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Note

Crustal reflections from the Alpine Fault Zone, South Island, New Zealand

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Abstract Initial results from a seismic experiment in the central South Island, New Zealand, have imaged a 40 ± 5° southeast-dipping zone at a depth of c. 22 km beneath the Mt Cook village. It is speculated that this reflector represents the down-dip extension of the Alpine Fault Zone.

Keywords seismic reflection; reverse moveout; dipping reflector; Alpine Fault Zone

INTRODUCTION

During March 1995, a seismic reflection experiment was carried out along the eastern shore of Lake Pukaki (Fig. 1) as the preliminary stage of a multi-year joint United States–New Zealand programme to investigate the Alpine Fault of the South Island of New Zealand. Advantage was taken of a straight and isolated road along the east shore of the lake to carry out a simple seismic experiment, where a 6 km long, 120-channel spread was laid out along the road, and shots of 25 kg were detonated at a water depth of 20 m in the lake. Shots were to the south of the 120-channel spread and offset by up to 4 km from the spread. At the northern end of the lake, the seismic line is c. 45 km from the Alpine Fault and at an azimuth of c. 60° to the strike of the fault.

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The major result from the survey is the presence of a lower crustal reflection between 9 and 10 s two-way travel time (twtt) with "reverse moveout" across the shot gathers. The reflection is the subject of this note. A simple interpretation can be made in terms of a uniform half-space over a dipping layer.

Figure 2 shows two shot gathers from the northern end of the line (Fig. 1). An obvious increase in signal amplitudes occurs at the location of peg 1220, and this is considered to relate to a substantial reduction in thickness of the glacial deposits overlying basement at this point (Melhuish et al.

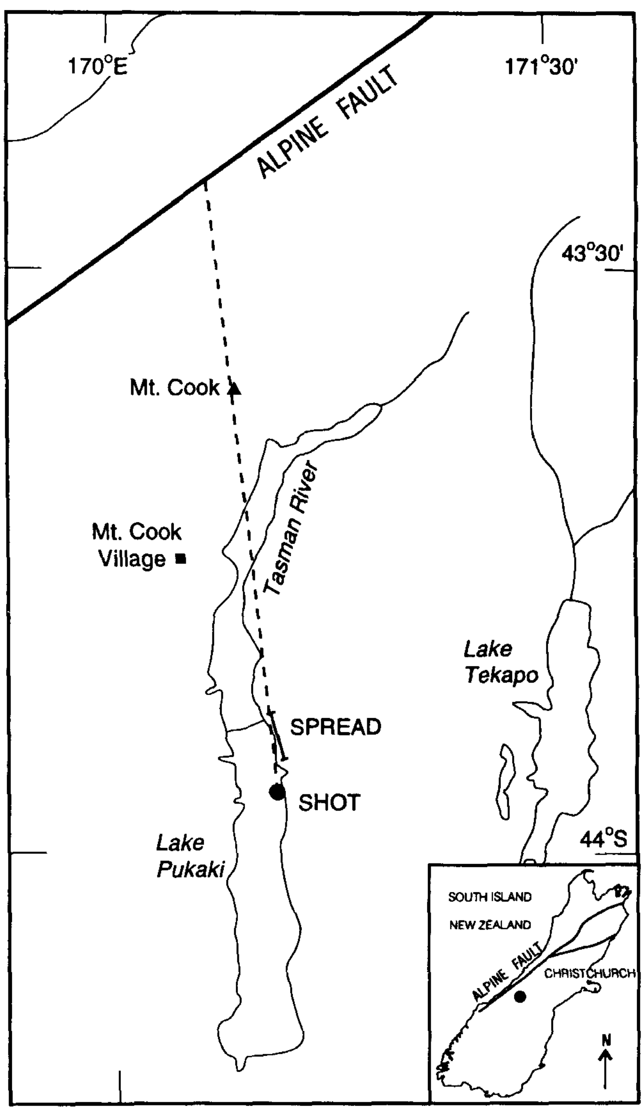

Fig. 1 Location map showing the shot and seismic spread in relation to the Alpine Fault.

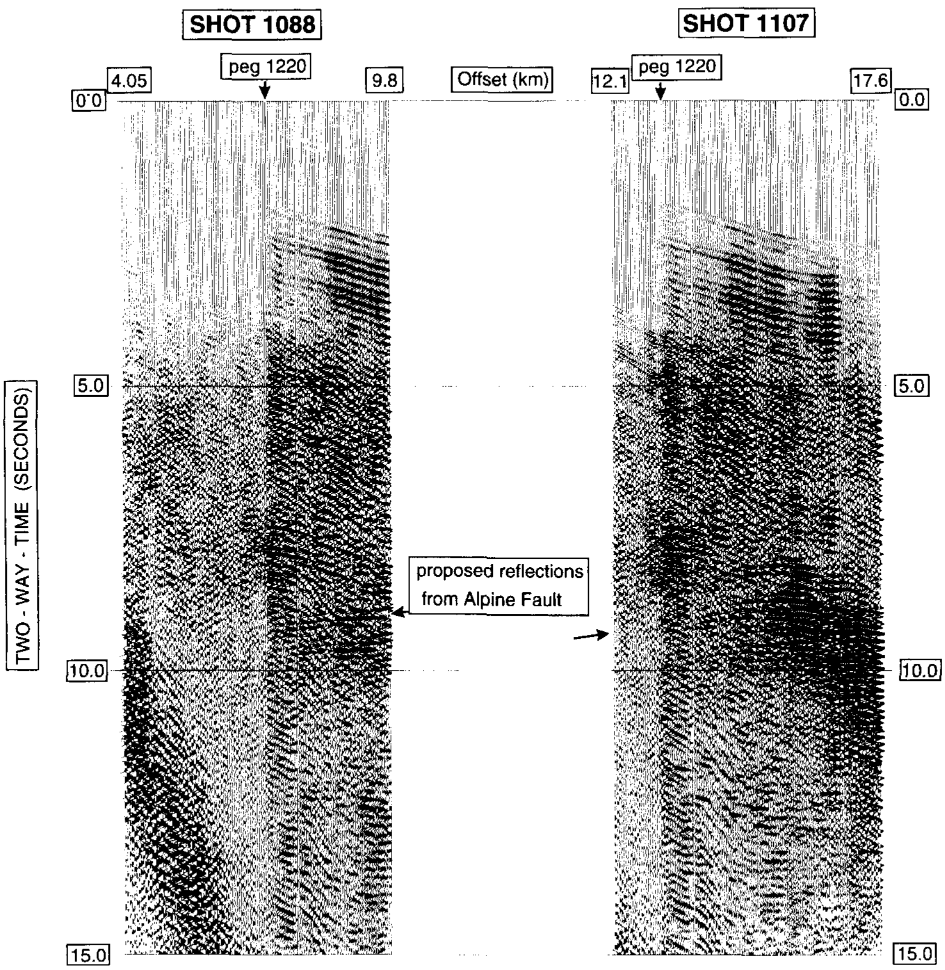

Fig. 2 Two shot gathers from near the end of Lake Pukaki. Increased signal amplitudes north of peg 1220 are attributed to thin glacial deposits overlying basement. Reflected energy with reverse moveout between 9 and 10 s twtt is arrowed. The deeper seismic reflections between 12 and 16 s twtt would correspond to depths of c. 36–50 km.

1995). Deep crustal reflections can be seen within the portion of the shot gathers to the north of peg 1220. In particular, there is a strong reflection between 9 and 10 s twtt, which has reverse moveout, and a deeper suite of subhorizontal reflectors starting at 12 s and extending to at least 15 s twtt.

RESULTS

In this note we restrict discussion to the dominant event with reverse moveout between 9 and 10 s twtt (Fig. 2). Reverse moveout is a term describing the arrival of a particular reflection earlier at the farthest geophone of a seismic spread than at the closest. A straightforward explanation for the event recorded at Lake Pukaki is that it is energy returned from a lower crustal layer that has an apparent dip to the south.

The arrival time for a reflection from a planar reflector with dip ϕ is described by a hyperbolic equation given by (Dobrin & Savit 1988, p. 222):

$$T^2 = 4H^2/Vrms^2 + X^2/Vrms^2 + 4(H/Vrms)\,X \sin\phi \quad (1)$$

where T = travel time, H is the perpendicular distance from the reflector to the shot point, and *V*rms is the"root mean square" velocity between the reflector and the ground surface. X, the offset, is either positive or negative for shooting down-dip and up-dip, respectively.

Figure 3 shows equation (1) plotted for values of X (offset) between 4 and 10 km and for *V*rms = 6200 m/s. This is a reasonable value for *V*rms of the crust based on the results of a 1983 seismic refraction survey (Smith et al. 1995, this issue). From Fig. 3 it can be seen that the magnitude of reverse moveout across a spread is a reasonably sensitive measure of dip of the reflector for a long offset of 4–10 km. For 20, 30, and 40° dips, the moveout is 216, 366, and 510 ms, respectively. We can measure the reverse moveout on a number of adjacent shot gathers to be 380 ± 20 ms. Thus, our best estimate of the reflector dip is 34 ± 5°.

If the reflection is from the downward projection of the Alpine Fault, then the dip estimate is only an apparent dip given that the azimuth of the seismic spread was c. 60° to the Alpine Fault (Fig. 1). If the seismic line is not in the direction of dip, the angle δ is the apparent dip, which is related to the true dip ϕ by (Dobrin & Savit 1988):

$$\sin(\delta) = \cos(\theta)\sin(\phi) \quad (2)$$

where θ is the angle between the shooting line and the direction in which the reflector dips.

Thus, for $\delta = 34°$, $\theta = 30°$, the true dip (ϕ) of the reflector is c. 40°. For an out of plane reflector, the apparent normal moveout velocity will be higher than the true velocity. For example, Levin (1971) shows in the simple case of one layer of velocity V overlying a reflector:

$$V_{nmo}/V = (1 - \sin^2(\phi)\cos^2(\theta))^{-0.5} \quad (3)$$

For $\phi = 40°$, the ratio V_{nmo}/V will change by c. 10% when θ is changed from 30° to 0°. This change in apparent velocity does not grossly affect the simple analysis produced here.

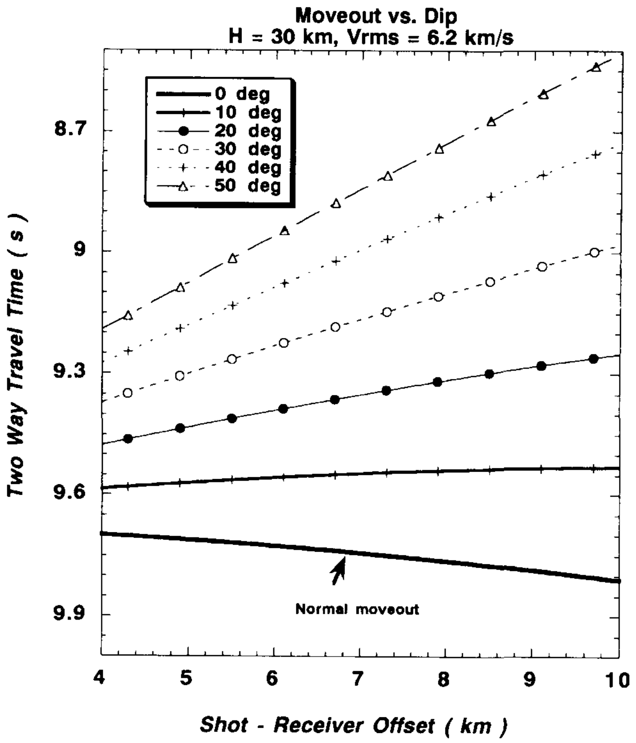

Fig. 3 Theoretical plot of moveout versus dip for equation (1) given in the text and plotted for values of *Vrms*, dip, and *H* (perpendicular distance from shot point to reflector) relevant to this study. "Normal" moveout is for a flat reflector. At these large receiver offsets (4–10 km), moveout is a sensitive measure of dip.

DISCUSSION

Our interpretation is summarised in Fig. 4. The part of the reflector giving rise to the observed reflections is at a perpendicular depth of c. 30 km from the shot to the reflector, or c. 22 km directly below Mt Cook Village (Fig. 4). When projected upward, the dipping reflector intersects the surface within a few kilometres of the surface trace of the Alpine Fault. Therefore, a straightforward interpretation of the lower crustal reflector is that it effectively represents the down-dip planar projection of the Alpine Fault.

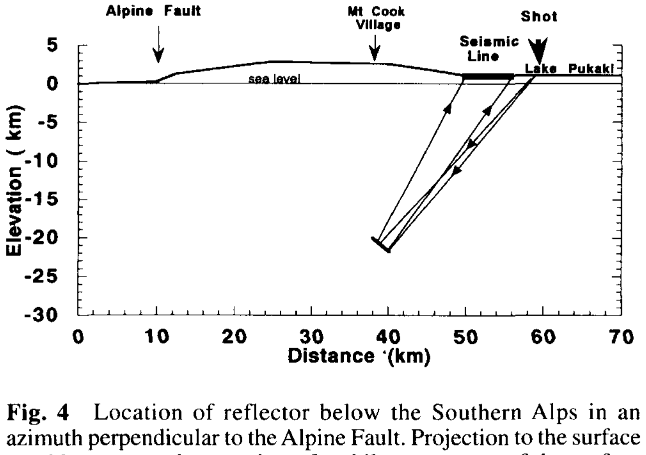

Fig. 4 Location of reflector below the Southern Alps in an azimuth perpendicular to the Alpine Fault. Projection to the surface would correspond to a point a few kilometres east of the surface exposure of the fault.

It is not clear if the proposed Alpine Fault reflector is the result of either an acoustic impedence contrast between two different rock types each side of the fault, or to a physical property change within a fault zone that may be several kilometres thick. The latter interpretation is preferred and is in broad agreement with previous studies that have speculated on mineralogical, structural, and geodynamic grounds that a ductile decollement within the garnet-oligoclase grade schist must exist to lower crustal depths (e.g., Sibson et al. 1979; Norris et al. 1990; Grapes & Watanabe 1992). In particular, the high strength of the event (Fig. 2) suggests that fluids in the decollement zone could be contributing to a high acoustic impedance.

Confirmation of our assertion that this deep reflector represents the expression of the Alpine Fault Zone at depth must await further processing of the Lake Pukaki data, three-dimensional modelling, and acquisition of more detailed seismic data from and adjacent to the Alpine Fault.

CONCLUSIONS

A deep crustal seismic experiment at Lake Pukaki has imaged reflections from a depth of c. 25 km which are interpreted to arise from the Alpine Fault. The reverse moveout reflections from 9 to 10 s twtt have originated at a reflecting surface which dips at $40 \pm 5°$ to the southeast and lies at a depth of 22 km beneath Mt Cook Village.

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