Wide Aperture Reflection-Refraction Profiling (WARRP): “An effective tool for sub-basalt exploration”- A Case Study

Manoj Kumar Bhartee and Karad Kapil

Summary

Seismic exploration of the sub-basalt is hampered by large deposits of basalts, which may cover possible hydrocarbon-bearing reservoirs underneath. There are several hypotheses as to why imaging beneath basalt is a problem. These include: the high impedance contrast between the basalt and the layers above; the thin-layering of the basalt due to the many flows which make up a basalt succession; and the rough interfaces on the top-basalt interface caused by weathering and emplacement mechanisms. In this case study an attempt has been made to understand the sub-basaltic features by 2D Sea Bottom Node (SBN) based Wide Aperture Reflection-Refraction Profiling (WARRP) data in Kerala-Konkan Basin of Western Offshore, India. In the present area Mesozoic sediments trapped under Deccan basalt in the western flank of India had been a challenge for petroleum exploration. Analyzing sub-basalt sediments by conventional seismic survey has always been a challenge due to massive nature of basalt. WARRP helped in refining the velocity model for data processing of 2D long offset streamer data. The technique helped in better understanding of base of basalt and intertrappean sediment in the basin.

Keywords: WARRP, Sub-basalt Exploration

Introduction

We describe an experimental four component (4C) Sea Bottom Node (SBN) based Wide Aperture Reflection-Refraction Profiling (WARRP) survey that was conducted in 2012 at Kerala-Konkan Basin in deep water block, at a water depth 400-2700m. The goal of this survey was to map Vp and Vs with sufficient accuracy of lateral velocity variations (to identify various lithological variations and delineate various basalt flows, sedimentary packs and basement rocks) and identify PmP(reflection from the crust/mantle boundary) in order to restrict crustal thickness and distinguish crustal provinces so that continental/ocean transition (if existing) can be accurately defined.

The imaging problem of sediments underlying basalt layers is caused due to several factors. The main element is the high reflectivity at the top basalt interface which impedes penetration of seismic energy into the deeper layers. Another is the scattering of energy; particularly of high frequency components caused by the rugged topography of the basaltic surface and the heterogeneity within the basalt, caused by successive lava flow. Extensive peg-leg multiple within stacked basaltic layers amplify the problem. In addition the seismic wave velocity in basalt is higher than those of surrounding sediments resulting in ray turning and wave-mode conversion of the seismic wave.

Kerala-Konkan Basin

The Kerala-Konkan basin located at South of 16 degree N latitude forms the southern part of the western continental margin of India and extends from Goa in the north to Cape Comorin in the south. Westward, the basin extends to Arabian Abyssal plain and on the eastern side it is bounded by peninsular shield (fig.1). Mature sediments with sufficient organic carbon content are present in the basin. Drilling results and adsorbed gas anomalies confirm generation of hydrocarbons in the basin.

Fig1 Structural and Geological map of Kerala-Konkan Basin
Description of the Problem

Hydrocarbon has been discovered all through coastal areas of India except Kerala-Konkan basin. In Kerala-Konkan the Tertiary and Mesozoic sediments are separated by a thick Basaltic layer. Imaging below basalts has always been a problem in oil exploration. The thick basalt is opaque and masks deeper seismic events below the basalt. Only few wells have penetrated and drilled below the basalt. Till date the petroleum system has not been established in this basin. Moreover the establishment of the hydrocarbon kitchen area, migration path and entrapment has to be established. Wells drilled in Kerala-Konkan has shown the presence of hydrocarbons while drilling but production testing results not encouraging this fact. To overcome the Trap problem and fulfill our objectives mentioned above, 2D Sea Bottom Node (SBN) based Wide Aperture Reflection-Refraction Profiling (WARRP) data have been acquired in the block.

WARRP

The wide aperture reflection-refraction profiling (WARRP) method exploit the wide angle reflected energy, diving waves as well as normal incidence reflections, in order to develop a velocity-depth model of a seismic time section from common shot or station gathers (Makris and Thieben, 1984; Makris et al., 1998; Dell’Aversana P. et al., 2000, Leven et al. 2004). Long offset data are required in order to observe the wave field of the diving waves and wide angle reflections that have penetrated deeper into the section. This modeling approach is also referred to as “node modeling” and was originally developed for Bottom Node (SBN). In order to make the concept evaluating offshore seismic data recorded by Sea more understandable we present diagram (figure 2 & 3) illustrating the basic principle of WARRP in a simple two layer case.

In fig.2 the green arrow is the incident ray of the P-wave. This is reflected and transmitted as P and S wave energy (blue and red arrows).

Fig. 3 illustrates the energy partition between the P and S phases and how a greater portion of the energy propagates in the reflected phase at angles of incidence beyond the critical angle and that beyond critical distances S-waves penetrate and map the structure where P-waves are no more transmitted.

WARRP has proven to be a powerful imaging tool for problem areas with high acoustic impedance layers masking underlying structure or geological formation with small impedance contrasts being undistinguishable by conventional methods (Markis and Thaieben, 1983, 1984). The classic examples for such geologically complex structures are sub-basalt, sub-salt or thrust areas. This method is based on utilizing the information of both refracted and wide angle reflected wave. The principle of SBN based WARRP spread is shown in fig. 4.
SBN Operation and Data Acquisition

Acquisition of approximately 800 LKM (7 SBN Lines) of SBN based WARRP data using 4 component receivers was carried out in KeralaKonkan basin during year 2012. It was single vessel carrying single source operation of minimum offset 40km, shot interval 37.5m, node spacing 2 km and 36 sec. of record length. Acquisition geometry had planned to double shoot each line with shot spacing of 75 m. in opposite direction to record PmP, Pn and avoid previous shot water wave interference. Total 407 SBN stations were deployed according to the preplot line (fig. 5).

Fig. 5 Preplot of SBN Line in location map

SBN units were manually planted (fig.6 show the different parts of node unit). These nodes are battery powered autonomous unit and can record data continuously for 30 days. After deploying from vessel each unit sinks to the sea bottom under the weight of an anchor. The SBN unit has no connection to the sea surface and is recovered by acoustic release system at the end of the survey.

Plantation and retrieval operations are shown in fig.7. Each SBN Station’s clock drift had verified before plantation and after retrieval. SBN stations clock data drift calculated through satellite clock analysis for QC. The volume of the source (5700 cubic inches) was carefully chosen to enable deeper penetration without significantly impacting recording bandwidth.

Common Receiver Gathers (CRG) was generated for QC work during data acquisition. Strong PmP reflections were visible on LMO applied with MOHO velocity (8 km/s) CRG of Geophone as well as Hydrophone in long-offset data (fig.8).

Comparison of LMO applied raw CRG shows a certain amount of converted wave energy of the Z component (vertical geophone), which is not present on the P component (Hydrophone). PP reflections are clearly seen on vertical component (Z) and hydrophone. Converted shear weaves (PS) are visible on the two horizontal components (X, Y). A comparison of all four components (three orthogonal component of geophone and one hydrophone) of LMO applied SBN data of line KK2-SBN-06 at position-22 are shown in fig.9. It is also clearly visible on vertical component of geophone (Z) and Hydrophone (P) has the receiver ghost, which is attenuate using PZ summation.
**Data Processing & Interpretation**

Data processing & interpretation of Sea Bed Node (SBN) was carried out by MGS based on Wide Aperture Reflection- Refraction Profiling (WARRP) along 7 profiles in the project area. The steps followed in the evaluation of Common station Gathers are first break tomography, layered tomography, forward modeling and pre-stack migration.

Interpretation of data reveals that thickness of basalt/sub basalt layer varies from 2 km to 4 km and the depth of the basement vary from 6-9km with velocity varying 5.8-7.9 km/sec. The Moho boundary uplift derived from PmP reflection is located in southern and south-western part of the area with varying depth from 17-19km. In the Eastern and Northern part of the area Moho goes down to 25-27 km, and 23-25 km respectively. Vp/Vs ratio showing 1.9 values on profile 5,6&7 which ravels possible S-wave velocity decrease and important according to geological concern.

**Conclusion**

The SBN based Wide Aperture Reflection-Refraction Profiling (WARRP) method allows the implementation of seismic arrays of any desired length and is practically weather independent and also allows the penetration of deep reflectors even where the impedance contrast is unfavorable.

WARRP also helped in refining the velocity model for data processing of 2D long offset streamer data. The technique helped in better understanding of base of basalt and intertrappean sediment in the basin.

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