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Using a Synthetic Continental Array to Study the Earth's Interior

B. L. N. Kennett* and R. D. van der Hilst**

Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia

A major field-based observation program (the "Skippy Project") is underway to synthesize an array covering the whole Australian continent, using a series of deployments of around 10 broadband seismometers for periods of 5 months at a time. Such a time period is long enough to exploit the favourable position of Australia relative to world seismicity to assemble a good sampling of global structure. The distance coverage from available events is very good, so that it is possible to build up composite record sections covering propagation from 10 to nearly 180°, with a full coverage of the body and surface wavefields. For deep events at regional ranges, the field arrays also yield good data on mantle reverberation patterns.

1. Introduction

The Australian continent is well placed relative to world seismicity for the study of the deep interior of the Earth, but the number of permanent seismic stations with high quality recording is rather limited. In order to supplement these permanent stations so that a uniform coverage of the whole continent can be obtained, we have embarked on a major field-based program to install arrays of portable broadband seismometers (van der Hilst *et al.*, 1994). This project, involving mobile arrays of up to 12 seismometers deployed at a time, will cover the whole Australian continent in a three and a half year period. We have chosen the project name "Skippy," after the bush kangaroo, since the array jumps from region to region. The first stations were installed in May 1993 and by October 1995 we will have covered all but the western third of the continent with an inter-station spacing of about 400 km. By the end of the experiment in late 1996 we will have occupied about 60 sites to supplement the permanent stations. We have found that a deployment of about 5 months at each site provides good coverage of the regional seismicity and also a wealth of data from more distant events.

2. Field Configuration and Data Handling

The portable stations used in the Skippy Project all employ a broadband Guralp CMG3-ESP seismometer, which has a flat response to velocity from at least 0.03 to 30 Hz. Four of the available seismometers have an extended lower limit to 0.015 Hz. The output from the seismometers is recorded on a Reftek 72A07-DAT recorder with 24-bit analogue-to-digital conversion. The sampling frequency is set at 25 samples/s, which allows us to record nearly 70 days of continuous data on a 2-Gbyte DAT tape. Time keeping is provided by a builtin Global Positioning System (GPS) clock which resets the internal clock each hour to keep timing errors below 1 ms. The feedback seismometer and the recorder both require significant power, and we therefore use a heavy-duty 12-V car battery recharged with a 60 W rating solar panel.

The field configuration is quite simple but effective for Australian conditions. The seismometer is placed on a concrete paving slab at the base of a 1 m deep hole. After the broadband seismometer is levelled and aligned, it is protected by a capped plastic pipe and the hole is carefully backfilled. The recording unit is wrapped in plastic and then covered with

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* To whom correspondence should be addressed.

** Present address: Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.

at least 40 cm of soil, which provides thermal insulation to keep the DAT unit below the advised maximum of 45°C as well as some degree of protection against cattle, cockatoos, and other wildlife. The solar panel with the GPS antenna is placed on a pole about 10 m away from the sensor, to minimise local noise production.

Once the field tapes return to RSES, they are copied to backup tapes and then data segments are extracted for events satisfying a simple magnitude-distance criterion. Events are selected using the preliminary Determination of Epicenters (PDE) published by the US Geological Survey. The extracted waveform data are converted to the SEED format and archived as network-day-volumes so that all the data available for a given event is accessible together.

It is intended that event data from the first stages of the Skippy Project will be released towards the end of 1996, and data for subsequent stages at 6-month intervals thereafter.

3. Record Sections for Whole Earth Propagation

The configuration of the field seismic arrays is illustrated in Fig. 1, which shows the progress of the arrays (SK1, SK2, SK3, BAS, and SK4) and the projected stations in western Australia (SK5). Figure 1 also displays the locations of those permanent seismic stations with high-fidelity recording, which are indicated by a double circle with a station name. The combination of the permanent and portable stations provides a good basis for studies of the Earth's deep interior. One class of study, associated with mantle reverberations, can be undertaken by exploiting the deep events in the Tonga–Kermadec region. Other studies, involving propagation to greater epicentral distances, can make use of the chain of seismicity extending through Japan to the north as well as more distant events in, for example, South America.

The wide range of available events from the Skippy experiment is shown in Fig. 2. Symbols indicate the locations of all events for which data have been extracted from the continuous data

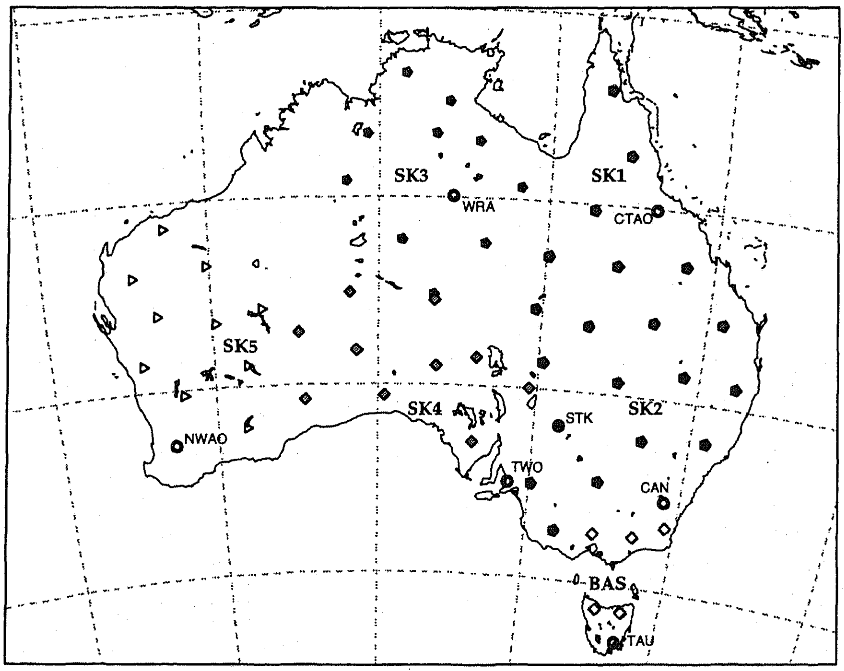

Fig. 1. Configuration of the field arrays in the Skippy Project. SK1: May–Oct. 1993; SK2: Nov. 1994–Mar. 1995; SK3: May–Oct. 1994; BAS: Nov. 1994–Feb. 1995; SK4: Mar.–Aug. 1995; SK5: planned Sept. 1995–Mar. 1996. Permanent stations with high fidelity recording are indicated by a double circle and station name.

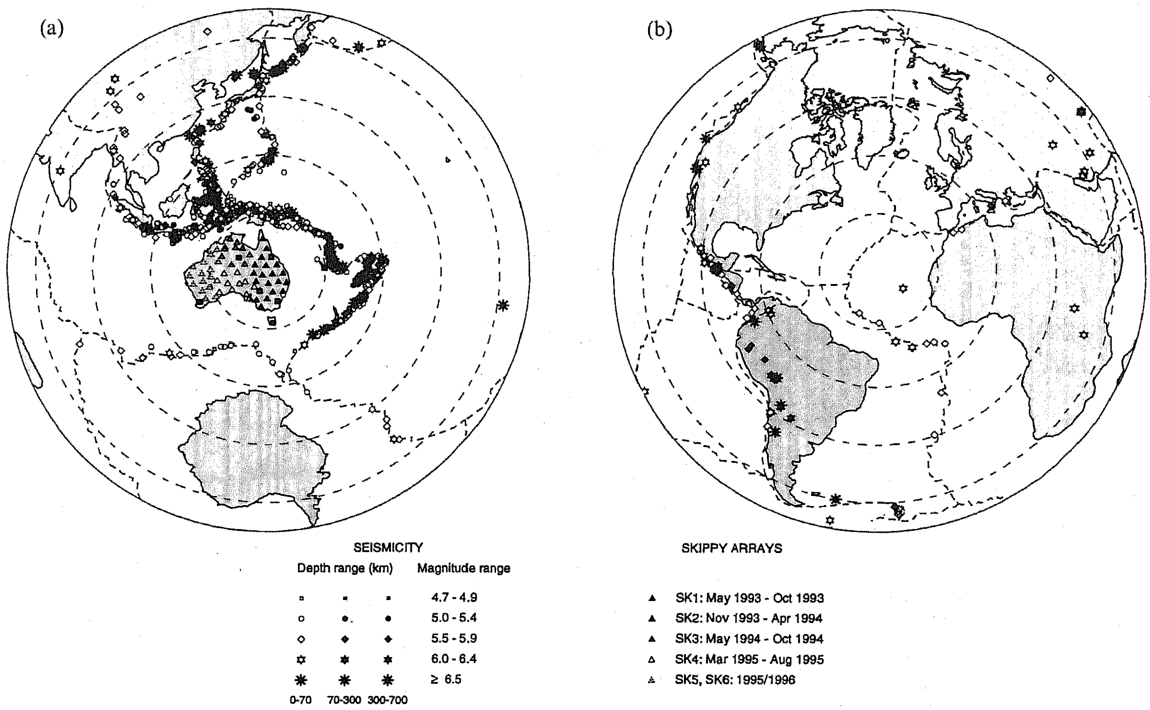

Fig. 2. Events for which data has been extracted from the continuous data for the Skippy experiment: (a) epicentral distances from 0 to 90°, (b) epicentral distances from 90 to 180°.

streams on the field tapes up to June 1995. The events are shown in two hemisphere presentations: out to 90° in a linear polar projection centred on Australia, and from 90 to 180° in a comparable projection about the antipole.

We can build up dense composite record sections from the recordings of this wide range of seismic events covering the distance range from 10 to 178°. With the continuous data available at 25 Hz sampling we can extract the entire seismic wavefield extending from the high-frequency body wave onsets through to the surface waves. Figure 3(a) displays a vertical component section extending out to 90° including the body and suface wavefields; all events have been corrected to surface focus. The expected arrival times for the major phases using the IASP91 model of Kennett and Engdahl (1991) are indicated by dotted lines in Fig. 3(a). The accompanying key diagram (Fig. 3(b)), on the same scale as the record section, shows the theoretical arrival times for a wider range of phases with identification of the different arrivals: phases leaving the source as P are indicated by solid lines and phases leaving as S by grey tone. The broadband recording enables us to see clearer the lower frequency of the S-wave arrivals compared with their P-wave counterparts, the large energy associated with the Rayleigh waves (LR) is even lower in frequency. Figure 4 extends the record section from 85 towards 180° and so covers the major arrivals which have travelled through the centre of the Earth. In Fig. 4(a) we have covered the full span of the major P and S phases but have not attempted to extend the time window to include the full surface wave contribution which lies well behind the SS arrivals. The accompanying key diagram (Fig. 4(b)) is once again on the same scale as the record section, and the same convention for phases is used as in Fig. 3(b). In both Figs. 3 and 4, nearly all the expected phases are clearly seen. However, because we have displayed vertical component sections there is only moderate energy in S phases at large distances on Figs. 3 and 4 (particularly for SKS), but such arrivals are clearly seen on sections for the radial and transverse components. One of the most striking features of Fig. 4 is the strength of the high-frequency PKP

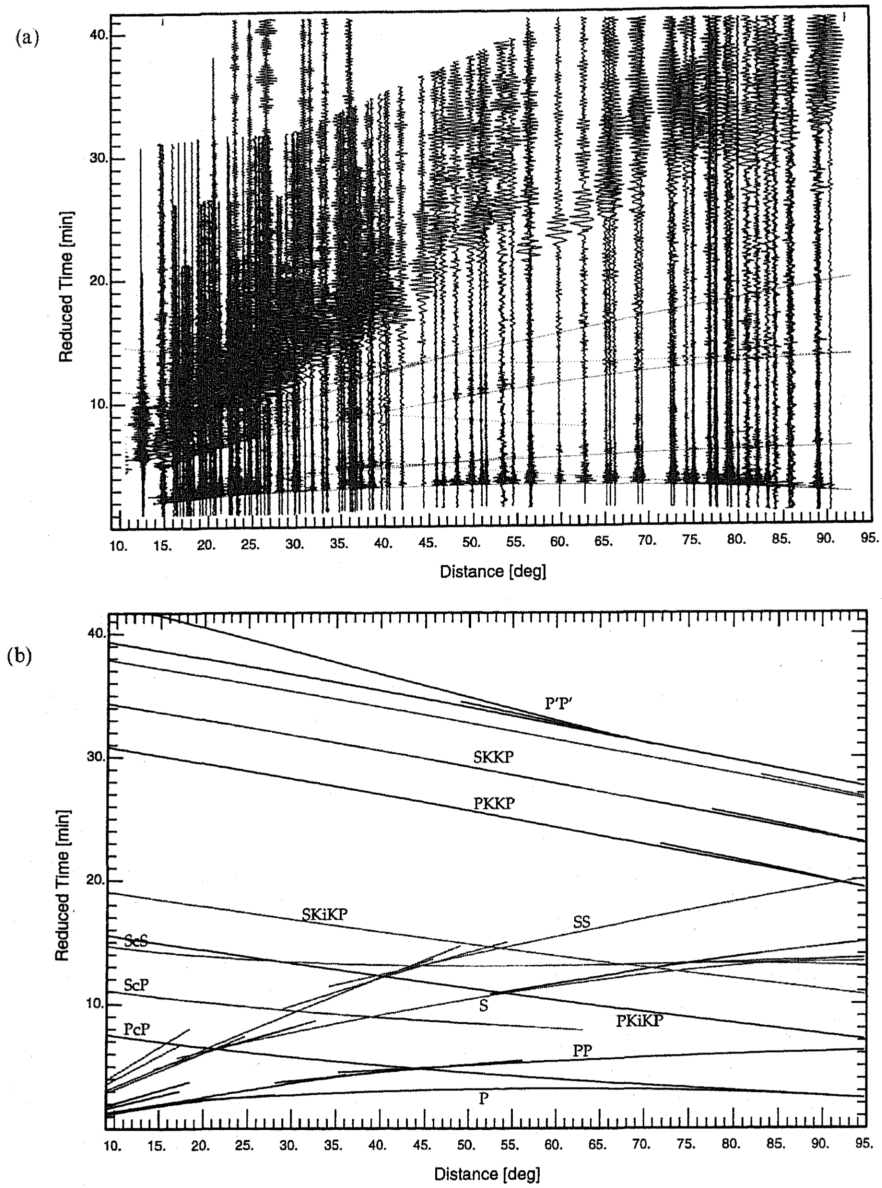

Fig. 3. (a) Composite record section for sources at epicentral distances from 10 to 90°, (b) key diagram of main seismic phases to aid interpretation of record section; phases leaving the source as P are indicated by solid lines and phases leaving as S by grey tone.

arrivals near the caustic at 145°; higher frequency arrivals associated with SKP, PKKP, and SKKP can be seen later in the record section.

Whole-earth record sections such as those displayed in Figs. 3 and 4 provide an overview of a wide range of seismic wave propagation phenomena and can be particularly valuable for the study of S-wave propagation, notably SV-waves which are generally well recorded at our Australian sites. A comparison of radial and tangential component sections enables an assessment of the significance of shear-wave splitting for different classes of wave

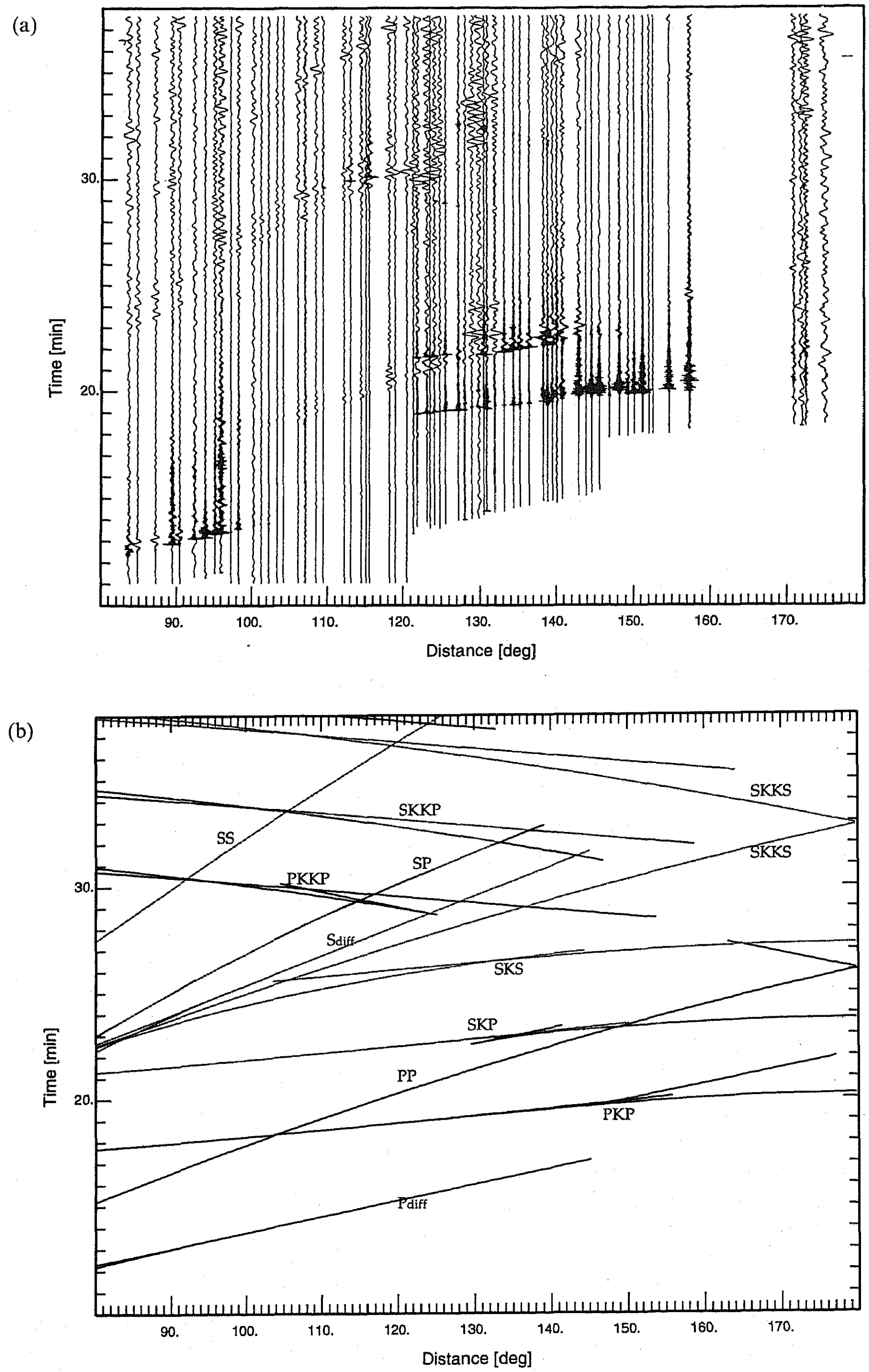

Fig. 4. (a) Composite record section for sources at epicentral distances from 85 to 180°, (b) key diagram of main seismic phases to aid interpretation of record section; phases leaving the source as P are indicated by solid lines and phases leaving as S by grey tone.

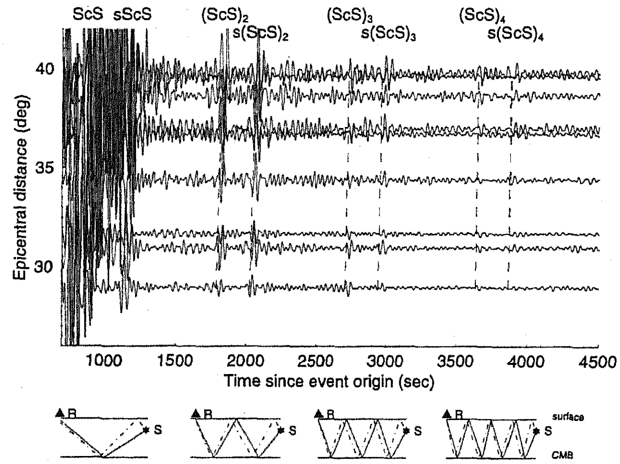

Fig. 5. Multiple-bounce ScS-waves (horizontally polarised) for the m_b 6.6 Tonga event of March 9, 1994 at a depth of 564 km recorded on the SK2 array. The character of each class of arrivals is indicated schematically beneath the record section.

propagation processes, and hence helps to constrain the location of possible anisotropy within the Earth. A major part of the analysis of data from the Skippy Project is directed towards delineating the three-dimensional variations in the lithosphere and upper mantle beneath the Australian region, using body-wave tomography and the partitioned waveform inversion scheme for the portion of the seismogram including the fundamental and higher surface-wave modes (Zielhuis and van der Hilst, 1996). The results of such studies can be used to correct teleseismic data for the influence of regional structures and so provide a "clean" window deep into the Earth.

4. Mantle Reverberation Studies

The distance from the Skippy arrays in Australia to zones of large, deep earthquakes is very effective for studying waves reflected from the core mantle boundary. SH-waves are totally reflected at both the surface and the core-mantle boundary and so bounce up and down through the whole mantle before being detected at a seismograph (Fig. 5). A record section of the multiple bounce ScS-waves for a m_b 6.6 event in Tonga at a depth of 564 km is illustrated in Fig. 5, along with a schematic diagram of the ray paths from source to receiver. Revenaugh and Jordan (1991) demonstrated that the details of the multiple ScS train can be used to provide constraints on structures in the upper mantle and transition zone as well as near the core-mantle boundary. Our ability to track the multiple arrivals across a group of stations provides significantly more information than can be found from a single record. By combining information from a number of sources, we hope to be able to build up the pattern of SH velocity variations in the mantle between the source zones and the various receiver deployments.

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