ultimate' energy carrier will probably emerge during the second quarter of the 21st Century and, most likely, it will be based upon methane.

We do not know what the most important resources will be in 100 years from now, but society will still need energy and a wide range of raw materials

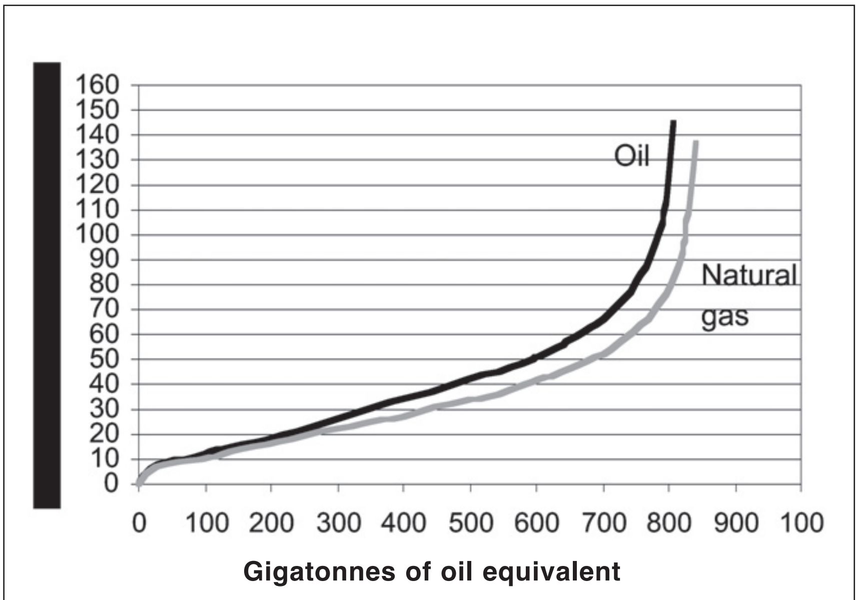
Over the past 40 years, many prominent scientists have observed that at some future time, the world will run out of oil. In the final analysis, though, such observations may be irrelevant. In the long run, the marginal costs of replacing depleted petroleum will be evaluated alongside convenience, quality, and costs of alternative energy services. At a certain point, non fossil energy sources become competitive.

Given the rate of technical change for all energy technologies it is reasonable to expect that a significant share of fossil energy occurrences will remain untapped. The desire to assess the extent of geological occurrences of fossil fuel resources at different price levels has therefore prompted many organizations to estimate the ultimate recoverable resources of the world according to different levels of cost.

Some key resource issues

Natural resources, politics and social impacts

The discovery of a major mineral deposit, e.g. one composed of platinum-group elements (PGE), in an industrialized country would be an economic asset but might have relatively little effect on the national economy. In contrast, a similar discovery in a developing country would have the potential either to assist greatly in its economic development or result in economic disruption and irreversible environmental degradation. Is it therefore socially responsible, in a global sense, to mine a deposit without first triggering other investments in a country with an economy based on a limited number of industries?



Aggregate quantity-cost curve for renewable petroleum resources.
The curve for natural gas excludes methane hydrates. R. Sinding-Larsen NTNU

Likewise, those who advocated economic development recognized a parallel between the protection of environmental endowments and the concept of protecting capital in a sustainable economy. A viable economy must live off its income without a net reduction in capital over time. Similarly, a population must live within the carrying capacity of its ecosystem, which represents a form of natural capital.

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Flaring represents a huge energy loss every year, and possible negative environmental consequences

Extraction of natural resources requires a clear focus on sustainable development, involving economic, environmental, and social/cultural aspects. Although we do not know what the most important resources will be in 100 years from now, we can be quite certain that society will still need energy and a wide range of raw materials. Future work will need to document known reserves and resources and update estimates of undiscovered resources for a variety of commodities regularly.

These resources will include:

- energy generation: conventional and unconventional oil and gas, coal, uranium, thorium, geothermal, solar and wind
- metallic minerals: copper, iron, manganese, molybdenum, nickel, tungsten, zinc, lead, gold, silver, tin, platinum, and palladium
- specialty and industrial minerals, including cement raw materials, rare-earth elements, diamonds
- water, both surface and groundwater (see Brochure #2 in this series).

A global approach to these and related questions is called for - an approach that, with appropriate international collaboration, could be achieved within the triennium of the International Year. Some global mineral resource assessments, involving inter-governmental collaboration, have already been initiated. Major uncertainties in estimating undiscovered resources remain, but it is beyond question that such an exercise is worthwhile.

New developments in geology have made many of the most valuable mineral resources traceable. These present an opportunity to address the relationship between natural resources and a swathe of social phenomena with a bearing on stability, governance and the advance of prosperity in a sustainable context.
In the past, these relationships have almost exclusively been handled at an aggregate level in national statistics; they have not been linked to specific geographical regions or individual commodities within a region, so interdisciplinary studies of this sort are innovative.

Geo-Methane, flaring, shallow accumulations and resources in deep lakes

"Flaring" is the burning of natural gas that cannot be sold or used because of economic or technical conditions. Flaring represents a huge energy loss every year, and possible negative environmental consequences. Methane from oil production is flared in many parts of the world because the economics of flaring are better than the alternatives (local use, development of a pipelines or re-injection into the reservoir).

One alternative is to convert methane gas to liquid hydrocarbons (GTL) that can be used for power plant energy generation, jet fuel, and kerosene. However, we are seriously ignorant of the scale of the flaring problem. This needs to be put right before we can set priorities and find appropriate measures against flaring. A global gas flaring public-private partnership was launched in 2002 to address this issue, led by the World Bank.

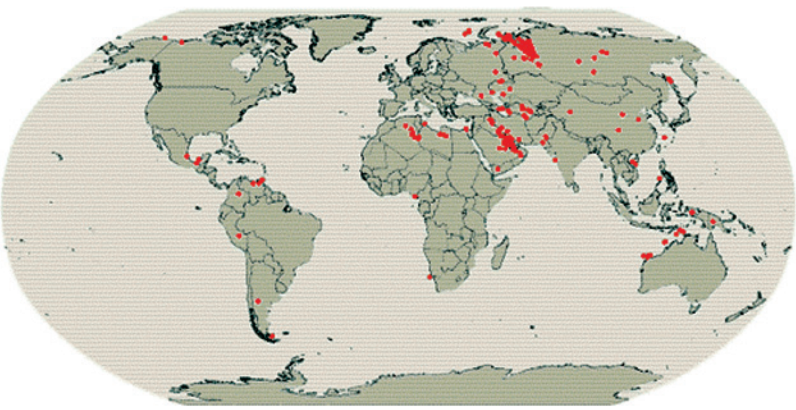
It is estimated that flaring in Africa alone represents an energy loss equivalent to $500 million a year. For reduced flaring to succeed, much of the currently flared gas will have to go to export markets. The emphasis must be on local markets, however, because it is there that gas can have a positive impact on economic development of poor areas. Even some small-scale uses of gas can have significant impact, providing local environmental benefits, for example by replacing wood burning. It is therefore important to assess the resource potential of all kinds of methane sources either from flaring, shallow accumulation or resources from deep lakes.

Huge amounts of gas resources are considered stranded when they occur too far from consumers and are difficult to transport. Gas-to-liquid conversion will permit the economic development of these remote natural gas discoveries currently deemed too distant from market to be economic, though they have the potential to supply the world's energy needs for the next 25 years.

Small surface occurrences of oil and gas are known all over the world. These may represent escapes of natural gas, seepages of liquid oils, deposits of semi-solid bitumens, and veins of asphalt impregnating porous rocks. Methane, the most common gas to escape to the surface, exists as a geological resource from biogenic sources, thermogenic (petroleum associated) sources, or as volcanic and hydrothermal gas. Large quantities of this gas can be found in petroleum reservoirs and in porous shallow deposits as biogenic gas in most basins or sub-basins containing sediment fills thicker than 1000 metres. Shallow methane gas created the blow-out in connection with the West Vanguard accident in the Norwegian Sea in 1985 - a spectacular release of large volumes of gas.

The methane of the deep waters of Lake Kivu on Rwanda's north-western border may hold enough gas reserves to supply a significant part of the country's electricity needs for hundreds of years if there are no disputes over the rights with the Democratic Republic of Congo, which also borders the lake. There are more than 120 lakes worldwide with anoxic saline waters at depths that could hold dissolved methane for local use. Such energy sources potentially could be jointly developed with biomethane from waste dumps or from shallow methane zones in nearby sediments.

Stranded Gas Fields - Preliminary Screening by Conoco



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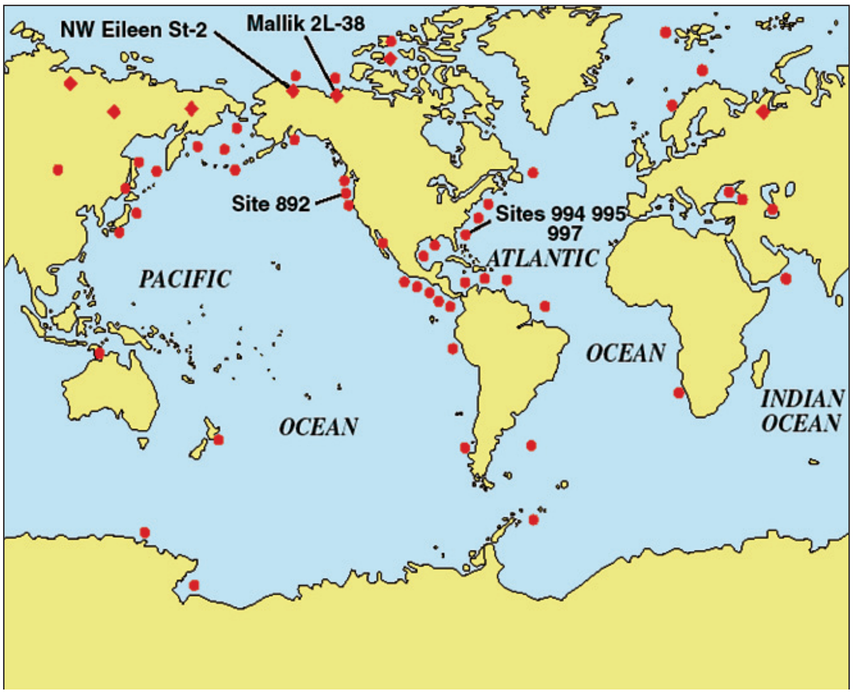
The volume of gas in hydrate reservoirs greatly exceeds the volume of known conventional gas resources



Location of known and inferred gas hydrate occurrences
(modified from Kvenvolden K A 1993 USGS Prof. Paper 1570)

Methane hydrate - potential energy source

Hydrates are found only in the polar regions of the far north or far south, and within water or seabed sediments at (water) depths greater than 300 metres. Thus they are accessible only to countries with the appropriate technology. At standard temperatures and pressures, methane is a hydrocarbon gas and is the main component of natural gas. Under conditions of relatively high pressure and low temperature (common in areas of perennially frozen ground ('permafrost') and on the sea bed of the continental slope), methane hydrates can be found as a solid, ice-like substance. Each cubic metre of methane hydrate is equivalent to 160-180 cubic metres of methane gas. Therefore, hydrates also have a capacity for storage and transportation. Methane can easily be released by injecting heat into a hydrate deposit.

The volume of methane sequestered in gas hydrates is enormous, but published world estimates are highly speculative. It is generally believed that the volume of gas in hydrate reservoirs greatly exceeds the volume of known conventional gas resources. Considering the size of remaining oil and gas reserves, and the large amount of natural gas available from coal-bed methane, there is not much commercial incentive at current prices to explore for methane hydrates. The current shift from oil to gas and, potentially, to gas hydrates will, however, be accelerated by a steady increase in the cost of fossil fuel and strategic supply considerations in areas of large consumption.

The International Year will help focus attention on how the geosciences can generate prosperity locally and globally

Mineral resources - availability and supply

Many mineral deposits are associated with igneous, mantle-derived melts, particularly when only a small fraction of mantle melt forms the minerals that are deposited. Detailed understanding of plate tectonic processes helps geologists to pinpoint where prospectors are most likely to find specific mineral suites.

Many mineral deposits become economic only after they have been reworked by weathering and erosion. Conversely, erosion or dissolution without reconcentration may destroy a mineral deposit! Geologists need a sound understanding of surface processes before they can build predictive models of ore formation/destruction. Despite recent advances, we remain far from any comprehensive understanding of these key processes and how they interact. The type of research needed to address such interdisciplinary studies, like the Platinum Group Elements (PGE) example (see later), is crucial for developing a sustainable resource base for future generations.

What renewable materials will be needed as new technologies and economies develop? Will solar energy become more economically viable if the price of hydrocarbon-based energy increases? What raw materials will be needed to build solar collectors required to serve major cities? What special material needs will there be to support hydrogen-fuel energy systems on a large scale, and where will those materials come from?

Summary of research agenda

The impact of the natural resource industry on the economies of many countries is so dominant that understanding their technological, social and geoscientific constraints commands broad interest. The International Year of Planet Earth will help focus attention on how the geosciences can generate prosperity locally and globally, as well as sustainability issues in both developed and developing countries.
This Theme shows how, for example, natural resources may sometimes be linked to corruption and social unrest on the one hand, and yet may also contribute to sustainable development.

The Theme will focus on answering three key questions.

1. How can our improved knowledge of valuable geological resource endowments feed through into better planning, governance, social stability and advancement, in a climate of sustainable development?

This question highlights the need to establish under what circumstances a lack of adequate knowledge impedes development and poses a threat to good governance, sustainable development and even peace. Ways of building institutions so as to ensure that natural resources are a blessing rather than a curse involves the study of legal aspects, policies, and institutional arrangements regionally, nationally and internationally. The aim of this interdisciplinary study is to compile baseline data that will provide new tools for improved understanding of the relationship between natural resources and societal trends. Such research will provide a well-rounded

('holistic') view of the entire value chain, as well as the political and societal consequences of a region's natural resource endowment and its potential development revenues. The work will provide guidelines and best practice protocols to help policymakers ascertain whether resource scarcity or abundance poses a threat to sustainable development. Specific projects under this heading might address the following questions:

- Can democratic institutions lessen any adverse effects associated with resource development?
- Can land use planning methods be used to resolve conflicting aims between different users in a region with overlapping claims?
- Do resource-rich areas attract foreign intervention that affects the social framework of the host nation?
- Do resource-rich areas tend to form separate states?
- Do revenues from fossil fuels weaken a state's institutional capacity?
- Is economic development part of the problem or part of the solution?
- What specific natural resources are particularly likely to lead to a decline in a country's quality of governance, or rise in lawlessness?
- What can be learned from the countries in which there is no history of resources leading to social unrest?
- How is it possible to promote the diversification of a country's economy, so that it is not based on one commodity alone?
- To what degree should the developed countries, in seeking to guarantee sustainable development, intervene to ensure that other industries are built up alongside emerging extractive industries?

This programme has great outreach potential because it addresses the relationship between resource wealth and national development - a subject of interest to all who seek to understand the reasons for success or failure in the governance of natural resource revenues. To understand the dangers ahead, we need to consider the hazards of oil-dependent development and resource abundance. The economics are simple, if counterintuitive.

So-called "Dutch disease" is the label given by development economists to an all-too-familiar set of symptoms; rapid capital inflows appreciate the exchange rate, erode the competitiveness of industries subject to international competition, promote current-account deficits, accelerate inflation, distort investment, and link the economy to volatile commodity markets. Thus, rather than generating prosperity, booming resource revenues can have the effect of stunting broad-based, sustainable development. Narrow, oil-led growth also tends to exacerbate social division.

2. To what extent can geo-methane and methane hydrates contribute to global energy production, and what is the likely environmental impact?

Society needs to gain a better understanding of the range of problems and opportunities posed by the potential use of shallow gas methane, methane from abolished flaring, and methane hydrates. The goal of this research is to help stakeholders assess the local and regional potential for sustainable use of methane as a resource.

This geoscience initiative aims to promote international cooperation in the research, identification and assessment of shallow gas methane, as well as methane hydrates, as an energy resource and as a transportation medium for remote natural gas.
Activities will include developing suitable methodology for assessing the economic potential of shallow gas methane together with gas otherwise flared, gas hydrate provinces and accumulations, as well as models for estimating environmental impact.
Specific projects under this heading might address the following questions:

- Can methane hydrate resources be estimated by a common quantitative "grade-tonnage" approach used to assess undiscovered mineral resources?
- How can we assess the regional and local resource potential of shallow methane, both as free gas and as methane dissolved in water?
- How can alignment of incentives and institutional development minimise flaring?
- How can we visualise methane hydrate accumulations in 3D?
- How soon can methane hydrates become a significant energy source?
- What is the role of gas hydrates as a geological hazard and as a climate mediator?
- What is the true nature of bottom simulating reflections (BSR) and how do they develop?
- What methods might be suitable for assessing shallow gas potential?
- What role do mud volcanoes play in the accumulation of methane hydrates and how much is released to the atmosphere?

3. Can the increasing industrial use of mineral resources and especially the Platinum Group Elements be supported by sustainable new production?

Interest in mineral deposits of the platinum group elements (PGE; Ru, Rh, Pd, Pt, Os, and Ir) is at an all-time high. Demand is growing rapidly for these metals, which are prized as catalysts for automotive fuel cells or pollution abatement systems.
Given that IGCP Project 479, *(Sustainable use of PGE in the 21st century: Risks and Opportunities)*, will end in 2007 having accumulated a large body of new knowledge, further work can build on this major data store.

Reserves of the PGE are primarily available in only two countries: Russia and South Africa. However the newly discovered deposits of Lac des Iles and Sudbury (Canada) and the Stillwater mine (Montana, USA) are significant producers of platinum group elements in North America. The palladium-rich Lac des Iles deposit is not analogous to the Bushveld Complex (Africa), which tends to confirm that PGE can be found in a greater variety of geological environments than originally thought.
PGE can also be transported in car-exhaust vapour or aqueous solution, leading to emission-related PGE pollution. Delivery of PGEs as active components to the biosphere may turn out to pose some environmental risks, including incorporation in living tissue, although whether or not this constitutes a risk to human health will require extensive scientific monitoring.

The aim is to understand the relationship between resources and conflict

Science programme

A panel of 20 eminent geoscientists from all parts of the world decided on a list of ten broad science themes - Groundwater, Hazards, Earth & Health, Climate, Resources, Megacities, Deep Earth, Ocean, Life and Soils.

The next step was to identify substantive science topics with clear deliverables within each broad theme. A "Key text" team was set up for each, tasked with working out an Action plan. Each team has now produced a theme prospectus, just like this one.

A series of Implementation Groups will then be created to set the work under the ten programmes in motion. Every effort will be made to involve specialists from countries with particular interest in (and need for) these programmes.

For more information - www.yearofplanetearth.org

Future supplies of PGE will most likely be discovered in parts of the world that combine vast geographical expanses with favourable geological settings, as well as a minimal history of mineral exploration. Using known deposit models, future supplies may come from currently uneconomic layers in the Bushveld Complex, poorly exposed and little-explored mafic and ultramafic layered intrusions (Africa, South America, Fennoscandia and Antarctica), and small intrusions associated with the emplacement of flood basalt provinces.

A potential new area is the Fennoscandian Shield, where large but low-grade deposits have been reported in layered complexes found over broad expanses of Finland and NW Russia. The geology and ore deposits of these regions tend to be poorly known. Results from research projects under this theme could help inform future strategies for PGE extraction and consumption worldwide.

The principal results obtained from IGCP Project 479 relate to recognition of potential new resources and the production of guidelines for their sustainable exploitation, particularly in the developing world. Further results from general research into PGE genesis and distribution, as well as the role of PGE in the surface environment need to be used in a way that profits not only large organizations but also individuals or small organizations with limited budgets.

What does the International Year's logo mean? The International Year is intended to bring together all scientists who study the Earth System. Thus, the solid Earth (lithosphere) is shown in red, the hydrosphere in dark blue, the biosphere in green and the atmosphere in light blue. The logo is based on an original designed for a similar initiative called Jahr der Geowissenschaften 2002 (Earth Sciences Year 2002) organised in Germany. The German Ministry of Education and Research presented the logo to the IUGS.

Specific projects under this heading might address the following questions:

- How can scientists get access to, and exploit the available databases on PGE resources?
- Are we constrained by our current models for the future discovery of world class PGE deposits?
- How comprehensive is the established world PGE resource Inventory?
- What are the environmental consequences of PGE extraction and industrial consumption?
- Can some of the currently sub-economic PGE deposits around the world be made economically viable by the establishment of markets for saleable by-products?
- Can we secure a future sustainable supply of PGE through exploration?

Such an approach, although differing in detail, could provide a useful framework for a wide range of research projects within the International Year that address other (and in many cases, more familiar) metal commodities such as iron, copper and gold, as well as non-metal resources (including industrial minerals, carbonates, talc, graphite, zeolites etc.) that are so essential to human development.

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The Outreach Programme will respond to grassroots demand, enabling national initiatives within an international framework

Outreach Programme

The Outreach Programme of the International Year is faced with a particular challenge of scale. With a potential $10m to spend, it is inconceivable that it could operate in a prescriptive way. No individual or committee can think of enough wise ways of spending such a sum globally. So the Outreach Programme will, like the Science Programme, operate as a funding body, receiving bids for financial support - for anything from web-based educational resources to commissioning works of art that will help reinforce to the general public the central message of the year. It will enable things to happen locally under the umbrella of an international scheme, lending profile and coherence.

A special Outreach Prospectus in this series (number 11) is available for those who are interested in applying for support.

Writing team

Richard Sinding-Larsen (Norwegian University of Science and Technology)
Martin Hovland (Statoil, Stavanger, Norway)
Deborah Shield (U.S.D.A. Forest Service, Forth Collins, U.S.A)
Nils Petter Gleditsch (Centre for the Study of Civil War, International Peace Research Institute in Oslo, Norway), plus many others.

Editing	Edward Derbyshire, Ted Nield
Photographs	Ted Nield, John Simmons www.geolsoc.org.uk/photos
Design	André van de Waal, Coördesign, Leiden

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International Year of Planet Earth

IUGS Secretariat
Geological Survey of Norway
N-7491 Trondheim
NORWAY
T + 47 73 90 40 40
F + 47 73 50 22 30
E iugs.secretariat@ngu.no

www.yearofplanetearth.org