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INDUCED ALTERATIONS TO THE ENERGY STATE WITHIN OIL AND GAS FIELDS: A NEW TECHNOLOGY FOR ENHANCED HYDROCARBON PRODUCTION

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ABSTRACT

Oil and gas fields are contained within viscoelastic media that have unique and distinguishing energy states. These media are not only inhomogeneous in terms of compostion (material and fluids distribution), but are also inhomogeneous with respect to 'energy state'. We have developed a technology whereby the energy state of such media can be measured, monitored, and altered so that net hydrocarbon production can be increased. The technology has been awarded patents by European (2005) and Eurasian (2000) regulatory bodies.

In brief the technology uses an approach where the stress distribution within the medium that contains the hydrocarbon field is initially characterized, then monitored over time using geophysical, topographical, and subsurface pressure measurements. These measurements are used to generate an energy model for the medium, and a predictive model for the effects of externally induced vibrational disturbances. Vibrations are then induced within the hydrocarbon field to raise its energy state. This in turn alters the stress state within the field, and the pressure distribution, resulting in enhanced fluid flow. Vibrations are induced at the earth's surface over an area typically 1.5 to 2.0 times larger than the underlying hydrocarbon field. The medium returns to its original state after a certain period of time following cessation of induced vibration. No damage is caused to the field during the operation. In order to optimize an enhanced level of hydrocarbon output, induced vibrations are repeated every 1.5-2 months.

This technology has been applied since 1994 to many hydrocarbon fields, achieving significant increase in production and decrease of water cut. We have proved in practice that the technology can be applied to a wide range of geological structures and reservoir characteristics. An observed added benefit is that the induced vibrations tend to correct non-optimal disturbances in the medium caused by previous uncontrolled exploitation.

INTRODUCTION

A technology that involves inducing subsurface vibrations from the ground surface over hydrocarbon fields has been developed for the purpose of enhancing oil production and recovery. This technology is based on new notions of the physical states and conditions of geological media (that for example, contain hydrocarbon fields). These physical states and conditions are modeled and modified in a targeted manner through vibrations induced at the surface, covering the whole hydrocarbon reservoir. Induced vibrations cause an increase in the stress state of the medium, which in turn leads to higher reservoir pressure, and consequent increase in hydrocarbon flow and recovery. Unlike conventional methods of enhanced hydrocarbon recovery that attempt to maintain reservoir pressure through water and gas injection into the reservoir, this technology increases and maintains reservoir pressure from outside of the hydrocarbon reservoir.

The scientific background of the Technology is based on the discovery of a physical law governing the propagation and interaction of weak high frequency seismic signals (microseisms) within a medium. The discovery was registered by the State Committee on Discoveries and Inventions of the USSR in March, 1988, with Priority from May, 1979 (author – I. H. Kerimov). Several related technical papers on the Technology are cited in the list of references provided in this paper.

In previous years various aspects of monitoring and management of the stress state of geologic media using this natural law were studied in many

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seismically active and inactive regions of the former USSR, as well as in the oilfields of Belorussia (1979), Azerbaijan (1982-1984), Yakutia (1984), Central Asia (1985-1988), Ukraine (1989-1990) and the Caspian Basin (1989-1993). The technology has been developed as a result of these studies.

The primary features of the technology are as follows:

1. Quantitative characterization of: the stress state of a hydrocarbon field, distribution of local internal volumes in the medium, sensitivity of these volumes to externally induced mechanical disturbances, and distribution of intensity level of background seismic noise.

2. The method of inducing vibrations using surface seismic vibrators in a spatially and temporally targeted manner over the hydrocarbon field.

Vibrations induced at the surface can cause intense seismic emission, leading to redistribution of the stress state within the sedimentary rock containing the hydrocarbon reservoir. This in turn causes an increase in horizontal and threshold reservoir pressure, leading to increased fluid flow and recovery. Numerous well known scientific studies describe effects of vibration impacts on hydrocarbon-bearing rocks that may lead to enhanced hydrocarbon flow and recovery: creation of new drainage channels**,** dilatancy of reservoir rocks, opening of pores, significant decrease of fluid viscosity, intensification of capillary effects, increase in filtration processes (particularly in finely-dispersed thin and poorly permeable volumes of rock). However, it should be noted that in our case is difficult to quantify the relative contribution of each of these mechanisms to enhanced fluid flow. It is the cumulative effect of these various mechanisms that result in enhanced hydrocarbon production during application of the technology.

Application of the Technology proceeds in the following manner:

1. Analysis of various existing data for the field (geological, geophysical, engineering, etc) and collection of new data including the following:

    - Conducting microseismic activity surveys over the field and surrounding area (dimensions of the total area is 1.5-2 bigger than dimensions of the oilfield);

    - conducting gravity, electromagnetic, and topographical surveys over the field and the surrounding area;

    - performing reservoir pressure measurements;

2. Development of a model characterizing the energy state of the medium containing the field, using data from the microseismic activity, electromagnetic, gravimetric and topographical surveys and results of data analysis.

3. Development of a vibrational impact model, which is based on the energy model for the medium.

4. Performance of surface vibrational impact tests to calibrate and validate the energy and vibrational impact models for the medium.

5. Administration of the vibrational impact program.

6. Periodically conducting surveys of microseismic activity, electromagnetic, and other monitor surveys, and updating the medium energy and vibrational impact models following the administration of vibrational impact program.

7. Repeated, (modified as necessary) administration of the vibrational impact program according to results of the above studies.

Application of the technology can cause enhanced hydrocarbon production to be sustained over a period of 2-6 months depending on the particular geological and geophysical properties of the medium and its pore fluids. During this period enhanced hydrocarbon production will gradually decline to the background output level (level of output prior to induced vibrations). In order to mitigate this decline, the induced vibration program has to be repeated regularly. Our previous experience suggests that repetition over a 2-3 month cycle optimizes the opposing parameters of benefit versus cost. It allows maintenance of high reservoir pressure with additional hydrocarbon production at stable levels.

The Technology is more environmentally friendly in comparison with other enhanced recovery methods. Increase in the stress state of the medium inhibits intrusion of subsurface water from external sources into the reservoir, and its subsequent deterioration. Furthermore, as the Technology does not involve pumping of water or chemical reagents into the reservoir during its implementation, this leads to economic and ecological benefits such as:

- increase of 15 -30% in rate of hydrocarbons extracted;
- reduction of environmental pollution;
- decrease in water-cut in extracted fluids of 5 – 12%
- sustained oil output at enhanced levels during long periods of time, thereby prolonging the productive lifetime of the field
- prevention of oil reservoir deterioration, and rehabilitation of previously caused damage
- increase in final oil recovery up to 60% or more

The Technology can be successfully applied in a wide variety of fields. But the most favorable geological, physical, chemical and production conditions for successful implementation of the Technology are the following:

- Regime of the reservoir's drive mechanism: water-drive or mixed;
- Reservoir depth: up to 3 000 meters
- Current cumulative output: no more than 80% of EUR
- Current oil recovery factor: 25 – 45%
- Oil density: no more than 0.90 g/sm^3;
- Current water-cut: no more than 70-95 %;
- Reservoir permeability: not lower than 0.2 mkm^2 (200 millidarcy);
- Reservoir porosity: no less than 18%;
- Oil viscosity in in-place conditions: no more than 5 centipoise;
- Type of oil-reservoir rock: clastics; mixed clastic-carbonate with carbonate components (marls, limy clay, dolomites etc.) no more than 10% of reservoir bulk volume;
- Low tectonic disturbances in the area of the field;
- Content of undesirable substances in oil composition: tars – less than 3%, alkanes – up to 6%, sulphur – up to 1.5%;
- Daily oilfield output – 7000 bbl/d or more.

Note: While the above are considered as ideal conditions, the Technology can be successfully implemented with lower profitability when conditions deviate from the ideal

METHOD OF APPLICATION AND RESULTS OF THE TECHNOLOGY

We describe here the results of application of the Technology to two commercial projects: from August 1995 to August 1996 at the Kala and the Old Kala oilfields, Absheron peninsula (Azerbaijan), and in 1996-2005 at Komarovskoye, Pervomayskoye and Bondujskoye oil fields, Tatarstan, (Russian Federation). During implementation of the technology at the Kala and Old Kala oilfields, the production team did not implement other methods of oil recovery. During implementation of the technology at Tatarstan, the production team implemented other methods of oil recovery. Both of these fields were at end of a secondary recovery stage when the Technology was applied. These examples show the effects of implementation of the Technology on various parameters: reservoir pressure, water-cut, seismic noise level, topography, gravity, electro-magnetism and production rate changes.

Topographic measurements

Monitoring of topographic changes during the period of application of the technology was largely performed using GPS devices with an accuracy range 5 millimeters. Following each application of induced vibrations, changes in the surface topography were observed over the oil fields. Induced vibrations caused the earth's surface to rise. Figures 1 and 2 show the magnitude of these changes at Kala and the Old Kala oilfields, and at Komarovskoye, Pervomayskoye and Bondujskoye oil fields respectively, after implementation of various cycles of the vibrational impact program.

It is well known that hydrocarbon production from a field can lower (not raise) the earth's surface above the field. Figures 1 and 2 show significant elevation changes that are opposite in sense to this expectation. Raising of the earth's surface is an indication of energy accumulation in the subsurface medium and increase in its stress state.

In addition to the rise in the earth's surface level, induced vibrations changed the pattern of horizontal motions observed at the earth's surface. Before the application of vibrational impact program, vectors of these motions had variable and chaotic directions. This indicates that due to the nature of previous production activity the medium had been exposed to chaotic stress distribution. This led to creation of microcracks within the medium of various lengths and direction. However, as a result of the more regular nature of induced vibrations, these horizontal motions gradually stabilized (in their direction and intensity) as the medium became more homogeneous, returning to its natural state. Figure 3 shows changes in horizontal surface motion on Pervomayskoe oil field during application of the vibrational impact program.

Microseisms level measurements

Relative increase in level of background microseisms has been observed after test vibrational impacts. Figure 4 shows maps of the sensitivity alteration (change in percentage terms of amplification of seismicity) following test vibrational impacts at various areas of Pervomayskoye and Bondyujskoye oil fields during November 1996 - September, 2001. The most responsive zones within an oilfield are detected based on changes of seismic noises patterns due to the test vibrations. These zones are considered the most suitable for vibrational impacts during repeat applications.

Gravimetric measurements

Changes in gravitational field intensity reflect changes in the density of rocks within the medium. Density changes occur as a result of alterations in the stress state of the medium. Changes in the gravitational field are a primary feature of the energy model of the medium. Accuracy of field gravimetric measurements was 2-5 microgals with observed variations in background level within 10-12 microgals. As a result of vibrational impacts, the gravitational field intensity increased at certain observation points by 70-120 microgals (selected points showed increase of 200 microgals). Figure 6 shows changes of levels in the gravitational field at Komarovskoye, Pervomayskoye and Bondujskoye oil fields during application of vibration impact programs.

Electromagnetic measurements

Electromagnetic measurements provide data in two important aspects. They allow assessment of energy distribution and characteristics within the medium at given depths. Electromagnetic measurements are very subtle and can be made over large areas in a relatively short period of time. This is the main reason for conducting them as repeat surveys along with microseismic activity surveys to monitor the energy state of the medium and the effectiveness of vibrational impacts. These electromagnetic surveys require use of special equipment. Finger 8 sub-meridian profiles of the oilfields before and during vibration impacts.

Reservoir pressure

Figure 8 shows reservoir pressure changes as a result of vibration program application in Komarovskoye, Pervomayskoye and Bondujskoye oil fields for the period from November 1996 until July 1998. Measurements were taken regularly (5-6 times a month) in designated wells (which were not used in active oil production) with subsurface pressure gauges.

Water-cut

Water-cut monitoring is one of the main bases to determine efficiency of the technology's implementation in general, and efficiency of conducted vibration impacts in every paticular case. Data on well productivity across the oilfield, and data on enhanced oil output and water-cut changes are also used to make alterrations to the vibrational impact program. Therefore, these measurements were taken 4 times a month with 4 samples taken each time from designated control wells (these comprise 25-30% of all producing wells). Water cut data from Kala and Old Kala and Tatarstan projects (Figure 9) show that implementation of the technology contributed to reduction of water-cut in 80 percent of producing wells and stabilization of water cut in the other 20 percent. Similar benefits were achieved at the Pervomayskoye (Figure 10), and Bondyujskoye(Figure 11) oil fields

Oil production

During the 9 month period when the vibration impact program was implemented (two vibration impacts cycles) at Kala and Old Kala oilfields, 4817 tons of additional oil out of 28901 tons of total oil were output (Figure 12). A similar record of oil production history at Pervomayskoye, Komarovskoye and Bondyujskoye oilfields from 1988 to 2005 is shown in Figure 13. In total 689.2 thousand tons of additional oil was output out of 4,345 thousand tons of the total oil production on Pervomayskoye, Komarovskoye and Bondyujskoye oilfields from December 1996 till July 2002. The additional oil output from July 2004 till May 2005 was over 125 thousand tons. This calculation of additional oil output did not consider the declining trend of oil production prior to implementation of the vibration impacts program.

The sustained increase in oil output from Pervomayskoye, Komarovskoye and Bondyujskoye oilfields with implementation of the vibrational impact technology over 9 years is evidence of its value in enhanced recovery programs.

CONCLUSIONS

New learnings concerning geological media that contain hydrocarbon fields, and the physical states and conditions in them, have led to an enhanced oil recovery technique. The latter involves inducing subsurface vibrations from the ground surface over hydrocarbon fields. These controlled vibrational impacts can result in sustained increase in volume of hydrocarbon output, and reduction of associated water-cut in produced fluids. The technology is environmentally friendly and can be used as the sole method of enhanced hydrocarbon recovery, or be used in conjunction with other methods of enhanced recovery. The technology has been awarded patents by European (2005) and Eurasian (2000) regulatory bodies. Effectiveness of the Technology as an enhanced hydrocarbon recovery technique has been demonstrated over many years and at several oil fields including the Kala and the Old Kala oilfields (Absheron peninsula, Azerbaijan), and the Komarovskoye, Pervomayskoye and Bondujskoye oil fields, (Tatarstan, Russian Federation).

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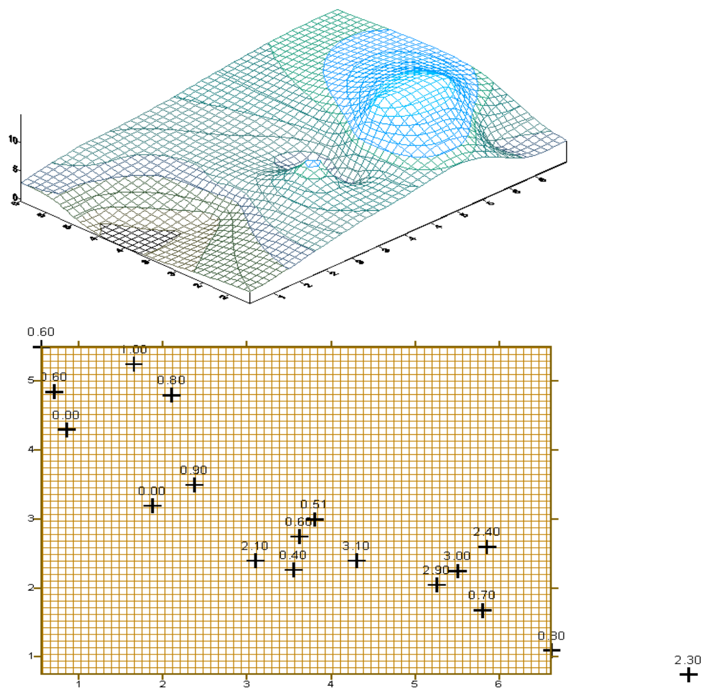


Figure 1 - Changes of the earth surface levels in Kala and the Old Kala oilfields (in centimeters).

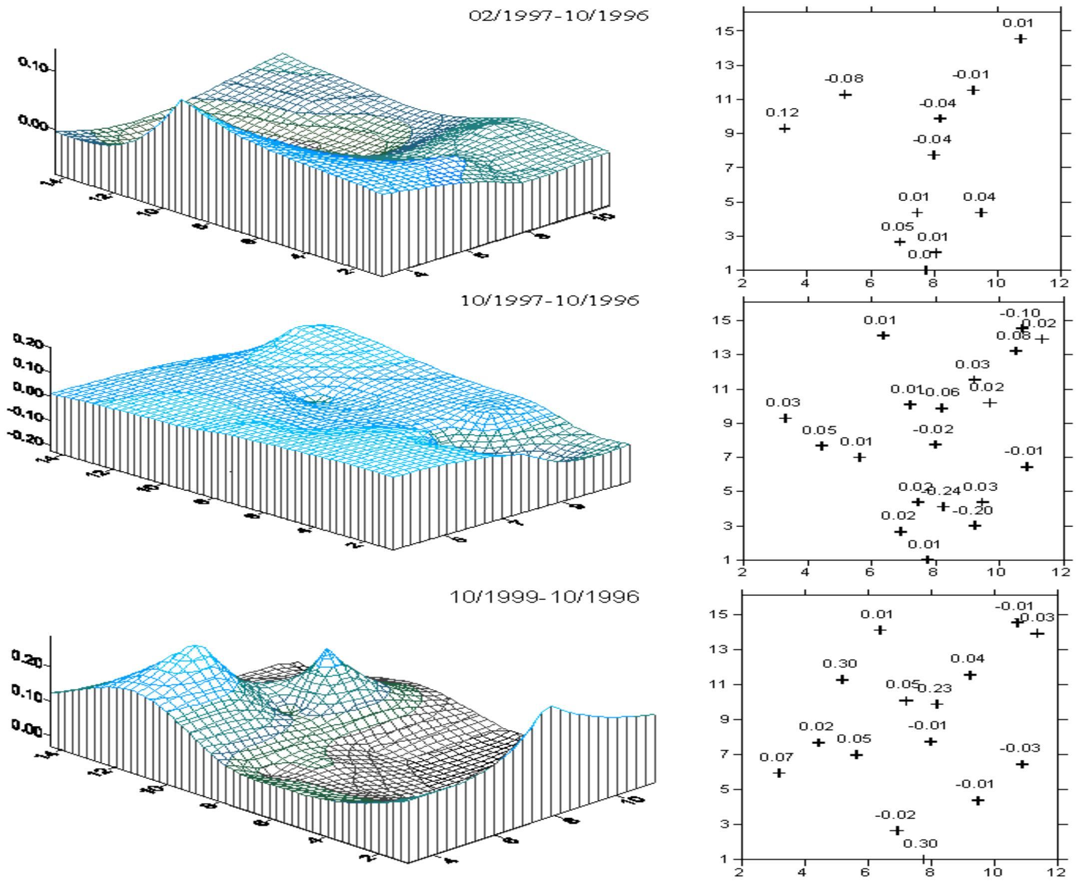


Figure 2 - Changes (in meters) of the earth surface levels at Komarovskoye, Pervomayskoye and Bondujskoye oil fields, Tatarstan, (Russian Federation) during the application of the vibration impact program.

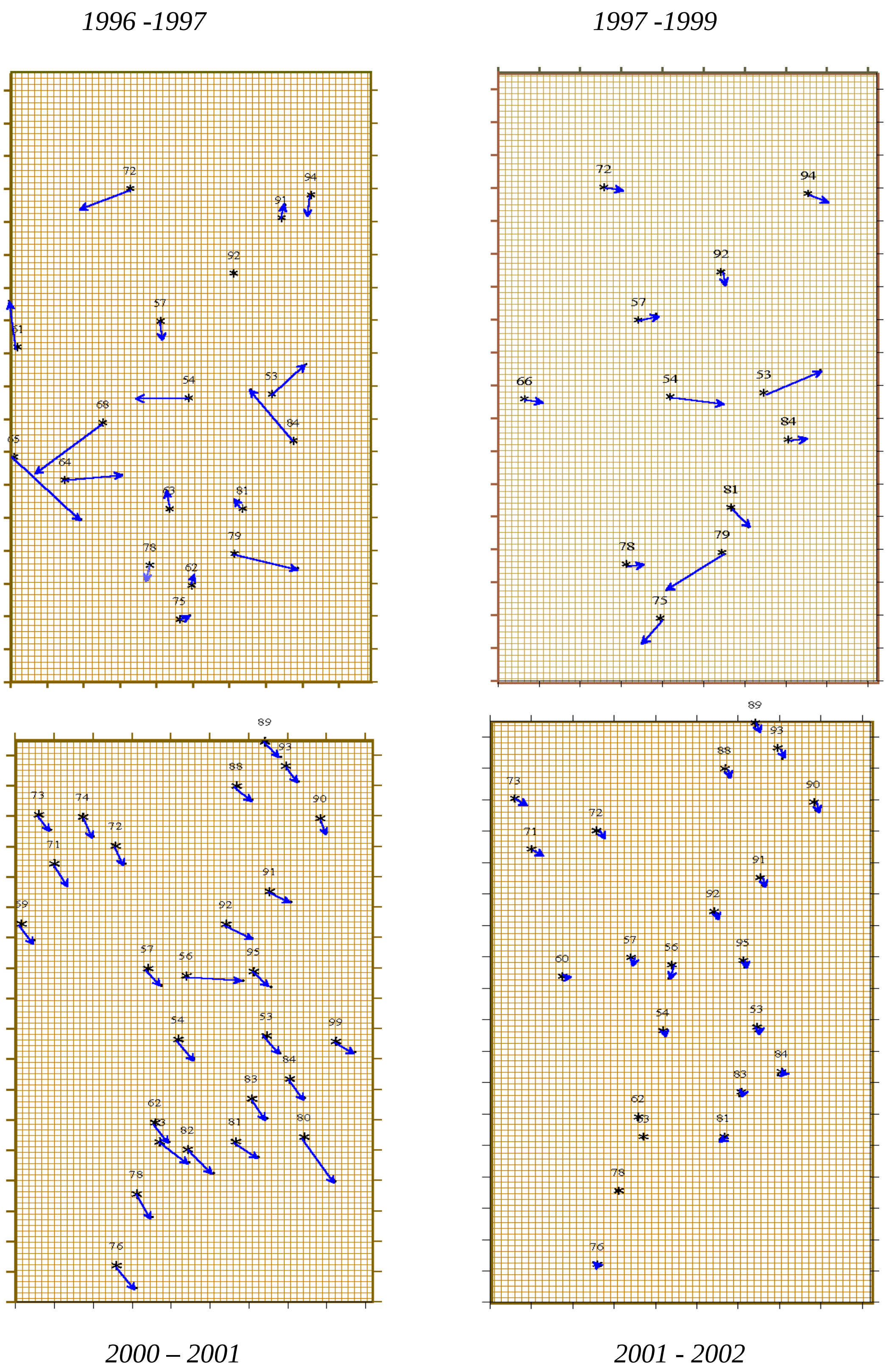


Figure 3 - Topography observation points with vectors of horizontal surface motion at Pervomayskoe oil field during various periods of observation

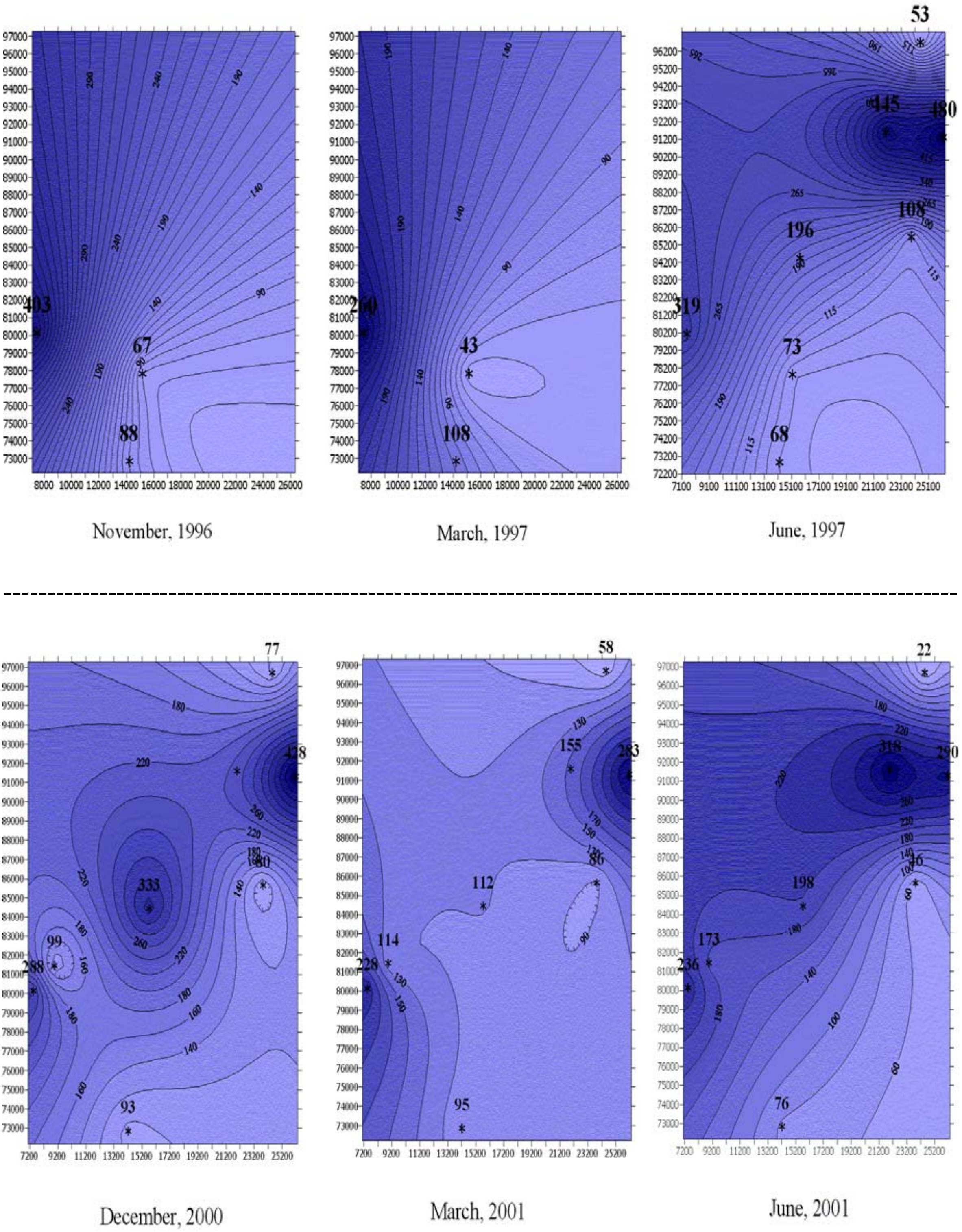


Figure 4 - Maps of sensitivity alteration (variation in percentage terms, of amplification of microseisms levels after the test vibrational impacts) for various areas of Pervomayskoye and Bondyujskoye oil fields during November, 1996 - September, 2001.

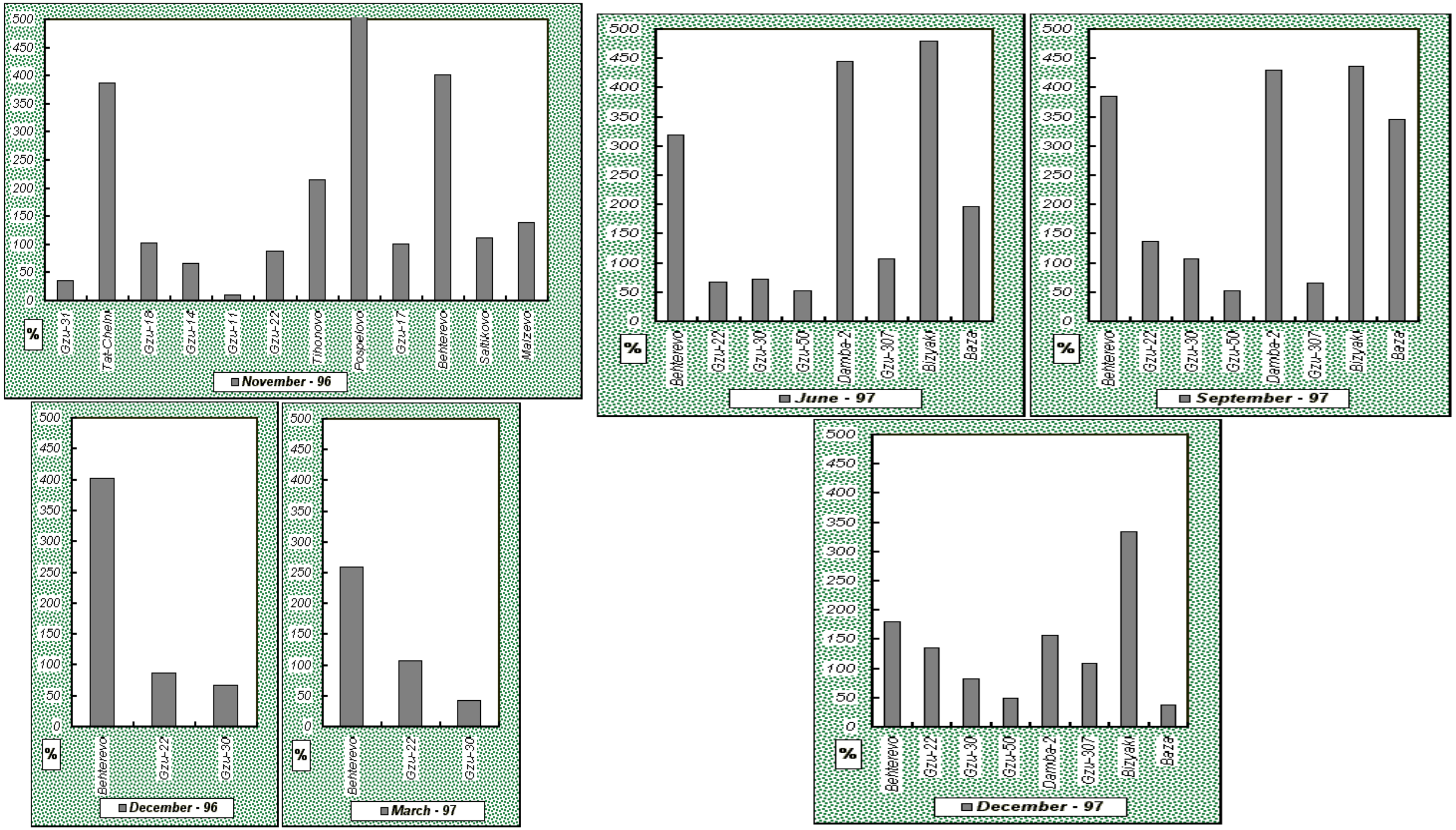


Figure 5 - Relative increase in background microseisms level (in %) at different parts of Pervomayskoye and Bondyujskoye oil fields (points 1-16) after each test impacts program application (November, 1996 – December, 1997).

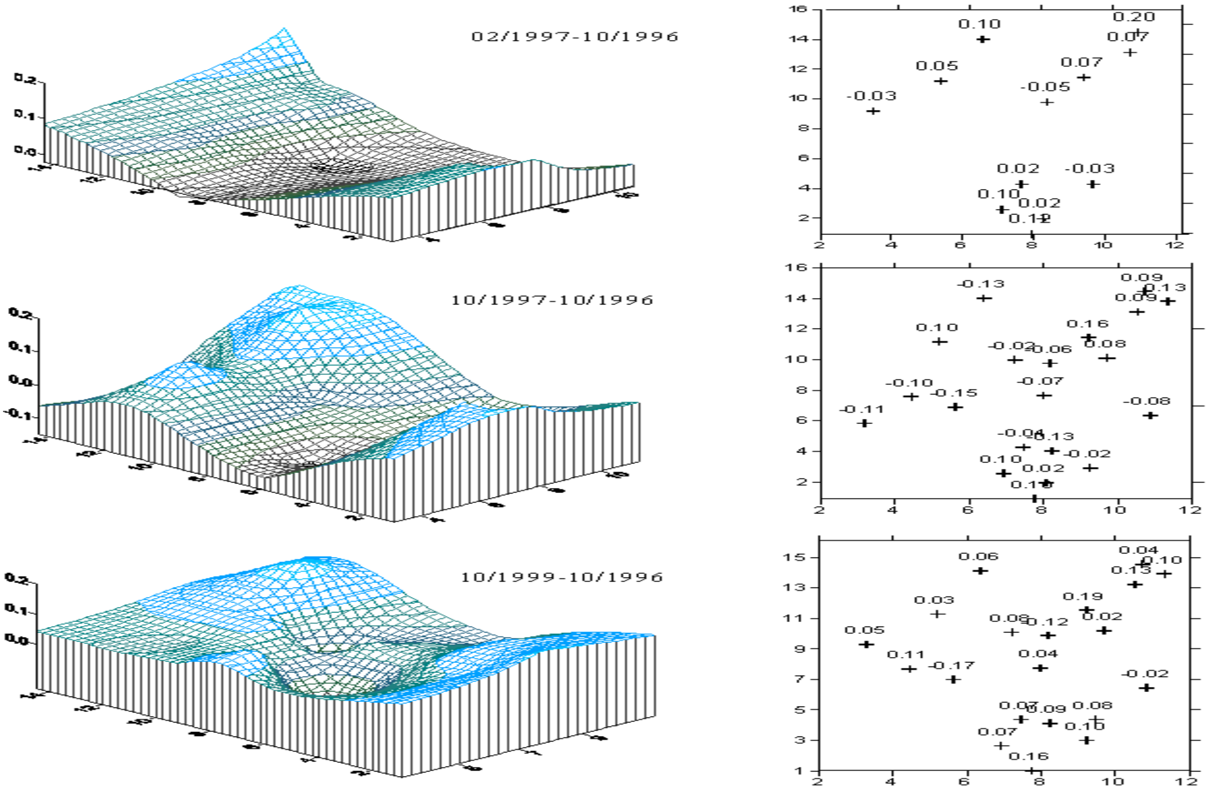


Figure 6 - Changes of levels of the gravitational field (in milligals) in Komarovskoye, Pervomayskoye and Bondujskoye oil fields during application of vibration impact program.

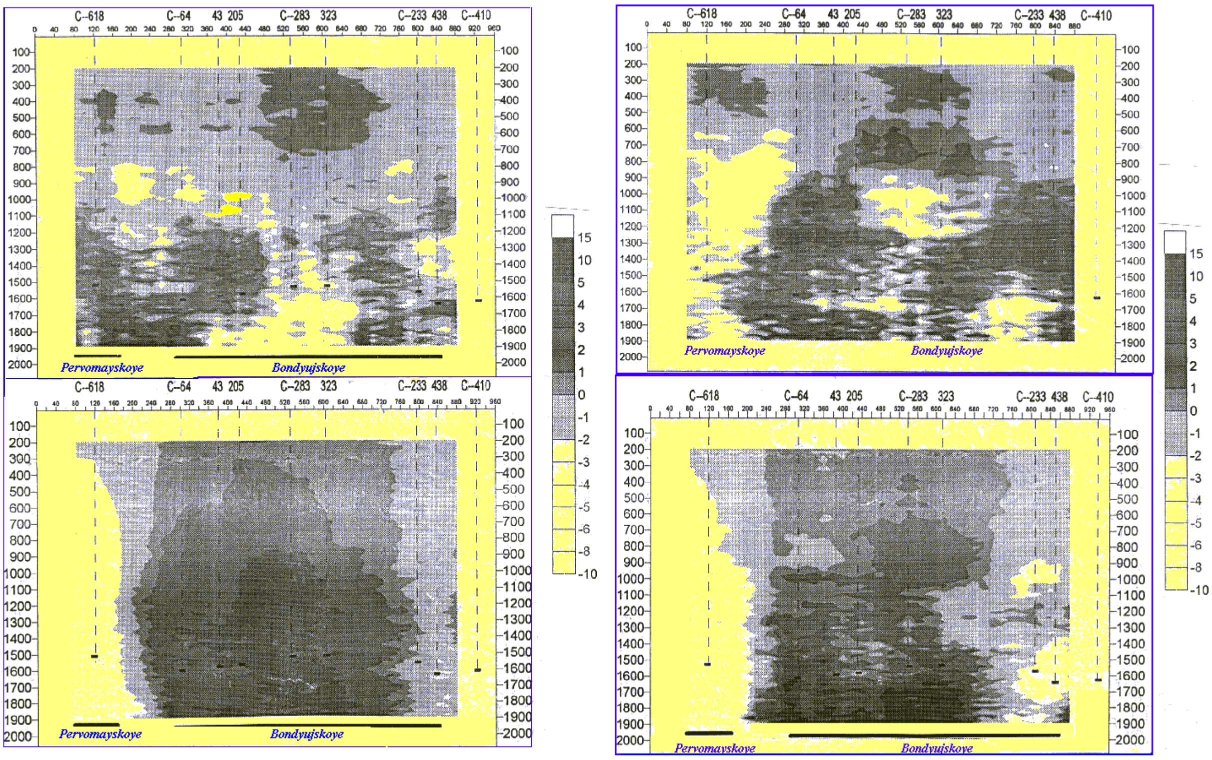


Figure 7 - Vertical cross sections of electromagnetic field energy distribution in the medium for sub-meridian profile 25 km (Pervomayskoye and Bondujskoye oil fields)

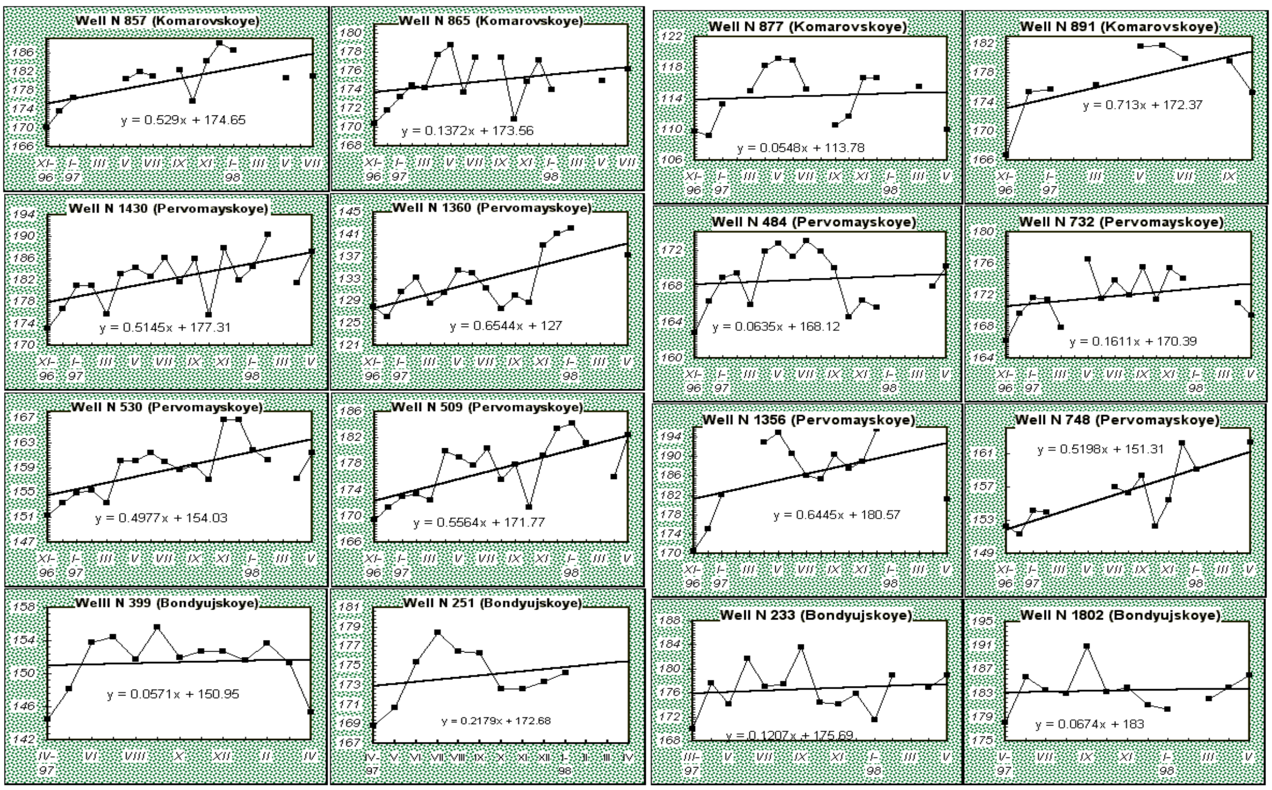
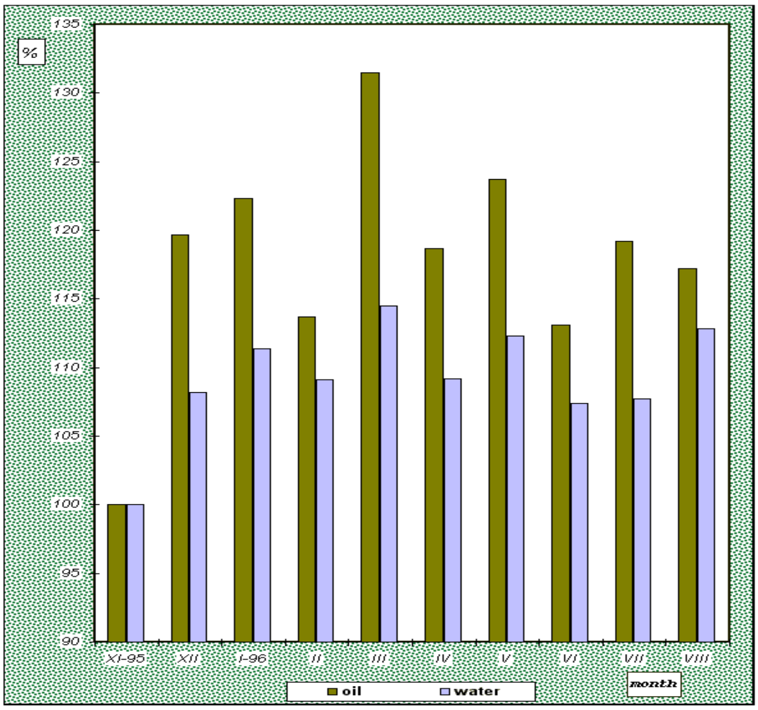


Figure 8 - Changes in reservoir pressure (in atmospheres) after vibration impacts at Komarovskoye, Pervomayskoye and Bondyujskoye oil fields (November, 1996 - July, 1998).



	XI-95	XII	I-96	II	III	IV	V	VI	VII	VIII
oil	100	119.7	122.3	113.7	131.5	118.7	123.7	113.1	119.2	117.2
water	100	108.2	111.4	109.1	114.5	109.2	112.3	107.4	107.7	112.8

Figure 9 - Decrease in water-cut of output liquid on Kala and Old Kala oilfields after two cycles of vibration impacts, conducted in December 1995 and February 1996 (relative correlation in % with water-cut level in November 1995)

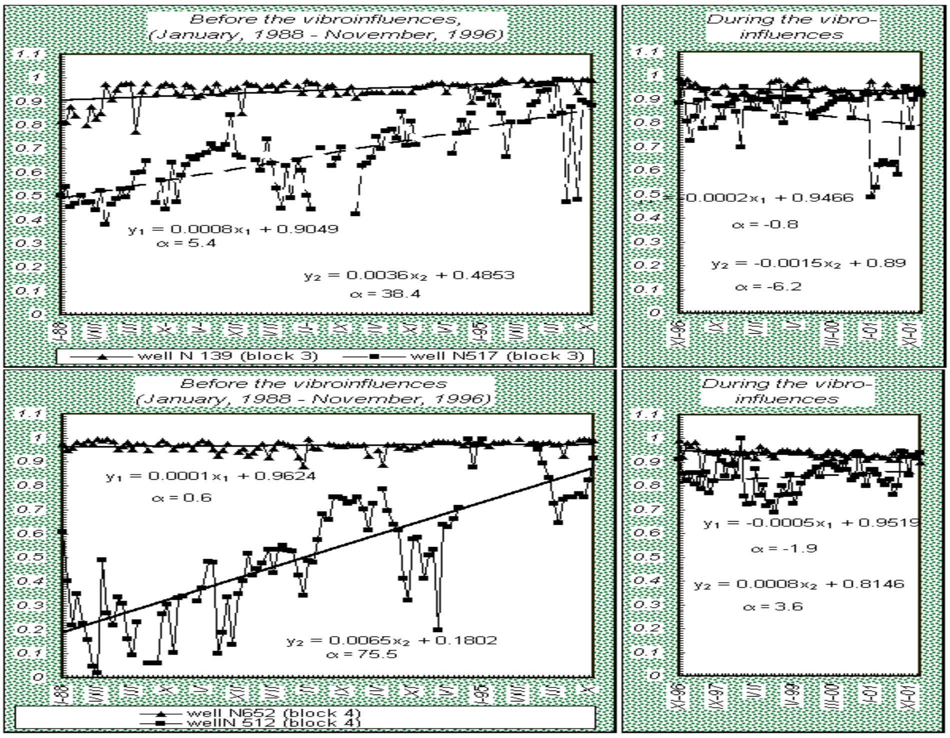


Figure 10 - Changes of the water-cut coefficients in various wells of Pervomayskoye oil field (January, 1988 - February, 2002)

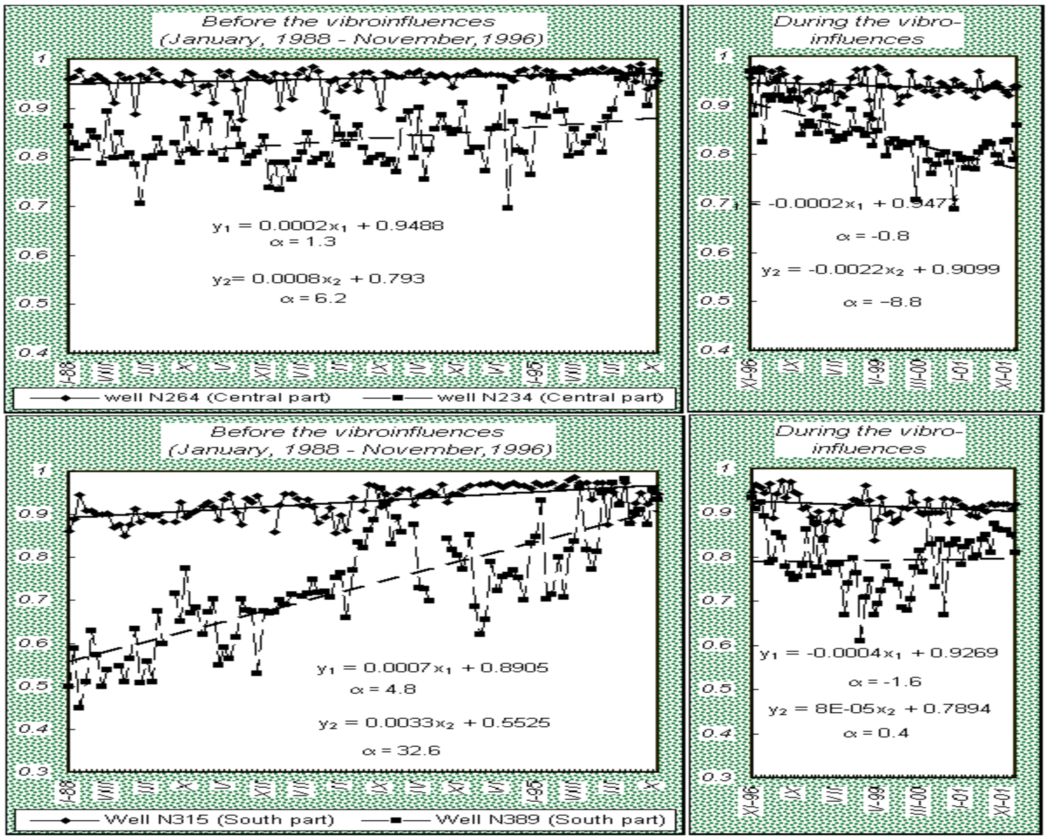


Figure 11 - Changes of the water-cut coefficients in various wells of Bondyujskoye oil field (January, 1988 - February, 2002).

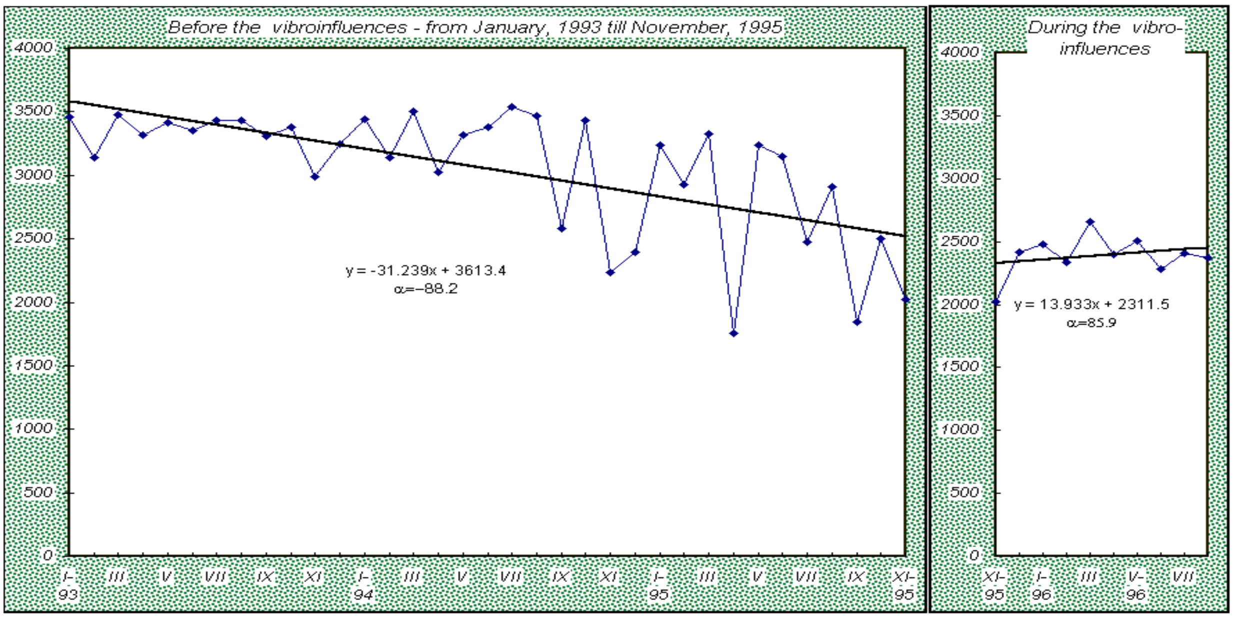


Figure 12 - Oil production change (tons) in "Kala" and "Old Kala" oil fields (January, 1993 - August, 1996).

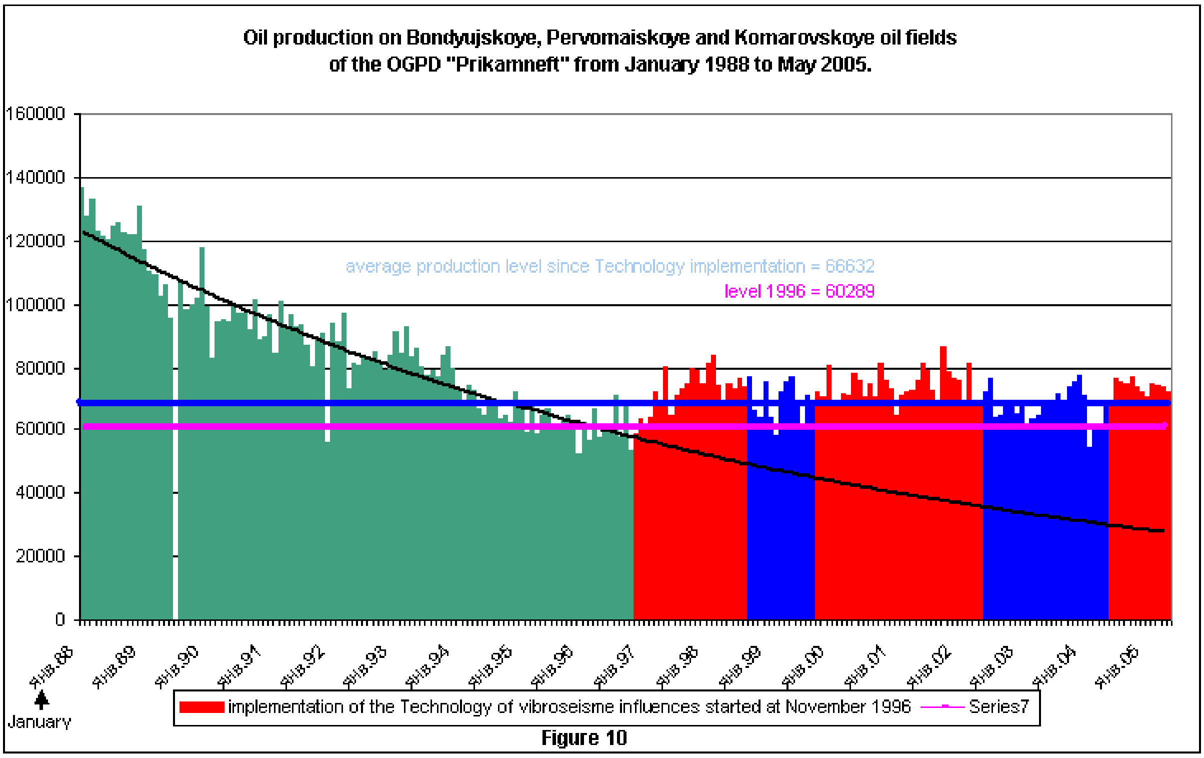


Figure 13 - Oil production (tons) at Pervomayskoye, Komarovskoye and Bondyujskoye oil fields. Oil production before implementation of the vibrational impact program is shown in green. The declining trend of oil production is highlighted by a black line. The periods of vibrational impact implementation are marked with red, and periods when the vibration program was halted are marked with blue The pink line shows average oil output in the fields for the last 3 months before commencement of the vibrational impact program). The blue line shows the average oil output during the period that the vibrational impact program was conducted.