P105

Particularities of Astrakhan Gas Field Deep Structure Resulting from Microseismic Sounding Technique Application

A.V. Gorbatikov* (Institute of Physics of the Earth, Rus.Acad.Sci.), M.Y. Stepanova (Institute of Physics of the Earth, Rus.Acad.Sci.), A.A. Tsukanov (JSC "Zarubezhneft"), S.L. Odintsov (JSC "Astrakhangazprom"), O.V. Tinakin (JSC "Astrakhangasprom") & A.Y. Komarov (JSC "Astrakhangasprom")

SUMMARY

On base of new passive seismic technique the deep structure of Astrakhan gas field was investigated. There was found a subvertical stock-type structure associated with the productive area sinking down to depths of at least 30-35 km. This structure was assumed to be a possible fluid conducting channel.

Introduction

Areal and profile surveys have been made according to microseismic sounding technique on the territory of Astrakhan Gas-Condensate Field (AGCF), south Russia. The large extended subvertical low velocity structure could be followed down to the depths of 30 km below the gas field. It probably could be interpreted as deep channel of fluid conduction.

Observation technique is based on space and frequency analysis of natural background microseismic field intensity in wide frequency range (from 0.03Hz to 1Hz). It allows estimating the morphology of 3-D models of relative velocities of S-seismic waves. The method utilizes waves of natural microseismic field as sounding signal. It is assumed that the basic contribution to the vertical component of a microseismic field is carried out at the expense of fundamental modes of Rayleigh surface waves of various frequencies.

Method and technique

In general case, as results of a considerable quantity of experiments and numerical modeling show, heterogeneities of the Earth crust distort a spectrum of a low-frequency microseismic field in its vicinity. And namely on the Earth surfaces above high velocity heterogeneities spectral amplitude of definite frequency f decreases, whereas above low velocity heterogeneity it increases. The frequency f is connected with depth of heterogeneity deposition H and velocity of fundamental Rayleigh mode $V_R(f)$ by the following relation $H = K*V_R(f) /f$, here K- is numerical factor close to 0.4. It occurs also due to a fact that zone of the shear stresses maximum in a fundamental Rayleigh mode (and so the zone of maximum sensitivity in relation to inclusions) is located at the depth of order 0.3λ where λ – is wavelength.

We solved the question about the accuracy of media structure determining and resolving capacity of the method on base of computer simulation (Fig.1) and experimental estimations. It was demonstrated that in case of exposing the large inclusions with microseismic waves from all different directions the position of vertical and horizontal boundaries in the absence of measurement errors could be recovered precisely. The heterogeneity character dimension must exceed 1.5λ (where λ – is Rayleigh wave length).

Depth and the lateral position of “focal points” of small heterogeneities (when dimension of heterogeneity is less than Fresnel zone) could also be recovered precisely independently from the relation between dimension and wave length. In this case however the shape of the heterogeneity takes a form of a generalized cloud with size of about Fresnel zone. If distance between two small inclusions is less Fresnel zone they will be observed as a united object with the common "focal point". Earlier experimental measurements for large geological objects demonstrated that the method accuracy of determining the vertical bonds positions could be estimated as ~5 % of sounding wave length, or ~10 % of heterogeneity deposition depth. Accuracy of determining the horizontal bounds is estimated as ~20 % of the depth.

The technique realizing this method was developed and tested in numerical simulations and a number of experimental researches. This technique allows defining the deep structure of complicated geological objects on the basis of background microseismic field utilization. The technique including measurements and processing implies: 1) Measurement of statistically steady microseismic spectra in all the points of a network or a profile. In order to achieve a statistical stability the microseismic signal was accumulated during stationarity period determined experimentally and equal approximately to 2 hours; 2) Plotting the map or profile of microseism intensity distribution for each frequency in the spectrum; 3) Corresponding of the map or profile intensity plot to a depth proceeding from a relation: $H(f) \approx 0.4\lambda(f) = 0.4\ V_R(f) / f$, where $H(f)$ – the depth of a layer for which the image is under construction, $\lambda(f)$ - the wavelength of fundamental Rayleigh mode, $V_R(f)$ - velocity of fundamental Rayleigh mode, ***f*** - frequency in the spectrum of microseismic signal which calculation is made for.

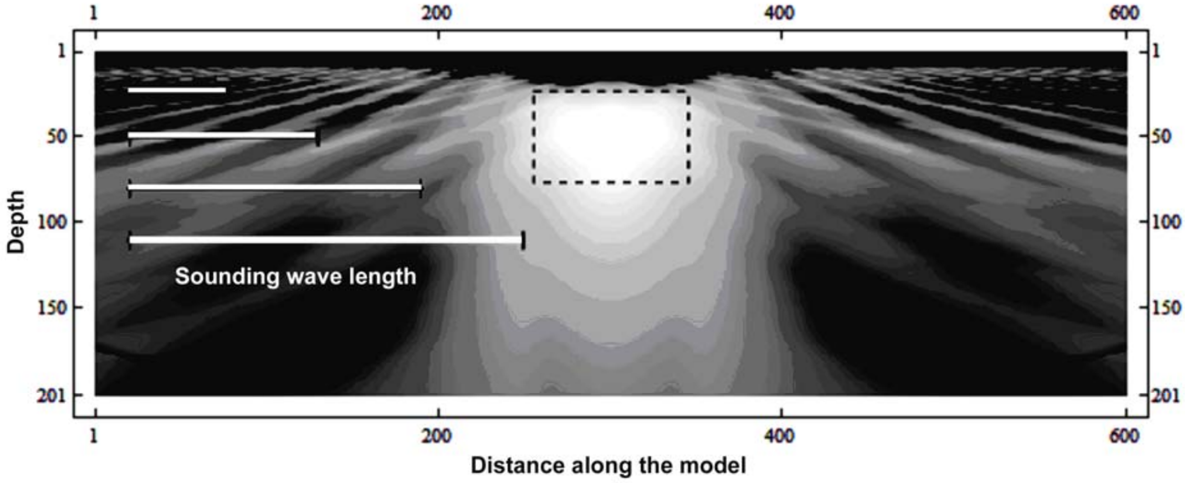

Figure1. *Example of a 2-D direct problem solution and subsequent resulting inversion for rectangular heterogeneity exposed from both directions with Rayleigh waves in a wide frequency range (or what is the same with a large number of waves with different lengths); the axes dimensions are presented in relative units.*

Results of research at the gas field territory

We conducted a study of AGCF area with the microseismic sounding method in 2003-2006. The measuring network contained 200 points. Average distance between measuring points was about 2-2.5 km. Resulting 3-D model of relative velocities below AGCF was compared with results of earlier independent geological and geophysical surveys. One can point out a good coincidence between morphology of salt depositions cover and configuration of porosity in the productive layer with results of microseimic survey obtained for corresponding depths.

Comparison between miroseismic sounding results and data from independent research along profile containing wells “Devonian 1, 2 & 3” is shown in the Fig.2. Thus on the industrial seismo-prospecting cross section (Fig.2a) in the depth range between 4 and 10 km two vertical zones could be revealed which were interpreted as zones of increased fissuring. In turn in the Fig.2b these zones could be distinguished in the equivalent depth range in a view of zones with increased relative intensity of microseismic field which corresponds to decreased velocities of shear seismic waves. A slight visible displacement in the mutual arrangement of these zones in different sections we explain by non ideal coincidence between measuring profiles. The agreement between microseismic sounding results with geological data we observe in the depth range of the salt depositions (down to 4 km). One can see that alternating along the profile salt domes and troughs appear in the microseismic section. Zones with depressed relative intensities correspond to salt domes as rocks with relatively higher seismic wave’s velocities, and zones with increased relative intensities correspond to inter dome troughs filled with terrigenous sediments with relatively lower seismic wave’s velocities. It could be distinguished as well that in the microseismic section at the depth of about 4 km the section pattern character is changing distinctly. According to drilling data at that depth a transition from Permian salt structures to carbonate depositions is observed. Similar change in the microseismic section character has place at the depth of about 10 km, which could be linked with known depth of basement deposition – 8-10 km.

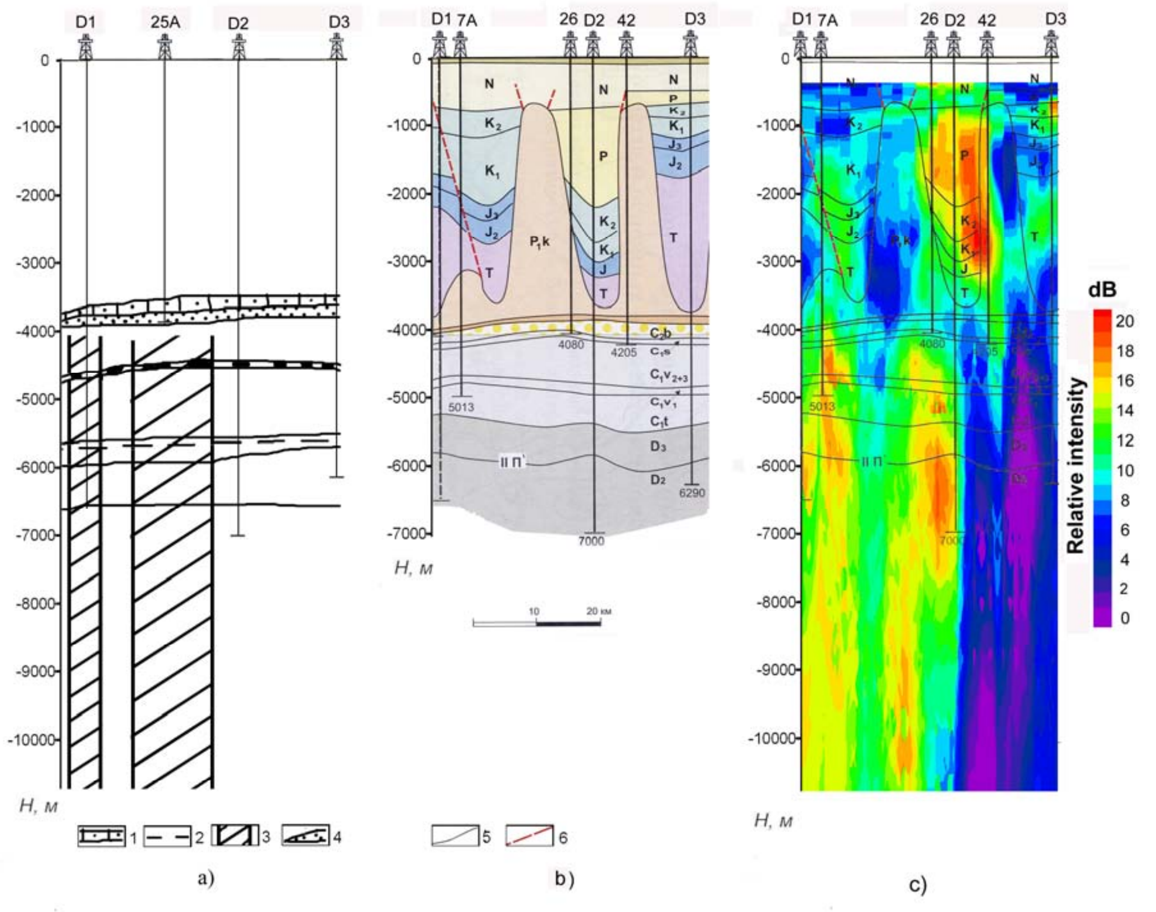

Fig.2. ***(a)*** *Geological and geophysical section of the Earth crust across Astrakhan arch (by Brodsky, Pykhalov, 2006). 1- siliceous-loamy deposits; 2- loamy deposits; 3- zones with anomaly increased fissuring; 4-Astrakhan gas field bed;* ***(b)****- Geological section along profile containing wells D1-D3 (by Volozh et al., 2008). 5-bounds of stratigraphic units and reflective horizons, 6- assumed tectonic abnormality.* ***(c)****- Microseismic sounding cross section.*

Microseismic sounding results analysis shows that for all the depths more than 10 km the character of relative intensity distribution remains constant. It differs from upper horizons both with pattern and with higher variations of intensity. In the Fig.3 the 3-D bodies represent zones outlined with surfaces of equivalent relative intensity. The dark blue tone corresponds to the relative intensity level 16 dB and indicates zones with increased velocities of seismic waves, and the dark yellow tone is outlining zones with decreased velocities of seismic waves and corresponds to the level 25 dB. One can distinguish in the figure four subvertical structures with decreased velocities (a,b,c & d) and three subvertical structures with increased velocities *(e, f, g)*. At the same time bodies a, b and c are merging down to a joint zone with decreased velocities at the most deep horizons. All the vertical structures could be followed from big depths and up to 10 km depth and their relative intensities drop down in proportion as approaching the surface. In the Fig.5 only bodies a, b & d approach visually the 10 km depth. The vertical body e has the lowest relative intensity in the low horizons and we associate it with positive gravimetric anomaly know in this place. The vertical structures with increased velocities we could interpret as volcanogenic formations. They fit well the deep volcanic edifices known for the AGCF territory and arranging along NW-SE line.

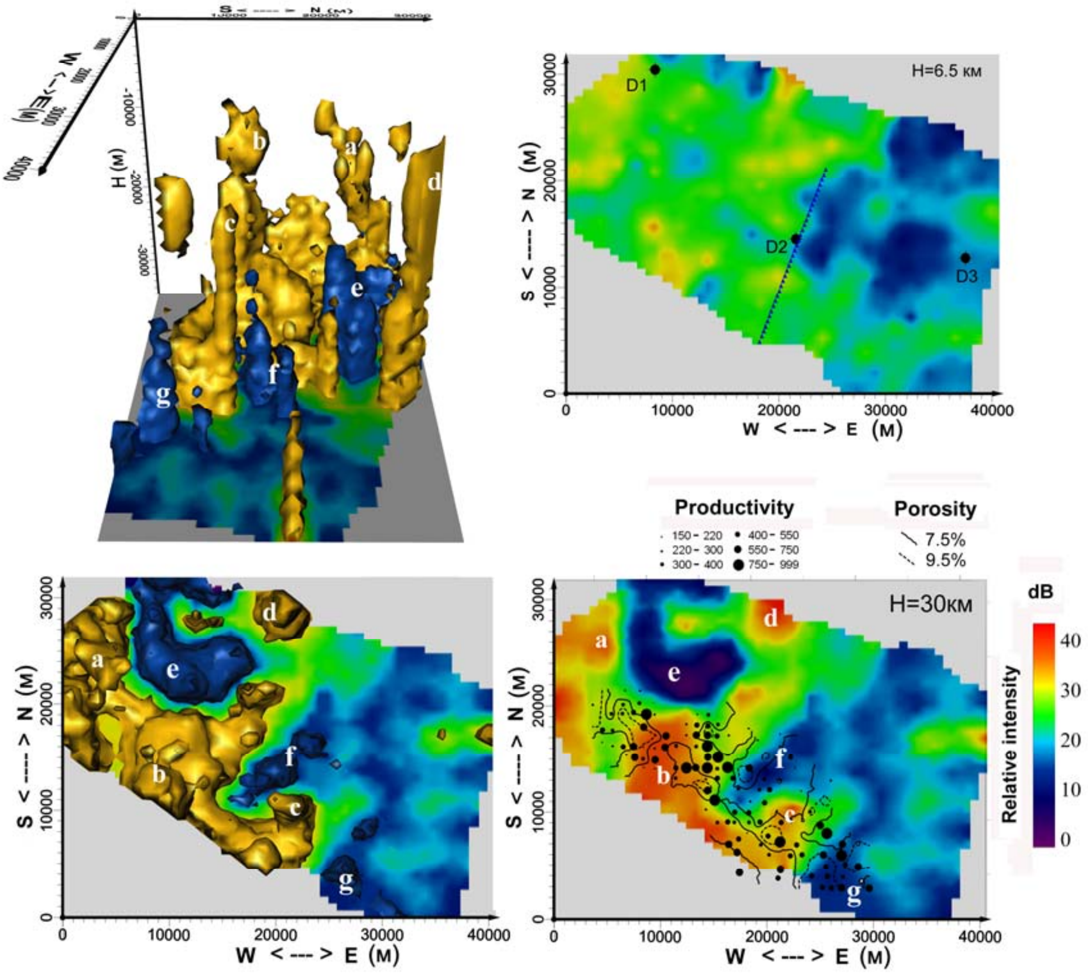

__Fig.3.__ Results of microseismic sounding for the depths down to 30 km.

In the Fig.3 (right side, down) the scheme of productivity and average porosity for gas field productive depth is imposed on the pattern with microseismic sounding results obtained for 30 km depth. We can see that positions of the wells with maximum productivity (marked with black circles) correlate with earlier revealed bodies b and c, and zone of increased productivity is extending along the direction SW from the body c. Many researchers before mentioned the controlling role of deep faults located in platform crystalline basement on the formation of hydrocarbon deposits in the sedimentary cover. In our case we could assume that lower seismic velocities are associated with high fluid conductivity, and visible extended subhorizontal zones and vertical bodies are associated with a deep fault system. This assumed fault system must be directly connected to three high velocity subvertical bodies e, f & g which are marked in the gravimetric field with positive anomalies and probably represent deep intrusions who's volcanic rocks were discovered with Devonian wells.

A coincidence between geological description of wells D1, D2 and D3 with microseimic 3-D resulting model could serve as independent verification of our assumption. On the horizontal section of microseismic model for the depth 6.5 km (Fig.3) one can see that wells D1 and D2 are located at the essentially different conditions than the well D3. According to microseimic data we could suspect here for D1 and D2 the higher fissuring comparing to D3. This assumption is in good correspondence to drilling results which evidently show the presence gas saturated volumes in D1 and D2 bedding at the depths of about 6-6.5 km as in contrast to D3.

Thus application of microseismic sounding technique could provide a good assistance in optimizing the AGCF exploitation in future and probably other hydrocarbon fields as well.