J. Geophys. 42, 103–110, 1976

Journal of Geophysics

A Lithospheric Seismic Profile in Britain

II. Preliminary Report on the Recording of a Local Earthquake * **

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Abstract. During recording for the 1974 Lithospheric Seismic Profile in Britain (LISPB), a local earthquake (magnitude 3.0) was recorded by 60 mobile stations forming a temporary linear array of about 400 km in length. Observation distances ranged from 80 to 300 km and the data is presented in this paper in the form of reduced travel-time record sections for *P* and *S* waves (vertical components).

Clear phase correlations are visible in the *P*-sections and the general pattern is similar to that observed on LISPB explosion data. Preliminary velocity-depth functions computed for both explosion and earthquake data are presented; as a result of these computations an improved focal depth for the earthquake is established.

The results demonstrate the strong relationship between high-quality earthquake data and high-quality explosion data when both are available in the same area. With a few explosions as control, earthquakes recorded on a closely spaced mobile array could be used to study the fine structure of the lithosphere. At the same time the extensive data then available permits a detailed study of the earthquake itself.

Key words: LISPB – Local earthquake – Velocity-depth functions – Improved focal depth.

1. Introduction

In recent years, explosion seismology – having the advantage of a controlled source – has almost completely replaced the study of near-earthquakes as a method for measuring the velocity-depth structure within the lithosphere. Modern

* Contribution no. 183 within a joint research program of the Geophysical Institutes in Germany sponsored by the Deutsche Forschungsgemeinschaft (German Research Society). Contribution no. 122, Geophysical Institute, University of Karlsruhe

** For part I, see Bamford *et al.*, 1976 explosion seismological data is usually of a very high quality with several explosions fired into closely spaced arrays of mobile recording stations.

Earthquakes, however, do offer the possibility of utilizing inexpensive sources of varying frequencies at a range of depths within the structure of interest, thereby broadening our knowledge of lithospheric structure. Unfortunately because earthquakes are at present essentially unpredictable, there is no area where explosion and earthquake data of comparable high quality have been used for lithospheric studies.

In this note, we describe a very fortunate accident that occurred during a major explosion-seismic experiment in the British Isles when a local earthquake was recorded on a temporary linear array of over sixty magnetic-tape recording stations.

2. Earthquake Studies in the British Isles

Britain is not a seismically active area and destructive earthquakes are very few and far between (for a historical account see Davison (1924)). Though there was an earthquake in the North Sea in 1931 which probably had a magnitude of about $5^1/_2$ there is little evidence that there have been any earthquakes of magnitude greater than 5 within the land area of Britain (Lilwall, private communication). Because of this there have been few continuously recording stations and most of the ones running at present have been established since 1960 and are concentrated in the North of England and the South of Scotland (e.g. Rookhope, Eskdalemuir (EKA and ESK), Lownet).

Instrumental studies of such earthquakes as have occurred have generally had to make the most of fairly sparse data and a few recent examples include those by Key *et al.*, 1964; Agger and Key, 1965; Cleary, 1967; Browning and Jacob, 1970; Crampin *et al.*, 1972; and Lilwall and Riddle, 1973. The situation has not been improved by the rather approximate knowledge of crustal structure in Britain. Probably the largest recent earthquake was the North of England earthquake in 1970 while the best located were those in the swarm in Glenalmond between 1970 and 1972. Early in 1974 there were earthquakes in both North and South Wales, and while these were not very well located because of the distribution of the national network, they have been the subject of a very extensive macroseismic survey (Browitt and Lilwall, private communication) and may provide the most satisfactory overall investigation of any British earthquakes up to that time.

3. LISPB 1974 and the Kintail Earthquake

During July and August 1974, a combined British-German group carried out a large explosion experiment (LISPB) to study the lithospheric structure of the British Isles. Details of this experiment are given elsewhere (Bamford *et al.*, 1975) but, in summary, sixty mobile stations (recording 3-components of ground-motion on analogue magnetic tape) were deployed at different times on various

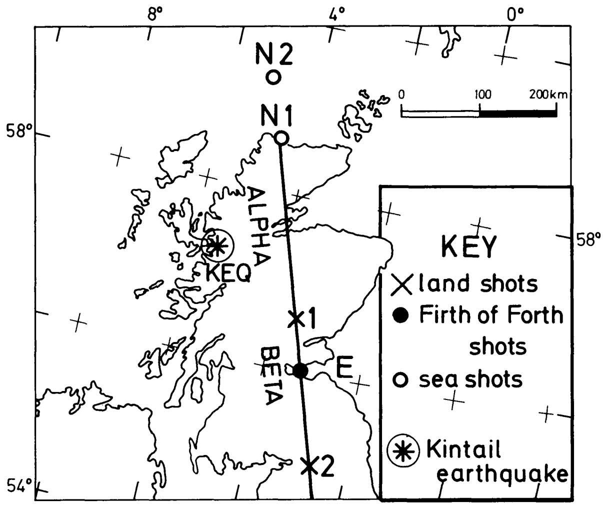

Fig. 1. KEQ location map. The recording stations were set up along lines ALPHA and BETA between shotpoints N1 and 2

Table 1. Data for the Kintail earthquake (KEQ)

Position	57.23°N 05.35°W
Date	6th August 1974
Origin Time	18 h 17 m 36.9 s GMT
Magnitude	$M_b^* = 3.0$ (For a discussion of M_b^*, see Jacob, Willmore, 1972)
Depth	14 km

segments such as ALPHA and BETA shown in Fig. 1. On 6th August 1974, these stations, supplemented by a temporary four-station array in the Grampian Highlands (southern half of segment ALPHA), were positioned at approximately 6–7 km intervals along segments ALPHA and BETA and thus formed a temporary array 400 km long. At about 1820 GMT the stations recorded the seismic waves from an earthquake in the Kintail area of Scotland (Fig. 1). Details of this earthquake (henceforth referred to as KEQ) are given in Table 1; it was one of a swarm of more than 20 events that occurred in the Kintail area during August and September 1974. The study of this group of earthquakes will be reported elsewhere (Crampin, personal communication).

4. KEQ Record Sections

The first-arrival data obtained on the LISPB line greatly facilitated the precise location of KEQ and the general study of the group of earthquakes. Fortunately, the gains of our temporary stations had been set for a large shot fired at position N2 (Fig. 1); thus gains increased southwards along ALPHA and BETA

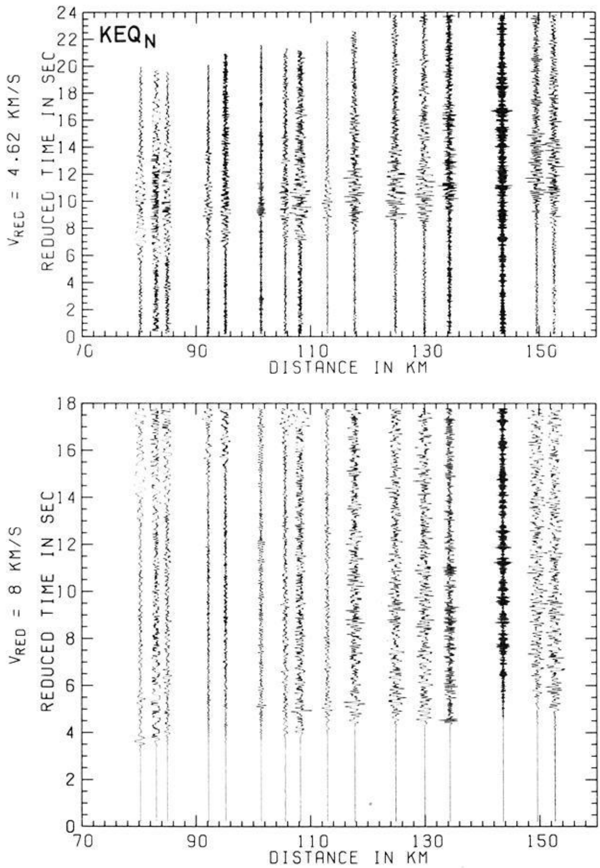

Fig. 2. Record sections of the vertical-component seismograms of the stations north of the point of minimum recording distance (KEQ_N). The upper section shows *S* waves (reduction velocity 4.62 km/s), the lower one *P* waves (reduction velocity 8.0 km/s)

and hence were ideal for recording KEQ out to about 300 km distance. Furthermore, this shock was an intermediate one in the series – the largest one would have completely overloaded our recorders. Therefore, we are able to present the digitized LISPB recordings of KEQ in the conventional form for the study of crust and upper mantle structure, that is as record sections with reduced travel-time plotted against distance. In Figs. 2 and 3, we show record sections compiled from the vertical components of ground motion at our stations. The minimum recording distance (80 km) was for stations at about the middle of segment ALPHA; observations north of this point are presented in Fig. 2 (KEQ_N), observations on the rest of ALPHA and on BETA in Fig. 3 (KEQ_S). In both figures, the upper record section shows the *S* waves and the lower one the *P* waves. In an effort to compare the two types of observation, scales have been adjusted in accordance with the nominal *P*/*S* velocity ratio of $\sqrt{3}$; thus the reduction velocity for *P* waves was 8 km/s and that for *S* waves 4.62 km/s

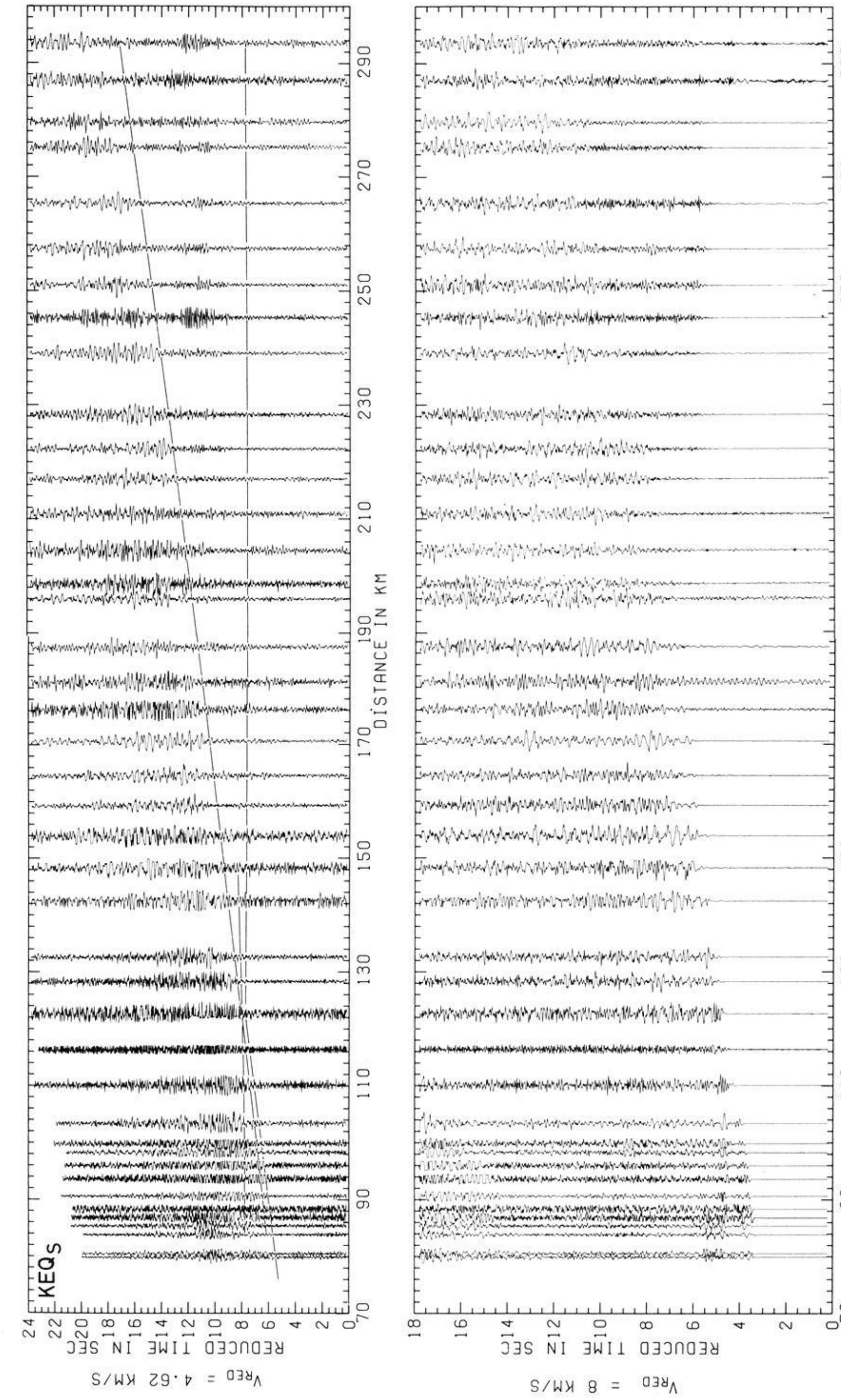

Fig. 3. Record sections of the vertical-component seismograms of the stations south of the point of minimum recording distance (KEQ_S). The upper section shows *S* waves (reduction velocity 4.62 km/s), the lower one *P* waves (reduction velocity 8.0 km/s). *S* travel-time curves drawn as broken lines in the upper section correspond to those for the model in Fig. 4b

whilst the time-scale for *S* waves was 1.15 cm per second in comparison with 2 cm per second for *P*.

It is possible to make several phase correlations within these sections. Within the *P* sections, a direct wave (velocity approximately 6.4 km/s) is a clear first-arrival between 80 and 110 km; beyond 110 km a weak P_n phase (apparent velocity about 8 km/s) is observed as a first-arrival out to 170 km. Especially on KEQ_S (Fig. 3), well developed second-arrivals are seen; a strong P_MP branch is observed at about 4.5 seconds reduced time between 80 and 110 km distance and another strong reflection is observed assymptotic to 6.4 km/s. Several phases can be observed on the *S* sections with the strongest travelling with a velocity of 3.7 km/s between 90 and 250 km distance.

Elsewhere (Bamford *et al.*, 1976), we have presented the explosion profiles obtained in this area, details of phase correlations and preliminary velocity-depth functions. The correlations on KEQ_S (Fig. 3) are rather similar to those on the explosion profiles and in particular the general pattern is quite similar

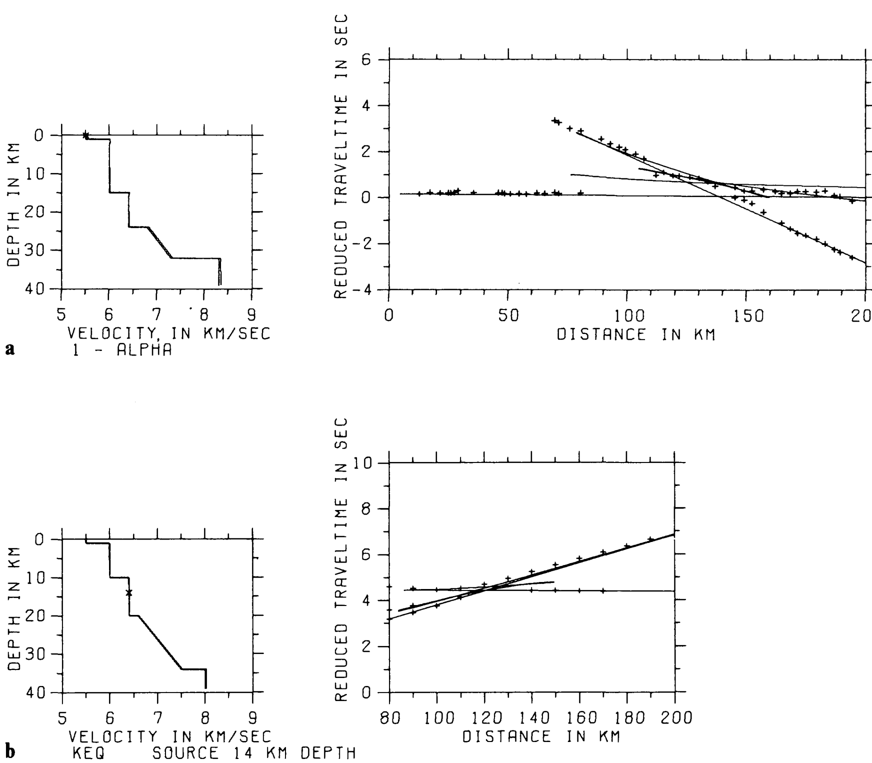

Fig. 4. (a) Velocity-depth function and travel-time diagram of the profile 1-ALPHA (from Bamford *et al.*, 1976). The travel-times are reduced with 6 km/s. In the travel-time diagram, the crosses indicate observed arrivals, the lines are the theoretical travel-time curves based on the model shown on the left side. (b) Velocity-depth function and travel-time diagram of the profile KEQ_S. The travel-times are reduced with 8 km/s. In the travel-time diagram, the crosses indicate observed arrivals, the lines are the theoretical travel-time curves based on the model shown on the left side. In the velocity-depth function, the cross indicates the position of the focus

to that observed on segment ALPHA from shotpoint 1. On geological grounds and on the basis of other seismic data in the area it is reasonable to expect that observations on KEQ_S and 1-ALPHA sample the same or at least rather similar crustal structure. The velocity-depth function presented for 1-ALPHA by Bamford *et al.* (1976) is shown in Fig. 4a. This model is somewhat more complicated than the simple one (with a two-layer crust) that was used for the initial earthquake location (provided by S. Crampin) and which implied a focal depth of less than 10 km. However, a similar velocity-depth function with modifications to the depths and characteristics of some layers, fits the observed KEQ_S travel-times quite well (Fig. 4b), although we must emphasize that this structure is not necessarily unique. In this model, the 6.4 km/s layer remains about 10 km thick, but the gradient zone beneath it is thickened so as to explain the relative separation of P_n and the phase reflected from the bottom of the 6.4 km/s layer. The small separation between this reflection and the P wave refracted at 6.4 km/s indicates that the source should be close to the middle of a 10 km thick layer. Arrivals through the top two layers are not observed and the depth to the 6.0/6.4 interface is controlled simply by requiring P_n arrivals to occur at the correct reduced time (about 6 seconds on the section reduced to 8 km/s). The total effect is to locate the earthquake at a depth of 14 km.

At this stage, no detailed interpretation of S phases has been attempted. However, the relationship between the P-velocity model shown in Fig. 4b and the corresponding S-velocity model can be tested simply by plotting the theoretical travel-times in Fig. 4b on the same scale as the observed P-sections and then overlaying them on the observed S-sections (already plotted according to the $\sqrt{3}$ relationship). These predicted S-travel-time curves are plotted in the upper part of Fig. 3, the observed KEQ_S S-section. They appear to agree quite well with observed phases, and this suggests that the nominal $\sqrt{3}$ ratio is in fact close to the real value.

5. Discussion

By a fortunate accident we have obtained near-earthquake and explosion data of high quality in the same area and thereby have a unique opportunity to broaden our knowledge of lithospheric structure. Clearly a detailed interpretation of the KEQ data should be carried out in conjunction with, and will add significantly to, the evaluation of our explosion data. In this paper we have presented some preliminary results of such a joint interpretation.

Our intention in presenting the KEQ data here is to show the strong relationship between high-quality earthquake data and high-quality explosion data when both are available in the same area. The two sorts of data contain slightly different but compatible information on crust-mantle structure; joint interpretation yields both an improved model of this structure and a much more reliable estimate of the source parameters of the earthquake. Thus, even at a preliminary stage of interpretation, an improved estimate of the focal depth of KEQ has been obtained.

Our conclusions are, we believe, important on both scientific and economic grounds for, as we seek a greater understanding of lithospheric structure and as our ability to locate earthquakes improves, the possibility of using an inexpensive natural source in seismically active areas will become increasingly attractive. With a few explosions as control, earthquakes recorded on a closely spaced mobile array could be used to study the fine structure of the lithosphere.

Furthermore, we note that because of the LISPB data there will be a larger body of instrumental data than for any previous British earthquake allowing a very detailed investigation. Investigation of the other earthquakes in the same series should benefit from the good solution for this one.

Acknowledgements. We are grateful to Stuart Crampin and Graham Neilson, IGS Seismology Unit, Edinburgh, for providing a preliminary location for KEQ.

The LISPB field experiments were supported by the National Environmental Research Council (NERC) and the German Research Society (Deutsche Forschungsgemeinschaft). We are grateful to Max Wyss for his comments on a first draft of this paper. Ingrid Hörnchen typed the manuscript.

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Received September 15, 1975