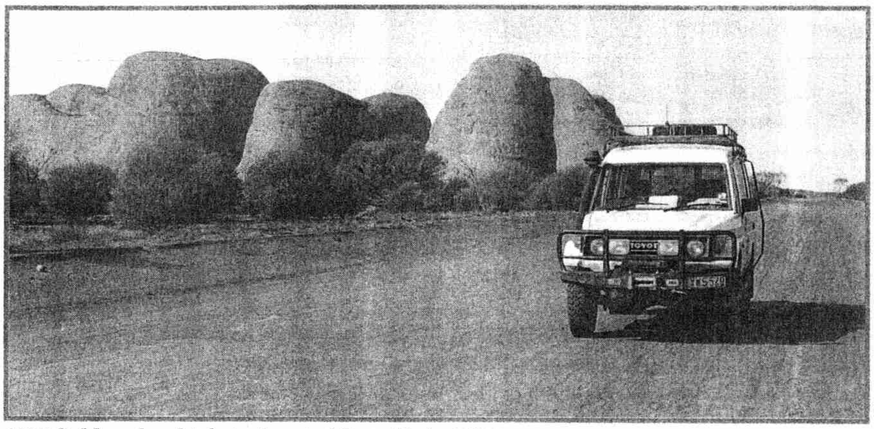
# The deep structure of the Australian continent

*Rob D. van der Hilst*
*and Chris B. Smith*

*Natural resources and commodities are crucial for the economy and prosperity of Australia. The days when pioneers could find rich mineral deposits by chance and good luck are long gone, and exploration for natural resources is now dependent on sophisticated technologies and advanced scientific research.*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***ANU fieldwork vehicle in front of Kata Tjula 1995***

A balanced combination of basic and applied research and active interaction between academia and industry is required to further our knowledge of existing deposits, and to provide guidance in finding new locations.

Earth sciences play a crucial role in understanding the formation of mineral deposits and the geological structures in which they develop, and in the characterisation and recognition of regions within Australia with new potential for the mining industry. Geoscientists study the earth's interior on many different scales: electron microscopy is used to study the properties and deformation of crystals fractions of millimetres in diameter. However, the earth as a planet is the object of study of, for instance, scientists operating large, worldwide networks of seismographs and an increasing number of scientific satellites, or for the study of the earth's magnetic field.

## The discovery of ore:
### the quest for more information

In mineral exploration, geoscientists use a variety of geological, geochemical and geophysical techniques to identify patterns suggestive of mineralisation at or near the surface of the earth's crust, and to home in on the ore occurrences themselves. But the first stage of exploration is the selection of an area considered prospective for the mineral commodity being sought. For this purpose, knowledge of the nature of existing worldwide mineral deposits, the processes that have formed them, and their geological framework are combined into a model for the ore environment. The geology of the country to be explored is then reviewed for analogies to this model.

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This approach to area selection works well when the ore body model is well founded, and when the regional geology is well known and good detailed maps and data are available for study. Some deposits are formed in the crustal environment (for example, coal through lithification of swampy vegetation, or kaolin through weathering of aluminosilicate minerals in rocks such as granite). For these the predictive model is well established. Others, such as platinum, diamonds, or nickel sulphide ores relate to processes of much deeper origin which cannot be seen happening at the earth's surface: of generation and upward movements of molten magma and fluids from depth. Geological maps are essentially two-dimensional, based on surface outcrops and on drill holes. These holes, from a few tenths of metre to one to three kilometres in length, only just penetrate the skin of the earth's crust, which extends down to some 30 km or more. Knowledge of the deeper mantle processes down to several hundred kilometres is therefore incomplete and highly theoretical.

## New technologies

Techniques from outside earth sciences are often adapted to change the frontiers of our knowledge. A good example is seismic tomography, a class of imaging techniques adopted from medical research in the early seventies. Instead of electromagnetic waves or Röentgen radiation, seismic tomography makes use of elastic waves emitted by natural sources, such as earthquakes or man-made explosions, to make a CAT (Computer Aided

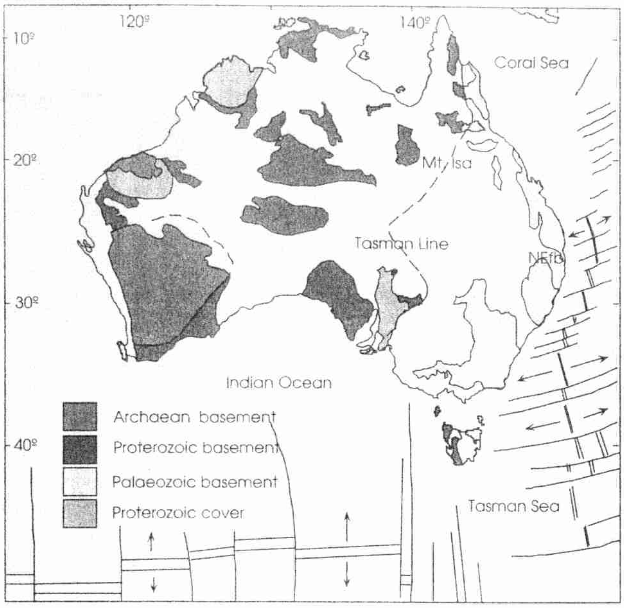


***Figure 1:** Schematic map showing principal geological domains of Australia, grouped according to age.*

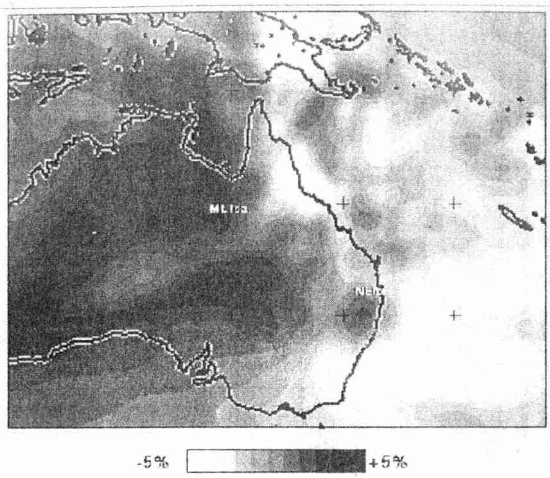


***Figure 2:** Lateral variation in seismic wave speed at a depth of about 140 km beneath the surface of the Australian continent constructed from the data collected when the Skippy array was operational in Queensland. The darker stippled areas represent thicker, more rigid lithosphere indicative of thicker lithosphere and therefore greater diamond potential. The structure in the western part of the continent is not yet well determined by the tomographic technique used. Large variations in seismic wave speed occur in the direct vicinity of the Mt Isa block and the New England fold belt (NEfb). These structures are detected to depths of at least 350 km.*

Tomography) scan of the earth's interior. Three-dimensional variations in rock properties and temperature have an effect on the propagation of seismic waves, and these effects can be observed in seismograms recorded at the earth's surface. Application of tomographic techniques have revolutionised our views of the internal structure of our planet. Seismic tomography is particularly useful to map the sub-surface of continents such as Australia, where very large areas are covered by bush or thick layers of sediments, with few rock outcrops to assist in the exploration of mineral deposits.

## The Skippy project

In a new project, the Australian National University's Research School of Earth Sciences (RSES) uses tomographic imaging techniques to map, in unprecedented detail, the three-dimensional seismic structure of the earth's interior beneath the Australasian region. The *Skippy* project, named after the bush kangaroo, exploits Australia's regional seismicity and makes use of recent advances in digital recording technology to collect high quality seismic data from over 60 sites across the continent.

Operating 60 stations simultaneously would be very expensive and technically demanding. Instead, restricted arrays of up to 12 portable recording systems with a spacing of around 400 km are used. Because of the high level of seismic activity in the Australasian region, a relatively short operation period of five months is long enough to achieve an excellent data coverage for the purpose of seismic imaging. At different times, the *Skippy* array is deployed at different locations in Australia, and plans call for covering the entire continent by the end of 1996. The data acquired by the *Skippy* stations is used along with data available from permanent seismic observatories in the region, such as the seismograph stations installed and operated by AGSO (the Australian Geological Survey Organisation).

The portable stations used in the *Skippy* project consist of a sensor that measures ground motion due to an earthquake; a recorder that digitises the analogue output signal of the sensor and writes the data to a storage medium; a clock and a power supply. The Global Positioning System (GPS), originally developed by the US Defence Department, but now widely applied for many civil and scientific purposes involving positioning and navigation, provides very accurate timing and station locations, even in remote regions. The data is stored on DAT (Digital Audio Tapes). Because of the high storage capacity of DAT the recording units can run autonomously for up to 70 days. [illegible] applied [illegible] alternative [illegible] which is [illegible] solar panel.

## Seismic structure

A primary objective of the *Skippy* project is to delineate the boundaries between the major geological units that form the Australian continent (Figure 1). After analysis of several thousand seismic records of large earthquakes occurring in the seismic belt surrounding the continent, it becomes possible to map – in three dimensions – the regions where seismic waves propagate faster or slower than average. Apart from variations in chemical composition, slow wave propagation is often associated with mantle regions where the temperature is high (sometimes so as to produce partial melting of mantle material), such as beneath volcanic regions. In contrast, fast wave propagation is often due to lower-than-average temperatures. This occurs, for example, where parts of the ocean floor are being recycled into the deeper mantle causing very deep (up to 700 km) earthquakes, or where the relatively cool earth's crust is anomalously thick. Figure 2 depicts lateral variations

***John Grant (on the right, Senior Technical Officer, RSES, ANU) and Rob van der Hilst in the sand dunes near the cattle station** Merty Merty **along the Old Strzelecki Track (eastern South Australia). They are digging up the field recorder in order to change a tape so the unit can run for another 70 days. The solar panel is visible on the left.***

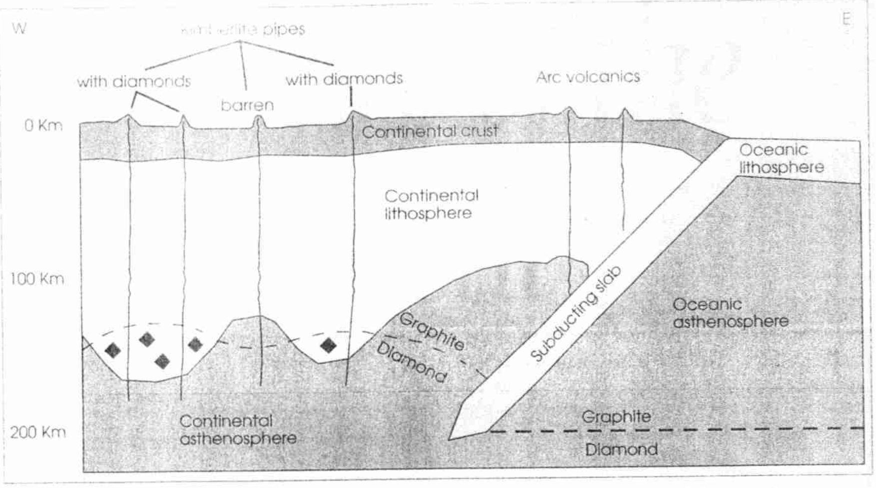


***Figure 3: Cartoon of a west-to-east cross section through the Australian continent, showing the more ancient western cratonic nucleus, and the younger subduction zone in the E beneath the Tasman Fold Belt.***

in shear wave speed beneath the eastern part of the Australian continent, at a depth of about 140 kilometres below the surface. The dark shading depict regions of fast wave propagation; the light colours indicate a slower-than-average seismic wave speed. The latter coincides with the volcanic province in Queensland. This figure displays a large contrast in Queensland and the adjacent Coral Sea to high wave speeds beneath the western part of Queensland, notably near Mount Isa, and the Northern Territory. The New England fold belt in eastern New South Wales (NEfb in Figure 1) stands out as a very deep structure with anomalously high seismic wave speeds. This tomographic model is being continuously updated as more and more seismic records from recent earthquakes are collected at sites all over Australia.

## The search for diamonds

The images of the geological structures at depth provided by the *Skippy* project have direct application to generation of ore body models and to area selection.

An example of this is the search for diamonds, which are brought to surface in volcanoes originating at depths of 150 km or more within the upper mantle, where pressures exceeding 40 kb* and temperatures of over 1000°C ensure that the natural form of crystalline carbon is diamond rather than graphite, the low pressure form developing at the earth's surface (Figure 3). Minerals found as inclusions in the diamond itself indicate that most of these stones grew within the higher part of the upper mantle. The mantle was depleted of its more volatile components by extensive [illegible] during degassing in the early history of the earth, when the ancient cratonic continents in the central and western parts of Australia (Figure 1) were formed. This depleted component of the mantle (known, together with the overlying crust, as the mechanically strong 'lithosphere') is colder and more rigid than the underlying part of the upper mantle: the 'asthenosphere'. This variation in composition and thermal structure influences the propagation of seismic waves, enabling its detection by the tomographic approach. Downward bulges of the lithosphere below 150 km are potential sites for diamond formation, and the *Skippy* program will therefore map out those parts of the continent most favourable for diamond exploration (Figure 2).

*Skippy* should also well define the location, downward dip, and extent of the boundary between the relatively young (Palaeozoic, 500-300Ma) Tasman Fold Belt (See ***Australasian Science*** Summer 1994) and the more ancient (more than 500Ma old) cratonic blocks to the west. This boundary, the 'Tasman Line', divides Australia into two essentially different metallogenic provinces. Characteristic mineralisation of the older cratons includes primary diamond pipes, carbonatities with associated rare earths and phosphate, Archean greenstone gold and komatiite-related nickel. The younger Tasman Fold Belt has potential for porphyry copper deposits and epithermal gold, associated with younger subduction-related volcanism.

The *Skippy* programme is therefore providing a third dimension to our understanding of Australian geology: the evidence of the earth's structure at depth. This will greatly improve our knowledge of the building blocks of the continent, and of the shape and relationships of the different geological environments. Through this it will improve our ability to predict appropriate areas for search for ore deposits, particularly those generated by deeper processes.

***Rob D. van der Hilst** is a Seismology Research Fellow at the Research School of Earth Sciences at ANU. He has worked and studied in England, The Netherlands, Botswana, the USA, Italy, Spain and Japan, in the fields of seismology and geodynamics. **Chris B. Smith** graduated with honours in geology at the University of Bristol. His work as an economic geologist has taken him to North America, Africa and Australia. He is Chief Consultant Geologist (Diamonds) for CRA Exploration Pty Ltd and was Chief Geologist during the successful search for diamonds which resulted in the Argyle Diamond Mine.*

***Footnote – Standard atmospheric pressure is about 1 bar =** $10^5 N/m^2$*