An Investigation of Systematic Location Errors of Microseismic Events

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Summary

This research focuses on the calculation of the systematic errors in hypocenter location by comparing travel time values from wave fields in heterogeneous and homogeneous media. Borehole logs from Sudbury, have been used in a ray algorithm to produce travel time values. The computed travel times were used to calculate the systematic errors in hypocenter location. It is observed that the heterogeneity of the elastic velocity parameters and the distribution of sensors are significant contributions to systematic error in location. The calculations vary with position of the receivers.

Introduction

Microseismic events are occurrences that are, at times, a cause for concern for workers underground. Therefore, the evaluation of their hypocenter-location-errors is absolutely crucial for the safety and well-being of various individuals and expensive projects. Examples of expensive projects include: costly geothermal projects, reservoir monitoring projects and in-mine monitoring. Rock properties such as P-wave velocity in the earth vary spatially and hence affect seismic wave travel times. However, most travel time analyses are based on constant velocity models. Consequently, this affects the accuracy of hypocenter locations. In this study, we investigate these location errors via ray tracing modeling methods.

Methodology

The main goal is to obtain errors in the spatial coordinates of microseismic hypocenters. The high frequency domain is used and thus ray tracing is applicable. The forward problem of finding travel time values begins with the homogeneous wave field. Such computations use constant P-wave and S-wave velocities and are typical of most microseismic analyses. These constant velocities are obtained by computing the mean values of the borehole logs from Sudbury, Ontario (Figure 1). Notice the raw logs contain great variability.

In this work, P and S-wave travel times are also computed for two other velocity models. The first model is a synthetic three layered model and the second model is a layered model obtained by making the logs in Figure 1 smooth (blue log, Figure 1). Making them smooth involves computing the average values for certain depth intervals. The average P-wave velocity of 6.50 km/s was computed over a depth interval of 500m. Noting that the depth range is less than 900m, the rock material of concern is bedrock and thus a Poisson's ratio of approximately 0.25 was used. Considering this ratio, as well as the P-wave information, an average S-wave velocity was deduced to be about 3.75 km/s.

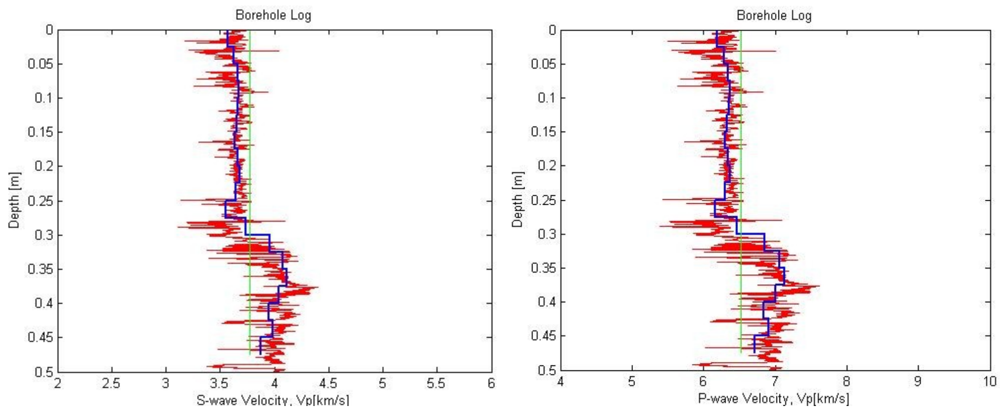


Fig. 1: Borehole logs from Sudbury, Ontario, Canada. The differences in the variability of the raw log (red) with respect to the smoothed log (blue) and the constant velocity log (green) can be clearly seen.

Travel time values were produced for both the P-wave and the S-wave velocity models and the results are shown in Figure 2.

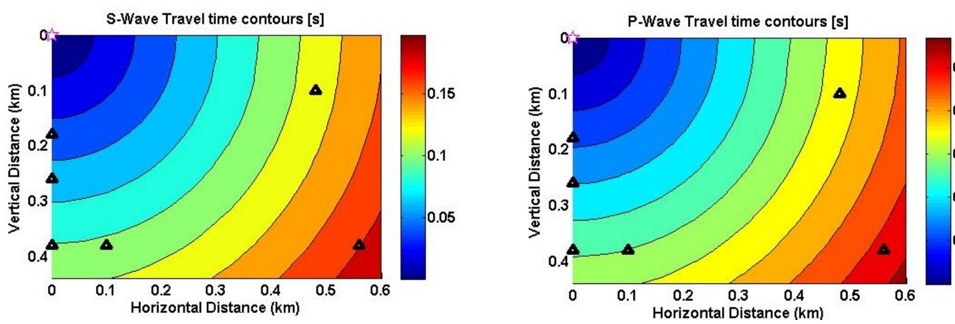
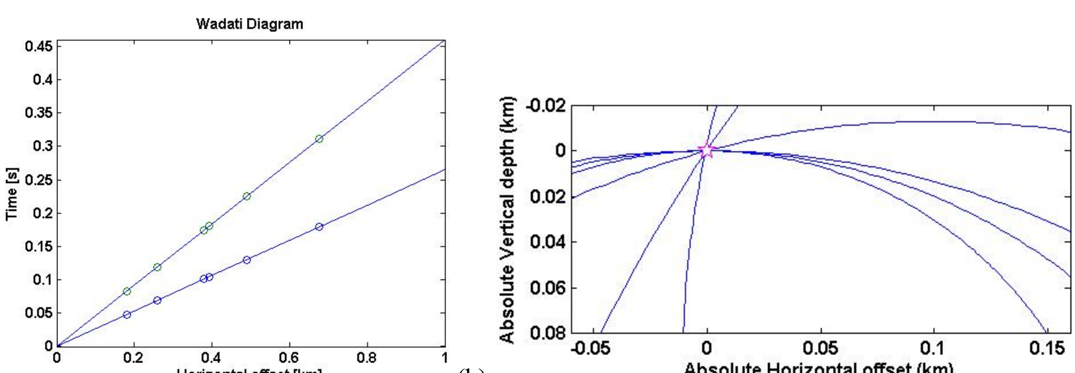


Fig. 2: Contour plots for the constant S-wave (left) and P-wave (right) velocities. The receivers correspond to the triangles in the plots.

As expected, the contours are spherical. Receivers have been subjectively set to obtain travel time values *only* for their positions. These P-wave and S-wave travel times can be plotted against the absolute distance to the source. This graph is called a Wadati Diagram and is shown below in Figure 3(a).



(a) (b)

Fig. 3(a): Wadati Diagram for homogeneous medium. **Fig. 3(b):** The Method of Circles for a homogeneous medium

The next step would involve computing travel times for a heterogeneous (e.g. layered) model. Once travel times are computed for these models, the differences in P-wave travel time and S-wave travel time can be obtained. Comparing these values to those obtained from the Wadati diagram will give an absolute distance from source (hypocenter). The “Method of Circles” diagrams are then used to illustrate the error in the hypocenter location. Circles with radii equal to the absolute distance from the source are drawn around each station. These circles are expected to have an intersection point that coincides with the hypocenter. The coincidence between the intersection point and the true hypocenter is achieved if the medium is homogeneous. However, with heterogeneous medium, you will have deviations. These deviations are the errors in hypocenter location.

Examples

The above fundamental theory was initially applied to a synthetic three-layered model as shown in Figure 4(a). Compute P and S-wave travel times are shown Figure 4(b) & (c):

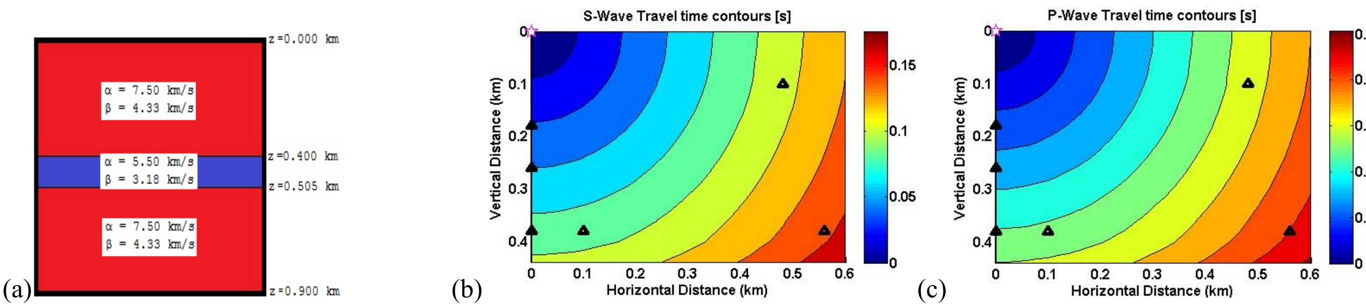


Fig. 4: Synthetic velocity model (a) along with contour plots of computed travel times for S-waves(b) and P-waves (c).

Notice that the results are different from the contours in the homogeneous velocity field. Receivers are in the same locations as in the homogeneous medium. The circles in Figure 4 appear to diverge from their spherical nature and this can be attributed to the refractive property of waves. Figure 5 below shows a “method of circles” image that depicts the amount of error in the source location. Notice the miss-location is ~60m in the vertical direction and ~50m in the horizontal direction. This underestimates the true source location by ~ 80m.

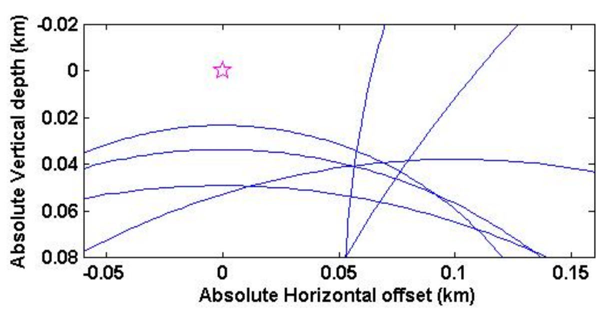


Fig 5: Method of Circles for the synthetic velocity log

Aside from synthetic velocity models, studies were done on a borehole in Sudbury. If we perform an analysis on errors that is analogous to the study performed with the synthetic layered data, we obtain the travel time contour plots in Figure 6.

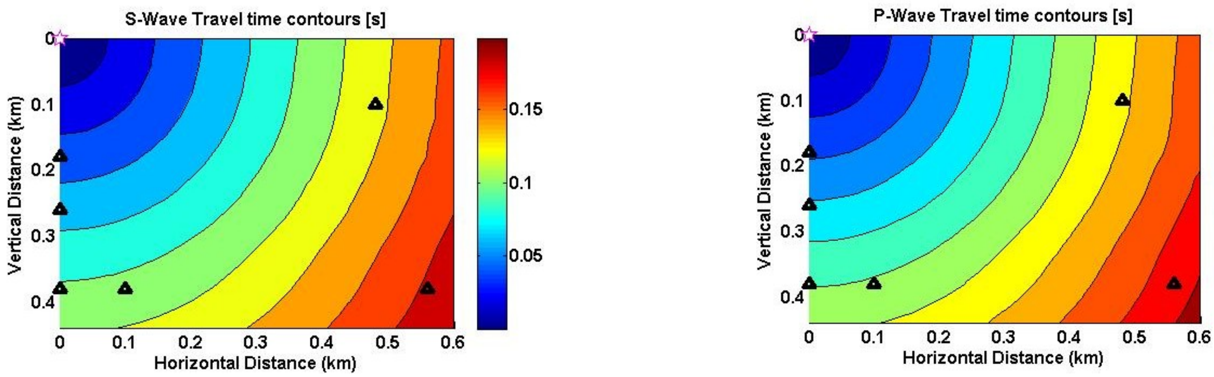


Fig. 6: Travel time contours from the smoothened P-wave and S-wave logs in Figure 1.

A similar analysis was performed on the Sudbury log (blue log, Figure 1), made smooth, and the computed travel time contour plots are shown in Figure 6. Notice the contour shapes in Figure 6 are different than those in Figure 3. Assuming the receivers and the source are precisely in the same locations as before, large errors in location are expected since the velocity model is highly variable. Figure 7 below displays the location error as estimated by the "method of circles" diagram. The true source location is underestimated by ~ 10m.

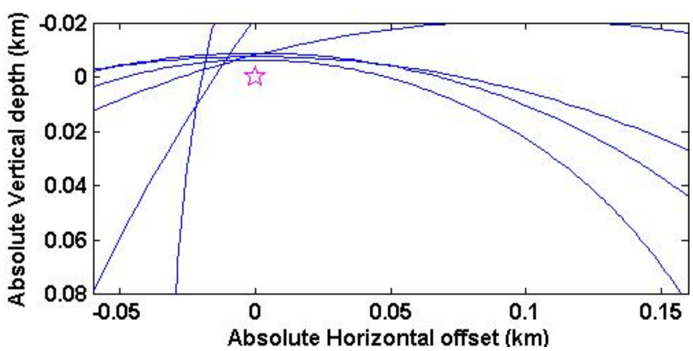


Fig 7: The "Method of Circles" diagram for the borehole's layered cake velocity model.

Conclusions and Outlook

From the above results, the errors in hypocenter location that are based on simple homogeneous models are quite large and significant. Note, the borehole data did not show *much* error; something unexpected. However, this can be attributed to the distribution of sensors. Clearly, the distribution is not giving the expected information. Future work will focus on two aspects: how other heterogeneous velocity models compare to homogeneity as well as how the distribution of sensors affects the source location of errors.

References

Lay, Thorne, and Terry C. Wallace. Modern Global Seismology. San Diego: Academic Press, Inc., 1995. Print