Geophysical Research Abstracts
Vol. 13, EGU2011-9130, 2011
EGU General Assembly 2011
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A novel approach setting boundary conditions in gravity field modelling

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According to potential field theory, the observed gravity is a potential field composed of the gravity effect of individual geological sources with density contrasts in the subsurface. Consequently the gravity field forward modelling of the upper crust is affected by the Moho geometry.

A novel isostatic approach can estimate the Moho geometry independent of gravity data and is therefore an additional constrain on potential field modelling. This approach utilizes crustal load to analytically calculate a flexural, isostatic Moho geometry. The flexural response of the Earth's crust due to loading can be estimated using a 4th order differential equation describing the flexure of a thin elastic plate. Until recently, the solution for this differential equation has been approximated by spectral methods with the disadvantage of lower lateral resolution. The analytical solution of an elastic plate (ASEP) is a novel approach which overcomes the drawbacks of the spectral method. The ASEP+ method allows the analytical calculation of a Moho geometry using as input absolute crustal loads(instead of pseudo or equivalent topography). Load is defined as product of density, thickness and gravity acceleration; the crustal load is the sum of basement load, sediment load and load of topography/water above a reference depth.

It is shown that the long-wave length part of the observed gravity field is already explained by a simple 3D density model using the calculated isostatic Moho geometry as boundary. Therefore, the ASEP Moho geometry is a first order approximation to the present crust - mantle boundary.

This approach has an important impact on the interpretation of the crustal architecture and two applications in hydrocarbon exploration will be shown; seismic imaging and frontier exploration.

Gravity modelling is an important tool to improve salt imaging due to the lower density of salt compared with surrounding sediments. The density model is transferred into crustal load in order to be used as input for the ASEP+ Moho estimations. This provided a more detailed crustal load distribution than by using a depth-density-function for the sediments, which would exclude the effect of salt. Without the lowered load of the salt structures, the Moho geometry would significantly differ. It was proven that the Moho geometry has a clear impact on the basement modelling and consequently on salt structure modelling.

The other field of application is frontier exploration, where a passive margin system is shown as example. In some segments along the continent-ocean transition zone the calculated ASEP Moho differs from the seismic interpreted Moho. A schematic cross-section of a 3D model established on key surfaces from seismic interpretations is shown. The seismic reflector related to p-wave velocity increase from 7.1-7.8 km/s is often interpreted as Moho, but corresponds to a metamorphic body (like, for example, serpentinized mantle). It is observed that the seismically interpreted Moho topography mirrors the top basement topography. This is a strong indication, that this boundary is also an isostatic equilibrium surface. Furthermore, with the assumption that top basement corresponds to a Paleo topography, this “Moho” boundary is the surface of equilibrium for the Paleo topography and not of the today present day isostatic topography.

Additionally, it is shown that the isostatic Moho (ASEP) explains the present gravity field observation and can therefore be interpreted as the ready state Moho. Conclusively, from an isostatic point of view, the seismic interpreted Moho would correspond to a Paleo-Moho.

Quantifying uncertainties are important for frontier exploration settings. We estimate uncertainties in sediment thickness/top to basement with maximal 8km. However, this leads to 1.5-2km uncertainty in depths for the gravity inverted Moho and only to maximal 400m uncertainty in Moho depths calculated with ASEP+ method. This shows that the ASEP+ method is not sensitive to the uncertainty of sediment thickness. Conclusively, the largest error occurs if a model is built on seismic observations only, and other observations are neglected. This error was quantified with 9km of Moho depth which accounts for 20% of the maximum value (44km), which is significant.

The knowledge about the correct crustal thickness and Moho depths is often crucial. These results shows how important it is to build structural geological models not only based on interpretation of seismic profiles but also to include other geophysical observations.