Passive Seismic Acquisition, Methodology & Operational overlook

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Abstract

With an increase in exploration activity in geologically complex areas, such as fold and thrust belts geophysical methods have to adjust accordingly. Exploration in these areas is promising, since they can indicate future “play openers”, it is, however, challenging, as well as expensive, and it is driving experts in the application of state-of-the-art techniques, one such technique is Passive Seismic Tomography. Planning the acquisition of such survey requires both **feasibility** and **acquisition modeling** in order to address *survey duration and resolution* issues, the methodology behind these steps will be presented here.

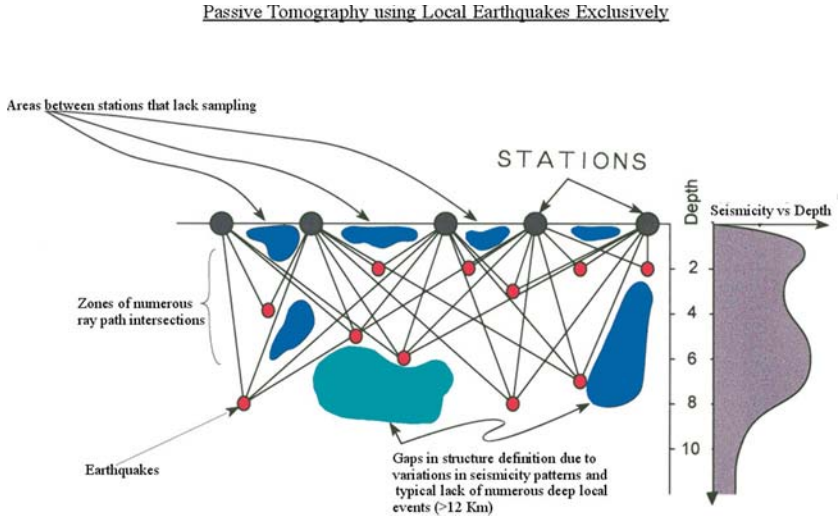
Introduction

Recent advances in seismograph design, monitoring methodologies and inversion algorithms, have resulted during the past few years in the application of a new exploration methodology: *passive seismic tomography.* Passive methods have for sometime now being applied to reservoir characterization projects, fault and fracture location and orientation. The step to the tomographic domain requires a different field set up and operational considerations that follow more or less the logic of 3D seismic surveys. The rationale for passive tomography is twofold: it is a **cost-effective manner** to image an area, and the technique has the added and important for our times, advantage of being **environmentally friendly**.
We will discuss here these operational considerations and methods used for preparation and execution of a passive survey, in short a feasibility study which includes**:** Expected Resolution & Accuracy, Level of natural seismicity, Monitoring time, Network geometry and QC tests.

Resolution and Accuracy

The issue of resolution and accuracy has to be addressed before any survey design. We give here a background explanation of how these parameters are characterized in terms of passive inversion. Modeling results will be used to quantify parameter selection.
In travel-time tomography, we use one wave length of the highest frequency in the signal spectrum, that is above the noise level, as the distance measure for the intrinsic spatial resolution. Equally important, is the resolution of structure that is achievable through the density of the spatial sampling of the medium by the wave field used. Obviously, to completely sample the properties of the medium at the limit of the intrinsic resolution capability, it would be necessary to detect many body waves that have traversed the entire volume. Due to the distribution of sources and receivers however, it is usually the case that some regions, within the volume to be investigated, will be well sampled while others will be undersampled, so properties of some volume elements cannot be determined, but only averages over larger elements of greater

dimensions may be obtained. This variability in spatial sampling is illustrated schematically for the passive tomography case in Figure 1 below.



As noted in Figure 1, shallow structure resolution can be improved substantially **by increasing** the number of recording stations or **periodic redeployments** of the stations of the network. As the resolution obtainable from the sampling done by one network configuration is defined, it becomes possible to determine new locations for network stations that could improve resolution in areas not well sampled by signals from the event locations. Therefore, after several months it is possible to re-deploy or densify the network in a manner that assures sampling in the zones not well resolved by the initial deployment.

Accuracy and resolution of passive tomographic imaging depends strongly on the ability to resolve the velocity model in the inversion procedure, as well as upon the density of sampling provided by the signal ray paths. Modeling of these parameters before hand helps improve the design of the passive network.

Natural Seismicity Level

The continuous recording procedure used is effective in detecting and locating seismic events in a well designed network, where the background noise is at normal levels, down to local magnitude levels of less than zero. This assumes that the average seismic station spatial separation interval is from 3 to 4 km. Thus, the number of events recorded almost at all stations of the network will depend on both the seismicity of the region and the detection capability of microseisms from the seismic network in a noisy environment. The latter depends on the transmission characteristics of the medium and can be predetermined quite easily from a short term (a few weeks) survey using several seismographs the field area. The low magnitude seismicity levels in the area can likewise be determined from a) ***a short term survey feasibility for 1-2 months, and b) a combination with existing worldwide earthquake data obtained by local networks and international monitoring organizations.***

Monitoring time

Estimating the survey duration starts by considering the national data first (location of planned survey) and then analyze our observations (field feasibility study) to confirm the expected results. The number of events and the low-end magnitude limit of recording at the array can be estimated prior to the network installation so that the time required to record a sufficient number of earthquakes providing the required tomographic structure resolution can be estimated with reasonable accuracy. Such an estimate of resolution is directly proportional to the product of the number of events detected times the number of stations recording the events. The total number of ray paths from local events that are obtained will, of course, vary with time. Estimation of results using these data for a typical period of recording will be shown during the presentation.

QC TESTS – Network geometry

The next step in the feasibility study is to perform a synthetic inversion test considering a homogeneous local seismicity of say 1000 events distributed over a depth of 18Km (Fig. 2). Usually the events are set to follow known trends of seismicity sources such as large faults. This way we examine the resolution power of a seismic network consisting in this case of an array of 64 stations (4x4km^2) and recording 64x1000 P-arrivals.

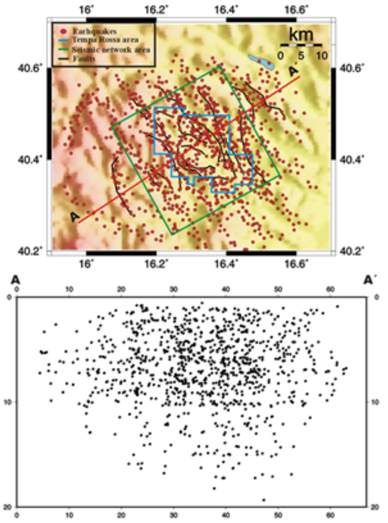


Figure 2. Source distribution spatially and in depth modeled within a study area.

Testing using the proposed network is done by applying velocity cell anomalies of the order of ±5% of the layer velocity at the corresponding depth. With this checkerboard test we will identify the types of artifacts produced in the velocity model by the combined effects of the inversion method and the spatial ray coverage, while providing an indication of the resolving power of the data set. Forward modeling is done to compute synthetic arrival times for the above mentioned source distribution, checker board velocity model and the proposed receiver geometry. The synthetic seismograms on each of the stations were used to invert for the 3D structure and compare the resolution power of the proposed network.

Accuracy results for a proposed network

Figure 3 a&b presents the inversion results for absolute velocity values (right figure) for 1.5 and 3km depths for the ±5% velocity variation. In order to judge the resolution power of the particular network we compare these figures with the initial model ones (left figure). It is clearly demonstrated that a very good reproduction occurs especially in the deeper strata using the proposed array geometry.

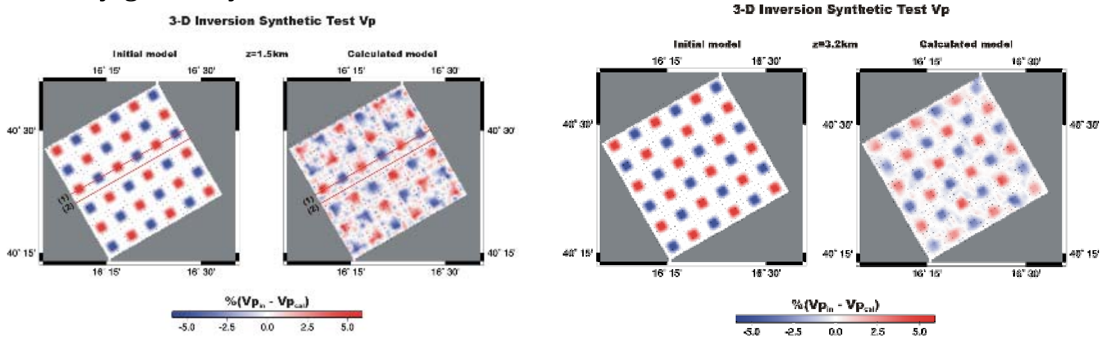
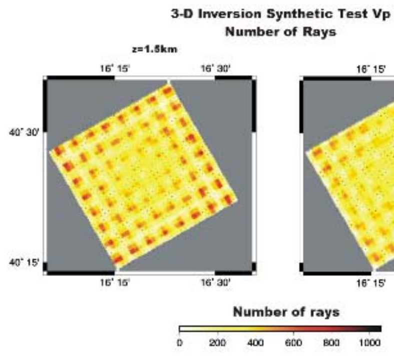


Figure 3 a)1.5km b) 3.2 km

Resolution results for a proposed network

Figure 4 a&b, presents the calculated number of rays per cell that reflect the resolution power of the method based on the above mentioned design for 1.5 & 2, 3.2 & 3.4 km. The number of rays, indicates the areas with increase confidence of results and can guide us to either modify the network geometry or pay more attention during the interpretation of the results.



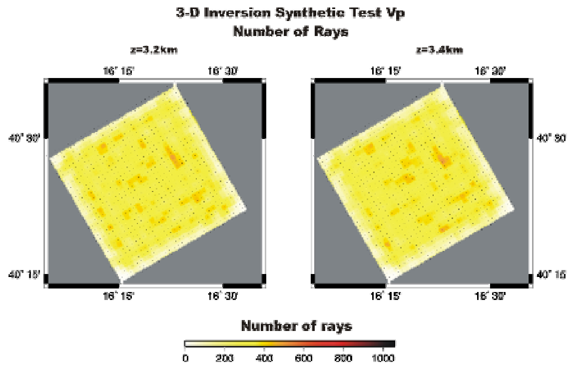
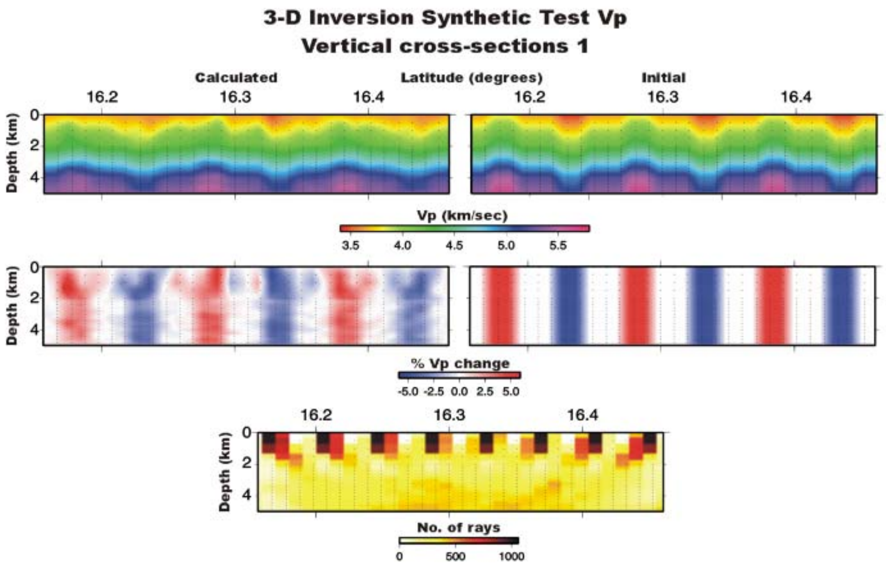


Figure 4 a) 1.5 & 2 Km b) 3.2 & 3.4 km

Cross sectional QC

Additionally QC can be done in cross sections. Figure 5 to the right shows the cross sectional initial and calculated results. As it can be seen in the target area (say 3km) we have anywhere from 300 to 500 rays per 200m cell, good enough to recover velocity variations as low as ±5%



Conclusions

We have presented here current methodologies used in the design and testing of a passive seismic network geometry in order to estimate reasonably well a velocity depth model in terms on Vp (structural) and Vp/Vs (lithological) terms.

Issues that evolve survey duration, station spacing and distribution must be considered using the means of local and regional seismicity and 3D modeling results. Resolution, accuracy as well as reliability checks must be done and are based on the power of the inversion algorithm to reconstruct velocity anomalies within the model of the order of ±5%.

Having considered the options under which the above limitations are obeyed then the proposed network design can be confidently used in a study. Synthetic and field data will be shown to bolster these conclusions.