BOREHOLE GEOPHYSICAL MEASUREMENTS USE FOR ESTIMATION THE EARTHQUAKE MAGNITUDES INDUCED BY HYDROCARBON EXPLOITATIONS. APPLICATION ON 15 HYDROCARBON FIELDS LOCATED IN MOLDAVIAN REGION OF ROMANIA

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L'utilisation des mesures géophysiques de sondage pour l'évaluation de la magnitude des tremblements de terre induits par les exploitations d'hydrocarbures. Application sur 15 gisements d'hydrocarbures situés dans la région de Moldavie (Roumanie). La Roumanie est considérée comme un pays ayant une grande densité de forages sur son territoire et, par conséquence, une quantité importante d'enregistrements de données physiques du sous-sol est conservée dans les archives de l'ancien Ministère du Pétrol. Le recueil de mesures associées aux sondages a débuté il y a 70 ans par des opérations de diagraphie, toutes ces données n'attendent qu'à être utilisées. Ainsi, une nouvelle méthodologie a été élaborée et développée, utilisant les mesures diagraphiques (well logs) enregistrées dans les anciens gisements d'hydrocarbures (brown-fields) roumains pour déterminer les principaux paramètres géomécaniques nécessaires au calcul de la magnitude de tremblements de terre, potentiellement induits par l'activité d'exploitation des hydrocarbures. La relation entre les principaux paramètres géomécaniques et la magnitude estimée de la sismicité induite a été translatée après l'analyse de données statistiques publiées dans la litterature scientifique étrangère. Les transformations (liens) entre les mesures diagraphiques et les paramètres géomécaniques mentionnés ci-dessus ont été realisées suivant une méthodologie de „normalisation" originale, élaborée par les auteurs de ce travail. Suivant les conseils de l'Institut de Géodynamique de l'Academie Roumaine, les applications de la méthodologie ont été effectuées dans la région de Moldavie en Roumanie; les résultats obtenus sont en concordance avec les magnitudes enregistrées par les tremblements de terre inscrites dans les régistres de l'Institut National pour la Recherche et Developpement pour la Physique de la Terre. En Roumanie, beaucoup de localités et d'agglomérations urbaines sont situées à proximité de champs d'exploitations d'hydrocarbures. La méthodologie décrite dans ce travail offre la possibilité d'acquérir des connaissances au sujet de paramètres géomécaniques et des niveaux de sismicité induite par les gisements d'hydrocarbures, permettant d'anticiper des événements considérés inattendus. Par conséquence, afin d'avoir une vision réelle de la situation, avec de très faibles coûts, par suite de l'existence des archives diagraphiques, cette méthodologie peut être recommandée et utilisée en toute confidence.

Key words: borehole geophysics, archived recording data, rock masses-geomechanical parameters, hydrocarbon field-induced seismicity, Moldavia, Romania.

1. INTRODUCTION

In many circumstances local or zonal seismic activities are associated with the existence of hydrocarbon producing fields.

The first example offered by scientific literature was coming from Goose Creek Oil Field (Texas – USA), where, in the early 1920, a remarkable activity of faulting, subsidence, seismic motions and earthquakes have been registered (Pratt, 1976).

Similar examples have been mentioned in the scientific literature, pointing out connections between seismic motions at the ground surface and some mechanical modifications in the solid framework of subsurface geological formations. Such subsurface events are caused by various processes taking place during the hydrocarbons exploitation (fluid depletion of rocks, pressure and stress changes, motions of injected fluids in the course of water flooding drive, etc.).

A lot of similar examples are coming from different zones located all over the world, *i.e.*: Willmington – California, Dallas and Forth Worth – Texas, Woodford – Oklahoma, Rocky Mountains – Colorado (all from USA), Lake Marakaibo (Venezuela), North Western Jawa

(Indonesia), Gazli (Uzbekistan), Romashkino (Russia), etc.

For those readers who are not yet informed by the impact of hydrocarbon industrial field activity in respect of induced regional seismic activity, a suite of published works, papers, reports and scientific contributions are indicated in the references part of this work: Segall (1980), Akramhodzhaev (1984), Simpson (1986), du Rouchet (1988), Rodionov (1989), Nicholson (1990), Grosso (1992), Davis (1993), Sadovsky (1998), Adushkin (2000), Maxwell (2008), Airhart (2012).

With the object of acquiring extensive and more detailed information on this subject matter, the references of all the above mentioned works are recommended.

2. THE ACTUAL STATE OF THE MATTER

The above presentation conclusions suggest that some of the earthquakes noticed at the ground surface of hydrocarbon producing fields are generated in rocks at depths of about few kilometers and that calls for an understanding of stresses in the hydrocarbon reservoir rocks as well as in the neighboring rock masses.

The knowledge of stresses existing at the moment of hydrocarbon prospect discovery, namely at its virgin stress state is essential for a thorough analyses of various states of stresses induced in boreholes during the drilling and subsequent production workable operations. Such operations bring about sundry internal pressures and alterations of hydraulic and thermal regimes around the borehole.

But, as far as is known, the exploration and production stages of hydrocarbons activity take place at a burst rate because at any time the following basic conditions must be ensured:

– wall borehole stability;

– well safety against possible unexpected disastrous blow-outs;

– the indispensable necessity of knowing at any moment the economic worth of hydrocarbon accumulation, as well as the associated economic risk circumstances.

Consequently, owing to these restrictive conditions imposed by the borehole drilling and subsequent exploitation activities the aspects required by a geomechanic strategy including stress measurements and seismic activity monitoring are reduced or neglected.

On the Romanian territory such problems have been rare occurrences and therefore wholly ignored.

3. TACKLING THE PROBLEMS ABROAD AND IN ROMANIA

The absence of geomechanic measurements at the ground surface coupled with the lack/ inexistence of any measurement of induced seismic activity, both in the rocks accumulating exploitable hydrocarbons and in the neighborhood rock masses belonging to the geological structures, brought Romania in an unfavorable position concerning the knowledge and consciousness of so-called men-induced seismicity. Still greater, the number of geological structures producing oil and gas in Romania exceeds nowadays the figure of 200.

Such being the situation, the authors of this work directed their steps towards the scientific literature from abroad (see the references) and more especially guided their way towards the countries in which recording methodologies for seismic activity monitoring have been set up in order to know (1) the virgin seismicity background, (2) induced changes in stress state, as well as (3) their levels during the hydrocarbon fields developments.

Most of the works quoted in our references are dealing with such subjects, but particularly, a special attention was straighten towards Russian oil and gas bearing fields because during the last century similar technologies (methods, tools, equipments) have been practiced and utilized in both countries Romania and Russia.

A worthy consideration was assigned to the works of Russian Academy of Sciences which, in cooperation with the Ministry of Fuel and Energy of Russian Federation, have been undertaken remarkable studies over the giant Romashkino hydrocarbon field, located in the Volga-Tatar Arch of the Volga-Ural province.

On this giant hydrocarbon field with a maximum dimension of 70 kilometers, an intensive activity of seismic monitoring was undertaken by the Tatarneftigeophysika, detailed data being published in the papers of Iskhakov, Adushkin and Rodionov.

During the time period 1986-1995 a number of 400 earthquakes with magnitudes between 1 and 4 were measured. The selected measurements of seismic activity were finally expressed as the sum of the cubic root of the energy for all earthquakes occurring into each square kilometer during one year.

A lot of geophysical, petrophysical, geomechanical measurements accompanied the ultimate research field study achieved on this extended areal.

Other works accomplished in USA, Russia, Great Britain and France devoted to the ascertainment of the relation between earthquake magnitudes generated during the hydrocarbons exploitation, the geomechanical parameters of solid rocks and their neighborhood rock masses have been attentively examined with the view to be applied in the near future research works to be undertaken in our country.

Distinct advantages were acquired in the following enumerated purposes:

– poroelastic forces in hydrocarbon reservoirs and the surrounding rocks causing block motions along faults;

– fluid pressure in fractures, crackly zones and faults;

– rock induced seismicity by fluid extraction and injection operations in reservoir rocks;

– changes of fluid stress in connection with large tectonic stresses/nearness orogens;

– correlation studies between key geomechanical variables and parameters characterizing hydrocarbon reservoir zones (depth and thickness of reservoir formations), rock solidity and permeability (initial/virgin pressure and temperature) and the earthquake magnitudes recorded in more than 200 world wide zones with hydrocarbon exploitation activities.

As a conclusion of this chapter it should be emphasized that abundant and valuable geomechanical works had been published all over the world. They are the consequence of observations that many suites of earthquakes have been induced by the development of hydrocarbons extractive industry. All these exemplifications may be carefully treated and considered as an earnest problem for many Romanian urban and agglomerated localities, putting simultaneously in guard the authorities. In this way the lack of knowledge and information must be quickly eliminated. Really, is it possible?

The existence of an appreciable activity of borehole geophysical measurements on the Romanian territory attempted the author's attention towards the utilization of the data coming from this domain of earth sciences. Such data might prove very useful for removing the Romanian geomechanical data poverty and the drawbacks pointed above.

4. ROMANIAN BOREHOLE MEASUREMENTS FUND AND ITS ESSENTIAL FEATURES

Romania is known as an oil producer since the middle of the 19th century. During about 160 years of certified activity by official documents an important bulk volume of geological works, drillings and hydrocarbon exploitation workings have been achieved.

According to an Annual Report of Petrom (1998) about 60,000 drillings, from which 23,000 exploitation wells have been drilled.

More than 420 wells have been drilled at depth over 4,000 m, a number of 90 at depth over 5,000 m, 18 wells over 6,000 m, the deepest well being drilled at Băicoi, at 7,025 m.

Original oil in place as well as gas in place located in more than 1,000 hydrocarbon reservoirs is registered by various reports and documents.

As a rule, in Romania the keenest interest of exploration and production activities was focused towards the hydrocarbon reservoirs during their hay-day life. Yet, the technologies routinely applied in the nowadays greenfields were not practiced in the early life of today's Romanian brownfields.

That's why it is believed that the use of new methodologies, data analyzes and reinterpretation techniques at the nowadays productive life may offer unexpected new information and even surprises.

In such circumstances the borehole geophysical measurements, well known under the name of well logging activity, struck the author's attention as a modality, rather than a strategy, to acquire a great knowledge about geomechanical data as well as about stresses distribution within the old hydrocarbon field (both in reservoir rocks and in the surrounding rock masses).

It is well known that well logging measurements activity developed after 1927 (date of coming into being) at an unexpected rate and undoubtedly the computer introduction within the field logging equipments allowed more sophisticated measurements, advanced log processing and very subtle interpretation techniques.

But, conventional electric logs were still in use, till nowadays, in countries of the former Easter European Block. There is a huge amount of electric logs in the oil companies' archives, quoting as a case Romania. Most experts are firmly convinced that many favorable hydrocarbon reservoirs have probably been considered noncommercial or disregarded for wanting a thorough quantitative interpretation of old conventional electric logs.

In Romania about 65% of approximately 60,000 wells drilled during petroleum history of the country were geophysically investigated by the DRR (Determination of Rock Resistivity, Negoiţă, 1966 and 1968). This method implemented on the Romanian territory since 1967, replaced the Russian BKZ method. The BKZ method was the common use of electric log investigation for exploration and production wells drilled during the period 1948-1967 and stands for about 15% of the existing boreholes on the whole country.

Various sorts of methodologies and equipments imported from USA, Russia, France, Hungary or manufactured in Romania, providing micro and macro focused electric investigations, radioactive logs, sonic logs and other type of logs were used to perform borehole investigation at 10% of the total number of wells, while the remainder of boreholes posses only a so-called standard simplified electric investigation.

It is necessary to underline that during the last 80 years a considerable amount of well logs and borehole measurements have been acquired on the Romanian territory, but, simultaneously it must be remembered at any moment the extremely diversity of equipments, apparatus, tools, electric multiconductor cables, radioactive sources, etc., customary used at well site operations.

At the end, all the recorded documents are processed and stocked in the archives of the former Petroleum Ministry.

And now, we consider wholly serviceably forwarding the equipment and technology diversity used from 1935 till the recent times. With that end in view Table 1 was prepared and discussed below.

Table 1

Equipments diversity in Romania

Denomination in Romania	**Imported from: Delivered by:**	**Our Code**
ASC – 3	RUSSIA	A
ROM – GIP	AUTOCHTONOUS	B
PGAC	P.G.A.C. – USA	C
SP – 50	DRESSER – USA	D
SP – 60	DRESSER + ROMANIA	E
SP – 1	DRESSER – SUA	F
SP – 2	DRESSER – ROMANIA	G
DRESSER – 3600	DRESSER – SUA	H
ASC – 4	RUSSIA	I
GMG	HUNGARY + ROMANIA	J
SCHLUMBERGER	SCHLUMBERGER– SUA	L
ATLAS	WESTERN ATLAS– SUA	M
GAS - CARROTAGE	FRANCE + ROMANIA	N

In the first column of this table are shown the well logging "units" (equipment and apparatus) mounted ordinary on trucks and used customary on field activity. The name of these "units" in the field activity as well as the produced recordings and documents, kept in the archives, are indicated in the "denomination" column.

The second column indicates the provenance of this "unit" (state proprietor of manufactory, delivering society), specifying also the cases in which the complex well logging "unit" is an "aggregate", a mixture of Romanian and foreign share parts or components.

The last column indicates a "codification" arbitrary selected for catalogues.

According to the Romanian rules, before the spading of each borehole a geophysical investigation program was established indicating at which depths the recording of geophysical investigations must be carried out. Each set of field operations achieved at a specified depth is called "run". The number of runs from the ground surface to the bottom hole is different from a borehole to another borehole, being a function of the final geologic objective. For instance at the deepest Romanian borehole (7000 Băicoi) a number of 22 runs have been achieved. In boreholes drilled at smaller depths the number of runs is reduced in a high degree (namely 2 or 3 runs).

But, it is necessary to draw attention to the fact that at each run the geophysical investigation is realized with different types of equipment depending on every day's availability of equipments.

In such way, at the same borehole, it is possible to have geophysical recordings with various equipment types coming from different providers, originated from different sources.

The dissimilar geophysical values recorded on well logs during the successive runs of "data acquisition phase" must be corrected and eliminated in the case of need. Improvements of field acquisition data by detecting and getting ride systematic and random errors will be treated in the following chapter.

5. SHORTCOMINGS IN THE FIELD DATA ACQUISITION AND THE CORRECTION OF SYSTEMATIC AND RANDOM ERRORS

The acquisition of well logging recordings, documents and other field measurements coming from extended time intervals needs to be revised by an experienced practitioner on field operations.

Such an extended and quite delicate subject will not be discussed or invoked in this work. But it is necessary to clear up that the borehole measurements performed in the actual brownfields need categorically some corrections which should be established by an expert in the field of well log data acquisition.

The wrong habitude of many persons implicated in log data processing to omit the "quality control" of field recordings without a previous elimination of systematic and random errors represents a wasted time and steers the efforts of borehole geophysics activity towards questionable results.

Such remarks are especially addressed to the persons involved in studies about the basin using "well logging prospecting" approaches (Negoiţă, 1987) for discovering the hydrocarbon source rocks, tight gas and shale gas formations and, of course, for geomechanical researches.

Some of the main problems claimed to be solved by a well logging-acquisition specialist in advance of any type of data processing are coming from the following causes.

1. The design of logging tools used in the last 80 years differentiated from one producing (manufacturing) society to an other, or in the frame of the same society at the moment of passing from an apparatus (tool model) to the next one.

For instance, taking the Schlumberger Company case, which created the successive Induction log-tool models: 5FF27, 5FF40, 6FF40, Deep Induction tool and so on. Referring to the Laterolog tools, the situation is similar, the successive models being: LL 3, LL 7, LL 8, LL 9, and so on. All these successive apparatus models indicate distinctive recording values.

Without other exemplifications a similar situation, may be sized with Russian, Dresser, PGAC, Wellex and other apparatus producers, but what it is necessary to be mentioned, is the fact that "geophysical recorded values" on log have not been the same. The differences in values, is the "job" of the expert in field acquisition, his work necessitating to be carried on prior to any data processing.

2. Electric insulation deficiencies on various multiconductor cables with 3, 4, 6 or 7 wiresheeted (metallic or nonmetallic, presumed to be perfect – flow less, but in fact with unknown quantities of electric current leakages; all sorts necessitating corrections.

3. Various radioactive neutron sources (beryllium-radium, berrylium-polonium, berrylium-plutonium, americium, etc.) using dissimilar calibration units for measurements (micrograms of radium equivalent per ton, microroentgen per hour, impulses/minute, API units, etc.) which during the well-site recordings will indicate different values, necessitating of course, to be corrected.

4. Improperly borehole environments recording mud treatments with various chemical hostile additives influencing the amplitude size of registered geophysical logs.

Most of the above mentioned shortcomings/ real troubles, have been noted in USA, quoting as a case in point, the well-known classic geological formations: Niobrara, Green River, Monterey, Woodford, Bakken as well as various zonal peculiarities in states as Wyoming, Montana, Texas, Louisiana, Ohio, Indiana, Pennsylvania, West Virginia, Kentucky, and so on.

That's why in many cases the values recorded by well logging field measurements are looked as questionable and the problems generated by apparatuses, tools, devices, cables and equipments are treated in the context of systematic errors and have to be solved and corrected by a field acquisition practitioner.

At a rough guess, a quarter of such measurements lack certainty and the United States Geological Survey recommended in many situations their "normalization" (log reconstruction, in acceptation of Schlumberger Company).

Beside that bulk volume of "systematic errors", the borehole measurements recorded on the Romanian territory includes in addition an appreciable volume of "random errors" caused by the working style and the organized structure for providing the well logging activity. Supplementary explanations closely related to the random errors will not be commented in this work because they pass beyond the main purposes of geomechanical targets concerning the earthquakes. But it must to recall the necessity of establishing random errors corrections by the assistance of a field operation well log recordings expert.

The sum of systematic and random errors disclosed anyhow can not be handled in the same way. Each well log suite has its own line of action and "normalization" techniques.

The stages of well log corrections for systematic and random errors are necessary to be done with an exquisite attitude because the results, of well log quantitative interpretation in most of the cases represents basic and final arguments of geologic decisions.

Correcting such log measurement suites entails a worldwide accepted confidence in using trustworthy source data for different geologic studies (petrophysics, geomechanics, sedimentology, geothermy, syntetical reports for solid and fluid reserves, etc.).

Many years ago, Negoiţă (1987) suggested an improved well log methodology based on "well log normalization" as a prospecting method for detecting the subtle traps within basinal geologic studies. Nowadays, the same methodology is proposed to be used with a view to provide better input data for calculating geomechanical parameters.

Such assumption entailed to fulfill the tasks of the above mentioned well log prospecting methodology, namely: (1) the normalization of well logs recorded in the recent or remote past, and supplementary, (2) adequate procedures to assess the tortuosity, the so-called cementation exponent (m) coming from Archie's (1950) and Winsauer (1952) equations. Taking in the computer log processing exact the same value for (m), namely, from the ground surface to the borehole bottom is a grievous mistake which needs to be eliminated for even.

Many thousands of papers, works, documents and books have been published in the domain of borehole geophysics. Few of them, in connection with the present work are quoted in our references (Schlumberger, 1972, 1982, 1996).

6. APPLICATIONS OF BOREHOLE MEASUREMENTS FOR GEOMECHANICAL PURPOSES

From the very outset it should be specified that borehole geophysical measurements for estimating the induced seismicity by hydrocarbon exploitation-industrial activity represents a pioneer study in Romania.

Reliable works undertaken in foreign countries attempted to establish statistical relations between earthquakes magnitudes registered in zones with hydrocarbon exploitation fields and distinctive geomechanical and petrophysical rock parameters.

A lot of examples coming from zones located all over the world have been published, trying to include their results in different patterns and statistical analysis frameworks.

World wide geological nature probably comes across throughout the Romanian country in the same way and correspondingly, the Romanian hydrocarbon field exhibit, more or less, the same physical peculiarities regarding the solid and fluids filling the rock void spaces.

So, at our turn, using similar reasoning and taking with an exquisite consideration foreign statistical analysis, we decided to use them and transferred their statistical results within the frame (limits) of Romanian territory, where our hydrocarbon exploitation – industrial activity took place.

Accepting the premises of these foreign studies, each geologic structure with hydrocarbon exploitable reservoirs is located in a certain geometrical space. The values of earthquakes magnitudes, possible to be generated within such geometrical volumes have been treated and established on the basis of statistical analysis including the following features (characteristics):

– stress directions and magnitudes;

– faulting system in the studied areal;

– the remoteness from a seismic active zone/ orogen;

– fluid volume and its motions in the hydrocarbon bearing system (reservoir rock and the neighbouring rock masses).

The main correspondents of geomechanical characteristics into the petrophysical system inferred from Romanian well logging measurements are given below:

– the reservoir rock depth, accurately established by several log types (electric, radioactive, sonic, etc.);

– the thickness of reservoir rock interval with hydrocarbon bearing fluids deduced from electric and radioactive logs;

– the rock solidity calculated from electric logs, radioactive logs (gamma-gamma, neutron-neutron), and certainly from the so-called gamma ray logging;

– stress direction and magnitudes determined by dipmeter and caliper logs;

– fault directions and their depth established from electric and dipmeter logs;

– fluid motions is established by a gamma-ray log and radioactive tracers measurements.

All borehole logs and measurements have to be previously submitted to a normalization process in order to use only standardized data. The lack of normalization means a computer processing with wrong input data and inaccurate final results.

7. APPLICATIONS ON THE MOLDAVIAN HYDROCARBON FIELDS

Using the well log recordings and accompanying documents achieved at each customary borehole geophysical operations the methodology described in this work may be carried into effect for (1) each well and extended to (2) any geological structure or (3) hydrocarbon field.

At the request of the Institute of Geodynamics of the Romanian Academy, the first application of the above mentioned methodology was undertaken on the Moldavian province (region) of Romania.

The most semnificative 15 hydrocarbon fields have been selected and well logging processed; their main zonal characteristic being indicated below:

– deposit and bottom hole depth = 600 m and 2,500 m, respectively;

– thickness of hydrocarbon producing interval = 10 ÷ 100 meters;

– reservoir rock solidity = 70% ÷ 90%;

– flowing well – reservoir initial pressure = 50 ÷ 200 bars;

– initial temperature after the casing perforation = 30 – 120°C.

The denomination of these 15 fields being involved in the applicative study are listed below in an alphabetical order:

Bacău, Cudalbi, Frasin, Găiceana, Glăvăneşti, Homocea, Independenţa, Mălini, Matca, Pipirig, Roman-Secuieni, Slănic, Taşbuga, Ţepu, Zemeş.

For a better localization, every field involved in this study was marked by a hatched zone in the map presented as Fig. 1.

On the same map are indicated the stress directions (azimuths) under the form of bars (lines) reported to the North. For the borehole location inscribed with number 15, the maximum stress is oriented towards NE, in a strict sense 53°.

As far as Moldavian stress determinations are concerned, a separated table is brought up in this applicative study Table 2. On the basis of dipmeter measurements recorded during 1995–1996 time period, in 20 exploration wells, detailed information regarding stress magnitudes are also delivered, a taking over from an antecedent study (Negoiţă, 2009).

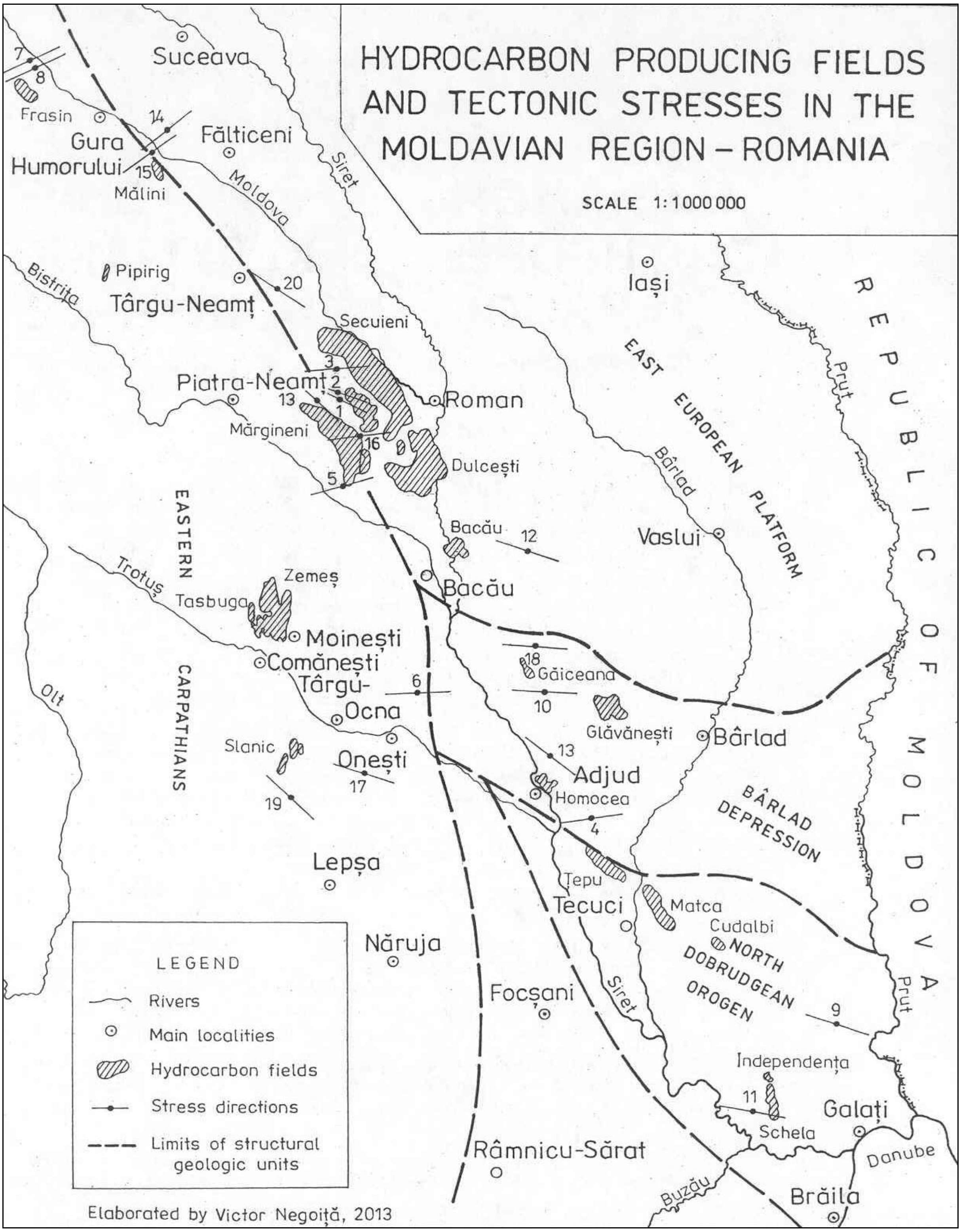

Fig. 1 – Hydrocarbon producing fields and tectonic stresses
in the Moldavian region – Romania.

Table 2

Stress determination from well log measurements in the Moldavian region (Romania)

No.	GEOGRAPHICAL COORDINATES AT THE MEASUREMENT LOCATION		DEPTH IN THE SUBSURFACE (m)	DIRECTION OF MAXIMUM STRESS (degrees)	MAGNITUDES	
	LATITUDE	LONGITUDE			EFFECTIVE STRESS (bars)	DIFFERENTIAL STRESS (bars)
1.	46°55”	25°57”	2698	119	318	186
2.	46°44”	26°52”	2105	134	248	193
3.	46°59”	26°37”	2404	88	317	197
4.	46°08”	27°17”	2494	86	316	195
5.	46°46”	26°41”	2713	72	292	186
6.	46°21”	26°50”	4850	82	533	163
7.	47°34”	25°47”	4200	71	592	199
8.	47°33”	25°48”	3790	60	327	181
9.	45°41”	28°03”	526	120	283	201
10.	46°14”	27°15”	2109	106	300	202
11.	43°34”	27°48”	1005	116	197	169
12.	46°36”	27°09”	1985	111	289	199
13.	46°12”	27°16”	1942	145	287	197
14.	47°25”	26°09”	1963	50	296	196
15.	47°22”	26°05”	2241	53	293	199
16.	46°53”	26°39”	2152	83	281	194
17.	46°08”	26°28”	1008	108	194	169
18.	46°17”	27°14”	2398	101	317	197
19.	46°08”	26°27”	1599	136	229	198
20.	47°12”	26°30”	2194	129	298	193

Simultaneously with stress determinations, a synopsis of geomechanical parameters causing and measuring the induced seismicity by oil and gas-industrial activity is shown in Table 3, intending to answer to the purpose of knowledge the parameters frequently offered by foreign scientific literature, namely: deposit geologic age and depth, reservoir interval thickness, rock solidity, reservoir initial pressure as well as the initial temperature.

All these input data are coming from borehole measurement documents, and recordings achieved in the Moldavian brownfields during the time period 1955–2000. The available types of geophysical investigation were the following: standard electric logs, D.R.R., micro and macro focused investigations by Laterolog and Induction log, Sonic and Radioactive logs (natural gamma radioactivity, neutron, neutron-neutron, gamma-gamma, temperature, caliper, etc.).

The above mentioned geophysical investigations have been used after a previous process of normalization for cleaning away the systematic and random errors, coming into sight owing to the well-log operating conditions.

The last information concerning the estimated magnitude level of the future seismicity to come, was finally, calculated and inscribed on the latest column of Table 3.

8. CONCLUSIONS

Romania is recognized all over the world as a country with a great density of boreholes on its onshore territory and thanks to this favorable advantage, a huge quantity of subterranean recordings of physical data are kept in the archives of the former Petroleum Ministry.

The borehole measurements activity started by well logging operations 70 years ago and all the recorded documents are looking for to be used.

For this reason a new methodology have been elaborated and promoted by using borehole measurements recorded within Romanian brownfields for determining the main geomechanical parameters, and far reaching, the magnitudes of possible induced earthquakes generated by hydrocarbons-producing activity.

Table 3

Seismic magnitudes induced by hydrocarbons exploitation over gas and oil fields located in Moldova (Romania)

No.	HYDROCARBON FIELDS LOCALITY	GEOLOGICAL AGE	DEPOSIT DEPTH (M)	SOLIDITY (%)	PRESSURE (bars)	TEMPERATURE (°C)	SEISMIC MAGNITUDE
1.	Bacău – BACĂU	Miocene	2100	0.80	200	83	2.561
2.	Cudalbi – TECUCI	Miocene	1940	0.80	195	76	2.973
3.	Frasin – GURA HOMORULUI	Lower Miocene	3700	0.87	340	97	2.031
4.	Găiceana – BACĂU	Miocene	2230	0.81	220	91	2.503
5.	Glăvăneşti – BÂRLAD	Miocene	1600	0.84	160	76	3.225
6.	Homocea – ADJUD	Miocene	2050	0.81	200	82	2.708
7.	Independenţa – GALAŢI	Pliocene	680	0.77	68	31	2.573
8.	Mălini – FĂLTICENI	Lower Miocene	1980	0.82	170	81	2.424
9.	Matca – TECUCI	Miocene	2150	0.81	225	87	2.498
10.	Pipirig – TÂRGU NEAMŢ	Eocene	780	0.86	75	35	1.948
11.	Secuieni – ROMAN	Lower Miocene	1500	0.80	150	60	2.945
12.	Slănic – TÂRGU OCNA	Oligocene	760	0.88	40	28	1.702
13.	Taşbuga – COMĂNEŞTI	Oligocene	2200	0.86	210	58	2.092
14.	Ţepu – TECUCI	Miocene	2350	0.80	225	89	2.425
15.	Zemeş – MOINEŞTI	Oligocene	800	0.85	55	32	1.856

The relation between the main geomechanical parameters and the estimated magnitudes of induced seismicity was taken over from statistical data analysis published in the scientific literature of foreign countries. The transformation/link of the Romanian well log measurements to the above mentioned geomechanical parameters was realized by an autochthonous normalization methodology elaborated by the authors of this work.

Advised by the Institute of Geodynamics of the Romanian Academy, the application of this methodology was carried out on the Moldavian province of Romania; the obtained results being in a bilateral accordance with the recorded earthquake inscribed in the registers of the National Institute of Research and Development for Earth Physics.

In Romania many localities and urban agglomerations are situated in the proximity of hydrocarbon exploitation fields. The methodology described in this work offers the possibility to have some knowledge about the geomechanical parameters and the levels of hydrocarbon fields-induced seismicity, in advance of any unexpected event. That's why, in order to have a real view of things with minimal tiny costs, the methodology proposed in this work is recommended to be used in all confidence.

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