Using a new approach of construction synthetic orthorhombic media: application on the estimative of Thomsen's parameters

Crislene da Silva[a], Jose J. S. de Figueiredo[a,b] and Leo Kirchhof Santos[b],

[a]UFPA, Faculdade de Geofísica, Laboratory of Petrophysics and Rock Physics Dr. Om Prakash Verma (LPRF), Belém, PA, Brasil. [b]Instituto Nacional de Ciência e Tecnologia – Geofísica do Petróleo (INCT-GP), Brazil.

This paper was prepared for presentation during the 15th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 31 July to 3 August, 2017.

Abstract

The goal of this work is to make artificial anisotropic synthetic samples with orthorhombic symmetry with different crack densities and relate these densities with Thomsen's parameters. For this purpose, we made four core samples with bedding planes and different number of parallel cracks. The first sample was made without fratcures and the others with 3, 4, and 6 fartcures, respectively. Based on the pulse transmission technique that propagates P- and S-waves through each sample to determine the waves' traveltimes and calculate their velocity in each direction for each sample. Those velocities were used to calculate Thomsen's parameters for orthorhombic media based on Tsvankin's notation.

Introduction

By definition, orthorhombic media has three perpendicular planes of symmetry and nine independent stiffness coefficients (figure 1). These planes of symmetry are usually associated with the coordinate planes to facilitate the calculations. This kind of anisotropy can be represented by a media with one system of parallel cracks in a background media with vertical transverse symmetry or two crack systems perpendicular to each other (Tsvankin, 1997). Here, the first representation is used because it can be exemplified by fractured shale or a set of bedded fractured sandstones, which usually are the relevant part of the geological scenario of most hydrocarbons reservoirs. Therefore, for the oil industry it's very important to be familiar with how the elastic properties of this media are affected by its crack density.

From laboratory experiments oriented crack systems have been observed to affect significantly the elastic properties of rocks and modify their seismic signatures by attenuating its amplitude and delaying the waves' arrivals. In the orthorhombic media analyzed here, the crack system is oriented in the [Y,Z] plane. As a result, we expect the velocity and the amplitude of both s and p-wave to be greater in the y-direction and smaller in the x-direction. We also expect the Thomsen's parameters related to the z-axis of symmetry (ε_3, γ_3, δ_3,) to be the larger.

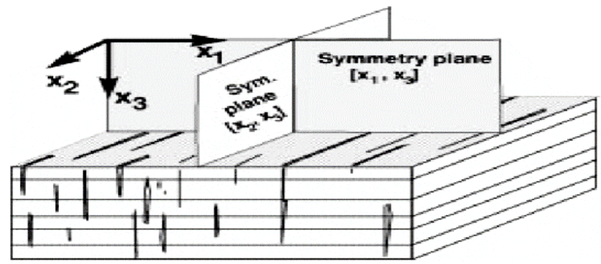

Figure 1 - Orthorhombic media composed by a VTI background and a vertical crack system in the [Y,Z] plane. Modified from Tsvankin (1997).

From laboratory experiments oriented crack systems have been observed to affect significantly the elastic properties of rocks and modify their seismic signatures by attenuating its amplitude and delaying the waves' arrivals. In the orthorhombic media analyzed here, the crack system is oriented in the [Y,Z] plane. As a result, we expect the velocity and the amplitude of both s and p-wave to be greater in the y-direction and smaller in the X-direction. We also expect the Thomsen's parameters related to the z-axis of symmetry (ε_3, γ_3, δ_3,) to be the larger.

Methodology

The methodology used here can be described in two stages. The first stage is referred to the manufacture of the orthorhombic core samples and the second one is referred to the measurement of the P- and S-wave traveltimes and the calculations of the Thomsen's parameters. It is important to quote that both stages of this work were made in the Laboratory of Petrophysics and Rock Physics Dr. Om Prakash Verma (LPRF) using a Ultrasonic System composed by a pulse receptor - model 5072PR – and a preamplifier – model 5660B- both of Olympus, a 50 Hz USB oscilloscope of Handscoop, and two transducers of 1 MHz (P-wave) and 500 kHz (S-wave).

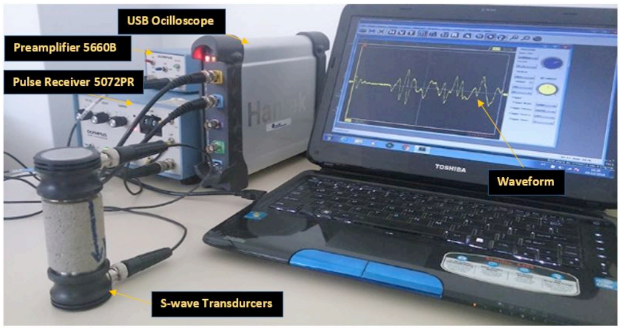

Figure 2 - Ultrassonic Measurement System.

A new technique developed by Santos et al. (2017) was used to make the orthorhombic core samples. This new technique consists of using a mixture of fine sand, cement, and a small amount of water to manufacture the background of the four orthorhombic core samples and to use thin slices of cuts A to generate the crack system. The proportion of solid material used in all the core samples was 65% of sand and 35% of cement. First, we pour one centimeter of the mixture into our mold and waited for about ten minutes to pour the next layer of 0.5 centimeter. In this second layer we introduced rectangular-thin slices of cuts A to generate the crack system in [Y,Z] plane. After that we deposited layers of 0.5 centimeters until the cuts A was totally emerged in the mixture. The time interval between each deposition was about five minutes and that proportioned a bedded background of week anisotropy in the core samples.

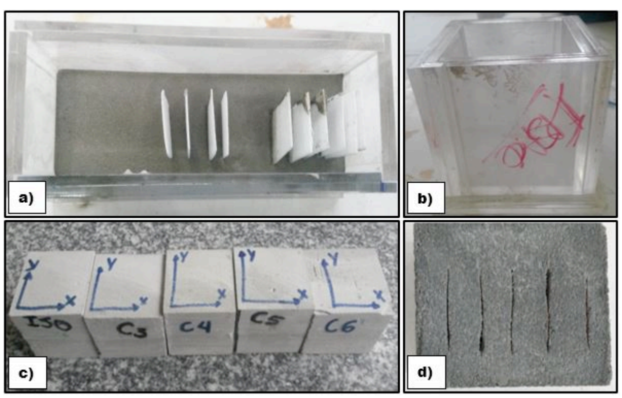

Figure 3 – Representation of core samples' manufacturing process: a) The inclusions in the c4 and c6 samples, b) acrylic rectangular mold, c) orthorhombic samples and d) photo of fracture swarm.

For the first sample, ISO, no cuts slice was introduced in order to make a VTI sample to attest the background anisotropy of the core samples. For C3, C4, c6 core samples, three, four, five and six slices of cuts were introduced, respectively. The last step was to emerge the core samples into thinner during about 2 hours in order to dissolve the cuts A and generate empty cracks inside the core samples.

Samples Dimensions and Physical Properties				
	ISO	c3	c4	c6
X (cm)	6,21	6,68	6,265	6,932
Y (cm)	6,21	6,12	6,1	6,096
Z (cm)	6,41	6,186	6,361	6,148
Volume (cm^3)	247,20	252,89	243,10	259,80
Mass (g)	483,57	496,4	467,55	488,07
Density (g/cm^3)	1,96	1,96	1,92	1,88

Table 1 - Dimensions and physical properties of the orthorhombic core samples.

The sampling rate per channel used in the Ultrasonic System to measure both P-wave and s-wave amplitudes for all the samples in the three directions was 0.01 µs.

As stated before, to calculate Thomsen's parameters for the core samples we used Tsvankin's notation (1997), which consists of using Thomsen's recipe for each symmetry plane of the media. Therefore, each sample has 9 parameters: ε_1, γ_1, δ_1, ε_2, γ_2, δ_2, ε_3, γ_3, δ_3, in which the subscript numbers are related to the axis of symmetry (the axis perpendicular to the symmetry plane analyzed). Here, we will limit ourselves on calculating just the epsilons and gammas for each sample.

Results

Figures 2 and 3 are examples of the P- and S-wave arrival time pickings executed in this work to calculate the velocities of both waves for each core sample.

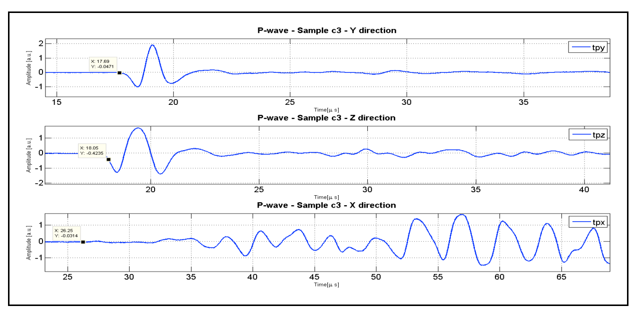

Figure 4 - P-wave traveltime picking example of sample c3 in the Y, X and Z directions.

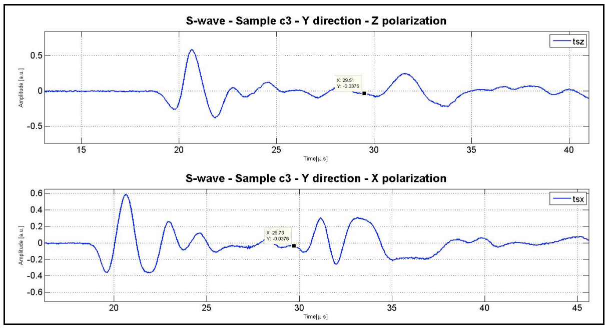

Figure 5 - S-wave traveltime picking example of c3 in the Y-direction (top-S2 and bottom-S1).

The P-wave and S-wave velocities for c3, c4 and c6 shown in Tables 2 and 4 are, in general, greater in the Y-direction and smaller in the X-direction (being the velocities in Z-direction intermediary), which was expected due to the their orthorhombic symmetry. For sample ISO, P-wave velocities in both Y and X directions are equal while in Z-direction it is smaller, which kinematically characterizes a VTI media.

Table 2 - P-wave velocities obtained from P-wave traveltime pickings.

	P-wave Velocities (m/s)			
	ISO	c3	c4	c6
Vpy	3397.155	3489.168	3620.178	3635.063
Vpz	3211.423	3453.936	3311.296	3394.809
Vpx	3397.155	2558.407	2350.844	3313.576

The behavior described in the last paragraph can be noticed in the graphs below.

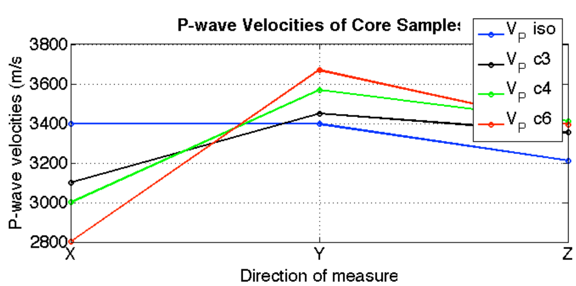

Figure 6 - P-wave velocity of each sample in relation to their direction showing the behavior expected for orthorhombic media.

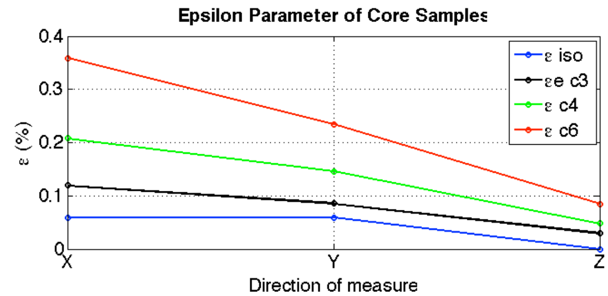

Figure 7 - Epsilon parameter of core samples showing the expected pattern for orthorhombic media.

As expected ε_3 is the greatest parameter for all the orthorhombic samples and it very small for the sample ISO (background VTI). This happens because the contrast between the P-wave velocity in the X-direction and the p-wave velocity in the Y-direction is the greatest (due to the X-direction being perpendicular to the plain of the crack system and the Y-direction being in-plane to both the plain of the crack system and the plain of the bedding planes). The values of the epsilon parameter are shown on Table 2.

Table 3 - Epsilon parameter of the samples showing, in general the pattern expected for orthorombic media with the crack sistem in the [Y,Z] plane.

	ISO	c3	c4	c6
ε1	0.060	12.000	20.770	35.900
ε2	0.060	8.500	14.610	23.470
ε3	0.000	3.000	4.770	23.000

From Table 4 we can observe the velocity differences between the S-wave polarized in the x-direction and the one polarized in the y-direction which for all the orthorhombic samples while in the VTI sample (ISO) there are equal. We also can observe that the velocities for the wave polarized in the Y-direction are smaller than the velocities of the ones polarized in the X-direction, which is theoretically the contrary of we were expecting. This also happens for the X-direction of propagation, the velocities of the S-wave polarized in the Z-direction are greater than the velocities of the ones polarized in the Y-direction. The Figure 8 shows the behavior of S-wave velocities (VS1 and VS2) for direction X, Y and Z.

Table 4 - S-wave velocities of the all samples showing the velocity differences between the s-wave polarizations when the direction of propagation is the Z-direction.

S-wave velocities (m/s)					
Direction	Polarization	ISO	c3	c4	c6
X	y	2217.000	1741.851	1699.674	1696.525
	z	2199.000	1718.991	1612.198	1580.483
Y	x	2217.000	2120.582	2077.657	2041.527
	z	2201.000	1983.150	1914.626	1855.143
Z	x	2161.160	1941.620	1878.618	1763.626
	y	2161.160	2106.948	2061.244	1992.223

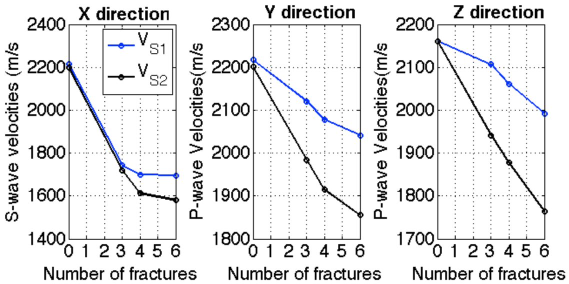

Figure 8 - S-wave velocities for all samples directions (X, Y, Z) as function of fracture number.

As can be noted, the X direction showed the smallest values of birefringence. The Table 5 shows the gamma parameter evaluated by the VS1 and VS2 velocities for directions X, Y and Z. The Figure 9 shows these parameters in the graphical form.

	Gamma Parameter (%)			
	ISO	c3	c4	c6
Ɣ1	0.822	1.339	5.573	7.612
Ɣ2	0.730	7.170	8.878	10.552
Ɣ3	0.000	7.539	8.468	10.816

Table 5 - Gamma parameter of the all samples showing, in general, greater values for γ_3.

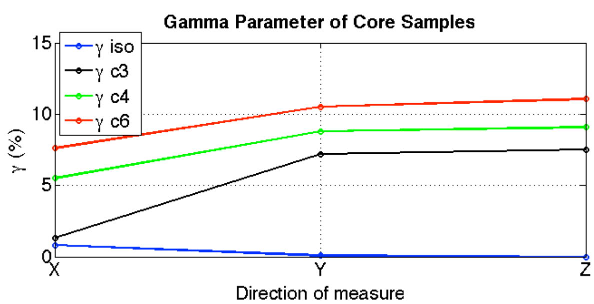

Figure 9 - Gamma parameter of all samples showing the expected pattern for orthorhombic media.

Conclusions

The samples C3, C4 and C6 that have orthorhombic symmetry can relate their Thomsen's parameters with the number of fracture in each sample. As we expected, the Thomsen's parameters increased with the number of cracks, hence, the sample c6 to have the greatest values for ε *and* γ.

However, as can be seen in Table 3, C_{66} has some of the smallest values calculated for both ε. Therefore, our results turned out to be conclusive in finding the relation between Thomsen's parameters and the number of fractures. We plan to address and expanded these problems in future experiments.

Acknoledgements

The authors would like to thank CAPES, INCT-GP and CNPq (Grant No.: 4590653/2014-6 and Grant No.: CNPQ 140174/2016-8) from Brazil and the graduate program at Federal University of Pará for the financial support in this research.

References

Santos, L. K., De Figueiredo, J. J. S., and Da Silva, C. B., 2016, A study of ultrasonic physical modeling of isotropic media based on dynamic similitude: Ultrasonics, **70,**227–237.

Santos, L. K., De Figueiredo, J. J. S., Macedo, D. L., and Da Silva, C. B., 2017, A new way to construct synthetic porous fractured medium: Journal of Pretoleum Science and Eng., **Manuscript under Revision.**

Thomsen, L. (1986), Weak elastic anisotropy. *Geophys.*, v. 51, p. 1954–1966.

Tsvankin, I., 1997. Anisotropic parameters and P-wave velocity for orthorhombic media: Geophysics, 62, 1292–1309.