INFLUENCE OF ROCK FRACTURING AND POROSITY ON SEISMIC WAVES BY MATHEMATICAL MODELING

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The study of elastic waves fields in fractured or porous medium is the main method of complex and unconventional oil and gas reservoirs detection at the stage of prospecting and exploration of deposits. This analysis is carried out to identify features of seismic wave propagation through the fractured (porous) zone. Based on analysis of elastic waves properties are allocated fracture zones that can contain hydrocarbons in carbonate rocks with high probability, as well as indicate presence of deep faults. In clastic sediments reservoirs are highly porous rocks, so effect of porosity on seismic signal also is studied in the paper. Described in this paper, the research helps to forecast of hydrocarbon deposits and deep structure of the Earth's crust for a more effective fields development.

The calculation was performed by our mathematical algorithm (finite-difference method within the elasto-brittle medium), which describes full seismic field including all emerging types of waves. Compared to physical experiments it has more flexible technology and methods, accuracy obtained values. The method allows to efficiently explore dynamic and spectral characteristics of seismic waves passing through the created models similar to structure of geological section.

In the first stage of works, seismic models describing the fractured zones with different geometry were created. The main cause of rocks fracturing is stress-strain state of the medium. Considerable amount of open cracks results in a significant attenuation of seismic waves and emergence of scattered waves on a set of cracks. Directional fracturing leads to anisotropy of rocks mechanical properties, whereby there is dependence of seismic wave propagation velocity from their propagation direction.

The simplest way to set fractured zone is assignment lower value of the elastic wave propagation velocity (the white area in the center of Fig. 1. Due to the non-uniform velocity values of the second layer on the seismic section diffracted wave and the corresponding multiples waves is observed.

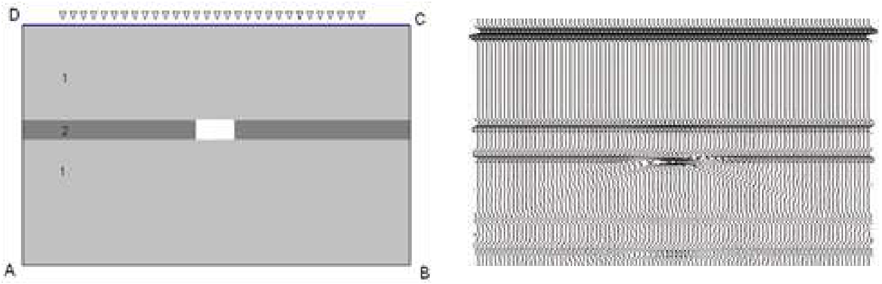

Fig. 1. The simplest model of fractured zone and calculated seismic section

The second model contains a more specific description of geological medium structure: multiple fracturing (2% first type cracks) is defined randomly in the center of the middle layer. Separate crack is described two sides and peaks. Edge cracks are horizontal so cracks behave like the first type (separation cracks). With the passage of alternating impulse, every single fracture generates scattered waves and the diffraction area. These features are clearly seen on the resulting model seismograms (Fig. 2). Diffraction begins immediately after reflected wave formation from 50 ms and by 175 ms reaches edges of the model.

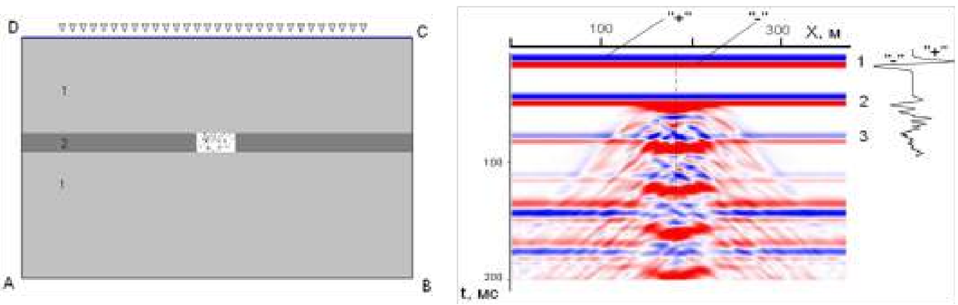

Fig. 2. Model with multiple fracturing and calculated seismic section

In a real medium tectonic stress, which leads to breach of rock continuity, acts irregularly, so often fissures do not occur randomly, but mostly in certain direction, that is anisotropy of fracture is observed, and it leads to anisotropy of seismic wave parameters.

In particular, wave pattern of the elastic wave propagation parallel continuous cracks, located across the studied site was calculated. This model was chosen by analogy with published physical experiment [3] on aluminum sample where cracks were set through 3 mm by saw cuts and examined various variants of saturation.

In general, calculated seismic field similar to the results of physical experiments (Fig.3): clear phase rotation with sufficiently high vibration amplitudes replaced by diffracted and damped wave picture at late times. The presence of waveguide effect (sharp decrease energy from central axis towards sample edges), is associated probably with microscopic inhomogeneity surface cuts, which are absent in mathematical model.

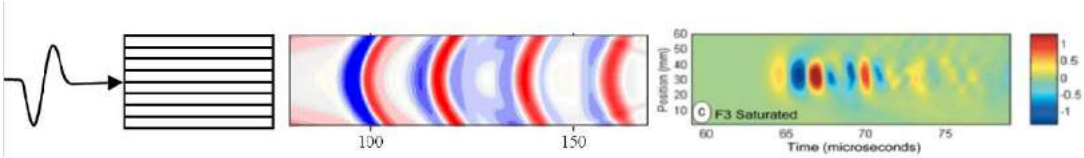

Fig. 3. Model with parallel cuts, calculated seismic section and seismic field from [3]

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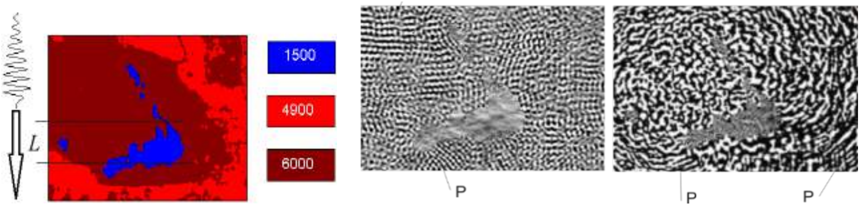

***Fig. 4. Model of single pore, result of seismic calculation and experimental wave field from* [2]**

The results of both mathematical modeling and physical experiment after wave passage through the pore and reflection from edges of the models show almost chaotic wave pattern. Some parts of in-phase arc compressional waves (letter P in Fig.4) are traced. In both cases pore is saturated with short-term fluctuations, the pores of the border is clearly expressed in seismic field. In general, the performed calculations have shown that single pore is clearly visible in wave field due to contrast of elastic properties, in this case explicit diffraction effects are observed in the seismic picture.

Comparison of seismic effects generated by single pore in mathematical and physical version of experiment confirmed the possibility of applying the algorithm for porous medium. The following model contains a middle layer in which pores are randomly set, and we can vary porosity coefficient in a wide range. The seismic effect from porous zone we can see in Fig. 5, which shows velocity field for the time when wave front reached the upper boundary of the layer containing voids and linear character of front has begun to change. Every single pore behaves as shown in the previous case, so in general there is amplitude reduction, signal scattering and decrease in its propagation velocity.

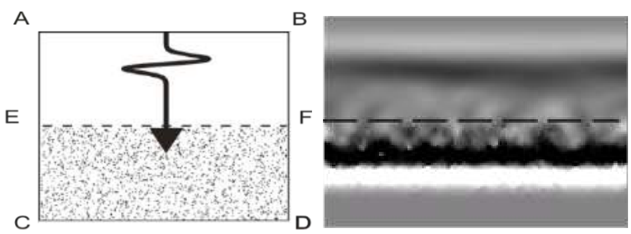

Fig. 5. Model porous layer and calculated seismic section

In this case, the objective was not only to obtain a high quality wave pattern, but also to apply techniques of quantitative interpretation - to determine P-waves propagation velocity after passing through the porous layer. This parameter was defined by inclination angle of travel-time curve of refracted wave in the plane (t, y) (the time, the vertical axis). The results were compared with the data in [1], which describes a physical experiment on porous samples, so we used the same pore size and characteristic parameters of waves in formulating parameters of our mathematical calculation. Series of computation for several porosity values (from 2% to 20%) was carried out. There is obvious linear dependence of velocity on porosity coefficient. Mathematical calculation error regarding laboratory test data for the above parameters of porosity does not exceed 2%.

Thus, the article discussed from unified positions fractured and porous media with description separate cracks and pores. During the research, we obtained wave pattern images for different models of media, and in some cases quantitative characteristics which can be used to processing and interpretation of real field data.

The derived results are compared with published data of other authors, including effects of laboratory experiments. At present, our work is focused on creation of algorithms to identify zones of irregularities in real seismic sections based on revealed regularities.

References

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LANDWIRTSCHAFTLICH BENUTZTE FLÄCHEN

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Deutschland ist ein dicht besiedeltes Land. Über 80 Millionen Menschen leben auf 35,7 Mio. Hektar. Seit Jahrhunderten bewohnt und bewirtschaftet der Mensch Deutschland intensiv. 13 % der Landfläche nutzt er für Siedlung und Verkehr. Auf 52 % der Fläche wird Landwirtschaft betrieben. Die Landwirtschaft ist damit die größte Flächennutzung in Deutschland. Danach folgen der Wald bzw. die Forstwirtschaft mit 32 %.

Die landwirtschaftlich genutzte Fläche (LF) ist eine landwirtschaftliche Flächenmaßeinheit, die in der Statistik und Verwaltung, insbesondere bei Produktionskennzahlen wie Erträgen verwendet wird. Sie wird häufig in Hektar (ha) angegeben.

Sie umfasst Ackerflächen, Dauerkulturflächen und Dauerweideflächen. Zu den Ackerflächen werden auch temporäre Weideflächen, Markt- und Gemüsegärten und zeitlich begrenzte Brachflächen gezählt. Zu den Dauerkulturflächen werden Ziersträucher, Obst- und Nussbaumanlagen und Weinflächen gezählt, aber kein Nutzholz. Zu den Dauerweideflächen zählen Flächen, die seit mindestens fünf Jahren als Futterquelle dienen [1].

Zu unterscheiden ist die landwirtschaftlich genutzte Fläche von der landwirtschaftlichen Nutzfläche (LN), die nicht die landwirtschaftlichen Flächen (z. B. Gebäude- oder Hofflächen) umfassen. Die LF eines landwirtschaftlichen Betriebes ist daher in der Regel kleiner als die LN.

Den Anteil landwirtschaftlicher Nutzfläche in Deutschland und deren Veränderung kann mit dem Monitor der Siedlungs- und Freiraumentwicklung (IÖR-Monitor) beobachtet werden. Die landwirtschaftlich genutzte Fläche ist unregelmäßig über das Bundesgebiet verteilt. Während in agrarisch geprägten, waldarmen Regionen hohe Werte erreicht werden, beispielsweise in Nordostdeutschland und weiten Teilen Niedersachsens, Thüringens, Sachsens, Baden-Württembergs und Bayerns. Städte weisen erwartungsgemäß fast durchweg einen deutlich geringeren Anteil an Landwirtschaftsfläche als die sie umgebenden Landkreise auf. Besonders niedrige Werte treten zum Beispiel in Großstädten wie Berlin und München sowie in Agglomerationsräumen wie dem Ruhrgebiet auf. Auch kleine Städte mit waldreichen Umgebungen wie Suhl oder Kaiserslautern und die Niederlausitz, das Sauerland, der Schwarzwald, der Bayerische Wald und teilweise der Alpenraum haben wenig landwirtschaftliche Nutzflächen zu verzeichnen. Dies lässt sich der geringen Bodenfruchtbarkeit der nährstoffarmen Böden erklären, die zum Beispiel in der Niederlausitz oft nicht für den Ackerbau ausreicht [2].

Im Jahr 2010 wurden in Deutschland insgesamt rund 16,7 Millionen Hektar landwirtschaftlich genutzt. Gemäß der Statistik ist das Diagramm die landwirtschaftliche genutzte Fläche in Deutschland in den Jahren 1949 bis 2015 geschaffen (Abb.).

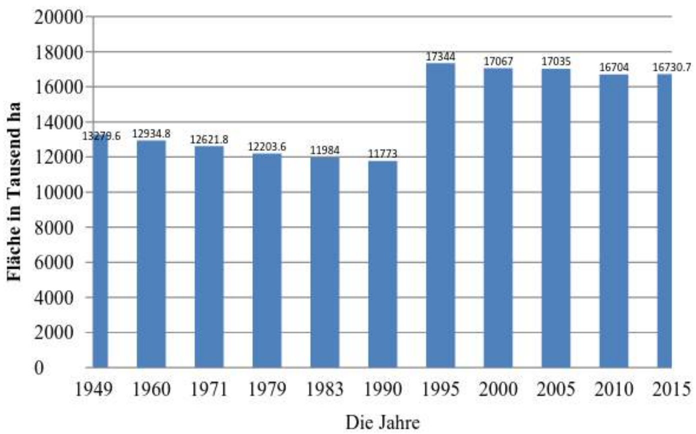

Abb. 1. Landwirtschaftliche Nutzfläche in Deutschland [4]