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## Application of Superdeep Drilling Technology for Study of the Earth Crust

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# Application of Superdeep Drilling Technology for Study of the Earth Crust

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**Abstract.** The article gives an overview of the methods of superdeep drilling using examples of world-famous wells and highlights urgent problems that require an early solution. The system vision of the indicated problems is presented and the possibility of their modification in order to improve the quality of geological scientific developments. It is shown that the new data obtained with the help of deep and superdeep drilling on the real deep structure of the earth's crust forced to make serious corrections in the interpretation of geophysical measurements.

## 1. Introduction

As known, progress depends on geological science. Rapidly developing industry requires more and more new minerals and in ever increasing quantities. To search for minerals and scientific forecast, a variety of modern geological developments are needed.

The issues of superdeep drilling have become especially urgent nowadays, since the reserve of minerals on the surface of the Earth is almost exhausted. The great importance in the development of superdeep drilling are problems that have not yet been solved, but the speed of their solution depends on social progress in general of the entire earthly civilization.

At present, the most important issues of superdeep drilling are:

- 1) difference in hydrostatic and lithostatic pressure during drilling;
- 2) ensuring reliable operation of drilling equipment at high temperatures;
- 3) the biggest problem arises with the measuring apparatus-swarm and electronics;
- 4) spontaneous bending of deep wells during drilling;
- 5) dead stuck to the drilling rig.

And similar problems.

Interests in these issues are due to the numerous variability of their solutions, without the existence of yet clear scientific development.



The emphasis in this article is on the significance of the above-mentioned issues in the case of super-deep drilling.

The purpose of this article is to give an overview of the methods of superdeep drilling using examples of world-famous wells and highlight current problems that require an early solution.

The article can be recommended for students who receive appropriate professional education.

## 2. History of the problem

Earth as an object of geological research is available for direct observation only from the surface of the earth, and the composition and structure of terrestrial depths can be judged only by indirect data. Therefore geologists strive to penetrate as far as possible into the Earth by drilling.

Drilling wells are most often used for prospecting and exploration of mineral deposits, for extracting water, oil and gas from the bore wells, for engineering surveys and other applied purposes. In addition, drilling in recent decades is increasingly being used as a method of solving fundamental scientific problems of modern geology. Results scientific drilling in many ways were unexpected and forced to reconsider the theoretical ideas, which previously seemed obvious and unshakable [1-22].

The beginning of systematic scientific drilling dates back to the 60s of the last century. In 1968, a special drilling vessel, «Glomar Challenger» (figure 1), was launched in the United States, and an international deepwater drilling program was launched in the oceans.

In 1985, a new vessel, JODES Resolution, was replaced, and the ocean drilling program was continued. For thirty years in the world-ocean drilled hundreds of wells that crossed loose sediments of the ocean floor and deepened into the underlying basalts. The deepest well drilled in the Pacific south of the coast of Costa Rica reached 2105 m below the ocean floor. The results of ocean drilling have opened a new page in geology, since there was practically no direct data on the structure of the ocean floor.



**Figure 1.** Special drilling vessel «Glomar Challenger».

Unlike relatively small wells that are drilled for exploration of solid minerals, wells of scientific drilling on the continents as a rule, belong to the category of deep (3-7 km) and super-deep (more than 7 km). In this respect, they are comparable only with wells drilled for prospecting, exploration and exploitation of deep-seated oil and gas fields, known for example in the south of the United States. Over the past 30

years, more than 350 wells with a depth of 6.5-7 km, 50 wells with a depth of more than 7 km and 4 wells with a depth of more than 9 km have been drilled in the states of Texas and Oklahoma. The deepest – Bert Rogers (9583 m) was drilled in 1973-1974 in just 502 days. Such a high speed of passage is due both to the capabilities of American technology and to the fact that drilling was done without core selection, i.e. without lifting the rock samples to the surface. Core sampling takes a lot of extra time, but it is absolutely necessary for scientific drilling. Therefore, deep and super deep exploration and exploration wells are of limited importance as sources of scientific information.

### **3. The superdeep drilling program in the Soviet Union**

The first program of systematic, continental superdeep drilling with scientific purposes was developed and implemented in the Soviet Union. The basic ideas of this program were established in 1960-1962. The first of the superdeep wells in the USSR – Aralsorskaya in Northern Kazakhstan – reached 5600 m, Saat-linskaya on the Kura-Araks lowland of Azerbaijan – 8200 m, Urengoisk in Western Siberia – 7800 m. Several more wells were laid: Krivoy Rog, Ural, Muruntau, Kuban. In May 1970, the drilling of the Kola superdeep well began in the north of the Murmansk region, 10 km from the city of Zapolyaroye. Its design depth was determined at 15 km.

For the foreign wells, only 3 wells have reached a depth of 9.1 to 9.6 km. It was planned that one of them (in Germany) would surpass Kola. However, drilling on all three, as well as on the SD, were shut down (closed) due to accidents.

In the following years, 10 more wells with depths from 4 to 9 km were drilled in the USSR. In 1986, a special state scientific enterprise «Nedra» (Yaroslavl) was established to carry out the program for the integrated study of the Earth's interior and superdeep drilling.

The successes of the Soviet Union stimulated the development of programs for scientific continental drilling in Germany, France, USA, Canada, Japan, Great Britain and other countries. One of the best-known outcomes was the drilling of the German superdeep well KTB-Oberpfalz in Bayern (1990-1994), which reached the depth of 9,101 m.

#### *3.1. Kola well*

Kola Superdeep well SD-3 is one of the main attractions of the region. Its depth is 12262 m, which is still unsurpassed.

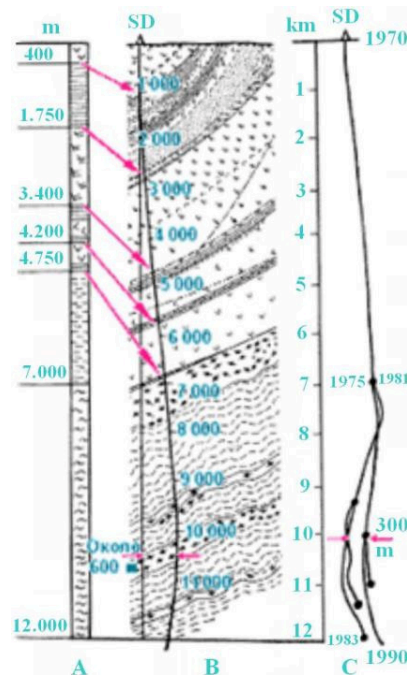
This is one of the few wells that were drilled not for exploration or production, but for purely scientific purposes: to study the oldest rocks of our planet and the processes going in them. The Kola Superdeep (state index – SD-3) was not the first and not the only one in the program of studying the deepest structure of the Earth. Today, the Kola Superdeep well is not being drilled, it was shutdown (closed) in 1992. In February 1995, the SD was transferred to the geo-laboratory model.

For drilling SD in 1970 a special exploration expedition was created (Kola GRES). A well and a drilling rig were constructed 10 km from Zapolyarny, next to the unknown lake named Vilgiskoddeiaivinjärvi, near the Wolf Mountain. The location of the drilling was chosen correctly: the Baltic Shield, to the surface of the oldest igneous rocks aged about 3 billion years. Drilling began in May 1970. Went to a depth of 7,263 m which took 4 years. It was conducted by a serial instrumental installation, which is usually used in the extraction of oil and gas. Next, it took almost an annual break for the installation of a special drilling rig Uralmash-15000. It was with this help that drilling actions were further conducted.

1983 was marked by a record, the depth of drilling exceeded 12 km. The Well became the deepest borehole in the world.

Kola Superdeep like other wells, it doesn't go straight vertically from the surface of the earth to the bottom of the borehole. The well crosses inclined layers of different density as shown in the figure 2.

At the same time it wriggles, because the driller constantly deviates towards less strong rocks. With significant deviations, the well is attempted to return to its place. Often there are accidents with the loss of drilling tools and parts of pipes. After that, we have to make a new trunk, stepping aside. So the largest accident on the Kola Super-deep well occurred on September 27, 1984 when 5 km of pipe stacked in the well. This was the biggest problem in the history of the Super-deep well, when it was necessary to start a new sidetracking from the depth of 7 km. A total of 12 such roundabouts were drilled in the well. For that, the scientists received an extremely valuable for scientific volumetric model of the earth's crust.



**Figure 2.** Cross-section of the Kola well.

On scientific significance, the drilling of superdeep well was not accidentally compared with a space expedition to another planet. Samples of rocks were extracted from the earth's interior are of no less interest than, for example, samples of the lunar soil. Thus, studies of the lunar soil showed almost complete identity to the rocks extracted from the Kola borehole from a depth of about 3 km. The drilling results brought many other questions. At the 10-kilometer depth, 14 species of microfascia – the petrified remains of ancient living organisms – were discovered. These findings showed that the life span on our planet is not 1.5, but 3 billion years. During drilling from the depths, where there are no sedimentary rocks, methane appeared. Thus, the theory of the purely biological origin of hydrocarbons was questioned. The borehole gave also a practical gift, at a depth of 1.6-1.8 km industrial copper-nickel ores were discovered, a new ores was discovered.

At the Kola Superdeep, turbine drilling was used as a type of drilling, which do not rotate the whole drilling string, but only the drilling head. A drilling mud pass through the pipe under pressure, rotating the turbine below it. The total length of the turbine was 46 m, it stopped by crown drill bit (it is often called a crown) with a diameter of 214 mm. In the middle there is an unopened column of rock – a core with a diameter of 60 mm. Through all the sections of the trumpets passes the pipe – the core receiver, where the columns of the extracted rock are collected.

The crushed rock (cuttings) along with the drilling mud was taken from the borehole to the surface. The weight of the drilling string submerged in the well with the drilling fluid was about 200 tons. Special designed pipes made of light alloys were used; a string of ordinary steel pipes busted due to its own weight. One run, determined by the wear of the drill bit, was usually 7-10 m. In 1991, drilling was stopped at a depth of 12,261 m. The Kola well still now is the deepest in the world.

### 3.2. *Saatlyn well*

In 1977, the Saatlyn well was drilled in the Kurinskaya valley in Azerbaijan. The design depth of this well was 11 km. The Saatlyn superdeep well, in the contrast to the Kola well, it was drilled in the region of the «young» continental crust of the Mediterranean mobile belt. The active geological development of this belt occurred in the so-called Alpine period, which began in the Mesozoic and continues at the present time. The well is located in Caucasian in the Kura region near the Kura and Araks rivers, the oil and gas rich area. The well reached a depth about 8,324 m. The aim of this well was to find out the possibilities of discovering oil and gas deposits at great depths and establish the position of the crystalline basement of the co-temporary Kura lowland formed between two large mountain ranges – the Greater and Lesser Caucasian.

Unfortunately, expectations were not met, to open the oil and gas bearing horizons within the Saatlyn (although the presence of small amounts of hydrocarbons was detected in some rocks). The well was likely to have landed directly in one of the large, long-term developing volcanic centers, where hydrocarbon accumulations are not created.

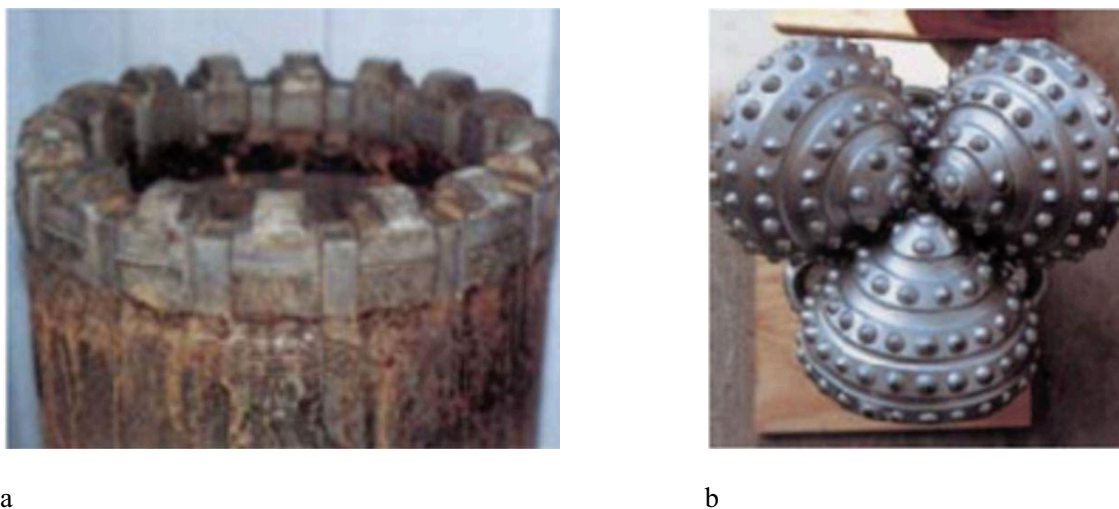
Despite the fact that the Saatlyn well did not reach the design depth of 15 km, the structure opened gave a lot of new information for understanding the deep structure of the Caucasian and the history of its development. First of all, it was possible to establish that the territory of the Kura valley in the Mesozoic was a sea, at the bottom of where volcanic processes were volatile. Huge masses of volcanic products formed first the seamounts, which then rose above the water and turned into a chain of volcanic islands – an island arc. It extended approximately from the south to the north in the same direction in which geophysicists have established a large deep anomaly in the structure of the earth's crust.

## 4. **Drilling of superdeep wells**

There are different ways of drilling. If the depth of the well is not long (hundreds of meters), then the motor on the surface rotates the column of steel drill pipes; at the bottom of pipe is attached a drill bit, reinforced with hard alloys or diamonds (Figure 3). While rotating the bit cuts a rock to cylindrical shape, which gradually fills a special inner (core) pipe. When drilling without core selection, drilling heads are often used, which are a system of several rotating cones reinforced with hard alloys.

If the walls of the borehole are unstable, a steel casing is lowered into it. During the drilling process, the pump constantly pushes a special clay solution (mud) into the well, which is necessary to give stability of the walls, cool the instrument (drilling bit), remove small particles of rock (sludge or cuttings) and other purposes. From time to time, a string of drill pipes is lifted to the surface using a winch mounted on a drilling rig, if necessary; they replace the bit with a new one and again lower the drilling tool to the bottom.





**Figure 3.** Drill bit (a) and cone heads (b), which were used in drilling a superdeep well KTB-Oberpfalz in Germany.

Drilling is accompanied by measurements of the physical properties of the rocks along the wellbore. To do this, a special cable device is lowered in the borehole and records the temperature, electrical conductivity, magnetic susceptibility and other properties of rocks. This process is called well logging.

As experience of drilling in the USA and other countries shows, increasing engine power and pressure of pumps that pour drilling mud, increasing hoisting capacity of winches and strength of steel pipes – this way it is possible to drill wells with a depth of up to 9-10 km. For deeper wells, the innovative engineering solutions are needed. Many of them were proposed and implemented during the implementation of programs of super-deep scientific drilling.

So, if the bottomhole is at a depth of many kilometers, it is advisable to use downhole motors not mounted on the surface, but at the bottom of the drill string, which itself does not rotate. Downhole motors have screw mechanisms that are driven by a drilling fluid injected under pressure into the well.

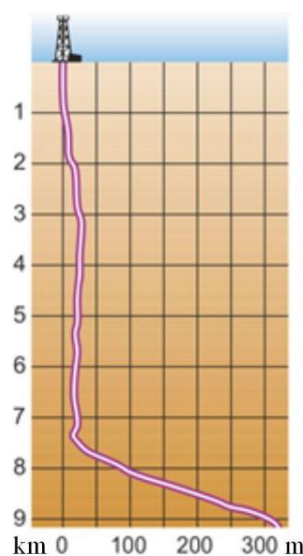
In order to reduce the weight of a string of drill pipes in several kilometers deep, these pipes are made of special lightweight, but rather strong and heat-resistant alloys. For example, when drilling the Kola well, aluminum alloys were used, which are 2-4 times lighter than steel. For the same purposes, it is proposed to use pipes that made of titanium alloys.

When the well reaches a highest depth, there is a significant difference between the hydrostatic pressure of the mud column and the lithostatic pressure due to the weight of the rocks. As a result, the walls of the well can be destroyed (bend in), which leads to serious complications during drilling. In order to balance the rock pressure, there is an increase of density of the drilling mud to about 2 g per centimeter cubic.

One of the most difficult technical problems is to ensure reliable operation of drilling equipment when there is existence of high temperatures in superdeep wells. This applies to metal parts, their joints, lubricants, drilling mud and measuring equipment. Although on the bottomhole, ie. At the lowest point of the Salton-sea well in the USA, at a height of 3220 m, a temperature of 355 °C was recorded, and in another well drilled to 1,440 m in one of the volcanic areas in the west of the USA, the measured temperature reached 465 °C, will allows drilling of superdeep wells at such high temperatures for a long time, since the temperature resistance does not exceed 200-300 °C. The most biggest problems are with measuring equipment, especially with electronics, which already fails at 150 °C. Water mud retains technological properties up to 230-250 °C. At a higher temperature, it is necessary to switch to the oil base mud and ap-

ply more complex mixtures. The high temperature of the earth's interior remains one of the main factors limiting the scientific of deep drilling.

Serious technical problems are associated with the spontaneous curvature of deep wells in the drilling process due to unbalanced fracture of the rocks at the bottom, geological heterogeneities. For example, the sidetrack of the Kola well was at the height of 12 km deviated from the vertical by 840 m. There are technical methods of keeping the well in an upright position. So, thanks to a successful construction of the KTB-Oberpfalz well in Germany, it stopped to the height of 7500 m, the world's most vertical well. However, it went deeper due to high pressures and temperatures, and the well went its own way – as a result, at a height of 7,401 m the well deviated 300 meters from the vertical illustrated in the figure 4.



**Figure 4.** Schematic section illustrating the sidetracking of KTB-Oberpfalz well in Germany.

Superdeep drilling requires the creation of special measuring equipment, which controls the conditions along the track at the bottom. Conventional logging technology with sensors that are lowered into the well on a heat-resistant cable is not very suitable for this purpose. Working telemetric and other electronic equipment, which is attached to the drilling tool is lowered and carried out upward by the flow of the drilling fluid. Sensor signals can be transmitted not by wires but by hydraulic means by creating pressure pulses in the drilling fluid.

Deep and superdeep wells have a telescopic design. Drilling starts with largest diameter (92 cm in the Kola well, 71 cm in the well KTB-Oberpfalz), then the well become small in diameter as the hole drilled down. The lower part of the Kola well was drilled with a diameter of 21.5 cm, and the diameter of the KTB-Oberpfalz well at the bottom was 16.5 cm.

The mechanical drilling speed averages 1-3 mph, for the one flight between the lifting operations; the average depth is 6-10 m. The average lifting speed of the drill string is 0.3-0.5 m/s. At least 10 % is spent on the well measurements. In general, drilling one superdeep well takes years and is very expensive. For example, drilling of one superdeep well in Germany cost 583 million in Germany currency. The cost of superdeep drilling in Russia was not less.

When drilling superdeep wells, there are often accidents caused by dead stuck drilling and other causes. It takes a long time to eliminate the accident, it is often impossible to eliminate them, you have to start drilling a new trunk. Therefore, a multi-kilometer column core with a diameter of 5 to 20 cm, which is one of the main, but not the only result of scientific drilling, becomes truly precious. Kern is carefully docu-



mented and stored in special rooms. His study involved large teams of specialists who conduct a variety of studies. For example, the material obtained while drilling a German superdeep well was studied by about 400 scientists, the results of these studies were published in 2000 scientific publications!

After the drilling of the superdeep well is over, it turns into a permanent laboratory. Specialists are monitoring the changes in the earth's interior along the wellbore and in the wellbore space, conducting various experiments. Such laboratories are based on the Kola and Vorotilovsk wells in Russia and KTB-Oberpfalts wells in Germany.

### **5. New drilling techniques and technologies**

Drilling of superdeep wells (more than 6000 m) has a number of features compared to drilling wells at the depths that have been developed. In particular, the initial geological data for the design of superdeep wells, as a rule, are predictive and do not have a sufficient degree of reliability; design solutions for drilling methods, well design, selection of technical drilling tools (drill pipes, bits), as well as materials for drilling and grouting mortars contain several possible options that are corrected or even changed as wells deepen; a large volume of research and development work is a necessary condition for ensuring optimal technical and technological solutions in conditions of multi-variant geological structure, etc.

Currently, only two main methods – turbine and rotary – satisfy the requirements of superdeep drilling. In the world practice of oil and gas prospecting, rotary drilling is mainly used, but calculations show that at a depth of more than 10,000 m, downhole motors remain the preferred method.

The well design, including the casing strings, their diameters and the depth of descent, is determined by taking into account many factors. The decisive role in crystalline rocks is played by their physical-chemical properties. For sedimentary rocks, it is important to avoid incompatibility of drilling conditions in different intervals of the section, and also to ensure the tightness of the annulus and the possibility of installing a pressure – releasing blowout equipment. When choosing a design, the resistance of pipes against mechanical wear and their strength properties, as well as the permissible weight of the pipe sections, are evaluated. In many respects, the casing string diameters in a well depends on the diameter of the last casing, which should correspond to the conditions of the studies carried out in it.

A fundamentally new method of drilling with an open hole of an optimal diameter was developed and implemented, which made it possible to reduce the metal capacity of the well construction 5 to 6 times (compared to oil and gas wells), to eliminate the wear of cemented casing strings, to prevent insuperable complications and thereby to allow drilling on deeper depths.

For the drilling of the Kola superdeep well, the domestic drilling rig BU-15000 with a lifting capacity of 400 tons was installed at the discharge pressure of 400 kg/cm<sup>2</sup> with the maximum automatic drilling processes (lowering and lifting of drilling bit). The installation is designed to drill wells to a depth of 15 km. Automatic allowed several times to increase the drilling speed.

Superdeep drilling led to modern well design and increased heat resistance of engines and oil-filled reducers, which could operate at temperatures up to 160-180 °C. They have become the main low-speed machines for working with roller cutters with sealed supports, diamond chisels.

Specifically for drilling superdeep wells, drilling bits and downhole motors with the corresponding deep-seated characteristics were designed, including those with an oil-filled sealed support, which provided working values 15-20 % higher than the average design parameters, and at great depths – by 70-100 %. Heat-resistant gearbox turbodrills that operate steadily at a rotational speed of 80-200 r/min have been developed. (The downhole motor operates from the energy of the fluid flow without rotating the pipe or with its rotation at a minimum speed of 2-4 r/m). The effective means of monitoring the turbodrill working on the bottom are streamlined and put into practice, without which are impossible to drill a downhole motor at depths of more than 8-9 km with process control over ground sensors. New types of core samplers with hydro-transportation of core into the storage chamber were put into production, which ensured

acceptable rock selection rates practically throughout the entire depth of the well. The new core shell allows to save from abrasion a significant part of the drill core and raise it to the surface: the percentage of core removal from greater depths rises by 2-3 times against the usual. A fundamental new technology for avoiding severe bottomhole complications by the method of unoriented drilling of a new trunk without the installation of a cement bridge was developed, which was successfully applied three times during drilling of the Kola superdeep well at depths of more than 7 km.

Scientists and designers have designed some of unique instruments and equipments, which ensured the implementation of the most comprehensive research package in the world. Among them, acoustic logging equipment, which made it possible to study the regularities of acoustic fields and determine the interval and reservoir velocities of propagation of elastic vibrations of transverse and longitudinal waves, and of spectrometric gamma-ray logging equipment that provided accurate spectrometric studies at temperatures up to 250 °C and pressures up to 210 MPa.

At the Kola superdeep well, an information and measuring systems were implemented, which included three main software and hardware subsystems for preparation for the process, drilling control and determination of the results of the process.

The Tyumen superdeep well (Russia) used an automatic drilling optimized station developed by «Soviet Union technology». The system provided optimization on the speed process or penetration of the bit, correctly selection of drilling mode with changing drilling conditions during the process, recognition at an early stage of occurrence of pre-emergency and emergency situations and their probable assessment.

## **6. Scientific results of superdeep drilling**

None of the superdeep wells has fully confirmed the geological section, which was assumed prior to drilling; in many cases the discrepancies turned out to be cardinal. This fact confirms the approximate character of modern knowledge about the deep structure of the continental crust and proves the need for deep scientific drilling. So, the Krivorozhskaya well was drilled in the center of the iron ore basin in order to prove that the ferruginous quartz, emerging on the surface in the form of a strip about 120 km long, is submerged to a depth of 6-8 km, and then bends again to the surface. The drilling results showed that the deep structure of this basin is not a curved fold, but a series of parallel inclined reservoirs that extend to a depth of more than 10 km. Hopes for the discovery of new deposits at the depths available for exploration were not justified.

The main task that faced the first super-deep wells – the Kola and Saatlyn wells, was to reach the point of the so-called basalt layer of the earth's crust, which had been distinguished by geophysical data indicating an increase in the speed of pass elastic waves and an increase in the density of the granite layer. The formation of such zone is caused by the fact that at a temperature of 60-100 °C, chemically and physically bound water and other volatile compounds go into a free state with the formation of hydraulic fractures and partial dissolution of rocks. This effect was then found in other deep and superdeep wells. Thus, it was proved that the wave pattern, which is fixed by seismic methods, reflects not so much the change in the composition of rocks with depth as the change in its stress state and filtration properties. It became clear that the two-layer model of the structure of the continental crust, at least, is not universal.

These results are important not only for the interpretation of geophysical data. They made it possible to re-evaluate the general conditions for the formation of the deep hydrosphere of the Earth and to understand the nature of certain phenomenal that had previously remained unexplained; in particular, the appearance of deep zones of excess pressure that did not correspond to the weight of overlying rocks, the counteraction of clay strata with compaction when they are submerged to depths, when they are transformed from traditional low permeability stops into porous oil and gas reservoirs.

As follows from the drilling materials of the Saatlyn well, groundwater can penetrate into the initially dry crystalline rocks from overlapping sedimentary strata (the mechanism of downward filtration). This

way, deep deposits of oil can be formed. The Tyumen superdeep well, drilled 20 km west of Urengoy to a depth of 7502 m, confirmed this conclusion. At depths of 6,424 m to the bottom, it opened the thickness of basalts, which, unlike the rocks of the same age and composition, exposed on the surface in eastern Siberia, turned out to be very porous and microfractured, since the water released during compaction of the overlying sedimentary strata interacted with underlying dry basalts so that, in the end, they turned into permeable deep reservoirs, favorable for the accumulation of gas condensate and gas deposits.

The study of the distribution of chemical elements in the bank of deep and superdeep wells led to the conclusion that the processes of geochemical migration with the study of increased local concentrations of various metals are characteristic not only of surface zone, but also occur at a depth of some kilometers. Thus, anomalously high gold and silver contents were found in the Kola well at a depth of about 10 km. Consequently, ores can lie at a very deep depth, which is consistent with the results of the exploration of some known locations, where the mineralization is traced by borehole a few kilometers from the surface. Thus, in the Kyzylkum Desert near the gold deposit Muruntau, which is one of the largest in the world, a deep well was drilled, as well as 4 satellite wells with a total depth of 5000 m. With their help, it was possible to study the composition and structure of ore-bearing sedimentary rocks, at a depth of 4000 m, the granite dome was opened. Gold Industrial mineralization was traced down up to a depth of 1100 m. According to the drilling data, gold reserves could be expected at the deep deposit, and estimation were about 3 thousand tons.

If the advisability of practical extraction of ores from of 5-10 km is problematic, the theoretical value of geochemical data obtained with superdeep drilling, combined with the discoveries that pertain to the preservation of high permeability and porosity of rocks to 10-12 km, is extremely large. These data confirm the possibility of large-scale circulation of heated waters, which interact with rocks of the earth's crust. If this is so, then the sources of ore matter in the deposits should be associated not with hypothetical subcrustal depths, but with real processes of redistribution of chemical elements in the upper and middle parts of the continental crust.

The great interest as the results of drilling the Vorotilovskaya well, which was laid 60 km to the north-east of Nizhny Novgorod to study the crater that formed when a large meteorite fell, and this happened about 200 million years ago and was followed by a powerful explosion. The rocks were crushed and broken into numerous cracks about 3 km deep. In the epicenter of the explosion under the influence of a blast wave, the crystal lattice of many minerals was disordered, and they turned into amorphous glasses. At the time of the explosion, the temperature reached 2000-3000 °C after the shock wave, when the pressure dropped sharply, the solid rocks melted and possibly partially evaporated. Later, the explosive crater was blocked by a younger sedimentary stratum. At 5374 m well depth revealed a full vertical section of the crater, which studied in detail all effects of the ancient explosion, the consequences of which strike the imagination. As a result of the impact of the meteorite, a large block of the earth's crust was first strongly compressed, and then advanced almost 2 km relative to its original position. A crater 80 km in diameter was formed on the surface, filled with crushed and partially melted material. Among the newly formed minerals, diamonds were also found that arose at the time of the explosion from organic carbon and which were originally enclosed in sedimentary rocks.

The main task of drilling a superdeep well was to obtain direct information about the foundation of the Ural mobile belt. Currently, experts are discussing two alternative models. One alternative suggests that Ural belt was vast ocean before. Another alternative suggests that the Ural belt was laid on a continental basis. Both models have far-reaching geological consequences. Direct information on the composition of the rocks lying now at a depth of 10-15 km will clarify this problem.

Thermophysical measurements in deep and superdeep wells have made it possible to significantly clarify the temperature distribution and the magnitude of the deep heat flux. It turned out that the temperature and density of the heat flux in many cases significantly exceed those estimates obtained by extrapolating

the data on the surface zone. Thus, in the Kola bore well the temperature at 12 km was 212 °C instead of the assumed 120 °C. Most likely, this is due to the fact that the lower part of the of this well was composed of granitic rocks that contained significantly more radioactive heating elements (U, Th, K) than the rocks of the basalt layer in the design. According to calculations, the temperature in the area of this well at a depth of 30 km is 460 °C, and at a depth of 42 km at the base of the earth's crust reaches 580 °C.

Anomalously high temperatures are typical characteristics of the Tyrnyauz well, drilled in the northern Caucasus. At 4 km the temperature rose up to 223 °C. This well crossed granites that were introduced into the earth's crust just 2 million years ago in the form of magnetic melt with an initial temperature of 900-700 °C. By now, the granites do not melt completely.

According to the project developed by special state scientific enterprise «Nedra» at the Tyrnyauz well, it was supposed to be main element of an experimental geothermal station, using the dry heated granites. To do this, it was planned to pump cold water into this well, and hot water through the second well drilled next to the surface. It was planned to cement the well up to 3457 m deep, on the interval of 350-400 m the well drilled inclined, and nearest well for lifting water. The water injected under pressure had to expand the cracks in the granite, increasing its permeability, heating up to 240 °C and rising to the top. According to calculations, such a design could provide hot water to the neighboring town of Tyrnyauz. Unfortunately, due to the economic difficulties, this interesting project remains unrealized. There are other, even more ambitious projects of deep drilling with the purpose of practical use of the Earth's heat.

## 7. Conclusion

Modern technology allows drilling wells on continents up to the depth of 10-15 km. Direct penetration to a higher depths requires new drilling technologies and remains a matter of the future. The first impressive scientific results allow us to hope that the necessary technical means will be designed soon enough.

The new data obtained by deep and superdeep drilling wells on the real deep crustal structure, including the phenomena of active «water – rock» interaction, which lead to the formation of inhomogeneities such as waveguides and false boundaries, made serious corrections in the interpretation of geophysical measurements.

It should be emphasized that the programs of scientific drilling includes a powerful stimulus for technical progress and international cooperation of scientists. For example, thanks to a such unique drilling equipment that was developed in the USSR, which allowed to drill the deepest well in the world (12.3 km). The experience of drilling a superdeep well in Germany was very useful in terms of organizing and conducting scientific research. In coming years probably, will be implemented a wide international program of deep scientific drilling on the planet, comparable in scale with drilling in the oceans. Now it became obvious that this is absolutely necessary for the further development of geological science.

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