Tectonophysics 602 (2013) 55–68

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

# High resolution regional crustal models from irregularly distributed data: Application to Asia and adjacent areas

Ward Stolk [a,b,*], Mikhail Kaban [b], Fred Beekman [a], Magdala Tesauro [b], Walter D. Mooney [c], Sierd Cloetingh [a]

[a] Utrecht University, Dept of Earth Sciences, P.O. Box 80.021, 3508 TA Utrecht, Netherlands
[b] Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Section 1.3, Telegrafenberg D-14473 Potsdam, Germany
[c] US Geological Survey, 345 Middlefield Road, Mail Stop 977, Menlo Park, CA 94025, US

ARTICLE INFO

*Article history:*
Received 11 July 2012
Received in revised form 14 January 2013
Accepted 24 January 2013
Available online 31 January 2013

*Keywords:*
Crustal model
Interpolation method
Remove–compute–restore
Asia

ABSTRACT

We propose a new methodology to obtain crustal models in areas where data is sparse and data spreading is heterogeneous. This new method involves both interpolating the depth to the Moho discontinuity between observations and estimating a velocity–depth curve for the crust at each interpolation location. The Moho observations are interpolated using a remove–compute–restore technique, used in for instance geodesy. Observations are corrected first for Airy type isostasy. The residual observations show less variation than the original observations, making interpolation more reliable. After interpolation, the applied correction is restored to the solution, leading to the final estimate of Moho depth. The crustal velocities have been estimated by fitting a velocity–depth curve through available data at each interpolation location. Uncertainty of the model is assessed, both for the Moho and the velocity model. The method has been applied successfully to Asia. The resulting crustal model is provided in digital form and can be used in various geophysical applications, for instance in assessing rheological properties and strength profiles of the lithosphere, the correcting gravity for the crustal effects, seismic tomography and geothermal modelling.



## 1. Introduction

In many continental areas, including the Asian continent, the crust has a long history of reworking due to tectonic deformation, leading to large heterogeneities (e.g. Artemieva, 2009, 2011, http://www.lithosphere.info/; Tesauro et al., 2008). Accurate knowledge of the crust and its heterogeneities is important for many disciplines in geology and geophysics, such as in seismic tomography where there exists a strong trade-off between crustal heterogeneity (especially Moho variations) and upper mantle velocities. Moreover, an anomalous crustal structure may mask deeper seated upper mantle heterogeneities, which are relevant for the construction and analysis of gravity, geothermal and magnetic models. In particular, determination of the dynamic topography, which is generated by mantle flow beneath the lithosphere (e.g. Ricard et al., 1984; Richards and Hage, 1984 and more recently Becker and Faccenna, 2011) requires correction for the crustal contribution to the observed topography. Therefore, a consistent 3-D model of the crust is important to better understand intraplate continental deformation caused by (de)coupled upper mantle–crustal tectonic processes.

To investigate the intraplate deformation across the Asian continent existing global crustal models such as Crust 5.1 (Mooney et al., 1998) and CRUST-2.0 (Bassin et al., 2000; Laske, http://igppweb.ucsd.edu/~gabi/crust2.html) can be used. However, uncertainties exist on the data and data quality used in the construction of these crustal models, and how these were derived from the type keys used to define different types of crustal structure. Moreover, the resolution of these models is often insufficient for detailed regional studies. Comparison of these global crustal models with new regional crustal models, e.g. EuCrust-07 (Tesauro et al., 2008) shows that even at the same resolution large discrepancies exist between the models. For instance, the difference in Moho depth between EuCrust-07 compartments (averaged over $2° \times 2°$) and Crust-2.0 exceeds 10 km in certain areas (Tesauro et al., 2008).

One of the first 3-D models of the crust for Central and Northern Eurasia has been constructed by Artemjev et al. (1994). This model describes variations of the depth to basement (sediment thickness) and Moho discontinuity, but also density variations within the sedimentary cover. This model was improved by incorporating new data and providing seismic velocities for the crystalline crust (Kaban, 2001). Later, the model has been extended to the south to include the entire Asian continent (Kaban et al., 2009). This model has been presented in several papers and finally included in the global model (e.g. Tesauro et al., 2012). However, all the improvements are related to Moho, which has been upgraded for limited areas: the Arabian Peninsula, India and some parts of South-eastern Asia. When this crustal model is compared with available seismic data still significant discrepancies in crustal structure show up, most likely due to the accumulation and integration of various types of geological and geophysical data that differ in quality

* Corresponding author at: Utrecht University, Dept of Earth Sciences, P.O. Box 80.021, 3508 TA Utrecht, Netherlands. Tel.: +31 30 253 7320; fax: +31 33 253 5030.
*E-mail address:* w.stolk@uu.nl (W. Stolk).

0040-1951/$ – see front matter 
http://dx.doi.org/10.1016/j.tecto.2013.01.022

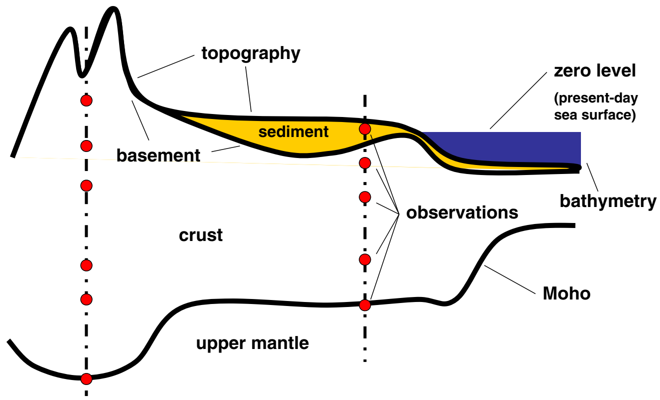


**Fig. 1.** Generic cross section of continental crust with anomalous features such as (left) thickened orogenic crust, (central) sedimentary basin, and (right) extended crust. The vertical dash-dotted lines indicate observation locations in the database.

**Table 1**
Example from GCS-gamma6 database, an entry has an identification number (ID), location (Loc) in latitude and longitude, followed by several layers discerned at that location. For each layer the P- and S-wave velocities ($v_p$ and $v_s$) are given as well as the layer thickness ($t_{layer}$) and the depth to the top of the layer ($z_{top}$). A letter indicates (indic) the type of the layer (s = sediment, c = crust and m = depth to Moho.)

| ID | Loc | $v_p$ [km/s] | $v_s$ [km/s] | $t_{layer}$ [km] | $z_{top}$ [km] | indic |
|---|---|---|---|---|---|---|
| 95 | 43.94 N | 1.75 | .00 | 1.00 | .00 | s |
| | 59.85 W | 3.10 | .00 | 1.30 | 1.00 | s |
| | | 3.80 | .00 | 2.30 | 2.30 | s |
| | | 5.40 | .00 | 9.20 | 4.60 | c |
| | | 6.23 | .00 | 21.20 | 13.80 | c |
| | | 8.00 | .00 | .00 | 35.00 | m |

and resolution. Also, in this model the velocity structure of the crystalline crust is taken from the global CRUST-2.0 (Bassin et al., 2000) model.

Existing models do not always clearly describe which data are used and by which method the model is derived from the source data. Often, they are compiled using very different regional maps, which are most times not sufficiently documented with respect to the original data used. For most models, the velocity structure is less well resolved than the estimated depth to Moho. Other models use gravity data in addition to seismic data, thereby implicitly assuming that the gravity signal coming from inside the crust or below the Moho discontinuity is known.

Here we present a new methodology to derive crustal models in areas where data coverage is essentially inhomogeneous. This new methodology formalises many aspects of the data analysis and allows us to assess uncertainties of the method itself. The new Moho depth and crustal P-wave velocity model for continental Asia presented in this paper are based on seismic and seismological data in the USGS database (Mooney, 2007).

## 2. Constructing a crustal model

The crust consists of several layers (Fig. 1). The crystalline crust is commonly overlain by sediments, ice and/or water. These layers are characterised by considerably diverse properties. The data coverage, both spatial and vertical, is also different for the sedimentary layer and crystalline crust. Therefore, we use different approaches for each of the layers.

In constructing a crustal model, first the boundaries of the crust need to be determined. The top of the crystalline crust, can be determined if topography/bathymetry and sediment thickness are known. Therefore, an analysis of the sedimentary cover is required at first. The lower boundary of the crystalline crust (depth to Moho) can be determined by interpolating seismic observations of the Moho. Subsequently velocity and density distribution can be determined for the crystalline crust layers and sediments.

### 2.1. Data

Currently the most complete dataset is compiled in the USGS database (Mooney, 2007, updated in 2011) in which all entries are digitisations from published seismic data (mainly refraction, reflection seismic sections and receiver function results), but no observations that make use of gravity data, magnetic anomalies or other have been used. Major contributions to the database come from the publications of Egorkin (1991, 1998) and unpublished reports by the GEON (1989, 1992) for Eastern Russia and Vol'vovskii and Vol'vovskii (1975) for the former USSR territory in general. Verba et al. (1992) are the most important contributors to entries concerning the Laptev Sea, whereas data in the Barents Sea mainly comes from Jackson (2002). Data in China comes from many sources, amongst which Youngsheng et al.,

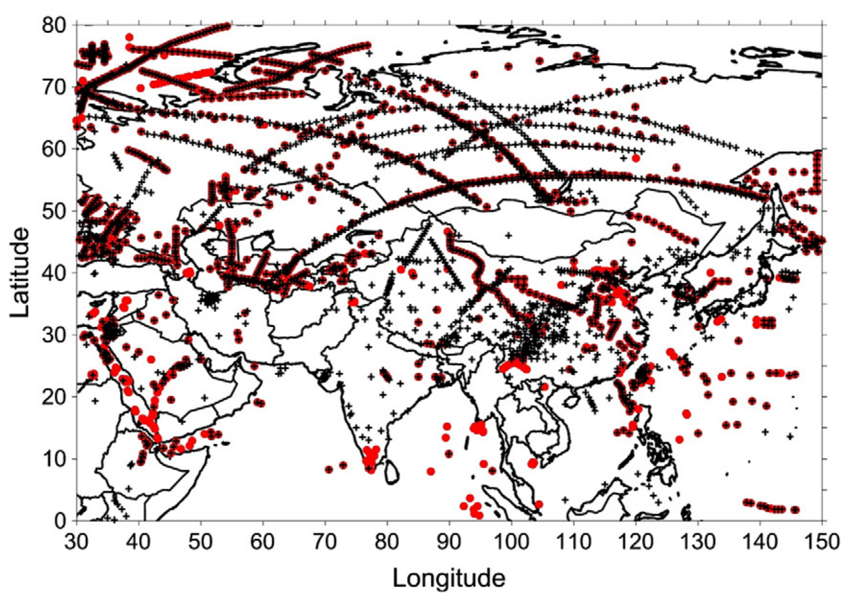


**Fig. 2.** Study area with locations of observations (black cross = Moho, red dot = one or multiple ($v$,$z$)-pairs).