

Ocean - *abyss of time*

Earth sciences for society

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



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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 accessible terms, why this particular theme has been chosen - 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.

The prospectus was written by a panel of world experts assembled by the Science Programme Committee of the Year.

To find out more...

To find out about the other research themes being pursued, please consult www.esfs.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.esfs.org and download the appropriate Expression of Interest (Science) form, and follow the instructions on submitting this to the International Year. If you cannot find an EoI form, on the site, it means that we are not yet ready to receive Expressions of Interest. Please keep visiting the Site.

1147 million people live

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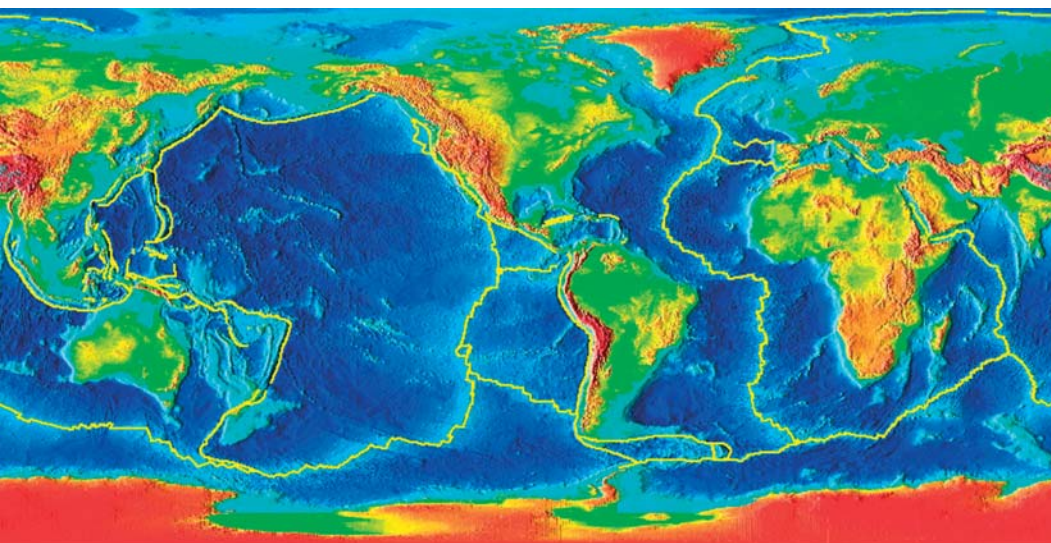
Behold, the sea!

The oceans, which began to be scientifically explored 200 years ago, hold the key to how the Earth works. For example, the ocean's sediments provide a record of climatic signals over the last 200 million years. Although our improving knowledge of the oceans has revolutionised our understanding of the planet as a whole (the best example being the sea-going expeditions after World War 2, which led to the theory of plate tectonics in the late 1960s) much more remains to be discovered – not only in the use of oceans to the benefit of humankind and the environment, but also in mitigating hazards around the continental margins. About 21% of the world's population, 1147 million people, live within 30km of a coastline.

Within the framework of plate tectonics, the birth of a new ocean spreading centre often involves the rupturing of a continent and this leads to the production of a pair of rifted continental margins (like opposing sides of the Atlantic Ocean today). Ocean floor is generated continuously at the global system of spreading ridges, and the ocean crust moves away from the ridge.

After its journey across the deep ocean basin, seafloor may disappear at an ocean trench, where the oceanic plate is subducted, often beneath a continent – as around the Pacific Ocean today. Therefore, most of the scientific questions of OCEAN are related to spreading ridges and continental margins, whether created by rifting (Atlantic) or subduction (Pacific).

Crustal Plate Boundaries



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 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.

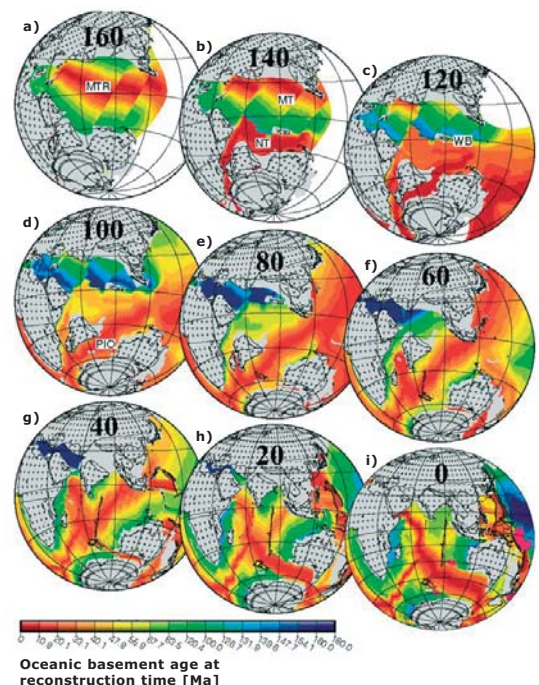
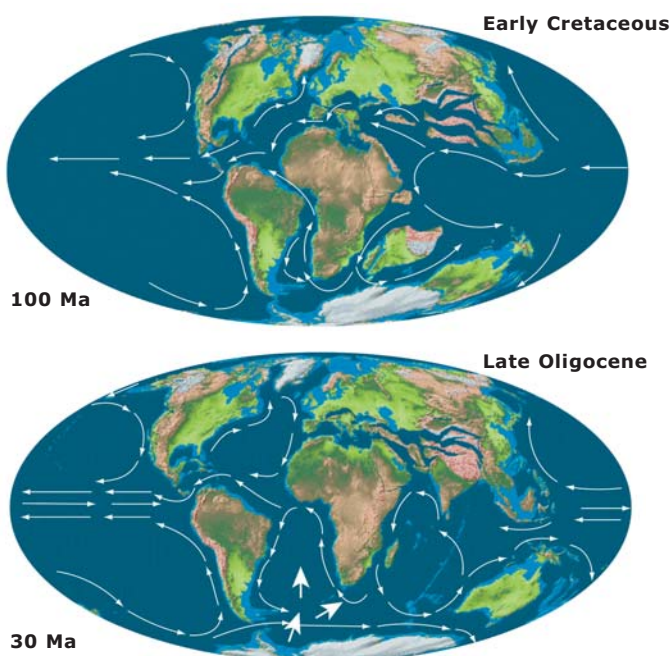
What does the International Year's logo mean? The International Year is intended to bring together all scientists who study the Earth System. Thus, the solid Earth (lithosphere) is shown in red, the hydrosphere in dark blue, the biosphere in green and the atmosphere in light blue. The logo is based on 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.

In the margins

Over the past decade the two international scientific initiatives of InterRidge and InterMARGINS have been organised to coordinate the international scientific effort to attack these scientific questions. In addition, a programme of scientific drilling in the oceans (Deep Sea Drilling Project, 1968-1983; Ocean Drilling Program, 1985-2003; Integrated Ocean Drilling Program, 2003-) has, over the past 40 years, led the Earth science community toward greater understanding of the Earth (including the ocean) as a dynamic system, using direct sampling of ocean sediments and underlying crust.

The International Year of Planet Earth's theme "Ocean" will focus on the following two key questions, which embrace key topics of InterRidge and InterMARGINS, respectively:

- How do the lithosphere, hydrosphere and biosphere interact at mid-ocean ridges, and what role did these interactions play in the origin of life on Earth?
- What Earth processes affect the formation and evolution of continental margins, and what benefits and threats do continental margins offer to mankind?



**Mid-ocean ridges are the site of the
most active volcanism and frequent
earthquakes on our planet**

Science programme

A panel of 20 eminent geoscientists from all parts of the world decided on a list of nine broad science themes -

Groundwater, Hazards, Earth & Health, Climate, Resources, Megacities, Deep Earth, Ocean, and Soils.

The next step is to identify substantive science topics with clear deliverables within each broad theme. A 'key-text' team has now been set up for each, tasked with working out an Action Plan. Each team will produce a text that will be published as a theme prospectus like this one.

A series of Implementation Groups will then be created to set the work under the nine 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.esfs.org

How do the lithosphere, hydrosphere and biosphere interact at mid-ocean ridges, and what role did these interactions play in the origin of life on Earth?

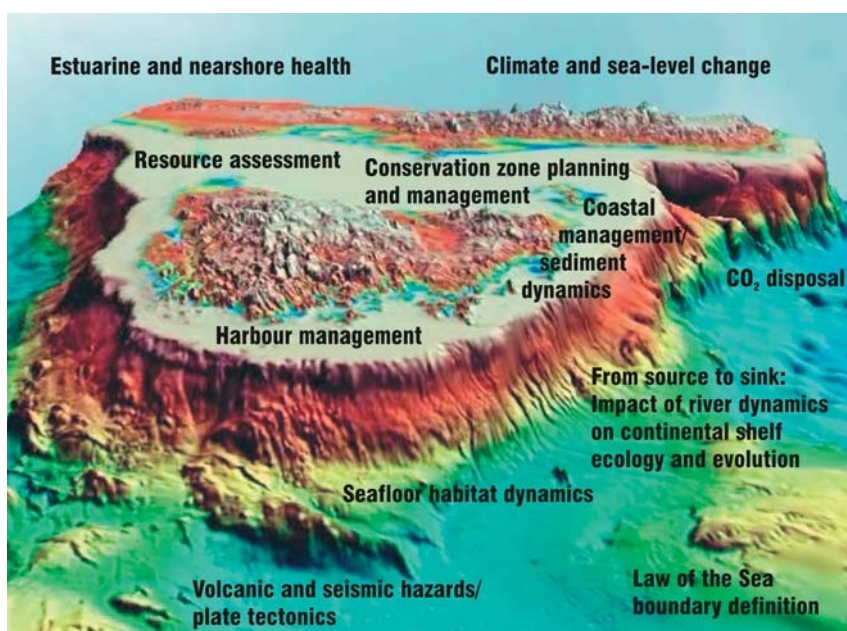
Huge cracks in the Earth's surface are formed when the tectonic plates that make up our planet's outer shell move apart. These cracks run mostly through the ocean basins, forming a 60,000km globe-encircling volcanic system known as mid-ocean ridges. With only one exception (Iceland) this volcanic belt is completely hidden from view beneath two to four kilometres of ocean. Nevertheless, it is along these ridges that molten rock ("magma") generated at depths between 20 to 80km within the Earth rises and erupts on the seafloor, slowly resurfacing vast areas of our planet as that seafloor spreads away from these ridges. The results are bizarre landscapes (strictly speaking, "bathyscapes"), of toxic hot springs and an abundance of life thriving independently of sunlight, all of which are constantly being remodeled by volcanic eruptions and earthquakes.

This is an interesting and largely unknown part of our planet for sure, but how important is this volcanic activity and the life it supports to the world as a whole? What part does it play, for example, in the production of mineral deposits, in controlling the chemical composition of the oceans, in the deep-sea food chain, and in the origin of life? In view of the enormous length of the ridges and their relative inaccessibility, answering these questions has required - and still requires - a global, coordinated international scientific collaboration.



Recent effort has shown just how important the ridges are for the deep ocean and potentially for humankind. The energy released by the cooling volcanic rock at the ridges is equal to about half of what is generated by the human race through burning fossil fuels and from nuclear power. At present this energy dissipates on and near the seafloor, driving the circulation of vast amounts of seawater through the oceanic crust. The output of this circulation is hot (up to 400°C) and acidic hydrothermal fluids, which carry dissolved metals and are laden with dissolved gases such as methane and hydrogen sulphide. When they vent on the seafloor, reactions between the hot, metal-laden vent fluids and the surrounding cold deep-sea water lead to the precipitation of metal sulphides, a reaction that has generated some of the largest metal ore bodies on Earth.

Hot, sulphide and metal-laden fluids do not sound like the ideal place for life to thrive, but it is precisely around these vents that the highest concentrations of biomass in the deep sea are found. The animals found at the hydrothermal vents are often quite strange by our standards, including giant worms without guts that feed by relying on bacteria in their tissues that in turn harness the energy from the normally toxic chemical, hydrogen sulphide. These and numerous other unique vent animals have much to teach us about how they can withstand, and even flourish in, the dynamic and hostile environment they inhabit. Furthermore, the microbes found in hydrothermal vents can live in even more extreme environments, and we have just begun to explore the enormous diversity of metabolic pathways (chains of biochemical reactions) found in bugs both above and below the seafloor. We already know that some can live at temperatures greater than any other form of life on the planet can tolerate, and in fact many scientists believe that it was in places like this that life first evolved on Earth.



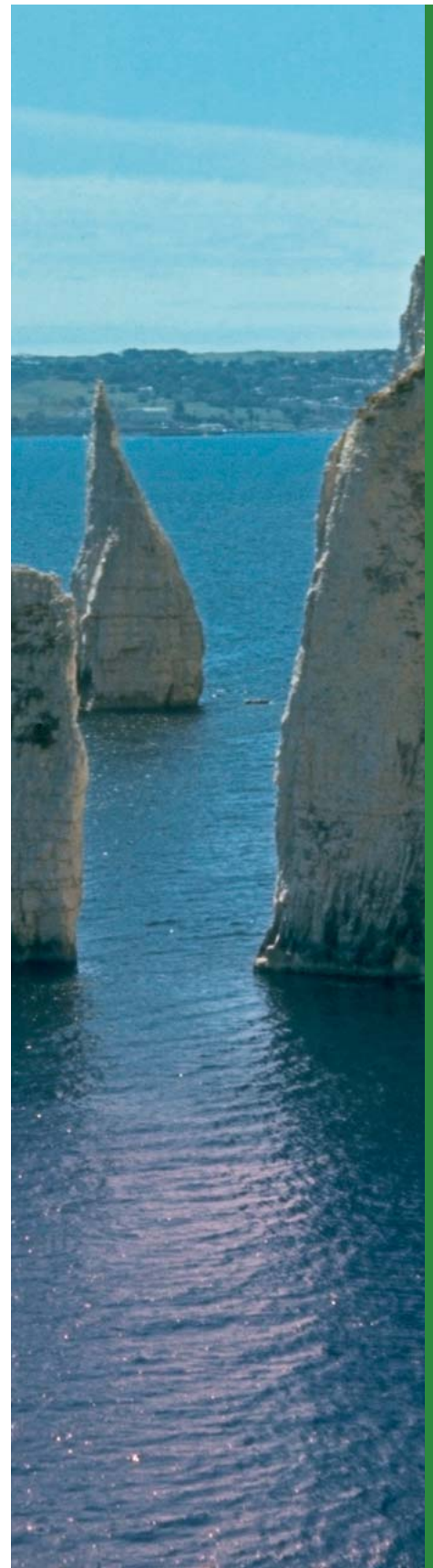
Mid-ocean ridges are the site of the most active volcanism and frequent earthquakes on our planet. As such they provide a unique natural laboratory for long-term monitoring of the interaction between submarine volcanoes, earthquakes, and changes in physical conditions in the deep ocean. For example, recent studies have indicated that moderate-sized earthquakes along the oceanic transform faults (which offset the spreading ridges) appear to be associated with much higher numbers of foreshocks but lower numbers of aftershocks in comparison to continental counterparts. Moreover, changes in ocean tides appear to have triggered seismicity in the vicinity of submarine volcanoes. New knowledge obtained from studying the way the rocky shell of the Earth (lithosphere) interacts with the hydrosphere in the mid-ocean ridge volcanic-tectonic system has important implications for applied research and the forecasting of volcanic and earthquake hazards on land.

Volcanic, tectonic, and hydrothermal processes at mid-ocean ridges also control the chemical composition of the Earth's oceanic lithosphere (the rocks that form the ocean floor) and the landscape of the vast abyssal plains. Beneath fast-spreading ridges, such as the East Pacific Rise, a steady-state lens of magma is often imaged, providing molten rock for the relatively frequent intrusion of magma sheets (dykes) and for the seafloor eruption events that they feed. The magma lens also supplies heat to drive hot-water (hydrothermal) circulation in the ocean crust.

At the slow and ultraslow ridges, such as the Mid-Atlantic Ridge and the Gakkel Ridge under the Arctic Ocean, however, magmatic events are much less frequent and the tectonic extension of the lithosphere by faulting is a significant component of seafloor spreading. We are only at the early stage of understanding what controls the cycles of magmatic/tectonic events at mid-ocean ridges.

Mid-ocean ridges and hotspots, such as Iceland, the Azores, and Galapagos islands, exhibit the greatest flow of heat from the Earth's mantle to the bottom of the oceans. The effects of such hotspots are manifested by shallowing and even emergence of the ocean floor (the two most dramatic cases being Hawaii in the Pacific ocean basin and Iceland at the Mid-Atlantic Ridge), increases in the thickness of the oceanic crust, changes in the style and intensity of seafloor volcanism, and evolving geometry of the seafloor spreading centres.

When a hotspot interacts with a mid-ocean ridge spreading centre, the lava that erupts on the ocean floor (and on the hotspot islands) also contains important information on the chemical composition of Earth's mantle. However, we do not yet know whether most of the hotspots found on the ocean basins have deep roots inside Earth's lower mantle, or are caused by anomalies in Earth's upper mantle. Future research effort on mid-ocean ridges and hotspots will help to address these and other fundamental questions.





Continental margins

also present hazards

to mankind



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.



What Earth processes affect the formation and evolution of continental margins, and what benefits and threats do continental margins offer to mankind?

The relatively steep slopes of the continental margins, which extend vertically over several kilometres, can affect the directions of ocean currents. Offshore winds may drive the upwelling of deeper, fertile bottom waters, which stimulate surface productivity over these margins. Continents are also the source of sediments, carried to the oceans by rivers and even by offshore winds. Sediments deposited on the continental margin, rich in organic carbon (particularly where they are several kilometres thick) can generate and host important resources such as hydrocarbons and gas hydrates, as well as diverse biological communities. Many continental margin sediments record some aspect of past climate change.

Continental margins also present hazards to mankind. The failure (landslide collapse) of sediment-laden slopes on a margin, however triggered, can generate tsunamis that threaten coastal communities far and wide. Conversely, wherever it may have been generated, the way a tsunami is expressed when it arrives at a margin is strongly influenced by local seabed relief on the continental margin and shelf, determining whether or not there is catastrophically damaging run-up on the land. Less clear at present is how possibly destabilising the effect of gradually rising sea level may be, triggered by global warming. Other margins, adjacent to active rifts or subduction zones, are subject to seismic or even submarine and subaerial volcanic hazards.

Continental margins receive waste from the land by way of rivers and human activities. Pollution generated by industrial, commercial and leisure activities can be concentrated by physical/chemical/biological processes on continental margins. Margins also play a part in naval defence activities (principally underwater sound signals), in the exploitation of fish stocks, in the exploration for hydrocarbons and in safe navigation.

Underpinning all of the above knowledge should be an understanding of the geological processes that accompany the formation of rifted (and rifting) margins, and subduction zone margins.

At rifted margins the primary influences on margin development are believed to be the (physical and chemical) nature of the original continental lithospheric plate: i.e., its deformation and flow characteristics, which controls its response to rifting. We also need to know the rate of lithospheric extension during rifting, the shape and distribution of major faults in the uppermost brittle part of the lithosphere, the extent of evaporites and magmatism as well as the subsidence history, if we are to develop predictive models of rifting and continental break-up.



“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. 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.

At subduction zones, the form and evolution of the convergent margin is strongly influenced by the fate of the incoming ocean sediments in the subduction process (whether they are scraped off and accreted to the overriding plate (“obducted”), or whether they are subducted). Similarly, at different scales, we need to understand the parts played by the rate and angle of subduction, by the temperature of the incoming oceanic crust, by fluids and pore pressure, by faults, by seismicity and volcanicity and by the fate of the lithospheric plates once they reach the asthenosphere, the weak layer of the mantle, which underlies the lithosphere.

The scientific problems to be tackled on continental margins vary in their scope and impact on human needs and activities and on the environment. They can be classed under the following headings:

- Deep Structure
- Sediments
- Resources and Fluids
- Hazards
- Data Assimilation
- Advances in technology



- Scientific problems on continental margins vary in scope and impact on human needs ●



Deep structure of rifted margins

The principal problems on rifted margins are to develop effective and predictive conceptual and numerical models for the evolution of the lithosphere during margin formation. This work requires information about the various rock types within the oceanic crust beneath the sediments, their mechanical and physical properties, age and emplacement history, and their response, whether brittle or ductile, to extension. Ideally, to gain a complete picture, on both sides of a rift margins should always be studied using the same tools along a common flow-line. The principal tools required are deep scientific drilling (including riser drilling) to penetrate both sediments and basement rocks and seismic methods (including 3D surveys); but other techniques, particularly new ones such as electrical conductivity and other geophysical measurements on or near the seabed, should be attempted.



● The advent of the Global

Positioning System (GPS) has

completely changed geodesy ●

Deep structure of subduction zones including sediments

Although the depositional history of sediments has little relevance to their eventual fate in a compressional margin, they are often closely involved with the deeper crust and mantle in the dynamic subduction process.

Large earthquakes that occur within the down-going slab represent the short period response of the oceanic plate to the subduction process, which moves at rates of a few centimetres per year. We should image earthquake-generating zones in 3D, using seismic and other geophysical parameters, to map the response of the slab to tectonic loading. Such understanding is extremely important if we are to extrapolate beyond what will be gained by drilling into the seismogenic zone, and emplacing various sensors there.

The advent of the Global Positioning System (GPS) has completely changed geodesy. We can now constantly monitor deformation taking place on land. This capability must be transported to the seafloor. Pilot experiments have already proved the feasibility of the concept. We should further expand this technique at sea to measure ongoing deformation of the Earth. If scientists can accurately quantify the deformation and sudden release of seismic energy involved in an earthquake, then this will lead to better understanding of island arc evolution, volcanism and hazard mitigation.

Subduction can be considered as a process that recycles material through the Earth: the so-called “subduction factory”. Our eventual goal is to understand the whole Earth material cycle. At shallow depths, carbon cycling in relation to, for example, methane hydrate development, would provide constraints on the global cycle. Deeper, the effect of the lithospheric input, such as the possible consequences of subducting serpentinitised oceanic crust or the products of mid-plate magmatism, is still not well understood.

Sediments on rifted margins

Sediments, onshore and offshore, reflect the extensional, erosional and depositional history of a rifted margin as well as its uplift and subsidence. While it is not absolutely necessary to study sediments on conjugate pairs of margins, a full understanding of the complete syn-rift and post-rift depositional history of a single margin requires geological mapping and sampling on land and – offshore - dense seismic surveys (including 3D surveys) and sampling (including drilling) so that megasequences and significant reflection horizons can be traced over large distances. Methods of estimating paleodepths from sediments should be improved. Studies of modern sediment systems also need to acquire sidescan sonar and multibeam bathymetric surveys and cores.





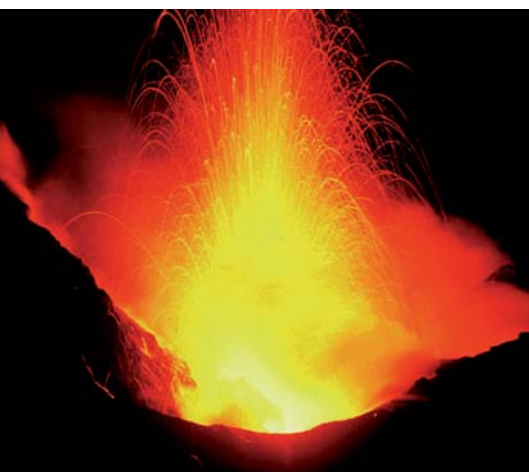
Resources and fluids

The principal resources found within rifted margins are hydrocarbons (oil and gas) and, within both rifted and compressional margins, gas hydrates. Probably the most important knowledge required in hydrocarbon exploration and the assessment of potential source rocks is the thermal history. This can be estimated from measuring the extent and volume of magmatism, the age and thickness of sediments and present-day heat flow. Methane hydrates occur in large quantities and are a potential source of energy. However, an environmentally safe and economic means of removing the methane from the seabed has yet to be identified. Further research is required in these areas.

Seeps of fluids from the seabed have been observed at both rifted and compressional margins. Such fluids are released at about ambient temperatures and are therefore called “cold seeps”. Cold seeps have now been found in diverse locations, such as on canyon walls, on active continental margins, from limestone escarpments, and above hydrocarbon deposits. Diverse bacterial types thrive in these environments, as do communities of animals that are utilising energy produced from reduced, chemical-rich fluids exiting the seafloor. We have only scratched the surface of appreciating the biodiversity of these animals and microbes, and the potential biotechnological applications inherent in their unique metabolisms. Acoustic surveys also provide evidence of cold seeps. The flow and chemistry of fluids at margins may also relate to the diagenesis of the underlying sediments. These are new research areas that require novel ideas and approaches.

Hazards

The problems of predicting hazards related to seismic and volcanic activity, while important at many subduction zone margins, are well known and are considered elsewhere (See Brochure 3 in this series: *Hazards: minimising risk, maximising awareness*).



The dangers posed by tsunamis are a particular problem in all margin areas that, to be minimised, require knowledge of potentially unstable sediment bodies and detailed bathymetric and topographic surveys of critical regions. Numerical simulations of tsunami propagation and run-up are also important means to predicting where tsunamis may cause maximum damage. It is likely that rising sea level and flooding driven by climate change will cause mass movements of people along coasts in coming decades. Well-informed choices of new coastal sites for towns and cities will need basic information about the risks from tsunamis.

● **The dangers posed by tsunamis**
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Only one Earth

The human race needs its planet. We depend on it completely, because we evolved from it, remain forever part of it, and can exist only by courtesy of the self-sustaining Earth System.

The more we learn, the more we understand that we must nurture the Earth as we would our children, for their sake.

Data assimilation

The United Nations Convention on the Law of the Sea (UNCLOS) empowers coastal states to make claims on their offshore seabed according to criteria laid down in international law. To support such claims many states have assimilated large quantities of data and have even carried out special surveys to collect swath bathymetry and other data. While some countries may wish to keep some of these data confidential, others may be more open and, indeed, some swath bathymetry has already been placed in the public domain. We suggest that a data centre is either identified or established to collect and merge all swath bathymetry, and perhaps other data, around the world's continental margins for the benefit of marine science and engineering.

Advances in technology and instrumentation

Exploring the volcanic, tectonic, and hydrothermal activity at mid-ocean ridges and continental margins has greatly promoted, and will continue to drive, the development of deep ocean exploration technology and tools, many of which will bring direct technological benefits to society.

Examples of new technologies include human-occupied vehicles (HOVs) that are capable of diving to great depth in the ocean, remote-operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and a new generation of deep ocean instruments to make *in situ* seismic, geophysical, acoustic, hydrothermal, chemical, and biological measurements. Emerging major technological advances also include the ability to make continuous time-series measurements at seafloor observatories, the use of conventional and fibre optical submarine cables to provide power supply to the seafloor observatories and transmission of data back to laboratories on land, and the scientific drilling of oceanic crust at mid-ocean ridges and deep into continental margins through the Integrated Ocean Drilling Program (IODP).



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