Alone in the dark: geodynamics without seismic velocities

Alexey Goncharov

Australian Geological Survey Organisation, GPO Box 378, Canberra ACT 2601, Australia, (email: Alexey.Goncharov@agso.gov.au, phone: +61 2 6249 9595, fax: +61 2 6249 9980)

Abstract

Accurate crustal velocity models derived from refraction/wide-angle seismic studies provide a reliable basis for development of geodynamics. Without such models, total thickness of sediments in deep basins, depth to the Moho, petrological composition, temperature regime and rheology of the crust will not be accurately defined. Knowledge of seismic velocities also provides constraints for gravity modelling and estimates of isostatic compensation of crustal loads.

Introduction

With the advent and growing success of deep crustal reflection seismics, refraction/wide-angle technology has become less popular amongst researchers. Recent successes with refraction/wide-angle studies in Australia, particularly those utilising very dense observation schemes, have demonstrated that conventional reflection technology has certain limitations. This paper reviews several examples illustrating the benefits for geodynamics of accurate velocity information derived from large-offset recording and utilisation of several types of seismic energy.

That enigmatic reflectivity

Results of the interpretation of the ocean-bottom seismograph (OBS) data from the North West Australian Margin suggest that prominent seismic reflectors in conventional reflection data do not necessarily correspond to significant bulk velocity discontinuities [1]. A good example is the definition of basement from reflection and refraction data in the Petrel sub-basin (Fig. 1).

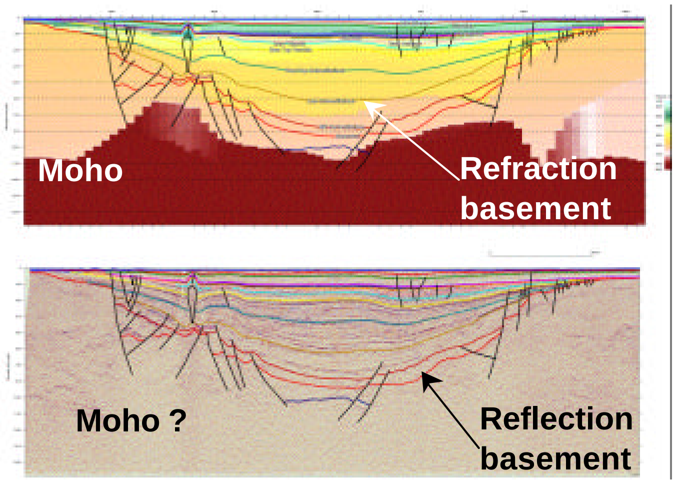

Figure 1. OBS-derived velocity model (upper panel) and conventional reflection section (lower panel) for the Petrel sub-basin line, Bonaparte Basin. Interpreted reflection horizons are superimposed on top of both images. Note significant (up to 7.5 km) deviation of the 'reflection basement' from the basement defined as velocity boundary in the upper image ('refraction basement').

Similar examples relate to imaging the Moho and top of underplating on several OBS lines: compare poor definition of the Moho in the conventional reflection image as opposed to its clear manifestation as a velocity boundary (Fig. 1).

From time to depth

Representation of geological information in the depth scale is critically important for successful geodynamic modelling. Seismic velocities derived from stacking of the conventional reflection data provide only a limited possibility for time-to-depth conversion. Even in the upper 4 s of reflection seismic data, as an example from one of the OBS lines shows, error of depth conversion utilising these velocities is less than 200 m for only ~ 50% of the section. Depth errors exceed 1 km in other parts of the upper 4 s section, and increase further with depth. Depth conversion with inappropriate velocities will not only under- or over-estimate the depth, it will also distort structural shapes.

From seismic velocities to crustal composition and temperature regime

Knowledge of crustal composition is essential for many aspects of geodynamics, particularly for the definition of the rheology of the crust. A common method to translate seismic velocities into crustal composition is to use velocity measurements on rock samples. The problem with this approach is that the number of rock types is too large and ambiguity too high. We have developed a different, essentially probabilistic, approach to estimate crustal petrology [2] which also defines SiO_2 distribution in the crust as a by-product. Our estimates for several regions show that the assumption of a mono-mineralic crust, still used in some rheological models, is an over simplification. Petrological models of the crust defined on the basis of seismic velocities can be further translated into models of heat generation, and eventually into temperature models.

From 'seismic isostasy' to crustal mass transfer

Analysis of seismic velocity distributions along vertical profiles through the crust has led to the conclusion that anomalously high velocity rocks in Precambrian regions (unlike the extended crust and continent-ocean transition at the NW Australian Margin) are underlain by anomalously low velocity rocks, so that 'seismic isostasy' is achieved well above the Moho [3]. In some regions models with balanced seismic velocity distribution translate into petrological models with balance in SiO_2 distribution also achieved above the Moho (*e.g.*, the crust of the Mount Isa Inlier in Northern Australia with its high-velocity mid-crustal anomaly [3]). A degree of balance in the SiO_2 distribution can be used as an additional criterion to distinguish between the regions where either vertical or horizontal mass transfer in the crust has prevailed.

Summary

The presented examples illustrate how seismic velocities can be used to the benefit of geodynamics: modelling of the petrology of the crust, accurate definition of the depth to the Moho and thickness of sediments. Other benefits are detection of underplated crust with implications for heat flow modelling and rheology, and also better constrained gravity modelling.

References

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