Hydrocarbon Exploration Using High Resolution Local Passive Seismic Tomography; An application to the Dehdasht region, south-west Iran

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ABSTRACT
With the growing global demand for energy resources, passive seismic tomography started to be used widely for producing 3D images of the sub-surface structures using micro-earthquakes as a new revolutionary method in hydrocarbon exploration even in difficult mountainous terrains areas. In this study we used non-linear travel-time tomography technique to resolve seismic velocity structures in the Dehdasht area/Zagros region. The study area can be considered as an excellent place for studying passive methods due to frequent occurrence of small to moderate earthquakes. More than 8000 small seismic events, micro-earthquakes, were detected to image a 3D volume of Vp and Vs sub-surface structures. The final 3D VP and Vp/VS velocity models reveal several high and low velocity anomalies in the upper 3.0 km of the study area where shallow low-angle thrusts and synclines signify the complexity of the volume studied. We present the results of local passive seismic tomography in one of the most prone structures of the Earth for the hydrocarbon exploration; showing that a 3D image of the given region can be obtained for hydrocarbon exploration purposes at lower cost compared to classical 2D *seismic control source studies*.

Keywords: Passive seismic tomography, hydrocarbon exploration, Zagros region, travel-time, direct P-phase, micro earthquakes,

INTRODUCTION
During the last decade, 3D passive local seismic tomography has repeatedly demonstrated its power as a tool for obtaining high resolution images of shallow sub-surface structures in geologically complex areas. Seismic waves in classical controlled source seismology are usually generated by surface sources such as explosions, vibroseis etc. The travel-times and amplitudes variations of these waves/signals are commonly used to model lateral heterogeneity and bulk physical properties of the subsurface structures. However, passive seismic tomography (PST) utilities P- and S-wave arrival-times generated from micro-earthquakes. In geologically complex areas such as the study area in Dehdasht area/south-west Iran, the seismic energy from micro-earthquakes travel upward from the seismic sources to the receivers and can thus be used to map the complex sub-surface structures more efficiently than the conventional method used in controlled source seismology, simply because seismic ray-paths are one-way from the hypocentre to the surface. In PST application very small micro-earthquakes (magnitude between -0.1 to 4.0 Richter scale) are used to image the shallow sub-surface structures. These micro-earthquakes occur everywhere in the Earth even in the shield area such as Sweden. These seismic events are considered high potential seismic sources for study very shallow structures. These micro-earthquakes are usually high-frequencies and carry valuable information about the Earth structures which cannot be obtained in e.g. using conventional methods in controlled source seismology. PST delivers a 3D image of a given region with much lower cost compared to a classical 2D controlled source seismology experiment. Note that in some circumstaneous such as difficult mountainous terrains areas, active seismic methods become inconvenient and sometimes very expensive in addition to limited range. While in such conditions, still PST can provide high resolution images of sub-surface structures.

Large majority of hydrocarbon reserves in Iran are located in giant onshore fields of the Zagros region in the south-west Iran. The Zagros region has been subjected to number of 2D and 3D seismic surveys in the past decades by The National Iranian Oil Company (NIOC). However, there is still a wealth of unexploited regions among them the study area, the Dehdasht region in south-west Iran, that is considered as a high potential area for hydrocarbon reservoir. Various geophysical methods e.g., electromagnetic and gravity surveys in addition to classical seismic control source studies failed to deliver high resolution images required for hydrocarbon exploration in the Dehdasht region mainly due to the presence of the Gachsaran Formation, which contains mainly of evaporites; marls, limestones, shales and salt. We present the results obtained based on PST showing a 3D volume of Vp and Vs sub-surface structures in the Dehdasht region. Note that two more presentations on designing and testing seismic equipment are given in this conference regarding the passive experiment in the Dehdasht region.

THE STUDY AREA

The tectonic characteristics of Dehdasht area, located in the Zagros Orogeny region, are mainly controlled by thrust faulting and folding. The structural trend in Dehdasht area follow NW-SE trend similar to the Zagros Fold Thrust Belt. Geological and geophysical (e.g. from gravity survey) studies suggest that Dehdasht area has a high potential oil reservoir. More than 100 3-component borehole sensors, with high sensitivity values, were deployed in an 400 km^2 area with spacing of order of 2 km, to image shallow sub-surface structures in a geologically complex area by NIOC (*http://en.nioc.ir/Portal/Home/*). The field campaign lasted for 8 months and was accompanied by application of automatically seismological routines to analyzed the continuous recorded data done by Dana Energy Company (*http://www.danaenergy.ir/en/*).

PASSIVE SEISMIC TOMOGRAPHY

High resolution detected/located seismic events are required to produce a 3D volume of Vp and Vs sub-surface structures. Automatic P-phase picking was done using SC3-*scautopick* seiscomp3 computer package (*http://www.seiscomp3.org/*, SC3). Tune parameters e.g., bandpass filtering, STA/LTA parameters were optimized after several tests using real-data. We also used SC3-*scautoloc* for automatic event detection/association. SC3-*scautoloc* tries to identify combinations of picks that correspond to a common seismic event. If the produced location meets certain consistency criteria, it is reported, i.e. passed on to other programs that take the origins as input. In general, about 8241 seismic events, micro-earthquakes, with magnitude range from 1.6 to 5.3 were detected by automatic phase picking and event detection algorithms between 2016-11-01 till 2017-07-4 (see Figure 1). Our final dataset contain about 43094 P- and 42301 S-phase travel-times in total 85395, giving an average of more than 80 observations per event.

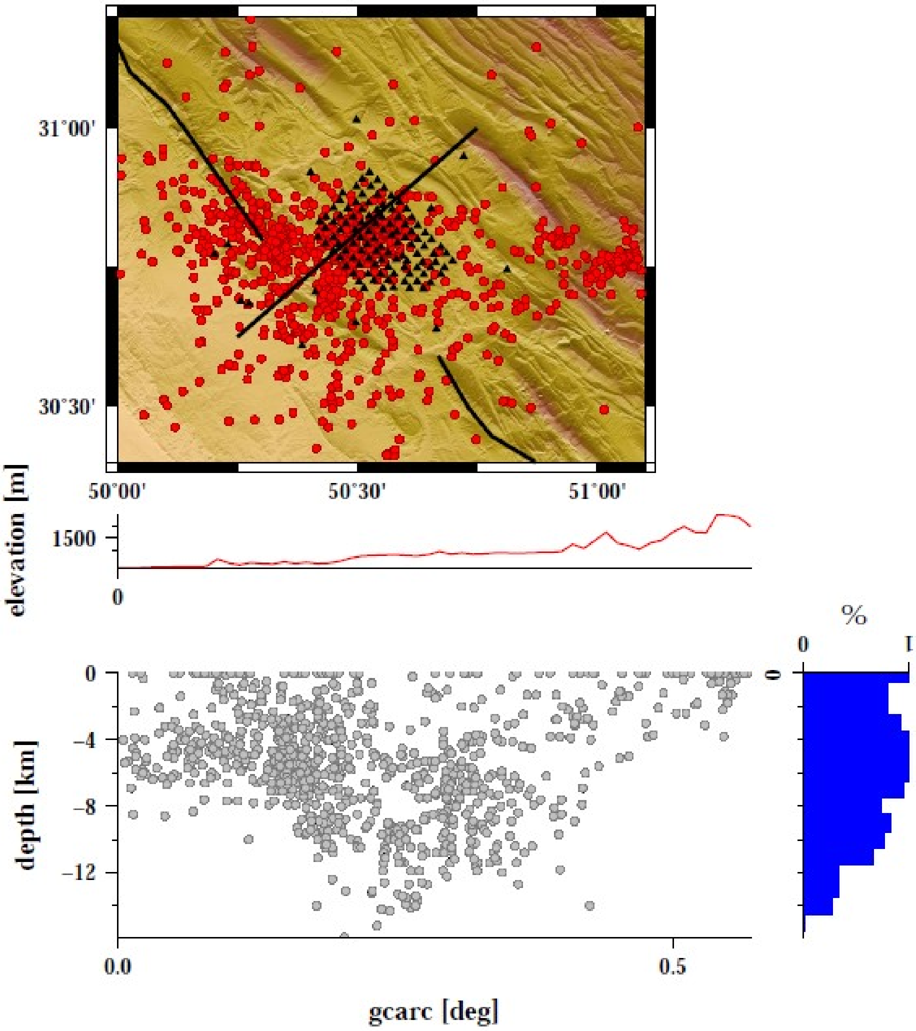

Figure 1. Figure shows seismicity recorded during the Dehdasht PST experiment map-view and also plotted a long a SW-NE profile. Note to clear NE-dipping seismicity in the upper 10km of the crust which was not clear in automatic event detection.

Solutions of 3D travel-time seismic tomography is highly non-linear and depend on the data quality and also on the 1D staring velocity model (e.g., Kissling et al. , 1994). An appropriate 1D starting model is thus required in order to avoid trapping in any local minima during inversion. 1D staring velocity model should be prepared based on simultaneous inversion of 1D velocities (Vp & Vs) and hypocentral parameter. Hypocenter locations are included in the inversion as unknowns, due to the coupling of hypocenter locations and velocities. Travel-times through the velocity model are calculated using full 3-D shooting ray tracing (Virieux and Fara, 1991). Thus model parameters consist of 3D velocity (Vp and Vp/Vs at different nodes) and also hypocenter locations indicating that the coupling between hypocenter locations and velocities is taken into account during the inversion. We used all available information about velocity structures of the study area including check shots etc to constrain the initial velocity model required for the inversion. We also used a damped least-squares iterative method to solve the non-linear tomography problem. Damping and other regularization parameters were then implemented to stabilize the inversion (Husen, et al., 2003; Rezaeifar et al., 2016). A cross-section along the final 3D Vp model resulted from the simultaneous inversion is depicted in Figure 2.

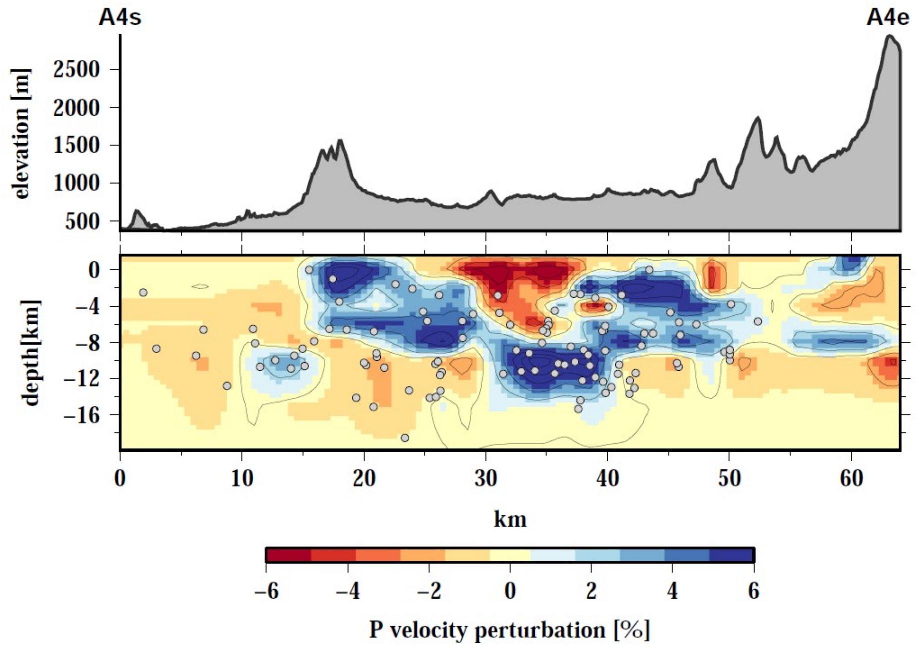

Figure 2. A vertical slice of inverted 3D wave velocity cube along SW-NE direction, in the middle of study area. P-phase result from the separate inversion is presented in perturbation (%). In the cross-section, circles denote hypocenters of relocated earthquakes in 3D velocity volume. Topography along the profile is also shown in the upper part. One of the most striking features of the resulted images is the almost perfect correlation between the pronounced syncline/anticline structures of the Zagros region and the low-high velocity anomalies resolved in some part of the models.

CONCLUSION(S)

The final 3D VP and Vp/VS velocity models reveal several high and low velocity anomalies in the upper 3.0 km of the study area. Cross sections through the resulting 3D models illustrate several interesting tectonic features including a NE-dipping seismicity associated to the MZF (Main Zagros Fault) and syncline/anticline structures in the shallow parts of the model. High velocity anomalies observed in these areas are generally addressed to as older, consolidated bodies while low velocity anomalies are related to the presence of fluids and or younger structures. We provide structural (Vp) and lithological (Vp/Vs) results for the study region, Dehdasht that can be used as an indication of regions of hydrocarbon potential. It has been observed that Vp/Vs is a sensitive measures to gas and liquid saturation reservoirs. In details, we provide the following information/images for the study area, Dehdasht :

- Absolute location of the seismic events relocated in 3D volume,
- High resolution 3D seismic tomography images of Vp and Vp/Vs,

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