WIDE APERTURE REFLECTION AND REFRACTION PROFILING (WARRP) IN ENVIRONMENTALLY SENSITIVE RAIN FOREST AREAS

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SUMMARY

Wide Aperture Reflection and Refraction Profiling (WARRP) has emerged as a viable and cost-effective method for seismic reconnaissance. It can provide an initial evaluation of the extent, depth and structure of a sedimentary basin, including a measurement of seismic velocities. It is a less costly method than conventional seismic methods which makes it extremely useful in identifying, and possibly reducing the size of, an area in which to focus a standard frontier area exploration program. Additionally, it has a smaller impact on the environment than other methods.

INTRODUCTION

WARRP, previously also known as Wide-Angle Reflection Profiling (WARP), evolved from the familiar refraction method of seismology. In that method, the source and receivers typically have a relatively large off-set and the first arrivals are assumed to be waves traveling along the interfaces between constant velocity layers. A better understanding of seismic wave propagation in variable velocity media, plus major advances in computer seismic modeling, now allow us to use near-offset and far off-set data simultaneously, without making assumptions about wave propagation paths. Reflected, refracted and diving waves are all used in the WARRP method.

Typically, the final WARRP output is a compressional wave velocity/depth model, delineating velocity structure, including major interfaces, as well as vertical and lateral velocity variations. Also by using information from converted waves, a shear wave (SV) velocity versus depth model can be derived, thus yielding Vp/Vs ratios which can be indicative of the nature of the formations being evaluated.

One advantage of the WARRP technique is that it has very little impact in environmentally sensitive areas such as rain forests. Because portable stand-alone recording units are deployed, and source points are sparse, there is no requirement to cut a continuous line through the jungle along the WARRP profile. Access to source and receiver points can be achieved from the nearest river, road or path. Cutting a path through the rain forest is kept to a bare minimum.

DATA ACQUISITION

Mobil and partners employed the WARRP method twice in Peru in rain forest zones. A typical profile length was approximately 50 to 80 km in length. A vertical and horizontal geophone pair were placed at 250 m intervals. A stand alone portable recording system, containing a cassette recorder, was located at every third receiver location, recording the signals from three geophone receiver groups. Each system could record continuously for approximately 10 days.

Source points were located at 3 km intervals along the profile. Portable drills were used to drill the shot holes. These were carried on foot, assembled and deployed at the shot point. Five four-meter holes were drilled and each loaded with 2 kg of explosives resulting in a charge size of 10 kg. In a few cases, such as at the end of a long profile, larger charges of up to 20 kg distributed over 10 holes were used to insure adequate energy at very long offsets (>60 km). Distributing charges over a number of holes reduced the possibility of blow-outs and associated damage from occurring. Only underbrush was cleared at each shot point as the shallow holes were distributed in a fashion to avoid large trees.

All the recording systems were activated at the time of their deployment and recorded continuously as the sources were detonated sequentially along the spread. Typically, all sources were set off within 48 hours of the deployment of the last recorder. This ensured that all receiver groups recorded data from near to far offsets in both directions. After the last shot, the geophones and recording systems were recovered and moved to the next profile.

A typical shot record is shown in Figure 1. Clear arrivals are seen at all offsets up to 30 km, and often further. A constant velocity moveout of 6km/sec has been applied to shorten the apparent time of the seismic section which otherwise could be as long as 20 seconds in length.

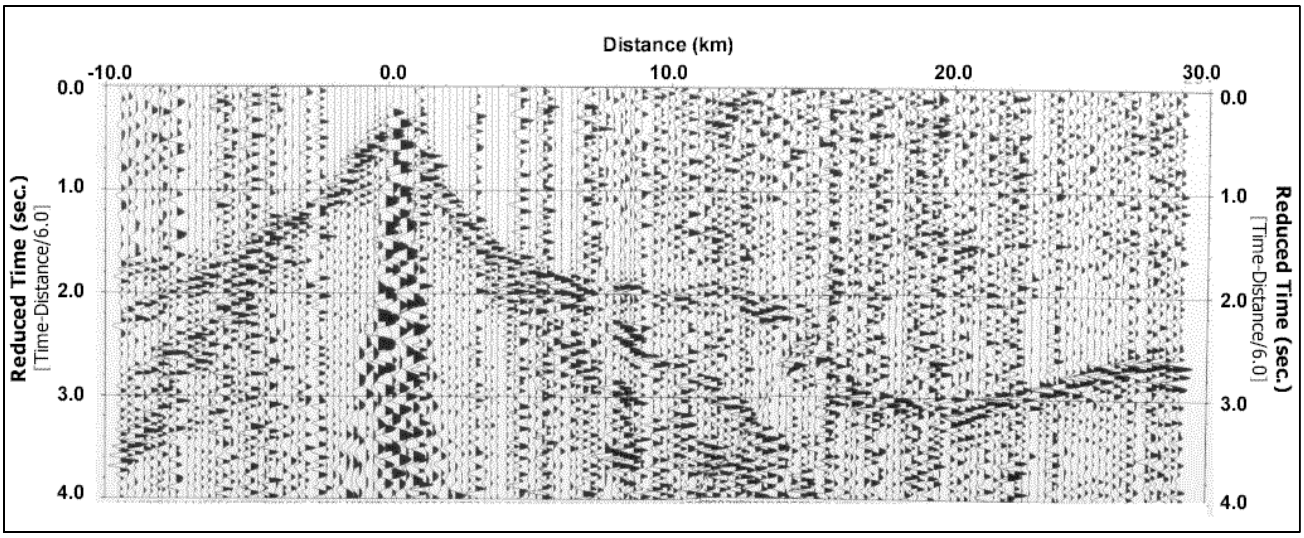

Figure 1. WARRP shot record

MODELLING AND INVERSION

The raw data were loaded onto a workstation and re-sorted into common shot gathers. For each shot gather the arrival times of the various events were picked. These arrival times were inverted to produce the required velocity/depth model. The inversion flow was as follows:

- Tau-P inversion of the first arrival times to yield a one-dimensional velocity/depth model at each shot print.
- Linear interpolation between the models to produce the initial velocity/depth model for the profile.
- Interactive forward modelling and arrival time comparison. This part of the process is iterative and is continued until all the model arrival times match the measured arrival times for every shot gather.

Figure 2 shows an initial model for a particular shot point and the raypaths generated for this model. The upper figure shows the computed model arrival times. These are compared with arrival times for equivalent events on actual shot gathers. Residual time differences are reduced by modifying the velocity field values and geometry. This iterative process is continued until an acceptable match is achieved which satisfies all the recorded data

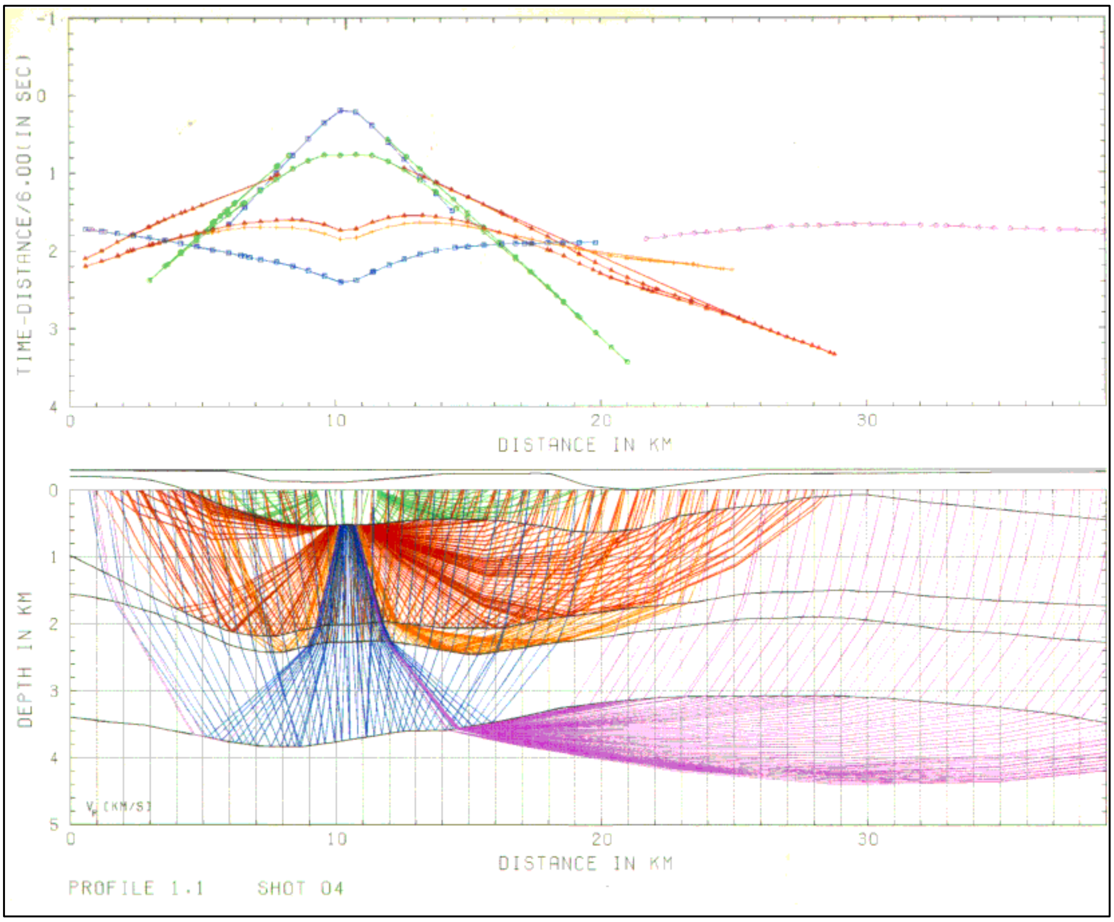

Figure 2. Lower portion of the figure depicts an initial velocity-depth model with raypaths illustrating pre- and post-critical reflections for a given source position. The upper portion depicts the computed arrival times for this particular source point and velocity model.

While the final velocity/depth model that matches the arrival times for the various reflectors (velocity boundaries) may not be an exact solution, it provides a good indication of the large structural features in an area that have associated velocity contrasts. In areas where velocity contrasts are small, the WARRP model may not indicate any velocity boundary but may indicate instead, a vertical and/or horizontal velocity gradient. Figure 3 shows an example of a resulting velocity/depth model. Velocity gradients are apparent, and the basement is clearly defined by higher velocities.

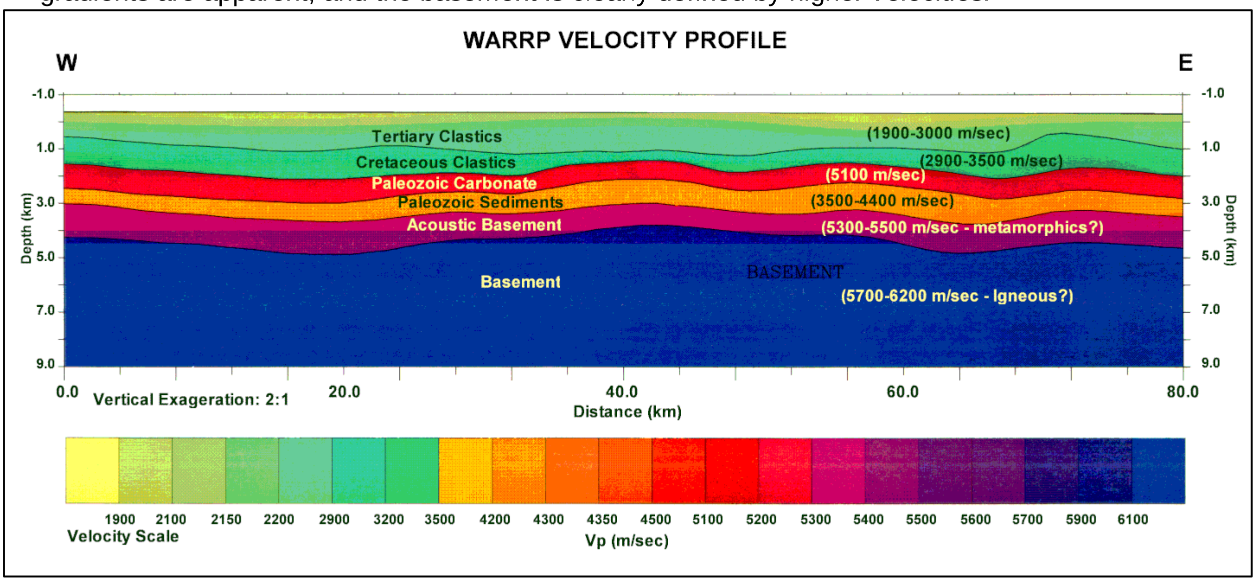

Figure 3. WARRP Velocity-depth model (2:1 vertical exaggeration)

COMPARISON TO CONVENTIONAL SEISMIC

In the Madre de Dios basin of Peru, Mobil and partners conducted a WARRP study in 1994. The results were used along with potential field data to delineate a potentially prospective area with possible structures within the foreland portion of the basin. This area, designated Lot 77 (Figure 4), was subsequently explored with conventional 2-D seismic in 1996. A seismic line was recorded (Figure 5a) sub-parallel to three WARRP profiles. Significant horizons interpreted from the seismic data were depth converted (Figure 5b) using seismic velocities calibrated by log data from the Los Amigos well, situated south of Lot 77. The three WARRP profiles were merged (Figure 5c) to compare the results of the two forms of seismic data.

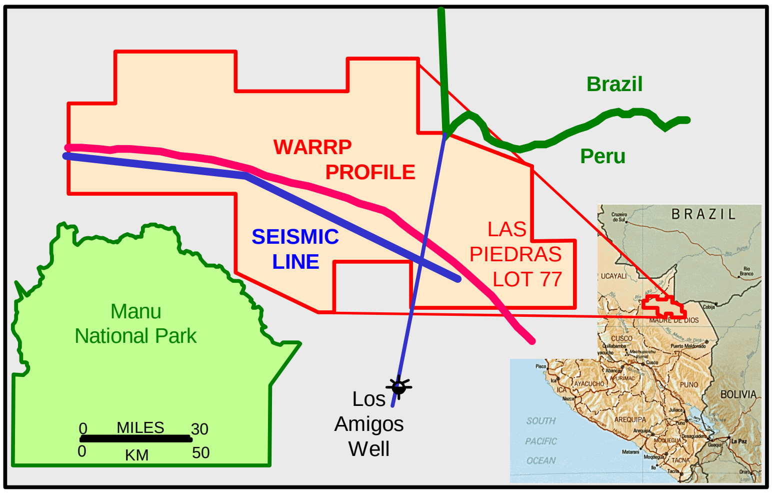

Figure 4. Map of Lot 77 in northwest Madre de Dios basin.

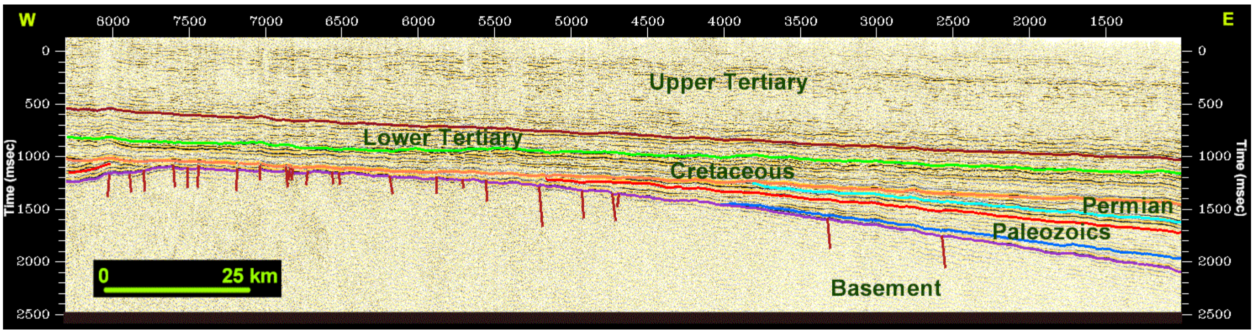

Figure 5a

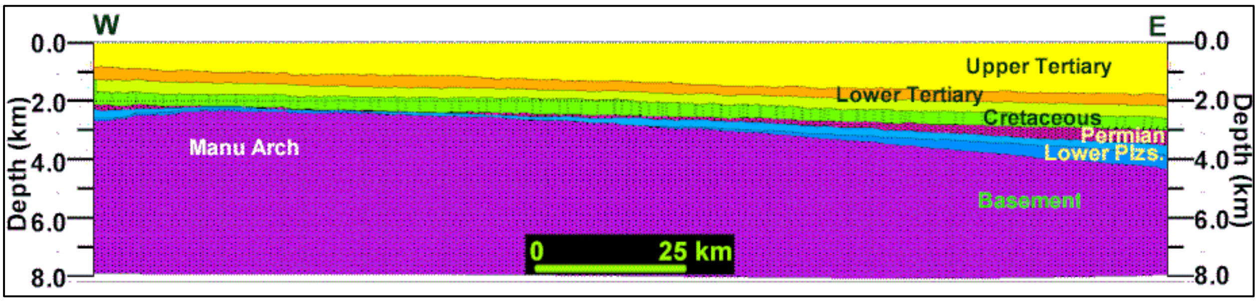

Figure 5b

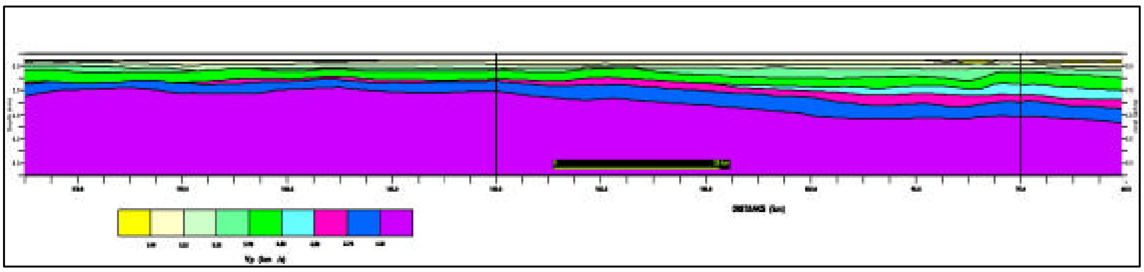

Figure 5c

Figure 5. Comparison 2-D seismic and WARRP data. Figure 5a shows seismic time section acquired sub-parallel to three WARRP profiles. Figure 5b depicts the interpreted seismic horizons depth converted using seismic velocities calibrated to the Los Amigos well data. Figure 5c shows three

WARRP profiles merged together to compare against depth converted seismic data (Fig. 5b). While scales are not identical, one can see that both sets of data have provided similar results in terms of large structural features.

In comparing Figures 5b and 5c, the reader must keep in mind that the seismic depth section and the WARRP velocity profile, while very similar to one another, do not depict the same results. They are similar to the extent that the seismic reflections and the WARRP velocity boundaries are caused by measurable impedance contrasts. And both forms of data are capable of providing similar results regarding about large scale structural features. However, at the scale and frequencies in question, the seismic data have significantly higher resolution (25-50 m) than the WARRP data (200-300 m). Furthermore, seismic data provide stratigraphic and lithologic information that WARRP does not.

CONCLUSIONS

The Wide Aperture Reflection and Refraction Profiling (WARRP) method has proved to be a viable tool for seismic reconnaissance, especially in difficult areas such as remote rain forests. It has also proven to be useful in areas of difficult seismic imaging such as beneath salt, basalt and carbonate platforms. WARRP results can indicate large scale structural features, and the resulting velocity-depth model can be used to determine velocities required for optimum imaging as well as depth conversion of conventional reflection data.

WARRP is also a considerably less costly method which can be used in new areas to help focus exploration programs to a smaller target area, minimizing overall costs and environmental impact.