Crustal fluids in tectonic evolution and mineral systems: evidence from the Yilgarn Craton

B.J. Drummond¹, B.E. Hobbs², R.W. Hobbs³ and B.R. Goleby¹

¹ pmd*CRC, Geoscience Australia, GPO Box 378, Canberra ACT 2601
² pmd*CRC, CSIRO Exploration and Mining, PO Box 1130 Bentley, WA 6102
³ Department of Earth Sciences, University of Durham, UK
Barry.Drummond@ga.gov.au

Introduction

In seismic reflection sections, some crust-penetrating shear zones appear as bright reflections whereas others do not. Those that are reflective often have a close spatial relationship to areas of altered rock, and in some cases to mineral deposits. Examples in areas of interest to the pmd*CRC include the Adelheid Fault and Marimo Structure in the Western and Eastern Successions of the Mount Isa Inlier, respectively, the Bardoc and Boorara Shear Zones in the Eastern Goldfields Province of the Yilgarn Craton in WA; and a number of shear zones in the Broken Hill area. Furthermore, the Western Fold Belt Mt Isa and the Eastern Goldfields Province contain sub-horizontal detachments, or shear zones, in the (present-day) upper crust that are seismically reflective.

In a number of cases, the reflections must come from the intrinsic reflectivity of the shear zones, rather than contrasts between the rocks either side of the shear zones. The causes of intrinsic shear zone reflectivity have been the subject of debate within the literature. Physical models based on laboratory measurements of rock properties suggest two causes – seismic anisotropy caused by crystal alignment and chemical alteration within the fault and wall rocks of the shear zone. Both of these effects would indicate fluid movement within the shear zone, but the relative effects are unclear, and neither effect can easily explain the high amplitudes of the reflections that are often observed.

Modelling Shear Zone Reflectivity – The Yilgarn Craton Detachment

Synthetic seismogram modeling of shear zone reflectivity showed the effects that 3D morphology on the surfaces of shear zones has when the shear zones are imaged in 2D seismic sections. The synthetic seismogram studies used the detachment surface in the Eastern Goldfields Province as an example. The research indicated a number of empirical tests that can be used to distinguish between a fault (modelled as single thin layer within a rock of uniform physical properties) and a shear zone (multiple anastamosing layers of different thicknesses embedded within a uniform rock) (Drummond et al., 2004b) (Figure 1). The modelling also indicated that the amplitudes of the signals would be much higher because of the effects of tuning between layers, and because of seismic energy being reflected into the plane of the seismic section from structure outside the plane of the section¹. The results of the modelling allow the sub-horizontal detachment imaged in the Eastern Goldfields Province to be characterised into regions of thick shear zones 10-20km across (in the plane of the seismic sections) consisting of multiple layers, linked by faults, also with an extent of 10-20km.

¹ Present research is being directed to develop methods for determining the minimum amount of alteration needed to explain the strength of the reflections, so this can be linked to other physical properties such as magnetic susceptibility and density to determine how much alteration is needed for faults and shear zones to be interpreted in regional potential field data.
The Detachment and Fluids

Drummond et al. (2000) drew parallels between the reflection character of the regional detachment and the bright reflectors imaged at 15-18km depth in Tibet. The Tibetan reflectors have been interpreted as fluids (brines or magmas). Drummond et al. (2004a) suggested that overpressured fluids focusing at that depth in an orogenic setting would provide weak zones which would be a locus for detachment formation. Zones of fluid focusing in the Archaean would be characterized today by shear zones in which rocks with altered anisotropic fabric wrap around lenses of protocrust. These zones would be linked laterally by faults characterized by single or only a few layers which broke through regions of little or no fluids.

In the seismic data available to date in the Kalgoolie region of the Eastern Goldfields Province, former fluid rich zones are interpreted on the basis of detachment reflection character under the western sides of the Kalgoolie (eg. Figure 2) and Mt Pleasant antiforms, and the eastern side of the Scotia-Kanowna antiform. Fluids in these zones would break into the brittle upper crust, presumably through deformation-induced permeability facilitated by high fluid pressures. In these three antiforms, concave-upwards reflectors link from the detachment upwards into the
core of the antiform. They can be interpreted as faults because of their reflection character, and would be excellent pathways for fluids from the detachment to migrate upwards into the antiforms. In the Kalgoorlie and Mt Pleasant antiforms, the direction of the faults is such as to have directed the fluids towards regions of known mineralization.

Deformation-driven induced permeability creation and destruction can lead to transitory fluid-rich zones at a range of depths in the crust (Cox, et al., 1990; Connolly & Podladchikov, 2004). In Tibet, the implied fluid-rich zones formed at a similar depth over distances of more than a hundred kilometres, and are reflective because the fluid-rich zones have a large seismic impedance contrast with the country rock. In the Kalgoorlie region, the detachment surface did not follow a compositional boundary everywhere. In some areas it is interpreted as the boundary between the greenstone succession and felsic basement, but in other areas it is through felsic basement below the greenstones. It is interpreted to be reflective in places because of chemical alteration and deformation induced anisotropy.

Detachment surfaces are not ubiquitous. However, other regions where detachment formation is not so pervasive have reflections that can be interpreted to result from alteration and anisotropy caused by fluid flux. For example, in the Laverton-Leonora region, sub-horizontal reflectors and linked concave upwards reflectors similar to those in the antiforms around Kalgoorlie are observed. In the seismic section in Figure 3, the reflections can be divided into two groups. In the top part of the diagram the regional geology is interpreted as a layered sequence in the upper left forming a roll over anticline on an amorphous piece of rock that may be granite. The form lines marking geological boundaries are dashed where there is uncertainty, but in most cases can be fairly confidently carried through other reflections that have a different orientation. Superimposed on the reflections that are interpreted as geological boundaries are a series of other reflections (bottom part of the figure) that sub-divide into sub-horizontal and feathering-
upward reflections. The sub-horizontal reflectors (H1, H2, and possibly a third, H3) can be interpreted as previous fluid rich zones that are now reflective because of alteration. Anisotropy due to deformation-induced fabric is not favoured as an explanation of these reflections because none of them offsets the reflectors attributed to the geological boundaries. Furthermore, the reflections are more like those of faults in the synthetic data than shear zones. Note that H1 lies in the core of an anticline and therefore was probably structurally related. In contrast, H2 cuts across stratigraphy, and would therefore have been controlled by fluid pressures. The feathering-upward reflectors would be breach faults driven by fluid pressures. They parallel but are separate from the boundary between the stratified rocks and the underlying inferred granite, and at depths close to H1 and H2 cross-cut the stratigraphy. The reflectivity of the breach faults would be due to alteration along the faults.

If this interpretation is correct, fluids would have moved systematically upwards and to the west through the crust in this region. We cannot tell from the available images whether the fluids were derived from the deep crust or from the stratified rocks to the east. The position of the fluid pathways regionally may have been controlled by the boundary between the stratified rocks and the ?granite, which can be followed in various forms down to the base of the crust where it offsets the Moho, but the actual pathways were not controlled locally by the stratigraphy or local structure.

Figure 3: Top: Migrated seismic section from east of Laverton in Western Australia. Black lines show geometry of rock packages (dashed where uncertain). Bottom: Sub-horizontal reflectors (H1, H2 and possibly H3) shown as thick lines link with concave upwards reflectors shown as thinner lines.

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References


