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First seismic imaging results of tectonically complex structures at shallow depths beneath the northwest Canterbury Plains, New Zealand

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ABSTRACT

Seismogenic structures underlie many regions of the vast Canterbury Plains on the South Island of New Zealand. Most of these structures are hidden beneath a layer of rapidly deposited Late Pleistocene sediments, the youth and thickness of which make the general application of conventional paleoseismological studies impractical. In an attempt to improve our understanding of potentially active structures in this region, we have acquired, processed and interpreted shallow seismic reflection data across the northwest Canterbury Plains. To separate the useful reflected signals from unusually high amplitude ambient and source-generated noise, we subjected the data to a specially tailored processing scheme that included time- and space-variant spectral balancing, custom static corrections and mutes, F-X deconvolution, DMO corrections and finite-difference migration. The final stacked and migrated seismic sections supply high-resolution images of the basement and overlying layered Cretaceous- to Quaternary-age supracrustal rocks that have been complexly faulted and folded. At one location, the uppermost Late Pleistocene layers appear to have been gently buckled.

1. Introduction

Seismic hazard and risk analyses require the reliable identification and characterisation of geological structures that are likely to generate earthquakes. Potentially active structures within the Canterbury Plains on the South Island of New Zealand are mostly buried beneath a variably thick veneer of gently inclined Quaternary sediments. Nevertheless, low levels of seismicity and some minor topographic undulations are evidence for recent tectonic activity beneath the Plains (Pettinga et al., 2001; Sissons et al., 2001) and Late Cenozoic faulting and folding can be inferred from rare outcrops within the Plains and from rock exposures in high standing hills and mountains to the west and north (Fig. 1; Jongens et al., 1999; Forsyth et al., 2008). Unfortunately, recurrence intervals of moderate to large earthquakes beneath much of the Plains are unknown because of the short history of European settlement in New Zealand; a comprehensive earthquake database over a necessarily long period is simply not available. Furthermore, because of the very recent nature of the top few metres to ten's of metres of unconsolidated sediments, paleoseismological techniques based on shallow trenches (McCalpin, 1996; Yeats et al., 1996) and/or 3-D ground-penetrating radar (GPR; Gross et al., 2004; McClymont et al., 2008a,b) are unlikely to be useful in many regions of the Plains. For this reason, we have recorded high-resolution seismic reflection data across an area of the northwest Canterbury Plains that is likely to be underlain by potentially active faults and folds (Fig. 1). We began this project fully aware that seismic surveying of active blind faults and folds can be a daunting task (Pratt et al., 2002).

Except for limited seismic reflection surveying by Finnemore (2004; see Fig. 1), previous structural analyses in the general vicinity of our investigation site have been restricted to geological mapping of the rare outcrops and geomorphological studies (McLennan, 1981; Cowan, 1992; Evans, 2000; Estrada, 2003; May, 2004). Hydrocarbon exploration seismic lines recorded southeast of the Malvern Hills and approximately 20 km to the east of our site led to the 1998 discoveries

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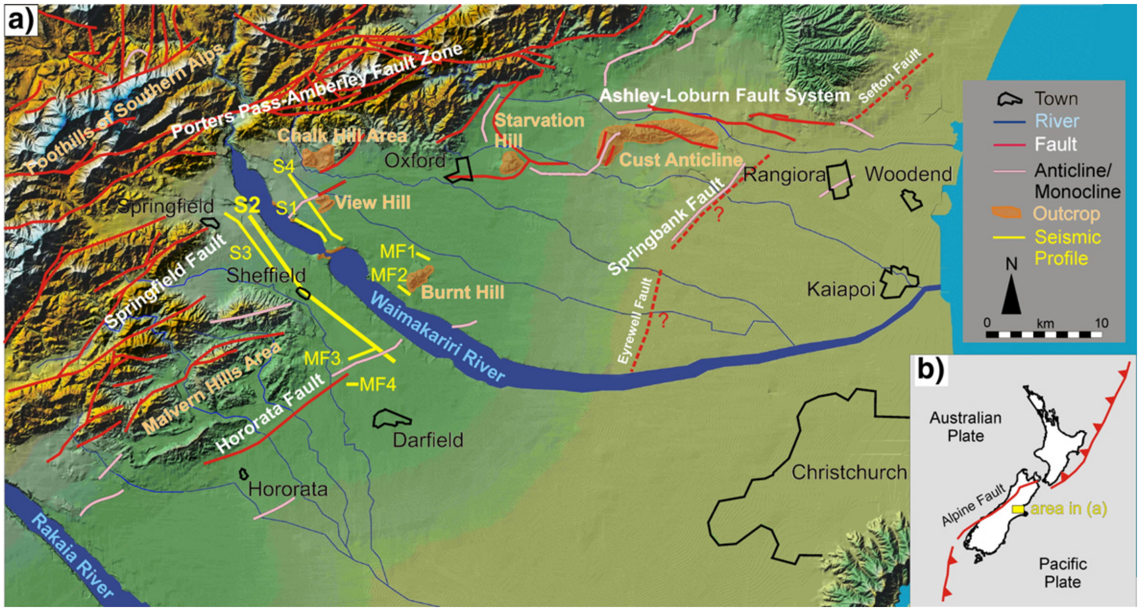

Fig. 1. (a) Selected features on the Canterbury Plains and adjacent mountains (modified from May, 2004). Topographic data from New Zealand Digital Elevation Model (based on Terralink data of NZMS Topographic series 1:50,000). Town and river outlines from Terralink. Fault outlines adapted from North Canterbury Active Tectonics GIS and Geology map of Christchurch Area (Forsyth et al., 2008). S1–S4 Seismic lines recorded by the ETH–New Zealand crew; MF1–MF2 seismic lines recorded by Finnemore (2004). The focus of this study is line S2. (b) NZ plate boundary setting and location of (a).

of the hidden Hororata and Springbank faults (Fig. 1; Jongens et al., 1999; Campbell et al., 2000). The Springbank thrust/reverse fault was further studied by Estrada (2003) using the hydrocarbon exploration and additional seismic reflection data, geomorphological mapping and morphometric analyses.

The generally low signal-to-noise ratios of our raw seismic data together with the variably thick Quaternary sedimentary layer and complex underlying geology resulted in numerous processing-related problems. Resolving these problems was key to deriving meaningful seismic reflection images of the shallow subsurface from ~10 m to ~1000 m depth. In this contribution, we concentrate on the processing challenges and preliminary interpretation of our longest (17.8 km) seismic line S2, which runs through the small town of Sheffield (Fig. 1).

After briefly reviewing the geological setting of our investigation site, we outline the acquisition of the 2D seismic reflection data set and summarise the difficulties associated with separating the reflections from the ambient and source-generated noise and with producing reliable images of structures throughout the target depth range. The critical processing steps that enable us to solve these problems are then described. Finally, we conclude with a provisional interpretation of the complex structures revealed by the surprisingly vivid seismic images.

2. General setting of the northwest Canterbury Plains investigation site

Our investigation site was located on the upper part of the Waimakariri River fan along the northwest margin of the Canterbury Plains, 35–50 km west-northwest of Christchurch (Figs. 1 and 2). Seismic reflection data were acquired along three roads (S2–S4) and across a river terrace (S1). All seismic lines were oriented roughly perpendicular to the expected general strike of structures.

Active tectonism on the South Island of New Zealand is dominated by the Alpine Fault, a major dextral transpressive zone that juxtaposes the Pacific and Australian plates (Fig. 1b). The Alpine Fault accommodates about 70% of the 30–40 mm/yr oblique plate convergence (Beavan and Haines, 2001; Sutherland and Berryman, 2006; Norris and Cooper, 2007), with the remaining plate motion being taken up by smaller networks of active faults that may extend to middle and lower crustal depths (Pettinga et al., 2001). One such network is the Porters Pass-Amberley Fault Zone in the hills adjacent to the northwest margin of the Canterbury Plains (Fig. 1; Cowan, 1992; Cowan et al., 1996). Given the close proximity to this fault zone, there is strong potential for hidden active faults and/or folds at our investigation site.

Based on adjacent rock exposures, basement underneath the northwest Canterbury Plains is inferred to be deformed Permian- to Triassic-age hard greywacke and argillite (Torlesse composite terrane) unconformably overlain by a blanket of Late Cretaceous to Tertiary sedimentary (sandstone, limestone, conglomerate) and volcanic rocks

Fig. 2. Photograph from the southeastern end of seismic line S2 looking to the northwest. Note the very even landscape with little surface evidence of subsurface geological complexity.