

# **The Role of Hypogenic Karst in Formation of Carbonate Reservoirs and Development of Oil Deposits\***

**Alexander V. Petukhov<sup>1</sup>**

Search and Discovery Article #42361 (2019)\*\*

Posted April 8, 2019

\*Adapted from oral presentation given at AAPG Middle East Region GTW, Regional Variations in Charge Systems and their Impact on Petroleum Fluid Properties in Exploration, Dubai, UAE, February 11-13, 2019

\*\*Datapages © 2019 Serial rights given by author. For all other rights contact author directly. DOI:10.1306/42361Petukhov2019

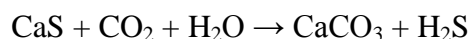
<sup>1</sup>St. Petersburg State University, Russia ([av\\_petukhov@mail.ru](mailto:av_petukhov@mail.ru))

## **Abstract**

It is known that the world's largest oil and gas fields in carbonate reservoirs are located in the Middle East, Europe, Africa, Asia, Australia, North and South America. Many of the oil and gas deposits are found in karst reservoirs from Proterozoic to Miocene. Study of karst processes in the reservoirs has shown that both pervasive faults and hydrocarbons' vertical migration with thermochemical sulfate reduction (TSR) play an important role in formation and evolution of the hypogenic (deep) karst. The available geological data of fields show that the volume of large cavities and karst caves in such carbonate reservoirs can reach 38%, and the daily oil production of wells can be more than 20,000 bpd.

Vertical migration of light hydrocarbons from oil and gas reservoirs to the surface is essential to discovery of some oil and gas deposits. Possible mechanisms of the vertical migration involve the vertical ascent of ultra-small gas bubbles through a network of interconnected micro fractures, fractures and faults, that have been called the vertical fracture corridors. High pressure and displacement of rocks during folding promote the development of “mechanic chemical reaction” between hydrocarbons and sulfates. The mechanic chemical reactions were first investigated by P.W. Bridgman (1949). Using modern equipment, we reproduced the TCP in the laboratory. It was found that under conditions of high pressures and shear deformations, the reduction of sulfate by hydrocarbons proceeds even under conditions of low temperatures. Thus, at high pressures and shear deformations, it is not the thermochemical reduction of sulfates (TSR), but the chemical reduction of sulfates (CSR). These reactions occur under high pressure and shearing stress which can arise into vertical fracture zones during the tectonic activity of folding. The reaction between hydrocarbons and sulfates proceeds in two stages, according to the Engler-Gofer scheme:

P+mechanical activity



Ascending fluids carrying CO<sub>2</sub> and H<sub>2</sub>S reach the surface in the vicinity of the karsting carbonate rocks. The CO<sub>2</sub> and carbonic acid dissolution is balanced by subsequent calcite cementation. The H<sub>2</sub>S arrives to the oxidation zone, sulfuric acid is formed which subsequently causes major dissolution and karstification. Significant pyrite mineralization during cementation filling of the fractures is a strong indication of H<sub>2</sub>S formation after generation of fractures. The reduction of sulfates by hydrocarbons according to this CSR scheme is confirmed by isotope determination of the secondary calcite and sulfur in karstified carbonate oil and gas reservoirs.

We can use this new understanding of fracture-karst zones formation and its distribution to give clear and valuable recommendations for improvement of exploration and development of carbonate reservoirs in different oil and gas bearing basins.

### **Selected References**

Duchene, H.R., 1999, Modern Analogs to Ancient Hydrocarbon-related Hypogenic Caves in West Texas and New Mexico: AAPG Bulletin, Abstract, v. 83/2, p. 388.

Duchene, H.R., 1999, Origin and Mineralogy of Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico: AAPG Bulletin, Abstract, v. 83/2, p. 388.

Klimchouk, A.B., 2013, Hypogene Speleogenesis, its hydrogeological significance and role in karst evolution: Simferopol, DIP, 180 p.

Mazzullo, S.J., and P.M. Harris, 1991, An overview of dissolution porosity development in the deep-burial environment, with examples from carbonate reservoirs in the Permian Basin, *in* M. Candelaria, ed., Permian Basin Plays - Tomorrow's Technology Today: West Texas Geological Society and Permian Basin Section, SEPM, Publication no. 91-89, p. 125-138.

Meshoulam, A., G.S. Ellis, and W.S., Ahmad et al., 2016, Study of thermochemical sulfate reduction mechanism using compound specific sulfur isotope analysis: *Geochimica et Cosmochimica Acta*, v. 188, p. 73-92. doi.org/10.1016/j.gca.2016.05.026

Mougin, P., V. Lamoureux-Var, A. Bariteau, and A.Y. Huc, 2007, Thermodynamic of thermochemical sulphate reduction: *Journal Petroleum Science and Engineering*, v. 58/3-4, p. 413-427. doi:10.1016/j.petrol.2007.01.005

Petukhov, A.V., 1996, Karst's formation and evolution in the Timan-Pechora region and new data on carbon cycle: 30th International Geological Congress, Abstracts, Beijing, China, v. 3, p. 432.

Petukhov, A.V., 1996, Characterisation of carbonate oil-gas bearing reservoirs in the Timan-Pechora basin and integrated exploration of high permeable zones' location: 30th International Geological Congress, Abstracts, Beijing, China, v. 2, p. 843.

Petukhov, A.V., 1996. Integrated exploration of fracture-karst zones in carbonate oil-gas bearing reservoirs of the Timan-Pechora basin: AAPG Hedberg Conference, Carbonate Reservoir of the World: Problems, Solutions and Strategies for the Future, Abstracts, Pau, France, p. 238-243.

Petukhov, A.V., 1996, Karstified oil-gas bearing reservoirs of the Timan-Pechora basin: AAPG Hedberg Conference, Carbonate Reservoir of the World: Problems, Solutions and Strategies for the Future, Abstracts, Pau, France, p.259-263.

Petukhov, A.V., 2010, Geodynamic model of hydrogen sulfide formation in natural gases and oils in the process of pulsed compression of rocks during earthquakes: Notes of the Mining Institute, St. Petersburg, v. 188, p. 189-194.

Wang, G.L., N.X. Li, B. Gao et al., 2013, Thermochemical sulfate reduction in fossil Ordovician deposits of the Majiang area: Evidence from a molecular-marker investigation: China Science Bulletin, v. 58, p. 3588-3594. doi:10.1007/s11434-013-5843-x

# **THE ROLE OF HYPOGENIC KARST IN FORMATION OF CARBONATE RESERVOIRS AND DEVELOPMENT OF OIL DEPOSITS**



**Prof. Alexander Petukhov**  
**St. Petersburg State University, Russia**



The carbonate formations are an important oil and gas reservoirs in the World. According to Schlumberger (2009), more than 60% of world oil reserves and over 40% gas reserves contained in carbonate rocks, and in some oil and gas regions, these shares are even higher (in the Middle East, for example, up to 70% of oil and 90% gas). According to the forecasts of the same company, the importance carbonate reservoirs dramatically will increase, compared to stocks in other breeds, during the first half of the 21st century.

Bright examples of communication with karst deposits hydrocarbons are most large giant and super giant deposits Middle East region (Saudi Arabia, Kuwait, Iraq, Iran, etc.), Southwest and Northeastern United States, Northeast Canada, Norway, France, Mediterranean region, European part of Russia and Eastern Siberia, Australia, Indonesia, China, Kazakhstan and many other states.

The study of carbonate reservoirs formed in different basins has shown the importance of tectonic fractures in the evolution of complex carbonate reservoirs. These fractures are formed during local tectonic folding. The pervasive faults and fractures generated during these folding episodes in carbonate rocks promote active filtration and leaching by surface and subsurface waters, containing corrosive components ( $\text{CO}_2$ ,  $\text{H}_2\text{S}$ , etc.). Highly permeable fracture-karst zones developed during leaching dramatically affect the processes of hydrocarbon migration and oil-gas accumulation.



# AAPG

Advancing the World of Petroleum Geosciences

## The Timan-Pechora oil and gas bearing basin



Largest oil and gas deposits in carbonate reservoirs of the Timan-Pechora basin are known to be in **Usinsk, Vuktyl, Kharyaga, Upper Vozey, West Tebuk** and other fields. In these fields oil and gas deposits are found in Lower and Upper Paleozoic karstified reservoirs from Ordovician to the Lower Perm.



# AAPG

Advancing the World of Petroleum Geosciences

## First citation about Ukhta oil and oil shale (domanik) of the Timan-Pechora Basin (1692)



*Nicolaes Witsen*

Dutch scientist, diplomat, industrialist, traveler and writer Nicolaas Witsen was at the Embassy of the Netherlands in Moscow during the reign of Tsar Alexei Mikhailovich between 1664 and 1665. He collected a wealth of material about the life of the people inhabiting in the vast north-eastern territory of Russia at that time, about the flora and fauna of these places, about the principal lakes and rivers at that time and sometimes about the transport routes and natural resources. The collected material was described by N. Witsen in a book called “Northern and Eastern Tartary” (Nord en OOST TARTARYE). The book was published in Amsterdam in 1692. When N. Witsen described the Ukhta river area he put attention to the existing oil there - River Ukhta is a feeder of Pechora River. On this river a half miles from portage there is a shallow where is secreted an oily substance that floats on water and is a black oil. There was also found a stone domanik that burns like a candle, and let myself black smoke.” Now domanik is famous source rock in Timan-Pechora and in Volga-Urals Basins. It is typical shale rock, like the Marcellus shale in the USA.





# AAPG

Advancing the World of Petroleum Geosciences

## Founder of the first handicraft oil industry in Russia, Fedor Priadunov (1745)



*F.S. Priadunov - portrait*

Fyodor Pryadunov was born in Arkhangelsk. He was an ore finder and discoverer of silver ore at the Bear Island in the White Sea. For many years he successfully engaged the searches of silver in North seaboard of Russia, copper and magnetite ores. In November of 1745 he asked to give him a "Extract" - a brief excerpt from a public document (license), in which was the name of Fedor Pryadunov:

"... In the Arkhangelsk province in Pustoozersky district along small river Ukhta he need to establishe the oil "factory", to extract the oil from the factory and sell that oil, then send to the Bergkolegiy the correct reports twice in the year - in January and July where the new factory will be built, plus to give to him ("Pryadunov") opportunity no pay tithes until two years, and after those two years recover the tithes from him, and that was given to him a decree .





# AAPG

Advancing the World of Petroleum Geosciences

## The first deep-well in northern Russia, was drilled on oil (1868)



*M.K Sidorov*

In 1865, the well known in Russian Siberian gold mines, the first guild merchant Mikhail Sidorov applies to get access to some oil fields and opening the oil business to Ukhta. In May 1868, he received the permit to lease a square mile near of a creek, which empties into the river Ukhta. In the same year a truster Sidorova's Lopatin with two "specialists" and twenty workers on the left bank of the river Ukhta in the place where naturally oil seeps to the surface, there was drilled the first well. Sidorov's proprietorship in Ukhta by September 1872 visited the Austrian Count Wilczek, the commander of the Austrian warship Baron Shternekk, a professor of geology and natural sciences at the Mining Academy in Vienna Gopher. The purpose of this visit by the request of M. Sidorov was a qualified assessment of the operations and promotion of its oil business and all of the Pechora area .



**M. Sidorov's well next to river Ukhta (1905)**



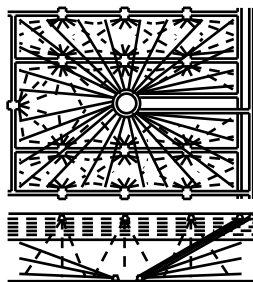
**The remains of the oil well Sidorov (left) and the obelisk,  
at the site of its drilling (right). 2008**

The Timan-Pechora basin is oldest in the Russia and in the world in oil production. There is a unique experience of studying fracturing and karst in oil reservoirs, including in the mine and surface mining of heavy oil and asphaltite (bitumen) directly.

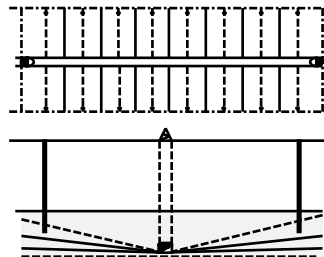
For example, the development of the Yarega heavy oil field, the large in the Timan-Pechora basin, began using mines in 1939. Annual production heavy oil at this field was more 1 million tons last year. Lukoil, which is the operator of this project, has a goal to increase oil production to 3 million tons per year in the coming years.

The Izhemskoye asphaltite deposit, associated with Upper Devonian karst limestone, was developed from 1933 to 1967.

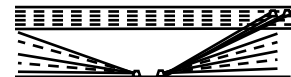
The development of the largest deposit of heavy oil in the Timan-Pechora basin of the Usinsk field associated with the Middle Carboniferous and Lower Perm fractured karst carbonate reservoir began in 1972. Now the project operator is Lukoil as well.



Two levels  
development system



Underground and surface  
system



One level development  
system

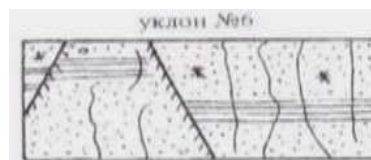
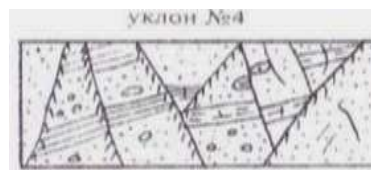
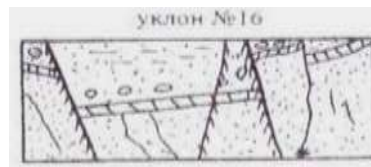
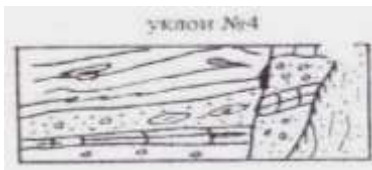
**All this systems including underground and surface systems has been patented**



# AAPG

*Advancing the World of Petroleum Geosciences*

## The sketches of tectonic fractures in the Middle Devonian sandstone reservoir of Yarega field (investigation of fractures from 1939 to today)



- tectonic fractures



- sandstones



- argillaceous interlayers



## Statistic data of quantity of fractures and faults at the mine №3 of Yarega heavy oil field

The names of mining workings	The area, m <sup>2</sup>	The total length of mining workings, m	number of fractures	Fractures density per 1 hectare	detection frequency per 1 m	Shift amplitude, m	
						0-2 m	2-10 m
Adit #102	11000	859	115	104	7,5	103	12
Adit БЭУ-П	3700	441	35	95	12,6	35	-
Main adit	6300	706	64	102	11,1	64	-
Whole	21000	1906	214	-	-	202	12
Average value	-	-	-	100,3	9	-	-



# AAPG

*Advancing the World of Petroleum Geosciences*

**Izhemskoe (Namedskoye) asphaltite deposit (development was conducted by underground galleries from 1933 to 1967)**





## Photos of asphaltite in caverns developed in carbonate rocks

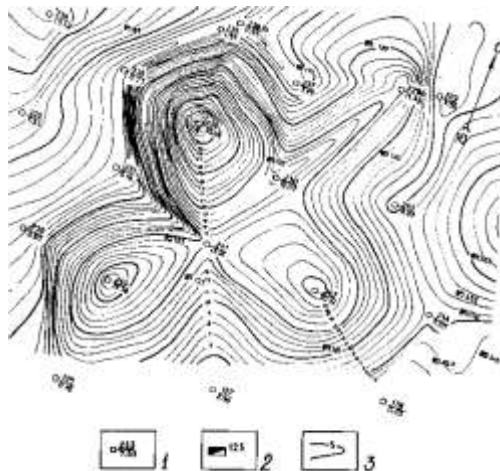




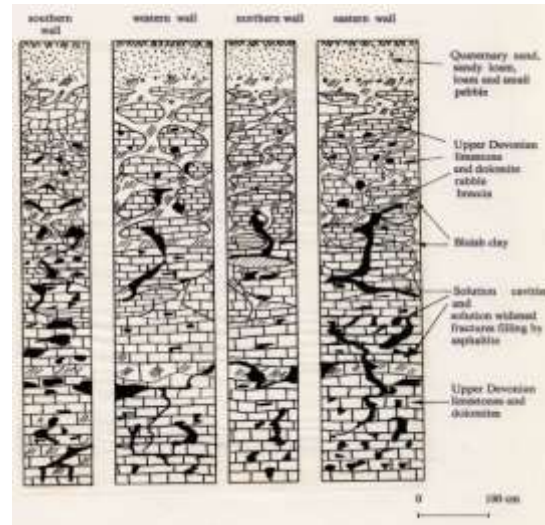
# AAPG

Advancing the World of Petroleum Geosciences

## Fractured karst zones in carbonate reservoirs of Izhemskoye field at the plane (left) and in the cross section (right)



The map of asphaltite content of 10 area in Izhemskoye (Nyamedskoe) asphaltite field. After L.A. Vokuev (1962) :  
1 - exploration wells 2 - exploration pits 3 - linear contours of asphaltite in percent per meter.



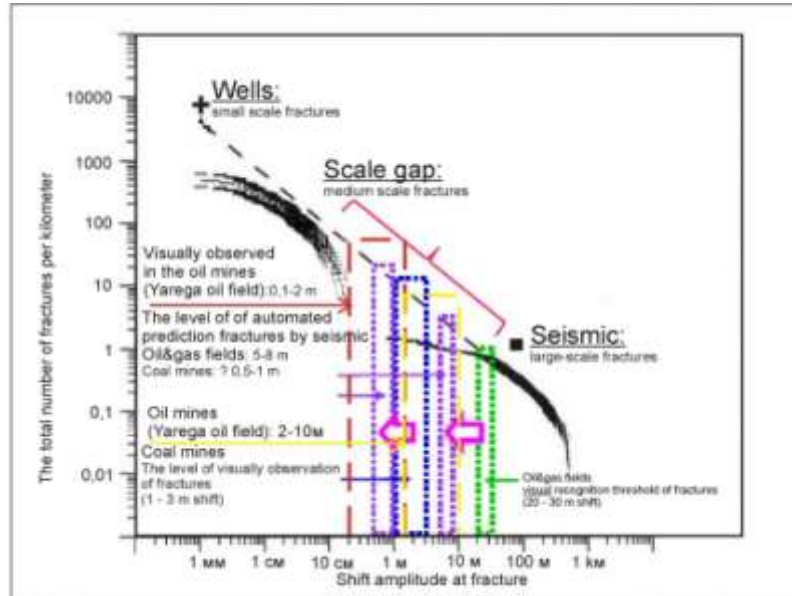
Sketch of the exploration pit № 17 in Upper Devonian carbonate rocks, Izhemskoye asphaltite field.



# AAPG

Advancing the World of Petroleum Geosciences

## Scaling invariance in the research of multiscale tectonic fractures and karst cavities



(after T. Needham et al. 1996 and R. Oppermann, 2012  
edit by A.V. Petukhov with statistic data of Yarega field )

**Exploitation experience at many fields of the Timan-Pechora basin has shown that fracture-karst zones influence the process of oil fields development. It is necessary to take into account these fracture-karst zones when the optimal system of field development is chosen.**

**An integrated exploration method has been developed for the detecting of high permeable zones related to fractured karst areas. This method includes the use a special interpretation of 3-D seismic data, electrical and gravity exploration data, aero-space photo interpretation, electric logging processed according to the special "GSC" program, the study of core and drilling data and other materials.**

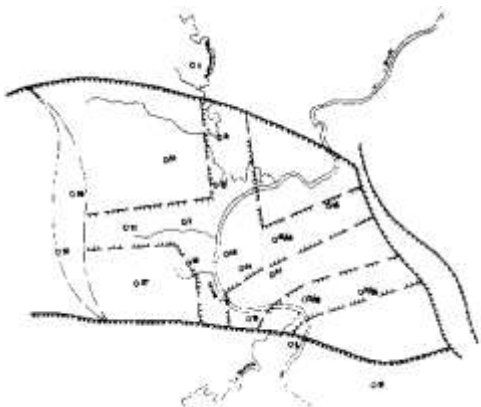




# AAPG

Advancing the World of Petroleum Geosciences

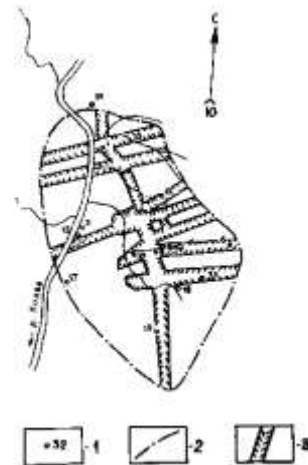
## Geomorphological anomalies at the areas of fractured karst zones



The ratio of the modern river network and fracture zones within Kharyaga oil field.



Map of fractured karst zones into the C2-P1 deposits of Usinsk oil field with elements of deciphering aerophotos and detecting of lineaments.



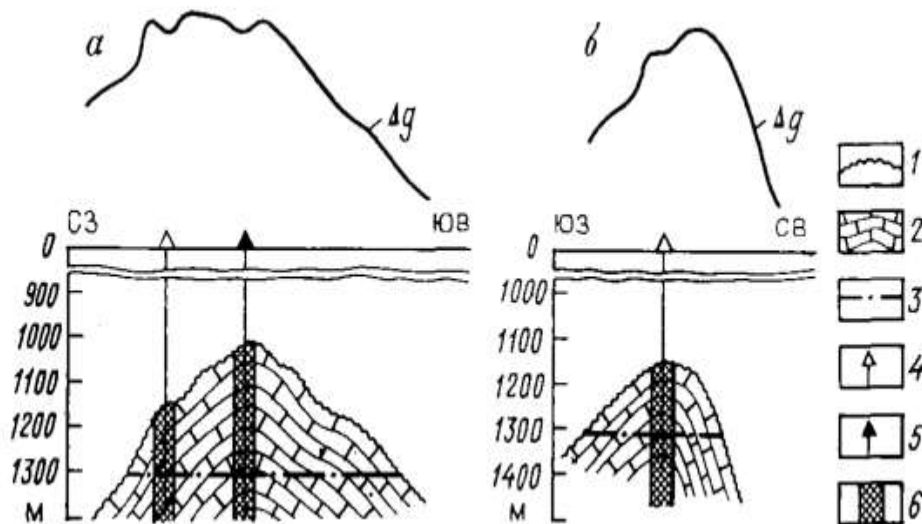
Relation between of fractured karst zones identified within Usinsk oil field and modern river network: 1 - exploration wells, 2 - oil-bearing contour C2-P1 deposits of heavy oil, 3 - zones of fractures and karst (sweet spots).



# AAPG

Advancing the World of Petroleum Geosciences

## Gravity anomalies at the areas of subvertical fractured karst zones



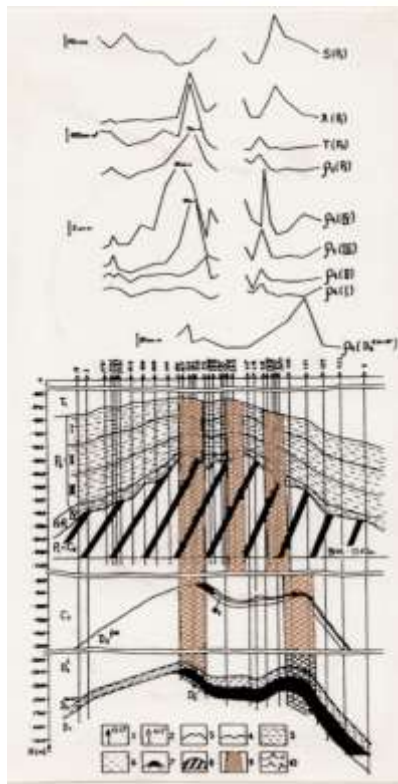
Longitudinal and transverse gravimetric profiles are indicating local anomalous conditions over fractured karst zones. 1- eroded top of Lower Perm-Middle Carboniferous limestones and dolomites; 2- Lower Perm-Middle Carboniferous limestones and dolomites; 3- oil-water contact; 4- prospecting wells; 5- production wells; 6- fractured karst zones («sweet spots»)



# AAPG

Advancing the World of Petroleum Geosciences

## Electrical anomalies in sealing horizons over fractured karst zones into Usinsk oil field (mapping with using of our special patent)



Profiles of electrical parameters are indicating anomalous conditions over the wells, which have been drilled into fractured karst zones: 1 – wells, which have been drilled into Lower Permian-Middle Carboniferous deposit of heavy oil; 2 – wells, which have been drilled into Devonian oil deposit; 3 – eroded tops of carbonate rocks; 4 – boundaries of strata; 5 – Upper and Lower Permian clayey rocks; 6 – Upper Devonian clayey rocks; 7 – Devonian deposits of light oil; 8 – Lower Permian-Middle Carboniferous deposit of heavy oil; 9 – fractured karst zones; 10 – profiles of electrical parameter of rocks over petroleum deposit.

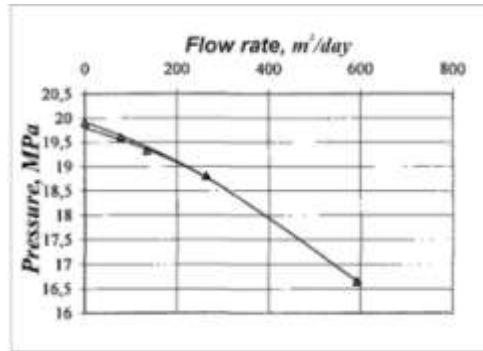




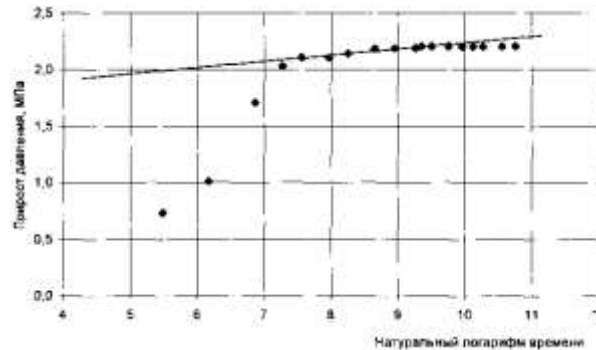
# AAPG

Advancing the World of Petroleum Geosciences

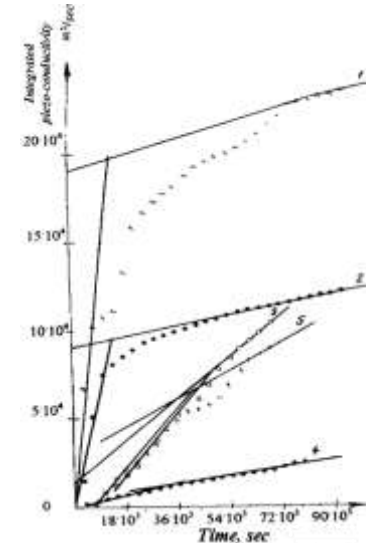
## Pressure transient analysis in fractured karst carbonate reservoirs of Timan-Pechora basin



IPR (Inflow Performance Relation) curve of well # 5 North Aresskoe oil field, 1806-1827 m, limestone D3 fm (after A. Bazylev).

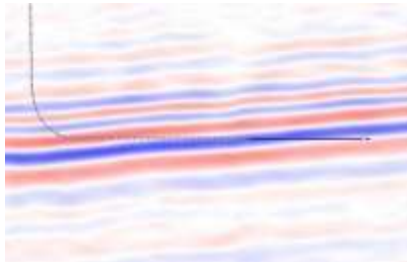


Pressure buildup plot of well 4, 2046,4-2050,4 m, limestone D3 fm, subsurface helix pressure gauge 2-250 (according to A. Bazylev)

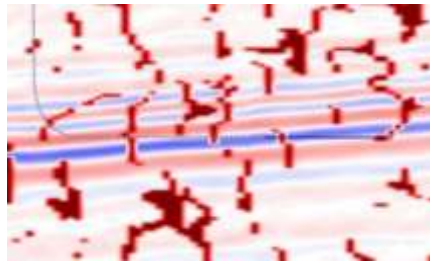


Integral distribution curves of piezo-conductivity over time, wells C2-P1 in Usinsk oil field (after A. Bazylev and T. Lukoshnikova)

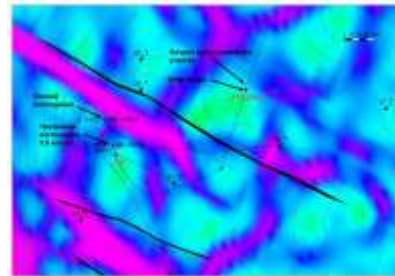
## The use a special interpretation of 3-D seismic data for detecting of fractured karst zones



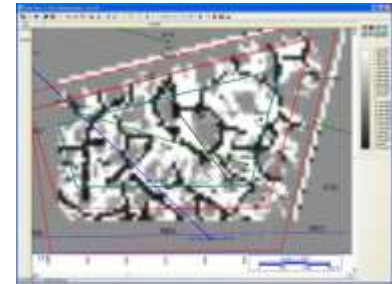
No seismic fractures identified or predicted from Reflectivity data: 'sub-seismic' faults "hit and miss" fracture development drilling.



Fractures identification: multiple seismic fractures and cavities penetrated by well: sub-visual fractures and cavities targeted fracture development possible!

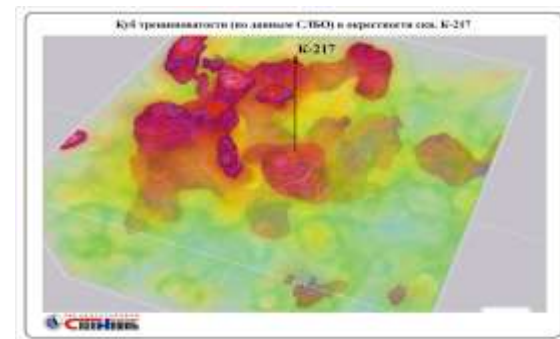
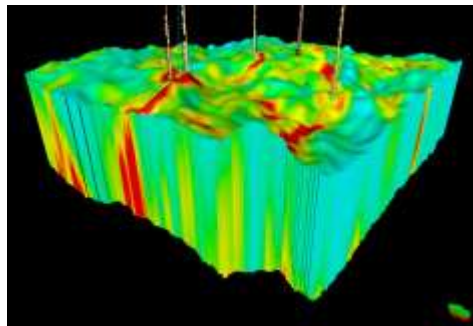
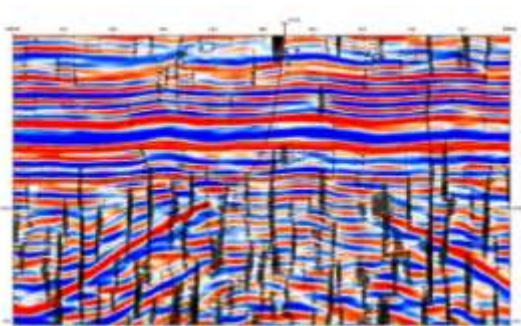


Geometric attribute "Curvature" (according to PetroTrace Global).



Interpretation of seismic data using technology OPPTimal and method F1a-FN (high resolution, low + high confidence).

**The use a special seismic method SLSV (Seismic Location by Side View) and stacked data of density parameter of singularity (SS), related to fractured karst carbonate rocks in the Kuyumba oil and gas field (Eastern Siberia)**



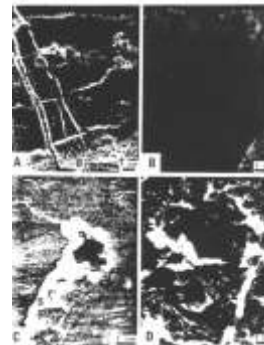
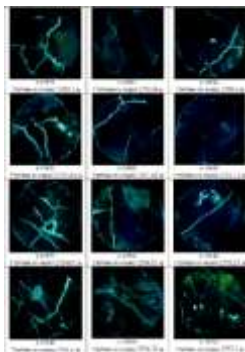
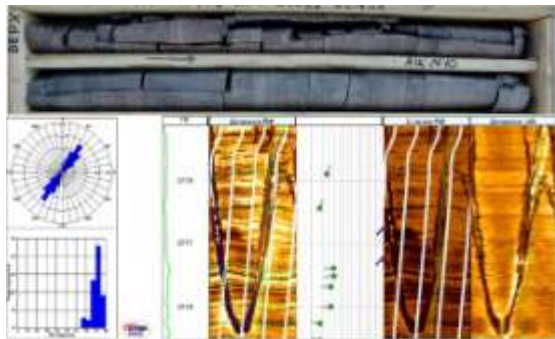
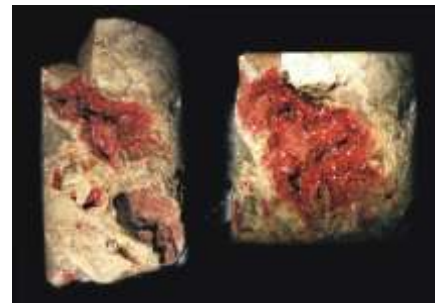
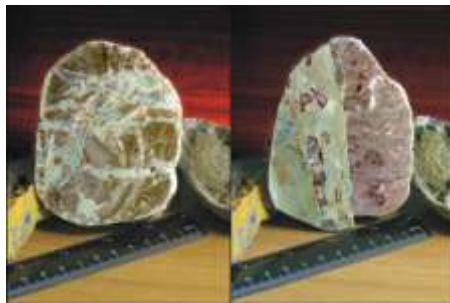
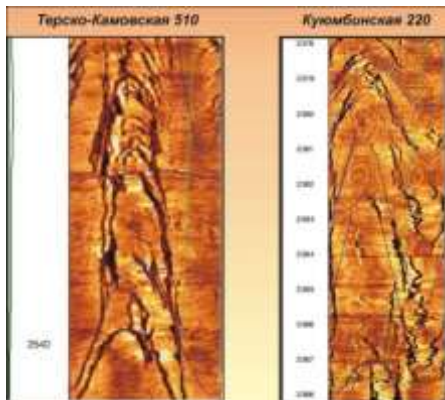
After «Slavneft-NPC», LLC



# AAPG

Advancing the World of Petroleum Geosciences

## Images of fractured karst reservoir at Schlumberger FMI log scanner and data of core investigation

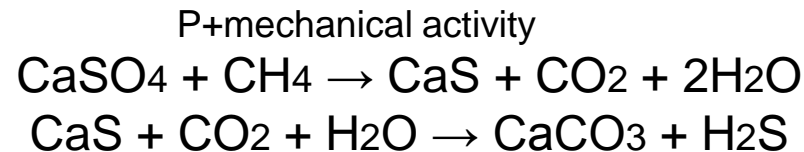




**The use of this integrated exploration method has been successful in finding new fractured karst zones in carbonate reservoirs. These fractured karst zones have been found in carbonate reservoirs occurring from 0 to greater than 3,000 m. The use of 3D seismic, gravitation prospecting, decipher of aerospace photo, log and other data has also allowed a greater understanding of the complexities, geometry, and tectonic relationship of fractured karst zones formation.**

# DATA AND METHODOLOGY

Vertical migration of light hydrocarbons from oil-gas reservoirs to the surface through sub-vertical fractured zones is essential to all founded oil and gas deposits. High pressure and displacement of rocks during the folds formation promote the development of “mechanic chemical reaction” between hydrocarbons and sulfates. These reactions are proceeded under high pressure and shearing stress which can arise into vertical fracture zones during the tectonic activity of the folds. The reaction between hydrocarbons and sulfates proceeds in two stages according to Engler-Gofer scheme:





**The special laboratory experiments have been made for simulation of earthquake conditions and CO<sub>2</sub> and H<sub>2</sub>S formation during high pressure and shear deformations.**

**Additionally, a direct visit and study was conducted hypogenic caves in the Russia (Timan-Pechora and Volga-Ural basins) and the USA (Permian basin) and a conceptual model has been developed for the formation of a hypogenic karst within oil and gas bearing basins.**

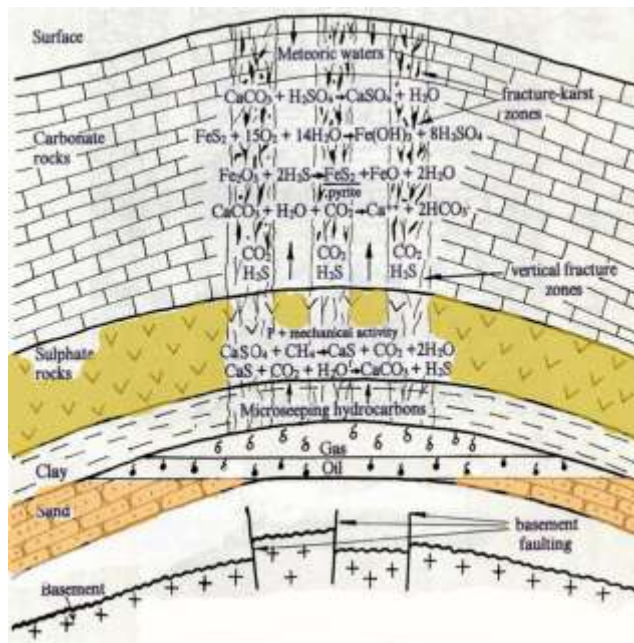


# AAPG

Advancing the World of Petroleum Geosciences

## Conceptual model for the formation of a hypogenic karst over petroleum deposits

Anomalies:  
geomorphological and seismic  
gravimetric  
electric  
hydrocarbon  
radiometric  
magnetic  
over fractured karst zones





## Laboratory equipment and data

Sulfates are highly oxidized and hydrocarbons are highly reduced. According to the chemical kinetics, these substances should enter into a chemical reaction, but the very high temperature threshold of this reaction is about  $1000^{\circ}\text{C}$ . With an increase in pressure and the presence of catalysts, the reaction temperature can be reduced, but laboratory experiments show that at 24 MPa, the reaction temperature is  $350^{\circ}\text{C}$  (Meshoulam A., Ellis G.S., Ahmad W. S., et. al., 2016). Such high temperature may be at the deep about 12000 m, but all discovered petroleum deposits are located at the deep no more than 10000 m.

The experiments were conducted at the Institute of Synthetic Polymer Materials of the Russian Academy of Sciences in Moscow. Next pictures you can see the results of the experiment.

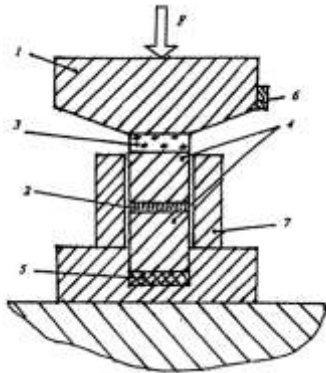


Fig. 1. Scheme of the experimental equipment: 1 – Bridgman anvil; 2 – sample ( $\text{CaSO}_4$  + paraffin); 3 - polypropylene plate; 4 - steel waveguides; 5 - piezo sensor.

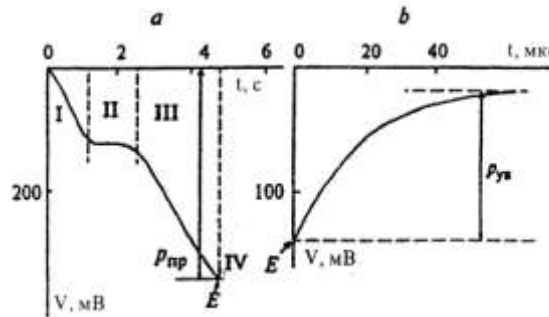


Fig. 2. Diagram of the rise (a) and release (b) of the pressure on the sample when simulating an earthquake: point E corresponds to the moment of a sharp pressure release (earthquake).

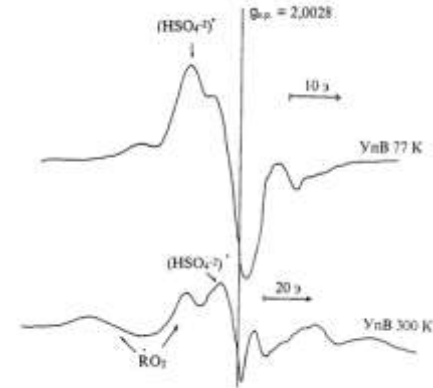


Fig. 3. EPR spectra from paramagnetic products, fixed in the system  $\text{CaSO}_4$  + paraffin after exposure to shear deformation pulses and high pressure at 77 K and 300 K.



## Traditional and new understanding about BSR and TSR

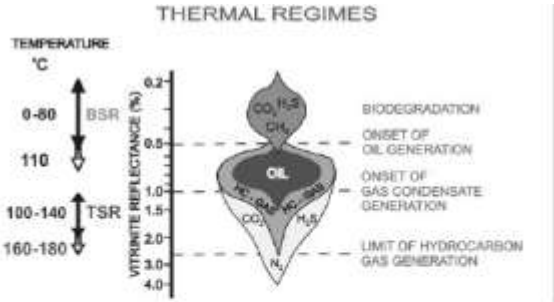


Figure 11. Generalized relationships between oil and gas generation, temperature, thermal maturity, and bacterial and thermochemical sulfate reduction (BSR and TSR, respectively), assuming normal geothermal gradients of 25 to 30°C/km (diagram is modified from Machel et al., 1995a). Solid arrows indicate the normal thermal regimes for BSR and TSR; hollow arrows denote extreme and geologically unusual conditions. Note that the upper part of the BSR temperature range overlaps with the lower part of the liquid oil window.

Using modern equipment, we reproduced the TSR in the laboratory. It was found that under conditions of high pressures and shear deformations, the reduction of sulfate by hydrocarbons proceeds even under conditions of low temperatures. Thus, at high pressures and shear deformations, it is not the thermochemical reduction of sulfates (TSR), but the chemical reduction of sulfates (CSR). These reactions are proceeded under high pressure and shearing stress which can arise into vertical fractured zones during the tectonic activity of the folds. The speed of the reaction very high and even shortly time of the earthquake is enough for H<sub>2</sub>S formation in large volumes. The experiment showed that traditional understanding about BSR and TSR is not correct. During earthquake can be chemical sulfate reduction in a wide range of temperatures from 0° C to 500° C and more.





# AAPG

*Advancing the World of Petroleum Geosciences*

## Field studies of hypogenic karst in the Guadalupe mountains







# AAPG

*Advancing the World of Petroleum Geosciences*

## Hypogenic caves of New Mexico and West Texas (Carlsbad National Park, NM and Sonora, TX)



## Results and interpretation

A generalization of empirical data on the distribution and characteristics of the manifestation of hypogenic karst in different oil and gas basins (Mazzullo and Harris, 1992; Machel, 1999; Petukhov, 1996, 2003; Duchene, 1999) and karst regions (Klimchouk, 2007; Klimchouk, Ford, 2009) revealed a wide prevalence of hypogenic karst in various geostructural conditions, in rocks of different lithological composition and age.

With an increase in the drilling of deep-lying oil and gas reservoirs during the search and development of hydrocarbon deposits, widespread distribution of canal-cavity structures of dissolution is revealed at considerable depths (up to 3-5 km or more), including in strata that have never been in subsurface conditions after the initial burial i.e. - where the surface paleocarst nature of karst occurrences is excluded. Hypogenic karst has a wide global distribution and probably far exceeds the distribution of the "traditional" epigenic (surface) karst.

## The morphology of cave channels, feeder channels and hypogenic cavities (after A.B. Klimchouk, 2013)



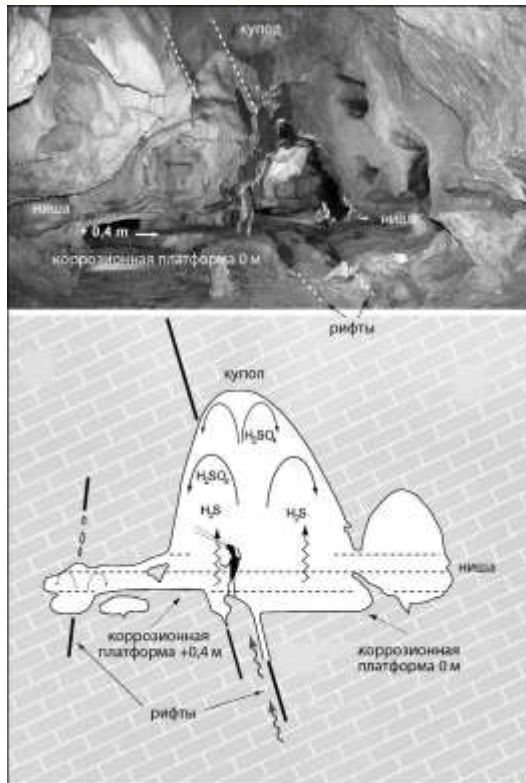
Foto: A.B. Klimchouk; F. Frumkin; R. Hines; G. Schindel, A.V. Petukhov





# AAPG

Advancing the World of Petroleum Geosciences

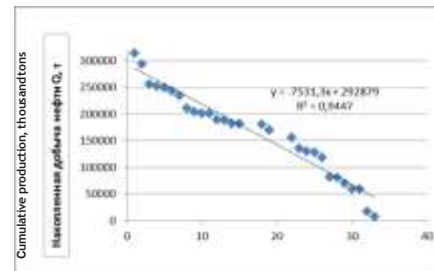
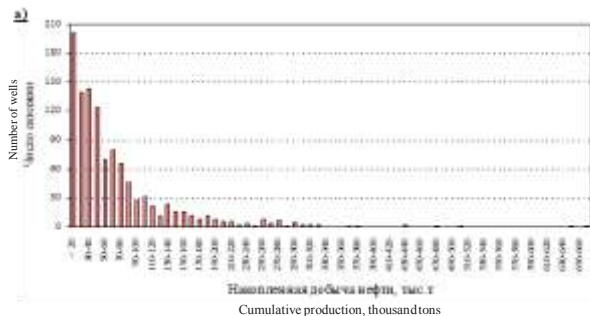
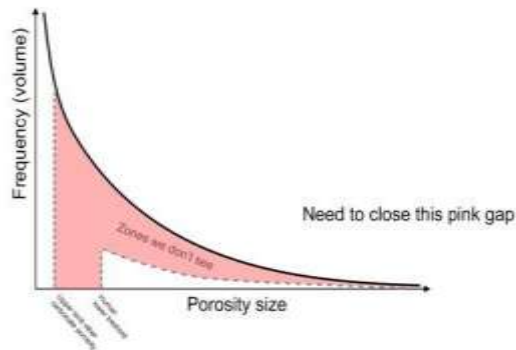


**Modification of the morphology of hypogenic caves in limestone by lateral expansion in the interval of the groundwater mirror and subaerial corrosion under the influence of sulfuric acid dissolution**

**Cave Du Chat, France.**

**(After Audra, 2009, photo by L. Mocochain)**

## Features of the distribution of producing wells in fractured karst reservoirs by cumulative production of oil





## CONCLUSION

Comparing the distribution of wells in cumulative production in porous-fractured reservoirs (left graph from above) and in fractured karst reservoirs (right graph from above), we can fill the pink gap and determine the volume of large cavities and caves. Calculations show that this volume is about 38 percent. It is also very important to note that in porous and fractured reservoirs we have a power-law distribution of wells by daily production and by accumulative production (left graph from above), and in fractured-karst areas we have a linear distribution of wells by daily production and by accumulative production (right graph from above). This feature can be used to identify fractured karst areas in carbonate reservoirs by processing statistical data on daily and cumulative oil production in wells that are drilled in the fields.

We are using this new understanding of fractured karst zones formations and its distribution to give clear and valuable recommendations for improvement of prospecting, exploration and development of carbonate reservoirs of oil and gas.