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A CONTRIBUTION OF THE ANISOTROPIC PARAMETER IN ROCK STRESS AND ITS EFFECT ON HYDROCARBON LOCATION

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ABSTRACT

This work represents an elaborate technique that can be used to evaluate the anisotropic parameter of sandstones and shales using seismic wave velocities, densities and rock elastic moduli. This parameter controls most anisotropic features of most situations in geophysical exploration. For this reson, the study of the effects of such an anisotropic parameter on the different elastic moduli ratios of sandstones and shales has been carried out.

The present work is concerned also with the effect of rock stress anisotropy on the hydrocarbon reservoir geometry using anisotropic parameter.

INTRODUCTION

The rocks that show bedding, banding or foliation are not isotropic. In seismic terms, true anisotropy, exhibits a velocity in the horizontal direction that differs completely from that in the vertical one. That is due to preferred orientation of the matrix particles or cracks, or thin bedding of layers.

Wave propagation in an anisotropic medium has been subject to several exprimental and theoretical studies (Uhrig and Van Melle (1955); Postama (1955); Van der stoep (1966); and others). The wave fronts in a homegeneous medium are nearly elliptical (postama, 1955), being characterized by the ratio of major (Horizontal or parallel to bedding) axis to minor axis which is the ratio of the horizontal to vertical velocity in the medium, called the anisotropic ratio. Waters (1987), stated that, most analyses of seismic wave velocities have assumed that the rocks were isotropic. When the layring is cyclic at high rate, compared with wavelengths of the wave involved, the rock assumes transversely isotropism in which the horizontal velocity is different from the vertical velocity even if the rock layer consists of single rock type. It is then possible that, due preferred orientation of the crystalline component, anisotropy is still present. In the particular illustration the shale anisotropy is higher than that of the sand, thus causing the shale phathes to take a shorter time.

The present work deals with the study of the relations between anisotropic parameter (denoted δ) and elastic modulus constants, using seismic wave velocities and densities for sandstone and shale, it concerns also with effect of rock stress anisotropy on reservoir geometry using this parameter and poisson's ratios on El Yusr Oil Field Area.

Relation Between Anisotropic Parameter (δ), Elastic Moduli And Poisson's Ratio (σ).

The evaluation of anisotropy is not very relevant to be obtained fromsurface seismic work alone. This was originally observed by postma (1955), who stated that anisotropic ratio can be obtained if vertical seismic profile (VSP) for compressional and shear waves (P and SH respectively) is available. Also Thomsen

(1986), relats the anisotropic parameters to these wave velocities. However, some of these wave velocities are not often availble. This urges the author to represent the relation between the anisotropic parameter (denoted δ) and elastic modulus ratios, using compressional and shear wave velocities, and densities.

Theoretical Foundation Of The Study :

This study is based upon theoretical calculation of elastic modulus ratios at different anisotropic parameter, using the components (C_{33}, C_{44} and C_{13}) which characterizes the elasticity of the medium. The components (C_{33}, C_{44} and C_{13}) are related to Lame's constants λ and U, bulk modulus K and anisotropic parameter (δ) as given by Thomsen 1986 equations :

$$C_{33} = \lambda + 2u = k + 4/3\,u, \quad \ldots\ldots(1)$$

$$C_{44} = u \quad \ldots\ldots(2)$$

and

$$\delta = \frac{[(C_{13} + C_{44})^2 - (C_{33} - C_{44})^2]}{2C_{33}(C_{33} - C_{44})} \quad \ldots\ldots(3)$$

them

$$C_{13} = [2\delta\, C_{33}(C_{33} - C_{44}) - (C_{33} - C_{44})^2]^{1/2}\, C_{44} \quad \ldots\ldots(4)$$

where C_{33} and C_{44} components can be calculated from equations (1) and (2), hence. The component C_{13} can be determined for different anisotropic parameter (δ) values, according to Thomsen (1986); C_{13} is equal to Lame's constants (λ)

The study of the relations between the anisotropic parameter (δ) and different elastic ratios (λ/ u), (λ/ k), (u-λ) / k and (u- /λ/u + λ) at different ratios of poisson,s ratio (σ) using seismic waave velocities and densities are carried out for sandstones and shales (Table 1 gives an example for the calculations of these elastic ratios). These relations (Figs. 1 - 4) reveal the following results :

1- There are inverse relations between the Iame's constants and shear ratio (λ/u) and poisson's ratio (σ) and also between Iame's constant and bulk modulus ratio (λ/k) and poisson's ratio (σ), see Figs. 1 and 2.

2- At the constant poisson's ratio, the (λ/u and (λ/k) ratios increase with anisotropic parameter, see Figs 1 and 2.

3- The lines which represent the relation between (u-λ)/k ratio and poisson's ratio intersect when (u-λ)/k ratio equals zero and poisson's ratio equals 0.25. This point represents perfect elastic bodies, see Fig. 3.

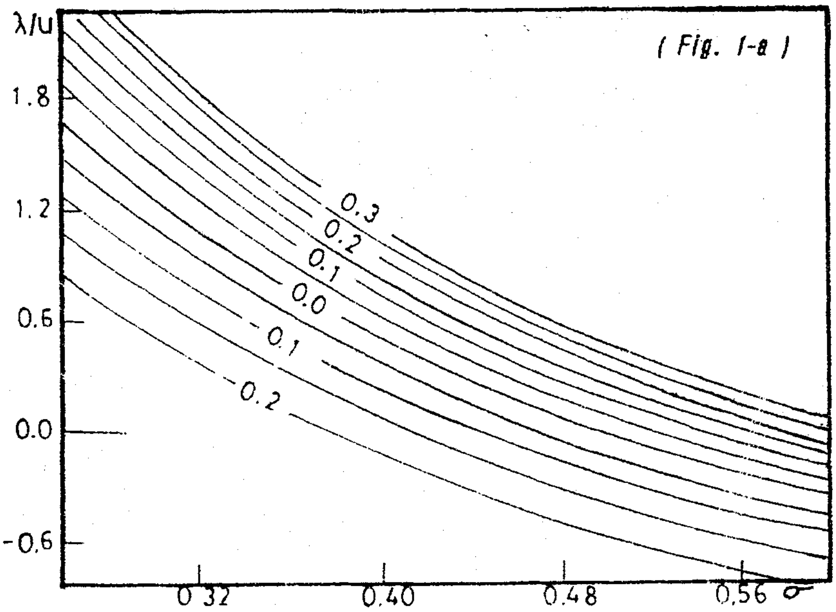
4- The relation between (u-λ)/(u+λ) and poisson's ratio is inverse linear relation and is not effect by anisotropic parameter, see Fig. 4.

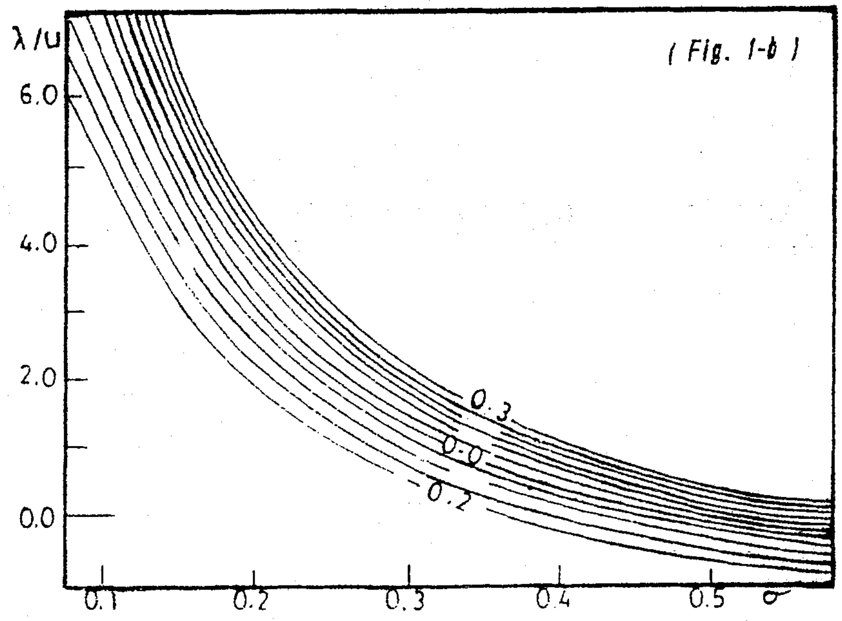
5- These relations which are represented by figures 1-3 can be used to evaluate anisotropic parameter (δ) as follows :

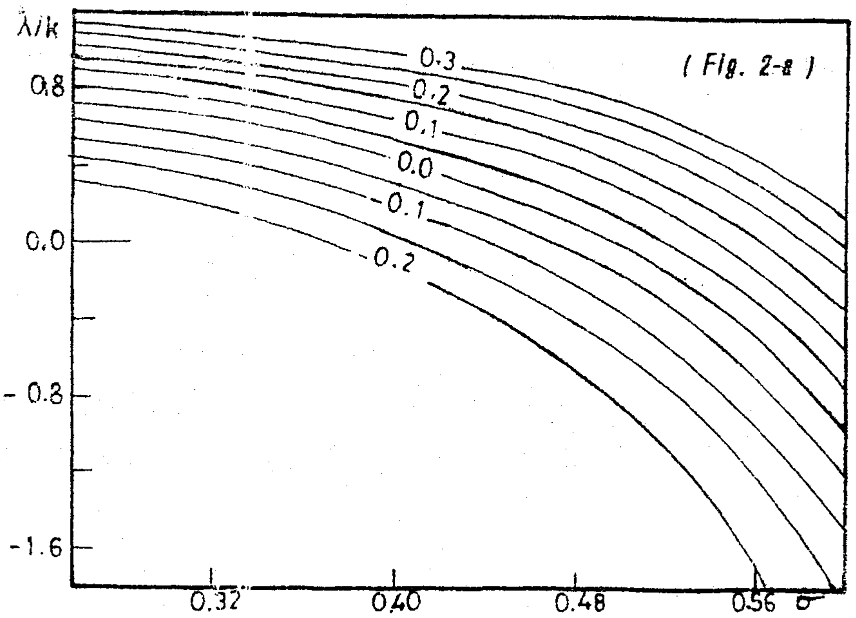
a- Elastic moduli (Lame's constant (λ), shear modulus (u) and bulk modulus (k) and poisson's ratio (σ) can be calculated using compressional and shear wave velocities (Vp and Vs respectively) and densities (σ) as follows :

Table (1) : Shows up values of different parameters taken from Thomsen's work 1986, (Vp, Vs, ρ and δ). Other parameters are introduced by the auther (u, λ k, σ, λ / u, λ / k, (u-λ) / k and (u-λ) / (u+λ).

Vp m/sec.	Vs m/sec.	ρ gm/cm^3.	δ	u.10^{10}	K, 10^{10} dynes/cm^2	λ .10^{10}	σ	λ /u	λ /k	(u-) / k	(u-) / (u+)
4237	3018	2.69	-.039	2.27	1.45	-.24	-.60	-.10	-.17	1.24	1.73
4206	2664	2.14	0.020	1.41	1.64	0.76	0.17	0.54	0.46	0.29	0.29
3688	2774	2.73	0.057	1.95	0.84	-.26	-.79	-.13	-.31	2.61	1.3
4633	3231	2.71	-.033	2.62	1.89	-.03	-.01	-.14	-.19	1.40	1.02
3982	2926	2.97	-.088	2.33	1.21	-.77	-.24	-.33	-.63	2.65	1.98
3368	1829	2.50	-.035	0.77	1.59	0.98	0.27	1.26	0.61	-.13	-.11
3810	2367	2.16	0.045	1.12	1.41	0.79	0.20	0.70	0.55	0.23	0.17
4839	2911	2.50	0.040	1.96	2.88	1.78	0.23	0.90	0.61	0.63	0.49
5029	2987	2.43	-.015	2.01	3.02	1.59	0.22	0.79	0.52	0.13	0.11
3383	2438	2.35	0.059	1.29	0.76	0.04	-.15	0.32	0.55	0.63	0.93
4846	3170	2.69	0.008	2.51	2.52	0.89	0.13	0.35	0.35	0.64	0.47
3901	2682	2.64	-.012	1.76	1.37	0.15	0.41	0.89	0.11	1.16	0.83
3749	[illegible]	2.92	0.078	1.86	1.32	0.36	0.81	0.19	0.27	1.12	0.67
4359	3048	2.81	0.000	2.42	1.72	0.10	0.21	0.04	0.63	1.34	0.91
4130	2380	2.64	0.120	1.38	2.33	1.86	0.28	1.34	0.80	-.20	-.14
1085	387	1.80	0.315	0.02	0.16	0.20	0.44	8.00	1.20	-1.0	-.77
2074	869	2.25	0.090	0.15	0.68	0.66	0.40	4.10	0.95	-.72	-.61
4721	2890	2.64	0.205	2.04	2.73	2.34	0.26	1.14	0.85	-.11	-.68
2106	887	2.25	0.175	0.16	0.70	0.74	0.40	4.53	1.05	-.82	-.63
3048	1490	2.42	-.050	0.49	1.42	0.98	0.33	1.96	0.69	-.33	-.32
2202	969	2.25	0.060	0.19	0.75	0.67	0.38	3.46	0.90	-.64	-.55
2745	1508	2.34	-.001	0.49	0.97	0.64	0.66	1.31	0.66	-.15	-.13
3377	1490	2.42	-.075	0.49	1.89	1.36	0.36	2.73	0.71	-.45	-.46


(Fig. 1-a)
λ/u
1.8
1.2
0.6
0.0
-0.6
0.32
0.40
0.48
0.56
σ
0.3
0.2
0.1
0.0
0.1
0.2


(Fig. 1-b)
λ/u
6.0
4.0
2.0
0.0
0.1
0.2
0.3
0.4
0.5
σ
0.3
0.0
0.2



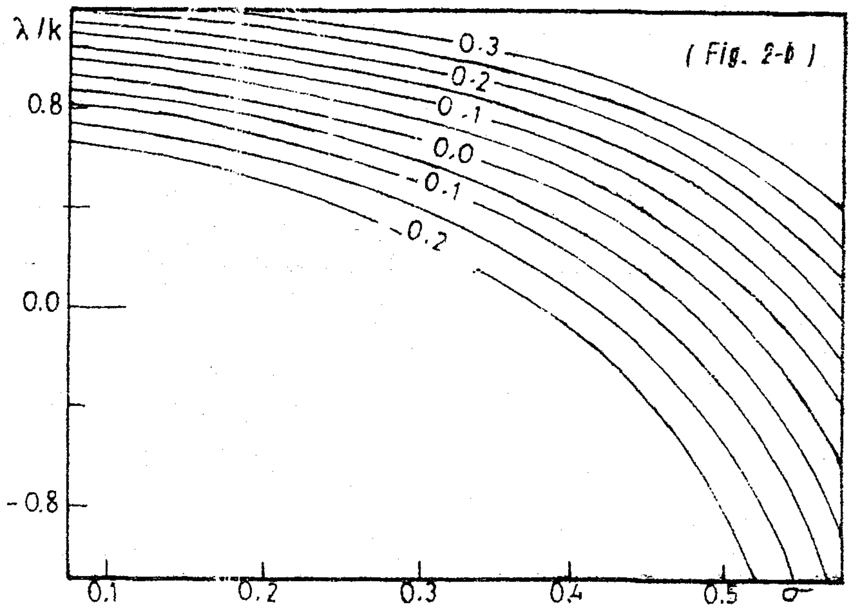


Fig. (2) : The relations between (λ/k) ratios and poisson's ratios (σ) at different anisotropic parameter (δ) values.
a- For sandstones. B- For shales.

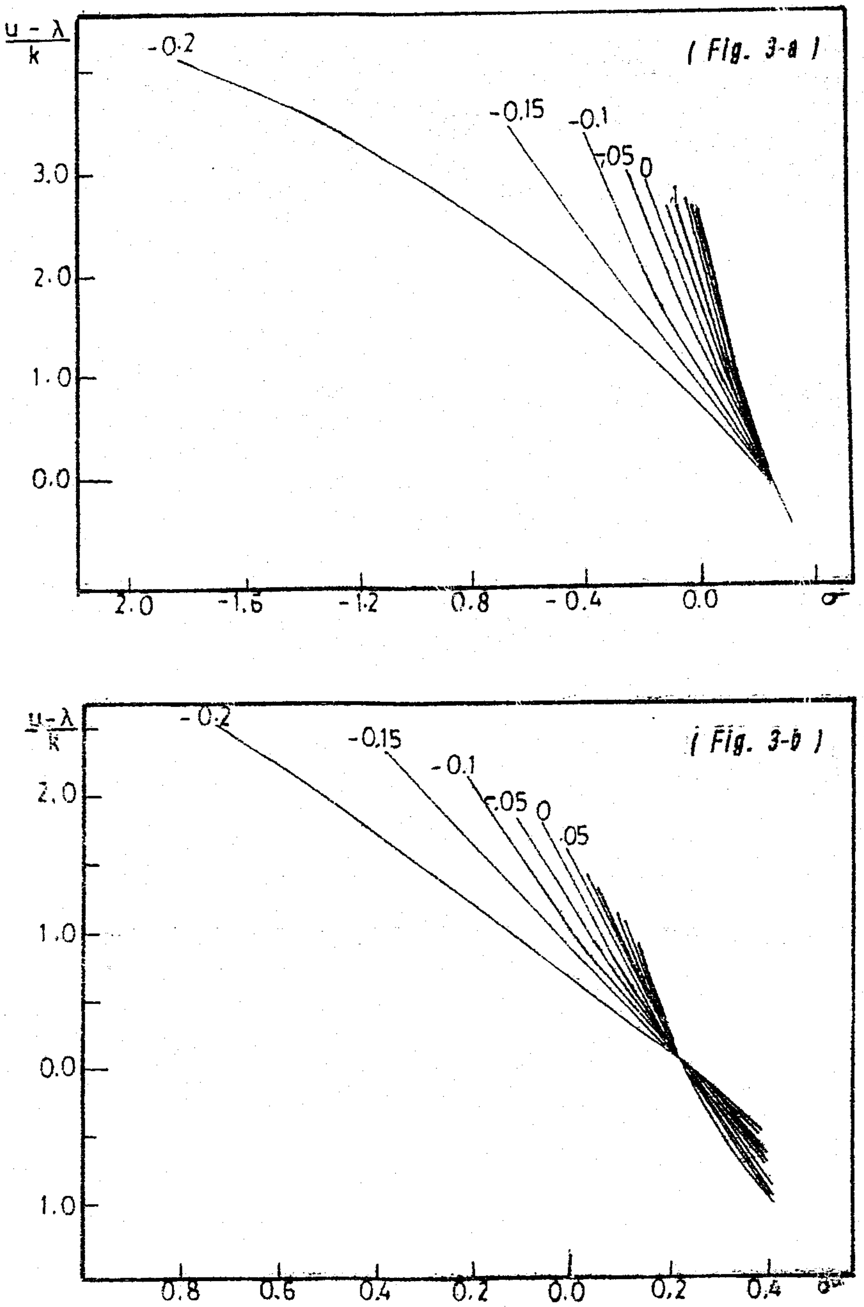


Fig. (3) : The relations between (u - λ/k) ratios and poisson's ratios (σ) at different anisotropic parameter (δ) values.

a- For sandstones. B- For shales.

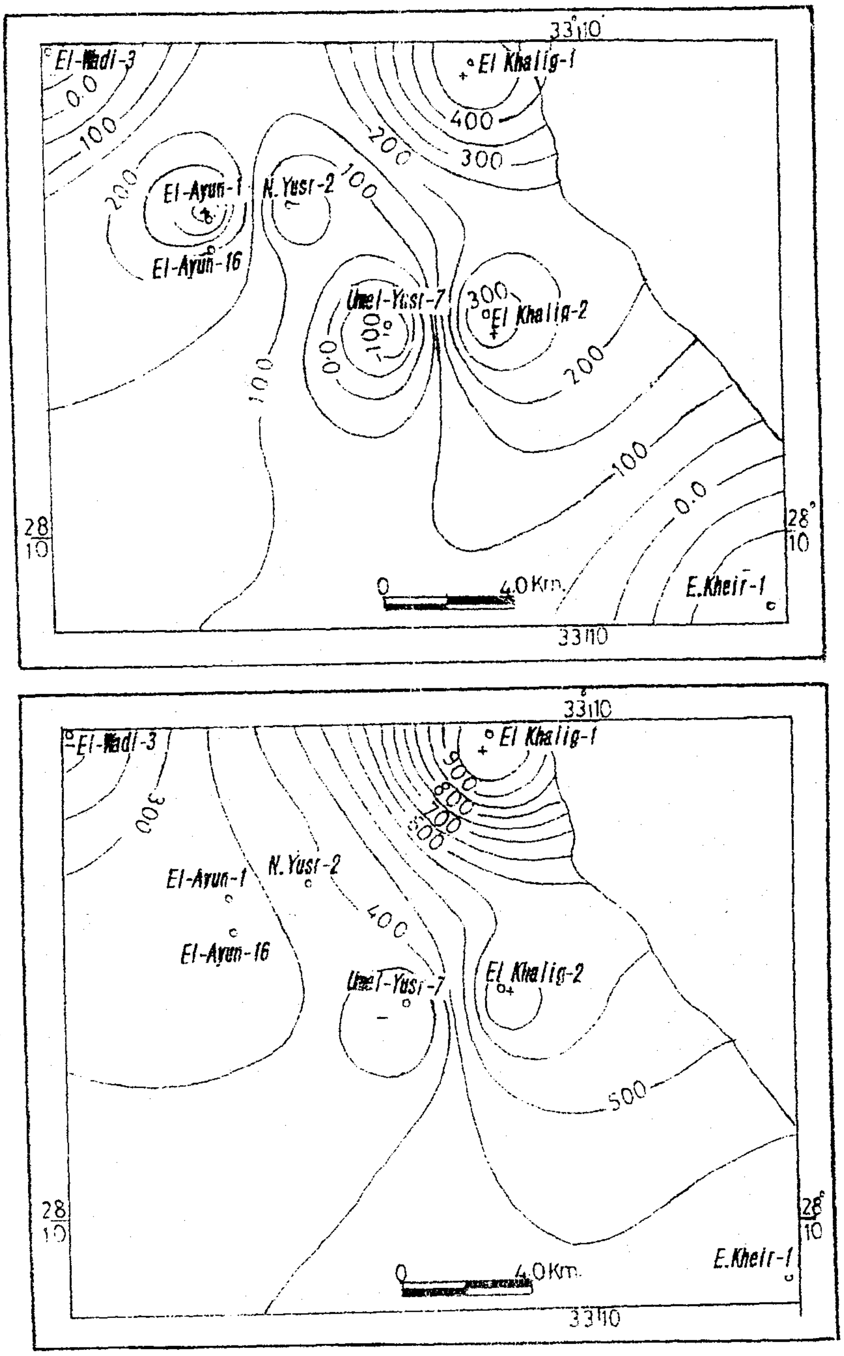


Fig. (5) : The effective horixomtal stress map for El Yusr Oil Field

a- considering anisotropic parameter (λ)

b- ignoring anisotropic parameter (λ)

$\lambda = (Vp^2 - 2Vs^2)\rho$ ....(5)

$k = \rho.(Vp^2 - (4/3)Vs^2)$: ....(6)

$u = \rho.\ Vs^2$ ....(7)

and $\sigma = \lambda\ /\ 2.\ (\lambda + u)$ ....(8)

b- The compressional wave velocities are determined from velocity survey or from sonic data.

c- The Shear wave velocities (Vs) can be computed using Meissner and Hegazi (1981) technique.

d- As one or more of (λ/u), (λ/k) and (u-λ)/k ratios are calculated, a horizontal line is drawn from its corresponding value (using figs. 1a, 2a and 3a for sandstones and figs. 1b, 2b and 3b for shales), and the vertical line is drawn from corresponding point of poisson's ratio for figures used for evaluation. The point of intersection of horizontal and vertical lines gives the value of the anisotropic parameter.

Effect of Anisotropic Parameter In Rock Stress.

The rock stress ratio (S_{11}/S_{33}) was expressed by equation of Thomsen (1986) as follows :

$S_{11}\ /\ S_{33} = 1 - 2Vs^2\ /\ Vp^2$ For isotropic case...................(8)

$S_{11}/S_{33}=(1-2Vs^2/Vp^2)+(1 - Vs^2\ /\ Vp^2)\ \{[1 + 2\ \delta\ /(1-Vs^2\ /Vp^2)]\ -1\}$

For anisotropic case.....................(9)

and

$S_{11}\ /\ S_{33} = (1 - 2Vs^2\ /\ Vp^2) + \delta$ For weak anisotropic case..(10)

where

S_{33} is the lithostatic vertical stress (S_{33} = -g ρ h)
g is the gravity acceleration.ρ, is the rock density,
h is the depth,
S_{11} is the lithostatic horizontal stress.

Also, Abd el Rahman and Abd el All * replaced the stress ratio (S_{11} / S_{33}) and horizontal stress (S_{11}) by effective stress ratio (S_{1eff} /S_{3eff} and horizontal effective stress (S_{1eff}) respectively for isotropic case. Considering, anisotropic conditions and weak anisotroy case, the stress ratio can be subsituted by effective stress ratio; hence the horizontal effective stress for these cases can be expressed as :

$$S_{11}/S_{33}=(1-2Vs^2/Vp^2)+(1-Vs^2/Vp^2)\{[1+2\delta/(1-Vs^2/Vp^2)]-1\}$$

For strong anisotropic case..........(11)

and

$$S_{1eff} = S_{3eff} \cdot [(1-2Vs^2/Vp^2)+\delta]$$

For weak anisotropic case............(12)

where S_{3eff} is the effective vertical stress given by Dominco (1974); using vertical stress (S_{33}) and fluid stress S_f as follows :

$$S_{3eff} = S_{33} - S_f$$

APPLICATION

Two maps of effective horizontal stress of El Yusr Oil Field

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* In press.

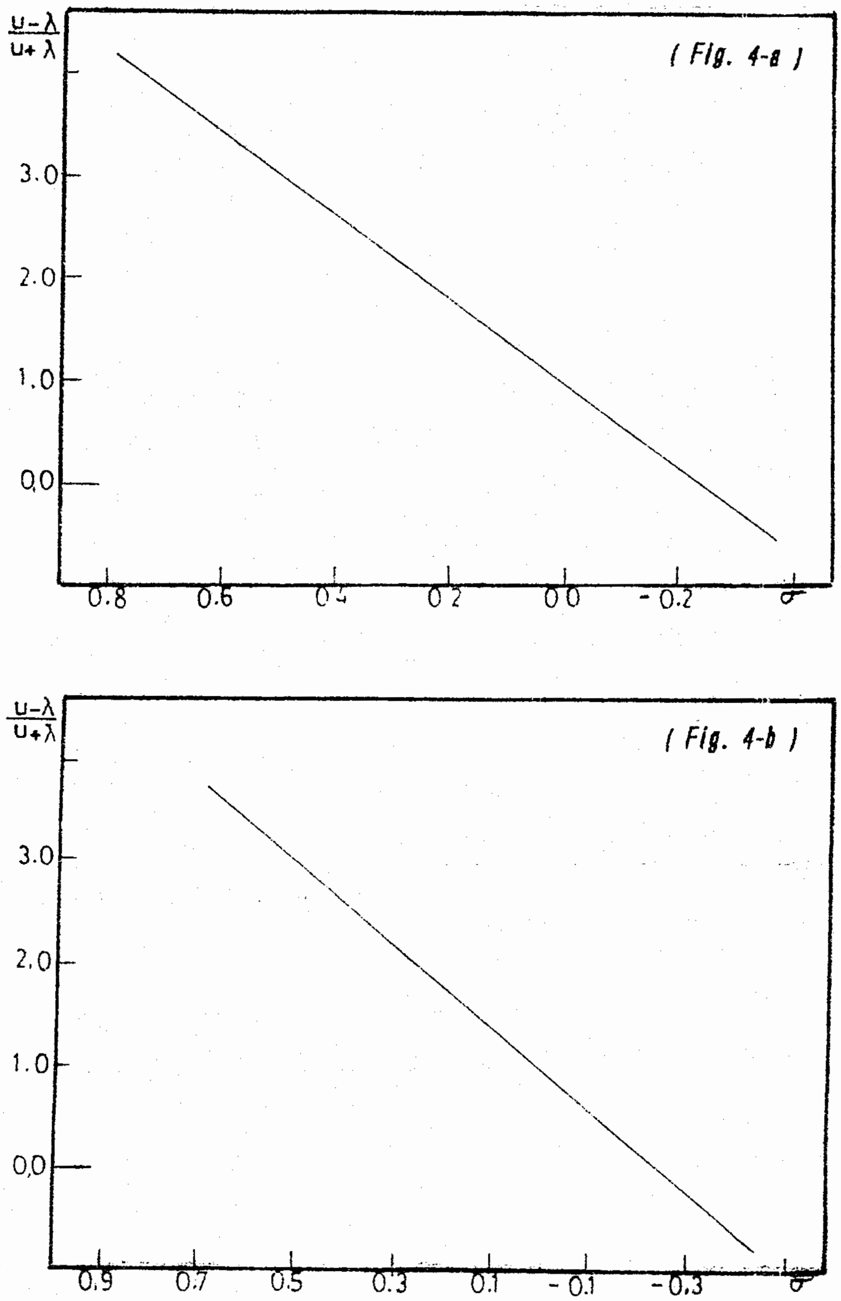

Fig. (4) : The relations between ($u - \lambda / u + \lambda$) ratios and poisson's ratios (σ) at different anisotropic parameter (δ) values.

a- For sandstones. B- For shales.

Table (2) : represents the values of calculation of elastic modulus ratios. poisson's ratios (σ) and estimated anisotropic parameters (δ) for different wells present in El Yusr Oil Field.

Vp m/sec.	Vs m/sec/	ρ gm/cm^3.	δ	u.10^{10}	K, 10^{10} dynes/cm2	.10^{10}	σ	λ/u	λ/k	(u-λ)/k	(u-λ)/(u+λ)
2917	1927	2.32	-.18	0.80	0.76	0.23	0.11	0.29	0.30	-.73	0.54
4152	2555	2.51	-.12	1.50	1.90	0.97	0.19	0.64	0.49	-.27	0.21
3503	2117	2.42	-.12	1.00	1.41	0.74	0.21	0.73	0.52	-.18	0.15
3503	2185	2.19	0.07	0.97	1.20	0.55	0.18	0.57	0.46	-.34	0.27
2789	1790	2.23	-.11	0.66	0.72	0.28	0.14	0.42	0.39	-.52	0.40
3124	2043	2.27	-.22	0.88	0.88	0.29	0.12	0.33	0.33	-.65	0.49
2814	1760	2.33	-.21	0.67	0.81	0.37	0.17	0.55	0.45	-.36	0.28
3292	2105	2.31	-.25	0.95	1.05	0.42	0.15	0.44	0.40	-.49	0.38

were constructed, one of them (Fig. 5a) considers the anisotropic parameter (δ) as being estimated in the present work (Table 2), while the other map (Fig. 5b) ignors it. Two maps exhibit the areal distribuation of effective low horizontal stresses and hence, the locations of hydrocarbon entrapments. The second map, however, fails to detect some low anomalies, especially in the western part of the map, indicating that this part is highly effected by the anisotropic parameter; besides showing different amplitudes. Accordingly, the anisotropic parameter (δ) is better to be considered when constructing the effective horizontal stresses map.

CONCLUSION

The present work gives the relations between the elastic modulus ratios (λ/k, and λ/u and u- λ/k), poisson's ratios (σ) and anisotropic parameter (δ), from which (δ) can be estimated. These relations can be estimated. Besides, also the effect of this parameter in areal distribuation of horizontal stress in El Yusr Oil Field Area are evident to detect the locations of hydrocarbon entrapment areas.

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أسهامات اللاسوية الهزية للاجهادات الصخرية فى الكشف عن هيدروكربوناتها

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هذا البحث بمثابة تطوير لاستخدام اللاسوية فى المجالات الهزية (السيزمية) فى الوصول إلى مكامن الهيروكربونية وذلك بانتقاء صخور الحجر الرملى والطفل وتعيين معاملات المرونة فى الاتجاهات المختلفة من خلال الجداول مرة ومن خلال تحليل تسجيلات الآبار المعقدة مرة أخرى بالأضافة إلى أدخال معاملات لم يدخلها الباحثون السابقون الذين اخذوا فى أعتبارهم بعض هذه المعاملات دون البعض الآخر .

ومن نتائج هذه الدراسة أن ظهرت بطريقة أفضل مواضع المواد الهيدروكربونية فى الخرائط المطورة أستخدم فى رسمها اللاسوية عنها فى الخرائط التى أهملت ولم تدخلها فى ألاعتبار .