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MULTIDISCIPLINARY INTERNATIONAL
SCIENTIFIC CONFERENCE

CONFERENCE PROCEEDINGS

BOOK 1
VOLUME 1

GEOLOGY
ENERGY AND FUELS
EXPLORATION AND MINING

26-29 MARCH 2019 | NOVOTEL, ATHENS, GREECE

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Published by SAIMA CONSULT LTD, Sofia, 1616, st. Beliya Kladenets, 15, fl. 3
Total print 100

ISSN 2603-5472
ISBN 978-619-7495-02-7
DOI 10.32008/GEOLINKS2019/B1/V1

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CHARACTERIZATION OF THE GEOMAGNETIC FIELD BY ANALYZING THE DATA RECORDED AT THE SURLARI GEOMAGNETIC OBSERVATORY

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ABSTRACT

In our paper we have described the steps to analyze the geomagnetic field's morphology, and the results of these, that will be included together with other multidisciplinary studies for the space weather forecast within the project in which we are partners.

Based on data processing are calculated the gradients of each component, as well as, spectral, statistical and correlation analyzes. All of these parameters are part of the geomagnetic database.

Web interface for the database meet the different handling needs of collected, raw or processed data. The server-side programming language used for design is php.

This allow us to select different periods for which access to stored data, required for different search filters and different parameters or data from different time periods can be compared.

For a more in-depth analysis of the stored data, through JavaScript programming language can be draw graphs for different parameters.

Access to the web interface can be done with or without authentication, depending on the need to ensure the security of certain data collected, stored and processed.

The application is scalable for different devices that will access it: mobile, tablets, laptops, or desktops. This application will be included in a project website „Institutional capacities and services for research, monitoring and forecasting of risks in extra-atmospheric space”, component project: „Space Weather", acronym: SAFESPACE, within the grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project Nr.16PCCDI/2018.

Keywords: *Geomagnetic observatory, database, data in real time, data acquisition, data processing*

INTRODUCTION

At the same time, a significant development in the procedures of processing primary data has been registered, based on standardized programmes. The new stage of this fundamental research, largely applicable in various fields, is also marked by the simultaneous observation of space-time distribution of terrestrial electromagnetic field by means of stations set on satellites circling on orbits around the Earth.

In Romania, fundamental research in this field has developed within a special unit, Surlari National Geomagnetic Observatory (SNGO), acronym: SUA in INTERMAGNET, in which have followed two main objectives [1], [2]:

- a permanent observation of planetary magnetic field within a world net of observatories;
- highlighting some local disturbances, through electromagnetic induction, related to the geological structure of our country's territory.

Data regarding geomagnetic field all over Romanian territory will be revaluated, along with rendering evident some peculiarities of very long-term variations, which require long time series, operation possible only in a few observatories with a longer and continuous activity [3]. SNGO's current data base - covering over 75 years of non-stop observation of the transitory part of the geomagnetic field – is an important patrimony, both for national and for planetary research. We should mention that out of the 180 observatories and fundamental stations forming current world net for monitoring terrestrial geomagnetic field, only 50 stations (SNGO included) can deliver complete time series comprising seven solar activity cycles [3], [4], [5], [6], [7], [8].

REMARKS ABOUT SURLARI GEOMAGNETIC OBSERVATORY

Geomagnetic field study in Romanian stations has started with irregular measurements, late XIX^{-th} century. In 1943, the foundation of SNGO marks the beginning of a new era in the systematic study of geomagnetic field by a continuous registration of its variations and by carrying out standard absolute measurements in a fundamental station. Observatory location was thoroughly established, so that meets the geomorphological and technological criteria. SNGO is located in Căldăruşani - Surlari astro-geodetic polygon, in an area without magnetic field anomalies or significant local heterogeneity of electrical conductivity in the basement and a sufficient distance from major industrial sources of disturbance. The Observatory covers an area of 3.56 hectares and comprises seven buildings and underground laboratory for geomagnetic sensors. Inside are installed specialized equipment's to multiparametric monitoring of fields of earth. These buildings were made during 1943-1969. The underground laboratory and the main buildings were renovated and modernized in 2006-2008 [3].

The design of the special geomagnetic recording laboratories was made after some well verified. Inside laboratories were built 18 specially designed pillars embedded deep in the ground, which are mounted high-resolution sensors.

In figure 1 and 2 are show two photos with General view and absolute measurement laboratory in SNGO.

Fig. 1 - General view in SNGO

Fig. 2 Absolute measurement laboratory in SNGO

Lately, SNGO has been concerned about:

- permanent knowledge of the structure and evolution of transitional geomagnetic field during several solar cycles [1], [2], [3];

- providing highly accurate absolute values of the magnetic field direction and intensity;

- characterization of the planetary and local "magnetic state" by the regular computing of geomagnetic activity indices;

- regular comparison of the base levels of geomagnetic records (national magnetic standards) to other planetary observatories;

- study of various temporal geomagnetic variations with periods in a very wide range in time from seconds to hundreds of years;

- determining the spatial distribution of the geomagnetic field, mainly at national level and integrate these images into continental or planetary maps. These distributions are obtained by repeated measurements in a network of points evenly distributed across the country. Determined values are used to obtain the secular variation of the normal geomagnetic field and binding of magnetic maps made in different times;

- contribution to establish periodic coefficients of the IGRF (International Geomagnetic Reference Field) in the IAGA with shaping local peculiarities reported in our country.

Since 1998, fundamental geomagnetic station of Romania, SNGO, was admitted as an planetary observatory in INTERMAGNET program fulfilling main obligations imposed in this capacity, mainly oriented towards the major aspects of planetary field, axis and the changes of Gaussian dipole moment , the International

Geomagnetic Reference Field - IGRF, the level of solar activity and disturbances related to the relationship Sun - Earth, the solar wind interference and interplanetary magnetic field, or structure of convection currents in the outer core - Earth's asthenosphere [4], [5], [6], [7], [8].

Permanent recordings made on SNGO or in stations temporarily installed in Romania are useful to eliminate variations with external causes, leading to application of corrections to the magnetometry survey in order to increase their accuracy because when is measured weak geomagnetic effects, these cuts are absolutely necessary for accurate localization of abnormalities of economic interest.

NETWORK INFRASTRUCTURE AND DATABASE OF SNGO

The goal of network infrastructure creation is to facilitate access to data recorded in a single format, automate pre-processing, and obtain a unique time basis (via GPS) for all data.

The operating system chosen to support the services provided is the distribution of Linux OpenSUSE 11.1 for services running on x86 machines and the services hosted on the Cisco router run under Cisco IOS 12.4T

Short description of network and infrastructure features at the SNGO:

- NAT local network access implemented natively by the Cisco-880 router
- VPN Remote access server in the Observer's local network for users located in other locations implemented through Cisco IOS 12.4T
- DHCP automatic configuration of network settings implemented with ISC dhcpd 3.1.1
- DNS address resolution by name and vice versa implemented with ISC BIND 9
- Integrated LDAP authentication of users in the local network implemented with open ldap 2 2.4.12
- NTP clock synchronization service for all computers connected to the local network implemented with ntpd 4.2.4
- Database server for storing data from all Surlari Geomagnetic Observatory acquisition systems implemented with MySql 5.0.67
- Web server hosts the observatory's web site deployed with Apache 2 2.2.10

2) Automatically, periodically (e.g., averaged over 5 seconds or 60 seconds) to the Web server.

- FTP server file transfer services for Intuitive users using Intranet vsftpd 2.0.7
- File server server for general use file storage with Samba 3.2.4

For implementation, these services have been grouped into 4 categories, taking into account their specificity, the need for hardware resources to run, and critical dependency between them. For implementation, the solution was chosen as each group to run on a separate server.

Cisco-880 router - runs NAT and VPN server services (already implemented and active)

netserv * - server for common network services: DHCP, DNS, LDAP
dbserv * - database server (Fig.3)
filer * - file server
webserv * - Web server and FTP

To reduce costs and reduce the number of computers installed, all are virtual machines running under VMware Server 2 on a single physical server for a high reliability (RAID 1 for dual hard drives, dual NIC mounted in fail-over architecture, UPS with monitoring software).

Modernization of the network infrastructure has been carried out so that it can provide all the services necessary for the exploitation (figure 3 and 4).

The software package consists of the following components:

- SQLServer.VI on the database server is designed to transmit measured values in two ways:

1) upon request, to applications installed on computers of different users; users can log in with a username and password to access the data stored on the database server;

2) Automatically, periodically (e.g., averaged over 5 seconds or 60 seconds) to the Web server.

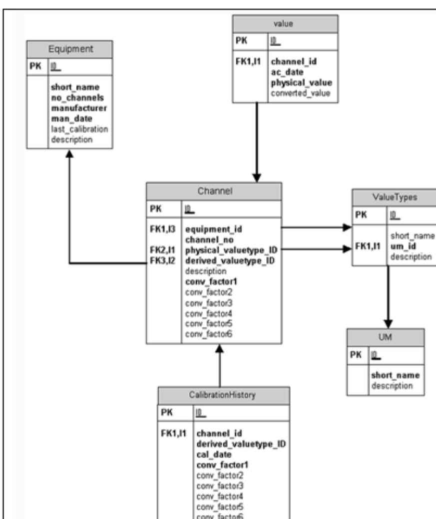

Fig. 3 - Sketch of the data server.
Description of each unit within the data server

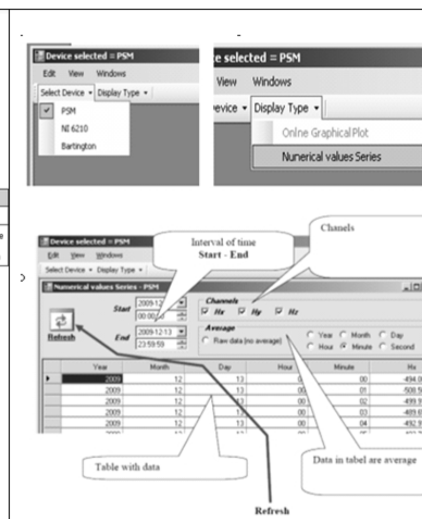

Fig.4 - Schematic overview of the database acquisition and management program.

Client VI, with multiple installations on different users' computers, has the role of allowing them to create on their own computers text files containing measured values retrieved from the database server (figure 3 and 4);

This allows the user to select the start and end moments of the time period for which the SQL Server VI, application will be requested, copy the measured values;

The user can specify, where appropriate, the path and file name in which the measured measurement values transmitted by the SQL Server VI application are saved;

- Web Server VI is installed on the Web server and receives the measured values, periodically transmitted by SQL Server VI and will save them in text files;

The files are daily, the file name is DD-MM-YY, and the files within a month will be stored in the same folder, the monthly folder name being MM-YY.

- Java Client VI, is installed on the Web server and is called by the actions of the various web page visitors and allows viewing of measured values in graphical form.

These software applications respect the SNGO internal network and public network connections, thus centralizing data acquisition and online transmission on Web Server.

Standard processing of geomagnetic data according to INTERMAGNET requirements includes calculating the average at one minute of Geomagnetic components.

Values and obtaining provisional data files, establishing the base level of records as well as adopting the baseline level and making definitive data.

This infrastructure and organizing of database from SNGO allow us to monitoring and make all processing procedures of data according to geomagnetic observatories reequipments.

PRINCIPLES OF PROCESSING USED FOR CHARACTERIZATION OF THE GEOMAGNETIC FIELD

By continuous monitoring of the geomagnetic field, discrete time-dependent signals for each component are obtained.

Depending on the predictability of the evolution over time, these signals cannot be considered deterministic signals with predictable evolution. Simple deterministic signals can be fully specified by a small number of parameters (amplitude, frequency, and phase).

The geomagnetic signals acquired can be considered as random signals, with a predictable evolution only in a probabilistic sense [9], [10].

The statistical dimensions for characterization of the localization and dispersion of a random variable are: mean value, variance, and quadratic mean value.

A stochastic process results from the variation in time of a random size, i.e. a random function of time, x (t), whose value for each moment considered will be a random size.

The main statistical parameters of a stochastic process are: average value, dispersion (variance), mean square value, autocorrelation function and autocovariance function.

Unlike the statistical parameters of random variables, which are numbers, the statistical parameters of stochastic processes are time functions.

Additional statistical parameters, able to characterize the internal structure of the process, are the function of autocorrelation and the function of autocovariance.

These parameters characterize, from a numerical point of view, the degree of dependence between process values that are at different time intervals. The functions of autocorrelation and autocovariance are deterministic.

One of the most used methods for determining the characteristics of a signal and evaluating its informational content is to analyse the spectrum of the signal. For a deterministic process defined by a given signal, a signal decomposition can occur in a large number of harmonic signals of various frequencies and amplitudes.

Modern approaches to spectral analysis are designed to overcome some of the deformations produced by classical methods and are quite effective especially for short analysis segments.

CONCLUSION

Preliminary data in the form of average values at one minute of recorded components contained in daily files that have the extension code of the observatory are corrected with the value of the base level adopted for each component for that day.

Files obtained in this way are processed with an application that converts them from daily text files into monthly binary files containing the minute averages of recorded and corrected components.

The final data set delivered to Geomagnetic Information Node (GIN) at the beginning of the year following the one for which they are calculated will contain 12 monthly binary files with geomagnetic components and magnetic activity indices for each month, a geomagnetic field component annual file, a file with the basic and calculated values for geomagnetic field records and a readme file containing data on the recording technique, the absolute measurements used in the observatory and the personnel carrying out these works.

The components of the geomagnetic field measured in the SNGO are: North (Hx), East (Hy), vertical down (Hz), declination (D), inclination (I) and the total component. From any of these three components, the four other components can easily be calculated by simple trigonometric relationships.

The geomagnetic data processing steps include correcting the values of the components of the geomagnetic field purchased with the vector magnetometer by adding the base values of each component to the values acquired by the flux-gate magnetometer. Then calculate the minute-averaged values of the corrected components with the provisional baseline value and the baseline by interpolation with a third-order polynomial function of the absolute measurement values.

Another step is to determine the ramps and spikes recorded and to remove them from the dataset or to replace them with data from the second acquisition system.

All modern techniques implemented in the SNGO processing module attempt to make advantage of any known information about geomagnetic signals for the good characterization of the geomagnetic field.

A new concept for database in SNGO includes following modules:

Database Module

A database will be designed in the MYSQL language to store both the gross measured values - F, H, X, Y, Z, D and I (at variable frequencies) and those resulting from processing in the forecasting module.

Application Hosting Module (Apache Server)

This module will host an application designed in php and javascript (Database Interface Database). To be able to do this, the Apache Server will have the mod_php enabled.

The web interface for the database

The interface will meet different handling needs of collected, raw or processed data. The server-side programming language used for design is php.

This will allow us to select different periods for which access to stored data will be required, different search filters (based on different parameters), or data from different time periods. For a more in-depth analysis of the stored data, javascript will draw graphs for different parameters.

Access to the web interface can be done with or without authentication, depending on the need to ensure the security of certain data collected, stored and processed.

ACKNOWLEDGEMENTS

We gratefully acknowledge the many and significant contributions and comments provided by our colleagues from geomagnetic observatories. The manual about observatories methodologies is based on the original document (INTERMAGNET Technical Reference).

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project Nr.16PCCDI/2018: Institutional capacities and services for research, monitoring and forecasting of risks in extra-atmospheric space”, within PNCDIII.

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CRITERIA FOR ASSESSING THE SCIENTIFIC SIGNIFICANCE OF PALEONTOLOGICAL COLLECTIONS ON THE EXAMPLE OF THE MINING MUSEUM (ST. PETERSBURG)

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ABSTRACT

The mining museum in St. Petersburg keeps a numerous of paleontological collections and materials on stratigraphy and historical geology. The story of its accumulation started at the first half of XIX century with the beginning of the earliest geological study of the European part of Russia (including the Russian journey of R. Murchison). The museum paleontological and stratigraphical fond includes the collections of scientific expeditions, personal geological excursions of scientists, acquisitions of the buying or exchange from abroad, collections, the study of which have not been published by the authors. Among the authors of the collections are some world-known paleontologists and geologists like Ch. Pander, A. Keyserling, G. Helmersen, K. Eichwald et al.

It is obvious that the greatest value have collections containing originals to books and articles on paleontology. These materials are well known among paleontologists thanks to Museum catalogues and references to samples in publications. However, most of the paleontological collections, numbering more than one hundred thousand samples, is unknown and is not in demand among specialists. Attribution and cataloguing of these collections requires a comprehensive analysis of their structure, including the definition of criteria for assessing their scientific or educational significance. Experience with paleontological collections in the Mining Museum has shown that the following criteria determine the greatest scientific value of the collections.

First: the origin from the classical sections described in the geological literature, which may be stratotypes or be in stratotypic areas. These samples can serve as a reference in the study of paleontological species, first described by the materials from these sections, if necessary, among them can be selected neotypus. Secondly, the value of the collection can be determined by its origin from the lost sections. The study of such materials allows to learn about the stratigraphic interval and faunistic characteristics of these deposits, which is especially important in the case of unique locations for the study area. Third: collections from hardly accessible regions. These are materials from areas where special paleontological and stratigraphic studies are not currently being carried out and which are difficult for specialists to visit for geographical or political reasons. Fourth: the value of paleontological collections may increase depending on how fully they characterize a particular geological formation (or geological region in which a number of formations are developed). From this point of view, the most valuable are the materials of long-term systematic studies. The proposed article considers the examples of the collections of the Mining Museum in Saint-Petersburg the most interesting from the point of view of all of the proposed criteria or their combinations.

Keywords: *paleontological collections, natural-science collections, paleontological museum, Mining Museum, geological heritage.*

INTRODUCTION

The problem discussed in this article is formulated as a result of work with paleontological collections in the Mining Museum in St. Petersburg. The Museum has a long history and keeps numerous samples of very different taxonomic composition, geological age and geographical origin. These facts result in a number of difficulties relating to the attribution, systematization and cataloguing of these collections. The Museum is almost 250 years old and about 200 years ago it began to accept paleontological collections for storage systematically. During this time, the Museum has gone through very different stages. Some changes related to the working conditions in the Museum: in different periods, the number of employees including qualified paleontologists changed significantly which affected the detail of the collection records. Some changes were related to the history of the country: the revolution, the arrests of leading experts, the war, preparations for evacuation, the siege of Leningrad and the bombing affected not only the maintenance and preservation of records, but also the storage of samples, the integrity of collections and the conformity of labels to samples. The scientific approach to the systematization of collections was also different: the collections received from different authors, which were the integral results of a particular researches, used to be recorded in the books of the income as a whole. However, later they could be used to form expositions on stratigraphy, regions or taxonomy that often led to the loss of information about the exact geographical and stratigraphic reference and attribution to a particular author.

Currently, the Museum faces a number of challenges. The first is the attribution of a huge number of samples, the clearing of their geographical and paleontological reference (if possible), the maximum possible restoration of author's collections. The second is the cataloging of samples so that they become known to paleontologists. Planning of this work required the identification of the most important collections, the cataloging of which is advisable to carry out in the first place.

Since the author assumes that the described problems can be typical not only for the Mining Museum but also for some other natural science museums, the article tells about the criteria for assessing the scientific significance of paleontological collections formulated on the example of the Mining Museum.

MATERIAL AND METHODS

Paleontological collection of the Mining Museum includes about one and a half hundred thousand samples. That part of them, which is the originals to monographs and articles on paleontology (about ten thousand samples), well-attributed and catalogued [1]. The proposed criteria are based on the analysis of the rest (most) of the collections and museum archives over the past two hundred years. We can say that most often the scientific value of these collections increases due to the factors listed below.

The origin from the typical and long-known sections described in the classical geological literature. This paragraph is more about the collections of the XIX century – the time when the chronostratigraphic chart was created, ideas about the systems were formed and the foundations of paleontological taxonomy were laid. During the XIX-early XX century Mining Museum actively acquired a collection of fossils that characterize the most famous geological formations in Europe. At the same time, the Museum received the materials of the first studies of sedimentary formations in Russia. In 1820th-1830th it was mainly collections from the outskirts of St. Petersburg, and later from more distant territories. It should be mentioned that the Museum holds specimens collected by N. I. Koksharov who accompanied R. I. Murchison in his journey in Russia in 1840-1841 [3], collections of the author of the fundamental work "Paleontology of Russia" (1854-1861) E. Eichwald, one of the founders of Russian paleontology Ch. Pander and many others.

The importance of these collections for paleontology due to the fact that the authors of the XIX century did not always indicate the holotypes for the species that they established. Sometimes the collection of originals for the monograph has not been saved or a type specimen has been lost. Then, collections about which it is known that this author worked with them, accompanied by his labels and originating from the same sections receive the main value. It is reasonable to choose a sample that will serve as a neotype among them.

Speaking of the importance of these collections for stratigraphy, the most obvious is to mention the possibility of using the huge material collected throughout Europe and Russia in stratotypic areas or other classical sections for the study of these sections by specialists and students. But in this case we will talk more about the methodological (or educational) value than about the scientific one. The scientific value may be due to the fact that they were collected in the XIX century. Modern experience of studing of the sections, known to the general public for a long time, shows that the picture of their faunal characteristics may differ significantly from that which develops in the study of historical collections. This is due to the handmade impoverishment of faunal complexes in sections due to long-term collecting. In addition, the study of modern collections often does not allow us to accurately understand about the fauna itself: for example, in many collections of the fauna of Ordovician of the Leningrad region, we can find much more representative samples, large with well-shown species characteristics. At the same time, the once famous sections themselves are often not rich in such samples. Therefore, it is necessary to get acquainted with the Museum collections, when working with such classical sections, not only with the collections of the originals to the monographs, which consist of the most typical single samples, specially selected by the author, but also with the materials of numerous collections that give the most complete idea of the faunal charatkeristics of the section.

The origin from the lost sections is the next feature that significantly increases the scientific value of paleontological collections. The example of such collections is the numerous materials from the outcrops of Ordovician on the Pulkovka river South of St. Petersburg. A series of outcrops on the river Pulkovka has been described by W. T. Strangways in 1821 during his travels around St. Petersburg [5], [6]. In 1830 it was studied by Ch. Pander [4]. During the XIX century it continued to arouse interest among geologists. To date, these sections have been lost largely due to landslide processes, in part probably due to road construction. The Museum has a large collection of fossils from these sections, collected in 1866 by an unknown author (the exact attribution of these samples is not possible due to the lack of records about them in the Museum archive, but there is reason to attribute them to G. Helmersen). The study of Ordovician brachiopods from this collection [7] made it possible to draw a conclusion about their taxonomic composition from the point of view of modern paleontology and to clarify the stratigraphic interval of Ordovician deposits that were exposed in these sections. Thus, it seems promising to study samples from the river Pulkovka in the collections of the Pander, Gelmersen, Kutargi and Eichwald.

The study of the collection of Ordovician outcrops on the Popovka river is of the same interest. These outcrops, which were of interest not only from the point of view of paleontology and stratigraphy, but also from the point of view of neotectonics, practically disappeared due to landslide processes and private constructions.

Currently, in the Mining Museum materials from a number of such lost sections in the Leningrad region has been identified, but further study of collections from other regions will probably reveal many more such collections from Russia and all around the world.

Collections from hardly accessible regions. The arguments for the high scientific value of collections originating from hard-to-reach regions generally coincide with those for lost outcrops, but here we are not talking about individual sections, but about large areas that are not available for study for an indefinite period due to geographical or political reasons. With regard to the Mountain Museum, we must first mention collections from the Arctic (Novaya Zemlya, Severnaya Zemlya, Franz Josef Land), sparsely populated areas of Siberia and Russian Far East, some areas of Central Asia. The study of stratigraphy and paleontology of these areas by private initiative researchers is impossible because of the need for expensive organization of expeditions and technical support. Special projects for the study of geological formations that allow working on the sections for a long time are very rare [2].In this case, samples of earlier collections can help the author. They, of course, will not replace a full detailed study of the section, but can serve to clarify the geographical distribution of the species or its morphological variability. The advantage of these collections in the Mining Museum is that most of them are collected in the second half of the XX century and therefore has an accurate geographical and stratigraphic reference.

Collections that fully characterize a particular geological formation or geological region. This paragraph is about the value of the collection, which is often not equal to the sum of the values of the samples. The scientific value of one sample can be determined by its safety, or the accuracy of its reference to the section and layer. But most often a single fossil has a high scientific value, if it is a paleontological rarity. Such a sample will be important primarily for paleontology itself, and in some cases (and in the presence of accurate reference) for stratigraphy. But such paleontological rarities are few. As for ordinary samples, which can be massively found in some formation, their value in the museum is usually small. However, the value of the collection consisting of these samples increases significantly if we are dealing with the results of collections from one cut described "with one eye". The same applies to the collections of one expedition purposefully explored a particular area. Here we have to say about the importance of these collections for biostratigraphy, faunal characteristics of the region, and from the point of view of paleontology itself about the possibility to study species variability, evolutionary features or area of distribution.

THEORY

The proposed analysis was an attempt to identify those features of Museum collections that make them important (and sometimes indispensable) for the researcher. Most often we are talking about those situations when the materials and facts interesting to the paleontologist can no longer be observed in nature and only the Museum can provide them. But sometimes it is about a practical advantage of opportunity of initial acquaintance with faunal complexes of interesting sections or regions.

RESULTS AND DISCUSSION

The result of the analysis was the definition and description of the four main criteria for the identification of those paleontological collections that can be most demanded by specialists and therefore should be attributed, studied and catalogued first of all. It is obvious that the greatest interest will represent the collection that respond several criteria. The author believes that these criteria can be extrapolated to other natural science collections, and their discussion among specialists can be interesting. They can serve both for the analysis of collections, and for substantiation of need of their more detailed studying.

This article did not consider the two other important aspects that determine the value of natural-science collections. It is historical and educational importance. These topics should be the subject of a separate discussion.

CONCLUSION

The above analysis of paleontological collections that were deposited in the Mining Museum for two hundred years showed that to identify the most valuable collections in scientific terms, it is necessary to pay attention to the following features:

- the origin of collection from the typical and long-known sections described in the classical geological literature,

- the origin of collection from the lost sections,
- collections from hardly accessible regions,
- collections that fully characterize a particular geological formation or geological region.

Of course, this list is not exhaustive and each collection should be considered individually. But it allows to select large segments from a huge mass of samples for further work.

In addition, the proposed list and its substantiation once again demonstrate that the Museum collections are not of only historical, but scientific value both as an additional material, and as a necessary source of information that can not be obtained from anywhere else.

ACKNOWLEDGEMENTS

The publication has been prepared in the context of a government order of Russia on «Forming of the integrated scientific and educational information complex based on the comprehensive research of the unique collections and exhibits of Mining museum» № 5.12856.2018/8.9.

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EVALUATION OF ORE-CONTROLLING GEOLOGICAL STRUCTURES USING REMOTE SENSING

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ABSTRACT

As a result of this work, remote sensing bases were obtained based on Landsat and Aster materials, a cosmostructural scheme in the East Balkhash site (Kazakhstan), and the main ore-controlling factors were identified, on the basis of which promising sites for the detection of endogenous mineralization were identified. The selected digital satellite images provide a given scale of research and have the maximum spectral completeness, that is, they cover the area of research in all possible spectral ranges. On cosmostructural schemes, objects of linear morphology show faults, areas of increased fracturing, geological boundaries, bedding elements, dyke bodies, and other elements that have a geological nature. To identify the linear structures, the whole complex of source and derivative space materials was used. In conditions of poorly dissected relief, methods for multi-oriented gradients and various filtering methods turned out to be especially effective for emphasizing linear structures. In identifying the ring and arc structures in the area of work, the following features were used: arc and ring borders between blocks with different texture of space materials; borders of landscape inhomogeneities, arc and ring morpholog. Radially ring structures are conventionally divided into structures of the second order and small. Structures with radii from 4 to 48 km are assigned to ring structures of the second order, and small structures with radii less than 4 km are assigned to small structures. Stratified complexes in the studied areas are clearly divided into loose and lithified ones. Neogen-Quaternary proluvial, alluvial-proluvial, alluvial, aeolian and undifferentiated sediments are classified as loose. The lithified stratified complexes are creased in folds with a predominant northwestern strike of the axes. In identifying the bodies of intrusive rocks, spectral libraries, textural features of satellite images and the authors' experience were used.

Keywords: *Remote sensing, Ore controlling factors, Cosmogeological scheme, Prospective blocs*

INTRODUCTION

At present, Applied Remote Sensing plays an important role in solving geological, terrestrial problems and observing coastal and ocean ekosystems [1], [2], [3], [4], [5], [7], [8], [9]. In addition, Remote Sensing provides building new knowledge about the Universe through observation of the Planetary and Solar systems, as well as beyond [7].

The initial data for the work was provided by the archival data of the Landsat ETM +, Aster satellite imagery and data processing materials, as well as data from the digital terrain models SRTM and AsterGDEM. To provide the work with the materials of the survey scale level, mosaics from the Landsat ETM + archival space images were used. For the preparation of mosaics, the photographs of 1999-2002 were used. These data are obtained from the library of satellite images and materials processed by the Maryland University (USA) (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp).

Space images of the average spatial resolution of two systems - Landsat ETM + and Aster, as well as mosaics of space images based on Landsat ETM + images were selected. Radar data SRTM (Shuttle Radar Topography Mission, 2000) and Aster GDEM (Aster Global Digital Elevation Model, 2011) were used to build a digital terrain model and calculate three-dimensional models.

Selected data provide a comprehensive spectral characteristic of the investigated area in the visible, infrared and thermal regions of the spectrum. All cosmic materials were selected taking into account local climatic features, depressed vegetation and lack of snow cover, which corresponds to the requirements for carrying out such work. The accuracy of the location, spatial and spectral characteristics of the selected remote survey data fully correspond to the scale of the work [3], [4], [5], [6], [8], [9], [10], [11], [12].

An original technological scheme for the preparation and processing of the space materials Landsat ETM +, Aster, SRTM and Aster GDEM was developed. It includes the following main blocks [1], [2], [6]:

- extraction of cosmic materials from archives and mapping into a single cartographic projection (Landsat maps only, Landsat mosaics are disseminated without map projection, and Aster data is in a geographic coordinate system);

- primary processing of source raster materials using channel classification algorithms, various enhancement procedures, a complex of methods for filtering and resampling images;

- decoding of mono-channel raster images;

- creation and processing of synthesized images of Landsat ETM+, Aster (Figure 1) multispectral imagery, as well as image mosaics with subsequent statistical filtering for all studied areas;

- creation of representative composites on the basis of the received materials;

- creation of derivative raster images with the use of "algebra of maps" and calculation of spectral indices based on Landsat and Aster materials;

- correlation analysis of mosaics of synthesized images Landsat ETM + and Aster by the method of main components;

- creation, processing and analysis of digital terrain models based on SRTM and AsterGDEM data;

- joint analysis of raster images and digital terrain models, construction of three-dimensional images, interpretation with the use of 3D visualization, creation and interpretation of anaglyphic (stereo) images; preparation of space-structured schemes (Figure 1).

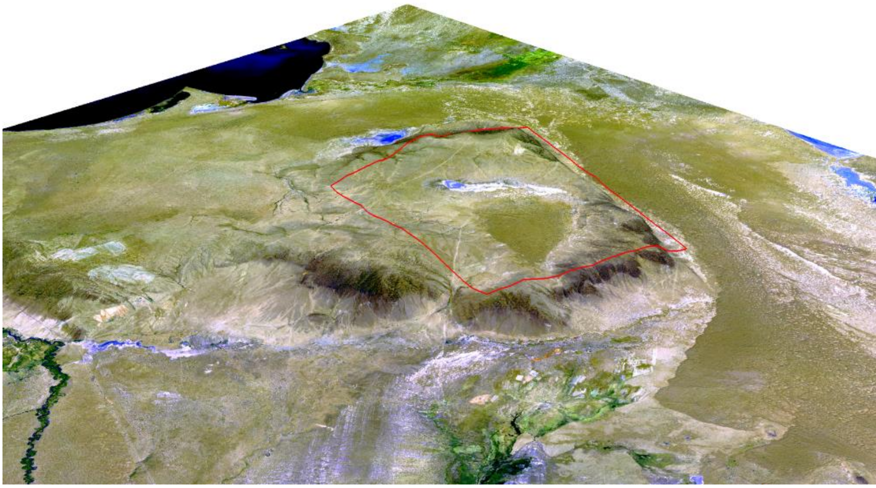

Figure 1 Perspective 3D image of the East Balkhash site based on Landsat ETM + and SRTM materials. View from the south. Vertical factor 10.

THE RESULTS OF INVESTIGATIONS

Cosmological structures of the East Balkhash site. On the area of the East Balkhash site, linear, ring and area, cosmogeological structures are distinguished.

More than 900 linear structures have been identified, among which about 640 received a geological interpretation. These structures include faults, geological boundaries and layered elements of lithified stratified complexes.

Disruptive disturbances in the Eastern Balkhash segment have a predominantly northwestern and sublatitudinal strike.

The main discontinuous disturbance is the right shift displacement located at the northeast border of the area. It has a northeast strike, and it is not possible to determine the displacement amplitude, due to the wide development of modern sediments and the flattened relief near the site.

Secondary discontinuous faults are related to sublatitudinal discontinuities associated with the main structure. The amplitudes of the right-shift displacements in such structures reach 860 m.

Other faults are mainly of the northeast trend.

Elements of stratification of stratified complexes are manifested over the entire area with the exception of areas with developed non-lithic Neogene-Quaternary sediments. In some cases, folded forms of their occurrence are established.

On the Eastern Balkhash section and in its immediate vicinity, ring structures with a radius from 0.13 to 48 km are mapped. It should be immediately noted that the site is located in the central part of a second-order magmatogenic telescopic ring structure with a radius of 48 km. Ring rings with smaller radii are “embedded” in this ring structure. The presence of such a complex of ring structures usually indicates a multi-layered position of intermediate magmatic foci.

According to possible formation mechanisms, all ring sections are conventionally divided into magmatogenic and hydrothermal-metasomatic. The reasons for this separation were the spatial alignment of ring structures with single manifestations of intrusive magmatism, signs of thermal effects on host rocks in the north-eastern part of the site and with traces of metasomatic changes. All these facts suggest the presence of a not deeply lying blind magmatic body of considerable size, with which the manifestations of minerals are possibly associated.

As areal bodies on the site, eolian and undifferentiated Neogene-Quaternary sediments, lithified complexes, an intrusive intrusive body exposed to erosion, presumably of medium composition, and a blind intrusive body of presumably acid composition, areas with traces of thermal effects and hydrothermal metasomatic changes of enclosing rocks were identified.

Stratified formations occupy almost the entire area of the site. Modern eolian deposits occupy a depression in the central part of the area, and undifferentiated Neogene-Quaternary formations are located in the northeast, central and southern parts of the site. The lithified complexes of presumably Middle Paleozoic age are exposed on elevations in the eastern, northern and western parts of the area.

In the eastern part of the site, a single stock of intrusion is presumably of medium composition. Its size is 1.8 by 0.67 km. In his exocontact, traces of thermal exposure are found - contact hornfels are assumed here. The same hornfelses are recorded in the northern and eastern parts of the area.

A blind intrusive body, presumably acidic, is mapped in the central part of the area. Signs of its release were traces of weak thermal effects on host rocks and the system of telescoped ring structures. Such systems of ring structures not only indicate the position of the magma chamber, but may also indicate its conditions of formation and occurrence. Thus, for the Kalgutinsky rare metal deposit located in the Gornyi Altai, the authors of the report showed that the systems of telescoped magmatogenic ring structures indicate the pulsating nature of the development of the magmatic system as a whole, and the eccentricity of the telescoped ring structures indicates a declination of the leg of the intrusive body. Based on the experience obtained, it can be argued that the blind, acidic intrusive body in the central part of the site has a southeast declination.

Of particular interest are traces of hydrothermal-metasomatic changes. Spectral analysis of Aster materials of these areas indicates the presence of newly formed muscovite, chlorite, carbonate, epidote. All these areas of hydrothermally altered rocks are exposed to rupture faults of the northwestern and sublatitudinal orientations [9].

PROSPECTS FOR THE EAST BALKHASH SITE

The prospects of the East Balkhash site are associated with the manifestation of endogenous mineralization and possible detection of groundwater.

Endogenous mineralization can be associated with the manifestation of intrusive magmatism, signs of which (single rod, areas of thermal impact on host rocks, and magmatogenic ring structures) are found within the area. Here you can expect a wide range of minerals - gold, copper, molybdenum, lead, zinc, tin, tungsten.

As remote factors of mineralization within the area it is proposed to consider: ring structures, or rather their arc segments and especially the junction areas of such arc segments with multidirectional faults; multidirectional faults; intrusive body; blind intrusive body; sites with traces of thermal effects on host rocks; areas with signs of hydrothermal-metasomatic changes.

Based on the remote factors of mineralization within the Eastern Balkhash site, as well as in its immediate vicinity, five promising areas were identified for the detection of endogenous mineralization (Figure 2). According to the degree of "perspective" plots are divided into queues.

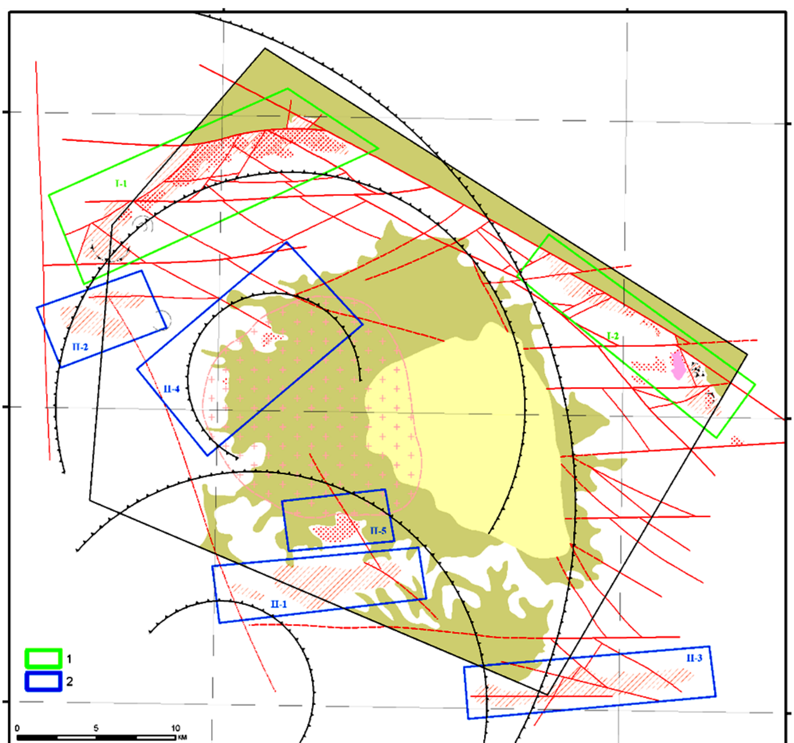

Figure 2 Perspective areas of Arganaty sites (Eastern Balkhash) for detection of endogenous mineralization: 1 – area of the first stage; 2 – area of the second stage.

Detection of underground artesian water is possible in the central part of the site.

For the formulation of prospecting works, a traditional minimal complex is proposed - deciphering materials of high-resolution space satellite surveys, ground-based search routes, lithochemical surveys using secondary diffuse halos, areal geophysical surveys, magnetometric, electrometric (EP and VP methods) and gamma spectrometric surveys. For the verification of the identified direct signs of minerals, a complex of surface mine workings is proposed. For the search of sections II-4 and II-5, it is proposed to include mapping and exploratory drilling in the work package.

CONCLUSION

As a result of the work, cosmostructural schemes of scale 1: 100000 were obtained. The main cosmogeological factors of mineralization have been identified, and perspective areas have been identified for the setting up of exploratory works for the first and second stages. Recommendations on a set of search methods are developed.

Geological and geophysical studies were carried out using various modifications of magnetic survey and electrical exploration methods. Deep-lying endogenous mineralization and buried geological structures are reliably distinguished by the results of the interpretation of satellite images. Perspective areas identified by cosmological and geological technology can be objects for further exploration and evaluation work. Ground-based geophysical studies, in our case magnetic and electrical exploration, provide for the selection of specific anomalies and the choice of locations for exploratory drilling wells.

Prospects of blocks can be associated with the manifestation of endogenous mineralization, placer gold content and tininess. With regard to endogenous mineralization, gold, molybdenum, tin, and copper deposits can be predicted at the site in connection with granitoid magmatism.

ACKNOWLEDGEMENTS

This work was supported by the scientific program BR05233713 «Comprehensive geological study of subsurface resources for the development of resource base and mining exploitation of new sources of ore raw materials in Kazakhstan».

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INFORMATION SYSTEM CONTROL AND MONITORING OF LAND ON THE COAL COMPANY

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ABSTRACT

The development of a coal pits requires the availability of land resources necessary for both coal mining and construction of the field's infrastructure. The land plots are geographically distant from each other, have different characteristics with terms of use. The absence of an uniform information and cartographic space of land resources of the coal mining company, leads to an increase in the share of subjectivity of decisions, increases the risks of financial losses of the company. In order to optimize financial flows and support decision-making in land use, SUEK has developed and implemented a system of information and analytical complex of land resources (hereinafter – the System). The system allows to collect at the same time information about land resources in all regions of the company's presence, to carry out its comprehensive analysis, as well as display objects on the map and in 3D. Simultaneously with the land resources, the system allows to collect and display information about license areas and real estate objects. The system is simple and intuitive, does not require special resources. Together with the company's data on the earth, the system allows to display data from external resources –from GOOGLE satellites, public maps.

Keywords: *coal mining, the broken lands, information system, management of land resources, maps.*

INTRODUCTION

The development of a coal pits requires the availability of land plots necessary for both coal mining and construction of the field's infrastructure (Fig.1). The Company for manufacturing operations in open coal mining use on more than 3000 total land area of 31 thousand hectares. Coal mining work is carried out on forest lands, settlements, lands for industrial use. The distribution of land by land category is shown in figure 1.

Coal mining in the company, and as a consequence, registration of land plots, are carried out in the Kemerovo region, the Republic of Buryatia, Chita region, Krasnoyarsk region, the Republic of Khakassia, Primorsky Krai, Vladivostok. The technology of development of the coal deposit provides for its gradual development. For the purpose of stage-by-stage development it is required to use not all lands at once, and also step-by-step. That is, part of the land used in the development. Further, in the absence of technological needs, these lands are recultivated [1], [2], [3]. At the same time, the rights to new lands necessary for further coal mining are being formalized. That is, when coal is extracted, there is a "movement" of land plots – some are eliminated due to the lack of need for them, new ones are issued for production.

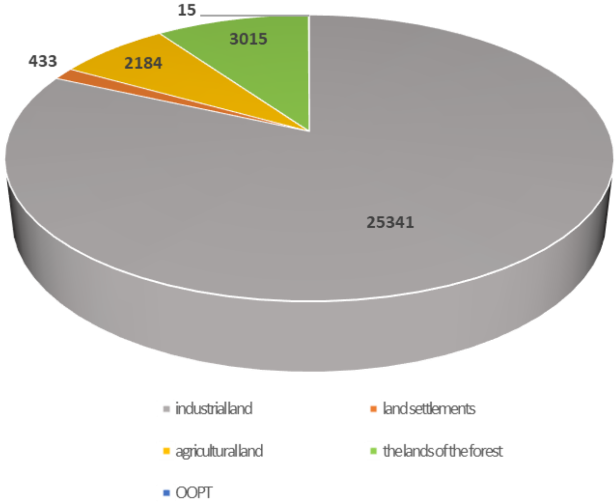


Fig.1 Land category

Management of a large array of geographically distributed data having different characteristics and being in "motion" is impossible without special software and hardware.

The software and hardware must provide:

- systematization of data;
-data analysis,
- automatic creation of reports,
- the construction of cartograms,
- visualization of current map data;
- connection of cartographic data with the relevant information in the database of the land and property complex;
- secure access to the processed information;
- minimize the financial cost of hardware and communication equipment.

METHODS OF RESEARCH

In Company since 2013 operates information and analytical system "Land and property complex "SUEK". The information and analytical system was developed together with JSC "KB Panorama», Russia. It consists of the following functional modules:

module of alphanumeric information on land and property assets;

the storage module, and visualization of spatial data (cartographic unit);

- reference module;

- module converting and integrating data;
- analytical module;
- reporting module;
- module archival storage;
- print data;
- access control module;
- module for publishing cartographic and statistical information on the WEB.

The system consists of two parts – server and client. The server part is a database in MS SQL Server format. The server part functions constantly. The client part is a set of executable files that have access to the MS SQL Server database and the spatial database. Spatial databases are a file storage in the GIS format "Panorama", which is accessed using the GIS kernel. The spatial data management interface allows you to query and change the description of individual objects or a set of objects selected by a given criterion, display maps with a change in scale, data composition and presentation form. The system provides the following scale series of vector maps– 1 : 500 000, 1 : 200 000, 1 : 100 000, 1 : 25 000, 1 : 5 000, 1 : 2 000, 1 :000, 1 : 500 [4].

The cartographic component of information resources involves the use of the following graphic material:

- a general map (maps),
- topographic map,
- cadastral plan,
- materials of geological mapping,
- aerospace materials and remote sensing data,
- thematic maps and charts.

The system allows you to work with cartographic material of any format (Fig.2).

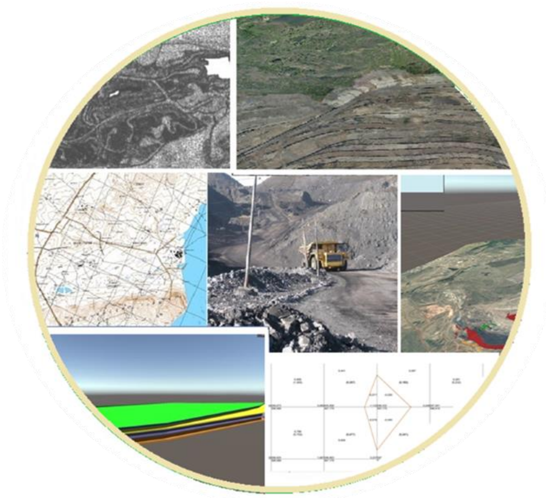


Fig.2. Cartographic material of any format

The system operates using terminal server technology and a thin client from Citrix. Citrix XenApp, allow you to execute server and client parts of applications on servers installed in the data center of SUEK, at the same time transfer to the user only the display screen. Providing access to data using Citrix technology increases the level of protection and reduces the load on the LAN, which allows secure access to the System from any device (including tablets, PDAs and communicators) at low speed Internet connection.

The statistical of the System is a WEB application that functions under the control of the Microsoft Internet Information Services WEB server and provides access to statistical information from the database of the system using a standard WEB browser [5].

The system software architecture is shown in Fig.3.

The system contains the following types of accounting objects:

mining company;
production unit;
license area;
mining lease;
land plot;
estate object.
For these objects of accounting their cartographic display is provided. - thematic maps and charts.

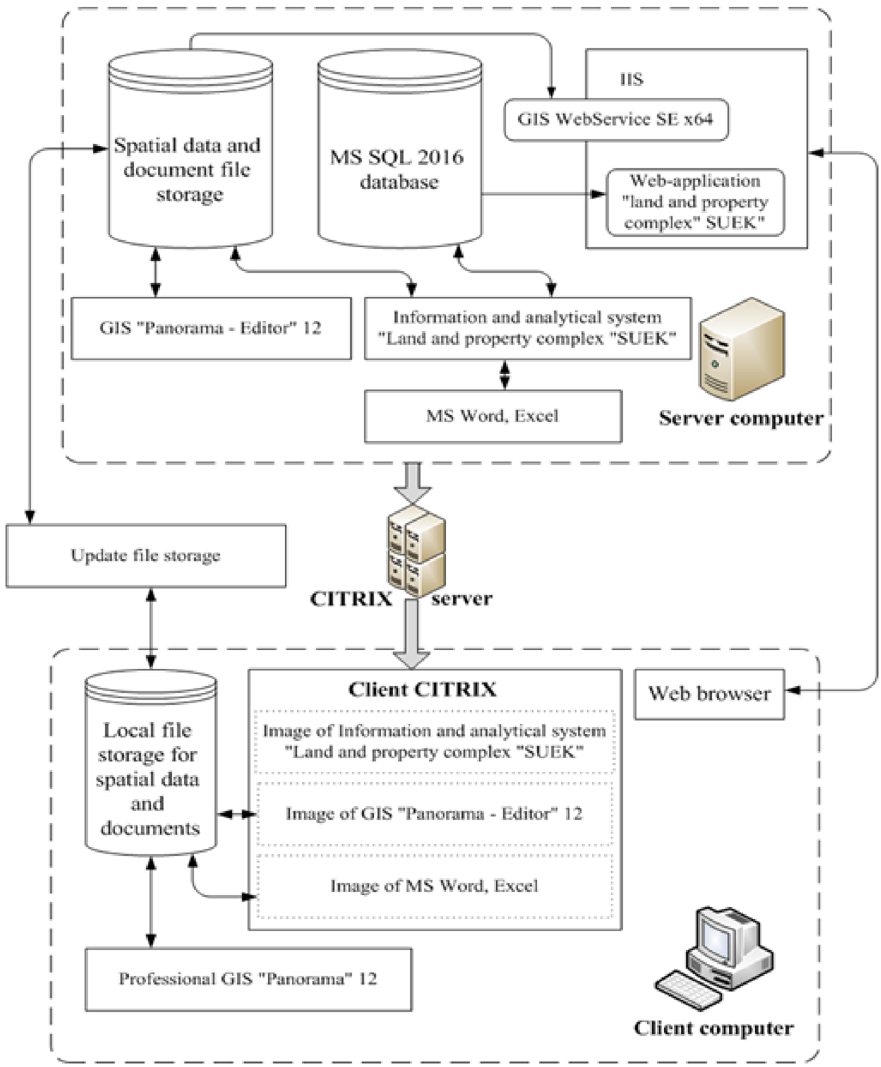


Fig.3 The system software architecture

RESULTS

The General view of the system is shown in figures 4-5.

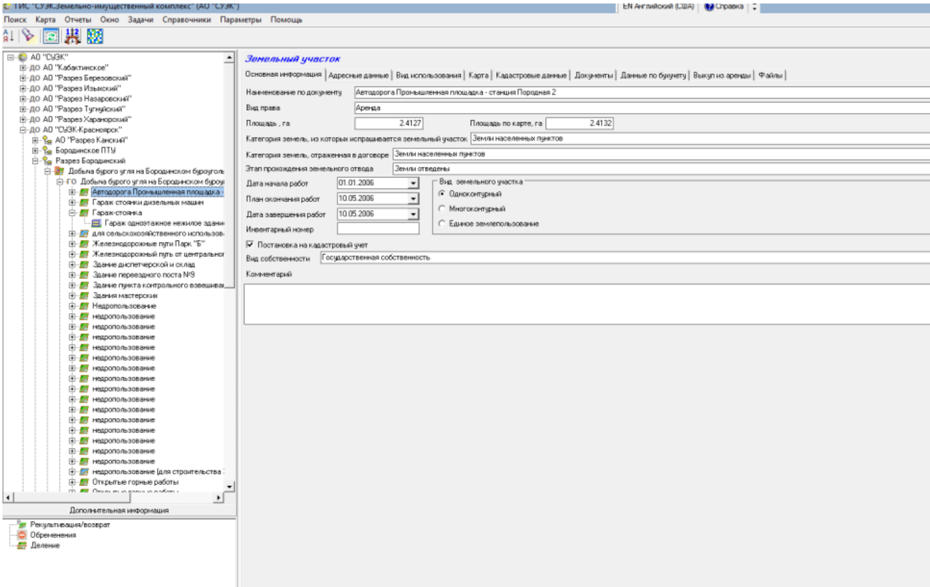


Fig.4. The attributive part of the system

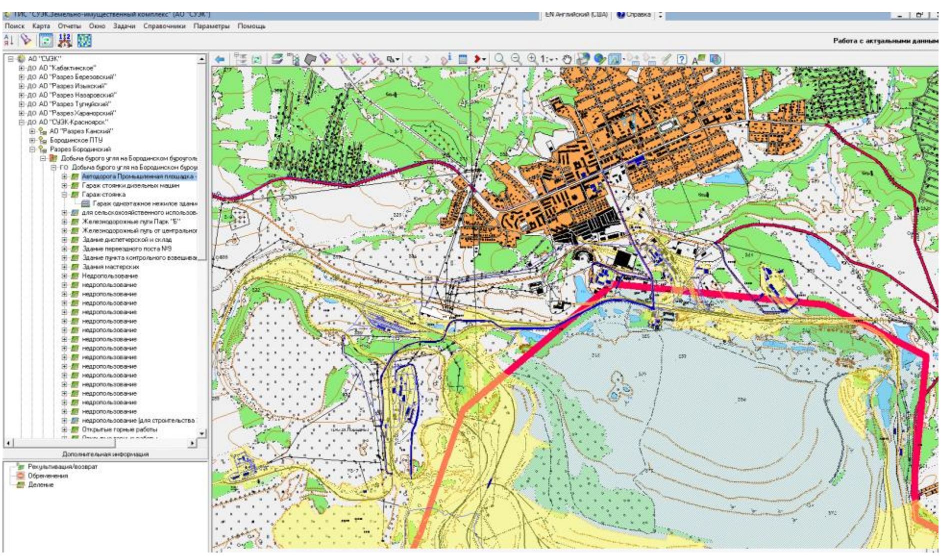


Fig.5. The attributive and map parts of the system

The system provides analytical and cartographic information about land resources. Figures 6-7 show different reports of lands.

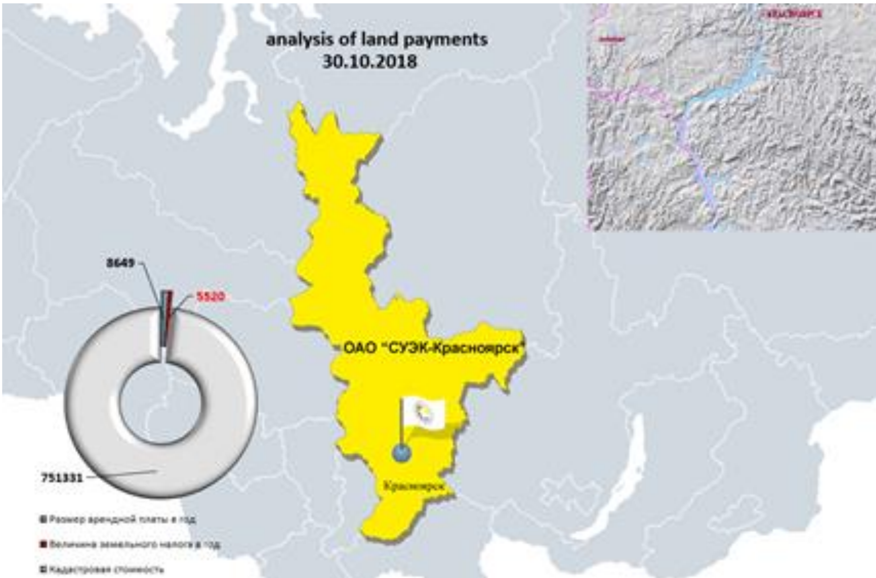


Fig.6. Report on the current date on land payments

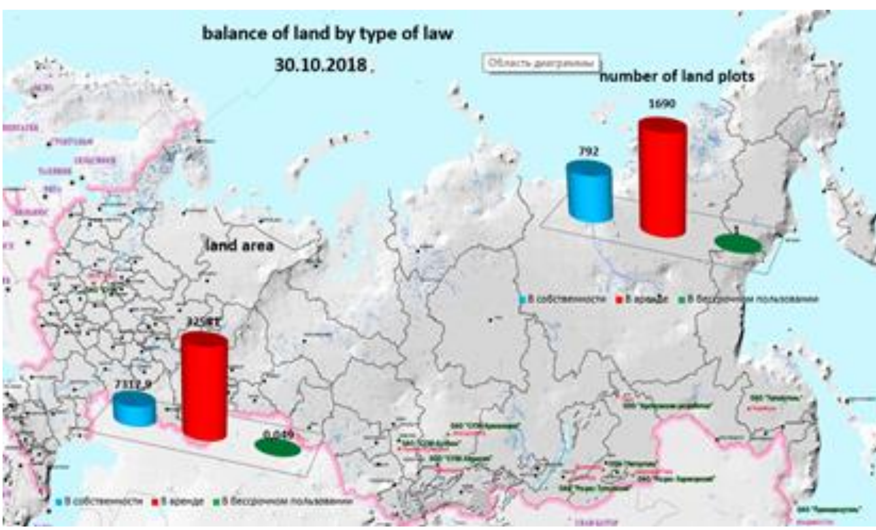
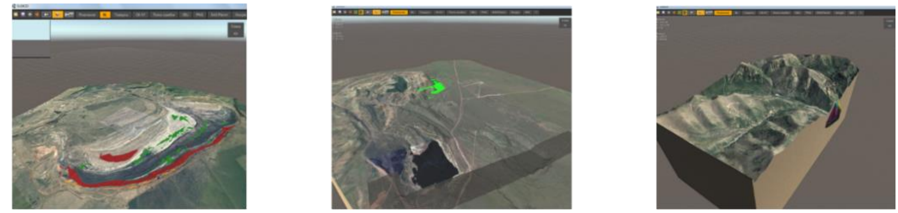
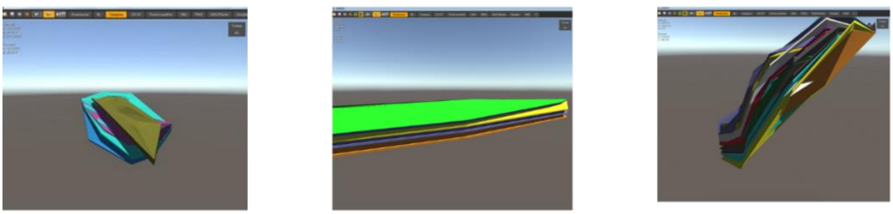


Fig.7. Report on land plots by type of law

Figure 8 shows the data of System in 3D format.



A three-dimensional model of coal pits



A three-dimensional model of coal beds

Fig.8. 3D format

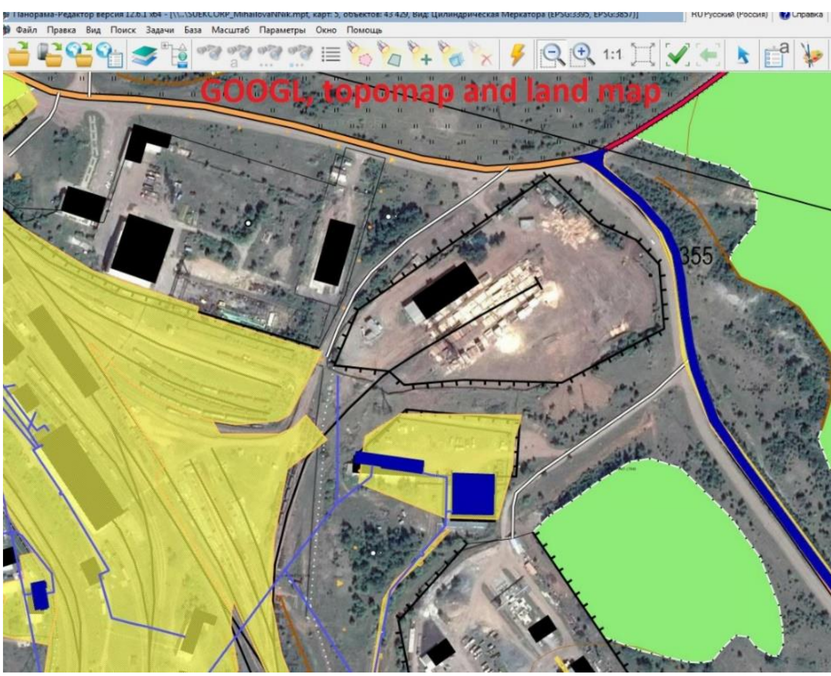


Fig.9. Visualization of objects in conjunction with external WEB-portals

In addition, to visual representation of data, the system allows to generate reports in Microsoft programs – for example, Excel.

CONCLUSION

The data used in the system should follow common goals, first of all, with regard to completeness reliability, integrity, unification of storage and access rules. The initial data for the system are such data as:spatial data, raster cartographic materials, atribute data of objects, import data, electronic copies of the permit documentations, service data, used in the functionality of the system, a library of law, accompanying documentation, metadata. The system allows you to work with cartographic material of any format.

The solution algorithm implemented in the system allows users to work simultaneously in different regions of the Company's presence. All information is collected in a single center of processing and analysis - in the head office of the Company.

The cartographic display of objects of accounting and their spatial location is provided for the following types of objects of accounting:

- license area;
- mining lease;
- land plot;
- real estate object.

In the spatial database for each enterprise of the Company the corresponding sets of spatial objects which contain spatial characteristics for one type of object of accounting are conducted. All feature sets use a single coordinate system

The system of land and property complex allows to significantly improve the efficiency of asset management of the company in terms of land management due to:

- systematization of information flows,
- operational data analysis,
- forecast of the situation,
- monitoring of changes in the legal framework,
- visual representation of spatial data, including 3D.

ABBREVIATIONS AND ACRONYMS

BD – database;

IAS LPC - information and analytical system «land and property complex of «SUEK»;

external data-data integrated into IAS LPC from other information systems;

spatial objects – means a mathematical representation (model) of a set of points on the earth's surface, set in accordance with some real or imaginary object, or a phenomenon that has a set of properties reflected in the attribute geographic information. A feature consists of two parts: a geometric part and an attribute part;

spatial data (geographical data, GEODATA) is data about spatial objects. Spatial data form the basis of information support of geographic information systems.

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INTEGRATING ROMANIAN GNSS PERMANENT NETWORKS FOR GEOSCIENCE PURPOSES

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ABSTRACT

Romania is covered by more than one hundred GNSS (Global Navigation Satellite System) permanent stations, that have been set up over the last seven years, maintained by different agencies and having different technical architectures and scientific objectives. Many of these stations provide support for geo-referencing applications such as surveying, the network being developed by National Agency for Cadaster and Land Registration (ANCPI) and by a private company, TopGeocart. Two networks are developed with scientific purposes: one developed by the National Institute for Earth Physics - NIEP and the other one developed by the National Institute for Research and Development on Marine Geology and Geo-ecology – GeoEcoMar. Several limiting factors were identified in terms of utilization: no site uniqueness, no file redundancy, no quality control or hardwire web service. Our goal is to collect all those GNSS data in order to standardize, perform quality control and harmonize for creating the metadata.

We present and discuss step by step all the implementation levels of standard tools necessary for generating, validating and disseminating pre-defined GNSS metadata, tools for generation and dissemination of metadata. All those will allow the end-users, and in particular, geo-scientists, to freely access the geodetic data, derived solutions, and associated metadata using a transparent and standardized process. Finally, we detail the technologies and software that were used and developed to build this e-infrastructure, the system output data and the conclusions derived in term of data volume, security and usefulness.

The involvement in EPOS – IP project as a member of GNSS Data and Products Working Group helps us evolve in the same direction, test and implement GLASS software package for the dissemination of GNSS data & dedicated processing outcomes, time-series, velocities, and strain-rates - to be created using state-of-the-art methodologies for a better understanding and completion of the tectonic puzzle pieces of Solid Earth processes in this challenging structure of Southeastern Europe.

Keywords*: GNSS metadata, GLASS, EPOS – IP*

INTRODUCTION

Romania is covered by more than one hundred GNSS permanent stations, that have been set up over the last seven years, maintained by different agencies and having different technical architectures and objectives.

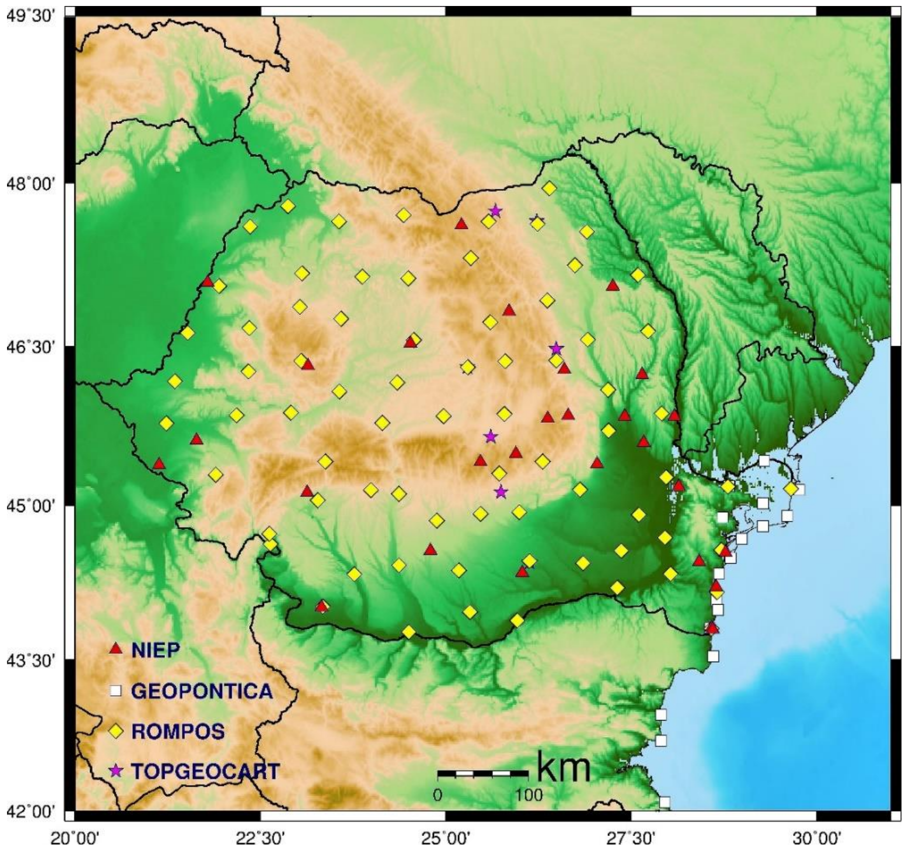

Figure 1: GNSS permanent reference networks in Romania: NIEP(red), TGREF(magenta), GeoPontica(white), ROMPOS(yellow)

The modern Romanian GNSS/GPS network started in 2001 when the first permanent station was installed on the Lacauti peak in the mountainous zone of the Carpathian Bending Zone, west of the Vrancea epicentral area. Since then the network has grown to 30 stations and is still expanding. The network was established as a result of an international research project based on a strategic partnership between: the National Institute for Earth Physics (NIEP), the Faculty of Geology and Geophysics – University of Bucharest (FGG), Delft University of Technology, the University of Utrecht and the Netherlands Research Center for Integrated Solid Earth Sciences (ISES). Starting with 2013, the GPS network is maintained and developed by NIEP. As network objectives can be mentioned: monitoring of crustal changes occurring in the Romanian territory in correlation with tectonic processes in South-East Europe (Africa-Europe plate interaction), observation of crustal movements in order to establish the surface-to-depth relationship of deep earthquakes in the area of the Eastern Carpathians bend zone (Vrancea region), improving the accuracy of the coordinates of the national seismic network stations. The network can also provide improved, reliable, high-accuracy environmental measurements for global weather forecasts, climate monitoring, earthquake precursors (ionospheric studies), coseismic studies, GNSS positioning and navigation, and other research for complementary purposes [1].

The GeoPontica permanent GPS network is developed and maintained by The National Research and Development Institute for Marine Geology and Geoecology (GeoEcoMar). GeoPontica (represented by 18 ground settlement stations) and provides data from the West side of the Black Sea geodetic networks – both in Romania and Bulgaria concerning the vertical movements of the Earth's Crust (isostasy, elevation, land subsidence, basining etc.)

The TGREF - TopGeocart permanent GPS network appeared as a natural response to the growing demands of users of the Leica GNSS equipment. TGref is in full development and currently covers RTK 8 cities in central and eastern Romania and provides DGPS corrections for almost the entire territory of the country.

The ROMPOS permanent network has 74 stations, is a commercial network with the goal of providing DGNSS/RTK correction services that are subsequently used for cadastral purposes, represents a project of the National Agency for Cadastre and Land Registration.

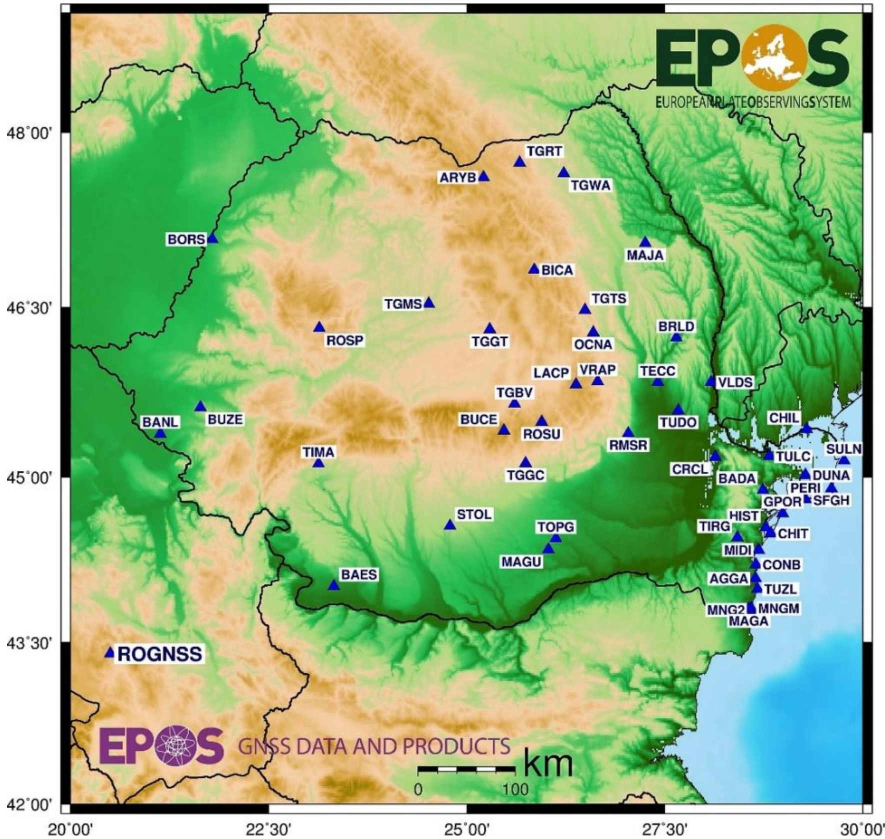

Figure 2: ROGNSS network, stations submitted in EPOS project

The networks being developed for different purposes, we found several limiting factors for data utilization: some of them had no site uniqueness, no file redundancy, no quality control or hardwire web service. Our goal was to collect all those GNSS data in order to standardize, perform quality control and harmonize for creating the metadata and use them for scientific purposes. After we performed the steps mentioned previously: site uniqueness, file redundancy, quality control or hardwire web service, metadata, we distributed the data to a dedicated online GNSS station metadata management and dissemination system called M3G for “Metadata Management and distribution system for Multiple GNSS Networks” at https://gnss-metadata.eu/ (Figure 3). Through M3G, an Operational Center maintains on-line the GNSS stations metadata for EPOS stations and performs various quality checks. The system is based on the model-view-control architecture. The architecture is divided into three components: 1) the model is managing the data of the application, 2) the controller is defining the working logic and 3) the view is interacting with the users. Management of the Operational Center Information includes the agency name, address, contact person emails, list of GNSS stations.

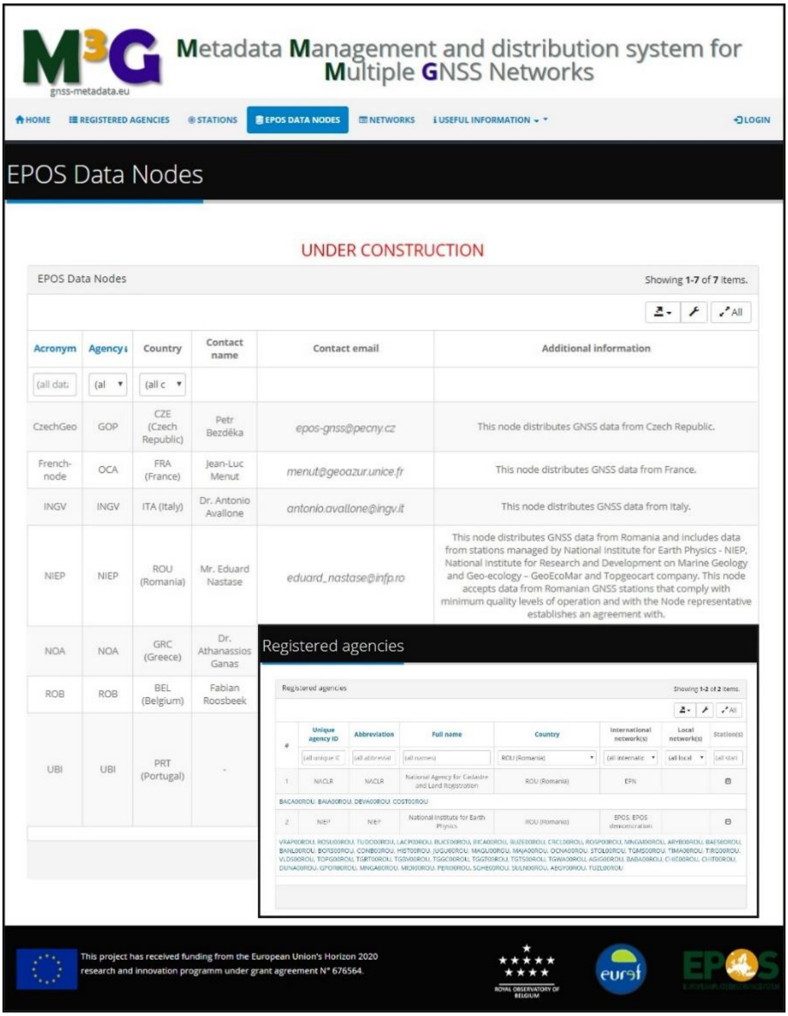

Figure 3: M3G data portal. EPOS NIEP Data Node and National registered agencies and stations

The involvement in EPOS (European Plate Observing System) project where we are a national GLASS node (Geodetic Linkage Advanced Software System, an integrated software package to be deployed in a GNSS infrastructure), helped us in achieving the objectives we envisaged. GLASS is an integrated software package deployed in a GNSS infrastructure to manage data and metadata. Developed from the original Geodetic Seamless Archive Centers (GSAC) concept that was created by UNAVCO (a non-profit university-governed consortium in United States that facilitates geoscience research and education using geodesy), GLASS is an open source platform, developed by EPOS GNSS Data and Products team, under Creative Commons licensing. It will make possible to compute the velocity of a station using external information to detect co-seismic offsets and co-seismic displacements associated with strong earthquakes.[2] GLASS network consists of individual nodes representing a structure for disseminating GNSS data and products. The integration starts from national RIs over national nodes up to EPOS integration service. In the GLASS philosophy, the GNSS raw data (RINEX) are not physically located at the GNSS data gateway but remain on the underlying data nodes. GLASS offers the means to make this data discoverable at the data portal. Figure 2 only shows the stations that are included in the NIEP GLASS node. This node distributes GNSS data from Romania and includes data from stations managed by the National Institute for Earth Physics - NIEP, National Institute for Research and Development on Marine Geology and Geo-ecology – GeoEcoMar and TopGeocart company. This node accepts data from Romanian GNSS Stations that comply with minimum quality levels of operation and in accordance with the representative Node’s established standards. The data from ROMPOS were not included in the agreement due to administrative rules, the network contributes only with the EUREF common stations.

Moving on with the testing procedure, test metadata was retrieved from https://gitlab.com/gpseurope/test-data-and-tools. Insertion of T1 metadata into the database proceeded with no errors and was confirmed, as well as the insertion of data center metadata.

For data services, a dedicated data portal for accessing data (RINEX) was created, as well as a metadata of stations from different local data centers. The GNSS Data Gateway (Figure 4) provides access to information about the GNSS stations, information on the file and allows to download data. Access to the metadata and data is provided through the web and a command line client.

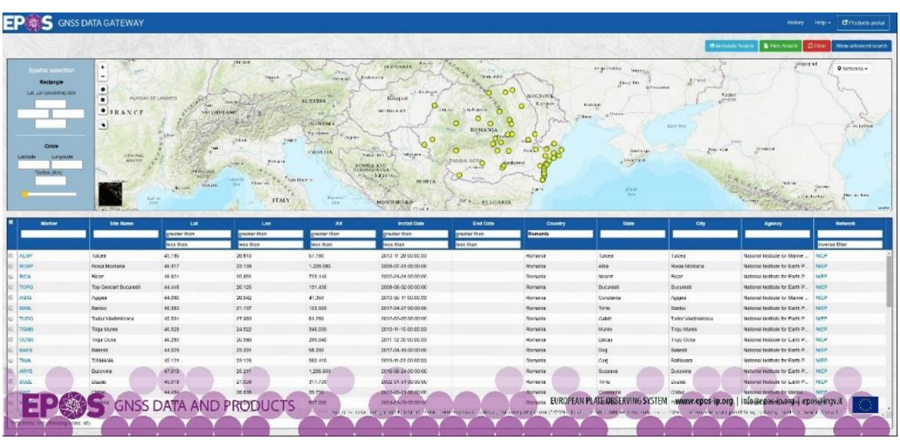

Figure 4: ROGNSS metadata interface on the GNSS Data Portal

The GNSS products consist of the multi-year positions and velocities of all stations (Figure 2) together with the position time series. The GNSS data of all sites are processed with the GNSS Inferred Positioning SYstem and Orbit Analysis SImulation Software - GIPSY-OASIS v.6.2 software, using the Precise Point Positioning - PPP strategy, [3] generating position solutions from each individual observation file. GIPSY is a state-of-the-art analysis tool, which includes a comprehensive suite of models to correct for all thinkable effects, ranging from wet and dry atmospheric distortions of the measurements to ocean loading displacements of the sites. The GNSS data were processed locally for all the permanents networks that are distributed homogeneously on the Romanian territory. Figure 5 shows the results of the horizontal component and time series of 4 stations from the networks detailed in the paper.

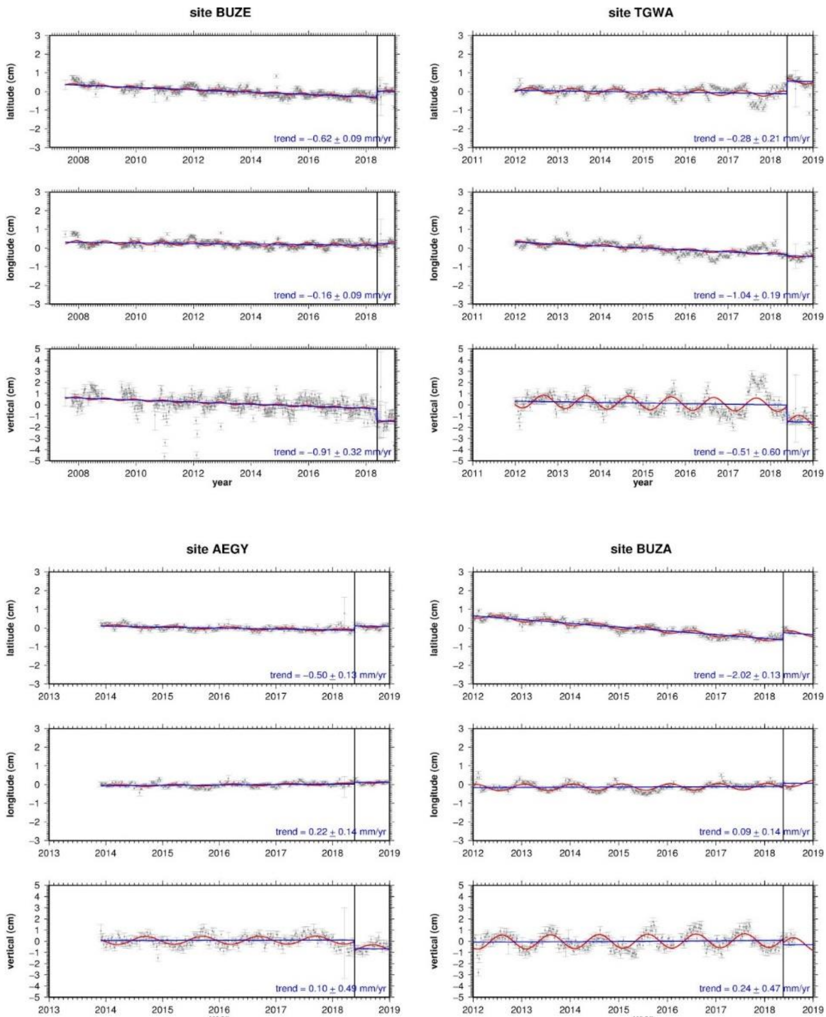

Figure 5: Four examples of the linear regression of the 3-D GPS position solutions

Figure 6: Horizontal motion vectors derived from the GPS observations

CONCLUSION

The work performed is very important because we managed to create a unique GNSS database from a homogeneous combination of all permanent networks and to create metadata in a proper, international standard format, for all stations. We think that for the future national and international projects, it will be easier to make a research study having all these stations at our disposal, to promote interdisciplinary interoperability**,** with a special focus on seismology and geology. With GNSS we can study deformation associated with earthquakes. These measurements are complementary to seismological data because they document the full earthquake cycle, including interseismic and transient postseismic processes, as well as coseismic deformation. [4]

The results obtained until now, having only NIEP stations, show that the area tends to move slightly southward relative to Eurasia, at velocity rates of about 2.5 – 3.0 mm/yr. [5] We speculate that this could be a far-field effect of slab roll-back due to the subduction of the African under the Eurasian plate at the Aegean trench, way far to the south.

Having now a dense and homogenous permanent network will help us to understand the geodynamic processes that occurred at national level (Romania) and there is a clear need to think of an interpretation into a large geodynamics framework, looking at the larger interaction effects between the Pancardi system, the southeastern East European and Scythian Platform, the Aegean System and all the way south to the North African Domain.

ACKNOWLEDGEMENTS

This paper was carried out within NUCLEU Program MULTIRISC, supported by MCI, project no PN19080201 and by a grant of the Romanian National Authority for Scientific Research, CNCS/CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0266, Contract No. 16PCCDI/2018.

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PALEONTOLOGICAL SUBSTRATE OF BEEKITE RINGS (ON THE EXAMPLE OF THE COLLECTIONS OF THE PHANEROZOIC INVERTEBRATES IN THE MINING UNIVERSITY, ST. PETERSBURG)

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ABSTRACT

Nowadays there is plenty of published mineralogical and geochemical literature, in which scientists are trying to explain the mechanism of the appearance of such a peculiar form of chalcedony as Beekite rings (special forms of silica, resulted by the secondary silicification of many fossils). From the paleontological point of view, Beekite occurs on various Phanerozoic invertebrates, mainly on Paleozoic brachiopods with a calcite skeleton. At the same time, it was repeatedly noticed that the partial silicification, typical in the formation of Beekite, is due to both environmental and biological factors. The authors discovered samples of the brachiopod of the suborder Syntrophiidina (genus *Porambonites* Pander, the Ordovician sediments of Baltoscandia) and some samples of the bivalves of the order of Dysodonta (specie *Pycnodonte simile* (Pusch), the Danian sediments of the Crimean Mountains), containing Beekite rings, in the collections of the Mining university. The representatives of the genus *Porambonites* Pander are characterized by theirs thin sculpture and numerous pits located between the costae. The collection shows different stages of the development of Beekite rings on brachiopod shells. The initial stage is characterized by the appearance of small rings (0,5 mm) on the shell's periphery; the ephebic stage is distinguished by the development of Beekite all over shell. The appearance of Beekite rings also varies from poorly developed, almost unexpressed on the relief of the shell to embossed rings with the siliceous crust and bubbly formations with very small diameter (0.1 mm). Specie *Pycnodonte simile* is characterized by thin concentric growth lines, special closely spaced near the external part of the left valve. Distribution of the initial centers of crystallization of aggregates was being controlled by concentric sculpture, clearly expressed in shell's micro-relief, and by features of valves microstructure. Taphonomic features of this species, such as burial of separated valves contributing to the development of aggregates on both internal and external valves, favoured the active siliconization. According to the previous investigations, appearance of the rings and intensity of its development depend on the amount of silica in solutions at this place and the character of the dissolution of carbonate minerals. By the authors' opinion uneven character of the distribution of Beekite rings on surface of shells of invertebrate is due to the features of the shells, i.s. more peculiar for specific minimal taxa. Flat concentric-zonal aggregates indicate the growth of

Beekite rings in conditions of the sufficiently limited space for the crystallization of silica. These conditions were possible both in the still non-litification sediment at the early stage of fossilization, and in the conditions of hypergenesis. Volcanic activity, bentonite interlayers, siliceous organisms were considered as a possible source of ones according to the previous investigations. The last two factors can be considered as presumably initiating the formation of the described structures in the situation with the Ordovician deposits of Baltoskandia. This is confirmed by both the appearance of multiple bentonite interlayers in the Ordovician deposits of the east of Baltoskandia and the formation of so-called sponge horizons. For the formation of Beekite rings on specimens of Bivalves from the Paleocene sediments of the Crimean Mountains, the biogenic factor was probably decisive.

Keywords: *Baltoscandia, Ordovician sediments, the Crimean Mountains, Paleocene sediments, Beekite rings, silicification of fossils*

INTRODUCTION

By Beekite rings are implied concentric-zonal structures that develop on the surface of carbonate fossils as a result of their partial silicification. Earlier Beekite rings were also mistaken for fossils. These structures were named after the English botanist Henry Beeke who first noticed them. Beekite rings appear on the surface of the shells of various systematic groups of the Phanerozoic invertebrates: brachiopods, bivalvias, cephalopods, corals, etc. The stratigraphic range of the distribution of Beekite rings is also extremely wide, although most part of fossils with these structures are from the Paleozoic deposits [2]. Unfortunately the formation of Beekite rings was more often dealt with from a mineralogical point of view, therefore the tafonomic, paleogeographic aspects of the formation of such structures were hardly considered. However the wide dissemination of these structures on the Phanerozoic fossils contributes to the intensification of interest in them and attempts to use horizons with fossils with Beekite rings to solve a wide range of geological problems.

MATERIAL AND METHODS

The authors in the collections of the Mining University revealed two groups of samples that have Beekite rings. The first group was found in the collections of various authors of the XIX century, devoted to the Ordovician invertebrates of St. Petersburg and Estland Governorates (modern Leningrad Region and Estonia). These are the brachiopod specimens of the suborder Syntrophiidina (genus *Porambonites* Pander): *Porambonites (Porambonites) altus* (Pander) and *Porambonites teretior* Eichwald. The second group is associated with the collection of Bivalves of the Department of Historical and Dynamic Geology of the Mining University represented by the species *Pycnodonta (Phygraea) simile* (Pusch) from the Danian sediments of the Crimean Mountains.

Since samples *Porambonites* Pander were taken from the unique collections of the 19th century belonging to the Mining Museum were possible only studies that did not violate the integrity of the samples: the study of the surface of the shells under the binocular microscope. In addition thin sections were made to determine the mineral composition and structure of the studied rings of the samples of Bivalves. An analysis of the elemental composition of one shell of *Pycnodonte (Phygraea) simile* was carried out using Raman spectroscopy in the St. Petersburg State University Resource Center under the guidance of leading specialist K.A. Benken. During the investigations was used Hitachi TM3000 Scanning Electron Microscope for chemical analysis of the substance (microprobe study).

GEOLOGICAL SETTING

The detected specimens of *Porambonites (Porambonites) altus* (Pander) (Fig. 1 a, b) were collected by Major Ozeretskovsky in the place Spitham (Estonia). This popular (in the 19th century) location of the Ordovician (then Silurian - approx. by Authors) invertebrates was a strip of coastal sands containing rounded pebbles of the Ordovician limestones and fossils [3]. The most outstanding Russian paleontologists (H. Pander, G.P. Helmersen, E. Eichwald and others) carried out by detailed paleontological collections on the north-west of the Russian Empire in the XIX century [6]. The whole, rounded shells *Porambonites (Porambonites) altus* were found in the Mining Museum collection. This species is characteristic for the Volkhov regional stage (Dapingian, Middle Ordovician) of Baltoskandia. Unfortunately the revision of the genus *Porambonites* Pander was not done and the exact stratigraphic and geographical distribution of the described species is not known.

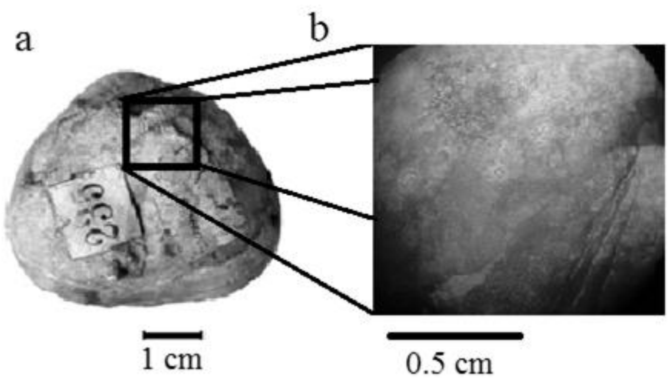

Fig. 1. Porambonites (Porambonites) altus (Pander) a - general view; b - rings under a binocular microscope

The samples Porambonites teretior Eichwald (Fig. 2 a, b) were identified as belonging to H. Pander's collection from the location Uchten (modern Uchtna), also located in northeastern Estonia. Currently this location is lost. Representatives of Porambonites teretior Eichwald species are found in sediments of the Kukruse regional stage (Lower Sandbian).

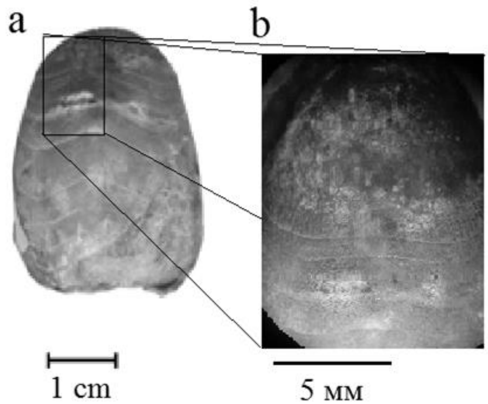

Fig.2. Porambonites teretior Eichwald a - top view; b - top view under the binocular microscope

Samples *Pycnodonte (Phygraea) simile* (Pusch) (Fig. 3 a, b) were collected from the interbed of siltstone light gray limestones belonging to the basal horizons of the Danian (the White-Stone regional stage, the south-western of the Crimean foothills, the Mai-Tepe or Danian cuesta). The collection includes only separated (exclusively left) valves. This species is common in the Maastrichtian and Danian sediments in Crimea, Danian sediments in Georgia, Maastrichtian, Danian and Thanetian sediments in Mangyshlak, the Upper Danian sediments in Poland, Thanetian sediments in Austria.

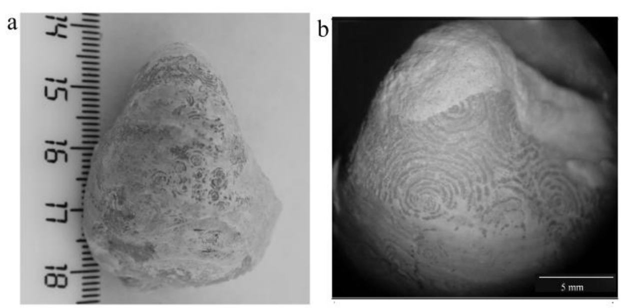

Fig. 3. Pycnodonte (Phygraea) simile (Pusch) a - top view; b - top view under the binocular microscope

In the collection of the Department of Historical and Dynamic Geology of the Mining University the authors also found samples with similar formations. There are samples of both this genus and other Cenozoic oysters of the Crimea. Unfortunately there is no geographical and stratigraphic binding of samples.

THEORY/CALCULATION

The most detailed features of the formation of Beekite rings were discussed in the book "Taphonomy..." [1]. As the main factors of selective silicification to which the Beekite rings can be attributed the above authors indicated the following:

1. Paleontological factor determined by the chemical composition and microstructure of the replaced shells. A large amount of organic material in the composition of the shell, the ratio of carbonate minerals in favor of more resistant to dissolution of calcite, the presence of porosity, a certain nature of the structure of the shell (the preference of the fibrous structure of parallel-layered) contribute to silicification. All this determines the predisposition to the silicification of certain large taxa: classes, orders.

2. Paleogeographic factor - the physical-geographical conditions at the moment are characterized quite widely. It is assumed possible the formation of such structures in both subaerial and aquatic conditions. Within the sea basins the possibility of the formation of such spheroids are considered in a wide range of depths from supralittoral zone to deep parts of the shelf and possibly the continental slope.

3. Sequence stratigraphic position or the connection of horizons with fossils with Beekite rings with certain stratigraphic levels can be presumably considered as another historical and geological factor. According to preliminary observations quite often these described silicified fossils are fixed at the border of parasequences. Thus the appearance of layers with a silicified biota in turn can presumably serve as an additional stratigraphic criterion. There is another example of the connection of horizons with Beekite rings with levels nearby to stratigraphic disagreements. This situation described N. Kazanci and B. Varol for alluvial Paleocene sediments of Central Anatolia [5].

4. Geochemical factor - volcanic activity, bentonite interlayers, siliceous organisms are considered as possible sources of silica.

5. Tectonic factor - volcanic activity nearby as a factor often contributing to the silicificated fossils and, in particular, the emergence of structures such as the Beekite rings/ That's why this form of silicification are usually considered with tectonically active areas and foreland basins. However a variety of collection materials do not confirm this assumption, demonstrating the widespread development of fossils with Beekite rings in platforms.

6. Stratigraphic factor - despite the fact that fossils with Beekite rings are typical for all Phanerozoic deposits, there is a clear dominance of Paleozoic instances. This is due to the predominance of forms with a calcite skeleton among the Paleozoic biota, compared with the Mesozoic and Cenozoic, when forms with an aragonite skeleton became dominant among invertebrates. Due to the more rapid dissolution rate of aragonite shells, neither complete nor partial silicification often occurs.

The main reason influencing the ambiguity of understanding the process of formation of Beekite rings is the polyvariance of the hypothesis of the formation of chalcedony and agate. One approach is based on the finding out of thermobaric conditions for the formation of chalcedony, based on the presence of water (or hydroxyls) in it. Thus, free pore water is lost at temperatures of 100–200 ° C. The most likely upper limit for the formation of chalcedony with helicoidal torsion of fibers is considered below this limit [4]. For the Jurassic agates of Namibia the temperature of formation was determined to be 85°C; however, according to other data, agates were formed at higher temperatures and pressures of 400°C, 340 Ba, 100-300°C, 3 Ba [8].In Rakin's book was determined the temperature of formation of agate about 33°C and pressure of about 100 atm. which correlates well with the cooling of the basalt cover with a capacity of 20 m and temperatures of 100-300°C. The most likely the possibility of chalcedony growth is in a very wide range of pressures, temperatures, and supersaturation of the solution.

RESULTS AND DISCUSSION

The brachiopods of Syntrophiidina suborder, Pentamerida order, Rhynchonellata class are characterized by a fibrous secondary layer, which, as mentioned above, is more favorable for the development of silicification of the type of Beekite rings. The key role here was probably played by organic shells, which contour each calcite crystal of this fibrous secondary layer. At the same time Pentamerida order is characterized by shells with a impunctate structure, to a lesser extent conducive to the development of silicification. Representatives of the whole family of Porambonitidae are characterized by a peculiar sculpture consisting of very thin radial ribs, small pits and thin but sharp concentric growth lines, the combination of these elements often gives the surface of the sinks a kind of "reticulation". When studying shells of the genus Porambonites Pander under the binocular microscope there are two zones of localization of Beekite rings. The first zone, characterized by rings that are less distinct in the microrelief of the shell, is localized near the lateral edges and the anterior edge of the ventral and dorsal valves. In this case there is a banded arrangement of rings, the direction of the bands coincides with the direction of growth lines (Fig. 1.2 - b). The second zone is localized in the posterior part of the valve and is characterized by rings that are more pronounced in the microrelief of the shell. This part of brachiopod shells is distinguished by the most thickened secondary layer.

There are also images of *Porambonites (Equirostra) baueri* Noetling with clearly visible similar Beekite rings on the site https://fossiilid.info/. These samples were also obtained from northeastern Estonia (Aluvere quarry), where, according to T. Maidla and L. Ainsaar [7], sandstone bentonite interlayers were recorded in the Sandbian sediments. In this situation this confirms the hypothesis of bentonite interlayers as a source of silica. However the Ordovician period is known as the stage of the Great Ordovician Biodiversification of many groups of marine invertebrates, both with siliceous (porifers) and carbonate skeleton. Taking into account the active development of the porifer in the Ordovician paleobasin of Baltoskandia (for example even so called "sponge" horizon among the Sandbian sediments in the west of the neighboring Leningrad Region) paleontological factor that contributed to the formation of the Beekite rings in the region on these fossils is also not excluded.

The microstructure of the shells of *Pycnodonte (Phygraea) simile* is characterized by the dominance of the layered type with rare intercalations inside the layered envelope of the vacuolar structure (characterized by irregularly shaped polyhedra of various sizes). The sculpture of the left valve consists of concentric, irregularly located growth lines. The active siliconation was favored by the taphonomic features of this species — the burial of separated valves, which promoted the development of aggregates of both the inner and outer surfaces of the valves.

Initially two types of rings were distinguished on *P. simile* shells — volumetric and flat; however, in the course of research, it was revealed that seemingly flat rings are covered with carbonate material, which is easily removed with hydrochloric acid. Shells of bivalvia are contained in siltstone glauconitic crinoidal-bryozoan limestone. There are a carbonate (micrit) rock, basal cement, quartz grain fraction 15%, plagioclase - 5%, glauconite - 10%, single biotite grains. Clusts are angular, medium size. The texture is massive. Bioclasts in the rock are represented by fragments of bivalve valves, fragments of bryozoan colonies, foraminifera, fragments of segments of crinoids.

A microprobe study of the composition of *P. simile* shell and Beekite rings showed exclusively carbonate composition of the shell and siliceous composition of the spheroids (Fig. 4).

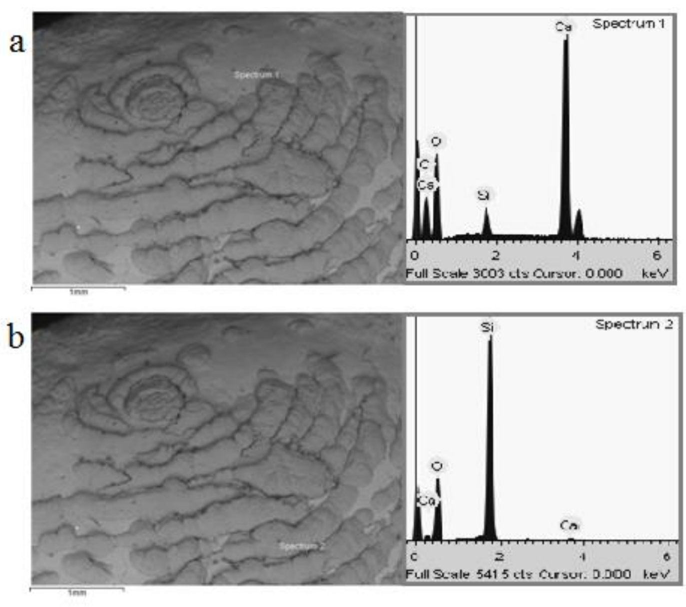

Fig.4. a - analysis results of the carbonate shell; b - results of the analysis of siliceous spheroids

The study of *P. simile* shells in thin sections showed that the mineral composition of the rings is full-crystal chalcedony, forming single generations (first order lamination) of spherulites with helicoidal torsion of fibers (second order lamination). The length of fibers in generation is from 0.5 mm to 1 mm (Fig. 5).

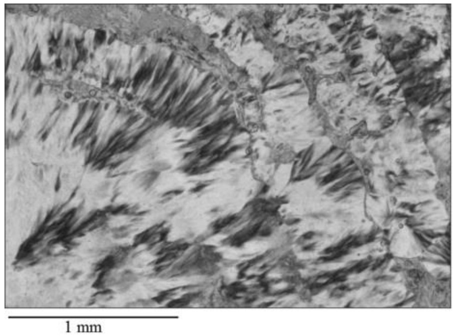

Fig.5. Fibers of chalcedony. Crossed nicols

The shape of spherulites is controlled by both geometric selection and shell relief overgrown with chalcedony. The banded distribution of Beekite rings is clearly observed according to the propagation of growth lines on specimens under the binocular microscope and in thin sections(Fig. 6).

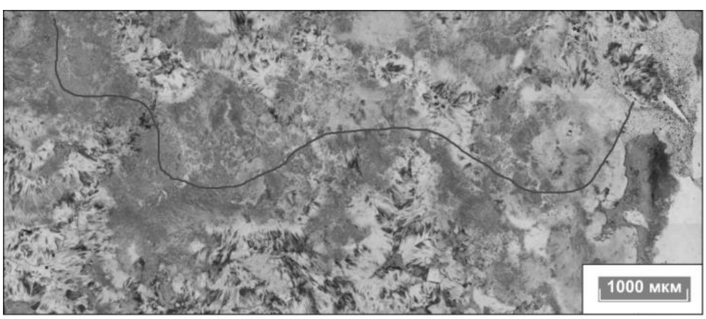

Fig. 6. The distribution of Beekite rings according to the spread of growth lines. Crossed nicols

The absence of microzonalities in the studied samples in terms of the refractive index of chalcedony [9] indicates the constancy of supersaturation on the crystallization front during the growth of one generation of chalcedony. This can be explained by the active circulation of the supersaturated silica solution in the rock. The development of chalcedony spherulites in one plane parallel to the shell indicates the presence of a geometric selection that prohibits the growth of chalcedony spherulites in directions not parallel to the surface of the shell. The growth of spherulites in the cavity formed around the shell during leaching of the cement or shell material is most likely.

The conditions and time of formation of the identified Beekite rings are ambiguous, the version is permissible both about the formation of structures before the diagenesis stage, at the early stage of the taphonomic cycle, and at the stage of hypergenesis. Arguments in favor of the latest version can serve as a "spotted" appearance of zones of such fossils, possibly confined to areas of increased fracturing and cavernous limestone. In such a situation, the source of silica could be jet meteoric water. The widespread distribution among the Crimean Cenozoic fossils of the Beekite rings indicates particularly favorable conditions for the formation of these structures. Perhaps the intense spread of this form of silica in the area is also due to hydrogeological features of the area. The Crimean peninsula is characterized by a wide development of various mineral and thermal waters. There are a high concentration of silicic acid in thermal waters, amounting to hundreds of mg/dm^3. On the territory of the Crimean peninsula there are three hydro-mineral areas: Crimean Mountains, Kerch Region, Steppe (Plain) Crimea. Currently thermal waters of different composition are characteristic, first of all, for the Steppe Crimea and the Kerch region. In the Crimean Mountains mainly sulphate and chloride (partly thermal in depth) waters are developed.

CONCLUSIONS

1. The distribution of Beekite rings on the surface of the Phanerozoic invertebrate shells is controlled by the characteristics of the skeleton morphology, namely the nature of the microstructure and sculpture. , These features are diagnostic signs of both large and small taxa. At the same time, judging by the shells of the bivalves, the sculpture plays a leading role. Thus the appearance of the Beekite rings on the fossil surface is inherent in specific small taxa.

2. As a source of silica for the formation of spherulites on Estonian brachiopods there could be bentonite layers or sponge horizons.

3. As a source of silica for the formation of spherulites on the bivalvia of different ages on the Crimean peninsula there could be reactive thermal waters.

The publication has been prepared in the context of a government order of Russia on "Forming of the integrated scientific and educational information complex based on the comprehensive research of the unique collections and exhibits of Mining museum" № 5.12856.2018/8.9.

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RESULTS OF MEASUREMENTS OF ULTRA-SMALL DEFORMATIONS OF THE EARTH'S CRUST AT THE TALAYA OBSERVATORY NEAR BAIKAL LAKE

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ABSTRACT

The paper discusses the systematic results of observations of deformation processes in the mountain tunnel (gallery) at the Talaya Observatory using a laser meter for ultra-low deformations of the Earth's crust. The current online and offline processing of incoming data has been completed. The processing of the results of observations and studied the behavior of the deformation process in the Earth's crust has been conducted in a wide frequency range on the eve of earthquakes in order to identify their precursors. A powerful oscillation buildup with periods of 25–60 minutes was found, which was caused by an earthquake with a magnitude of M = 5.2 east of Shikotan Island. The analysis was carried out and the averaged spectra of the main harmonics prevailing in the deformation signal in the range of oscillations with the longest period (ROLP) range were obtained. Harmonics with periods of 205 and 160 minutes are the most evident, which corresponds to the multiplicity to the star day duration. Of particular interest are the 160 minute oscillations, since such oscillations are of a cosmological nature and are found both on the Sun and outside the Solar System.

Keywords: *laser deformograph, short-term precursors of earthquakes, Baikal region, mountain tunnel, modern deformation velocity field*

INTRODUCTION

Regular recording of Earth's crust oscillations under the influence of external gravitational forces allows collecting a lot of information about the crustal structure, processes in it and possible changes [1], [2], [3], [4], [5]. [6], [7], [8]. It also allows to scientists to predict upcoming events, including earthquakes. Unfortunately, not enough monitoring tools for seismic events have been created at present, and with the help of existing and acting tools, not enough information has been collected to predict future seismic events with high confidence, including their level of danger and the exact location of their epicenter. Therefore, it is extremely important to increase the amount of accumulated information and, if possible, to increase the number of collection points for this information. To this end Siberian Branch of the Federal Research Center unified geophysical service of the Russian Academy of Sciences (SIBGSRAS, Novosibirsk, Russia) has developed and manufactured several samples of laser meters for ultra-small oscillations of the Earth's crust in two orthogonal directions [9], [10]. Such devices are installed and operated at several points in Russia and Kazakhstan. This paper reports on some of the studies performed in the mountain tunnel at the Talaya Observatory (South Baikal). An experimental model of a laser measuring instrument for small deformations of the Earth's crust (deformograph) with a measuring base of 25 m is operated there.

1. STATEMENT OF THE PROBLEM

Using the developed device [11], [12], it is necessary to collect data on Earth's crust oscillations under the action of external gravitational forces (from the Sun and the Moon). The device allows us to record changes in the distance of 25 m between the reflectors, fixed in the rock. Measurements are carried out in two mutually orthogonal directions, namely, in the directions north-south, west-east. In some versions, measurements are also made in the vertical direction. At the same time, increments of the lengths of all specified distances are recorded in the absolute scale and relative to the available reference measurement base, which serves as a reference, since it is not connected with the rock. This method allows us to exclude the influence of the atmosphere and other unaccounted factors on the measurement result. The 24-hours recording of these data allows us to study the spectra of these oscillations, as well as detect relatively short-term changes in these spectra and detect unusual signal bursts, usually associated with significant seismic events, such as an earthquake, even if the measurement point is significantly removed from the epicenter. The collected data are processed in accordance with the theory and accepted practice of processing these data, the results are used by experts for forecasts, as well as for proposals for further modification of the measuring equipment for even more informative measurements.

2. GEOLOGICAL AND GEOPHYSICAL CHARACTERISTICS OF THE PLACE OF INFORMATION RETRIEVAL

Observatory “Talaya” is located in the southwestern part of the Baikal folded area. Coordinates of the station: 51°40'48.00"N, 103°38'24.00"E. According to the seismic zoning map, this is a zone of possible 8-9-ball earthquakes. About 10 km to the north of the station, the Main Sayan Fault passes, and in 12 km to the south of it there are disruptive violations of the north-western strike. Due to the use of observations on a large number of weak shocks, a rather detailed picture of the stress state of the crust in the main part of the Baikal Rift was obtained. In the overwhelming majority of cases, a consistent orientation of the stress axes is found.

The Big Talaya site is located in the northern part of the Slyudyansky industrial mining region.

3. BRIEF DESCRIPTION OF THE USED EQUIPMENT

The experimental measuring complex installed in the gallery was made on the basis of two He-Ne lasers interconnected in frequency with accuracy to the phase [12]. The hardware part of the device allows us to receive signals at a carrier frequency of 1 MHz, the phase of which depends on the distance between the mirrors fastened to the rock.

The length of both measurement arms is 25 m. The deformograph signals are recorded using a computer with a sampling frequency of 0.5 Hz. The digital data processing system used below allows you to isolate and analyze the recorded oscillations in any frequency range. The basis of this system consists of two digital filters, an important feature of which is that they do not change the phase of the filtered signals.

Software is a complex of real-time programs that provide interaction between the operator and the computer performing the task. It allows controlling the progress of its execution. On interruptions from the system timer, the software interrogates the phase shift meters and interrogates the seismic sensor and the atmospheric pressure meter using a multi-channel analog-digital converter. The software also performs preliminary processing of measurement results and writes them to a hard disk with simultaneous visualization on the display screen. In addition, the software provides viewing of data for the past 24 hours. For channels recording the deformation, it is possible to view with compensation and without compensation for the influence of the atmosphere on the deformographic data.

4. RESEARCH RESULTS AND THEIR ANALYSIS

To obtain information about the deformation processes in the gallery, data arrays on the variations of phase signals obtained from two independent measuring channels of the deformograph, a compensation arm and a geophone are analyzed.

Information on the deformation in two independent orthogonal directions is obtained by programmatically subtracting phase signals recorded in digital form in the measuring channels and the compensation arm, with an equalizing coefficient proportional to the ratio of the geometric lengths of the measuring and reference base.

For further processing, the following arrays of deformographic measurements are used.

1. The time series of the deformation process in the first measuring arm of the interferometer.

2. The time series of the deformation process in the second measuring arm (orthogonal to the first).

3. The time series of difference deformation between the first and second measuring arms, obtained by direct subtraction of the phase signals at the corresponding phase shift meter.

4. Time series of seismic sensor signal.

The greatest interest could be only an earthquake that occurred on September 5, 2015 at a distance of 147 km from the observation station. It had an energy class of K = 12.3 and was suitable for the criteria for eliminating regional seismic events that had been developed earlier, however, at that time, preventive work was carried out with the deformograph.

In addition to round-the-clock recording of signals from the meter, a systematic analysis of the detected deformation signals was carried out, consisting in the study of tidal diurnal and daily deformations, the dynamics of their variations over time, the study of the spectra of the Earth's natural oscillations in a wide frequency range with reference to planetary seismicity and solar activity. As a result, a number of anomalous features in the behavior of the deformation process were found. One of the interesting features is presented as an example in Fig. 1.

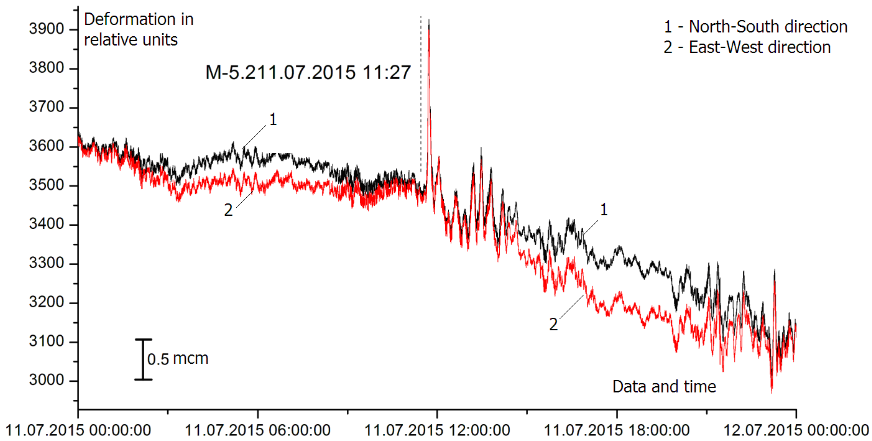

Figure 1: The deformation process, registered during 07/11/2015

The graphs depict unfiltered deformation signal registered in two orthogonal arms from July 11 to July 12, 2015. The figure clearly shows the difference in the character of the deformation signal on the right and left. At 11: 37GMT, there was a sharp synchronous jump in both arms, followed by a powerful buildup of oscillations with periods of 25–60 min. According to the earthquake catalog of the US Geological Survey (USGS), 10 minutes earlier, a large earthquake with a magnitude of M = 5.2 east of Shikotan Island occurred (43.889° N 148.011°E, depth – 40.6 km). Despite the removal of 3500 km, such an earthquake can cause such a buildup. So there is a similar jup in the compensation shoulder of the deformograph, which is consistent with periodically observed earlier similar effects in the behavior of the deformation process after large earthquakes.

In addition to the deformographic analysis of data, studies of deformational oscillations in the range of 1–5 hours were initiated, which corresponds to the range of oscillations with the longest period (ROLP), on almost the entire array of data obtained in 15 years of observations from 1999 to 2015. A spectral analysis of deformographic data series with the duration of 30 and 60 days was carried out.

A fragment of one of the sections of such rows is shown in Fig. 2. It shows unfiltered records of the deformation process in the two channels of the deformograph, their difference signal, as well as variations in atmospheric pressure, recorded using the compensating arm of the deformograph. As an example in Fig. 2 shows a one-month data set, covering another earthquake (in India). The graphs corresponding to the deformation data and their differences show the moment of arrival of the signal from the catastrophic earthquake that occurred on January 26, 2001 in India, in the state of Gujarat. It happened at 03:16:40 (UTC) and had a magnitude of 7.9. Despite the fact that it naturally influenced the ROLP process in the local time domain, this influence is insignificant when analyzing the ROLP spectrum throughout the entire study area.

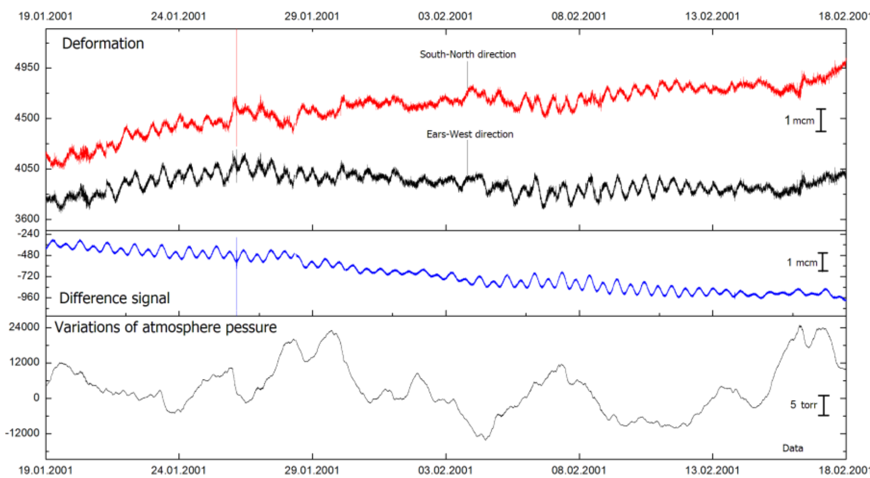

Figure 2: An example of a segment of the deformographic record with a duration of 1 month

In order to reveal the main harmonics dominating in the deformation signal in the ROLP range, the procedure of averaging the spectra obtained from all available continuous sections with the duration of 1 and 2 months was carried out. The averaged spectra obtained are presented in Fig. 3, where the gray graph corresponds to the spectrum of 60 days duration, and the blue graph corresponds to 30 days duration. The 60 days spectrum is noisier compared to 30 days spectrum. This is due to the fact that the number of continuous deformation plots with the duration of 60 days is significantly less than the number of 30 days plots.

In the both spectra more than a dozen different harmonics can be clearly distinguished. Their main parts are marked on the figure by arrows, over which the periods of these harmonics are written in minutes. Harmonics with periods of 205 and 160 minutes are the most clear, which corresponds to the multiplicity of the star day (i.e., the period of 24 hours) with coefficients 7 and 9, respectively. In addition, harmonics with periods of 286, 238 and 179, with multiples of star day with the coefficients 5, 6 and 8, also have a high signal-to-noise ratio. Of particular interest are the 160 minutes oscillations, since such oscillations are cosmological in nature and are detected as on the Sun, and beyond the solar system. A similar series of harmonics are distinguished by other researchers in the analysis of seismic noise.

Earlier we revealed the similarity of the spectra of deformation signals synchronously recorded in spaced apart points of the Earth - "Talaya" - "Talgar". The similarity between the spectra of lithosphere deformations and variations in atmospheric pressure is also shown, and the relationship between their variations in this range is revealed. Based on these assumptions, it was expected to obtain a similarity in the averaged spectra of atmospheric and lithosphere oscillations. A similar comparison is shown in Fig. 4. The following harmonics stand out most vividly in both spectra: 286, 238, 205, 196, 179, 160, 140, 125, 102, 98, 94, 82, 76. In the figure above, these harmonics are marked with dotted lines.

A study was made of the behavior of the spectra throughout the year depending on the month of observation. For this, the energy of the spectrum was calculated for each of the 80 continuous deformographic regions with the duration of 1 *month*.

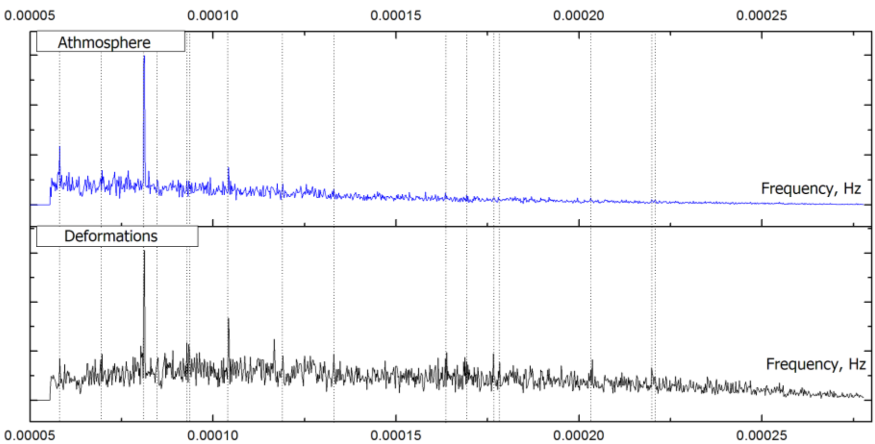

Figure 3: Averaged deformation spectra

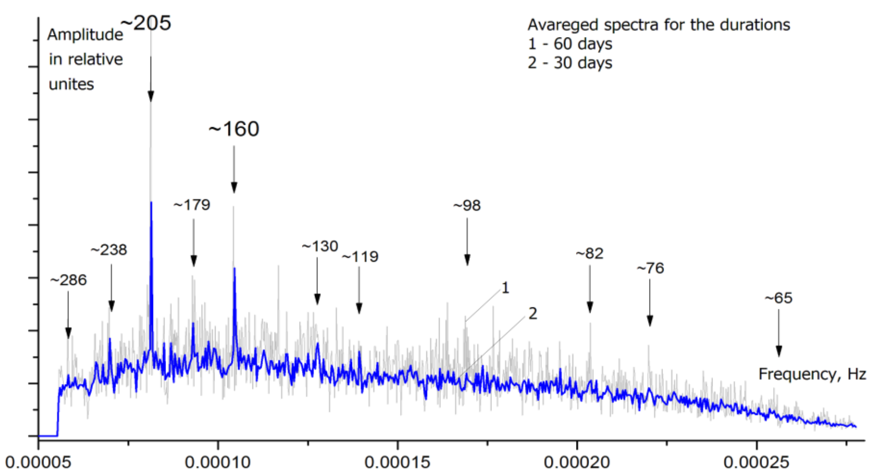

Figure 4: Comparison of averaged spectra of atmospheric and lithosphere oscillations

The obtained results are marked with dots in the corresponding column in Fig. 5. The averaged value for the three neighboring months is shown by crosses, and the continuous line is the resulting smooth curve. The graph shows that the energy of the spectra changes during the year depending on the month, and in summer it is more than in winter, and the maximum falls in June-July, i.e. the changes are clearly seasonal.

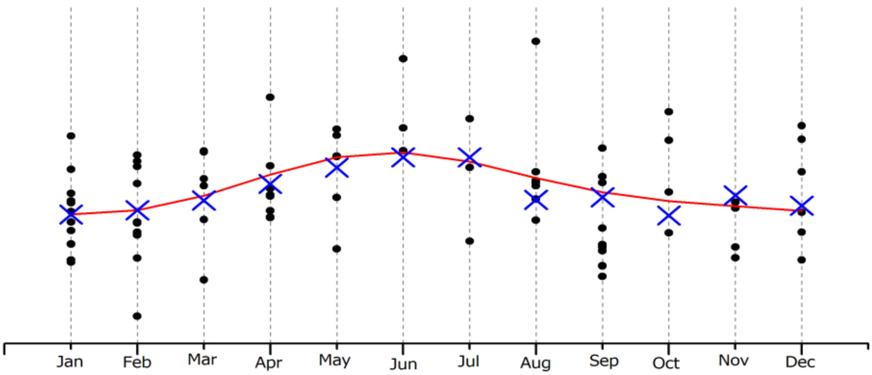

Figure 5: The energy distribution of the spectra of deformagrams depending on the month of observation

In order to look at the behavior of specific harmonics during the year, the procedure of averaging the spectra of 30 daily portions of the deformographic data recorded in different years, but starting in one month, was carried out. Thus, for each month of the year, an average spectrum of deformation oscillations was obtained in the range from 1 to 5 *hours*. The resulting spectra are shown in Fig. 6.

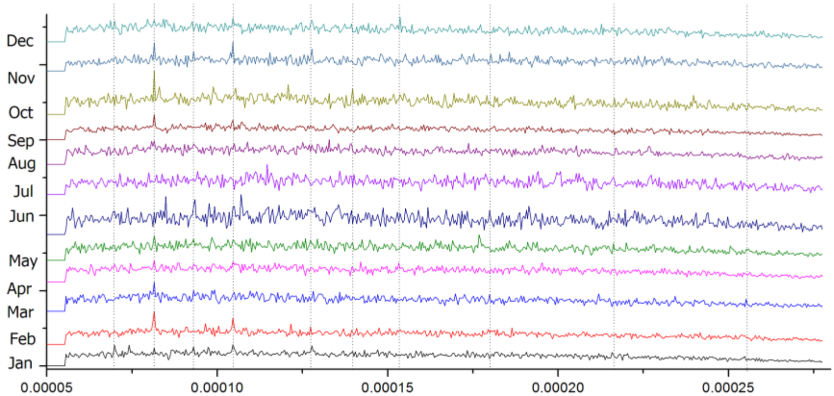

Figure 6: Averaged spectra of ROLP depending on the month of observation

For convenience of comparison, this figure shows a series of vertical straight lines tied to some distinct harmonics, which clearly change their behavior depending on the month of averaging. In particular, the harmonic with a period of 205 *minutes* is clearly distinguished from February to May and from September to November, the rest of the time it is slightly noticeable against the background of neighboring harmonics. Another bright harmonic having a period of 160 *minutes* is best distinguished between November and February.

CONCLUSION

The paper presents the obtained systematic series of observations of deformation processes in the tunnel at the Talaya Observatory using a He-Ne laser deformograph. The current online processing of incoming data has been completed. The processing of the results of observations and studied the behavior of the deformation process in the Earth's crust in a wide frequency range on the eve of earthquakes in order to identify their precursors has been conducted.

A powerful oscillation buildup with periods of 25–60 min was found, which is caused by an earthquake with a magnitude of M = 5.2 east of Shikotan Island (43.889°N 148.011°E, depth is 40.6 km). The analysis was carried out and the averaged spectra of the main harmonics prevailing in the deformation signal in the ROLP range were obtained. Harmonics with periods of 205 and 160 minutes stand out most clearly, which corresponds to the multiplicity of the sidereal day. Of particular interest are the 160 minutes oscillations, since such oscillations are of a cosmological nature and are found both on the Sun and outside the Solar System.

The spectra of deformation signals synchronously recorded in spaced points of the Earth - “Talaya” - “Talgar” are investigated. A similarity is obtained in the averaged spectra of atmospheric and lithosphere oscillations. The following harmonics stand out most clearly in both spectra: 286, 238, 205, 196, 179, 160, 140, 125, 102, 98, 94, 82, 76.

It was found that the energy of the spectra changes during the year depending on the month, and in summer it is more than in winter, and the maximum falls in June-July, i.e. the changes are clearly seasonal. It was found that the harmonic with a period of 205 minutes is clearly distinguished from February to May and from September to November. Another bright harmonic having a period of 160 minutes is best distinguished between November and February.

Analysis of laser deformograph records obtained after a catastrophic earthquake in Japan (March 11, 2011, M = 9.1), allowed us to determine the values of the natural oscillation periods of the Earth. In the spectra, frequencies of torsion and spheroid oscillations with periods of 57 min are distinguished as well as with periods 35.5 min.; 25.8 min.; 20 min..; 13.5 min.; 11.8 min.; 9.0 min.; 6.1 min.; 4.9 min.; 4.2 min., 3.8 min. and 3.6 min. Different frequency intervals are determined by the properties of different areas of the Earth's interior. It is shown that a laser deformograph can serve as an important part of the instrumental complex for studying the natural oscillations of the Earth.

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STATISTICAL AND SPECTRAL TOOLS FOR ANALYSING OF DISTURBANCE OF GEOMAGNETIC FIELD

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ABSTRACT

In this paper we performed the wavelet and statistical analysis for the geomagnetic data recorded in the Geomagnetic Surlari Observatory with acquisition periodicity of 0.5 second to 1 minute. We have selected several recording periods in the cases of solar quiet day variation, solar disturbance daily variation and geomagnetic storm periods.

For wavelet analysis I used MATLAB and compared the answer for used of different mother functions at different levels.

The rapid sampling rate allowed us to highlight micro pulsations and pulsations with periods of time between 2 seconds (minimum detection limit for a discreet signal with a sample interval of 0.5 seconds) and 10 minutes (in the case of Pc5 class pulsations and irregular pulsations from the class Pi3).

Also, we highlighted the continuous pulsations from classes Pc2, Pc3 and Pc4, as well as irregular pulsations from classes Pi1 and Pi2.

In order to identify the periodicities more than one hour, to half-day and one day periods, we used a series of data for at least 4 days, sampled at 1 minute.

For studying the geomagnetic field morphology in the periods before geomagnetic perturbations, we have developed a series of programs to highlight the associated phenomena of geomagnetic sub-storms and storms.

Keywords: *disturbance of geomagnetic field, wavelet, spectral analysis, MATLAB*

INTRODUCTION

Traditional geomagnetic measurements in observatories lead to the knowledge of the geomagnetic field, that define its direction and the intensity of its elements after certain directions.

The geomagnetic elements are: 1) magnetic declination D, represented by the angle between projection on the horizontal of the field and the north direction, 2) magnetic inclination I, i.e. the angle between the total field direction and its projection on the horizontal plane and 3) horizontal component H, the projection of the total magnetic field F on the horizontal plane.

Also, can be use in the geomagnetic observatory records, the following changes: declination changes ΔD, variations of the horizontal and vertical component, ΔH and ΔZ.

Usually, are recording three orthogonal elements: North component (X), east component (Y) and vertical component downward (Z), that are performed by means of devices, based on magnetic induction, as so type fluxgate magnetic sensors.

These parameters vary depending on the location of the observation point on Earth. Reported to a local reference system, defined by the horizontal and the north direction, i.e. to the tri-rectangular axis system oriented in the directions north, east and vertical (downward), the geomagnetic field is determined without ambiguity, if are known three geomagnetic elements: either two angles and the total intensity (or the intensity of a component of it), or two components of the intensity and an angle, or the intensity of three components.

For measuring declination and inclination of the geomagnetic field in absolute terms, to establish the base level of permanent records, usually are used fluxgate magnetometers mounted on a nonmagnetic theodolite and for absolute total magnetic field are used proton precession magnetometers [1], [2].

ANALYSIS METHODS OF GEOMAGNETIC FIELD

In many papers we present several applications, examples and results of the statistical and spectral methods of analysis of the geomagnetic data [3].

For this purpose, we used methods and algorithms as numerical derivation in time, polynomial regression, correlation factor determination, spectral analysis and wavelet analysis. With these algorithms we have been developed work's program sequences in MATLAB [4], [5], [6] and Auto Signal [7] to study the geomagnetic field morphology and to determine the spectrum of geomagnetic phenomena at different time intervals.

Through derivation on time, the removal of periodic components is achieved and geomagnetic disturbances are clearly highlighted.

Another way of processing the data we used was spectral analysis of the signals. Through spectral analysis performed with Fast Fourier Transform, a temporal signal is decomposed into real and complexes parts. This transform provides a complete spectre of the frequencies that make up the signal, but it does not keep any information as to when these occur.

The Fourier series is a linear combination of mono-frequential signals and describes the behaviour of the original signal in time and frequency. It highlights the temporal evolution of the signal and its frequency content. If we apply direct Fourier transform to a signal is obtained the spectral function of the signal (spectral characteristic), which is a signal parameter. Spectral function is a complex quantity, which can be continuous or discrete, periodic or no periodic.

If the spectral function is discrete is called complex amplitude spectrum and characterization sizes in polar coordinates are called amplitude spectrum, respectively phase spectrum.

Even if the signal is periodic but the time window isn't chosen to be a multiple of the signal period (an integer number of periods), the spectral function obtained may be distorted. This may occur where signal acquisition isn't adapted to the signal periodicities or where periodicities of the signal purchased are not known.

If the time window is chosen correctly then the actual virtual sequence coincides with infinite duration signal, otherwise the virtual signal is distorted compared the real signal. Using a time window for signal processing is equivalent to the filtering problem, but the goal is to mitigate potential discontinuities at the end of finite segment of the data evolution over time.

In order to achieve the best possible accuracy, the spectral window used (Fourier transform of the time window) must satisfy the following basic requirements:

• main lobe of the window should be very narrow;

• main lobe contains most of the window energy;

• the energy of the secondary lobes must be evenly distributed between them

Generally, these three requirements cannot be met by any window because the first two requirements are contradictory. From this point of view, we can say that there is no optimal window, each providing a compromise between the three requirements.

Bartlett temporal window provides a strong suppression of side lobes of the corresponding spectral window, however, increases the width of the main lobe and reduces its amplitude.

The Hamming time window provides a stronger suppression of the side lobes and minimizing the main lobe amplitude for the chosen frequency.

A large time window leads to a good resolution in frequency, but a low resolution in time domain (narrowband spectrogram) and a short time window determine a good location in time, but a poor frequency resolution (broadband spectrogram).

If the assessment of the power spectrum is based on direct application of Fourier transform followed by mediation, then we deal with the averaged periodogram. Mediation is usually done by dividing the signal into a variable number of segments, possibly overlapping, followed by Fourier transform calculation of all these segments (average for minute, hourly or daily of the geomagnetic signals).

Given the need for a high-performance signal analysis, many variations of spectral analysis of this type have been developed, generally called periodograms. Thus, one of the most popular periodogram mediated assessment procedures is attributed to Welch, who is a modification of the original segmentation scheme, developed by Bartlett.[4]

Modern approaches of spectral analysis are designed to overcome some of the distortions produced by traditional methods and are very effective especially for short segments of analysis.

According to the Heisenberg uncertainty principle, is not possible accurate and simultaneous localization in both time domain and frequency domain.

Wavelet analysis preserves the information in the time domain and those in the frequency domain. A discussion about wavelets begins with Haar wavelet, the first and simplest. The Haar wavelet is discontinuous, and resembles a step function. It represents the same wavelet as Daubechies db1,that we used in our examples. The Daubechies wavelets *dbN*, where db is the "surname" of the wavelet and *N* is the order , are a family of orthogonal wavelets defining a discrete wavelet transform. The family of Daubechies wavelets have the property of linear phase, which is needed for signal and image reconstruction. By using two wavelets, one for decomposition and the other for reconstruction instead of the same single one, many properties are derived. Its are characterized by a maximal number of vanishing moments for some given support. With each wavelet type of this class, there is a scaling function (father wavelet) which generates an orthogonal multiresolution analysis.

Function *wt = cwt(x)* returns the continuous wavelet transform of *x*. The input, *x* is a real- or complex-valued vector with double-precision, or a single-variable sampled with equal equidistance, that must have at least four samples. The minimum and maximum scales are determined automatically based on the wavelet's energy spread in frequency and time. If *x* is real-valued (respectively, complex-valued) *wt* is a 2-D matrix (respectively, 3-D matrix) where each row (respectively, 2-D matrix) corresponds to one scale. The column size of *wt* is equal to the length of *x*.

In this paper we refer to methods of analysis of geomagnetic records and especially to the wavelet method for the analysis of disturbance of geomagnetic field. We also performed a wavelet analysis that gives us additional information on the relationship between frequency and time of occurrence. Based on complex analyses, where wavelet analyses are of particular importance, predictions of major geomagnetic disruptions can be made [8], [9], [10].

EXPERIMENTAL RESULTS

In our example, we used the data recorded at the Surlari Geomagnetic Observatory at a frequency of 2Hz to identify correlations occurring between the high frequency oscillations of the geomagnetic field components over 4 days (2018, August 24, 00:00:00 to August 28, 00:00:00). We used in Fourier and wavelet analysis 691200 samples at 2 Hz sampling rates or 5760 samples at 0.0166 Hz sampling rates, where we can view the predominant frequencies for each point and can be distinguished range of frequencies.

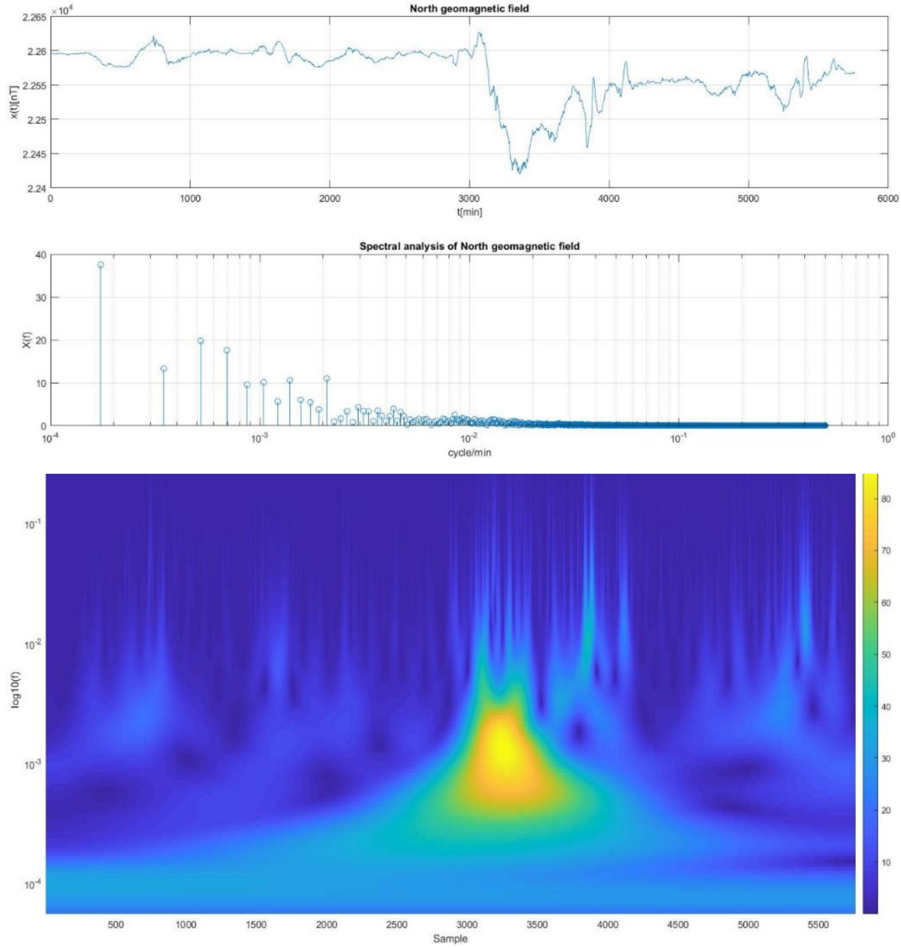

Fig.1 – Time series (up), spectral analysis (middle) and wavelet analysis (down) for North geomagnetic field, with sampling rates 0.0166 Hz (1-minute period).

The values on the scale determines the compression of wavelet. The lower scale are correlates better with high frequencies. Small scale coefficients of continuous wavelet transform CWT highlight the fine features of the input signal. Increasing the scale values of scale allow highlight low frequency content of the signal.

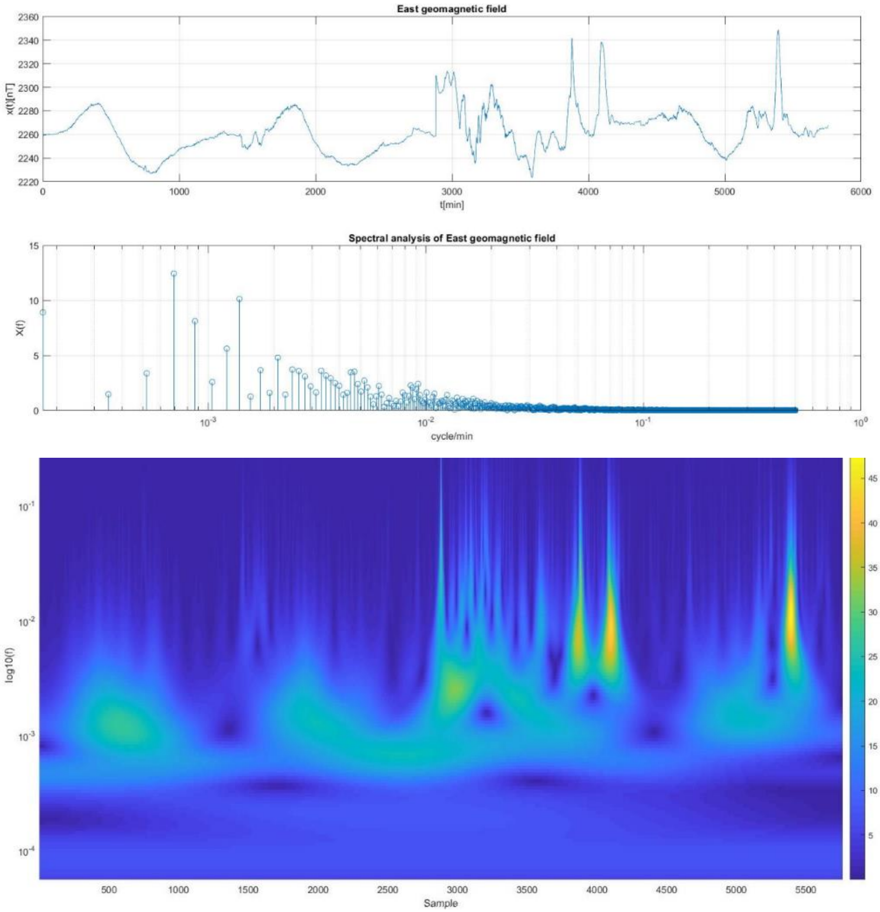

Fig.2 - Time series (up), spectral analysis (middle) and wavelet analysis (down) for East geomagnetic field, with sampling rates 0.0166 Hz (1minute period).

In fig. 1-4, we used for Fourier analysis the MATLAB code:

load table.txt; X1= table (:,1); X2= table (:,2); X3= table (:,3); N=length(X1); t=1:1:N; fe=1/N; x=X1'; Xt=fft(x); Xm=abs(Xt); X=Xm(1,1:N/2+1)/(N/2); f=[0:N/2]*fe; subplot(211); plot(t,x); grid; xlabel('t[min]'); ylabel('x(t)[ ]'); title(' '); subplot(212); stem(f,X); xlabel('f[o.5Hz]'); ylabel('X(f)'); grid; title('')

Also, for wavelet analysis we used function Daubechies db1, the same wavelet as Haar, with following code:

load table.txt; SX=table(:,1); signal = SX; lev = 5; wname = 'db1'; nbcol = 64; [c,l] =wavedec(signal,lev,wname);len = length(signal); cfd = zeros(lev,len); for k = 1:lev; d = detcoef(c,l,k); d = d(:)'; d = d(ones(1,2^k),:); cfd(k,:) = wkeep1(d(:)',len); end

cfd = cfd(:); I = find(abs(cfd)<sqrt(eps)); cfd(I) = zeros(size(I)); cfd = reshape(cfd,lev,len); cfd = wcodemat(cfd,nbcol,'row'); h211 = subplot(2,1,1);

```
h211.XTick = []; plot(signal,'r'); title('Analyzed signal.'); ax = gca; ax.XLim = [1 length(signal)]; subplot(2,1,2); colormap(cool(128)); image(cfd); tics = 1:lev; labs = int2str(tics'); ax = gca; ax.YTickLabelMode = 'manual'; ax.YDir = 'normal'; ax.Box = 'On'; ax.YTick = tics; ax.YTickLabel = labs; title('Discrete Transform, absolute coefficients.'); ylabel('Level'); figure;[cfs,f] = cwt(signal,1,'waveletparameters',[3 3.1]); hp = pcolor(1:length(signal),f,abs(cfs)); hp.EdgeColor = 'none'; set(gca,'YScale','log'); xlabel('Sample'); ylabel('log10(f)');
```

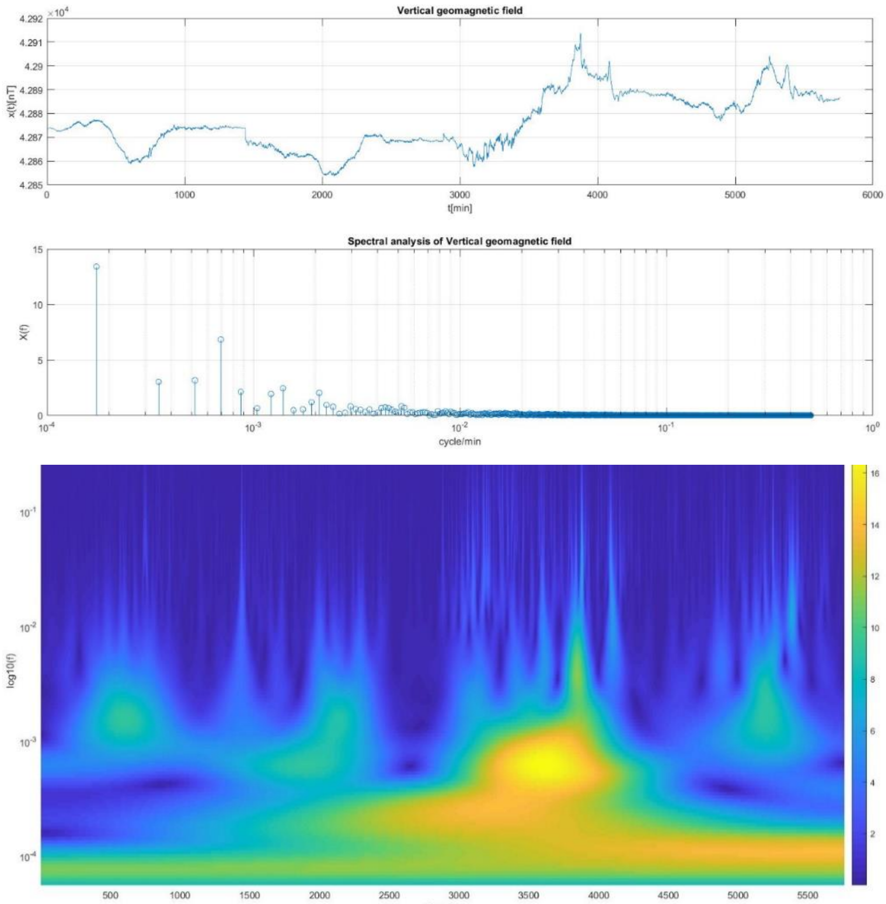

Fig.3 – Time series (up), spectral analysis (middle) and wavelet analysis (down) for vertical geomagnetic field, with sampling rates 0.0166 Hz (1 minute period).

While for the 4-day series we have 5760 samples (Figures 1-3), for the one-day time series we used the maximum sampling density (2Hz), which corresponds to 172800 samples (Figures 4). Here, in the graphs of 26 August, the elements of the geomagnetic storm can be more accurately identified.

Amplitude in the North direction had variations of up to 200 nT, in the East direction up to 100 nT and in the vertical direction up to 50 nT.

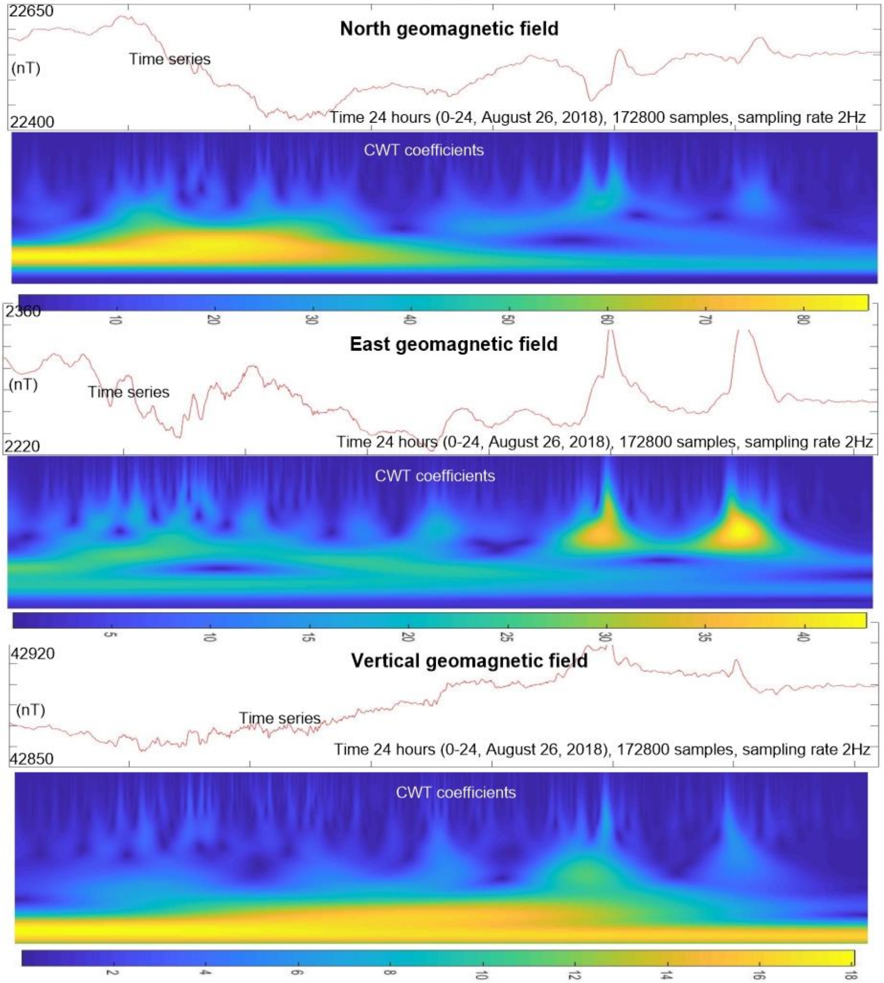

Fig.4 – Time series (up) and wavelet analysis (down) for three orthogonal elements North, East and vertical geomagnetic field, with sampling rates 2 Hz for August 26, 2018.

CONCLUSION

Geomagnetic field elements can be estimated with good accuracy for magnetically calm days. For agitated days, and even more so during magnetic storms, the variation of the declination parameter becomes significant. A geomagnetic storm is known to have different characteristics (amplitudes, gradient, geomagnetic coefficients) depending on the latitude at which it is measured. Thus, at the beginning of a geomagnetic storm, the data from the closest to ground (geomagnetic observation points) is needed on-line for the corrections of the guidance systems.

Geomagnetic storms are created after periods of high-speed solar wind and a southward directed solar wind magnetic field transferring energy from the solar wind into Earth's magnetosphere. Also, these storms are associated with solar coronal mass ejections.

Geomagnetic disturbances are the sum of disturbance produced by: solar corpuscular flux at the magnetopause, magnetospheric ring currents, magnetospheric tail current, ionospheric currents and induced ground currents.

In addition to calculating the geomagnetic activity tri-oral indices Kp, observatory records were subjected to a morphological analysis procedure resulting in the selection of the 10 quiet day variation, 10 disturbance daily variation and the geomagnetic phenomena of SFE and SSC type.

From these information's reported to the World Data Center (from each geomagnetic observatory from INTERMAGNET network) was selected the 5 quiet international days and 5 international disturbance days.

Because the wavelet coefficients are complex valued, the coefficients provide phase and amplitude information of the signal being analyzed. Analytic wavelets are well suited for studying how the frequency content in real world nonstationary signals evolves as a function of time been a good choice when doing time-frequency analysis with the CWT.

In our examples fig. 1-4, wavelet analysis shows predominant frequencies and amplitude for each moment.

ACKNOWLEDGEMENTS

We gratefully acknowledge the many and significant contributions and comments provided by our colleagues from geomagnetic observatories. The manual about observatories methodologies is based on the original document (INTERMAGNET Technical Reference).

The experimental results, are part of work supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project Nr.16PCCDI/2018: „Institutional capacities and services for research, monitoring and forecasting of risks in extra-atmospheric space", component project 2: „Space Weather", within PNCDIII.

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THE RESULTS OF LONG-TERM REGISTRATION OF MICRO-DEFORMATIONS OF THE EARTH'S CRUST IN THE AREA OF LAKE BAIKAL

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ABSTRACT

Long-term registration of small deformations of the Earth's crust with the subsequent data processing is necessary for solving many actual problems. Such deformations are measured predominantly using unique laser measurer (deformograph). Experimental data allow us to investigate the frequency spectrum of deformations and on the basis of this analysis to draw conclusions about the level of seismic activity in the region. Variations of the tidal parameters allow estimating the parameters of the fractured zone. Measurements of deformations in two orthogonal directions are carried out using an original automated laser measurer for ultra-small movements of the Earth's crust. The advantage of the laser measuring complex created for measurements in the mountain tunnel is that even in the presence of the atmosphere it possesses a high relative sensitivity of the order of 10^{-9}-10^{-10} to small displacements in a wide range of oscillation periods of 10^{0}-10^{7} s. It allows recording of the Earth's own and tidal oscillations, deterministic daily variations of micro deformational oscillations, as well as features of the deformation processes in the Earth's crust that accompany seismicity. This paper presents the results of long-term monitoring of oscillations of the Earth's crust in the area of Lake Baikal, measured in the observatory Talaya in mountain tunnel with a laser meter.

Keywords: *laser deformation measurer, short-term precursors of earthquakes, Baikal region, methods of gallery deformation registrations, modern field of strain rates*

INTRODUCTION

The Siberian Branch of the Federal Research Center unified geophysical service of the Russian Academy of Sciences (SIBGSRAS, Novosibirsk, Russia) has developed and manufactured several variants of laser meters for ultra-small deformations of the Earth's crust in two orthogonal directions [1], [2]. The devices were used in Altai Mountain Region, in Kazakhstan and other regions. It is used for the longest time in the long-term working mode at the Talaya observatory near Lake Baikal. This paper proposes the results of the development and improvement of methods for recording and interpreting minor deformations of the Earth's crust using the mentioned measuring complexes of highly sensitive laser equipment in the Baikal seismic zone. The study of deformation processes is due to the need to fill in the lack of information about the signs of preparing strong earthquakes and, as a result, the lack of reliable methods for their prediction. This deficiency is especially acute in the Baikal seismic zone, where the insufficient technical equipment of the existing geodynamic polygons does not allow achieving sufficiently reliable results for the detection of earthquake precursors. At present, an experimental sample of a two-coordinate strain gauge based on two He-Ne laser emitters has been used successfully for a long time in the gallery in the Talaya Observatory (Southern Baikal). The measuring base of the device is 25 m. With its help, deformation processes are recorded in order to study the geodynamics of the Earth's crust of the Baikal rift zone and the registration of deformation precursors of earthquakes.

1. LONG-TERM MEASUREMENT RESULTS

The laser deformograph at the Talaya station can be used as a tool to study the natural oscillations of the Earth, seiches of the Baikal Lake, tidal deformations of the Earth and slow deformations in the seismically active Baikal region. Let us consider examples of the use of an laser deformograph installed in the mountain tunnel in the seismic station. The position of the Talaya seismic station is shown in Fig. 1 [3].

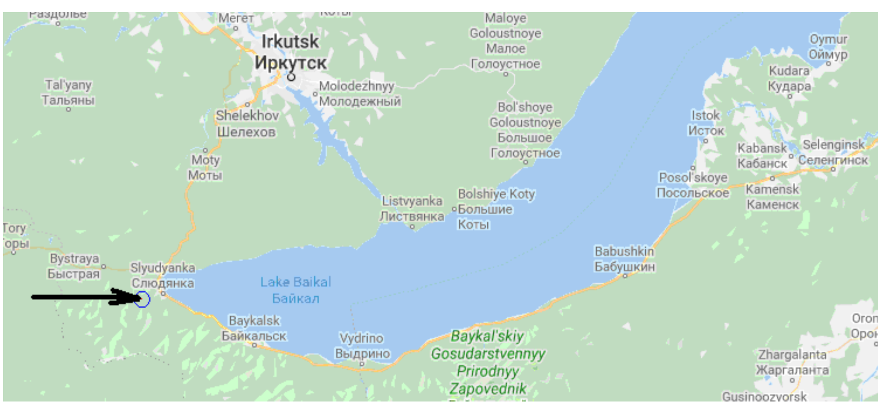

Figure 1: Position of Talaya station near Slyudyanka village near Lake Baikal

2. THE EARTH'S OWN OSCILLATIONS ACCORDING THE COLLECTED DEFORMATION DATA

The Earth's own oscillations are one of the important areas of geophysical prospecting. Experimentally, the natural oscillations join seismology and gravimetry. Periods of natural oscillations are known from 57 min to 35.5 min.;

25.8 min.; 20 min.; 13.5 min.; 11.8 min.; 8.4 min and less. An example of the spectral analysis of the deformograph recording (Mokh Observatory, Germany) after the Sumatran earthquake (December 26, 2004, M = 9) is given in [4]. Let us turn to the records of the laser deformograph obtained at the Talaya station (Fig. 2) during the period of the catastrophic earthquake in Japan (March 11, 2011, M = 9.1). As usual, we analys the registration records obtained from measurements with a 25-meter laser strain gauge along two orthogonal axes (–24°N, + 66°N) and difference deformation. Fig. 3 shows filtered deformations records for the same period in which the low frequency component is eliminated. Fig. 4 shows the difference signal, which shows the effect of the earthquake that took place on 11.03.2011. Fig. 5 shows the difference signal after filtering it with a high-pass filter, while the entire interval is stretched along the time axis, the entire axis represents the interval of two days. It can be concluded that the indicated oscillations are well distinguished by the used instrumentation; they appear in the difference signal no less clearly than in the signal along the individual arms of the interferometer.

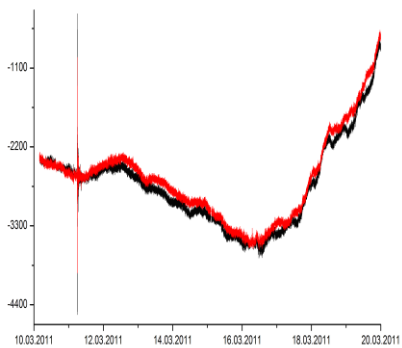

Figure 2: The graph of deformation in two azimuths from March 10 to March 20, 2011, including the date of the earthquake on March 11, 2011 (M = 9.1)

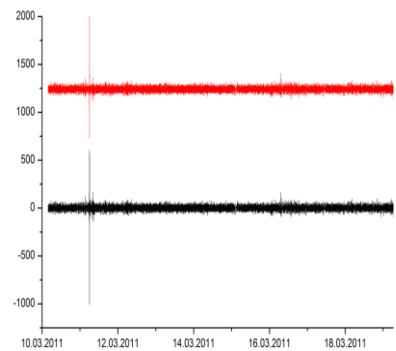

Figure 3: Filtered deformation records for 10 days, including the date of the earthquake on March 11, 2011, in the range of 1 min - 1 hour

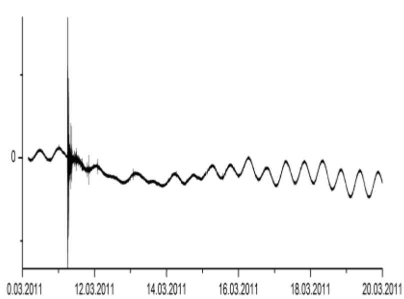

Figure 4: Difference signal, earthquake effect on the 03/11/2011 and tidal variations

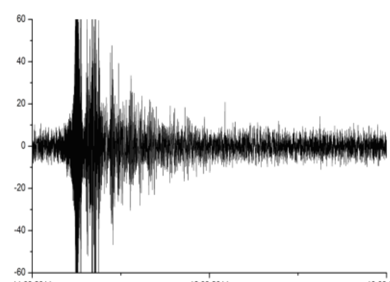

Figure 5: Filtered differential signal (2 days of recording)

3. VIBRATION SPECTRUM STUDIES

To study the processes it is also advisable to construct the spectra of the obtained oscillations. Fig. 6 shows the spectra at various times after an earthquake. It is possible to note changes in the spectrum for the day following the earthquake. There are separate peaks in the frequency range from 0.0003 Hz to 0.0015 Hz: 0.00029 Hz (which corresponds to period of 57 min.); 0.00047 Hz (35.5 min.); 0.00065 Hz (25.8 min.); 0.00083 Hz (20 min.); 0.00123 Hz (13.5 min.) and 0.00141 Hz (11.8 min.). Fig. 7 shows the spectra of the difference signal. In the spectra, frequencies of torsion and spherical vibrations are distinguished. From experimental data more than 1000 periods of natural oscillations are known.

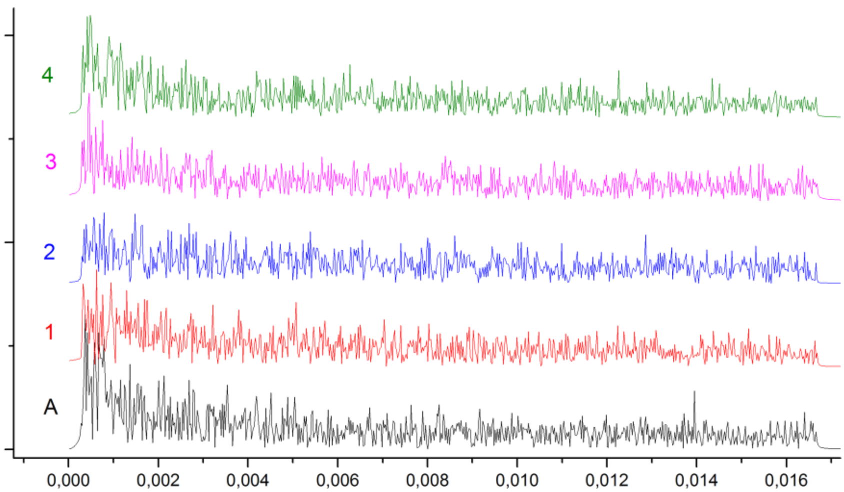

Figure 6: Spectra of the deformation signal in a window 6 hours long: A - immediately after an earthquake; 1 – after 1 day; 2 – after 2 days; 3 – after 3 days; 4 – after 4 days

Since the Earth's core is liquid, and torsion vibrations are transverse vibrations, they are associated only with solid regions of the Earth and are determined by the distribution of the density and shear modulus in the shell (mantle) and crust. It is known that, due to the study of natural oscillations, of two models of the Earth: a) the Gutenberg model with a layer of lowered speeds of seismic waves at depths of 50 km ÷ 250 km and the model; b) Jeffreys model, which does not have such a layer, self-oscillations very strongly favor “preference” Gutenberg models. Spherical vibrations capture the entire Earth, which allows studying the core of the Earth along with the crust and the shell. Different frequency intervals are determined by the properties of different areas of the Earth's interior.

Therefore, natural oscillations allow one to study not only the integral properties of the globe, like tides in the body of the Earth, but also differential ones. As shown, the above laser deformograph can serve as an important part of the instrumental complex for studying the natural oscillations of the Earth.

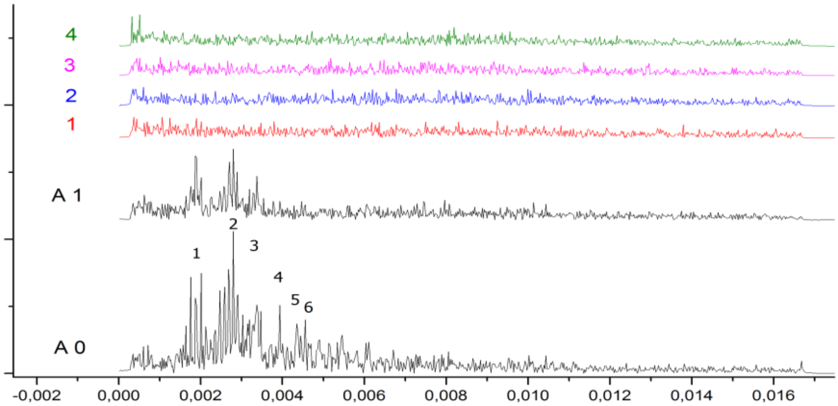

Figure 7: Spectra for the difference: A0 - immediately after an earthquake; A1 - after 3 hours. The approximate value of the harmonics: F1 = 0.00184435421 Hz, F2 = 0.00272346129 Hz, F3 = 0.00335752109 Hz, F4 = 0.00390581435 Hz, F5 = 0.0042917638 Hz, F6 = 0.00456437888 Hz (corresponds to periods in minutes: 9.0365; 6.11966; 4.96397; 4.26714; 3.88340 and 3.65146)

4. TIDES AND SEICHES OF BAIKAL LAKE

Consider the natural oscillations of Baikal Lake, i.e. seiches. They can be observed by measuring the level of the waters of Baikal or the displacement of its ice cover (in winter). In the GPS measurements in 2007, there were variations in vertical displacements of the ice cover with periods ranging from 4 hours to one day (see Fig. 8). Consider these vibrations, which, loading the Earth's surface (the bottom of Baikal Lake), cause deformations of the Earth's crust, which can then be recorded by laser deformograph in the tunnel of the Talaya seismic station located 7 km from the lake (see Fig. 1).

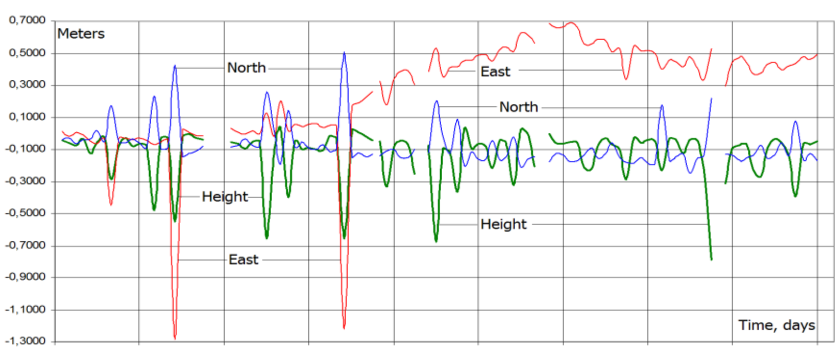

Figure 8: The results of GPS measurements in height, in azimuth to the East and in the azimuth to the North. Offsets of the "Balok" ice point relative to the "Baza" coastal point, at 3 km from it. Time is from 12h 03/06/2008 to 00h 08/03/2008. The picture shows a seiche period of 4 ÷ 5 hours

These variations are related to the tides and seiches of the lake. Let turn to the nature of these effects. The tides of Baikal Lake were considered in the works of the period from 1920 to 1960, and for similar in size and location of Tanganyika Lake in Africa; a detailed analysis is given in [5]. It is known that at the Tankhoi and Peschanaya points tidal semi-diurnal waves (M2) were observed with amplitude of 5-6 mm with a 20% error. For the Baikal Lake analogue, Tanganyika Lake in Africa (the lake is 638 km long and the average depth is 800 m), observations were made at Albertville, where the lake is 75 km wide. The median position of the item allows you to register a unimodal 4 hour seiche, a bimodal 2 hour seiche and 40 minute seiche. Taking into account the short period of natural oscillations of lakes, the static theory of tides can be used to analyze tides with a period of 12 hours or more. Normal gravimetric and oblique factors were obtained for the Baikal region and the tidal deformation model was chosen [6], [7], [8], [9]. Using the tidal analysis method HICUM to estimate the amplitudes of the main tidal waves at Listvyanka, we obtain values: from 7.8 ÷ 7.9 mm (M_2) to 20.9 mm (M_f) and from 4.3 ÷ 4.6 mm (O1) to 6.38 ÷ 6.9 mm (K_1). Full tide reaches several centimeters. The long-period tide is complicated by seasonal variations in lake level. Using the static tide theory, we analyze the periodic variations using the ETERNA method [10]. Table 1 presents the results of the analysis when using the version of the slopes in the azimuth of East. However, the phase shift for the M2 wave and other main waves turns out to be great; therefore, a search with a minimum phase shift was found, it turned out that it is better to use the azimuth "70°N" (see Table 2).

Table 1: Tidal analysis of a series of 282 days (April 28, 2007 - March 5, 2008), ETERNA program (1) Verification, azimuth angle 90°

Wave	Amplitude [*mm*]	SNR	Amplitude factor	Error	Phase shift [°]	Error [°]
O1	3.442	26.6	0.672	0.025	13.05	1.44
P1S1K1	4.532	35.9	0.629	0.017	19.34	0.99
N2	1.238	8.6	0.662	0.077	9.42	4.42
M2	7.962	51.7	0.815	0.015	13.79	0.90
S2K2	3.562	24.0	0.784	0.032	26.02	1.87

Table 2: Tidal analysis of a series of 282 days (April 28, 2007 — March 5, 2008), ETERNA program (1) Verification, azimuth angle is 70°

Wave	Amplitude [*mm*]	SNR	Amplitude factor	Error	Phase shift [°]	Error [°]
O1	3.441	26.6	0.710	0.026	6.83	1.53
P1S1K1	4.533	35.9	0.665	0.018	13.16	1.05
N2	1.235	8.6	0.675	0.078	-6.20	4.50
M2	7.964	51.7	0.834	0.016	-2.17	0.92
S2K2	3.562	24.0	0.802	0.033	10.05	1.95

We use this model of tilt in azimuth of 70°N for the analysis of Baikal tides. The relation between the vertical displacement Δr and the inclination of the surface ε [11] is known:

$$\Delta r = (L/2)\cdot\sin\varepsilon, \quad \varepsilon(\text{rad}) = 2\Delta r/L.$$

Here L is the width of the lake in a given azimuth. For wave M_2, we observe a vertical displacement of 7.964 mm. The corresponding vertical slope is:

$$\varepsilon = A_{th}\cdot\gamma_{th}.$$

The astronomical amplitude A_{th} (9.544 ms) for a solid Earth is modulated by the elastic response of the Earth according to the ratio for the amplitude factor $\gamma_{th} = 1 + k - h = 0.69125$. Its theoretical value, according to the results obtained for Talaya station, is γ_{NS}= 0.704 and γ_{EW} = 0.710 [10]. Therefore, we assume ε(ms) = 6.597 and ε(rad) = 31.98 nrad. Substituting these values in the ratio:

$$L = 2\Delta r/\varepsilon \text{ (rad)}.$$

The calculation gives L = 498 km. The same calculations give for L = 412 km (S_2), L = 420 km (O_1) and L = 440 km (K_1) waves. These calculations are made similarly to the analysis for Tanganyika Lake, where assumptions about zeroing tidal amplitudes in the center of the lake are made. In our case, for Baikal Lake, for the length L it is more correct to choose the ratio:

$$L = \Delta r/\varepsilon \text{ (rad)}.$$

This gives a value of L ranging from 206 km to 249 km, which corresponds to the size of the southern depression of the lake (see Fig. 9).

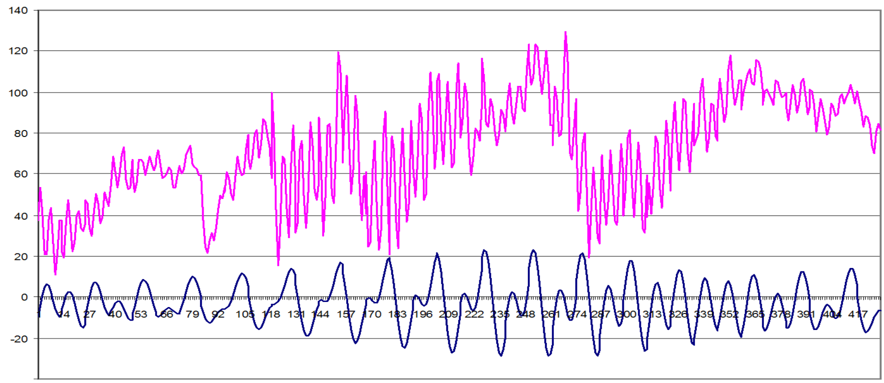

***Figure 9**: Variations of the level of Baikal Lake with the exception of the tidal effect – seiches (row 1, in mm) and the theoretical tidal curve. Generate seiches at high tide. Double amplitude of seiches reaches 60 mm at Listvyanka*

The two-week wave Mf has an amplitude higher than the theoretical one, which requires the further development of the dynamic tide theory at Baikal. Two-week modulation of the tide, along with earthquakes and abrupt changes in atmospheric pressure, is one of the causes of standing waves – seiches on Baikal (see Fig. 11). Excluding tidal variations from observations of the level and making spectral analysis, we obtain seiches periods: 4 h 33 m, 2 h 33 m, 1 h 28 m and 1 h 06 m for the item Listvyanka. Nodal lines of seiches are located at a distance of 280 km, 130 km, 360 km and 540 km, respectively, from the southern part of the lake (Kultuk settlement).

The theoretical periods of seiches are related by the equation:

$$T_n = 2l / (n\sqrt{gH}).$$

Here *l* is the length of the lake, H is its average depth, g = 9.8 m / s2 and n is mode. For the first seiche mode with a period of 4.6 hours, we obtain the value of an average depth of 630 m. The amplitude of the seiches has seasonal changes. The first mode of seiche is well manifested in the records of the lake level at the Listvyanka station and in the data of ice measurements of displacements. Simulation of tidal and seiche effects of Baikal Lake is important for the development of monitoring measurements in the Baikal region. Periodic load at the bottom of the lake at level 1 KPa manifests itself in various types of high-precision geophysical measurements. We now turn to the results of observations in this frequency range by a laser deformograph at the Talaya station. The spectral analysis of the materials was performed using a filter whose amplitude-frequency characteristic is shown in Fig. 10. Among the obtained frequencies, besides those noted in Listvyanka (periods of 4.55 hours; 2.55 hours; 1.47 hours and 1.1 hours), oscillations with a period of 3.4 hours (205.5 minutes) are distinguished. The summer frequency spectrum is richer, which may be due to the filtration properties of the ice layer on Baikal Lake. The deformation spectra for the winter and summer periods of observations are analyzed, a typical example of which is shown in Fig. 11.

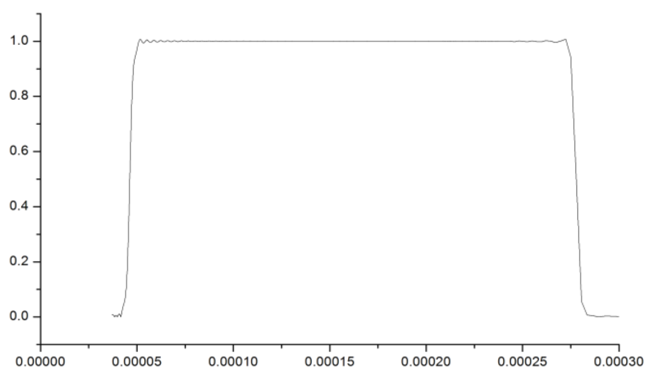

***Figure 10**: Frequency characteristics of the filter*

In the future, fluctuations from the seiche period of Lake Baikal can be used to build a dynamic model of the lake level, and the presence of these periods in deformograms should be taken into account in further analysis and interpretation.

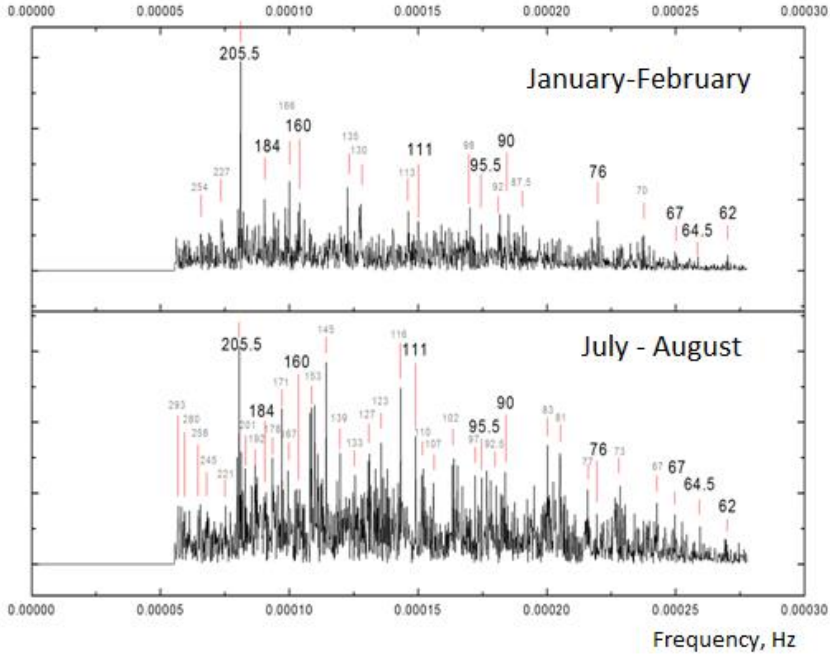

Figure 11: Spectra for winter and summer periods of observations

5. TIDAL DEFORMATIONS AND VARIATIONS OF TIDAL PARAMETERS DURING TIME

Tidal deformations of the Earth cover the entire planet from its center to the surface. They have an amplitude of 10^{-8} units, and the tidal force is accurately calculated [4]. Experimental selection of tidal models for southern Baikal was carried out using data obtained using digital tidal gravimeters and laser deformographs [5], [6]. Reflection of the effects of the cavity, local features of the Earth's crust and in tidal deformations for the Talaya station reach 10% in amplitude and 9° in the phase shift [9]. The greatest interest in the analysis of tidal oscillations is the 12-hour harmonic (wave M2), since the information contained in this signal is less noisy, while the 24-hour tidal harmonic is usually distorted by daily variations of meteorological parameters. The results of the tidal analysis were performed using the ETERNA.3.0 program according to the annual data of difference deformations. Fig. 12 and 13 show variations of the amplitude factor and phase shift (difference from the normal state + 65.4°) for the period from 1995 to 2015. Usually, graphs were based on quarterly data. In the last years, due to the instability of the power supply at the seismic stations, the average annual data was used. As can be noted from the results of the analysis, the perennial variations of the parameters lie within a few percent. Variations in the phase shift after the Kultuk earthquake (M = 6.3, 25 km from Talaya station, 08.27.2008) smoothed out (see Fig. 13), which apparently reflects the state of the geological environment of the area. In epochs of strong earthquakes, variations in tidal parameters reach 3–4% in amplitude and 1–3° in the phase shift. Anomalies can be caused by changes in hydrodynamic conditions in the zone of a deep fault (1-3 km from the observation point) and deformation of the Earth's crust in the era of a strong earthquake.

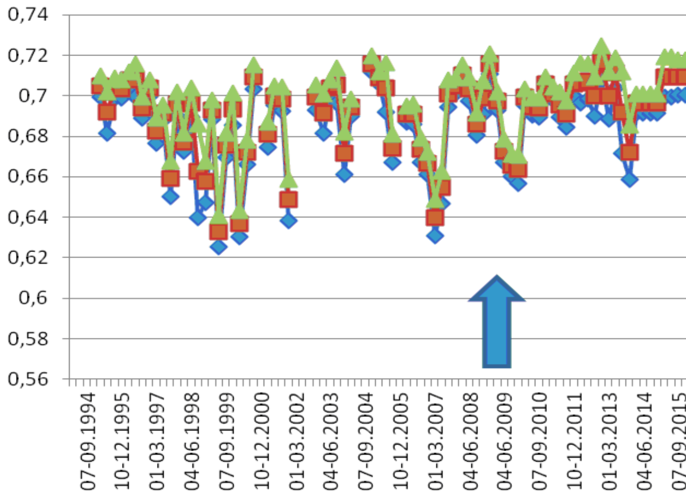

Figure 12*: Amplitude factor (1990–2015)*

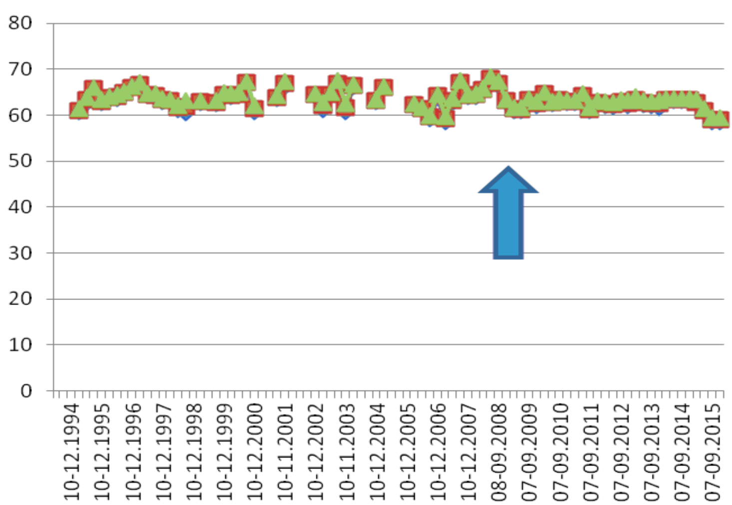

Figure 13*: Phase shift (1990 – 2015), the normal value is 65.4°*

6. LONG-TERM PERENNIAL VARIATIONS

Periodic variations of perennial changes in deformations reflect variations in local deformation of near-fault zones (in our case, the Main Sayan Fault, located a few kilometers north of the station). Long-term changes of deformations show the prevailing direction of deformation and reflect the development of the seismic process in the region. The local level for deformations was investigated according to the data obtained in the 90-meter tunnel of the Talaya seismic station. Here at the bases of 1 m – 25 m the annual strain rate reaches a year. This characteristic, apparently, is local (in contrast to the data of space geodesy). In the past two years, due to the instability of the power supply at the seismic station, the data on the course of deformation during the year is unreliable; therefore, only information from previous years was used in the analysis. Over long time series (1985–2013), the deformation is cyclical in nature (periods from 3 to 18 years), the average strain rate becomes comparable with the definitions on large bases. In moments of strong regional earthquakes, local deformation reflects the regional character (co-seismic changes up to 3·10-6 per year). Measurements in two orthogonal azimuths allow one to obtain the values of the first invariant of the strain tensor – the bulk strain and to analyze its behavior in time.

To exclude the seasonal component, the total results for the annual period are analyzed. Fig. 14 shows changes in the rate of accumulation of volumetric strain in time; the arrows also show the moments of Busingolsky (12.27.1991, M = 6.5-7.0), Zunmurinsky (June 29, 1995, M = 5.6-5.8), South Baikal (25.02.1999, M = 5.9-6.1) and Kultuk earthquakes (August 27, 2008, M = 6.3). Starting from the period of 1994–1996, the Main Sayan fault is blocked by GPS data, during this period according to the laser deformograph, until 2001 there is a slight variation in the volume strain, and then from 2001 until the Kultuk earthquake, an accumulation of tensile strain occurs. Obtained with strong earthquakes (M > 6) co-seismic changes of deformations and displacements allow testing dislocation models of earthquakes, which gives additional information to determine the parameters of strong earthquakes: the position of the epicenter, hypocenter, depth, position of the nodal plane and the direction of movement in the earthquake source. An analysis of the areas of anomalous displacements and deformations obtained before the event showed that their sizes correspond to areas of significant co-seismic effects. The accumulation of deformation stretching continued after the 2008 Kultuk earthquake. In recent years, it has been replaced by compression (4·10-7 per year).

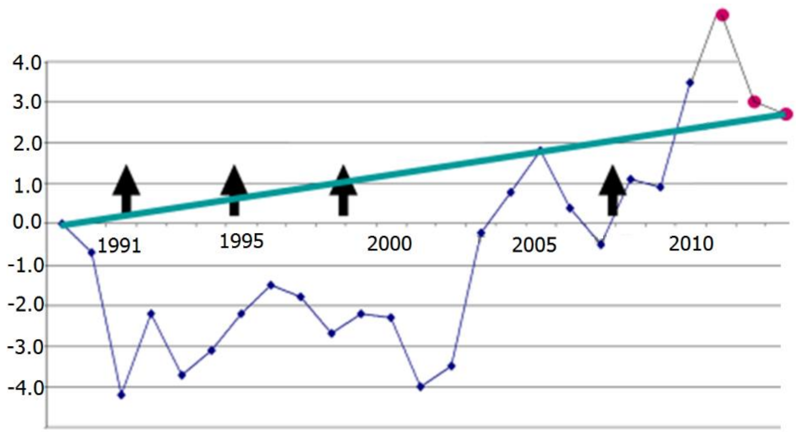

***Figure 14**: The change in volume strain (×106) for the period from 1989 to 2013 (areal deformation is equal to the sum of changes in two orthogonal azimuths; volumetric deformation is equal to areal one multiplied to 2/3); the slope of the middle line is 10-7 per year.*

CONCLUSION

The paper reports about observations of conduct of the deformation processes in the tunnel of the Talaya Observatory using a He-Ne laser measuring device. The current on-line processing of the incoming data of deformographic observations has been completed.

Analysis of laser deformograph records obtained after a catastrophic earthquake in Japan (March 11, 2011, M = 9.1), allowed us to determine the values of the natural oscillation periods of the Earth. In the spectra, frequencies of torsion and spherical oscillations with periods of 57 min are distinguished; 35.5 min.; 25.8 min.; 20 min.; 13.5 min.; 11.8 min.; 9.0 min.; 6.1 min; 4.9 min; 4.2 min.; 3.8 min. and 3.6 min. Different frequency intervals are determined by the properties of different areas of the Earth's interior. It is shown that a laser deformograph can serve as an important part of the instrumental complex for studying the natural oscillations of the Earth. The natural oscillations of Baikal Lake (seiches) are investigated. Using the available digital records of deformations, the spectra for the winter and summer periods of observations were analyzed. The summer frequency spectrum is richer, which may be due to the filtration properties of the ice layer on Lake Baikal in winter. Further, oscillations with a period of seiches of Lake Baikal can be used to build a dynamic model of the lake level, and one should also take into account the presence of these periods in deformograms with further analysis and interpretation.

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THE ROLE OF 3D SEISMIC INTERPRETATION FOR BUILDING STRUCTURAL MODEL – CASE STUDY IN THE MUNTENIA OIL FIELD (ROMANIA)

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ABSTRACT

Geological image which we can build on an oil reservoir plays an important role during its production life, from appraisal phase (seismic works, exploration wells, appraisal wells) to the last stage of reservoir production. The geological image of the reservoir includes four sections: (1) structural schematization in which are defined the shape and external geometry of the reservoir, as well as the accidents (faults, erosions) affecting the reservoir; (2) architectural schematization that is referring to internal geometry of the reservoir, the knowledge of the development of the various sedimentary facieses, the evolution of the reservoir petrophysical parameters in the saturated hydrocarbon zone and in adjacent aquifer; (3) tectonic schematization that is referring to building of a fracturing diagram considering the existing tensions regime inside the reservoir; (4) fluid media referring to the nature of the fluids stored into the reservoir and their distribution. Finally, understanding hydrocarbon accumulation mechanism is one of the key issues that should be solved for effective hydrocarbon production.

Structural schematization it is one of the important phases of the building geological image of the reservoir in which are defined the external geometry of the reservoir as well as the faults that affects the reservoir.

In the paper the authors emphasize the importance of fault characterization and the structure model for an oilfield located in the Eastern Carpathians Foredeep known as Diapir Folds Zone. The Diapir Folds Zone is the most prolific petroleum province in Romania.

The oilfield studied is composed of two main zones: East and West. The east zone is a faulted monocline with oil reservoirs in the Meotian formations of deeper southern flank and shallower northern flank. The exploration of the east structure started in 1835 with the shallow Meotian of the northern flank, and in 1951 with the Meotian of the down-dropped of the southern flank.

The west zone was recently discovered (2011-2012) based on the new 3D seismic interpretation. The main geological formations are Oligocene represented by Kliwa sandstones (complexes I-V). Till now was completed only 2D model, but recently was delivered a 3D model using Schlumberger Petrel software.

Using modeling-while-interpreting capabilities of Petrel seismic interpretations we can easily move from seismic interpretation to structural model building. Integrated work analysis including all 3D geological data developed a new static model.

Keywords: *Diapir Folds Zone, 3D seismic, faults, Petrel static model, 3D modeling, uncertainties*

INTRODUCTION

Reservoir modeling includes the characterization of the internal gridded properties distribution and the simulation of fluid production (oil and water). Nonetheless, the distribution of petrophysical model is often in relation with production data. This, conditioning static modeling to production data is a challenging but essential task to provide reservoir predictions.

The study focuses on the application of 3D static model using 3-D seismic and well log data for proper optimization and development hydrocarbon potential in the oil field X from Romania.

Faults have always been a controversial and difficult topic in petroleum geology, because they control the evolution of basins, but also the essential factors and processes of petroleum system.

The geological conditions of field reservoirs in Muntenia region (fig. 1) special with influence of Diapir Folds Zone are complicated and not easy to be define. [1]

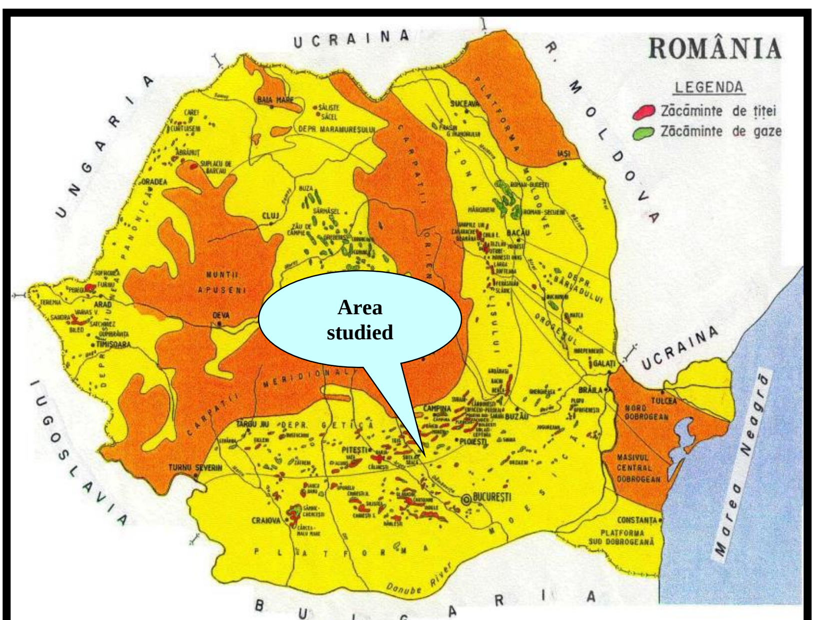

Fig. 1 Map showing location area

GEOLOGIC SETTINGS

The first time when was discover oil and gas accumulation on this area was in 1967 based on one exploration well. After this discovery were decided to do 2D seismic interpretation. Based on several seismic line the new structure looks to have a fault system oriented W-E, but later the 3D seismic will give another face for the fault system.

Wells drilled (145 wells) on the studied structure intercepted a stratigraphic column of sedimentary formations of the last two cycles, also deposits belonging to Paleocene and Neogene. [2]

In this paper will be presented the changes done in structural model for the Oligocene Upper Kliwa. The entire column of Oligocene is around 500 m and is typically met in this area of Romania.

In the current model can be seen stratiform reservoirs, delimited on the vertical by impermeable layers with continuity on the surface. Hence, on the basis of the correlations of well logs and of the vertical distribution of the rock properties, the Upper Kliwa (Oligocene), was divided into five complexes, named from up to down ″KI″, ″KII″, ″KIII″, ″KIV″and ″KV″ (Fig 2).

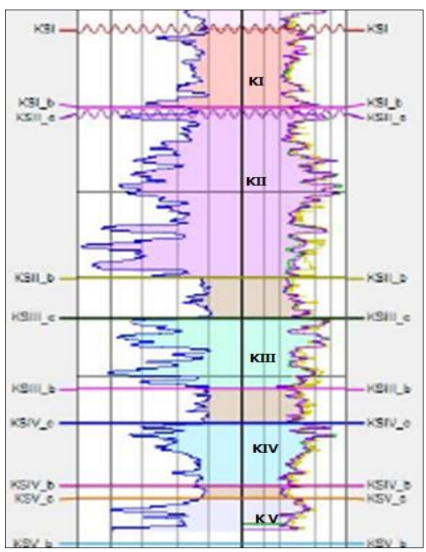

Fig.2 Electric profile showing KI, KII, KIII, KIV, KV

Using the core description, FMI analysis and all existing logs for all 145 wells drilled on this field, the main characteristics of the productive layers have been summarize in table 1.

Table 1. Main characteristics of Upper Kliwa complexes

Layer	Thickness of layer (m)	Lithology description
Upper Kliwa I	30-40	Intercalated sands
Upper Kliwa II	100-120	Sandstones
Upper Kliwa III	30-40	Siliceous sandstones
Upper Kliwa IV	40-50	Shaly sandstones
Upper Kliwa V	30-40	Sandstones

TECTONIC SETTINGS

In the actual study was a challenge for geologist to merge together from tectonic point of view the major zones of the field east area and west area (Fig 3). Based on network wells correlations and using the new 3D seismic information was demonstrated that between west and east area is a strong geological relation .the local tectonic system is comparable with regional fault system. [3]

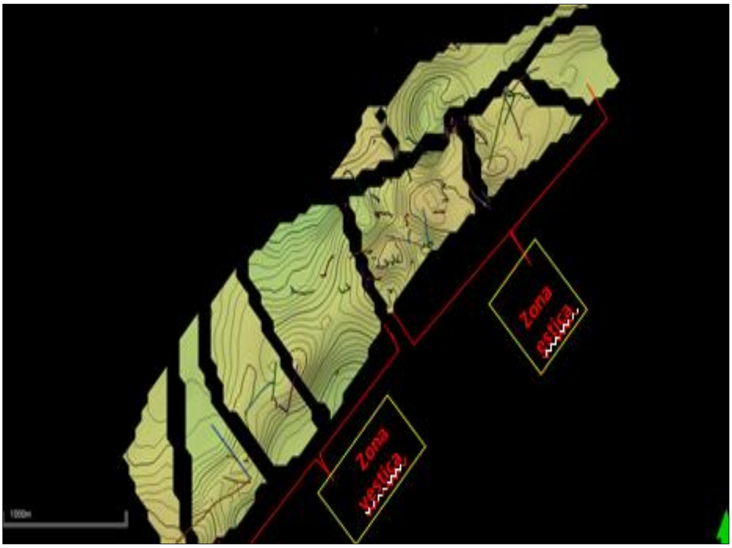

Fig. 3 Major zones for X structure – old interpretation

As a result of the 3D seismic interpretation (Fig. 4) the local geology was changed from previous studies. A new structural image have been created by geologist in order to capture seismic information, well log correlations, production data.

During analysis have met many uncertainties and were included in usual workflow. [5]

All the data, interpretation and uncertainties have been run with Petrel Software. [6]

In the old geological model the fault’s trend was W- E and in the actual interpretation the faults have NE-SW trend.

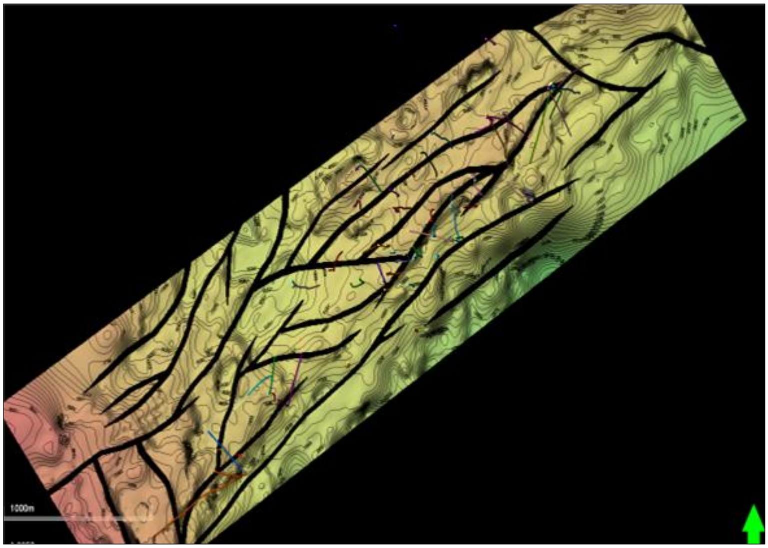

Fig. 4 The new structure surface from 3D seismic – new interpretation

The structure X has a system of longitudinal faults along the NE- SW direction and a system of transversal faults oriented almost perpendicular on the first system .These two fault systems are compartmenting the structure in few tectonic blocks (Fig. 5).

The current structural image of X field has been modified from old images (Fig.3) as a consequence of drilling the new wells. The interpretation of the 3D seismic and the conceptual model built tries to put together in a good agreement all the available data.[4] The recent wells drilled on the western part confirmed the geological model.

The new west area was an area with strong impact in the next future analysis giving the possibility for future drillings.

The west zone was recently discovered based on new drillings and confirmed by the new 3D seismic interpretation.

The entire analysis have been done with Petrel software which help the geologist in including different uncertainties. [5,6]

Using computer modeling to simulate hydrocarbon reservoir behavior is an arduous task. And the static model, especially the fault system, are playing a major role in modeling. It is very important for the geologist to understand his role in manipulating all existing data and to provide the most significant geological model.[7]

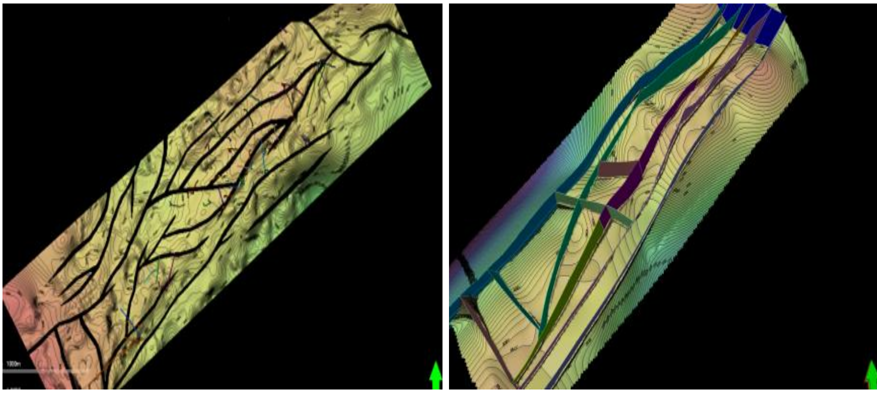

Fig. 5 The new structural image including 3D seismic interpretation

CONCLUSIONS

1. On the X structure, hydrocarbon reservoirs have been found at the level of Oligocene – Upper Kliwa (KI, KII, KIII, KIV, KV).
2. Reservoirs rocks consists of alternating siliceous sandstone and anoxic shale in the Oligocene.
3. The evolution of production, the information obtained by drilling the new wells and the interpretation of the 3D seismic lead to the change of the structural image and the reconsidering of the values of the physical properties.
4. In the actual interpretation the structural model have been changed because of new faults interpretation from 3D.
5. For designing the future production of the reservoir on the X structure, the following were taken into consideration: aspects related to the present displacement drives, current wells, the level of production of the wells by infill/redrill wells including sidetracks.
6. For a better understanding for geological model is very important to have an integrated and multidisciplinary analysis.
7. The need for reservoir simulation stems from the requirement for petroleum engineers to obtain accurate performance predictions for a hydrocarbon reservoir under different operating conditions. Factors contributing to this risk include the complexity of the reservoir.

ACKNOWLEDGEMENTS

The authors are grateful to the integrated multidisciplinary team from OMV Petrom where have developed the field study and providing the original seismic, geological and production data.

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Section

ENERGY AND FUELS

Energy systems, renewable energy sources
Solar and wind technologies
Production, use and management of fuel
Drilling and tomography methods

4D GEOMECHANICS IN INTEGRATION OF ENERGY EVOLUTION, RESERVOIRS AND OIL FORMATIONS AS PER A. EINSTEIN'S FORMULA

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ABSTRACT

The authors present the theory is numerical / analytical method of multi-scaled *4D* geo-mechanics – geo-dynamics of energy integration in geo-physical rhythms of Eigen-solution of Navier-Stokes equations for multi-level geological time space of evolution in structural compacted mass transfer at the basis of Newton's Differential Law $Q'=\rho dS\cdot\partial^2\xi/\partial t^2$ following the integration formula of A. Einstein - $\boldsymbol{E}(\boldsymbol{u},t)=\rho VC^2+\ +\int^V\int^T\rho\langle uv\rangle dtdx$. They establish the geophysical seismic rhythms of geological cycles in deep structural formations of the Volga-Urals and Siberia and Kamchatka at dissipative emission, adsorption and nuclear magnetic resonance. The authors propose the systematic velocity model of convective diffusion drift of $\rho\langle uv\rangle$ in deep phase components of heterogenic structures with complexly structured geology in off-shore and global aeration of Middle Ridges from the Urals to the Rocky Mountains. They have also considered the energy time space of more than 4.5 billion years to find the organic markers of quantum photo-synthesis and multiple circulating energy waves in physical and chemical reactions of compacted formation genesis in fissile and relict shales, including the facies with symmetrical absolutely-saturated porosity of classical fields.

Keywords: *evolution, phase knobs, conductivity, relaxation, basin*

INTRODUCTION

The present-day changing infrastructure of dynamic processes in world economy, social and anthropological processes, ecology and global geological warming forces the scientists to resolve the innovative fundamental problems. We need new conceptual and phenomenological, evolutionary/topological integrated energy models of genesis synthesis and development evolution of the substance from molecules of gas, fluids and phase knobs of reservoir formations in geosphere, anthroposphere up impulse reflection and neurons. It is necessary to create structural models to evaluate geological risks in processes of commissioning and development of compacted shale and low-permeable reservoirs, extra-heavy oil with and natural bitumen, having reserves in energy resources several times higher than the traditional ones. To explore, drill and develop the reservoirs in formations with deep genesis it is required to have *4D* systematic parametrical geo-mechanical solutions in integrated models of fluid dynamics of stress-deformed status of heterogeneous bodies 0. The similar fundamental tasks include the geo-informative modeling of geo-physical synergy rhythms in deep genesis, as a "standard integration of *TOTAL and N+1"* substance.

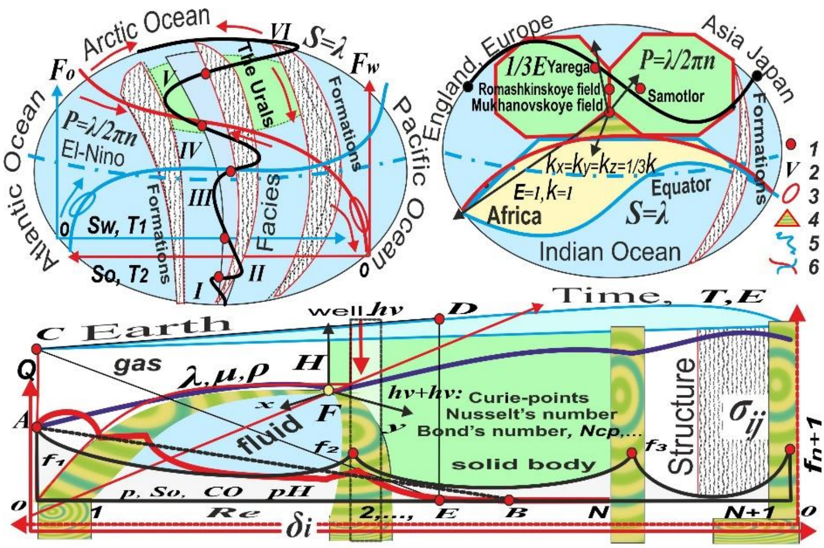

Fig. 1. Heterogenic Stress Stable Phase Diagram of Reservoir Integration Conductivity and evolution of Earth's Geodite Geology

Let's consider the heterogenic stable diagram of evolution-integrated processes of material synthesis and development in view of scales in its molecular-dynamic mobility and define phase permeability in deformed porosity and shale content for heterogenic structure of solid bodies in formations of dispersed condensation, e.g. at well bottom-hole, in well-to-well space and at the facies boundaries (Fig. 1), where 1 – phase knobs, 2 – geological cycles, 3 – nematic phase components, 4 – elements of facies, 5 – longitudinal wave S, 6 – phase permeability; CDE – filtration zones, AB – Darcy law, Q – rate (quality), Re – Reynolds number, CO – concentration of shale contents, phase carbonization and crystalline water, f_i – geo-physical rhythms of contacts, F – additive contacts of geo-physical synergy, p, So – pressure, phase saturation, (1,..,N) – nematic components of seismic emission, hv – integration energy constant, δ_i – sheared layer, fracturing.

APPLIED METHODS

At the basis of mass transfer solution integration in deformed porous media we have defines phase permeability on energy-conducting multi-level reservoirs, and conducted *4D* energy integration of space and time as per A. Einstein's formula

$$\boldsymbol{E}(\boldsymbol{u},t) = \rho VC^2 + \int^V\int^T \rho\langle uv\rangle dtdx \tag{1}$$

Here, correlation $\rho\langle uv\rangle$ of density ρ and pulsing $\langle uv\rangle$ horizontal and vertical velocities 0. The proposed method eliminates Heisenberg's uncertainty principle thus relating energy with time by $\Delta\boldsymbol{E}\Delta t \geq h$ correlation. We followed the structurally compact geo-dynamics of diffusive-porous kinetics in mass transfer according to

Newton's Law ($Q'=\rho dS\partial^2\xi/\partial t^2$) and integrated global synergy of energy subduction in the ocean-off-shore and deep aeration driftage of the continents, Middle Oceanic Ridges of the Urals and the Rock Mountains. We have fixed the boundary harmonic conditions of geo-physical rhythms in synergy of deep structures of the Urals and Siberia (dissipative zones of Fresnel and Poisson spots, absorption of kinetic and potential energy, adsorption and nuclear-magnetic resonance) and have proposed the systematic *4D* petro-physics in integration of multi-scaled repositions and mobility of evolution structural systems 0, including the oil and gas hydro-carbons. We have also obtained the integral correlation of diffusive-molecular dependence in velocities of phase components inside heterogenic stress-stable structures with mineral resource base and region zoning, Fig 2.

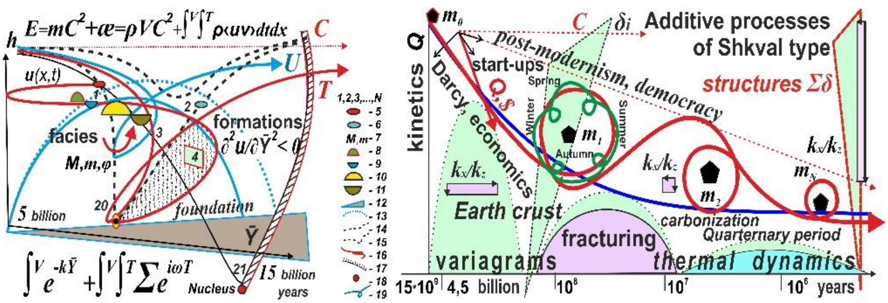

Fig. 2. Multi-scaled Integration Method for Eigen-solutions of Geological Evolution and Additive Procedures Through the use of A. Einstein's Formula

Legend for *1,..,N* – material status, 4 – structure element, *5* – ozone holes ω_0, *6* – Polar lights ω_k, *7* – impulse moments (mass), *8* – Zhiguly dislocation , *9* - facies, 10 – fields (formations), *11* – allochthones of Domanik, *12* - foundation, *13* - stratosphere. Here, *14* – curvature of space; *15* – nematic of phases (regmatic fracturing); *16* – velocity profile (deformation); *17* – the Ural Mountains; *18* – stress-stability regions, *19* - evolution, *20* – nucleus of the Earth, *21* – Poisson points (zones of Fresnel). The authors of the paper propose the method of evolutionary-topological energy physical-hydrodynamic petro-saturation of the profile and the use of multi-scaled многомасштабных self-similar integration solutions as per A. Einstein's. The created geo-dynamic models provide for the complex construction of geo-physical, geological and field studies the similar *3D* grid of stratified pools that contain the information on reservoirs and lithological barriers, fluidal contacts, porosity, permeability, oil- and gas-saturation. To saturate the geological grid with filtration capacity properties they have used various methods of interpolation: stochastic and deterministic, evolutionary-analytical and topological, including stress-stability deformations of geological time space micro-structure, Fig. 2.

ENERGY INTEGRATION OF CONVECTIVE DIFFUSION STRUCTURE

Let's consider the multi-level multi-potential flow of deformed structure with thickness *H*, porosity *m* with minimum velocity u^* and capillary imbibition of scale $l^*=\nu/u^*$, where, ν – kinetic viscosity. At the structure contacts permeable as per Darcy and deformed relaxation time structure there appear the pulsing impulses and pressure. We use structurally compacted kinetics of seismic geo-dynamics for mass transfer of velocity shifts in deep off-shore area and combined compacted – de-compacted aeration of the Ural Mountain Ridge 0. Let's give the additional boundary conditions to geo-physical rhythms of dissipative zones of Fresnel and Poisson points, like absorption structure and nuclear-magnetic relaxation. At the basis of the equations for the deformed porous space we will define the quality of multi-level reservoirs 0, 0.

The task to calculate kinematic and dynamic characteristics of sheared layer that is affected by the pulsing pressure loads is made as follows 0. The system of these equations is resolved as the generalized Hooke's law (Newton)

$$\sigma_{ij,j}=\rho\partial^2\xi_i/\partial t^2;\ \sigma_{ij}=\mu(\xi_{i,j}+\xi_{j,i})+\lambda\delta_{ij}\xi_{i,i} \tag{2}$$

Here, $\sigma_{ii}/3=p$ - pressure, ξ - shifts, λ, μ - Lame's parameters. Viscous-elastic relaxation $\mu(t)=\mu_o+\Sigma^n_{j=1}\mu_j e^{-t/\tau j}$ is described by a relaxation time spectrum τ_j for shear and elasticity modules:

$$\mu(\omega)=\mu_o+\Sigma^n_{j=1}\mu_j(\omega\tau_j)^2/(1+(\omega\tau_j)^2)-i\Sigma^n_{j=1}\mu_j\omega\tau_j/(1+(\omega\tau_j)^2),\ \lambda(\omega)=\lambda_o-2/3(\mu(\omega)+\mu_o), \tag{3}$$

Fluid movement is describes by the equations on conservation of movement numbers by Navier-Stokes and continuity

$$\partial v_i/\partial t+v_jv_{i,j}-\langle v_jv_{i,j}\rangle+v_jU_{i,j}+U_jv_{i,j}=-1/\rho\partial p/\partial x_i+\nu\nabla^2v_i;\ v_{i,i}=0;\ \ vU'_2=u^{*2}+\langle v_1v_2\rangle, \tag{4}$$

Where, $\langle v_jv_{i,j}\rangle=1/4(v_{i,j}v_j^*+v_{i,j}^*v_j)$, *- complex combination, U_i, v_i – mean pulsing velocity. Additional boundary conditions:

$\sigma^{q-1}|_{x2=hq}=\sigma^{q}|_{x2=hq}$, $\xi^{q-1}|_{x2=hq}=\xi^{q}|_{x2=hq}$, $q=1\text{-}N$.

The first layer is stable $\xi|_{x2=0}=0$ or free $\sigma|_{x2=0}=0$, at $\eta=(R_0-x_2)/l^*=0$:

$$u=\partial\xi_1/\partial t-\xi_2U'_y,\ v=\partial\xi_2/\partial t-\xi_1U'_y,\ \partial u/\partial\eta+ikv=\sigma_{12}/\rho u_*^2,\ -p+\partial v/\partial\eta=\sigma_{22}/\rho u_*^2 \tag{5}$$

The differential equations (4) have the solution in a form of progressive waves $F=s(x_2)exp[i(k_1x+k_3z-kCt)]$, where $s=\varphi,\psi$ – longitudinal and transversal waves, k – wave number, C – phase velocity. Neglecting the velocity quadratic pulsing we get

$$v_i(\eta)=a_ie^{-k\eta}+1/k\int G_i(t)\,sh\,ik(\eta-t)dt,\quad p(\eta)=b_oe^{-ik\eta}+1/ik\int G(t)\,sh\,ik(\eta-t)dt \tag{6}$$

In this case the alternating dimensionless values are $G_1=\Theta_1+v_2U'+ik_1p$, $G_2=\Theta_2+p'$, $G_3=\Theta_3+ik_1p$, $\Theta_i=-ikcv_i$, $G=-ik_1U'v_2$, $U'=1+\langle v_1v_2\rangle$, a_i,b_o – are constants. So, we get integral solutions for correlation $\rho\langle uv\rangle$ distributed parameters of multi-potential mass transfer and of front Σ_R, where beside the linear part (as per Darcy) there are the integral components of combined permeability. Combining the mean inflow by Dupuis $U=Q/(2\pi RHmu^*)=ln(\eta/æ)+C_æ$ with convective-diffusive outflow (6) at the boundary of Σ_R, we get $æ=mu^*/RU'(R)$ and $C_æ=U(R)/u^*-ln(R/æ)$. Additive energy boundary Σ_R of zonal-film phase contact and front structure forms the complex combined phase-selective anisotropy of porous outflow permeability

«*3d*-day and *3d*-night» with viscous-elastic conductivity for geo-physical rhythms in compacted matrix.

INTRINSIC TIME SPACE POLARIZATION FORMS

Equation (2), registered in cylindrical system of coordinates, have the form of differential equations of Bessel's type 0. Solutions in the resulted system are registered in a form of longitudinal and transversal waves with complex wave number *k* for the equation of the fourth order*:*

$$\varphi(z_\varphi)=a_1J_o(z_\varphi)+a_2Y_o(z_\varphi);\ \psi(z_\psi)=a_3 J_1(z_\psi)+a_4Y_1(z_\psi) \quad (7)$$

Where, $J_o(z_\varphi)$, $Y_o(z_\varphi)$ *- Bessel's functions,* $z_s=k_sr$, $s=\varphi,\psi$*. Satisfying the boundary conditions we get a system of equations of the fourth order. This result in characteristic equation of intrinsic frequencies in sheared layer (convective-diffusional fracturing* δ_i*)* det $\{A\}=0$**,** *where* $\{A\}$ *– characteristic matrix. Fig. 3, a) presents calculated phase velocities* $c_\phi = c/c_o$ *and attenuation factors* Im(k) *of permeable membrane that depends upon the frequency* $\omega_к=\omega h/c_o$*, where* $c_o=(\mu(3\lambda+2\mu)/(\lambda+\mu)\rho)^{1/2}$*. Practically starting from zero frequency there appear the bending wave that is defines by Young's modulus. When frequency is increasing phase velocity is aiming towards the transversal wave velocity. At intrinsic velocities there are sharp reductions in attenuation factors. At frequency* $\omega_к \sim 1$ *amplitude becomes several times larger than the thickness of sheared layer thus forming powerful transversal outbreaks of seized-up densityu.Anisotropy factor becomes less than* 1*, thus increasing the deformation velocity, especially for heavy shale-fluid and shale formations in overlapping layers and outbreaks of displacing agents during the development process.*

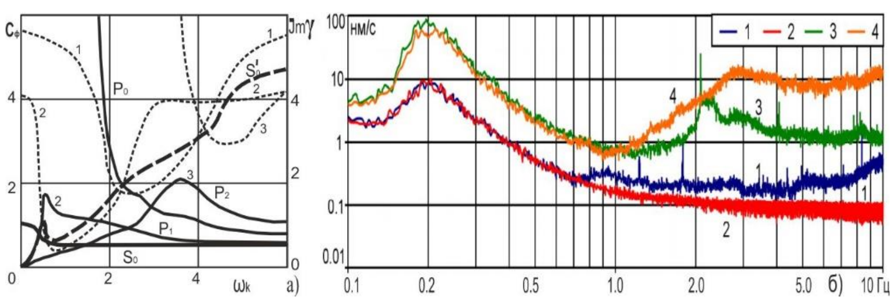

Fig.3. (a) Calculated amplitudes of phase velocities and attenuation factors, longitudinal S and transversal P waves in a layer of dissipative structure and (b) field seismic amplitude-frequency spectrum

With zero shear stresses the diffusion in dissipation equalized by velocity is $\Phi=\omega/4\int i\ \{[\lambda^*(\omega)-\lambda(\omega)]\varepsilon_{ii}\cdot\varepsilon_{ii}^*+[\mu^*(\omega)-\mu(\omega)]\varepsilon_{ij}\cdot\varepsilon_{ij}^*\}dx$, where ε_{ij} - deformation. The same time when the normal stresses are attenuated the tangential stresses are increasing and pressure gradients are re-birthing into tangential stresses. Symmetrical pressure is split into asymmetrical stresses, radial velocity of the mean outflow – into molecular-diffusive pulsing impulses. Anisotropy factor of permeability becomes lesser that *1*. Sheared stresses that coincide in the direction with the mean velocity, i.e. if torque is coinciding with filtration flow direction, they increase the diffusion ‹*p*v› and impregnation velocity ‹uv›. Otherwise thet reduce them thus making displacement front more selective, re-distributive, heterogenic-phase by density and concentration.

Fig. 3, b) presents field amplitude-frequency spectrum obtained at seismic stations (1-4) located within the boundaries of Voronezh crystalline massif at the ancient East-European platform. Studies 0 show that within the frequency range from 0.1 to 0.3 Hz the micro-seismic noise is mainly formed by microseism of de-compacted migration channel that is out-coming from the Atlantic Ocean. The analysis of daily changes in micro-seismic noise within the frequency range from 1.0 to 8.0 Hz had shown that correlation of time variations in micro-seismic noise in this frequency range is allocated to the fact that formation of relatively high-frequency component is affected by the geological structure and anthropogenic load.

RESULTS

Applying the analytical methods of evolutionary integration of geo-physical synergy additive rhythms with geological cycles as per the formula of A. Einstein, we have resolved the problem of global multi-scaled high-amplitude geo-modelling of regional natural mineral resources. Using the example of multi-scaled petro-physics of *4D* heterogenic stability in Terrigenous and Carbonate reservoirs of the Zhiguli dislocation in the Volga-Urals Oil Province 0 for facies element 4 (Fig.1-3), Jurassic fault ridges in Siberia gas pipe formations at Taymyr and Sakhalin, we are presenting the solution in *4D* geo-mechanics of velocity drift. We have obtained the geo-physical field of compacted impulse mass transfer of southern and northern oceanic oscillations and El Nino oceanic stream (evolution as per O.Yu. Schmidt, type of Bessel or Kozyrev beams). The paper presents the multi-scaled dynamic solutions of heterogenic stable structures of geo-physical cells in seismic zones of Fresnel and Poisson points. Here we consider the global process of deep-water ocean off-shore harmonic drifts in view of secondary aeration rhythms of Middle Oceanic Ridges of the Urals and the Rockies with harmonic boundary conditions of compacted time space. Applying the physical and mathematic integration method of additive synergy of geo-physical rhythms with seismic emission of phase components in carbonic reservoir systems in conditions of mass conservation, we get impulse moments and energy in view of gravitational stability constants.

We propose proven innovative evolutionary topological solutions in the development of reservoir qualities by complex tracing of geological evolution. We have used the structural dynamic method of phase conductivity, additive geology of Carbonate evolution covering the period of for more than 4.5 billion years. We have created the stable algorithms of filtration fields in deep genesis porous concentration that is combines with filtration-diffusive matrix and molecular mobility of drift velocity. We have creates and tested the *4D* integral model of «*3d*-day and *3d*-night» geo-mechanics and fluid dynamics of the reservoirs 0, combines with conductivity of katagenesis various stages in maturity, mineral concentration and fracturing of the mountain destruction.

The task with the integration of geological cycle evolutions, deep genesis of time space in complicated systems with mineral material resource location is resolved. Aa a results of synergy in geo-physical rhythms of integration (Fig. 4) with the numerous inverted seismic emission we have created the gravitational models of gas and oil dislocations in the area of global aeration of the Middle Oceanic Ridge in the Urals. Asymmetrical examples of stages in geological evolution like the shifting of the Earth's gravitational nucleus geodite by 500 *km* and the birth of the Moon are additive phenomena of geo-physical synergy.

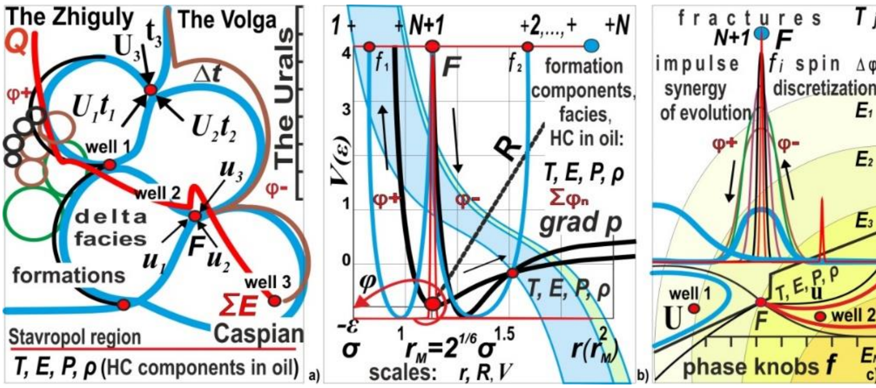

Fig. 4. Zoning of geo-energy fluid-dynamics impulses in evolution and development of heterogenic-phase facies systems of the Urals

CONCLUSION

- We propose the convective-diffusional multi-scaled method of *4D* geo-mechanics in mass-transfer as by Bessel's beam for the integration model of geo-physical zones (by Fresnel and Poisson), geo-spheres as per A. Einstein's formula. There are the proofs verified by the long-time lab and field studies that are numerically tested by evolution-topological intrinsic solutions for geological structure of time space.
- In zones with sheared dislocation there are the areas with emitted significant potential energy, with transition of mechanical energy into thermal energy thus speeding-up the processes of mass transfer. The emitted thermal energy of dynamic processes is in many times activating the processes of vertical and lateral migration, forming abnormally high formation pressures, introduction of water-cut sectors and reservoir traps.
- Dissipative sheared layers are correlated with convective diffusion of capillary jammed phases. Diffusive properties in sheared layers are defining the optimum-resonant character of velocities. In cases with the growth in critical wave number there is the reduction in diffusive and dissipative functions. Blocking the process of mass transfer by a sheared layer increases the residual saturation thus reducing phase displacement.
- Dispersion analysis of intrinsic fluctuations in sheared layer of seismic emission and displacement front had shown that fixed phase jammed layers have

no actual phase velocities and this goes to filtration suppression and attenuation in stagnant sectors.

- We have obtained the solution on fluid dynamics for the structures with many-time inverted core dissolution and destruction. We propose the adaptive compacted packaged models of natural and man-made synthetic reservoirs. We have created an integrated conductivity model for various maturity structures of stages in katagenesis, many-time conversion of dissolution and destruction. We have obtained the energy integration of facies geo-physical synergy in Buzuluk depression and the development of Zhiguli dislocation in the area of the Volga-Urals and the Caspian, as well as for the horsts of Jurassic and Taymyr in Siberia.

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COSTS OF ENERGY LOST DURING THE LNG REGASIFICATION AT ŚWINOUJŚCIE TERMINAL

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ABSTRACT

Nowadays, LNG plays an increasingly important role in the world's energy balance. The traditional natural gas supply model requires transportation via a gas network from the extraction site to the final recipient. This solution is limited by too long distance or large water reservoirs (e.g. an ocean) in between of the manufacturer and the recipient. Given that the largest natural gas deposits are in: Indonesia, Malaysia, Algeria, Qatar, Trinidad and Tobago, Nigeria, Australia, Brunei, Oman and UAE, there is a need for its transportation over long distances. In such cases, the effective transport of natural gas is made possible via its liquifying, accomplished by lowering the temperature to about-161°C. However, it requires LNG export and import terminals to be build. The processes of condensing and regasification of gas are quite energetically and environmentally costly links of LNG supply chain. There are possibilities to minimize them, treating LNG not only as a fuel, but also as a source of low temperature heat. During the LNG regasification, the cold "stored" within is usually released into the environment, which causes a significant loss. The ever-increasing energy prices and an environmental consciousness, have resulted in development and implementation of technical solutions effectively utilizing cold waste from the LNG regasification process in variety of industries. This article presents possible potential for usage of cold waste from LNG regasification process in the Świnoujście terminal and benefits associated. For this purpose, a characteristics of currently used regasification system based on the SCV exchangers was performed, then its energetic analysis followed. A concept of regasification system, in which cold waste is used to supply a cold store, will also be presented. Not only energy aspects resulting from cold recovery from the process were accounted in the following analysis, but also a reduction of environmental impact of the system in question. Basing on carried out research, the cost of energy lost in the LNG regasification process in the Świnoujście terminal was indicated.

Keywords: *LNG, waste cold, efficiency, regasification*

INTRODUCTION

The liquification of natural gas (NG) allows for its efficient transport over long distance since in this state its volume is about 600 times lower than in a gas state. The LNG abbreviation is commonly used for an NG in liquid state. However, to achieve and maintain NG's liquid state, significant energy inputs are necessary. The liquification of NG requires decreasing its temperature to about -162°C in a pressure of 1bar. The amount of heat extracted from NG during this process varies from 600 to 650 kJ/m^3. This value is related to quantity composition of the NG, mainly to the methane content, for which this value is 654 kJ/m^3. To accomplish the supply of liquified gas, an adequate infrastructure is necessary. Generally, at the LNG production plant the facility should provide: liquification of NG, its storage in liquid state and loading on carries. While, at the receiver, the facility should allow unloading, storage and regasification of LNG. The individual steps of the supply of natural gas from extraction to delivery to the final consignee are called the LNG supply chain. This chain remains in almost unchanged form since 1964 [1] and consists of four main cells: The production sector, which includes: mining – locating natural gas deposits, gas extraction and delivery to the export terminal; Export terminal - liquification, storage, loading LNG on carriers; Transport; Import Terminal: receiving, storage and regasification of LNG, deliver NG to final customers.

It is crucial that the individual links of the LNG supply chain have the lowest cost. This has a huge impact on the price of the final product, i.e. its competitiveness. According to the analysis presented at work [2], an average of 41% of the total costs associated with LNG delivery is the cost of its liquification. The remaining links represent 21% of LNG regasification and storage, 20% of transport and 18% of natural gas extraction. Regardless of the technology adopted, the condensing process is the most energy-intensive link in the supply chain. However, when LNG is used not only as a fuel, but also as a source of low-temperature heat (cold), there is a real opportunity to improve the efficiency of the LNG supply chain and consequently to reduce the price of the final product. Cold, which is accumulated in the gas during its liquification, in the process of regasification can be used in cold stores [3], electricity production [4] or other technological processes such as liquification of gases, desalination of water, production of ice for food purposes, etc. [5]. Unfortunately, there is a whole range of regasification systems in operation, where the cold accumulated in LNG remains unused e.g. terminal Świnoujście. The purpose of this article is to assess the potential for exploiting the waste cold from the LNG regasification process in the Świnoujście terminal and the benefits associated with it. The analysis covered energy, economic and environmental impacts.

ENERGY ASPECTS OF THE LNG REGASIFICATION PROCESS

The amount of heat *q* supplied to LNG during the regasification process equals its enthalpy increment. In the lgp-h chart, a straight line coinciding with constant pressure illustrates the transition of LNG from liquid to gas state during regasification (fig.1). As the regasification process usually occurs at supercritical pressures, it is difficult to clearly indicate the moment of transition from the liquid to the gas state. In order to simplify the analysis, LNG was treated as pure methane (CH_4). Then, using the lgp-h charts for methane, the theoretical heat demand in the regasification process was determined.

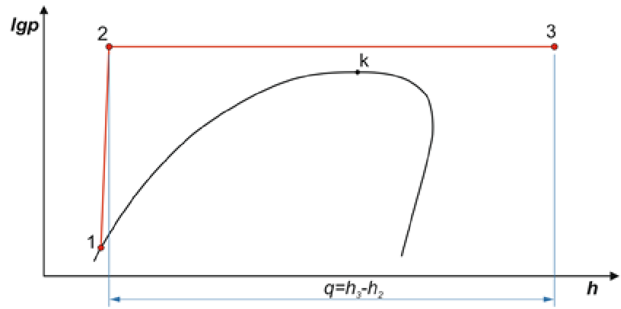

Figure 1. LNG regasification: 1-2 increasing of LNG pressure, 2-3 – regasification

The calculations were carried out assuming that the initial temperature of saturated LNG is -162 °C and the final temperature of gas, after the regasification process is 5°C. Pressure has a great impact on the amount of heat, which has to be supplied to LNG during regasification. Increasing of the LNG pressure before regasification (to one dictated by parameters of the network) is justified energetically and economically. For the gas to be compressed to pressure required by the pipeline after regasification, the required power would be very high: the ratio of the pumping power needs of NG to the needs of LNG is greater than 20 [4]. In figure 2, the heat demand in the regasification process depending on the pressure in which the process occurs is presented.

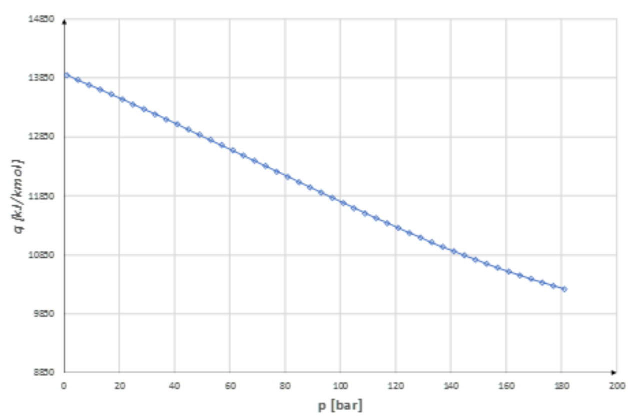

Figure 2. Specific heat supplied to LNG during regasification depending on the pressure

According to figure 2, the higher the pressure, the less heat should be supplied during the regasification process, meaning less waste cold will be available from this process. Thus, in systems where cold recovery is planned, the process should be preferably carried out at the lowest possible pressures, opposed to systems without cold recovery. For example, at a pressure of 120 bar, the heat suppled to the LNG is approximately 11350 kJ/kmol, while at a pressure of 80 bar this value is about 12176 kJ/kmol. Therefore, in the second case for each kmol of regasified gas, about 826 kJ more heat should be delivered (that is, so much more cold will be available for regasification). In a situation where heat for regasification is produced e.g. as a result of gas combustion, these are already considerable differences. Even more so, the efficiency of regasification systems is counted in billions of cubic meters. To thoroughly analyse the problem, the power of the pumps should also be considered.

When considering the thermal parameters in which the regasification process is carried out, the temperature should also be paid attention. As has been demonstrated in many times, the more heat source temperature differs from the ambient temperature the higher its usable energy potential, which can be seen introducing the concept of degree of heat value, $\frac{T-T_o}{T}$. [6], defined as:

$$\frac{T-T_o}{T} = \frac{-\Delta B_{zr}}{Q} \tag{1}$$

Where: T-the absolute temperature of the heat source, T_o - the ambient temperature,
($-\Delta B_{zr}$) – The decrease of heat source Egzegy, Q – The amount of heat given by this source.

Most generally, the degree of heat value expresses an egzergia relative to the unit of heat and can be considered as a measure of the technical-economic value of heat. Figure 2 shows the graphical interpretation of this indicator in the temperature function.

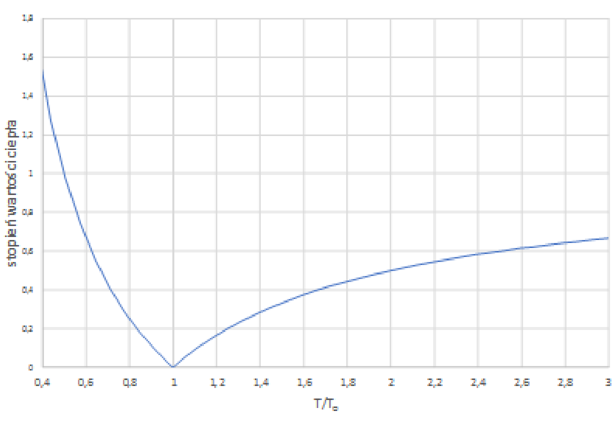

Figure 2. Degree of heat value [6]

Figure 2 shows that, as the ambient temperature approaches, the degree of heat value decreases rapidly to zero. In the temperature range of 0.67 < T/To < 2 The degree of heat value is less than 0.5. The lower the temperature of the heat source, the degree of heat value gets higher values. Therefore, it is justified to treat LNG not only as a fuel, but also as a source of low-temperature heat. And the heat stream fed to LNG during regasification as a potential profit and not a loss.

LNG REGASIFICATION AT THE TERMINAL ŚWINOUJŚCIE

LNG terminal in Świnoujście is able to provide the efficiency of regasification at the level of 75 000 Nm^3/h up to 656 000 Nm^3/h (nominally: 570 000 Nm^3/h). Figure 3 shows the terminal blueprint.

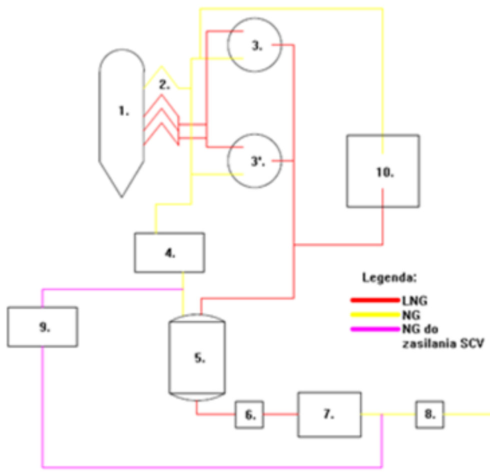

Figure 3. Terminal blueprint: 1– LNG carriers, 2– handlers, 3– storage tank nr 1, 3'– storage tank nr 2, 4– compressor BOG, 5– condenser BOG, 6 – high pressure pump, 7– SCV heat exchangers, 8– measurement station, 9- NG station [7]

When operating at maximum regasification capacity (656 000 Nm^3/h), the LNG flow rate is 1150 m^3/h. The Pressure at pumps reaches 84 barg, which corresponds to the pressure required by the NG gas pipeline. Once the pressure is reached, LNG is routed to the evaporators. The LNG Terminal in Świnoujście has five SCV (Submerged Combustion vaporizer) type evaporators with a nominal power of 27.5 MW each. During normal operation, four SCV Evaporators are operating and one remains at ready. In SCV type evaporators, the heat necessary for regasification comes from the combustion process of the gaseous fuel, which is a specially prepared NG. NG preparation for combustion in the SCV consists in cleaning, normalizing its pressure and temperature to the required values: 5 barg and 5°C. Such prepared fuel is burned in a special compartment using the air provided by fans. At the evaporator outlet, the temperature sensor measures NG temperature and sets the corresponding fuel pump output to the evaporator torch nozzles accordingly. Gases from the combustion process heat a water bath, in which stainless steel heat exchanger tubes are immersed. In these tubes, the flowing LNG is subjected to a regasification process.

In addition, the SCV is equipped with two electric heaters, which serve to maintain the water bath temperature above 5 °C, especially during the winter. Carbon dioxide from the combustion process causes the acidification of water in the evaporator. To maintain a neutral pH of the bath, an alkalizating caustic soda is put into the water. There is no need to replenish water in the evaporator, because the steam vapor in the combustion process liquifies and replenishes resulting deficiencies. Excess water is removed by overflow pipes and routed to the treatment unit. After leaving the vaporizers, natural gas is directed to the measurement station. Here the amount of gas transmitted and its parameters is assessed.

Maximum efficiency of the regasification system in the Świnoujście terminal is 570 000 Nm^3/h. Considering the efficiency of regasification given in units of Nm3/h is for normal conditions (i.e. p_n = 1.01 bar, T_n = 273,15 K), as well by adopting the temperature and Gas pressure after regasification (i.e. T = 275,15 °C, p = 85 bar), the regasification capacity in units of m3/h can be calculated. For this purpose, the Clapeyron equation should be used, treating methane as a perfect gas:

$$\frac{p_{\mathrm{n}}\dot{V}_{\mathrm{n}}}{T_{\mathrm{n}}} = \frac{\mathrm{p}\dot{V}_{NG}}{\mathrm{T}} \tag{2}$$

Hence, the LNG mass flow rate, counted at the output to the SCV:

$$\dot{m} = \dot{V}_{NG} \cdot \rho \tag{3}$$

As already mentioned, during the regasification, which takes place at a constant pressure of 85 bar, LNG is experiencing a temperature rise from about 113.15 K to 275.15 K. Using the REFPROP the enthalpy values at the beginning and end of the process was established. By introducing the mass flux of the working fluid to the equation (1), a dependence allowing to determine the heat flux brought to the LNG during the transition from the liquid state into the gas. The mass flow rate of the regasified gas is determined by the LNG volume flow rate. Table 1 shows the results of the calculation.

Table 1 Results of the calculation

$\dot{V}_{LNG}$ [m^3/h]	$\dot{V}_{NG}$ [m^3/h]	$\dot{m}$ [kg/h]	Δh [kJ/kg]	$\dot{Q}$ [MW]
1160	6 822	498 365	738,52	102

As the current form, at the Świnoujście terminal, the heat necessary for LNG regasification is produced by burning NG fuel. Basing on available data, it is possible to approximately determine the fuel stream which is burned in SVC heat exchangers. The energy balance of the heat exchanger, with certain simplification assumptions, can be saved as:

$$\dot{v}_f \cdot W_f \cdot \eta = \dot{V}_{LNG} \cdot \rho \cdot \int_{T_{in}}^{T_{out}} c_p dT \tag{4}$$

where: $\dot{v}_f$ - fuel gas flux [m^3/s], W_f - calorific value of fuel gas [J/m^3], η – efficiency of SCV exchanger [-],$\dot{V}_{LNG}$- vaporization capacity of the SCV [m^3/s], ϱ – density [kg/m^3], c_p – specific heat of LNG (NG) [J/kgK], T_{in}, T_{out} – inlet and outlet temperature of LNG respectively [K].

The energy value of W_f fuel gas was assumed to be 32 MJ/m^3 and the efficiency of the SCV exchanger at the level of η = 0.95 [8]. Hence, determined by the equation (4), the estimated unit fuel consumption in the regasification process is 0.024m^3/kglng. assuming that the annual quantity of the regasified gas on the terminal is 3000000000m^3, the fuel consumed as a supply for SCV exchangers is

63 721 072 m^3/year. With the price of gas for the Polish markets at the level of 2 zł/m^3, the cost of the fuel itself to supply the SCV exchangers is 127 442 145 zł/year. Therefore, we lose not only a lot of cold but we also pay a high price.

POTENTIAL USAGE COLD

An interesting solution for waste cold from the regasification process in the LNG terminal in Świnoujście usage is a generation of electricity that could be used for internal terminal or to power external objects e.g. Container terminal. The electricity produced could, for example, serve For the supply of refrigerated containers (according to the design, the terminal will have 584 connections for refrigerated containers). Assuming that the consumption of electricity by a single container is at 6 kw, total electricity demand for refrigerated containers would be around 3.5 MW. In the literature there is a large number of publications on this issue [4], [9], [10], [11]. Nevertheless, in this article, the main attention has been driven to the use of waste cold for purposes of refrigeration, cryogenics or air conditioning. Important factor of this possibility is locating customers with direct use of waste cold in close proximity to the Regasification station, ie. up to 2 km. The Transport of cold at considerable distances would entail large losses of cold, significant energy inputs which leads to a decline in the cost-effectiveness of the process. The objects in Świnoujście area that meet the distance requirement are: fish processing plant; Fishing harbor; Meat processing and vacuum packaging company.

Assuming that in the vicinity of the terminal Świnoujście is a cold store with a nominal cooling capacity of 2 MW. The refrigeration system is a typical compressor system, with R717 as a working factor. The storage temperatures of the products in the Chambers are maintained at three levels: freezing chamber-20°C, dry chamber 0°C and positive chamber 5°C. With some approximation, it can be assumed that the cooling efficiency coefficient of such systems is approx. 2, then the electric power needed to drive the refrigeration compressors and other refrigeration equipment would be about 1000kw. Assuming that the cold store is working 365 days a year, on average 15 hours/day, the annual energy consumption would be 5 475 000 kWh, which at the price of electricity at 0.6 PLN/kwh gives the cost of Operation of 2 628 000 zł/year. Most power plants in Poland use coal as fuel. The Calorific value of hard coal is 21.34 MJ/kg. The efficiency of a coal power plant maxes at 45%. Therefore, in order to produce 1 MWh of electricity, almost 245 kg of hard coal is needed. The CO_2 emission factor for coal is 93.80 kgCO2/GJ [12]. Thus, as a result of refrigerated operation, CO_2 emissions to the atmosphere will be 1848.8 kgCO_2/year. Using cold waste from the regasification process to supply cold stores could save not money only, but above all could take care of the environment by reducing greenhouse gas emissions into the atmosphere.

The cold from the process of regasification can also be accumulated in the so-called cold-tanks (cold accumulators) made of PCM materials. This solution allows to offset the use of cold in time and space. Namely, charged accumulators (made of suitable PCM material), can be used as a source of cold for air conditioning systems in nearby hotels or pensions. The environmental cost of the air conditioning system equipped with cold accumulators will certainly be incomparably smaller than in a typical compressor refrigeration unit. Cold accumulators can be also used for an air conditioning of large-size stores or storage cooling systems. There is also a possibility of direct regasification cold usage for air conditioning purposes. Although the Hotel center is far away from the terminal and the installation of suitable installations could be difficult, still it is not impossible. Such a network would have to be treated like a district heating network then, and a terminal like a CHP, except in that case gas and usable cold would be considered as terminal products.

CONCLUSION

In case of a classical regasification station, the whole "cold" is lost: it is released into the environment. Taking the cold waste available from the regasification process into account, as well as existing solutions for the use of this cold, this potential is worth considering in construction of new terminals. LNG Terminal working with the use of waste cold from the regasification process for refrigeration or electricity production would attract entrepreneurs. They would be able to expand their investments near the LNG terminal. Due to the fact that LNG terminals operate in the immediate vicinity of seas and oceans, this would be an investment primarily from the maritime sector. For example, construction of a cold store in Swinoujscie, which would be fed by the waste-heat could result in a rebirth of Polish fishing on a large scale. The container terminal which is being built in Świnoujście could benefit from the use of electricity produced by using cold waste.

At the same time, it should be noted that the implementation of a regasification plant with the use of cold waste does not eliminate the need to equip the terminal with a classic solution. This is due to the significantly lower regasification performance of the described solutions in relation to the currently used installations. However, the cost of construction of a terminal equipped with two different branches of regasification (including the use of cold waste) would be little higher than the cost of constructing a classical terminal with the same efficiency of regasification. Any price difference could be reimbursed by the sale of "cold". The ecological and financial aspect of the regasification plant with the use of cold waste is also the reason for further development. The use of cold will result in an even lower environmental impact of the LNG by using waste energy. Electricity or cold storage would have a competitive price compared to the current classic supply solutions for these media. Further developing this branch of the LNG industry is well worthy, as natural gas is slowly pushing out oil and coal. In a couple of years, natural gas will be used not only for the supply of domestic gas installations, but it becomes even more popular as a propellant. Then re-gasification stations will have enormous regasification capacities, and the amount of cold waste available from this process will continue to grow.

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DEVELOPMENT OF MAIN MARINE BOILERS' STRUCTURES

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ABSTRACT

Based on the literature sources, the paper presents an analysis of the structural solutions for marine main boilers aimed at their efficiency improvement. A particular attention has been paid to the utilization of waste heat from exhaust gas exiting the boilers. Using the technical documentation and the operational tests results, the characteristic values and technical parameters have been determined: the parameters and volume of generated steam, efficiency and performance subject to the fuel type, unit fuel consumption.

Keywords: *marine main boilers, construction, technical parameters, waste heat recovery*

INTRODUCTION

Steam ship propulsion system was developed in the middle of 19th century. Initially, piston steam engines were used as main and auxiliary engines. They were fed with saturated steam while in the 20th century, steam superheated up to 250 ^{0}C and of the pressure up to 2MPa, was used. For the purpose of generating the said steam, flame tube-smoke tube boilers were installed. They characterize with large dimensions and weight due to a large water capacity and low efficiency in the range from 70% to 75%. As the breakthrough, the use of steam turbines as propelling devices for the main and auxiliary engines is considered. This situation took place at the turn of the 19th and 20th centuries. Among the factors affecting the efficiency and performance of the steam turbine are the parameters of the steam fed. Along with the steam pressure and superheat temperature increase, the steam turbine performance is higher. Generating steam of high parameters required to create a new design of main boilers. As a result, water tube boilers were developed and they have been used up-to-day. They are equipped with steam-water drum and water drum. Due to that, for the first time, a directed circulation of water and wet steam was employed. It significantly improved the heat exchange process. Along with the development of metallurgy, the materials used thereby characterize with increased resistance to high temperatures, which enables to obtain higher superheat temperature. New-structured boilers characterized with the efficiency in the range of 82-84% [4].

Changing parameters of steam generated in main boilers, from the last 70 years, are shown in Figure 1. As it may be noticed on the figure, the highest increase of working pressure and temperature of the steam occurred in the years 1950-1960. During this decade the steam pressure increased from 3 to 6 MPa, and the temperature of superheated steam from 400 ^{0}C to 500 ^{0}C. The intention to increase the marine steam turbine power systems resulted in further improvement of generated steam parameters.

In the mid-1990s, the steam pressure generated in marine boilers increased to

6 -7 MPa, and the superheating temperature to 525 ^{0}C. The experimental marine steam turbine power systems are equipped with steam boilers producing steam at a pressure of 10-12 MPa and a superheat temperature of 560 ^{0}C.

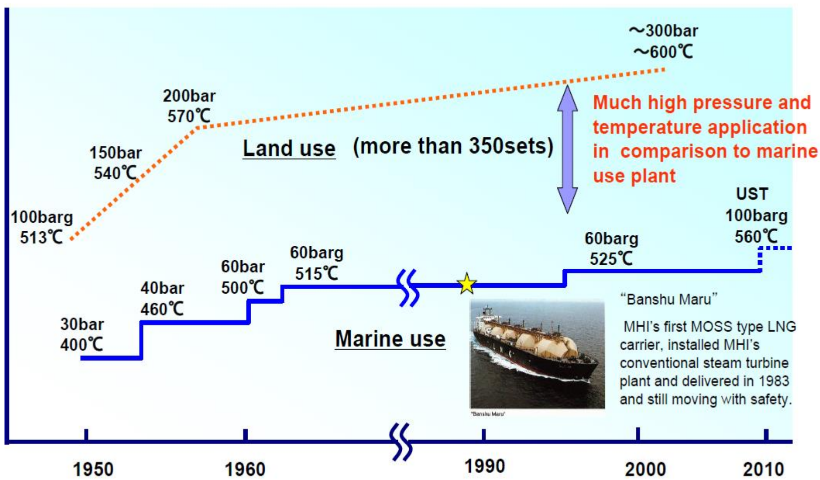

Fig.1. Evolution of steam operating parameters in marine and land use [3], [6].

When compared with the land steam boilers used by the energy industry, the parameters of the steam generated by marine boilers (Fig.1.) are much lower. It is mainly due to the fact that the marine boilers operate in unstable conditions (storms, vibrations). Other reasons for that situation may be considered as often changes to the requirement for steam, a limited number of boiler operators, reduced velocity of natural circulation along with increasing pressure, rising boilers' weight accompanied by increasing pressure, higher purchase cost of materials used to construct a boiler along with an increase of superheat temperature. Steam turbine power systems were widely used between 1960 and 2005 on high load capacity ships with large demand for power (tankers, passengers' ships, LNG ships). The power at those ships, in the range from 20 to 50 MW, might have been generated only by steam turbines as there were no internal combustion engines of that power.

The development of the diesel engines, increase of their power, engagement of dual fuel engines have resulted in lower number of ships being equipped with a steam propulsion system. Currently, orders for only 10% of the constructed LNG tankers include the requirement of having steam propulsion system installed [1]. The main reason for such a situation is a low performance of the steam systems which equals from 36% to 38% and which is significantly lower than the efficiency of the modern combustion systems. The latter one's performance is higher than 50%. The intention to improve the efficiency resulted in the development of experimental steam turbine power systems e.g. Ultra Steam Turbine (UST) Plant. The parameters of the plant are presented in Figure 1. Apart from improving the steam parameters, inter-stage steam superheating and carnotization of the power cycle, new structures of boilers were implemented. Due to the said structures, natural circulation velocity increased along with the waste heat utilization. The system performance increased up to 40 % [3].

Based on the literature sources, vessel technical documentation, operational tests results, the author has presented in the paper an analysis of the structural solutions for marine main boilers and their technical and operational parameters. The discussion below refers to the main boilers produced by Mitsubishi, Kawasaki, Greens Power, Combustion Engineering.

NATURAL CIRCULATION

Providing natural circulation of the highest possible velocity is one of the major tasks of steam boilers' designers. An increase in the water flow rate results in increased convective heat transfer coefficient but, simultaneously, increases the flow resistance in water tubes, which should be taken into consideration during the selection of boiler tubes' diameter.

A scheme showing the natural circulation in a water-tube boiler presents Figure 2.

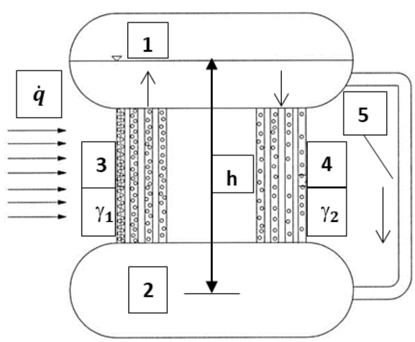

Fig.2. Natural circulation in a steam boiler.

1-steam-water drum, 2-water drum, 3-riser tubes, 4-downcomer tubes, 5-downcomer water tube, γ_1,γ_2-wet steam specific weight, h-distance between drums, q-heat flux.

Source: Authors' elaboration.

The figure above presents a system where a steam-water drum (1) and a water drum (2) are connected by boiler tubes (3 and 4). When heating the boiler tubes with a heat flux (q), the heat will be more intensively exchanged on tubes 3 where wet steam is generated. The steam is of higher dryness degree than the wet steam generated in tubes 4. Due to differences in the wet steam specific weight, hydraulic pressure occurs and triggers the natural circulation in the boiler. The wet steam will flow up the tubes 3, while in tubes 4 water, and then wet steam, flows downwards. Therefore, tubes 3 are called riser tubes and tubes 4 are named downcomer tubes.

The hydraulic pressure affecting the natural circulation velocity may be determined using formula 1 [7]:

$$H = h(\gamma_2 - \gamma_1) \quad [N/m^2] \qquad (1)$$

H – hydraulic pressure [N/m^2]
h – distance between drums [m]
γ_1 – minimum value of wet steam specific weight [kg/m^3]
γ_2 - maximum value of wet steam specific weight [kg/m^3]

The hydraulic pressure depends on the distance (h) between the drums and the difference between the specific weights (γ_1 and γ_2) of wet steam in riser tubes and downcomer tubes. At every volume of generated steam, the maximum circulation velocity is obtained when γ_2 is of the maximum value, which means that there is water in the tubes. This is a result of using downcomer tubes 5 (Fig. 2.) connecting steam-water drum and a water drum, which have no contact with exhaust gas. The downcomer water tubes' diameter in modern boilers is up to 300mm [5], [7]. Given increased flow resistance in downcomer tubes caused by countercurrent flow of steam bubbles, the diameter of downcomer tubes used in the boilers is greater compared to riser tubes.

The performed analyzes and numerical simulations have shown that for marine boilers, effective heat exchange associated with natural circulation occurs for working pressure below7 MPa [5], [7]. Hence, for a majority of main boilers, the working pressure values are in the range from 6 to 7 MPa.

In experimental marine steam turbine power systems, higher working pressure was employed and it equaled from 10 to 12 MPa. The natural circulation performance was provided by larger distance between the drums. It resulted in increased boilers' height and in the need to extend the boilers' room and its proper location in the hull. A second method that may be applied is removing the water drum and replacing it with a manifold. A scheme of a boiler with water manifold is presented in Figure 3.

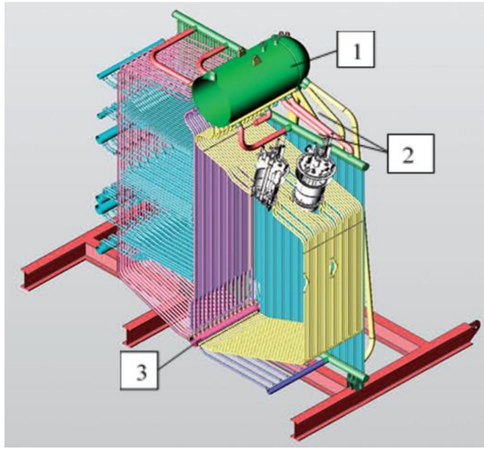

Fig.3. Greens Power boiler, ESD IV [8].
1– water–steam drum; 2 – downcomer water tubes; 3 – water collector

A water collector (3) organizes and directs natural circulation in opposition to the up-to-date used water drum, where wet steam is transported by downcomer tubes to a large volume room. It disturbs the flow and results in higher flow resistance.

WASTE HEAT UTILIZATION

In case of marine boilers, we should consider waste heat in the exhaust gas and radiant heat. If there is no waste heat recovery system installed, the exhaust gas temperature after the boiler shall equal from 340 to 400 ^{0}C, and exhaust loss shall be 15% -18% [5], [7].

In the modern solutions for marine main boilers, waste heat in the exhaust gas is used to heat water feeding the boiler and/or the air used for the combustion process. The heat exchange surface and the heating temperature are established so that the temperature of exhaust gas discharged from the boiler (depending on the Sulphur content in the liquid fuel) equaled from 130 ^{0}C to 160 ^{0}C [7]. Certain boilers' designs include using radiant heat for the purpose of heating the air. The air absorbs the heat from the boiler shell when flowing through special chambers.

Examples of options for waste heat recovery in marine main boilers are shown in Figure 4.

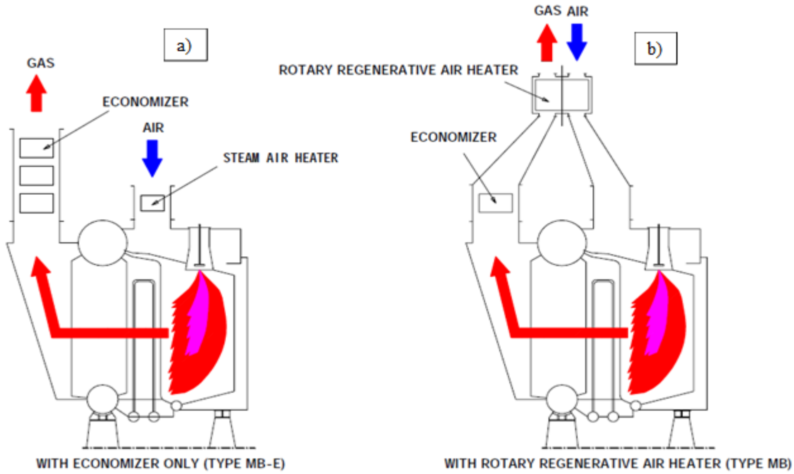

Fig.4. Options of waste heat utilization for MB boiler of Mitsubishi: a) multistage water heater b) water and air heater. [3], [6]

In case of MB boilers of Mitsubishi, two methods of exhaust gas waste heat utilization have been proposed. The first method (Fig. 4a) includes using total available waste heat to heat water feeding the boiler in a multistage water heater. For the purpose of heating the air, a heat exchanger fed with saturated steam of the pressure from 0.6 to 2.0 MPa were assembled. [3], [6]. The second method (Fig. 4b) consists in the dividing the waste heat for the purpose of heating both the water feeding the boiler and the air needed in the combustion process

DISCUSSION

The collected data and the performed analysis constituted the grounds for drawing up Table 1. It includes the basic technical and operational parameters of selected marine main boilers.

Table1 Basic technical parameters of selected marine main boilers [3], [6], [8], [9], [10]

Producer	Boiler type	Steaming rate range	Steam parameters		Temp. of air to be combusted	Feed water temp.	Boiler performance
			Pressure	Temp.			
		D [t/h]	p [MPa]	t [°C]	t_p [°C]	t_w [°C]	η [%]
Mitsubishi	MB	23-75	6,15	515	150	210	90,0
	MB-E	15-70	6,15	515	120	138	88,5
	MBR	40-70	10	560	120	138	88,5
Kawasaki	UM	47-143	6,1	525	155	205	90,0
	UME	47-143	6,1	525	130	145	88,5
	UFR	50-140	10,3	525	130	195	90,2

	UTR-II	35-100	12	565	133	229	90,2
Greens Power	ESDIV	36-65	6,2	515	165	180	91,3
Combustion Engineering	V2M8	30-85	6,2	515	290	183	89,4
	V2M9	60-140	6,6	515	200	190	90,0

The variation range for the main boilers' performance, at the minimum volume of generated steam, equals from 88.5% to 91.3%. The highest performance at the level of 91.3% is reached by ESD IV boiler despite the low use of waste heat. The reason for this state of affairs is replacing the water drum with a water distribution system (Fig. 3) which resulted in improved performance of the natural circulation and hence better heat exchange. Boilers of higher steam working pressure (10-12 MPa) and of the superheated steam temperature equaled to 560 ^{0}C and 565 ^{0}C, achieve high efficiency of 90%, except for the MBR boiler. Its performance at the working pressure of 10 MPa equals to 88.5%. This is a result of secondary steam superheating in MBR boiler in an additional heater equipped with a combustion chamber with its own burner. That means that an suitable amount of fuel is combusted in order to obtain the temperature of steam re-superheated equaled to the temperature of primary steam one (560 ^{0}C). Due to exhaust gas waste heat, it I possible to heat water feeding the boiler to the temperature from 138 ^{0}C to 229 ^{0}C and the air to the temperature from 120 ^{0}C to 290 ^{0}C. It should be noted that the waste heat volume, that is available, is used to heat two media namely water and air. It means that it is necessary to select the medium that would reach the higher heating temperature. For example, at the maximum heating temperature of 290 ^{0}C, the temperature of feeding water equals to 183 ^{0}C, while at the maximum water temperature of 229 ^{0}C, the air temperature shall reach 133 ^{0}C.

The relation between the applied method and the exhaust gas temperature after the boiler and the exhaust loss value is presented in Table 2.

Table 2. Relation between the applied method and the exhaust gas temperature after the boiler and the exhaust loss [2,4,5,7]

Use of waste heat	Exhaust gas temp. after boiler	Exhaust loss
	t_s [^{0}C]	S_w [%]
No use	340-400	15-18
Heating water	200-230	10-12
Heating water and air	130-160	5-6

During the analysis of data included in Table 2, it may be noted that along with increased use of exhaust gas waste heat, the exhaust gas temperature is decreasing after the boiler. It contributes to the drop in the value of the highest boiler loss, namely exhaust loss. When compared with boilers where no waste heat was used, the loss value is 3 times lower.

As the analysis and tests proved [2], [4], [7], if the temperature of water feeding the boiler increases by 10 K, at constant fuel consumption, the generated steam volume will increase by 2%-2.5%.

If feeding water is heated in an atmospheric degasser and the air is removed, it should be noted that its temperature, before an internal combustion heater, equals to

100 ^{0}C. Hence, heating water in that heat exchanger up to the maximum applicable temperature of 229 ^{0}C (Table 1), shall result in increased volume of generated saturated steam by ca. 25%. In contrast, the increase of 100 K of the air temperature, required for the combustion process, results in an increase of the combustion temperature by 70 K. This causes that the amount of heat absorbed in the boiler is higher [7]. A steam boiler performance is also affected by the type of used fuel.

The varied efficiency of a selected boiler, fed with liquid and gas fuel, is shown in Figure 4.

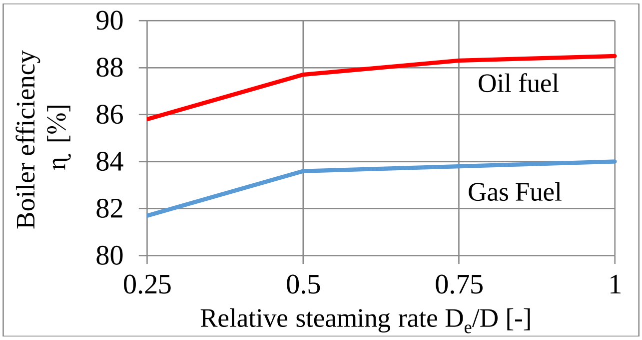

Fig.4. MB-E boiler efficiency in relations to the type of fuel and generated steam volume. Source: Authors' elaboration.

Analyzing the course of the curves in Fig. 4, it can be stated that the efficiency of the boiler depends to a large extent on the type of fuel. In the case of using gas as a fuel, the efficiency of the boiler is lower by about 4.5% in the whole range of the analyzed relative steaming rate, compared to the efficiency of the boiler fueled with liquid fuel. This situation is caused by different values of air required for the combustion process and the excess air ratio supplied to the boiler's combustion chamber. In order to calculate combustion processes and heat exchange in the boiler, the heating value of the liquid fuel is assumed to be equal to WO = 43 MJ / kg and in terms of gas WG = 55 MJ / kg [5], [7]. Analysis of stoichiometric combustion processes, after taking into account the calorific values of both fuels, showed that the theoretical amount of air required is about 40% higher than in the case of combusting liquid fuel. In addition, the recommended air-fuel ratio is 0.1 higher for gas combustion. That means a further increase in the actual amount of air supplied to the combustion chamber of a gas-fired boiler. Taking into account the heat balance of the combustion process, it should be stated that the increasing amount of air supplied, that does not participate in the combustion process, reduces the combustion temperature, and thus the amount of heat available for the heat exchange processes in the boiler also decreases. Literature sources show that a change in the value of the air-fuel ratio by 0.1 affects the combustion temperature by 100 K [5], [7].

CONCLUSION

- Modern marine boilers should be considered as highly efficient power plants (88.5%-91.3%) in a wide range of generated steam volume (25%-100%). Such high efficiency was achieved due to the recovery of heat contained in the exhaust gas;
- The advantage of boilers is the possibility of feeding them with liquid fuel and gas in any proportions. The gas supply system is characterized by a simple construction and low gas parameters (pressure 0.3-4,0 MPa and temperature 40 ^{0}C [3,6]). Therefore, steam turbine power systems are used mainly on LNG vessels, where gas for feeding boilers is supplied directly from cargo tanks. Modern dual-fuel combustion engines also enable gas combustion. However, for high-power low-speed engines, much higher parameters are required (pressure equaled from 200 MPa to 250 MPa and temperature of 40 ^{0}C). It is also necessary to construct an additional gas fuel system with cryogenic liquid gas tanks, pumps, heat exchangers and compressors;
- It has been proved that gas-fired boilers operate with a 4.5% lower efficiency, which will affect the efficiency of the steam turbine power system. The advantages of gas as a fuel include: the use of naturally evaporated gas, the lack of post-catalytic products used in the process of processing of crude oil causing high-temperature corrosion, higher combustion quality resulting in reduced loss of incomplete combustion. Therefore, less sludge accumulates on the heat exchange surface and the volume of emitted harmful exhaust components is reduced;
- Further boiler structure development will be directed to and focused on improving the efficiency of natural circulation and heat exchange efficiency.

ACKNOWLEDGEMENTS

This research outcome has been achieved under the research project no. 2/S/IESO/2018 financed from a subsidy of the Polish Ministry of Science and Higher Educations for statutory activities of Maritime University of Szczecin.

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ENERGETIC OPTIMIZATION AND ENVIRONMENTAL PROTECTION BY USING SOLAR ENERGY ON SECURITY PONTOONS ON THE DANUBE

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ABSTRACT

The renewable energy resources available to Romania create favorable conditions for their use both to reduce the consumption of classic fuel based on hydrocarbons and to reduce their negative impact on the environment.

The first part of the paper presents the technical solutions adopted for the capture, storage and use of thermal and photovoltaic solar energy as well as for the implementation of these systems in the specific spaces available, ensuring the proper functioning of human crewed pontoons for the accomplishment of the missions specific

In the second part of the article, a number of issues are presentedemerged and solved during the commissioning of the combined / hybrid system,of use, at the same time, of classical / chemical energy and renewable solar thermal and photovoltaic energy, in order to optimize and improve energy efficiency.Finally, favorable conclusions are presented on the use and possibility of generalizing the use of the systems presented.

Keywords: *Renewable energy, energy conversion, combined energy systems, hybride energy systems, solar energy, pontoon*

INTRODUCTION

Monitoring and securing of traffic on the Danube, especially in the border area, requires the use / location of floating pontoons (Figure 1) necessary to live of gendarmerie crews responsible for coastguard operations. Ensuring the security service implies adequate living conditions that require the availability of adequate energy sources.

In current practice, the pontoons are powered by generating sets where the electric generator is driven by a thermal motor, usually a diesel engine, which uses diesel as primary chemical energy.

In this situation, the reduction of pollutants in the Danube area at present, until their elimination in the near future, becomes an immediate goal of action, for which adequate technical solutions, implemented, tested and validated must be identified.

The specific objective of the researches was to establish technical solutions for the use of solar renewable energy [1], [2], in order to reduce the classical energy consumption and to protect the environment, applicable in the conditions specific to the river pontoons.

The general objective of the research is that, after the development of a combined / hybrid system for the use of solar thermal and photovoltaic renewable energy, to be extensed/generalized of this system to the entire flotilla of existing pontoons in Romania, as well as to create the posibility, that on the commercial bases, to ofer to all partners interested in these systems.

Fig. 1 Surveillance pontoon

METHODOLOGY

If all the equipment on the surveillance pontoon in Danube Delta would be in operation it would consume an aggregate power of 15 kW. Depending on operating conditions (day, night, surveillance) and certain coefficients of simultaneity, the power consumption can vary between 1.5 kW and 7.5 kW maximum. The average consumption of 10 kW Diesel Genset fitted to the pontoon is 2.8 liters per hour and in the maximum load consumes 3.7 liters per hour. Diesel fuel consumption varies between 30 and 80 liters per day. Electricity consumption for domestic hot water boiler is 7.2 kWh / 24 h. The average power consumed by the equipments on the pontoon is 5.5 kW. In order to optimize energy consumption has been set as a target, the reduction of the energy produced by the diesel genset with 20 % [3]. Thus 1.1 kw must be obtained with solar panels both in sunny days and in less sunny days in the winter. For this, two technical solutions have been established for obtaining domestic hot water and one for obtaining electricity. Electricity consumption of the domestic hot water boiler is reduced by the use of thermal solar panels. The functional schemes of the two installations comprising two solar thermal panels, an array of photovoltaic panels and equipment for the conversion and storage of solar energy.

Group of thermal solar panels

The electric boiler is replaced by a solar thermal boiler that allows heating of water both by electricity or by coil heat exchanger. For this, 2 thermal solar panels with 10 vacuum tubes and a solar station were installed. The features of one solar panel are: peak output (G=1000W/m², η0): 1 kW, maximum pressure: 6 bar, tubes number: 10, heat loss coeff.: <0.8 W/m^2 °C, absorbtion surface: 0,8 m^2.

In the location of the pontoon global annual irradiation is 1500…1700 kWh/m^2 (Figure 2) [4]. For calculations, an average value of 1600 kWh/m^2 was taken. Taking into account the effective surface and efficiency, it is obtained that over a year, 1 m^2 of thermal panel produces an energy of 1600 kWh/m^2 ·0,75 = 1200 kWh/m^2 , and during one day will produce 1200 kWh / 365 days = 3,29 kWh / day / m^2 .

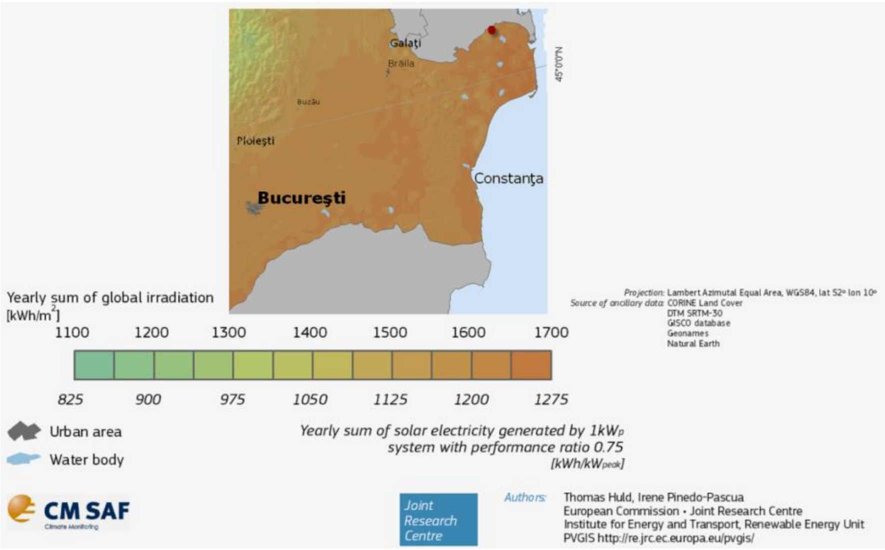

Fig. 2 Global irradiation and solar electricity potential for SE Romania [4]

Fig. 3 Surveillance pontoon endowed with solar energy solutions

In the calculation methodology of small solar thermal system provided by ESTIF [5], are given values for losses and efficiency for different applications (Table 1).

Table 1

Application	Pipe Losses in% of Collector Output	Extra Tank Losses in % of CollectorOutput	Boiler Efficiency in %	Boiler Stand-by Losses in % of CollectorOutput
Domestic hotwater DHW Boiler Back-up	10%	5%	85%	15%
Domestic hotwater DHW Electric Back-up	10%	5%	100%	0%

Considering the summed surface of the two panels, the energy produced by the thermal panels system in one day will be: 1,6 m^2 · 3,29 kWh / day / m^2 = 5,264 kWh.

To find out the energy transferred to the cold water through the coil heat exchanger in the boiler was considered a 85% overall transfer efficiency and it results $E_{tr} = 5{,}264\ kWh \cdot 0.85 = 4.47\ kWh$.

Energy requirement for boiler water heating is given by the formula

$$Q = m \cdot c \cdot \Delta T \qquad [1]$$

where m – volume of the boiler: 0,08 m^3; c – heat capacity of water: 1,16 kWh/m^3K;

ΔT – temperature diference – hot water and cold water temperature: 40 K

$$Q = 0{,}08 \cdot 1{,}16 \cdot 40 = 3{,}712\ kWh$$

Thus it follows that the energy production of solar panels cover energy requirement for heating water in the boiler, even providing a surplus of energy. With the help of solar thermal panels, the energy consumed by the electric boiler is reduced by 62%.

European Solar Thermal Industry Federation propose a simple calculation methodology to determine the energy yield of small thermal systems which is based on a few selected paramethers and the assumption of a constant mean themperature in the collector [5].

For the installation of solar panels on the roof of the pontoon, some structures attached to the roof of the pontoon were designed. The mode of installation of the solar panels on the roof of the pontoon can be seen in Figure 4.

Fig. 4 Solar panels and mounting rails on the roof of the pontoon

Area of photovoltaic panels

For the photovoltaic panels dimensioning, is needed the amount of electrical energy to be supplied by photovoltaic panels in one day so that to reduce the diesel genset consumption by 20% thus 5,5 kW ·24 h · 0,2 = 26,4 kWh. In order to achieve a 27 kWh average production capacity over a year, 30 photovoltaic panels of 265 W are needed.

For storage of electricity, 12 batteries are used with the following characteristics: voltage U = 12 V, capacity C = 220 Ah. The energy stored by them is E = U [V]· C [Ah] · 12 = 12 V · 220 Ah · 12 = 31680 Wh.

In order to obtain 1000 discharge cycles specific to gel batteries, the battery discharge depth must be limited to 40%. Then the available battery energy is Eb = 31,68 kWh · 40 % = 12,67 kWh. Under these conditions, the essential equipment that consumes 1,1 kW can be powered from batteries ~ 11 hours (12,67 kWh / 1,1 kW).

The performances of the photovoltaic system were simulated with an on-line tool made available by PVGIS [6], [7] (Fig. 5).

Fig. 5 Performance of off-grid PV: PV energy output © PVGIS, 2017 [5]

For batteries charging is used a charger model SmartSolar 250/100, and for energy management and for DC/AC conversion is used a unitQuattro 48/8000. Quattro unit contains an inverter and has a function for switching energy sources (grid, genset, solar). Both units are produced by the company Victron Energy (Figure 6a). For boiler water heating is used a closed loop system with a solar station that circulates a mixture of water with antifreeze from the solar collector to the heat exchanger inside the boiler (Figure 6b).

a

b

Fig. 6 Equipments installed on board of the pontoon

RESULTS

Statistics on the consumption and production of the solar installation were obtained through VRM Victron Energy Portal [8]. The equipments are connected to the internet via a Venus GX unit. At the site of the pontoon, the internet was provided with an LTE modem.

Figure 7 shows the energy consumed over a day from the grid (genset), battery and solar. It can be seen that solar energy is available after sunrise at 6 AM and is interrupted when the supplied electricity is too weak after 15:30. If the energy supplied by the solar system during certain periods (mostly in the summer) can not be consumed or stored in batteries, the system can be configured to deliver energy to the grid. By installing a bi-directional meter can be reduced the cost of the invoices paid to the electricity supplier.

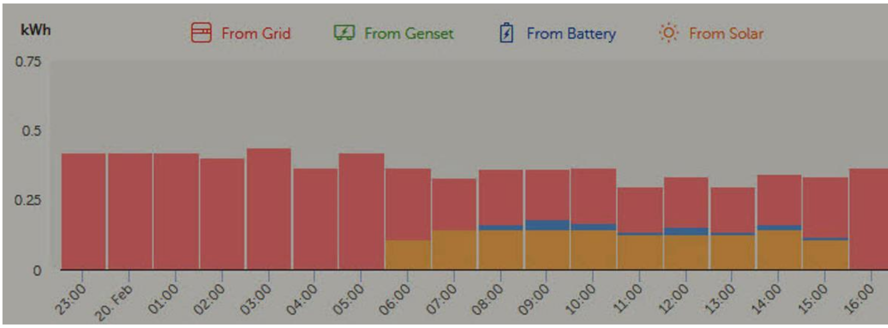

Fig. 7 - Energy consumption [8]

Figure 8 shows the variation in photovoltaic energy production over a day. The diagram shows the large variation in production due to atmospheric conditions (variable sky due to clouds or fog).

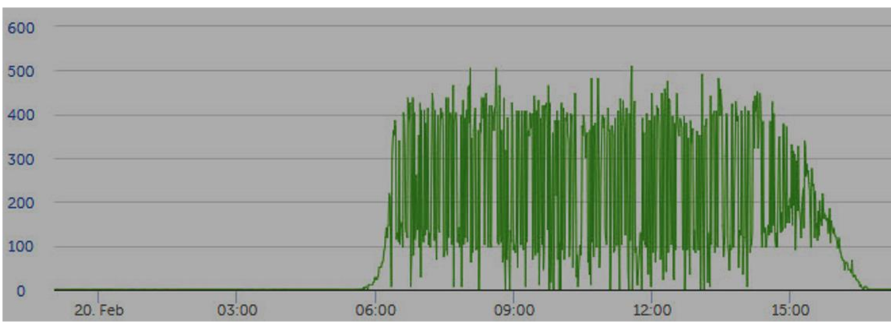

Fig. 8 - PV Yield [W] [8]

Figure 9 shows how is used the energy produced by photovoltaic panels on the pontoon as long as the sun is in the sky. One part is used to charge the batteries, and most of it is used directly for consumption.

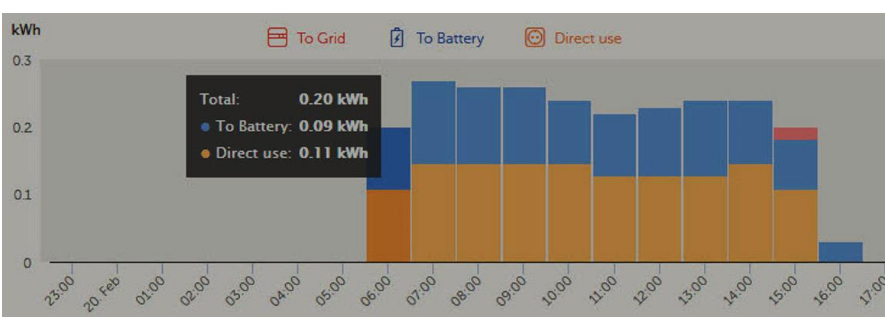

Fig. 9 - Solar consumption [8]

Figure 10 shows consumption over the course of a few days since mid-February. Solar production is not high, which is justified by the period in which the data were recorded. For February 17, consumption was 84% from grid, 1% from battery and 15% from solar.

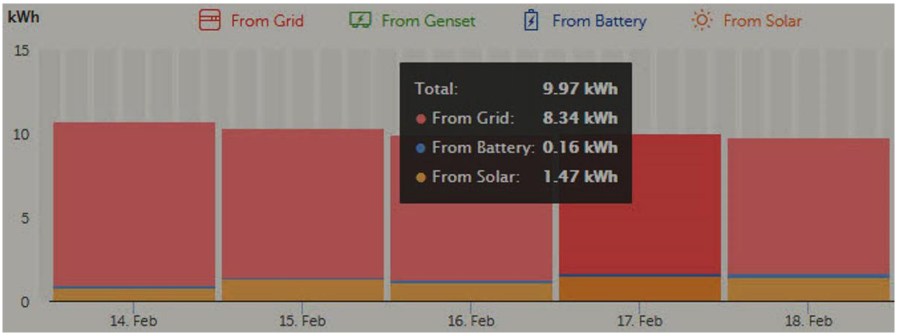

Fig. 10 - Daily consumption [8]

In Figure 11 there are diagrams of battery voltage variation and variation of charging current from the solar charger. In the period when the solar charger is active, it is noticeable that the battery voltage is higher. The load current varies as the intensity of the solar radiation that reaches the surface of the solar panels varies.

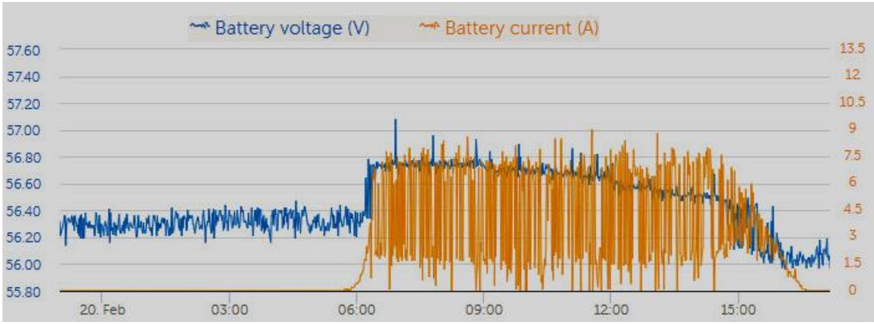

Fig. 11 – Variation of battery voltage and charging current [8]

CONCLUSION

The technical solution, adopted and developed by the INOE 2000-IHP Institute in Romania, proved to be in line with the specific requirements of pontoons operation, in terms of reducing the consumption of classical fuel and reducing the negative impact on the environment.

The 30 photovoltaic panels and two solar thermal panels ensure the reduction of fuel consumption for the generator (or energy from grid where it is available) according to the proposed target (20%), in the summer months production is even higher than consumption.

If at night the electricity consumption was high and in the morning the batteries drop below the set threshold (40%), the diesel genset will automatically start operating until the sun rises and become operational the solar power. After the solar power resumes, the genset stops automatically.

The system can be remotely monitored via the internet connection and the VRM Victron Energy Portal.

The technical solutions adopted have a strong generalizing character, and after a real-time testing period, actions / activities will be initiated to generalize the tested technical solutions.

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ROLE OF DIGITAL TECHNOLOGIES IN THE DEVELOPMENT OF OIL AND GAS INDUSTRIES. ECONOMIC ISSUES OF THE IMPLEMENTATION

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ABSTRACT

Currently, the priority growth areas for the oil and gas industries in Russia are the development of hard-to-recover oil and gas reserves, the development and implementation of innovative technologies for the exploration and production of hydrocarbons in the hard-to-reach regions of Eastern Siberia and the Arctic shelf. Solving these problems calls for intensifying the implementation of information technologies in the oil and gas complex. In the oil and gas industry, there is a global trend towards digital transformation. Companies are mastering a number of key technologies to determine their competitive advantage in years to come. Information technologies allow the production cost optimization as well as improvements of workflow, logistics and financial operations efficiency. In particular, the article notes that the use of modern digital technologies can significantly increase the speed and efficiency of geophysical research in the oil and gas complex. Examples of the successful use of IT solutions by domestic oil and gas companies have been provided. Economic and institutional challenges that limit the introducing national software for carrying out geophysical activities in the oil and gas complex have been identified. Prospects for the development of information technologies in other areas of the oil and gas complex, i.e. processing and transportation of oil and gas — have been reviewed.

Keywords: *oil and gas complex, geophysical researches, software, digital technologies, import substitution.*

INTRODUCTION

One of the important prospects for further development of the IT infrastructure in the Russian oil and gas industry is the automation of the full range of activities related to the oil and gas development, production, transportation and processing. The key challenge of the industry is to implement the idea of a “digital field”, that is to develop a unified system to control the oil reservoir and control the oil extraction process.

The concept of a “digital field” is implemented provided that a variety of technologies are comprehensively employed, and it implies the following:

- all types of equipment at the field are standardized, their uninterrupted operation ensured;

- information about any workflow enters information systems on a real-time basis;

- all physical objects and assets are equipped with sensors that continuously transmit information to control systems, thus eliminating data corruption, errors, or human factor [1];

- the readings are promptly processed by analytical systems, thus enabling the mining operator to make informed decisions in a timely manner.

Currently, technology-based methods of parametric and structural identification are widely used. IT system includes hardware and software immediately developed for the implementation of operational control over the consumption parameters used in the engineering networks industry.

Scientific and technical progress in the oil and gas complex and geological exploration is currently manifested in a significant increase in the processing and interpretation
of digital data. Increasingly severe geological conditions of oil and gas bedding, as well as more intense development of hard-to-recover reserves, and growing number of horizontal wells have toughened the requirements for accuracy and speed of processing geological and geophysical information, and for detailing the geological structure of complex reservoirs. The main goal pursued by information technologies in the oil and gas complex is to reduce the cost of extracting the amount of oil and gas required to the minimum. Furthermore, the development of information technologies makes it possible to increase labor productivity, the rational use of natural resources, and to ensure the smooth operation of equipment.

It is geophysical research that the process of digitalization in the oil and gas complex began with. The search and exploration of new hydrocarbon deposits on the continental shelf of Russia have necessitated a significant amount of marine geophysical research, in particular, 3D seismic survey [3]. This required the employment of the latest technical means and efficient personnel both for the performance of these activities, and for the interpretation of the data obtained.

The use of state-of-the art software, digital methods of processing geophysical data makes possible the replacement of traditional approaches based on correlation and regression analysis. Currently, digitally implemented algorithms can be successfully applied to simulate oil and gas deposits.

PROBLEM STATEMENT

Currently, Russia experiences a serious lag in the creation of domestic computer systems in the oil and gas industry, but active government support may provide opportunities to accelerate the development of large-scale service business as a necessary component of information technologies.

The use of digital algorithms plays a crucial role in improvement of interpretation of the results of geophysical research. Artificial intelligence provides allows for automated integration of various geological and geophysical information to be subsequently included in digital models of deposits.

Need for digitalization increases with the increase in the volume of geophysical data and the number of similar operations. The following points also encourage the companies to use high technologies:

- competition in the oilfield service industry and the reduction of the work schedule determined by customers;

- the need to improve labor efficiency, which requires that the exploration company focuses on the development and implementation of new algorithms, as well as on the automation of labor of the professionals, while maintaining and/or improving the quality of work performed.

RESEARCH QUESTIONS

A striking example of a company that successfully implements Instrument 4.0 in all business segments in the oil and gas complex is Gazprom Neft. In the exploration segment, the company takes advantage of artificial intelligence to analyze huge volumes of initial geological information and create a digital image of a deposit. This makes it possible to predict the quantity and quality of reserves, to form a strategy for the development of deposits, and to assess risks in an unbiased manner. To address this challenge, a unique project "Cognitive Geologist" has been created, aimed at applying cognitive algorithms and intelligent big data processing technologies. The program allows for speeding up the exploration cycle by reducing time and labor [1].

In addition, in order to comprehensively analyze, process and integrate into a model the available geological and geophysical information about a deposit, Gazprom Neft has designed a special decision-making IT platform, viz. digital workplace for geologists GeoMate [3]. The program ensures speeding up the process of making a decision about where to drill wells, how many reserves are recovered, and what changes in the deposit geology occurred, taking into account the updated figures.

It should also be noted that an important technological solution was the generation of a geological exploration database at Gazprom Neft. This "search engine" can handle digital data in the field of exploration and extraction in any programs used by the company. This development has centralized the control over exploration in all divisions of the company, and reduced time and labor costs for searching and verifying data [1].

At present, there are also much smaller enterprises engaged in the development of new digital technologies in the field of geophysics. In particular, VRS Geo Technology, LLC has developed and successfully employ the technique of high-resolution seismic to study thin-layer oil-bearing areas [5]. The technique allows clarification of the boundaries of oil and gas deposits according to the outer contours of oil and gas bearing areas; an in-depth comprehensive geological and geophysical interpretation of the results of processing geophysical data using HRV-Geo technology, geophysical research into well logging and drilling; a preliminary estimate of hydrocarbon resources based on high-resolution seismic data.

It should be noted that the use of information technology also provides means to the solving of critical production problems in transportation and processing of oil and gas.

Application of information technologies for the transportation of oil and gas has ensured a high level of security. This was made possible by a comprehensive and fully automated calculation of cyclic and static strength, vibration strength and seismic resistance using computer. Implementation of IT technologies in oil and gas transportation allows for accurate pipeline modeling on-the-spot and development of measures aimed at optimizing the operation of the entire pipeline system. Special software provides an opportunity in a short time to compile a report or to obtain statistical data necessary for making adjustments to the laying of the pipeline so that it runs in the areas with normal environmental conditions.

Efficient oil and gas processing is almost impossible without monitoring or recording devices, computing or information-measuring equipment, or self-adjusting devices. Studying and monitoring of oil and gas processing contribute to the development of more efficient methods for processing raw materials at new oil and gas refineries.

However, despite the given examples of successful use of digital technologies for performing geophysical activities by Russian companies, it should be noted that Russia seriously lags behind in the creation of domestic computer systems [4]. Today, when economic and political risks increase, Russian subsoil users and service companies are not ready to make long-term investments in computing capacities or perpetual licenses for specialized software with long-term payback periods [6].

It should be recognized that under the economic sanctions that become tougher, the largest domestic companies tend to disregard sanction risks and continue to purchase foreign software and IT solutions. According to experts, the dependence of Russian exploration companies on imported programs, technologies and equipment remains at 90% [7].

In the author's opinion [2], this problem is systemic in nature and is related neither to the quality of domestic software, nor to the costs for its production or promotion. The current system obstacles hinder the extensive use of domestic software and IT solutions, as well as make the largest oil and gas companies unperceptive to scientific and technological progress.

These obstacles can be divided into 4 categories:

1. Monopolism on the part of oil and gas corporations. Monopoly abuse in the fuel and energy complex of Russia is historical and is intensifying due to the differential rent received from the production of hydrocarbons in favorable conditions. It also increases with the overwhelming predominance of a corporation in a particular region, as well as in the acquisition of production and service companies [2]. In this situation, the most unprofitable contracts are put on the free market under discriminatory conditions for contractors. Meanwhile, foreign companies can either press their contractual conditions, or refuse the contract. Thus, the monopolies will receive additional benefits at the expense of their own

contractors. Independent contractors who are not affiliated with corporations have significant difficulty in surviving in the market.

2. Inefficient decision-making system within the largest oil and gas corporations, based on the deprivation of production managers from the right to dispose financial resources and make procurement decisions. In this case, risk are managed according to deviations, with the events that have already occurred taken into account.

3. Lack of interest in financing and consuming domestic innovations by the IT industry [3]. Effective decisions in the field of innovation can be made if corporations define and set problems, finance research and implementation of developments, while preserving the independence of research, education and engineering organizations. In Russia, large corporations seek to provide solutions to their problems on their own, while independent contractors have significant difficulties in reaching the commercial stage at minimal cost.

4. The lack of leverage on the promotion of decisions and state policy within the largest oil and gas corporations, including those with state participation, on the part of ministries and agencies, as well as other public structures; the lack of a coherent government policy to promote and support domestic software and IT solutions in the oil and gas complex. It should be noted that the mechanisms of influence of public authorities on the introduction of domestic software in the oil and gas complex are ineffective [2]. This inefficiency has the following reasons:

- the lack of interest of corporations in import substitution in the IT industry;

- the lack of a state mechanism of protectionism and support in the IT industry, while in the defense industry and agriculture such mechanisms are in place;

- the lack of permanent professional sites for the development of solutions and policies in the field of software and IT-technologies;

- the lack of a clear system of software standardization and certification, as well as a system of assessment of software compliance with the problems to be solved;

- insufficient state control over the use of unlicensed programs.

CONCLUSION

Information technology in the oil and gas complex can be widely used at all stages, namely, oil and gas exploration, extraction, transportation and processing. Expenses for IT are becoming one of the major expenditure items of the leading companies, which improves utilization of deposits and an increase in production growth. Oil service companies make a significant contribution to this process, offering solutions to the challenging task of automation of all information processes and improvement of their effectiveness.

Obviously, the use of information technologies will allow the automation of production processes on a fuller scale, as well as the “training” of industrial equipment to receive and process inconsistent or incomplete data obtained from different wells, and then synthesize them into a single piece of information that ensures more efficient development of an oil or gas deposit.

The task of cost reduction in production, transportation and processing of hydrocarbons provides an opportunity to ensure the automation of basic processes in the design and technological control over exploratory drilling, the calculation of drilling parameters, and management of geological and geophysical data.

Today, special attention is paid to the development of special-purpose databases and software for geological exploration and production, the systems of three-dimensional design and automated monitoring of oil refining facilities being developed and implemented.

The technologies of construction of “intelligent” injection and production wells, creation of operations control centers on a real-time basis, construction of fiber-optic systems for collecting and transmitting information are most sought after by the Russian oil and gas companies.

However, it should be particularly emphasized that people in the “digital” oil and gas have remained one of the most crucial assets of companies. In this context, their activities are becoming more creative and intellectual.

In view of the foregoing, for solving economic and institutional problems associated with implementation of digital technologies in the oil and gas complex, it is possible to arrive at the following conclusions and formulate the following recommendations:

1. It is necessary to assess the consequences of the almost complete dependence of geophysical studies in the oil and gas complex on foreign software and IT solutions.

2. Effective import substitution program in the field of software for geophysical activities should be developed by the expert community and industry-leading enterprises.

3. It is extremely important to create a system of the domestic software standardization and certification, as well as to develop modern regulations and state industrial standards in this area.

4. It is necessary to develop financing mechanisms and quotas for the procurement of domestic software and IT solutions.

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SHALE GAS EXPLOITATION IN THE VISION OF DIFFERENT FEATURES WITHIN EUROPE (ROMANIA) VS UNITED STATES

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ABSTRACT

In the context of growing energy demand, the need to find new conventional hydrocarbon resources and the need to emancipate from the monopoly of some countries holding such resources, the opportunity to approach unconventional hydrocarbon production seems to be crucial. The boom of unconventional hydrocarbons production started with the improvement of the technology that involves the drilling of horizontal wells with the hydraulic fracturing of particularly compact clay formations has been a major success in the United States of America.

The trend to extrapolate the advanced technology in America to other countries, there are particularities of approach, and specific conditions that differentiate Europe, implicitly Romania, from North America. To illustrate the particularities of the approach of unconventional hydrocarbons production, the paper presents some aspects regarding to the procedures necessary for the exploration, development and production of shale gas in Romania.

The paper includes assessment methodologies, characteristics of the stages of exploration, development, production and concepts of risk management which should have been assumed by the concessions agreements. Presentation of the exploration phase, with explanation of the role of the seismic prospection and exploration well drilling is detailed, adding the implications of the need to fulfilling the minimum exploration program; the assessment parameters and their possible determinations in the cores, well diagraphies, seismic sections, sophisticated data processing are explained.

Starting from the geological setting (stratigraphy and tectonics) of the Moesian Platform which is succinctly presented, the litostratigraphy of the Dobrogea sector of this unit (East Moesia) is detailed. The presentation of the geochemical parameters of some Paleozoic formations and the assessment of some Paleozoic formations from the point of view of their unconventional hydrocarbon potential, underlying the approach evoked by the minimal exploration program for the assessment of the shale gas perspectives in South Dobrogea.

In the paper there are underlines inappropriate comparison and approach of the shale gas exploration between concessions in the Europe (Romania) versus United States of America.

Keywords: *South Dobrogea, Paleozoic formations, shale gas potential, exploration concessions, unconventional hydrocarbon resources*

INTRODUCTION

The paper presents some aspects regarding the procedures necessary for the exploration, development and production of shale gas. It includes assessment methodologies, desiderata/characteristics of the stages of exploration, development, production and notions of risk management.

Starting from the case study of some exploration perimeters in South Dobrogea (Romania), concessions awarded by Chevron in a Public Bid Call 2010, the paper shows the inconsistencies in the approach to shale gas development in Europe versus the US. Reference is made to the flexibility of the seismic prospecting in order to avoid some restrictions in the exploration stage. All considerations (assertions) highlight the need to comply with the minimal compulsory program of a concession agreement.

The paper is referring to case study of some exploration perimeters in the South Dobrogea, which were the subject of the petroleum agreements between Chevron and the National Agency of Mineral Resources. After ratification of these petroleum agreements, Chevron Romania Holding BV had should go to perform in the first stage seismic prospections and geochemical analysis, then exploration by drilling to see if there are commercial resources, and finally could go to the production stage.

SHALE GAS ASSESSMENT METHODOLOGIES

The assessment and selection of future shale formations are based on a combination of factors that includes: (1) Data, information availability; (2) Dependency on natural gas imports at country level; (3) Presence of known shale formations; (4) Observations and activities of certain companies or governments directed towards resources development. The estimate diagnosis is based on data available within specific and published literature and studies, so as to estimate the risked oil and natural gas in place resources, followed by the recoverable resource estimate of resources that are not technically proven. The methodology expresses the intent to convey the best use for some insufficient data so as to perform an initial estimate of a shale formation. The oil and gas risked in place estimates are derived from: (1) Initial estimate of in place resources volume, correlated with the task on, (2) Success factor, (3) Recovery factor for the formation of interest. [1], [2]

The implementation of such assessment includes the completion of the following specific steps: (1) Conduct a preliminary review of a basin and selection of some assessable shale formations (to be assessed); (2) Determine the areal extent of the shale formations within the basin and in addition to other necessary parameters, to especially estimate its overall thickness; (3) Determine the prospective area deemed likely to be suitable for development based on the following criteria: rock depth, quality, and the experience in application of expert judge; (4) Estimate the natural gas in-place, seen as a combination of free gas and adsorbed gas that is contained within the prospective area. The oil in-place estimate is based on pore space oil volumes; (5) Establish and apply a composite success factor consisting of two parts: a factor of formation success probability as an indicator of how much is known or unknown about the shale formation and a success factor of prospective area as an indicator of geologic complexity and/or lack of access that could prevent portions of the prospective area from development; (6) For shale oil, it is aimed at identifying those US shales that best match the geophysical characteristics of the new formation so as to estimate the oil in-place recovery factors (for shale gas, the recovery factor is established based on: geologic complexity; pore size; formation pressure, and clay content with implications in formations ability to be hydraulically fractured). The gas phase of a formation includes: dry natural gas, associated natural gas, wet natural gas. Consequently, estimates of shale gas resources also include light wet hydrocarbons that are typically coproduced (associated) with natural gas. (7) Technically recoverable resources represent volumes of oil and natural gas that may be produced with current technology, regardless of oil and natural gas prices and production costs. These resources are determined by multiplying the risked oil or natural gas in-place by a recovery factor. The recovery factors of shale oil (typically lower than shale gas recovery factors, due to viscosity and capillary forces of oil) are 3-7% and exceptionally being > 10% or < 15 %. For the recovery factor, we have combined known production rates controlled by factors like: (1) mineralogy, (2) geologic complexity, (3) proper technological practices for the recovery of shale gas. [1], [2], [3], [4], [5]

There is an uncertainty level related to the extrapolation of recovery data related to the age reduced to maximum 30 years of the shale gas wells. The significant variation of shales geophysical characteristics throughout the formation and the difficulty of analogue matching with known formations, a shale formations resource potential cannot be fully determined until extensive production tests are conducted on the respective formation. It is a need to drill at least some exploration wells.

The initial assessment of shale gas resources requires the development of several stages: (1) Identify the stratigraphic sequence of potential reservoirs (especially argillites rich in organic matter) from Palaeozoic basin (pay zones); (2) Establish the surface extension of selected reservoirs and definition of prospective areas (plays); (3) Define surfaces with higher gas potential within each area (sweet spots); (4) Estimate of gas quantities in these reservoirs, which are contained in this manner (geological resource or OGIP); (5) Calculation of technically recoverable resources from the gas resource generated by the shale reservoirs. [1], [2], [5]

SOUTH DOBROGEA SHALE GAS POTENTIAL

EX-19 Adamclisi, EX-18 Vama Veche, and EX-17 Costinesti perimeters (fig. 1) are located in South-East Romania (Dobrogea region, Constanta county), being neighbored in the east by Black Sea and in the south by the state border between Romania and Bulgaria. The above mentioned perimeters are framed from geologic-structural point of view in the South Dobrogea region, included in the eastern side

(East Moesia) of Moesian Platform (fig. 2). Stratigraphically, the South Dobrogea region include a crystalline basement (Ovidiu group (Archaic) and Palazu group (Lower Proterozoic); followed by a poorly metamorphosed in facies of green schists = Cocosu group, Upper Proterozoic = Vendian), followed by a cover of Palaeozoic to Neozoic (4 sedimentary cycles) that has a cumulated thickness of 3,500 meters. The lithology of the Palaeozoic formations is documented based on sixteen wells that have been drilled in South Dobrogea. More interesting from the point of view of shale gas potential is Tandarei Formation = Lower clastic group (Upper Cambrian – Middle Devonian) of Middle Cambrian – Upper Carboniferous megasequence. Lower clastic group include: Cambrian-Ordovician – clastic bed formations consisting of arkosian sandstones and quartzitic sandstones with silt and silty clay intercalations (Tandarei Formation); Silurian strata consisting of clay shales with graptolites (Tandarei and Smirna Formations); Lower Devonian include quartzitic sandstones with silty clay intercalations, conglomerates, limestones (Tandarei Formation). [5], [6], [7], [8]

Fig. 1 Map showing location of 17, 18 and 19 blocks for shale gas exploration in Romania

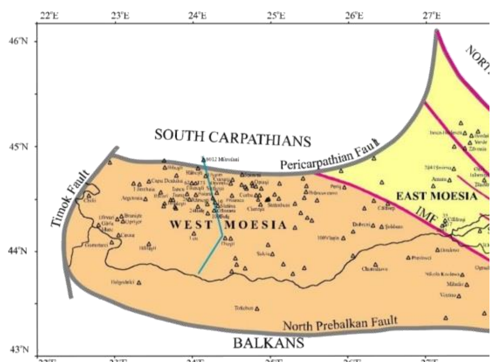

Fig. 2. Tectonic sketch of Moesian Platform with the distribution of the main wells that have crossed the Palaeozoic formations. [6]

Assessment of formations rich in organic matter of Lower Silurian – Devonian show that they have been buried deeper than the 4,000 m of Paleozoic, Mesozoic and Neozoic formations. The geochemical analysis shows TOC 0.54-4.48%; extractable organic matter = 180-2461 ppm; extractable organic matter generation index (EOM/TOC ratio) = 0.02-0.11; HC/TOC ratio= 0.01-0.06. Pyrolysis data are S1 = 0.12 mg HC / g of rock, S2 = 1.05 mg HC / g of rock; HI = 50 mg; SPI = 1 tHC / m^2, Tmax ≥ 500. Kerogen that based the formation of organic matter is a type II kerogen. [5], [6], [7], [8]

A proper assessment of the shale gas potential in Dobrogea is rather difficult due to the fact that existing information is scarce and poor. Moreover, the following issues need to be considered: (1) The study on the shale gas potential of East Moesia and especially Tandarei formation shows an inchoate potential of geological and engineering knowledge; (2) It is a poor knowledge of kerogen dynamics, physical properties of the rock, mineralogy and subtle changes of facies and fracking character; (3) The lack of seismic profiles of high quality; (4) Total lack or an insufficient number of wells drilled to investigate wide areas potentially hosting resources; (5) The additional effort required to reconsider: different data of palaeontology analyses (in general, poor ones), major lacks of radiometric dating, controversial aspects of absolute ages, with results in interpretation with poor basis or even forced interpretations; (6) The lack of information on: petrophysical parameters, lutites mineralogy, quartz diagenesis, facies variations, natural fracturing, thermal history and dynamics associated with kerogen maturation, pyrolysis date for the maturation models. [5], [6], [7], [8]

For South Dobrogea region the perspective formations, which have a shale gas potential (expected from existing data and from extrapolating such data) are from Palaeozoic – Mesozoic age and they develop on large areas, and they can be found at depths of 2,500-3,000 m within eastern side of Moesian Platform. The map of Romanian hydrocarbon fields distribution proves that the (conventional) deposits are discovered to date only west of Danube River. If the EX-17, EX-18, EX-19 exploration blocks were seismically explored, they would have been provided a continuous geological image of both sides of Danube River. All these aspects may be known by performing a detailed exploration, where several wells are drilled, allowing collecting and study of cores, and also collection of relevant information on the existing resources and support the need to fulfill the minimum exploration program. The potential of unconventional resources in Romania, especially South Dobrogea remains to be explored.

TYPICAL FEATURES OF UNCONVENTIONAL SHALE GAS EXPLORATION IN US VS EUROPE (ROMANIA) – COMPARISON INOPPORTUNITIES

The revolution of shale gas currently in development in US was not repeated elsewhere, i.e. especially in Europe (although significant volumes of unconventional deposits are present in Poland, France, Germany, Hungary, Sweden, Turkey and UK). In order to secure expertise within the shale gas sector, several European companies have been established as joint ventures with US companies. It may be emphasized some different approaches in unconventional shale gas development between Europe and US:

1. Geology of Europe is less favourable for an economic development;
2. The fiscal policy is not favourable in Europe, as opposed to the tax decreases that provided the necessary incentive in US, which are not valid in Europe; there are differences of perceptions with respect to management and funding risks costs;
3. Onshore drilling services fewer in Europe than in US and Europe does not have the shale gas expertise of US operators;
4. More stringent environmental and safety regulations in Europe than US. Also in the case of Europe and Romania, an approach oriented on legislation, regulations, restrictions and education is required;

5. Public acceptance is reduced on shale gas development and the environmental impact for Europe. The ecologic impact of hydraulic fracturing is not thoroughly assessed, except in US;
6. The increased sensitivity of Europe than US to the potential effect of slowing down investments in non-renewable energy sources;
7. Difference in familiarization and different education with respect to oil operations, lower in Europe than in US. The US public is accustomed with drilling activities, considering their long history of onshore drilling;
8. Different population densities in Europe and US: in Europe 100-200 inhabitants per km^2, higher than US average of 30 inhabitants per km^2. The shale gas potential areas in US are often located in poorly populated areas;
9. Aside poor education on shale gas development both in Europe and Romania, it is expected to have more local opposition, due to the fact that the benefits of gas productions shall be secured by national governments and not local landlords, as it is the case in US. In Romania, the underground is in government property;
10. Even though, after years of speculations, some progress has been recorded in developing European shale gas deposits (in more advance countries like Poland), the still is an uncertainty related to the more vocal opposition of population, especially due to an insufficient communication. Moreover, there is uncertainty in Europe and in Romania related to the low geologic shale gas potential;
11. One of the reasons for which the start of shale gas production in Europe is rather slow is related to the negative impact on the environment due to the use and pollution of water, air emissions (volatile compounds, methane, and greenhouse gases), community impacts (land use, biodiversity, sound pollution, traffic). The main causes leading to consequences and risks would be: (1) development of activities within large areas; (2) geologic conditions (deep aquifers, abandoned wells, potential faults that may become pollution paths or they may result in multiple earthquakes); (3) cumulative impacts of multiple wells; (4) use of dangerous chemicals; (5) use of a large quantity of water, and some of that water would be unrecoverable; (6) volume and characteristics of wastes; (7) release of gases in the air, (8) flare burn during drilling;
12. A comparison between EX-17, EX-18, EX-19 perimeters from South Dobrogea with the large oil fields where gas is produced in US (Marcellus, Bathrust, Barnett, Niobrara, Eagle Ford etc.), is not suitable due to the flagrant differences existing between them, as related to (1) geological conditions (depth, formation thickness, geochemical conditions, etc.), (2) technological conditions, (3) demographic conditions, (4) proximity of small or large localities, (5) the different density of wells drilled in American fields as opposed to the Romanian situation (where there are many localities with archaeological sites, civil-military-industrial-touristic sites, among which the sea side proximity must be emphasized);
13. The infrastructure differences are also emphasized, which were also known and they should have considered them. The issue of a high intensity approach in Europe/Romania is connected to the availability of

information. It starts with geology and ends with production and economic infrastructure. Among the major differences of successful development of unconventional natural gas in US and Europe/Romania, it must be reminded here the areas assessment, which may facilitate or not development, or they may complicate or stop such development. In the development of unconventional gas operations, groups and institutions that may have different visions on the future actions are involved;

14. There are differences on market access. The gas markets in Europe are not fully liberalized. Some members of the European community made moderate or insignificant progress towards liberalization of gas market. Moreover, imports of gas for EU are increasingly diversified, with a view to access prices lower than the Russian prices;
15. In Europe, there is also a competition from the gas delivered through a pipeline or LNG. Recent imports of LNG in Europe at spot prices have been slightly lower than the prices of the gas delivered through pipelines based on a long-term contract. One can acknowledge that the stagnation of shale gas capitalization in Europe is an advantage on medium term for US and Canada, whose gas exports of LNG towards Europe are unavoidable;
16. If compared to US, in Europe the benefits of the shale gas appear to be rather limited due to several major issues: (1) The certain shale gas reserves are lower than initially estimated; (2) Placement on rather deeper geological layers, requiring more expensive exploration and production if compared to the more advantageous conditions in US; (3) At a high population density in Europe, the collateral damages are more threatening, and the public opposition is consequently stronger; (4) Additional infrastructure investments are necessary in some areas;
17. Even with the best political support of governments and regulating authorities, oil companies, and with the application of best practices, shale gas will not be able to change the rules of the energy game in Europe, neither the offer security, nor the reduction of emissions, however, at particular country level, the results may be remarkable, depending on the national supporting policies and depending on the reserves potential;
18. Pursuant to some representative studies, the shale gas extracted from own resources shall cover only 6-14 % of the internal need of Europe, a level that is insufficient for the liberation of Europe from the import gas dependency. It is an argument of the will of Romanian Government to continue its task of shale gas development.

CONCLUSIONS

The methodology used to conduct the seismic prospection in South Dobrogea was a high resolution method, based on the small distance between channels and the deep depth of investigation (6 milisec), as premises of an optimum interpretation. The fact that the entire designed profiles grid was not developed reduced the interpretation options (the assessment on the extension of the formation and the correct estimate of their thickness) with expected generation capacities. It is clear that the entire designed grid was mandatory so as to facilitate mapping of the formations both at overall and detail scales, intent clearly anticipated from the very beginning. A special and comparing processing of the seismic profiles would have led to the optimization of the formations correlating, as well as the lithofacial variations both horizontal and vertical.

With respect to the design of seismic alignments in the restricted areas (such as social sites – villages, military, industrial, civil, religious, touristic, natural protected areas, stubborn landlords refusing leasing the property), the data acquisition technology allows bypassing restriction and their mitigation. We would like to technologically stipulate the possibility of shortening the profiles, abandonment, and deviation with the risk of getting a rather poor signal, with an increased effort of seismic processing and interpretation. Another aspect would be, so as to have credibility and to complete the optimum data processing (especially in the case of a poor signal recorded due to deviation of the alignment), distribution of primary data would have been an option not to a single unit, but to several witness units for processing and interpretation. Efforts could have been made from social and bureaucratic points of view to increase the price of leasing from small landlords or more effort in securing the permits faster. As to the early statements of the investor, one can see an inconsistency recorded in time, as the desire for communication and follow-up on works dropped.

Any interpretation and assessment of the petroleum potential (both conventional and unconventional) are not feasible due to the lack of the entire seismic grid that was proposed and designed during preliminary stage, pursuant to the minimal schedule, and due to the lack of exploration wells. We need to emphasize the need to drilling wells both for securing core data and well geophysics data, but also for the calibration opportunities of the data secured from geophysics extrapolations. Meeting the proposals included in the minimum exploration program, as provided in the oil agreements, appears to be a mandatory duty for Romanian government as related to the minimal information of the explored areas, with a view on the presence or absence of a potential for mineral resources and their conditions (both geologic and economic).

To conclude, the areas with restrictive access may, theoretically, produce certain discomforts for the exploration and production activities (the activities cannot be scheduled as easily as in the case of vacant areas, with no economic activity), but these are well-known and are somehow considered upon participating in the leasing bidding (as it is the case in most of the countries where such activities are being developed) and it does not have a major impact on the timely development of exploration activity and in the end on the production activity. Moreover, for a better knowledge of existing resources it is critical to complete the mandatory minimal schedule, a schedule that in this case could have been completed, the issues faced being rather normal in such cases and could have been addressed with a rather minimum effort.

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Section

EXPLORATION AND MINING

Locating and evaluating mineral deposits,
designing and constructing mines
Developing and supervising mining operations
Exploration and mining geology, mining science

EXPERIMENTAL IDENTIFICATION OF THE DYNAMIC LOAD OF CONICAL PICKS DURING THE CUTTING PROCESS OF TRANSVERSE CUTTING HEADS OF BOOM–TYPE ROADHEADER

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ABSTRACT

The boom–type roadheaders are commonly used for drilling roadways in underground mines and tunnels in civil engineering. Rock cutting in the heading face of the roadways or tunnels is carried out on the principle of cutting with picks, most often conical. The cutting tools are subjected to strong dynamic loads that are the reaction of the rock cut to the cutting picks. This applies in particular to the cutting of hard rocks. The high variability of the pick load has an unfavorable effect on the fatigue strength and the durability of picks and pick holders, the durability of the main roadheader components and the course of the cutting process. The article presents selected results of the R–130 roadheader (manufactured by Famur S.A.) obtained during simulated excavation of the heading face at the experimental stand in the Technological Hall of the Faculty of Mining and Geology at the Silesian University of Technology. During these tests, forces acting directly on the three conical picks of the cutting head were recorded. This enabled the identification of the size and nature of the actual load of the picks on the cutting head of the roadheader while cutting the rock mass with various workability in different conditions of this process. For the recording of components of the picks load, an innovative, autonomous measurement & recording system was used. This system has been built inside the cutting head of the tested roadheader. It has been equipped with specially designed pick holders (measuring devices) with built–in force sensors.

Keywords: *roadheader, cutting process, conical picks, dynamic load, experimental tests*

INTRODUCTION

The boom–type roadheaders (fig.1) are heavy duty machines commonly used in underground mining and tunnelling for drilling of roadways, chambers and tunnels. Rock cutting is done here on the basis of cutting with picks installed in pick holders located on the side surface of the cutting head. One longitudinal or two transverse cutting heads are placed at the end of a movable boom, which is swung in a parallel plane and perpendicularly to the floor. The cutting heads are moving in this way on the surface of the heading face of the roadway or tunnel. It is therefore possible to drill roadways or tunnels of any shape and with a different size of its cross-section. This is a big advantage of this type of machines compared to TBM machines, which can only drill excavations of a circular cross-section of a given diameter [6]. The ability to move the cutting heads on any path allows for adapting of the heading face cutting technology to the geological structure of the rock massive, in order to ensure the optimal working conditions of the roadheader, maximize the drill speed and obtain the established shape of the excavation cross-section [9].

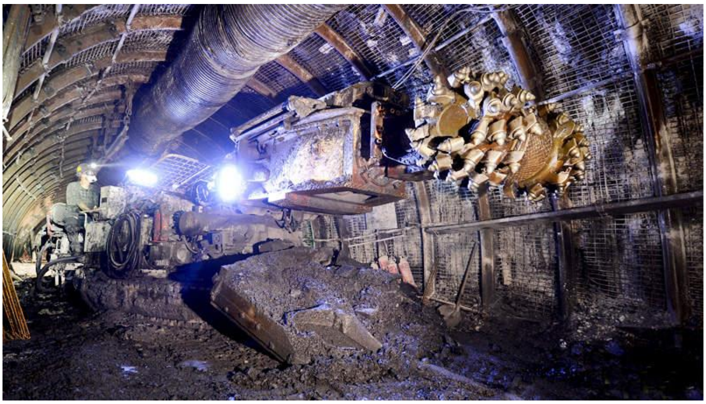

Fig. 1. A boom–type roadheader equipped with transverse cutting heads in the underground mine's roadway (www.mining-technology.com)

During mining, in particular of hard rocks, the cutting picks are subjected to strong dynamic loads. This is due, on the one hand, to the mechanical properties of the rock (the brittleness of the rock), the way in which the roadheader's picks interact with the cut rock and the process of the breakout of the grains of the excavated material. Due to the geometry, especially of the conical picks, the rock is subject to crushing, as well as elastic and plastic deformation at the bottom of the furrow made by the pick. The dynamic character of the process of cutting rocks with mining cutting machines' picks is confirmed by the results of many years of experimental research and theoretical work (e.g. [5], [8]). The large fluctuation of the pick load is the source of intense vibrations of the boom of the roadheader, transferred through construction nodes to other components of the roadheader, as well as the high dynamic loads of its drives. The dynamic nature of the picks' load is also one of the causes of their intensive wear and tear and even premature destruction (e.g. breakage) of an ad hoc or fatigue nature.

So far, the experimental research of cutting rock with mining cutting machines' picks have focused mainly on the implementation of this process with a single pick. Specially constructed test stands or adapted metal-working machines were used for this purpose. Moreover, the research of the cutting process is carried out on samples of natural rock or of equivalent materials such as cement-sand masses. From the point of view of the dynamics of the rock cutting process, such kind of bench tests don't give a full picture of the actual nature and size of the load of the cutting picks. The dynamic properties of the stands for testing the cutting process with a single pick, and often also the parameters at which the cutting process is carried out at the workstation differ significantly from the real conditions that we deal with in the case of cutting machines. What is more, the actual rock cutting process is carried out with multi-pick cutting heads, not a single pick. The interaction that occurs in the system: the cutting machine – the cut rock, the interaction between neighbouring picks of the cutting head and stochastic variability of mechanical properties of the cut rock, make the course of the picks' load obtained in laboratory conditions differ from the actual ones. In many cases, these tests are limited to determining only the cutting force, assuming that this force has the most important meaning [4], [5], [10]. From the point of view of the analysis of the mining machine's dynamics, this is a far-reaching simplification.

Identification of the actual course of the dynamic load of the cutting picks by means of measurement is basically possible only directly on the roadheader, while cutting the rock with it. This is an extremely difficult undertaking, especially in operational conditions. It requires a design of the measuring and recording system that could be installed in the cutting head and an adaptation of the cutting machine to these needs.

The article presents the selected results of the measurements of the conical picks' dynamic load on the cutting head of a R–130 roadheader (manufactured by Famur S.A.) with transverse cutting heads. These measurements were carried out in laboratory conditions during a simulated excavation of the heading face. The experimental roadheader cut the surface of the cement-sand block. This block consisted of five layers of varied uniaxial compressive strength (UCS), ranging from 33 to 69 MPa. The cutting was carried out while moving the cutting heads parallel to the floor. Time courses of dynamic load components of three selected picks were recorded, with which one of the cutting heads was equipped. The cutting process was carried out at different values of the parameters characterizing it: the web of cut z, cut height h, the angular velocity of the cutting heads $\dot{\varphi}_G$ and the speed of their movement v.

MEASURING SYSTEM

The measurement of the dynamic load of roadheader picks in the conditions of simulating the cutting of the cement-sand block included time courses of three mutually perpendicular components, i.e. cutting force (F_C), normal force (F_N) and sideway force (F_S) – fig.2 – for three selected conical picks on the cutting head of the tested roadheader. These picks are positioned in different places of the cutting head. An innovative, autonomous measurement & recording system was used for this purpose. It was installed in the cutting head and moved with it. Due to the fact that during mining the cutting heads of the roadheader make a rotational movement around their axis of rotation and are moved along the surface of the heading face as a result of the deflection of the roadheader's boom parallel and perpendicular to the floor, the measurement & recording system could not be connected in any way to the stationary elements of the test stand via power and signal cables. Hence, the measuring system developed for these tests was equipped with its own battery power system. The recording of data was carried out on the memory card of the recorder built inside the hub of the cutting head.

Measurement of the three components of the dynamic load of individual conical picks was carried out with the use of the three-axis force sensors type 9077C of a Swiss company KISTLER. They were built into specially designed pick holders (measuring devices) (fig.3) attached to the side surface of the cutting head in place of standard pick holders. The design of the measuring pick holders allows the use of conventional roadheaders' picks, so that they don't disrupt the rock cutting process. The type of force sensors and their metrological characteristics were selected on the basis of a computer simulation of the load to which the conical picks are subjected during the cutting of rocks with mechanical properties corresponding with the test conditions.

The force sensors in the measuring pick holders are connected with cables to the power source and the recording unit. These elements have been installed in a cylindrical housing with dimensions adapted to the diameter and the depth of the hub in the cutting head (fig.4). The data logger used allows the recording of time courses of 10 parameters (three load components of each of the three picks and a synchronization signal) with a frequency of up to 1000 Hz. The capacity of the memory card and the capacity of the batteries supplying the measuring devices and the data logger allow to measure the load of picks for up to 24 hours. By recording the synchronization signal (generated with every rotation of the cutting head) it was possible to synchronize the data with a stationary recorder, in which the position of the cutting head on the surface of the cut block was recorded. This was the basis for determining the conditions of cutting. The transmission of the measurement data to a PC computer for further processing and analysis was carried out via a wireless network after stopping the data logging. The ongoing control of the measurement system is possible with the use of dedicated software installed on a PC, laptop, tablet, or smartphone. The remote communication with the data recorder is carried out via WLAN.

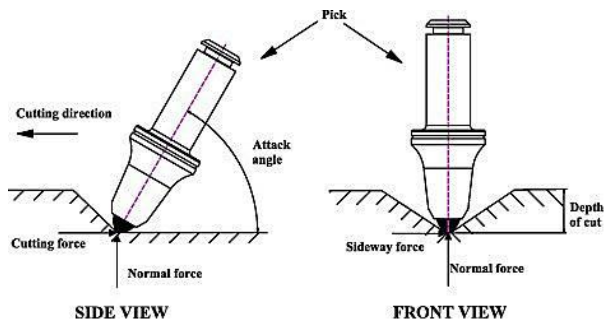

Fig. 2. The components of the loads of conical picks of mining machines [11]: the cutting force, the normal force and the sideway force

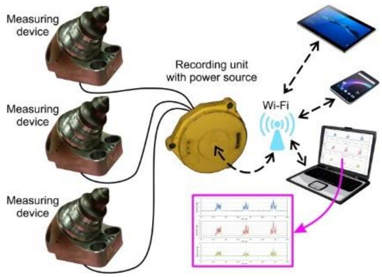

Fig. 3. The measurement & recording system of the dynamic load for three picks placed on the cutting head of a roadheader

Fig. 4. The measurement & recording system mounted on the cutting head of the roadheader

THE REAL TIME COURSES OF THE DYNAMIC LOAD OF PICKS DURING THE CUTTING PROCESS – SELECTED EXAMPLES

Figure 5 shows an example of the dynamic load components of one of the roadheaders' picks (No. 28) generated by the cutting process when making the upper cut with a height of h = 125 mm and a web of cut of z = 200 mm. The cutting head was moved with the speed $v \approx$ 35 mm/s, and its angular velocity $\dot{\varphi}_G$ was equal to 5.5 rad/s. During the presented fragment of measurement, the cutting head was cutting the layer with UCS σ_C = 50 MPa. During the 10-second measurement period the cutting head made nine revolutions. As we can see, the load of cutting picks is characterized by a high variability. For example, the cutting force F_C acting on the conical pick No. 28 in the analysed nine revolutions of the cutting head reached peak values ranging from 3.3 to 6.3 kN. Mean values of this force in subsequent cutting cycles were, however, in the range from 1.2 to 2.2 kN. The peak value of the normal force F_N for this pick was in the range from 4.5 to 9.2 kN, and its average value ranged from 1.8 to 3.2 kN. The average value of the sideway force F_S was close to zero, and the peak values didn't exceed 3 kN.

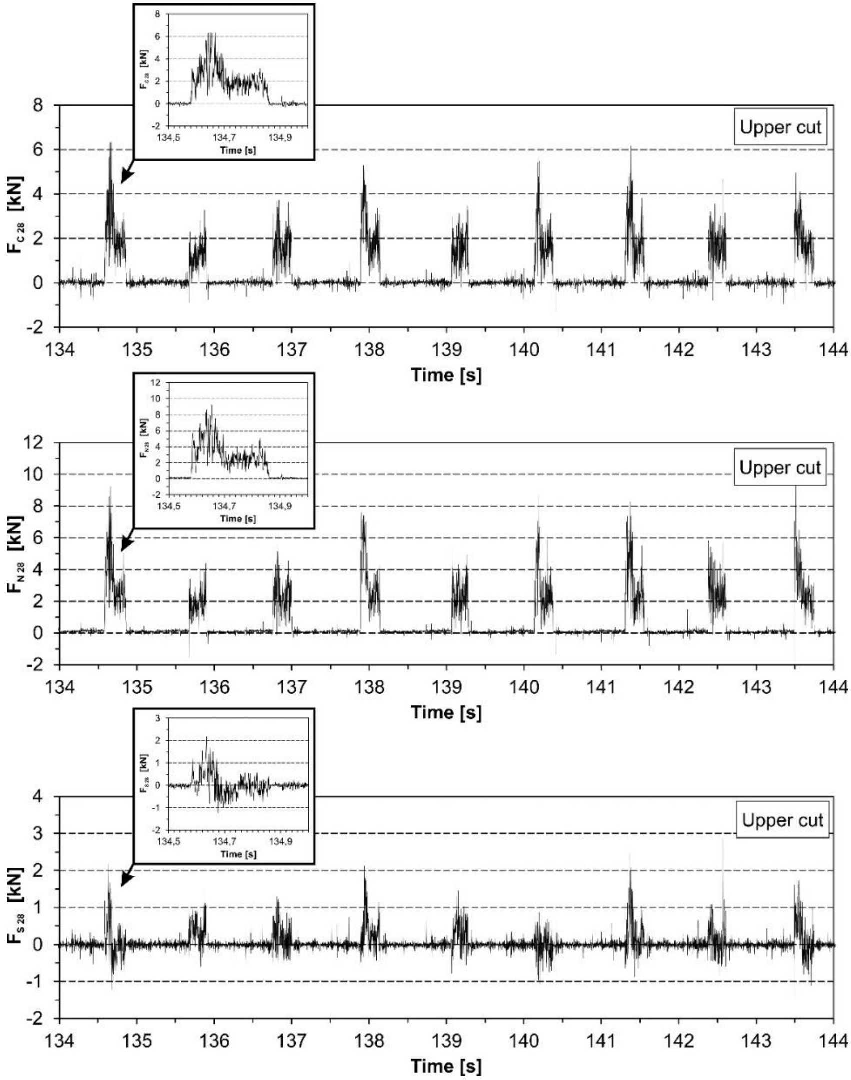

Fig. 5. Sample time courses of the components of pick load during making the upper cut (nine revolutions of the cutting head)

Although it is assumed that the depth of cut performed by a given pick is roughly constant when cutting with the transverse heads of the roadheader parallel to the floor, the courses of the components of the pick load are characterized by a high variability. This applies in particular to the cutting force (F_C) and the normal force (F_N). When the pick comes in contact with the cut rock, the strength increases. This effect is particularly noticeable when making the upper cut. The entry of the pick into the cutting zone is accompanied by a hit to the surface of the excavated rock. The influence of the pick on the cut rock causes the grains of the spoil to break away. Due to the brittle properties of natural rocks and the cement-sand masses cut during the discussed studies, the size of grains of spoil following the moving pick is strongly diversified. This is one of the important sources of high variability of the pick load, leading to high dynamics of the mining machine. The character of the normal force course F_N is similar to the nature of the cutting force F_C. This can be seen on enlarged excerpts of the time courses shown in fig.5. The course of sideway force F_S differs from the course of the other two components. This force essentially oscillates around zero.

ANALYSIS OF THE DYNAMIC LOAD OF THE ROADHEADER' PICKS

The observations of time courses of dynamic load components of picks during the cutting process indicate the existence of mutual relations between them. It can be expected that these relations will depend to a large extent on the mechanical properties of the rock being mined. The relationship between forces: the normal F_N and the sideway F_S from the cutting force F_C for cut material is well described by the linear regression (fig.6). The carried out statistical tests confirmed the significance of the correlation coefficient of the studied relationships (the test probability p was lower than the assumed significance level α = 0.05, which allowed to reject the null hypothesis about the lack of correlation [2]). The values of the correlation coefficients r were respectively: 0.95 – for $F_N=f(F_C)$ and 0.8 – for $F_S=f(F_C)$. The significance tests of coefficients of regression equations of the dependences studied here showed that the slopes significantly differ from zero (test probability p <0.05). The obtained linear regression model of the dependence $F_N=f(F_C)$ passes near the point (0,0) – the intercept differs slightly from zero (p = 0.2). In the case of the sideway force dependence on the cutting force, the regression model doesn't pass through the point (0,0), since the intercept differs significantly from zero (p <0.05). The obtained mean values of the ratio of pick load components F_N^m / F_C^m and F_S^m / F_C^m for the cutting layer with UCS σ_C = 62 MPa were respectively: 3.2 and 0.4. This means that on average the normal force was slightly more than 3–times greater than the cutting force, while the average value of the sideway force constituted only 40% of the average cutting force value. From the point of view of the load of the cutting head, its drive and the body of the roadheader, the two components of the pick load, that is: the cutting force and the normal force, are therefore of significant importance. Due to the relatively small values of the sideway force acting on the picks during mining, it is often ignored.

With the increase of UCS of the material being cut, the value of the load ratio of the picks increased (fig.7). This concerned in particular the ratio of the normal force to the cutting force determined for mean values F_N^m / F_C^m (solid line) and peak values $F_N^{\max} / F_C^{\max}$ (dash-dotted line) of the course of components of the pick load. As we can see, this is a nonlinear relationship, which can be approximated with a polynomial of degree 2. In the tested range of UCS of cement-sand masses, i.e. from 33 to 62 MPa, the ratio of average values of the normal and the cutting forces varied from about 1.5 to 3.2. The ratio of peak values of these forces ($F_N^{\max} / F_C^{\max}$) was slightly lower. With the increase of UCS of the excavated material, it varied from 1.3 to 2.9. The range of variation in the ratio of average values of the sideway and the cutting forces (F_S^m / F_C^m) was in the range from 0.1 to 0.43 (dashed line). Slightly higher values were obtained for the ratio of peak values of these loads (F_S^{max} / F_C^{max}). However, they didn't exceed 0.6.

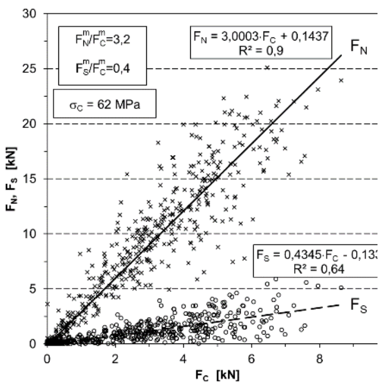

Fig. 6. The dependence of normal F_N and sideway F_S forces on the cutting force F_C

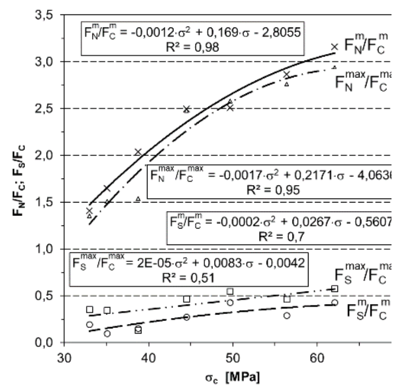

Fig. 7. The dependence of the ratio of pick load components on the UCS

As the publications show (e.g. [1], [7], [11], [12]), the ratio of the normal force to the cutting force for rocks of natural origin can also be of a wide range – usually of the range of about 1 to 2. However, it may exceed the value of 3. Such high values of the F_N/F_C force ratio may take place during mining of very hard rocks, such as sandstone [3].

The average values of the ratio of the normal force to the cutting force obtained during the cutting process of the cement-sand masses correspond to the values obtained during the excavation of hard rocks of natural origin.

CONCLUSION

The presented in this work results of experimental investigations carried out in the conditions of simulated excavation of the cement-sand block with the R–130 roadheader are a source of valuable knowledge about the state of real dynamic load of conical picks of a mining machine. Thanks to the use of an innovative measurement & recording system, it has been possible to register the course of forces acting on selected picks arranged on the cutting head of the tested roadheader. The registered characteristics, after the confrontation with the conditions of the mining process, allowed to identify the size and nature of the dynamic load of conical picks and to link it to the mining process parameters, including, inter alia, mechanical properties of the excavated material (cement-sand masses with different UCS). The recorded load patterns reflect the real response of the cut rock to the penetration of the picks. In this case, not only the mechanical properties of the rock and the geometry of the picks used are taken into account, but also the dynamic properties and the technical characteristics of an actual mining machine (roadheader) as well as interactions occurring in the system: the machine – the cut rock. The obtained pick load conditions are therefore the real answer of the tested object to the pursuance of the mining process with given values of the parameters of this process. Such possibilities are not provided by laboratory stands commonly used in the research of the rock cutting process with a single pick or even a group of picks.

ACKNOWLEDGEMENTS

The work has been implemented under the research project titled "*Control of roadheader cutting heads movement for reduction of energy consumption of mining and dynamic loads*" co–financed by the Polish National Centre for Research and Development under the Applied Research Projects (agreement no. PBS3/B2/15/2015).

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IMPLEMENTATION OF MECHANICAL LOGGING ON THE OLON-SHIBIRSKOYE COALFIELD

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ABSTRACT

The article is dedicated to the results of mechanical logging implementation on the Olon-Shibirskoye coalfield. Previous investigations had shown that non-core drilling could potentially provide information on geological composition of a coalfield and on the ash content of coal by the means of mechanical logging. Since then, the equation of the correspondence between drilling velocity and ash content has been modified as the result of analyzing a greater amount of data. The next step of the research was examining the implementation of mechanical logging for operational exploitation on the Olon-Shibirskoye coalfield. For this stage, thirty-one boreholes were drilled with the implementation of mechanical logging. Results of this drilling were compared to the geological exploration data that had been obtained earlier in the same area and several drilling process requirements had been developed. The drilling process should be constant, without any intervention of a drill operator, otherwise the results might appear corrupt. The intervention caused by rocks falling into a borehole is aimed at removing drilled solids from the borehole. In order to prevent rocks getting into boreholes, a number of well parameters, which may lead to the falling of rocks, should be taken into consideration: well depth, the amount of coal beds that well crosses, fractures, faulting or other dislocations of rocks, as well as the inclination of a borehole axis.

Keywords: *coal, ash content, mechanical logging, non-core drilling, mining*

INTRODUCTION

As far as geological conditions and quality of coal are the main parameters for coal mining [1], the geological exploration has great importance. Also, exploratory drilling as basic method, is an expensive one and takes a lot of time to perform, especially if we talk about core drilling [2]. Despite on these downsides the core drilling provides the most complete information on geological conditions and quality of coal. However, we need to keep costs down and aspire to implement methods that are able to provide all necessary information with lower costs if compared to conventional methods. According to our previous research mechanical logging can be useful in exploratory drilling as an additional or even alternative method to core drilling and other geophysical methods [3].

Mechanical logging is geophysical method that collects drilling parameters through the process of drilling a well. There is a number of parameters, such as pressure on the bottom of the hole, torque, air irrigation pressure, rotation of drilling bit, and the most important parameter: drilling velocity. Drilling velocity shows how fast drilling bit is moving through rocks. Due to certain differences between physical properties of bituminous coals and overburden rocks [4], the drilling process parameters considerably differ.

The geological survey of JSC SUEK has been using the method of mechanical logging since 2010 for estimation of depths of coal bed's roofs and thicknesses of coal beds. The practice of using it has revealed that the drilling velocity is the most useful parameter in the mechanical well logging method.

In our previous research we have found that it is potentially possible to estimate the ash content of coal beds. In this study we had a task to examine method and to find its limitations.

GEOLOGICAL SETTING

The Olon-Shibirskoye coalfield is located on the border between Republic of Buryatia and Zabaykalsky Krai and is one of two currently developing coalfields in Tugnuiskaya basin. Tugnuiskaya basin stretches out for more than 100 km from the river Kharauz in the east to the river Khilok in the west, the width of basin is 20-22 km. From the north and the south, the basin is bounded by deep tectonic faults. The basin is divided into seven synclinal structures by tectonic faults that stretch out to the north-east and north-west. One of these synclinal structures is the Olon-Shibirskoye coalfield. The coalfield is bounded by Tsagan-Dabanskiy and Zaganskiy ridge branches in the north and in the east, whereas the Kapsal anticline high bounds the coalfield in the south.

The coalfield consists of early and middle Jurassic deposits overlay the residual soil of Paleozoic granitoids. The Quaternary deposits overlay the Jurassic coal-bearing strata. Jurassic coal-bearing strata is divided into Ichetuiskaya igneous sedimentary formation ($J_{1\text{-}2\text{ič}}$) and Tugnuiskaya terrigenous coal-bearing formation (J_{2tg}).

All coal beds consist of bituminous flame coal. Coals are high quality fuel for steam-electric power generation.

MATERIALS AND METHODOLOGY

For this study we took mechanical well logging data on thirty-one boreholes. These boreholes have different parameters such as: depth, number of coal beds that were crossed, inclination and quantity of loose material near the wellhead. Using this data, we have estimated ash content and compared it with data that was obtained in the result of previous geological exploration with core samples and geophysical well logs.

Since previous research we have added more data for correlation between ash content and drilling velocity. Thereby the linear dependency is turned to be more precise then the exponential (Figure 1).

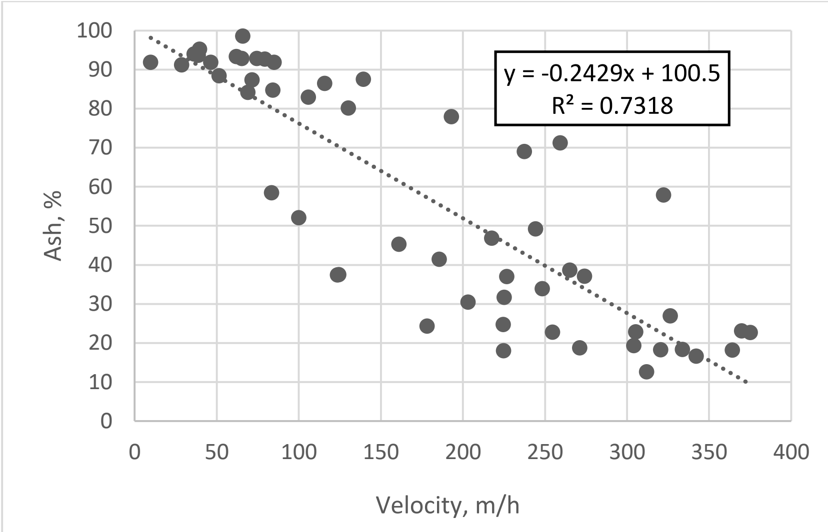

Figure 1 The drilling velocity dependence on the ash content

Also, we have examined if other drilling parameters, except drilling velocity, correlate with ash content. It turned out that pressure on the bottom of the hole, torque, air irrigation pressure, rotation of drilling bit, are not correlate with ash content (Table 1).

Table 1. Correlation coefficients between ash content and drilling parameters

Parameter	A, %
Velocity, m/h	-0.86
Pressure, atm	-0.01
Torque, atm	0.37
Air, atm	0.20
Rotation, rpm	0.11

RESULTS AND DISCUSSION

Analysis of mechanical well logging data has shown that accuracy of ash content estimation depends on different parameters of borehole such as: depth, number of coal beds that were crossed, inclination and quantity of loose material near the wellhead. These parameters control the quantity of rocks and loose materials falling into the well, that causes drill operator to slow down the drilling process in order to remove drill solids from the borehole with air flow. The most adequate accuracy of ash content estimation was found in vertical boreholes, that has a little quantity of loose material near the wellhead. One of exploratory borehole (well 1) was drilled near the borehole that was drilled on the stage of geological exploration (well 2270) so we could compare its data (Figure 2).

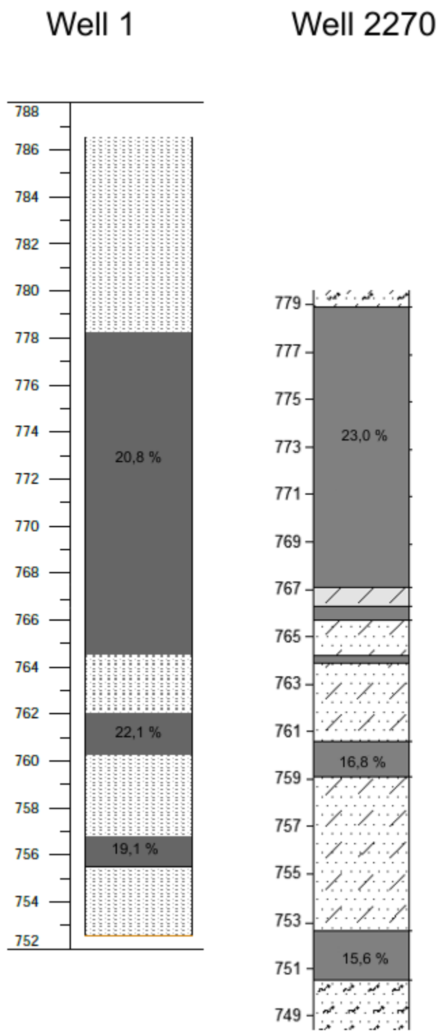

Figure 2. The comparison between two boreholes. Well 1 was drilled with implementation of mechanical logging, well 2270 was drilled with core drilling. Vertical - altitude

As we can see, the difference between ash content estimation is not exceed 5,3 %. However, we believe that this method could provide more accurate estimation. In order to reduce inaccuracy, we developed several requirements for drilling process. These requirements will prevent drill operator from intervention to drilling process.

1. All loose material should be removed from the surface where drilling will take place.
2. Boreholes should be vertical, greater inclination leads to bigger inaccuracy.
3. The deeper the borehole, the less accurate ash content estimation might be.

Obviously, the amount of analyzed data is still insufficient for precise ash content estimation. However, the current data allows to estimate the approximate ash content. The goal for the further research is to examine method with the all above-mentioned recommendations in mind.

CONCLUSION

The method of mechanical logging can be useful in exploratory drilling as an alternative or in addition to core drilling and other geophysical methods on coalfields. It can provide information about boundaries between coal and overburden rocks, in addition we have shown that we are able to estimate ash content in coal. Our priority goal is to improve accuracy of this method.

Also, we have developed several drilling process requirements that will provide more accurate data. For this purpose, the following should be taken into consideration in process of drilling: well depth, the amount of coal beds that well crosses, fractures, faulting or other dislocations of rocks, quantity of loose material near wellhead, as well as the inclination of a borehole axis.

Besides above-mentioned, the further research will also concern following issues:

1. possible methods of the evaluation of moisture, fracturing and other parameters of coal;
2. dividing the overburden rocks by their composition;
3. the estimation of the geological setting of the coalfield and the tectonic dislocations.

Thus, this paper shows the experience of implementation of the mechanical logging method on the open pit coal mine.

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IS THERE A FUTURE FOR OIL AND GAS EXPLORATION IN ROMANIA ?

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ABSTRACT

Romania is classified as a mature hydrocarbon province, but it is still the most important producer in the Central and South-Eastern European countries. Oil production in Romania has steadily declined overtime. Even if the earlier discovered fields have a high rate of depletion and the new discoveries do not compensate entirely the consumption, Romanian sedimentary basins have petroleum prospectivity. Thus, significant hydrocarbon potential remains in exploration, near-field opportunity and field rehabilitation.

Significant oil exploration potential is still present in Romania. The general trend is near-field opportunity, going deeper and applying new technologies (3D seismic surveys, regional long-offset 2D lines for structurally complex and deep leads/prospects, AVO analysis of shallow targets and 2D/3D structural balancing) and new concepts (subtle traps).

There is still an ongoing effort to redevelop mature oilfields in Romania; currently are used technologies as directional drilling, steam injection, water injection, polymer injection, and in-situ combustion.

Romanian hydrocarbon basins have still areas with oil and gas resources entrapped in all kind of traps, especially subtle ones, and there is a great chance for new commercial discoveries. Potential new discoveries in Romania of conventional oil and gas fields are connected with foreland plays in little explored deep, subtle traps, deep overthrusted structures and deep offshore area. New oil and/or gas fields could be discovered at shallower depths in traps overlooked as a consequence of poor seismic results or insufficient research. The resource appraisal simulation for petroleum prospects analysis in Romania confirmed that the new prospects are primarily gas prone.

The skills and the ability of exploration geoscientists will play an important role in any future success. The current Romanian proved reserves of 600 MMBOE oil and 100 BCM gas could be significant improved in the next years.

In the paper we are underlined some future targets in the exploring for oil and gas in the main Romanian hydrocarbon basins.

Keywords: *Romanian hydrocarbon basins, oil and gas resources, oil exploration potential, future targets, new technologies*

INTRODUCTION

Romania is one of the most important hydrocarbon provinces of Central and South Eastern Europe. Oil production started in 1854 and since then over 950 oil and gas fields have been discovered. The cumulative oil production exceeded 5.30 billion barrels oil whereas cumulative gas production exceeded 44.2 trillion cubic feet. [1], [2]

In the geological framework of the Romanian territory, the major structural element is represented by the Carpathian Orogen, part of the greater Alpine Orogenic belt. In front of the Carpathians there are located the platform areas (Moldavian Platform, Scythian Platform, and Moesian Platform). Between East and South Carpathians and the foreland, the Carpathian Foredeep (Pericarpathian Depression) is defined (in its turn divided in Miocene Zone, Diapir Folds Zone, and Getic Depression). The three branches of the Romanian Carpathians confine the Transylvanian Basin and, in the western part of Romania the Pannonian Basin is developed.

The major structural units with hydrocarbon potential correspond to the orogenic type basins (Transylvanian, Pannonian, Carpathians Flysch and Molasse), or to the foreland type basins (Moldavian Platform, Moesian Platform, Western Black Sea Basin). We can talk about thermogenic petroleum systems (Carpathian, Pannonian, Moesian, Euxinic), or biogenic ones (Transylvanian, Pericarpathian, Euxinic) (fig. 1). [3]

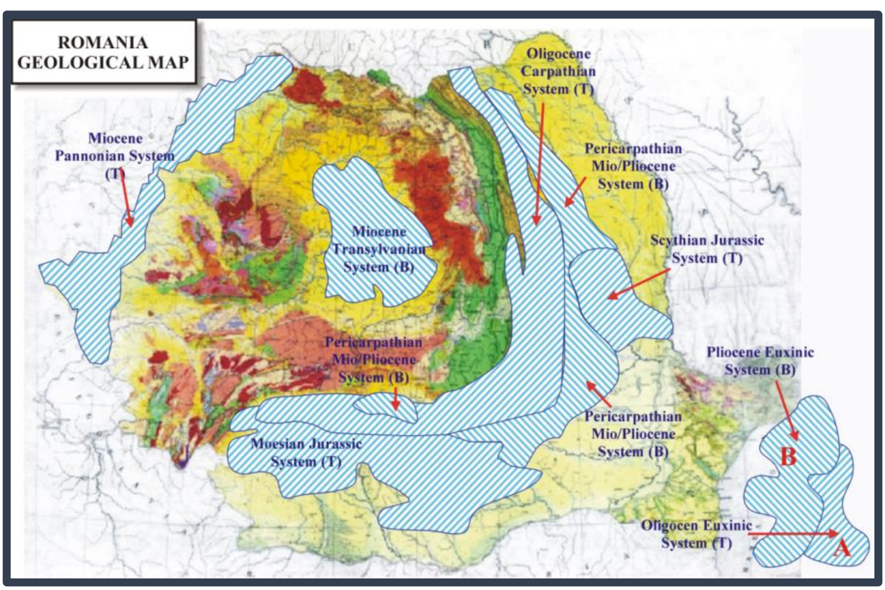

Figure 1. Distribution of petroleum systems in Romania. [3]

GEOLOGICAL SETTING

Eastern Carpathians. The outermost Eastern Carpathians are thin-skinned nappes built by Late Cretaceous to Early Miocene foredeep sediments thrusted over the Eastern European margin during the Miocene. This was a typical soft collision process where deformation was accommodated by thin-skinned in-sequence deformation. Later, in the Pliocene, due to the locked collision boundary, thick skinned inversion of basement structures occurred along with crustal-scale folding and uplift of the entire Carpathian Orogen. The petroleum system consists of Oligocene and Lower Miocene source rocks (menilite and dysodile shales), Paleogene to Lower Miocene turbidite sandstone reservoirs, and traps formed by structural closures, mostly faulted anticlines. [1], [2], [3], [4], [5], [6]

Diapir Folds Zone (Eastern Carpathian Foredeep) is so far the most prolific hydrocarbon province in Romania. During more than 100 years of exploration and production, over 50 oil and gas fields in the Pliocene, Miocene, and Oligocene have been discovered in the region. Diapir Folds Zone is characterized by the presence of salt-cored folds. Generally salt tectonics resulted in forming of asymmetric faulted anticline, faulted monocline, thrust folds. The petroleum system consists of Oligocene dysodiles shales and menilites considered the main hydrocarbon source rocks and Neogene black marlstones and claystones are likely secondary sources; all are thought to be at their maximum thermal maturation. The oil and gas are stored in Oligocene to Upper Pliocene reservoirs in structural or combined traps. [1], [2], [3], [4], [5], [6]

Getic Depression is also one of the most prolific areas for hydrocarbons in the Carpathian Orogen and evolved during Tertiary time as foredeep of the Southern Carpathians. The overall compressional tectonic regime was manifested by mostly thin-skinned in-sequence deformation of which the magnitude increases from west to east. Thick-skinned inversion of former extensional faults has been observed as well, mainly in the western part of the basin. The petroleum system consists of Oligocene marine source rocks that produce oil and gas stored in Oligocene to Pontian reservoirs in structural or combined traps. Trap formation is Middle Miocene with a minor reactivation during the Late Pliocene event. [1], [2], [3], [4], [5], [6]

Transylvanian Basin is a relatively cold back-arc basin known as a biogenic gas province. The biogenic gas is sourced from deep-marine Middle Miocene shales and is stored in multi-stored turbidite reservoirs in structural traps, frequently salt-cored folds. Exploration started 100 years ago and more than 80 gas fields were discovered in the so called “gaseiferous“ formation which includes over 3,000 meters of Badenian, Sarmatian and Pliocene deposits. [1], [2], [3], [4], [5], [6]

Pannonian Basin is a Miocene extensional back-arc basin system. The petroleum system is represented by Middle Miocene oil-prone syn-rift lacustrine shales source rocks and weathered basement rocks, shallow marine syn-rift reservoirs and Late Miocene post-rift turbidites reservoirs. Most discoveries lie in structural closures – faulted blocks or drape folds over basement highs. Stratigraphic traps are predominantly in Late Miocene turbidites that onlap basement highs. [1], [2], [3], [4], [5], [6]

Moesian Platform is also one of the most prolific petroleum province in Romania. The platform was involved in Paleozoic and Triassic compressional deformations, Permian-Triassic and Jurassic extension, and were weakly affected by the closure of the Alpine Tethys. The petroleum system are represented by Paleozoic and Mesozoic source rocks characterized by an effective thermogenic-medium geothermic gradient that produced oil, gas and condensate stored in Paleozoic to Pliocene reservoirs. [1], [2], [3], [4], [5], [6]

Moldavian Platform which represents the west-southwestern part of the East European Platform, is the oldest platform unit in Romania. The Moldavian movements generated a folded, complex tectonic structure in molasse deposits, and led to their overthrusting over the descending foreland, along a NNW-SSE system faults. The petroleum system consists of Paleozoic shales and Miocene shales source rocks that produced hydrocarbons (especially gas) stored in stratigraphic or combination traps of the Miocene clastic reservoirs (sourced mostly by Sarmatian shales). [1], [2], [3], [4], [5], [6]

Western Black Sea Basin represents the Cretaceous back-arc of the Pontides and is one of the most promising hydrocarbon-bearing areas in the South-East Europe. Its hydrocarbon potential has been proved by the oil and gas fields discovered on the Romanian shelf. The Western Black Sea Basin is characterized by a variety of traps and reservoirs. Two different petroleum systems are recognized in the Western Black Sea Basin: Mesozoic (thermogenic) and Pontian (biogenic). The Mesozoic petroleum system consists of an oil-rich source, likely Early Cretaceous, which charge Mesozoic and Eocene limestones. This system is likely over-mature in the deep offshore. The Pontian petroleum system is formed by dry-gas found in deltaic sands on clinoform topsets. Some of this gas is biogenic sourced by Pontian shales, but thermogenic components are present, likely charged by the Oligocene. [1], [2], [3], [4], [5], [6]

FUTURE TARGETS IN OIL AND GAS EXPLORATION

Eastern Carpathians. Exploration targeted relatively shallow traps with more than 50 oil and a few gas fields being discovered. Current exploration continues to look for opportunities in the shallow section, but also considers near-field opportunity and going deeper, where potentially large gas structures exist. The presence of these is suggested by seismic data backed by structural balancing. These deep structures (fig. 2) developed in the Oligocene-Early Burdigalian and were subsequently modified by continued deformation on deeper detachments. [1], [2], [3]

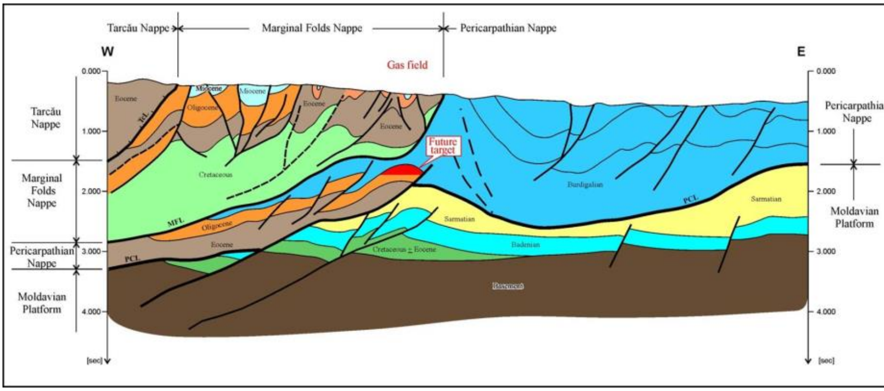

Figure 2. Geological cross-section in the Eastern Carpathians. [7]

Diapir Folds Zone. Analysis of geophysical and wells data in conjunction with information from the literature indicates that Oligocene-Lower Miocene source rocks played the most important role in thermogenic hydrocarbons bearing. So far the Oligocene deposits of high and even medium depths did not have results comparable with the potential of hydrocarbons generation and the volume of traps. Future exploration targets (fig. 3) are representing by near-field opportunity and Tertiary deep faulted anticlines, roll-over anticlines, truncations and pinch-outs, paleovalleys. [1], [2], [3]

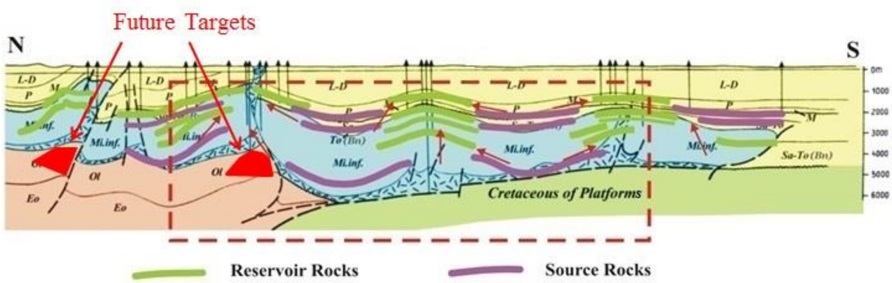

Figure 3. Geological cross-section in the Diapir Folds Zone [3]

Getic Depression. Exploration focused on relatively shallow depths (2-4 km), where large undiscovered traps are unlikely to exist to date. New play concepts focused on deeper levels (4-6 km, i.e. the Paleogene of the Getic Basin and the Mesozoic of the under thrusted Moesian Platform), where potentially large gas accumulations are present. This is suggested by the current – yet low quality seismic data, backed by new balanced structural models and basin modeling. Future exploration targets (fig. 4) are representing by near-field opportunity and Tertiary deep faulted anticlines, roll-over anticlines, truncations and pinch-outs, paleovalleys. [1], [2], [3]

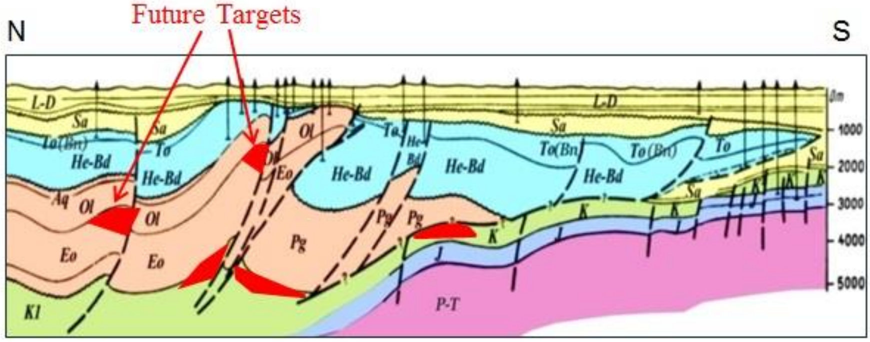

Figure 4. Geological cross-section in the Getic Depression [3]

Transylvanian Basin. Today, limited exploration potential is left in structural closures. Most prospective areas (fig. 5) are the slope channels and fans in the northern and eastern part of the basin, subsalt Mesozoic and Paleogene formations in structural traps in the center part. [1], [2], [3]

Pannonian Basin. Future exploration targets (fig. 6) are associated with structural or stratigraphic traps in the deeper Miocene, paleo-deltaic systems or roll-over structures of Upper Miocene-Pliocene. The “basin-center tight gas” play that is currently explored in the Hungarian part of the basin extends into Romania as well. [1], [2], [3]

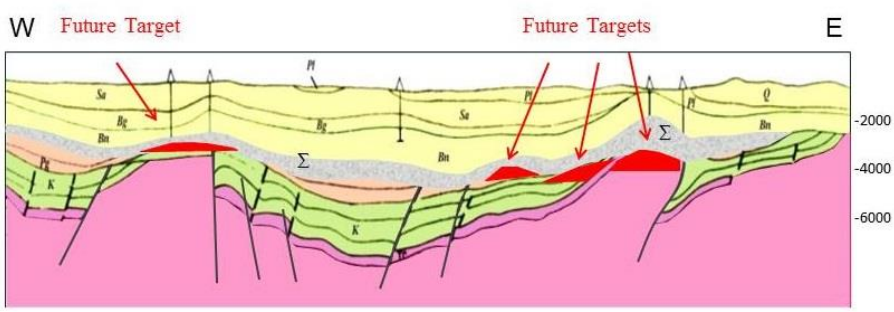

Figure 5. Geological cross-section in the Transylvanian Basin [3]

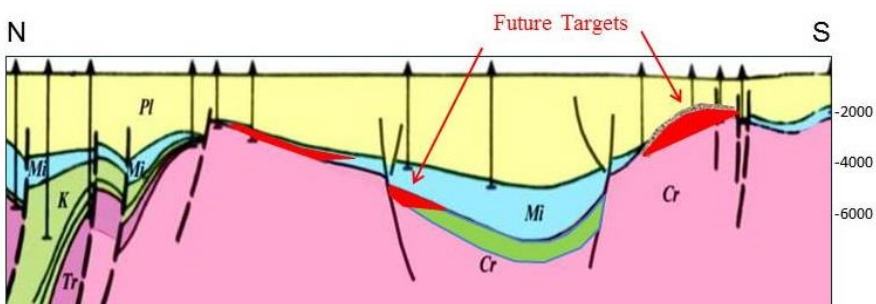

Figure 6. Geological cross-section in the Pannonian Basin [3]

Moesian Platform. The unconventional shale gas potential of Silurian to Lower Devonian and Middle Jurassic shales is being investigated. The most prospective areas of the platform are the Permian to Triassic rift shoulders because the shales seems to be in the gas window and relatively shallow for drilling. For the future, near-field opportunity and, in the platform southern part, the subtle traps in carbonate deposits (facies variations, karst phenomena, diagenetic processes) are very important. [1], [2], [3]

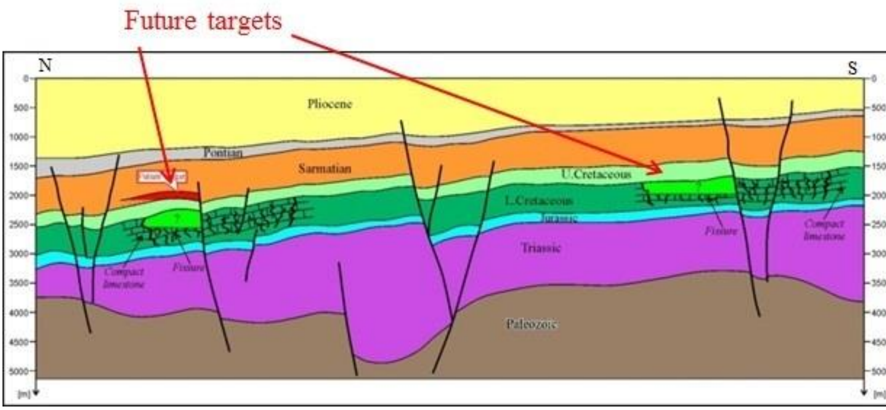

Figure 7. Geological cross-section in the Moesian Platform [3]

Moldavian Platform. The western part of the Moldavian Platform at the contact with East Carpathian Orogen proved to still contain many hydrocarbons prospects, especially gaseiferous ones in deep Badenian and Cretaceous faulted anticlines or in deltaic Sarmatian sediments. [1], [2], [3]

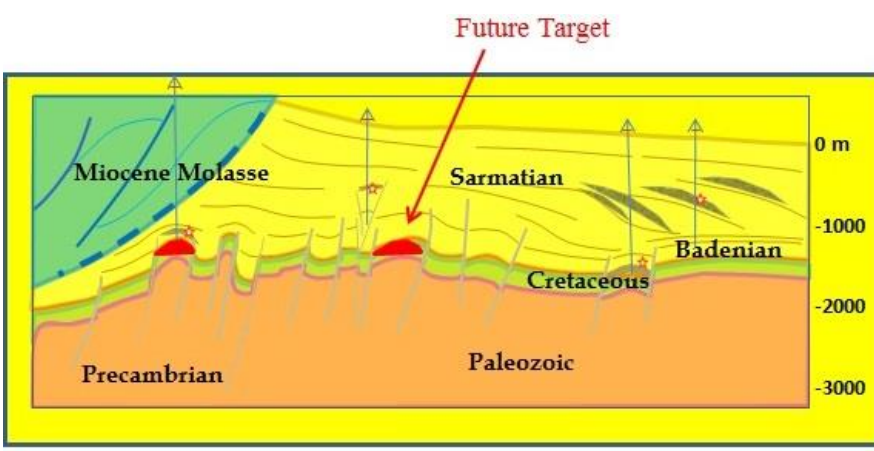

Figure 8. Geological cross-section in the Moldavian Platform [3]

Western Black Sea Basin. The basin presents conditions for biogenic gas accumulation in Upper Pliocene/Pontian sands, clay sands and thin sandstones in large anticlines, or in subtle stratigraphic traps (turbidites, paleovalleys). The source rocks can be the hemipelagic Upper Miocene-Pliocene lutites deposited during transgressive events, in medium geothermal gradient conditions. The main traps are structural type and are related to euxinic threshold. Recent 3D basin modeling results confirm that the Maykop section is in the early oil to wet gas window in the deeper part of the Romanian Black Sea and is getting more mature towards the central parts of the basin. The expulsion of hydrocarbons has started during the Late Miocene and is ongoing today. Current exploration continues in the shallow section, but there are attempts to open new plays represented by slope and basin-floor fans located farther offshore in the basin. [1], [2], [3]

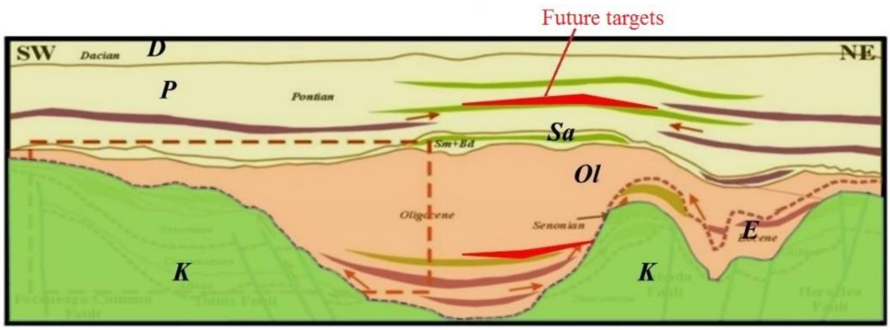

Figure 9. Geological cross-section in the Western Black Sea Basin [3]

CONCLUSIONS

In the Romanian territory, the most of the geological units of the Carpathians (especially the External Carpathians) and their foreland gathered the geological, geochemical and thermodynamic requirements for oil and gas generation, accumulation and preservation. Romanian hydrocarbon basins have still areas with oil and gas resources entrapped in all kind of traps, especially subtle ones such as structural uplifts, deep faulted anticlines, paleo-deltaic systems, turbidites, truncations, pinch-outs, channels, reefs, diagenetic structures, strike-slip structures, diapir structures.

Romania is classified as a mature hydrocarbon province, but significant hydrocarbon potential remains in exploration, near-field opportunity and field rehabilitation. Significant oil exploration potential is still present in Romania. The general trend is near-field opportunity, going deeper and applying new technologies (3D seismic surveys, regional long-offset 2D lines for structurally complex and deep leads/prospects, AVO analysis of shallow targets and 2D/3D structural balancing) and new concepts (subtle traps). Regarding field rehabilitation the most beneficial technologies are 3D seismic, directional drilling, fracturing stimulations and enhanced oil recovery.

The skills and the ability of exploration geoscientists will play an important role in any future success. The current Romanian proved reserves of 600 MMBOE oil and 100 BCM gas could be significant improved in the next years.

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SOME ASPECTS REGARDING THE UNDERGROUND STORAGE OF NATURAL GAS IN SALINE DEPOSITS

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ABSTRACT

Natural gases represent the energy which can be stored in large quantities, in the same state as that in which it is used to the final consumer, without being subject to the transformations and disruption. One of the fundamental problems of gas industry is taking over the peaks of hourly and seasonal consumption, caused by the random nature of the gas demand, depending on the nature of the industrial consumers (with a relative constant gas demand) and those non-industrial (mainly household consumers with large hourly and seasonal fluctuations) and the possibilities of import, with approximately uniform and limited capabilities, in the period of day or all of the cold season.

The underground storage of natural gas represents a solution for gas supply of consumers in the case of damages to the pipelines, and the coverage of the peaks of consumption in cold season. Compensations for the required gas flows for heating are doing by transferring from the fields with a high dynamic potential in an underground storage near the big consumers.

The construction of the cavern in the saline deposits in view of the underground natural gas storage shall be made by the deep wells with direct or indirect circulation. By direct circulation, freshwater is injected through the working space with the smallest diameter, and the brine is evacuated in the annular space. The advantages of this method are: (1) eliminates the danger of dissolution of the salt from the surrounding area of the shaker of the last column cemented, due to the near-saturation concentration of ascended brine; (2) reducing the consumption of the insulating fluid given the lower cross-sectional diameter of the cavern ceiling; (3) performing a cavern of ovoid elongated shape with a maximum cross-sectional diameter at the base. By reverse circulation, freshwater is pumped in the annular space between the two casings, and the brine is evacuated in the casing with the smallest diameter. The advantage of this method is development of high ascending speeds in the inside of the casing with a small diameter, ensuring an efficient evacuation of insoluble material which will be deposited at the cavern bottom.

The underground gas storage in the saline deposits has the following advantages: (1) the large area of salt bodies spreading on the Earth; (2) the duration of the production process is few weeks, being possible to carry out several cycles per year; (3) the operating costs are lower than in the depleted reservoirs or aquifers.

In the paper the authors reviews some aspects regarding the underground storage of natural gas in the saline deposits in terms of selections criteria of salt cavern, designing, drilling technology, factors of stability, salt cavern deformation, production behavior.

Keywords: *saline deposits, underground gas storage, selection criteria, cavern designing and construction, stability and production behavior*

INTRODUCTION

Underground storage of natural gas is a practical solution for: (1) gas supplying of consumers in case of the damages of large gas pipelines, by temporary replacement of primary gas sources, (2) balancing of gas consumption – domestic gas production – natural gas import over a year with direct consequences on natural gas purchase prices and the attractiveness of the contracts, (3) coverage of peaks consumption in the cold season by balancing the gas flows required for heating; (4) transfer of gas from fields with a high dynamic potential into underground storages near major consumers.

Underground storage of natural gas in saline deposits is easier to apply because: (1) the salt deposit has a low permeability (10^{-21}-10^{-24} m^2) which allows good sealing; (2) has good mechanical properties; (3) is soluble in water, which makes the cavern easier to build; (4) large salt deposits are spreading on the Earth. [1]

GEOLOGICAL AND TECHNOLOGICAL SETTING

Selection criteria of the saline deposits for underground gas storage. In order to be eligible for underground storage of natural gas, saline deposits must meet some selection criteria. Thus, the caverns formed in the salt massifs for the purpose of natural gas storage used in various projects around the world (Germany, Portugal, China) have the following characteristics [2]:

1) depth: 1000-3000 m;
2) thickness: tens to hundreds of meters;
3) volume: 30,000,000-500,000,000 m^3;
4) pressure gradient at the shoe of the operating casing: 1.50-2.50 bar/10 m;
5) pressure gradient at the average depth of the cavern: 2 bar/10 m;
6) pressure: 25-225 bar.

Design and building of a salt cavern. Usually, building of a salt cavern by dissolution/leaching consists of exposing the salt deposits in a drilled hole, inject fresh water in the hole, allow time for dissolution and disposal of the resulting brine from the hole. As the salt dissolves, the hole enlarges into the form of a cavern.

The following phases are recorded for building of the salt caverns: (1) selection of the location; (2) drilling and casing of the wells; (3) salt sealing; (4) brine disposal; (5) wells completion; (5) cleaning the cavern and filling; (6) final trials; (7) operation. [3]

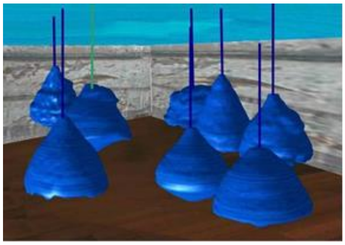

Fig. 1. The shapes of several existing salt caverns of Jintan salt mine. [4]

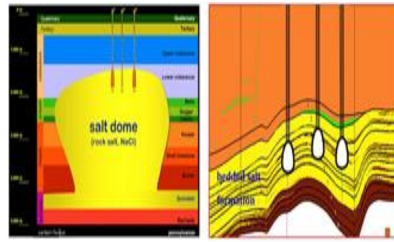

Fig. 2. Salt caverns in different salt deposits. [5]

The technology of building the salt cavern. Building of a salt cavern is done by deep wells by means of the freshwater circulation. The wells are equipped with two concentric tubing strings, the outside string for protection and the inside string for injection or evacuation. Two methods are used to salt dissolution through pumping of freshwater:

1) *Direct circulation*: freshwater is injected through the working space with the smallest diameter, and the brine is evacuated in the annular space. The advantages of this method are: (1) eliminates the danger of dissolution of the salt from the surrounding area of the shaker of the last column cemented, due to the near-saturation concentration of ascended brine; (2) reducing the consumption of the insulating fluid given the lower cross-sectional diameter of the cavern ceiling; (3) performing a cavern of ovoid elongated shape with a maximum cross-sectional diameter at the base. [6]

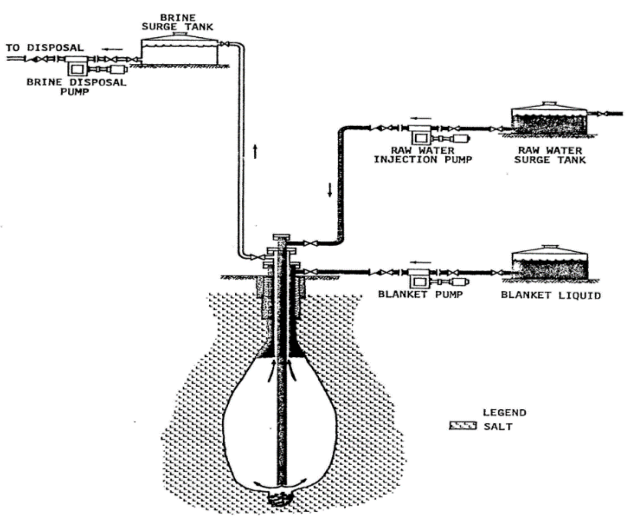

Fig. 3 Salt cavern building using direct circulation. [6]

2) *Reverse circulation*: freshwater is pumped in the annular space between the two casings, and the brine is evacuated in the casing with the smallest

diameter. The advantage of this method is development of high ascending speeds in the inside of the casing with a small diameter, ensuring an efficient evacuation of insoluble material which will be deposited at the cavern bottom.

In order to make an upper limit in the vertical dimensioning of the salt cavern and to prevent dissolution of the salt around the last cemented casing, a light nonleaching and noncorrosive fluid is injected into the annular space between last casing and production tubing. The inert fluid blanket may be a type of liquid petroleum products, liquefied gases or air. When brine is discharged into the sea or other waters, the inert fluid blanket is propane-butane which is separated and released into the atmosphere, making it environmentally and economically.

The salt leached caverns are connected to the surface via concentric tubing strings for moving the natural gas in and out of the cavern. At the surface level the well-head, equipped with valves, occupies a very limited space, and all associated piping is buried underground. The pumping facilities, metering equipment and related support facilities such as control buildings and fire protection systems are centralised into a single area thus ensuring minimal land occupation and environmental impact.

Factors that influence the dissolution process. Among the most important factors that influence salt saturation of fresh water are: (1) pumped flow rate; and (2) diffusion phenomena occurring at the wall of the cavern.

Within the pumped flow rate, meaning the circulation flow, the saturation of the fresh water through its circulation has a very large weight in the dissolution process [7] and is determined by:

1) Fluid temperature differences in the cavern and thermal balancing tendencies. These temperature differences that exist between freshwater injected and almost stagnant brine in the cavern lead to thermal convection phenomena and therefore also to an internal secondary circulation between fluid packages with different temperatures.
2) The tendency of the gravitational separation of the fluids from the underground storage depending on the density, namely the degree of saturation. Due to the lower density the fresh water or unsaturated packages tend to rise in the tank before the densest. Their movement leads to a stirring with a tendency to uniformity of saturation, and hence an internal secondary circulation between the brine packages of different concentrations, and due to these phenomena, the salt wall remains in constant contact with an unsaturated fluid.
3) Chemical composition and solubility of elements forming the mineralogical complex under development. The chemical composition of the rock directly influences the dissolution rate of the solid salt, which can vary within appreciable limits. Prior to the launch of such a project, it is necessary to analyze the cores from the interval during which the underground deposit is to be made, for the determination of the mineralogical composition and the dissolution rates.

4) Pressure gradients that appear in the store during circulation. They lead to different flow rates in the cavern sections and secondary circulation by replacing fluid from the wall with a less saturated fluid. The phenomenon is significant only in the first stage, because with the increase of the deposit diameter, its efficiency decreases.

GEOTECHNICAL SETTING

Factors that influence the stability of salt caverns. Building of salt caverns for gas storage purposes involves assessing as accurately as possible the structural behavior of the underground openings, their size and the deformation velocity of the salt at relatively constant temperatures for long periods of time.

The use of salt caverns created by salt dissolution involves, when it is put into operation, replacing the brine with the gas to be stored and vice versa. The life span of gas deposits in salt caverns is closely correlated with their stability over time and implicitly with the mechanics of the salt massifs. In the salt massif, the creation of a cavern causes redistribution of tensions in time and space and in the same time generates a field of displacements, which is also dependent on time and space. Tensions and displacements are influenced by several factors, so there is another type of salt behavior in each area of interest studied. [8]

Cavern stability is assessed by quantifying these stress and strain states generated during salt dissolution and during operation as deposits. There are two phases in redistributing tensions around the salt cavern [7]:

1. Phase I is generated by the brine pressure during the cavern building. In this case the pressure generated by the brine limits the manifestation of pressures from the salt massif, but caverns can be destroyed by block dislocation, depositing at the base of the cavern and leading to changing of its shape and size;
2. Phase II is generated by the cavern acting as a gas storage when cyclical pressure changes occur in the cavern, the pressure having maximum values during natural gas extraction.

The state of tension is changing during the gas injection to strengthen the cavern walls due to the increase in the pressure of the natural gas. During the gas extraction, high values of concentrated stress occur in the direction of decreasing the resilience potential of the cavern walls. The extraction of the gas can be done at constant volume or under constant pressure, in which case geomechanical phenomena specific to each process can occur. These phenomena that overlapped with the effects generated by each process, amplified the damage around the cavern.

If the effect of changing the tension state can be considered to be approximately constant for each cycle, the secondary effect that accompanies it will have an increasing intensity. The lower the minimum pressure of the gas in the cavern and the longer the value of the gas, the more the fissures and breakage areas will be more pronounced. The cumulative effects that lead to the structural weakening of the salt massif around the cavern are loss of tightness, in which case it would compromise the storage quality.

In the building of the salt cavern for the underground storage of natural gas an economic analysis of the potential losses must be made. These losses may be: (1) irrecoverable losses, which are the amount of natural gas assimilated to the walls of the cavern due to the permeability of the salt massif; (2) partially recoverable losses, represented by the quantity of natural gas solubilized in brine; (3) fully recoverable losses, represented by the amount of natural gas to be left in the cavern to maintain its stability. [8]

Calculation of cavern deformation. Due to the minimal pressure in the cavern during emptying, problems arise in establishing the cavern and preventing deformation due to salt plasticity. This phenomenon is called convergent deformation and determines the gradual loss of the useful volume of the cavern.

The equations describing this phenomenon take into account the deformation of the cylinder or the sphere cavern shape and have the following formula [7]:

$$\frac{\Delta V}{V} = -200 \times A \times \exp\left(-\frac{Q}{RT}\right) \times \left(\frac{\sqrt{3}}{2}\right)^{n+1} \times \left[\frac{2(P_0 - P_i)}{n \times \sigma_c}\right]^n \times t \quad \text{(cylinder shape)}$$

$$\frac{\Delta V}{V} = -150 \times A \times \exp\left(-\frac{Q}{RT}\right) \times \left[\frac{3(P_0 - P_i)}{2n \times \sigma_c}\right]^n \times t \quad \text{(sphere shape)}$$

where:

A, *Q* and *n* – parameters that depend by the temperature and the considered model;
T – absolute temperature in the salt deposit;
P_0 – triaxial pressure “in situ” (approx. 2 bar/10 m depth);
P_i – pressure in the cavern (bar);
R – salt constant (cal/mol·K).
σ_c – constant for effort in the stabilized material (kg/cm)

Reducing salt caverns spreads in all directions and reaching to the surface can cause the subsidence phenomenon with negative effects on the environment.

Typically, the calculations for modeling the cavern in the salt massifs use the following values:

R = 1.98 [cal/mol·K]
σ_c = 0.07 [kg/cm]
A = $3.27 \text{x} 10^{-17}$ [in/in per sec]
Q = 12,900 [cal/mol]
n = 5

These values were determined in the laboratory researches after various analyses of salt samples collected by the operating wells.

CONCLUSIONS

Underground gas storage is an efficient process that combines the constant supply of natural gas through transport pipelines with variable market demands that depend on season or economic considerations.

Besides the function of covering the consumption peaks, underground gas deposits also have the strategic role of ensuring the supply of gas in case of emergencies (natural disasters, earthquakes, etc.). In warm season, when pipeline transport capacity exceeds consumption demand, natural gas is stored to be extracted most often during the cold season, when gas consumption increases greatly, or according to the economic considerations of that period. Coverage of seasonal consumption peaks can be done by underground gas storage located near major consumer centers.

The underground gas storage in the salt caverns has the following benefits: (1) the large area of salt massifs spreading on the Earth; (2) small cushion gas requirement (≈ 20-30%); (3) high deliverability rate; (4) short duration of the production process (10-20 days), being possible to carry out several cycles per year; (5) the operating costs are lower than in the depleted reservoirs or aquifers.

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VENTILATION SYSTEMS IN LONGWALL WORKINGS WITH A POWERED LONGWALL COMPLEX

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ABSTRACT

One of the main problems when carrying out underground mining is to ensure an adequate amount of fresh air in mining excavations. In particular, this applies to longwall workings with powered longwall complexes. These high-performance machine sets enable fast and efficient mining of the rock mass along with the transport of output outside the face zone. The factor affecting their efficiency and effectiveness is adequate ventilation of excavations. The article presents the analysis of ventilation methods of longwall excavations in hard coal mines in Poland and modern systems of registration and monitoring of ventilation parameters in longwall excavations. These solutions require the use of advanced IT and telecommunications solutions. It conforms to the ideas of industry 4.0, which are increasingly used in mining. The practical application of cyber-physical systems can significantly improve the safety and efficiency of mining operations. The example presented in the paper concerns a new longwall excavation, prepared for operation. The use of digital recording and data transmission systems enables the current diagnosis of the methane hazard. The presented concept and research results should improve the efficiency of the entire mining process.

Keywords: *methane hazard, ventilation, industry 4.0, mining*

INTRODUCTION

Underground hard coal mining is increasingly applying high efficiency longwall systems. They consist of a mining machine, a longwall conveyor and a powered roof support). The mining process is related to various types of natural and technical hazards, due to its intensity and operation of deeper layers. In order to ensure the continuity of the operation process and its safety, it is necessary to properly recognize and project these hazards. This requires the use of modern techniques, technologies, devices and machines, as well as appropriate knowledge about phenomena that are linked with the mining exploitation process is required. One of the most dangerous hazards related to the mining process is methane hazard [3], [8], [9]. Methane content in coal seams greatly impacts on the safety of people and machines. This hazard arises as a result of the release of methane during the mining process. Determining the methane content in coal seams is an important step to assess the methane hazard in the seam. This particularly refers to new seams. In the last 10 years (2009-2018) there have been 8 tragic events around the world caused by methane. As a result, 541 miners were killed. Three hundred and one people were killed in an accident in Turkey in 2014, which is the event in the mine caused by methane that resulted in the highest number of deaths. Other accidents with high number of deaths took place in Poland in 2009, 20 miners, an, in Russia in 2010, 66 victims. In the same year in the United States 29 miners were killed [12]. It can be concluded that methane is a highly dangerous gas and constitutes a real threat to mining operations.

The mines with the highest methane level in 2016 in Poland were KWK Budryk (146 million m^3 CH_4) and Pniówek (103.96 million m^3 CH_4) [5]. The amount of methane emitted in hard coal mining is high due to the increasing depth of exploitation, higher methane content of deeper seams, occurrence of a "pocket" of methane trapped under pressure in the zones of tectonic disturbances and high concentration of extraction.

The article presents a new approach to ventilation of longwall excavations. Currently applied methods of ventilating a longwall excavation are discussed including their advantages and disadvantages. An example of determination of ventilation parameters for a newly designed longwall in the conditions of a high methane hazard in the mine of Polska Grupa Górnicza SA was also presented. The article should be treated as an introduction to the analysis of the effectiveness of ventilation of underground excavations.

CHARACTERSTIC OF APPLIED VENTILATION SYSTEMS

The factor significantly impacting on the safety of persons working in underground coal mines is effective ventilation of these excavations. The main purpose of ventilation of excavations is to provide fresh air to the crew and reduce the gas hazard associated with the operation. Among natural hazards, the most important from the point of view of ventilation safety are methane and fire hazards [1], [2], [3], [10]. The methane hazard and the fire hazard are examples of associated hazards, strongly related to each other. When selecting the method of ventilation in the longwall, mining ventilation services have to often select the be safer and more effective system in the case of the co-occurrence of both these hazards. Generally, the ventilation method, which is better suited to eliminate methane hazard, is less beneficial if there is a fire hazard. This problem occurs mainly in case of a goaf, a highly porous medium, subject to both types of hazard [1], [2], [6], [10].

Ventilation of longwall workings is aimed at distributing air in the walls in such a way as to limit the flow of methane to excavations, increase the temperature and effectively dilute the gases and dust that occur there. The extraction longwalls are ventilated using various methods, including longwall walkways [7], [11]. The most frequently used methods of ventilation are the U, Y and Z methods as well as the H method which requires maintaining longwall walkways. There are two types of methods to carry out the ventilation. The first one runs starting from the borders of the field of exploitation. The second one runs towards the borders. The U method of ventilation of the exploitation longwall is shown in Figure 1a.

The air in the U system is supplied and discharged from the longwall through main gates. It is in contact with goafs along their entire length, hence it is necessary to seal them. The main advantage of this method is the possibility of simultaneous carrying out preparatory works and coal exploitation. This method has a positive effect on the mining process carried in the areas where the rock burst hazard occurs. In the case of high intensity of air flow through the goafs, the fire hazard increases, which is a fundamental disadvantage of this method of ventilating. This system is not recommended when level of methane in the longwall is very high, with a relatively high temperature increase and because of the danger of spontaneous ignition of coal in the caving.

a) b)

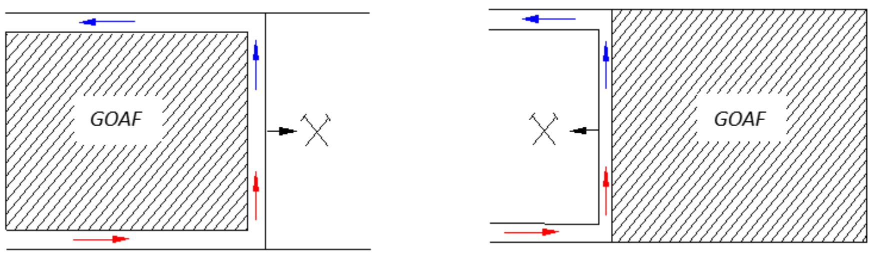

Fig. 1. Schemes of U ventilation systems that reach the borders of the field of operation (a) and applied starting from the borders (b)

In the U ventilation system applied starting from the field borders (Fig. 1b), the air is supplied through the bottom gate and transported away through the top gate. This method of ventilation of the longwalls has two basic advantages, namely, there is a limited air flow through the goafs, and as a result, a limited fire risk in the goafs. The advantage of this method is also the ability to recognize changes in the methane content of the seam. Disadvantages of this method of longwall ventilation include elevation of methane and thus an increase of methane hazard at the outlet from the longwall and the necessity of using additional ventilation devices at the intersection of the longwall −ventilation gate [1], [2], [3], [4]. The disadvantage of this ventilation system is also the supply of heat to the wall of goafs.

a) b)

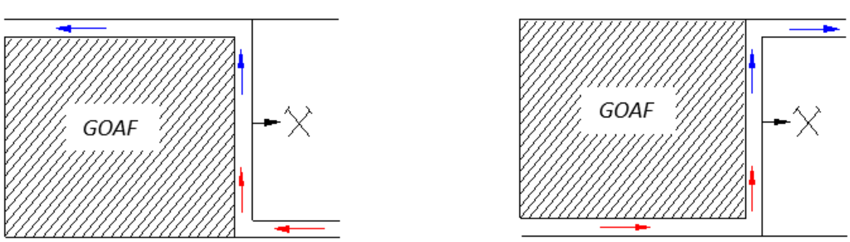

Fig. 2. Schemes of U ventilation systems and applied starting from the borders (a) and that reach the borders of the field of operation (b)

In the Z ventilation system running from the field boundaries (Fig. 2a), the air flowing through the extracted longwall is in contact along its entire length with the goafs and top gate adjacent to the goafs. The air stream with methane does not accumulate in the longwall, because it only flows out in the top gate, which results in a smaller methane hazard in the longwall. The main drawback of this method of ventilation is the possibility of free flow of air through the goaf for a long period of time which increases the fire hazard in the goaf and leads to an endogenous fire.

In the Z system reaching the borders (Fig. 2b), the air stream supplied to the longwall through the bottom gate also influences the goaf and elutes the accumulated methane. It causes that the mixture of gases flowing through the longwall creates a serious methane hazard in the upper section of the longwall. The temperature of air flowing through the goafs can be very high thus creating unfavourable climatic conditions in the longwall. The air migrating to goafs also may lead to fire. This system is not beneficial in case of any ventilation hazards.

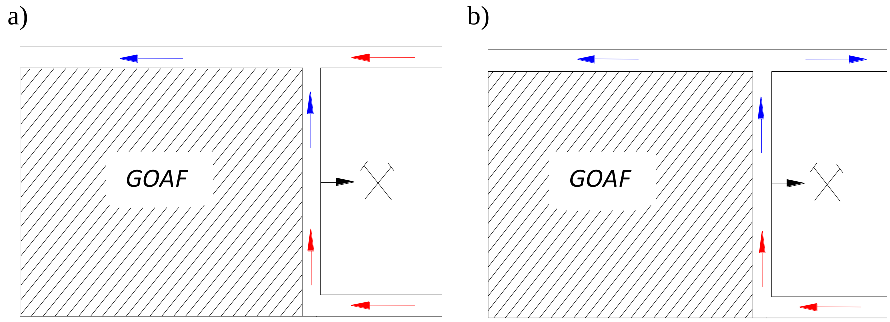

Fig. 3. Schemes of Y ventilation systems with reblowing through the top gate (a) and with the air discharge in two directions (b)

In the Y system with reblowing through the top gate (Fig. 3), the air stream is supplied through the bottom gate to the longwall, and additionally through the fail gate (reblowing). The used air is discharged from the longwall through the top gate (along the goafs). This method for ventilation is used in the areas where methane outflows from goafs is substantial. The methane transported from them to the top gate is diluted with more air. Such a system is advantageous because it limits the methane hazard as it moves away the zone of dangerous concentrations of methane in the goaf from the working areas. In contrast, the disadvantage of the above system is the possibility of air flow through the goafs, which may increase the self-heating of coal in the goaf, thus increasing the fire hazard. In order to limit the volume of air escaping through the goafs, it is necessary to seal off the sidewalls of longwalls located near the goafs.

The variant of the Y system with reblowing through the top gate is used in low-thickness seams, when the air cannot flow through the longwall in the amount adequate to the existing methane.

There are two types of the Y system, long and short. The long Y system is applied when there are no issues with maintaining proper dimension of the excavation following the longwall. The second type, the short Y system, is used when maintaining the dimension of the excavation located behind the caving of the longwall is not possible. This gallery is maintained only on such a section, on which it is possible to maintain proper dimensions.

In the Y ventilation system with air extraction in two directions (Fig. 3b), the air flow is supplied to the longwall through the bottom gate and carried away in two directions through the top gate. In the section of the top gate, the air does not come into contact with the goafs and there are no high concentrations of methane, because it is partially discharged from the goaf along with the used air through the top gate maintained along the goafs. This method is preferred when operating in conditions of rock burst hazard. The disadvantage of this method of ventilation is the increased fire hazard in the goaf and the necessity of sealing the main gate sidewalls. This system combines the advantages of U and Z systems, simultaneously eliminating some of their disadvantages. This system is used at high walls, because the whole air must flow through the longwall. The large amount of air and its high speed also have a positive effect on climatic conditions and air pollination with the respirable fraction.

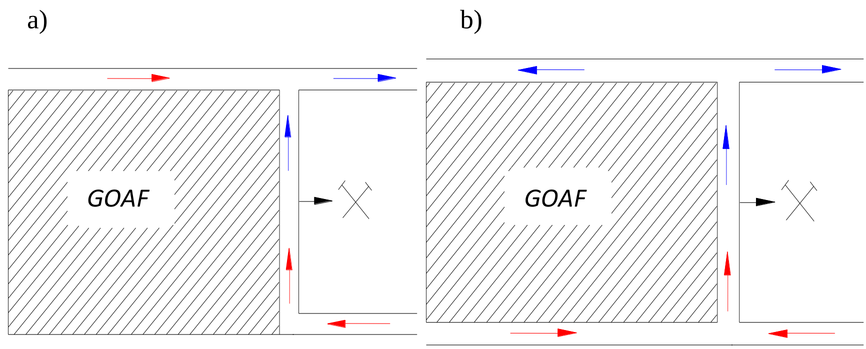

Fig. 4. Layout of the Y ventilation system with reblowing through the top gate starting from the goafs and using the H system.

In the Y system with reblowing through the top gate (Fig. 4a), the air stream is supplied through the bottom gate to the longwall, and additionally through the top gate (reblowing) maintained along the goafs. In this case, it is necessary to seal it. The used air is discharged from the longwall through a top gate. Ventilation of longwalls in this way increases the methane hazard in its corner and contributes to the inflow of heat to the longwall from goafs. This ventilation system is preferred in the case of a fire hazard, because it is possible to supply neutral substances to goafs. The system can be used in low longwalls with medium methane level.

The H ventilation system (fig. 4b) requires maintaining longwall main gates located near the goafs. Fresh air is supplied to the longwall through the bottom gate (also maintained from the side of the goaf), and it is discharged from the longwall through the top gate (including towards the goaf). This method is characterized by a strong ventilation of the goafs, it is therefore beneficial for use in the case of rockburst hazard, methane and climatic hazard. However, the use of this method is disadvantageous due to possible endogenous fire in the goaf.

OPTIMAL VENTILATION MODEL

To determine the optimal method of ventilation, it is necessary to analyse the natural hazards and the expected geological disturbances resulting from the mining activities carried out so far. Based on the methane level projections, the amount of methane to be extracted during mining is anticipated, taking into account the progress rate and methane level in the goafs. In such cases, forecasts of the methane hazard condition are also carried out [4].

The chapter presents an example of determining ventilation parameters and the route of supplying fresh air to a longwall working. The subject longwall area is presented in Figure 6.

In the analysed case, the methane content ranges from 31.26 m3/min for the extraction of 2000 Mg/day to 35.36 m3/min for the production of 2400 Mg/day. The tested seam 408/1 in the IIIz area was classified as the third category of methane hazard. Due to the methane hazard, the amount of air which should be supplied to the longwall depending on the progress of this longwall was assumed. The following daily wall progress was assumed for calculations: 1.87 m, 2.49 m, 2.81 m, 3.12 m, which are supposed to correspond to the actual values of the daily production. The longwall will be operated at a depth of around 600 ÷ 620 m. The calculations include the amount of air supplied to the longwall through the gate and auxiliary lute. The amount of necessary air was calculated from the following dependence:

$$Q_m = \frac{K \times q_m(100-E)}{n_2 - n_1} [m^3/min] \quad (1)$$

where:

K − factor taking into account the peak evolution of CH_4 = 1.55,
n_2 − permissible methane concentration in the outlet airflow - 2.0% (from the area of 1.5%),
n_1 − methane concentration in the inlet airflow, 0.0%,
E − efficiency of demethanization - 55%,
q_m − predicted methane content, corresponding to the adopted quantities of progress and extraction, based on measurements and tests.

Calculated for individual assumed sizes of progress and the corresponding extraction quantities, the minimum amounts of Q_m air carried away from the longwall due to extraction and gas content of the deposit are:

- for extraction of 1,200Mg/day: Qm = 773 (573 + 200) m3/min,
- for extraction of 1,600Mg/day: Qm = 938 (738 + 200) m3/min,
- for extraction of 1,800Mg/day: Qm = 1016 (816 + 200) m3/min,
- for extraction of 2,000Mg/day: Qm = 1090 (890 + 200) m3/min,
- for extraction of 2,400Mg/day: Qm = 1234 (1034+200) m3/min,
- for extraction of 2,400Mg/day: Qm = 1234 (934 + 300) m3/min,

Figure 5 presents a scheme of ventilation of an exploitation longwall equipped with a powered roof support.

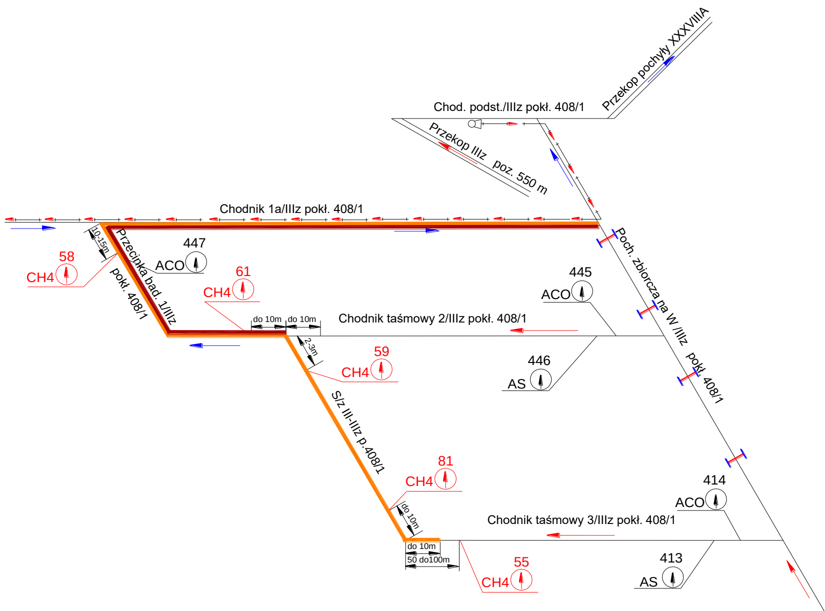

Fig. 5. Adopted ventilation system for the designed longwall complex

CONCLUSION

Continuous mining of coal in an underground mine requires actions aimed at limiting and preventing natural hazards. The increasing depth of exploitation is a factor influencing the increase of methane hazard. In order to ensure the appropriate conditions of ventilation in the longwall, there is often the need to use new methods to limit the methane hazard. On the basis of projected methane hazard and air demand for an exemplary longwall with different extraction volumes, the required airflow was determined. The determined efficiency of this airflow should ensure effective ventilation of the mining area. When determining the size of the airflow, the depth of exploitation was also taken into account.

The obtained results and the authors' experience indicate that in the further stages of the conducted operation it is necessary to check the determined values and modify them. Some ventilation parameters may change during operation, and then the whole system may be disturbed. There is no doubt that an effective ventilation system in coal mines is the basis for efficient and safe operation.

The authors of the article believe that their work on the efficiency of ventilation of longwall workings will contribute to the improvement of work safety.

ACKNOWLEDGEMENTS

The work is the result of research conducted as part of the project carried out by Polska Grupa Górnicza S.A. "Learning Organization" Its aim is to strive to actively guide the future of the company.

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