Error Propagation in Positioning of Seismic Profiles in Undulating Terrain – A Case Study From Himalayan Foothills

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ABSTRACT

Seismic survey is one of the most widely used geophysical methods for hydrocarbon exploration. This method is based on measurement of earth response (reflected energy) to induced sound energy from sources located near surface. Depending upon the geometry of surface observation points (receiver locations) and source locations, the survey is called two dimensional (2-D) or three dimensional (3-D) seismic survey. In 2-D seismic survey it is ideally expected that the source and receiver locations are located at fixed interval in a straight line. However, the accuracy of spacing of such surface observation points depends largely on availability of control points, accessibility along projected line and surface topography. In practice, while surveying for a 2-D straight line the geophone and shot point locations are placed at regular intervals along the surface irrespective of the surface geometry. This results in variable shot / receiver interval in the undulating terrain.

While processing the data acquired in highly undulating terrain, special care has to be taken to accurately image the subsurface. In this paper an attempt is made to identify the effect of surface undulations on seismic profile layout. In such cases it is impossible to keep the source / receiver interval constant between adjacent sources / receivers due to variable slope and lack of line of sight between sources / receivers which in turn violate the basic assumption of seismic data processing of a straight line geometry for subsurface imaging. In a case study pertaining to data acquired in Himalayan foothills area of OIL's operations, the cumulative error estimated in actual and planned source / receiver interval was about 800 m in a 11.5 km long profile. This error if not accounted properly in data processing, may result in erroneous subsurface image.

INTRODUCTION

There are various geophysical methods for mapping subsurface resources of the earth. In all these methods the physical properties measured on the earth surface are interpreted to locate exact position of various geologic features within subsurface which have accumulation of resources like hydrocarbons and other minerals. These surface measurements are processed with respect to the gridded topographic map of the area and then downward continued to the target depths to generate new map, depicting features with commercial viability for exploration of the resources. Each geophysical method results in variety of maps useful for exploration of different mineral resources. For Hydrocarbon exploration, seismic method is the most extensively used technique and helps in generation of various maps for identification and estimation of hydrocarbon reserves.

Through the spatial information contained in maps, cartography plays a key role in the collection, annotation and interpretation of all types of exploration data. In exploration activities conducted globally over all types of terrain, whether it is on land or at sea or over transition zones, for assigning the surface position to the subsurface features of interest, the survey measurements on ground and their subsequent processing is very important and needs high degree of accuracy. Hydrocarbon exploration, in particular, requires a very accurate positioning of the subsurface locations (Spradley, 1985). This makes the navigation or survey measurements stringent and the maps prepared based on these stringent measurements are only used for further analysis and positioning of the subsurface reservoir locations on ground. Now a days with the availability of DGPS system and other equipments like Total Stations, and data loggers (SOKKIA Total Station /SDR-33 operational manual), the surveying has become very fast and accurate.

PLANNING OF SURVEY WORK FOR SEISMIC EXPLORATION

In planning a survey, it is customary for a prospect area to be subdivided into a grid of seismic profiles based on the geologic, topographic and previous geophysical work, which provide the desired density of sampling to meet program objectives. With the help of the plan map and Differential Global Positioning System (DGPS), some reference points are fixed on ground. Seismic profiles are positioned with respect to the known reference points and prominent features on ground in the area. At the same time, these reference points are used for fixing more control points in the area to further maintain the accuracy of the survey. After fixing the reference points, there are various survey methods for profile location marking on the ground. Out of these methods, the traversing and line setting out are the two main methods, which are used throughout the survey work.

The requirement for seismic data processing for accurate subsurface mapping survey is that the profile direction, receiver point interval and shot point interval should be constant for a seismic profile. Even with available latest technology for surveying it is a tedious task in logistically difficult areas where line of sight between consecutive points is not clear and slope varies from point to point. The direction of the profile can be maintained within tolerance limit (Spradley, 1985) for seismic data processing. Normally, 2-D data for a straight line is processed by assuming constant source /receiver interval. However, this assumption can give various processing pitfalls and the resultant positioning of common depth points (CDPs) will be erroneous and may lead to misjudge the subsurface feature location. In this paper we have tried to quantify the error due to variable source / receiver point interval in an undulating terrain. We have selected one seismic profile from the operational area of Ganga Valley Project, Oil India Limited.

CASE STUDY

A case study from OIL's operational area (figure-1) in foothills of Himalayas is presented. The detailed map of the area with elevation contours and seismic lines recorded during the field season 2001-2002 is shown in figure-2. The elevation contours in the area indicate 525 m variation (from 225 m to 750 m) in source / receiver elevations as we proceed towards north depicting highly undulating terrain in northern part of the study area. Straight lines shown by black colour (figure –2), are planned seismic profiles. For seismic survey along these planned seismic profiles, the line stacking survey was done with the help of latest technology like DGPS, Total stations, data loggers etc.

To study the effect of undulating topography on fixing of source / receiver points at constant interval we have selected one 11.5 km long seismic profile (shown by green colour line in figure - 2) in the northern part of the study area. Figure - 3 shows the graph of elevation -vs- ground stations fixed along the profile, which indicate that elevation changes rapidly from point to point. The undulating topography depicted from figure - 3 indicates that fixing of ground stations (source / receiver points) at constant interval is a challenging task in such type of terrain even with the help of latest technology. However, it is the basic requirement of seismic data processing and interpretation for accurate subsurface mapping. At the time of designing of geophysical parameters the source /receiver interval was decided to be 50 m which is shown by the straight line in figure - 4. This planned source / receiver interval when plotted should be a straight line, of the length equal to the sum of all intervals, parallel to the axis of source / receivers which have been plotted in figure - 4 and is shown by black colour. The actual source / receiver interval against source / receiver stations are shown by red curve in figure - 4 which deviates a lot from the planned straight line. This deviation against source /receivers is plotted in figure – 5. When we analyze figure – 3 and figure – 4 together, it is very clear that at the places of drastic elevation changes we could not maintain fixed 50 m source / receiver interval between consecutive shot / receiver locations. It rather varied from 29 m to 52 m. The variation in source / receiver interval will create an error in positioning of common depth points generated at the time of seismic data processing.

In the study area we have used latest state-of-the art technology for surveying to minimize the survey error. The supplied information is the line direction, source / receiver point interval and the elevation of each source / receiver point. As has been said earlier, in ideal situation the source / receiver interval is kept fixed and subsequent data processing and interpretation is based on this assumption. However, as we have observed from figure – 4 and figure – 5, the source / receiver interval deviates from the planned value. The seismic processing methodology for 2-D straight profile does not take variable source / receiver interval into consideration properly for subsurface mapping. Therefore, to find out the actual error in position of sources / receivers, the seismic profile was loaded by assuming constant source / receiver interval and also with measured source receiver interval. The error in the position of sources /receivers was calculated. Figure – 6 is the plot of the error against source / receiver points. This error is near to zero in plane area. As we proceed towards hilly terrain, where elevation changes drastically, the error increases continuously. Furthermore, analysis of error plot (figure – 6) vis – a – vis elevation plot (figure – 3) indicates that error is constant in the zone of plane areas (source /receiver points: 90-140; 260-290). Figure – 6 also indicates that the cumulative error in the positioning of last source /receiver points will be about 800 m for a seismic profile of 11.5 km if the data is processed using constant source / receiver point interval.

CONCLUSION

2-D seismic survey in highly undulating terrain may result in erroneous subsurface mapping if accurate and realistic surface measurements are not considered for data processing and interpretation. The present study indicates a possible mis-positioning of the subsurface CDP points 800 m in 11.5 km long profile due to undulating surface terrain.

ACKNOWLEDGEMENT

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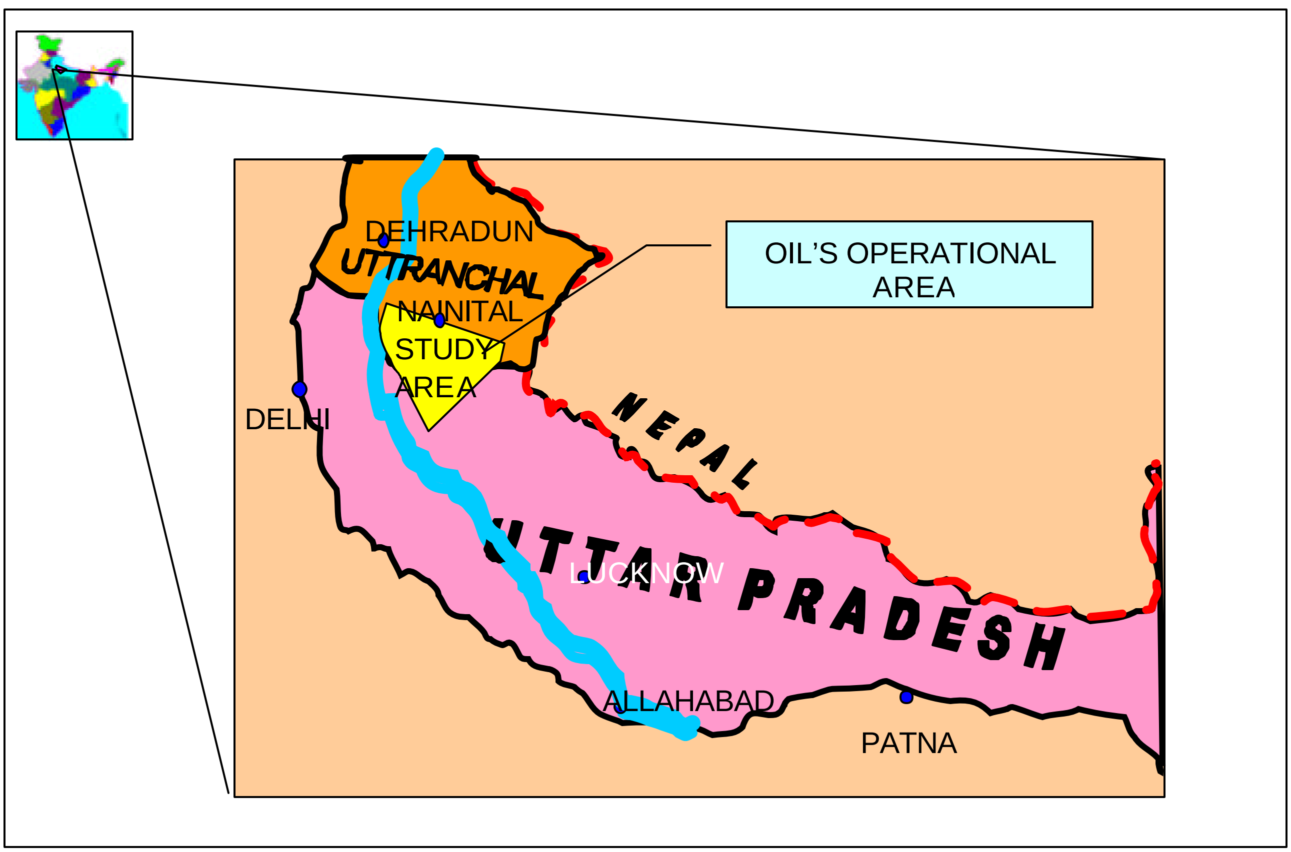


FIGURE - 1: LOCATION MAP OF STUDY AREA

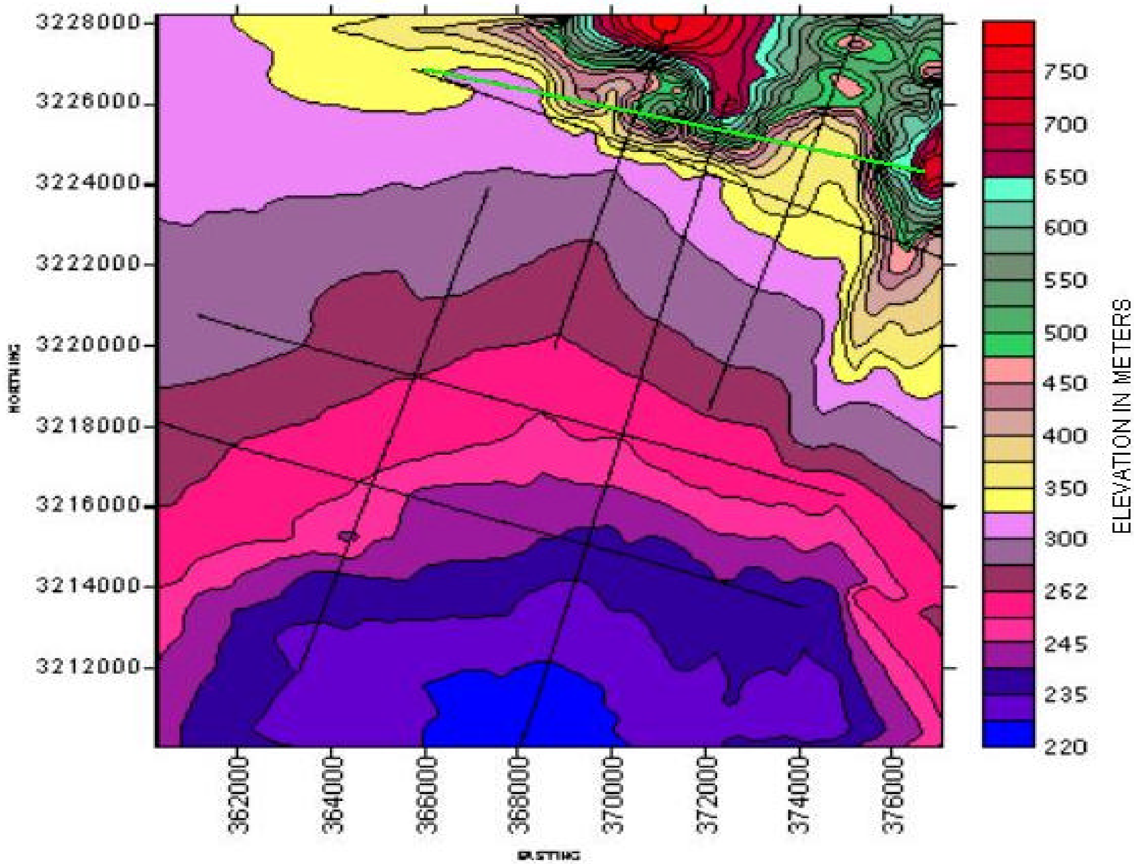


FIGURE – 2: MAP SHOWING SURVEY LINES WITH ELEVATION CONTOURS

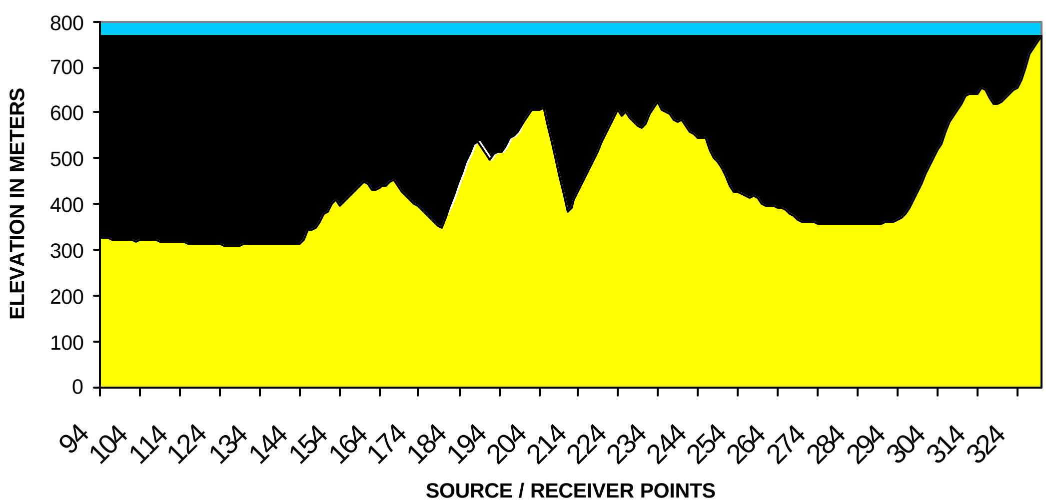


FIGURE – 3: ELEVATION ALONG SEISMIC PROFILE STUDIED

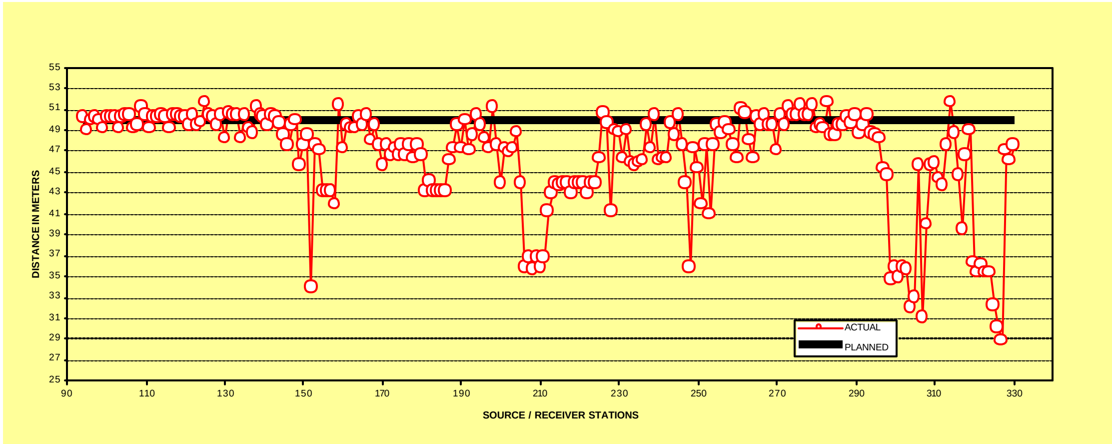
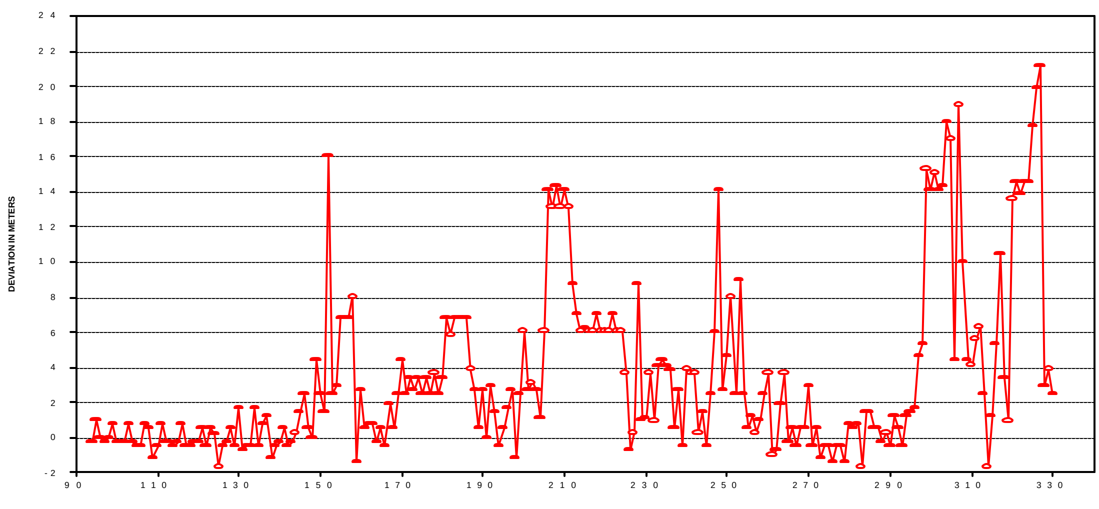


FIGURE – 4: PLOT OF THE PLANNED AND ACTUAL SOURCE / RECEIVER INTERVALS



\ FIGURE – 5: PLOT OF THE DEVIATION IN HORIZONTAL DISTANCE FROM THE DESIRED VALUE

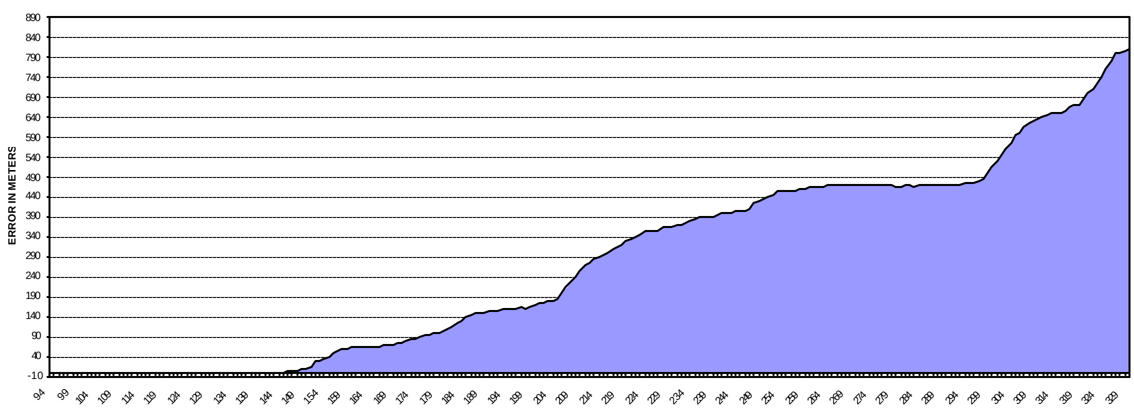


FIGURE – 6: ERROR IN POSITIONING BETWEEN PLANNED LOCATIONS AND ACTUAL AND MEASURED LOCATIONS