PRESENT STATE OF STRESS DETERMINATION IN THE TRANSYLVANIAN BASIN USING BOREHOLES MEASUREMENTS

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1. INTRODUCTION

The Transylvanian Basin is located in the Eastern part of the Alps–Carpathian–Pannonian system on the Romanian territory. It has a roughly circular shape and a Cretaceous to Miocene 8 km thickness sedimentary fill. The basin margins are represented by the East Carpathian Mountains, the South Carpathian Mountains and the Apuseni Mountains.

As a result of its tectonic evolution, the Transylvanian Basin is characterized by the following peculiar features: normal thickness lithosphere (100 km), low heat flow (30–60 mWm^{-2}) and a crustal thickness of 33–36 km, increasing from the central area to the basin borders.

Nevertheless, the geodynamic information related to the present day-stresses acting within the terrestrial upper crust of the Transylvanian Basin is very scarce and the few data coming from previous published papers (Neguț *et al.*, 1994; Zugrăvescu *et al.*, 1999) have not been included in the World Stress Map (Fucks *et al.*, 1999).

That is why in the last five years the research programs of the Geodynamic Institute of the Romanian Academy were directed on topics concerning a better understanding of various geodynamic processes taking place in this areal.

Among other things it represents an intensively explored region for hydrocarbon resources, in which during the last 60 years a lot of gas deposits have been discovered. More than 2 000 boreholes drilled in this region investigated the entire Pliocene and Miocene sedimentary fill from the ground surface to 5 km deep.

For this reason the stress study of the Geodynamic Institute was entirely based on borehole geophysical measurements existing in the archives of oil and gas companies, and consequently without any extra-cost.

2. METHODOLOGY USED FOR BOREHOLE DATA PROCESSING

With this end in view, the available well log suites coming from 53 exploration boreholes whose bottom holes-depth were less than 4 km have been selected, collected and finally processed. All these boreholes have been geophysically

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investigated in open hole conditions with Schlumberger and Wester Atlas equipments including always the Stratigraphic High-Resolution Dipmeter Tool (SHDT) or the Dipmeter.

The field data processing was performed according to the Schlumberger instructions (Schlumberger 1982, 1989, 1996), the interpretation methods devised in our institute were based on the "breakout technique" both of them being finally coupled in a such way to comply with the requests of the World Stress Map.

In this context we want to mention that special rules were assessed in order to ascertain the causes of breakouts (initiation and enlargements) on the basis of well wall stability and the pressure differential between the drilling mud and the fluid filling the rock pore space.

In our breakout inferred stress study of the Transylvanian Basin upper crust we consent with the linear, isotropic poroelastic stress-strain theory assuming the strain plane orthogonal to the borehole axis. On these terms the ellipsoid of stresses was defined by giving the directions of its three axes and the corresponding stress magnitudes S_1, S_2, S_3, known as principal stresses.

Roughly speaking within depositional basin, whether tectonically inactive or undergoing extension, the maximum stress (S_1) is represented by the geostatic load/overburden, both intermediate stress (S_2) and least stress (S_3) being located in the horizontal plane.

The combination of extensional and strike slip regimes existing in the Transylvanian Basin supported our assumption to consider that the principal stress is oriented vertically ($S_1 = S_v$), the greater horizontal stress as being ($S_2 = S_H$) and finally, the least horizontal stress to be ($S_3 = S_h$).

The last horizontal stress was expressed as a fraction of the geostatic load (S_1) using a variable coefficient whose value was calculated on the basis of Poisson's Ratio. Both, rock elastic parameters Poisson's Ratio and Young's modulus have been derived in our study from wave velocities and bulk volume densities recorded by well logging measurements.

The final results of our determinations related to stress horizontal components-orientations have been presented in two different variants:

– a graphical one, in which all maximum stress component-azimuths were plotted on a regional map as arrows, indicating at the base of arrow the geographical co-ordinates / borehole site locality;

– a second one, displaying the so called "stress file" prepared and stored in the Stress Data Bank of the Geodynamic Institute. This stress file includes a lot of information concerning: well geographical co-ordinates, borehole intervals with continuous SHDT/Dipmeter measurements, the type of other recorded well logging measurements, lithology of geological formations passed through, boundaries between them on the basis of geological age, physical and chemical characteristics of drilling mud, borehole deviation, pressure and bottom hole maximum temperature, etc.

On the basis of different physical measurements acquired during the well logging operations (Gamma Ray Radioactivity, Spectral Log, Neutron and Density Log, Sonic Log, Electric resistivity / conductivity and Dipmeter) the following types of information were also established and reported to in the "stress data file":

– the azimuth of maximum horizontal principal stress;

– the azimuth of least horizontal principal stress;

– the magnitude of the above mentioned stresses for some "in house studies".

Because the basical data of our study have been provided by the open hole-geophysical measurements performed during the drilling period of gas producing-wells, we have been constrained to present the distribution of stress orientation within the Transylvanian Basin in a closed relation to the framework of gas-geological activity.

3. THE GEOLOGICAL FRAMEWORK FROM WHICH THE STRESS DETERMINATION ORIGINATES

According to the official reports elaborated during the last 30 years, the gas bearing-geological structures of the Transylvanian Basin are joined making up five gas producing – structural groups: the northern, the western, the southern, the eastern and the central.

We are aware of the differences existing between the gas bearing-sedimentary sequences framework and the stress orientation – geodynamic framework, but this connection has been chosen solely for a better localization of the points and domains in which the measurements have been carried out.

All the specific well logging measurements necessary to our stress study were accomplished on post saliferous-rock sequences belonging to the Pliocene–Upper Miocene sedimentary cycle. The thickness of this sedimentary sequence varies from a geological structure to another, from tens to hundreds or even to thousands metres.

These sedimentary sequences are composed from four main rock types, namely: sand/sandstones, silt/siltstones, shales and clayey marls.

The mineral composition of detrital particles in these siliciclastics sediments incorporates: quartz (15–65%), detrital carbonates (5–40%), feldspar and mica (10–35%), clay minerals (kaolinite, smectite and illite 8–40%), as well as miscellaneous heavy minerals and lithic rock fragments (1–5%).

Well log-petrophysical analyses (Negoiță, 1985) established the fact that sands have the highest void ratio values, being followed in decreasing order by argillaceous and silty sands and sandstones.

Formation compaction as a result of physical, chemical and mineralogical phenomena governed mainly by the burial depth and overburden pressure provided a near equilibrium compaction and a near hydrostatic fluid pressure. In one way or another, void ratios as a function of depth or formation age, takes finally the following values in the studied area (see Negoiță, 1985).

Lithology	**Pliocene**	**Upper Miocene**
Sands	0.408–0.351	0.219–0.176
Sandstones	0.123–0.098	0.098–0.075
Silts and dirty formations	0.265–0.204	0.123–0.086

Laboratory analyses leads to the conclusion that average pore diameter is about 3.5–4.5 microns in the case of rocks with a content of 5–10% argillaceous fractions and about 0.5–1.5 microns in the case of rocks with contents of 10–20% argillaceous fractions (Oltean, 1991).

4. PRESENTATION OF THE RESULTS

The main characteristics of stress orientation in the five groups of gas producing-geological structures are presented below:

1. *Northern Group*

The areal of this group (Fig. 1) is situated on the northern part of the Mureş river, being enclosed in the polygon formed by the following localities: Cluj – Dej – Bistrița – Grebeniş – Luduş – Turda.

Among the most representative gas producing-geological structures we mention: Sărmăşel, Buza, Strugureni, Delureni, Grebeniş, Zău de Câmpie.

The extreme values of maximum stress orientation are: 80° – 130°.

The average value of all stress orientations is 104°.

2. *Western group*

The areal of this group (Fig. 2) is situated between Mureş and Târnava Mare rivers, being enclosed in the polygon formed by the following localities: Turda – Luduş – Iernut – Târnăveni – Deleni – Blaj.

Among the most representative gas producing-geological structures we recall: Bogata, Iernut, Deleni, Tăuni, Cetatea de Baltă, Luduş.

The extreme values of maximum stress orientation are: 72° – 112°.

The average value of all stress orientations is 92°.

3. *Southern group*

The areal of this group (Fig. 3) is situated between Târnava Mare and Olt rivers, being enclosed in the polygon formed by the following localities: Luduş – Sibiu – Ucea – Agnita – Sighişoara – Copşa Mică.

Among the most representative gas producing-geological structures we mention: Alămor, Ruşi, Ilimbav, Săsăuş, Copşa Mică, Noul Săsesc.

The extreme values of maximum stress orientation are: 10° – 45°.

The average value of all stress orientations is 25°.

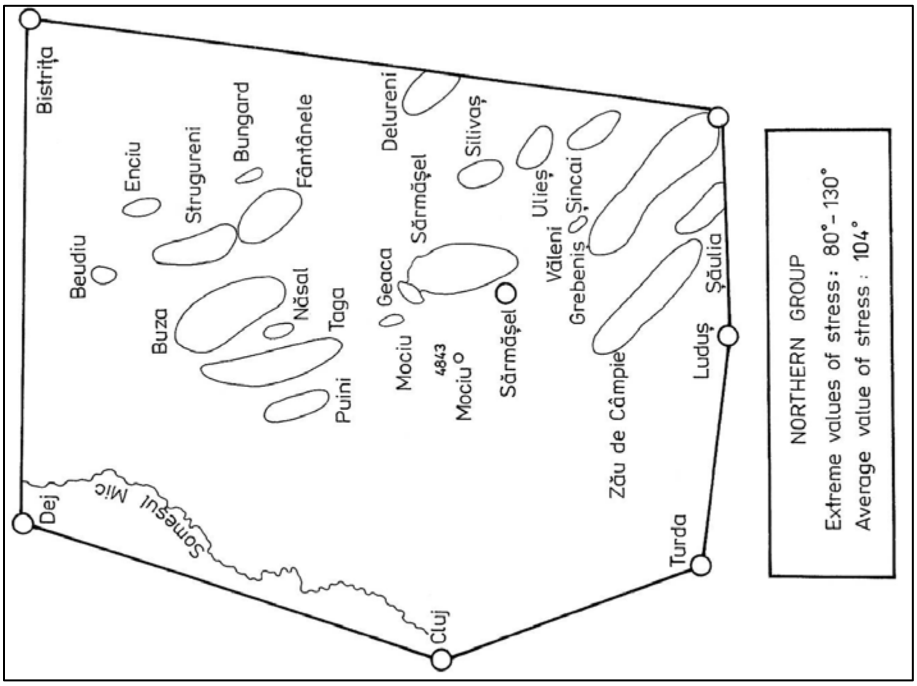

Fig. 1 – Stresses of the Northern Group–geological structures.

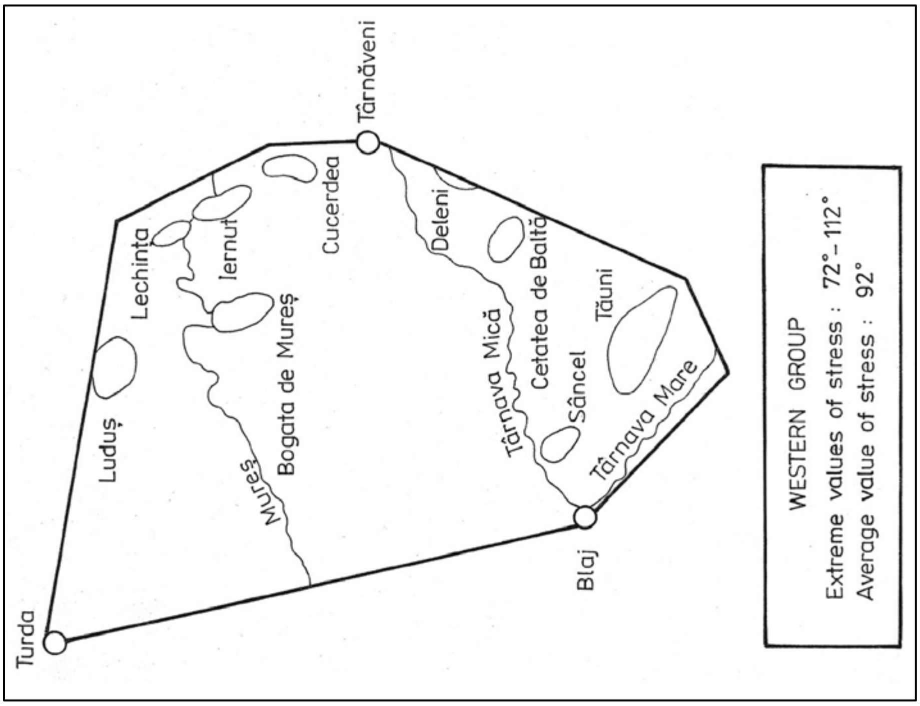

Fig. 2 – Stresses of the Western Group–geological structures

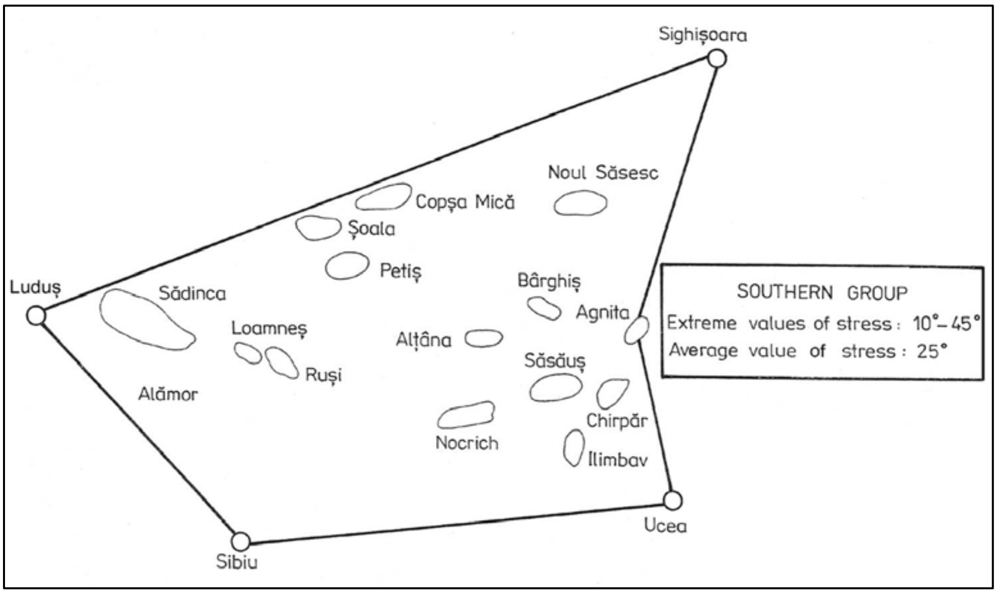

Fig. 3 – Stresses of the Southern Group–geological structures.

4. *Eastern group*

The areal of this group (Fig. 4) is situated near the Eastern Carpathians border, being enclosed in the polygon formed by the following localities: Agnita – Rupea – Odorhei – Sovata – Ghindari – Sighişoara.

Carrying on, some of the most representative gas producing-geological structures are listed: Daia–Ţelina, Buneşti, Cristur, Lupeni, Porumbeni, Şoimuş, Eliseni.

The extreme values of maximum stress orientation are: 60° – 135°.

The average value of all stress orientations is 104°.

5. *Central group*

This group (Fig. 5) is located exactly in the center of the Transylvanian Basin possessing common borders with all the four gas producing-geological structure groups reported to formerly. The approximate areal is situated in the polygon formed by the following localities: Sighişoara – Măgherani – Reghin – Crăieşti – Band – Mediaş – Dumbrăveni.

From the most representative gas producing-geological structures may be mentioned: Corunca, Târgu Mureş, Eremieni, Bazna, Dumbrăvioara, Petrilaca, Filitelnic, Nadeş.

The extreme values of maximum stress orientation are 110° – 175°.

The average value of all stress orientations is 150°.

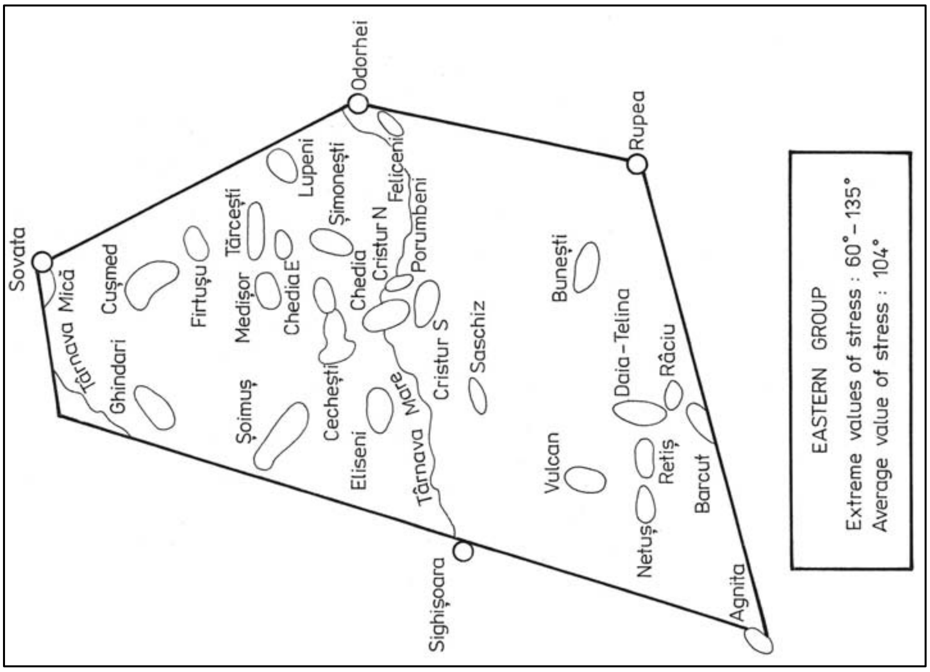

Fig. 4 – Stresses of the Eastern Group–geological structures.

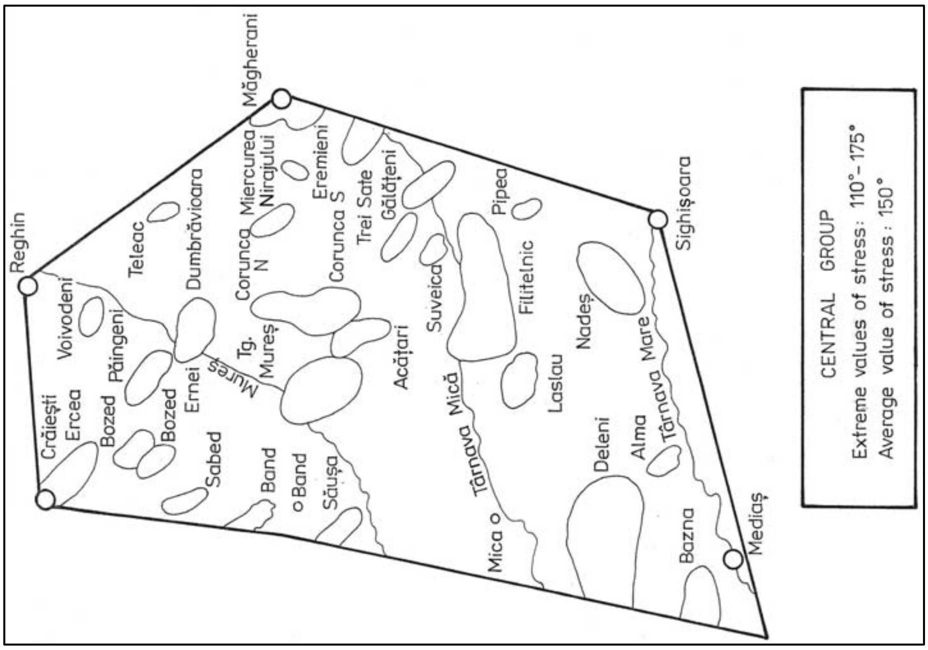

Fig. 5 – Stresses of the Central Group–geological structures.

As a general observation, in the Transylvanian Basin most of the variations related to stress orientation within the depth interval "ground surface – Saliferous Upper Miocene" follow a normal (perpendicular) direction against the Carpathian mountainous chain. The stress orientation found on some geological structures (Sărmăşel 118°, Bogata 112°, Alțâna 20°, Nocrich 8°, Săsăuş 38°, Buneşti 86°, Feliceni 132°) are relevant in this respect.

Yet, some characteristic behaviours of stress orientations on the Transylvanian Basin zone need to be remarked and discussed.

The first one is represented by the "Central group" where the average stress orientation of 150° is equivalent to the general stress orientation trend existing in the Central and Western Europe (the so called Midplate stress domain) with average stress orientation of 145°.

The second one, is represented by the most south-western zone of the Transylvanian Basin where an obvious N–S direction of stress orientation was pointed-out, more or less equivalent to the stress orientation noticed in the south of Poland as well as in the most eastern part of Slovakian territory (Fuchs, 1999). In addition, for this south-western part of the basin we suppose the existence of some deep local fault processes generating stress field perturbations.

The quality data resulted from our 53 stress orientation-determinations assigned according to the "World Stress Map ranking quality scheme" may be placed between A and C rank orders. It is opportune to recall that WSM quality scheme starts with the best A ranking quality and ends to E ranking quality.

Our 53 selected stress orientation-determinations may be integrated in the ranking scheme as follows: (A = 7, B = 22 and C = 24 determinations) and therefore, the specific percentages related to the data quality are (A = 13.2%, B = 41.5%, C = 45.3%).

Stress magnitudes have also been calculated for some special works, on the basis of well logging data and pressure measurements recorded during the drilling period of the boreholes.

Generally, in the Transylvanian basin the vertical stress increases with depth taking for the vertical stress gradient values between 22 MPa/km and 24 MPa/km. Formation fluid pressure gradients in the Pliocene–Post Salifeorus Upper Miocene depth interval seldom exceed 13 MPa/km, few occurrences of 15–16 MPa/km in the Filitelnic – Corunca gas fields being recorded (Fig. 6, Table 1).

In such circumstances the least horizontal stress gradients calculated on the basis of Poinson's ratio and vertical stress gradient indicated values of 13–15 MPa/km, confirming several leak-off tests carried out during the drilling period of boreholes.

Finally, the analysis of stress magnitudes stated that maximum principal stress is vertical, while the minimum horizontal stress is roughly 62% of the vertical stress magnitude; the average values of these two stress-gradients are respectively 23 MPa/km and 14.2 MPa/km.

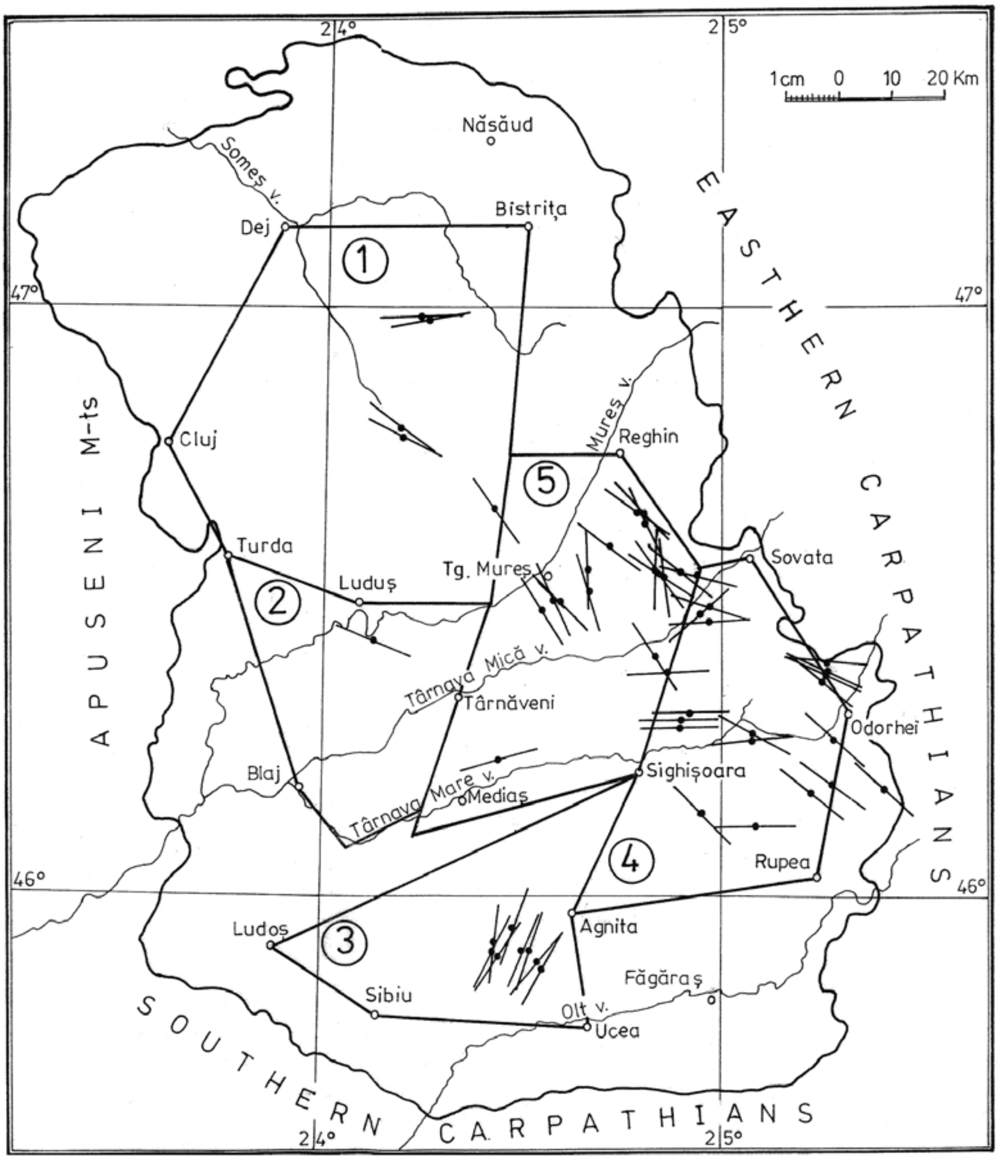

Fig. 6 – The directions of maximum horizontal stresses in the Transylvanian Basin.

Table 1

Stress directions within Transylvanian Basin

Well number	**Latitude**	**Longitude**	**Maximum stress**	**Minimum stress**	**Apparatus type**
1.	45º 56′ 33″	24º 28′ 47″	20 º	110 º	ATLAS
2.	46º 26′ 46″	24º 07′ 07″	112 º	22 º	SCHLUMBERGER
3.	46º 07′ 25″	25º 04′ 50″	86 º	176 º	SCHLUMBERGER
4.	48º 08′ 31″	24º 56′ 55″	138 º	48 º	ATLAS
5.	46º 33′36 ″	24º 39′ 00″	171 º	81 º	ATLAS
6.	46º 30′ 52″	24º 39′ 46″	167 º	77 º	SCHLUMBERGER
7.	46º 13′ 42″	24º 26′ 29″	72 º	162 º	SCHLUMBERGER
8.	46º 33′ 03″	24º 30′ 18″	135 º	45 º	SCHLUMBERGER
9.	46º 32′ 05″	24º 50′ 34″	172 º	82 º	SCHLUMBERGER
10.	46º 33′ 28″	24º 49′ 14″	144 º	54 º	ATLAS
11.	46º 32′ 45″	24º 50′ 55″	171 º	81 º	ATLAS
12.	46º 32′ 49″	24º 49′ 43″	179 º	89 º	SCHLUMBERGER
13.	45º 53′ 15″	24º 33′ 26″	163 º	73 º	SCHLUMBERGER
14.	46º 13′ 33″	25º 16′ 51″	132 º	42 º	SCHLUMBERGER
15.	46º 11′ 23″	25º 17′ 38″	128 º	38 º	ATLAS
16.	46º 15′ 32″	25º 17′ 03″	103 º	13 º	ATLAS
17.	46º 22′ 15″	24º 43′ 01″	149 º	59 º	SCHLUMBERGER
18.	46º 29′ 22″	24º 58′ 02″	109 º	19 º	SCHLUMBERGER
19.	46º 28′ 30″	24º 56′ 55″	48 º	138 º	SCHLUMBERGER
20.	46º 28′ 07″	24º 57′ 40″	85 º	175 º	ATLAS
21.	46º 22′ 26″	25º 15′ 30″	116 º	26 º	SCHLUMBERGER
22.	46º 22′ 52″	25º 15′ 32″	114 º	24 º	SCHLUMBERGER
23.	46º 23′ 32″	25º 15′ 37″	96 º	6 º	SCHLUMBERGER
24.	46º 22′ 59″	25º 15′ 11″	121 º	31 º	SCHLUMBERGER
25.	46º 32′ 50″	24º 54′ 02″	128 º	38 º	SCHLUMBERGER
26.	46º 32′ 03″	24º 54′ 51″	108 º	18 º	SCHLUMBERGER
27.	45º 54′ 08″	24º 29′ 57″	21 º	111 º	SCHLUMBERGER
28.	45º 54′ 19″	24º 26′ 20″	25 º	115 º	SCHLUMBERGER
29.	45º 53′ 58″	24º 26′ 09″	33 º	123 º	SCHLUMBERGER
30.	45º 54′ 19″	24º 26′ 43″	8 º	98 º	SCHLUMBERGER
31.	45º 54′ 41″	24º 30′ 41″	19 º	109 º	SCHLUMBERGER
32.	46º 10′ 25″	25º 13′ 53″	130 º	40 º	ATLAS
33.	46º 39′ 50″	24º 45′ 52″	136 º	46 º	SCHLUMBERGER
34.	46º 36′ 27″	24º 42′ 31″	137 º	47 º	ATLAS
35.	46º 39′ 06″	24º 46′ 33″	128 º	38 º	SCHLUMBERGER
36.	46º 39′ 33″	24º 47′ 18″	154 º	64º	ATLAS
37.	46º 40′ 09″	24º 46′ 40″	148 º	58 º	SCHLUMBERGER
38.	46º 15′ 33″	24º 05′ 12″	80 º	170 º	SCHLUMBERGER
39.	46º 16′ 07″	25º 05′ 02″	118 º	28 º	SCHLUMBERGER
40.	46º 39′ 49″	24º 25′ 27″	146 º	56 º	SCHLUMBERGER
41.	46º 17′ 41″	24º 54′ 33″	95 º	5 º	SCHLUMBERGER
42.	46º 18′ 10″	24º 55′ 08″	88 º	178 º	SCHLUMBERGER

Table 1 (continued)

Well number	Latitude	Longitude	Maximum stress	Minimum stress	Apparatus type
43.	46º 17′ 05″	24º 54′ 23″	86 º	176 º	SCHLUMBERGER
44.	46º 53′ 01″	24º 33′ 27″	29 º	119 º	SCHLUMBERGER
45.	46º 53′ 15″	24º 33′ 26″	38 º	128 º	SCHLUMBERGER
46.	46º 47′ 24″	24º 11′ 34″	118 º	28 º	SCHLUMBERGER
47.	46º 48′ 14″	24º 11′ 17″	130 º	40 º	SCHLUMBERGER
48.	46º 24′ 30″	24º 50′ 07″	146 º	56 º	SCHLUMBERGER
49.	46º 58′ 39″	24º 14′ 40″	78 º	168 º	ATLAS
50.	46º 58′ 57″	24º 13′ 55″	88 º	178 º	SCHLUMBERGER
51.	46º 23′ 12″	24º 52′ 09″	85 º	175 º	SCHLUMBERGER
52.	46º 31′ 31″	24º 34′ 21″	155 º	65 º	ATLAS
53.	46º 31′ 07″	24º 34′ 43″	143 º	53 º	ATLAS

5. CONCLUSIONS

On the basis of borehole measurements carried out during the well logging operations a stress study was undertaken by the Geodynamics Institute of the Romanian Academy.

With this end in view the available well log suites coming from 53 boreholes were selected, collected and finally processed.

The field data processing was performed according to Schlumberger instructions, the interpretation method devised in our institute was based on the “breakout technique”, both of them being finally coupled in such a way to comply with the requests of the World Stress Map quality conditions.

The Transylvanian Basin areal was divided into five distinct zones on which the stress orientation–determinations have been carried out. The final results are scheduled and stress orientation–determinations have been also presented in a graphical form at the end of this work.

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REFERENCES

FUCHS, K., MŰLLER, B., SPERNER, B., REINECKER, J. (1999), *World Stress Map of the Central and Eastern Europe*, WSM Project-Document, Rel, 1999, World Stress Map Project, Heidelberg Academy of Sciences and Humanities and Karlsruhe University Geophysical Institute.

NEGOIȚĂ, V., STOICESCU, J., BUCĂTARU, I. (1985), *Research study regarding the methods for improving the well log interpretation in the geological formations of the Transylvanian Basin*. Research theme of Oil and Gas Research Institute Câmpina. Unpublished work in Romanian.

NEGUȚ, A., DINU, C., SAVU, I., BARDAN, R., NEGUȚ, M.L., CRAICIU, I. (1994), *Stress orientation determination in Romania by borehole break-outs. Geodynamic significance*. Rev. roum. géol., géophys., géogr. (Géophysique), **38**, p. 45–46.

OLTEAN, I. (1991), *A contribution concerning the physico-chemical parameters of gas deposits from Transylvanian Basin Miocene*. Ph Thesis Degree, in Romanian.
SCHLUMBERGER (1982), *Well evaluation developments. Continental Europe*.
SCHLUMBERGER (1989), *Log interpretation. Principles/Applications*.
SCHLUMBERGER (1996), *Log interpretation charts*.
ZUGRĂVESCU, D., POLONIC, G., NEGOIŢĂ, V. (1999), *A preliminary report on the break-out inferred stresses in the Transylvanian Basin*. Romanian Journal of Tectonics and Regional Geology, Vol. 77, Supplement no.1, 43–44, Abstract.

STADIUL ACTUAL PRIVIND DETERMINAREA STRESULUI ÎN BAZINUL TRANSILVANIEI CU AJUTORUL DIAGRAFIILOR

DOREL ZUGRĂVESCU, GABRIELA POLONIC, VICTOR NEGOIŢĂ

(REZUMAT)

Studiile geodinamice bazate pe înregistrările diagrafice în puţurile de foraj au cunoscut un remarcabil interes după 1997, prin cercetările conduse de Institutul de Geodinamică.

În acest context, prezenta lucrare îşi propune expunerea regimului actual al stresurilor rezultate din măsurătorile şi interpretările diagrafice înfăptuite într-un mare număr de sondaje care fac parte din Bazinul Transilvaniei. În final, se reţin evaluările făcute pentru 53 de foraje diferite care se pot integra în aşa-zisele norme A, B, C ale schemei de calitate a Hărţii Mondiale de Stresuri.

Orientările (azimuturile) componentelor orizontale ale stresurilor maximale şi minimale au fost stabilite analizându-se ovalizarea găurii de sondă (metoda *breakout*-urilor) şi au fost înregistrate cu ajutorul diagrafiilor pandajmetrice.

Cea mai mare parte a echipamentelor pandajmetrice combinate, puse în serviciu pe teritoriul României de către Western Atlas (Dipmeter) şi Schlumberger (SHDT şi BGT), dispun de un microdiametror cu patru braţe cuplate în perechi deschizându-se până la 30" şi, la nevoie, 40" prin adăugarea prelungitoarelor şi care oferă două curbe de diametre independente măsurate în două planuri perpendiculare.

Un integrator al volumului găurii de sondă, plasat în aparatura de fund, oferă posibilitatea determinării zonelor fracturate, cavernate şi ovalizate legate de fenomenele tectonice ale stresului.

Orientările componentei de stres maximal şi minimal, pentru fiecare din cele 5 compartimente geologice care împart Bazinul Transilvaniei, au fost calculate şi prezentate în formă tabelară şi grafică.

De asemenea, câteva determinări privind magnitudinea stresului au fost efectuate şi, în final, exprimate sub forma gradienţilor componentei maximale de stres, a gradienţilor componentei minimale de stres şi a gradientului presiunii fluidului care umple spaţiul poros al formaţiunilor geologice.

Key words: stress, borehole, breakout, well logging.