Imaging Crustal and Moho Configuration in NW region of Deccan Synclise, Gujarat Using Pre-Stack Depth Migration of Wide-Angle Seismic Data

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Summary

Seismic techniques provide the highest resolution measurements of the crust and have been conducted worldwide basis. In this paper we present results of Kirchhoff’s Pre-stack Depth Migration (PSDM) applied to the above wide-angle seismic data. The crustal structure obtained in the region is defined by bands of southward dipping reflectors, revealing crustal thinning towards the north and dipping towards the south. The PSDM section obtained is in agreement with regional trend of gravity anomaly. The crustal depth variation in the section indicates that the area under study is disturbed tectonically and could be associated with the increased seismicity of the area.

Introduction

The Deccan Trap covers about 500,000 sq km of the region in India. The thickness of the trap varies from a few hundred m in the west and in the east to a few km in the center of the region (Kaila et al., 1985). This region is one of the best examples of fissure eruptions during Upper Cretaceous-Eocene period. The refraction/wide-angle reflection seismic data of 25 seconds record length was acquired by NGRI along 140 km long Mavli-Gulkumar profile and 90 km long Sinor-Valod profile during 2001-2002/2003 in Deccan synclise region, Gujarat, India. The survey consisted of recording common source gathers in the varying apertures 12-50 km. Due to low foldage the normal CDP type stack processing was not effective in this wide-angle data set. For this reason, we have subjected this data set to 2D-Kirchhoff’s PSDM to image the deeper crustal structure and crust mantle transition. Finally the output image was interpreted to reveal the geologic structure beneath the study area.

Field layout and data acquisition

The survey was conducted between latitudes of 20° 30' N –22° 30' N and longitude of 72° 30' E –74° E. The location of the seismic profiles is outlined over the geological map in figure 1. The profiles are (a) North-South aligned Mavli-Gulkumar profile passing through surface exposures of Trap except a patch of Alluvium (Recent) between SP3 and SP9, and (b) North-South aligned Sinor-Valod profile in the west of Mavli-Gulkumar profile which passes through Trap except alluvium patch between SP1 and SP3.

Every spread of 11.9 km length with 120 geophone groups, each placed at every 100 m interval was recorded with a number of shot points of varying offsets (10–50 km) to have proper details regarding shallow reflections as well as the basement configuration. To enhance the signal strength, string of 10 geophones of natural frequency 10
Hz were connected in series and bunched system at each geophone position. VHF, HF communication was used to detonate the charges through ShotPro/GM300 and to register the blast instant at the recording unit. For acquisition of data, Radio Frequency Telemetry (EAGLE 88) was used.

Data was recorded simultaneously in the form of analog on thermal sensitive paper and digital (SEG–D format) in cartridge with a sampling interval of 2 ms. With the low-cut filter out, the system provides considerably wide band of frequencies up to 125 Hz. A notch filter (50 Hz frequency) was kept in operation to minimize the effects of power line pick up. Record length of 25 seconds is maintained throughout the profile.

For drilling the shot holes, DTH and URB2A – rigs were deployed. Shot holes were drilled in general to a depth of 20m – 25m and loaded on an average with 50kg high-energy explosives. Either rectangular or triangular pattern of holes, with an interval of about 10m from hole to hole has been adopted. Open case Gelignite (OCG) 83 mm/ Telgex LD 83 mm was used as the explosive source. The explosive charges tied with detonating fuse were lowered down to the shot holes, and then packed/covered by mud, drill cuts, and water, which were subsequently detonated by electric detonators.

Recording parameters

- **Low-cut filter**: open
- **Antialias on**: 125 Hz
- **Notch filter**: 50 Hz
- **Recording format**: SEG–D
- **Preampilifier gain**: 48 dB
- **Sampling interval**: 2 ms
- **Recording length**: 25 seconds
- **Geophone interval**: 100 m
- **Shot interval**: 10 km

Theory and Methodology used for PSDM

Migration

Prior to migration, a variety of processing steps including trace editing, trace muting, amplitude balancing, F-K filtering etc. were applied to the wide-angle shot gather. After merging all the preprocessed shot gathers common offset binning was performed to have a better CDP coverage in each offset bin. The Kirchhoff’s PSDM was then implemented in 2D, from the flat datum.

PSDM of wide-angle seismic data represents an extension of traditional imaging with near-vertical incidence data because it includes a larger component of the recorded wave field (Zelt et. al., 1998). It performs migration by applying Green’s functions to each CDP location. The Green’s function used here is obtained using a Maximum Amplitude Ray Tracing method, which, in addition to being very fast, computes proper and maximum amplitudes and does not require a smoothed velocity field. It works well with all but the most complicated velocity fields and provides good handling of steep dips, up to 90° and beyond i.e. turning-ray energy (ProMAX 2D – Advanced Techniques User Training Manual).

The velocity model used for the PSDM was taken partly from the restricted report for 0-5 km depth and for 5-60 km depth from Kaila et al. (1981, 1989) respectively. The variation of velocity in the study area is from 1.9 km/s at surface to 8.2 km/s at crust mantle transition in the upper mantle. Thus, a 2D depth section is obtained along the profiles with prominent features at different depths.

Results and Discussion

Results

Basic extrusives, which are of late cretaceous to early Eocene age are known as the Deccan Traps and represent an episode of volcanism marking the close of the Mesozoic era. The Deccan traps encountered at varying depths below the tertiary sedimentary sequence in a number of wells drilled in western part of the study area by ONGC, thus confirming the idea that they essentially form the basement of the tertiary sediments within the tertiary area. Near Rajpipla, a 600 m thick section of Bagh beds of Cretaceous age is reported (Kaila et. al., 1981). Result along the two profiles is as follows:

**Mavli-Gulkumar Profile**

Depth–migrated section along Mavli- Gulkumar profile (N-S) is shown in figure-2. The depth of middle crust is varying between of 18.5 km to 20.5 km. Below the middle crust the imaged section shows layered reflections, which are continuous over an approximate distance of 40 km between SP1 and SP5. The lower crust is imaged at a depth of 22.5 km near Mavli and, dipping towards south, attained a depth of 29.0 km near Gulkumar. The Moho is mapped at a depth of 34 km near Mavli and has deepened again to a depth of 43 km near Gulkumar.
Sinor-Valod Profile

Depth–migrated section along Sinor-Valod profile (N-S) is shown in figure-3. The depth of middle crust is varying between depth of 19.5 km to 24 km depth. The lower crust is imaged at a depth of 29 km near Sinor to 33 km near Valod. The Moho is mapped at a depth of 37.5 to 43 km. In the PSDM section two normal faults in the upper crust are seen, which has become listric at depth and has merged into reflective lower crust.

Discussion

The crustal depth section obtained from the PSDM reveals crustal thinning towards the north and dipping towards the south. This nature of crustal depth variation in the backdrop of geological information indicates that the area under study is disturbed tectonically and could be associated with the increased seismicity of the area. A large number of middle to lower crustal sub-horizontal reflectors can be interpreted as result of detachment faulting. These detachment faults often become listric with depth in the middle or lower crust. The south dipping reflectors soling at the base of the crust are interpreted as additional evidence for the transfer of strain from the upper crustal levels down to the Moho and the mantle. The reflectivity within the lower crust is less continuous. This is probably related to the steeply dipping faults dissecting the crust. Gravity studies carried out earlier in this area also reveals the same trend of Moho (Singh, 1998, 2000). Thus, there is agreement between regional trend of gravity anomaly in the study area and the Moho configuration as obtained from the PSDM. PSDM section reveals a highly reflective lower crust.

The origin of lower crustal reflectivity is an unknown; phenomena, as the deep reflections originate from boundaries separating layers of contrasting seismic impedance (product of velocity and density), they must hold important clues for improving our knowledge of deep crustal composition. Several causes have been suggested for the presence of deep crustal reflections for example (a) Presence of free aqueous fluids (Matthews, 1986; Newton, 1991), (b) Ductile shear zones (Reston, 1988), and (c) Mafic intrusions and under-plating of partial melts derived from the upper mantle (Meissner, 1973; Lynn et. al., 1981; Mckenzie, 1984; Warner, 1990; Nelson, 1991). It is often suggested that the majority of reflections are produced by first-order lithological contrasts related to intrusions of mafic melts into the lower crust. The layering could be sub-horizontal because of gravity that controls the geometry of the intrusions. According to Singh and Mckenzie (1993), the explanation for presence of such reflections is layering of mafic/ultramafic intrusions (of partial melts) derived from the upper mantle. According to Mooney and Meissner (1992), layering could be compositional, metamorphic or mineralogical. Ductile deformation in the crust plays an active role in enhancing the lower crustal reflectivity and this could be one of the explanations for the presence of number of reflections from the lower crust. According to Green et. al. (1991), fractional crystallization such as gabbro in the lower crust with remaining liquid fractions rising higher into the upper crust or surface might be one of the reasons for the type of structural and compositional variations in the region and thus enhancing the lower crustal reflectivity. High lower crustal reflectivity can also be associated with high porosity. There is evidence of the presence of fluid in the lower crust in the study area (Singh and Singh, 1996).

Due to thinning of the crust by ductile stretching, the thinning of the upper and the lower crust might have occurred. However, from the present crustal configuration it is impossible to decide which and what combination of factors has contributed to the present day depth of Moho in the study area. It can be said that high reflectivity of lower crust could be the combined effect of all the aforesaid
factors. The crustal depth image section has brought out a significant variation in the Moho configuration.

Conclusions

PSDM has the potential to image the deep-crustal features. PSDM technique was able to handle the low coverage of the data and the crooked line geometry. A large-scale sub-crustal structure in the Deccan Syncline area, which is defined by bands of southward dipping reflectors, is in agreement with regional trend of gravity anomaly. PSDM section reveals highly reflective lower crust; lithological layering, ductile stretching, partial melts etc. could be the reasons for this high reflectivity.

Acknowledgements

We are thankful to the Director, NGRI, for permission to publish this work. We acknowledge the Controlled Source Seismic Field Party for their efforts in Data Acquisition.

References


ProMAX 2D – Advanced Techniques User Training Manual, Pre-Stack Depth Migration, 14(1-20), Landmark.


