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STUDY OF POOL FLOODING PROCESS FOR MONITORING THE OIL RESERVES RECOVERY

The urgency of study of basic regularities of pool water flooding is predetermined by the fact that complex structural multiple zone oil pools are developed by wells being drilled according to a rather simple geometric pattern. So, two mutually functioning systems – the deposits of a given structure and the selected system of development – in most cases do not correspond to each other to a certain extent that negatively influence on basic technological factors of the development.

The value of information about the process and condition of pool water flooding is in its results of a complex influence of geologic structure features and of applied development system on recovery of reserves in multiple zone pools.

METHODS IN STUDYING OF POOL WATER FLOODING PROCESS

The main source of information about the initial distribution of hydrocarbons are the geophysical surveys in open hole producing wells, which are drilled in bringing the pool into development. The efficiency of posterior monitoring the process of reservoir water flooding and oil reserves recovery depends sufficiently on the extent of reliable notion about the initial distribution of oil and water in the deposit. Very often this problem is a very complicated one, because within some deposits the area of ambiguity interpretation includes 70% of investigated beds. In such cases it is necessary to apply additional information the content of which differs for each specific pool.

Study of pool flooding process consists in a combined application of geophysical survey results and oilfield data at various stages of a deposit development. The combination of information sources about the reservoirs being water flooded depends on formation water salinity, on applied system and state of a pool development, on methods of producing wells operation, on equipping of geophysical entity [5]. For the majority of pool several drilling stages is typical. After reservoir development according to technological scheme the details of geologic structure are correlated and the need of compaction of wells spacing is grounded. In sections of similar wells, drilled after a certain period of development, separate beds or intervals of the reservoir may be water flooded. The indication of pool flooding with saline water is the reducing of its resistivity factor and resistivity differentiation in a rather homogeneous bed by lithology due to different displacement factor through reservoirs thickness. At low salinity value, the flooded pool does not differ from the oil bearing one according to resistivity value. The sufficient changing in water salinity through the cross-section of the effect of development allows to delineate flooded bed according to SP chart in combination with LL. The latter is necessary for taking into account the possible impact of lithology changing on SP log. Very often within the interval of water flooded bed the value of IL and LL are close. It is explained by the absence of penetration zone at the moment, when the survey is going to be done due to a high filtration rate of injected water in the reservoir interval. The results of geophysical investigation of well allow to carry out the monitoring of moving front of injected water and the most important is to estimate the size of water flooded area through formation-pool thickness.

In cased bore holes in deposits with high salinity of formation water, the measurements by pulse neutron methods in non perforated intervals of a bed allow to delineate the pools flooded with formation water. At low salinity value the feature of water flooding may be the appearance of radiogeochemical anomaly, temperature reducing due to cooling of water flooded interval of a pool, however it is necessary to take into account that the cooling front is sufficiently later than displacement front [5].

Measurements in running wells of flow rate and fluid content in the perforated interval of a bed allow to estimate the share of participation of each bed in the borehole operation and to delineate the intervals of water flowing into a borehole. But the utility of this method is quite limited due to the fact that the majority of producing wells are operated with mechanical methods. These surveys are carried out at borehole stimulation by a compression but due to low intensity of inflow and unstable mode of the well operation, the obtained readings make available to solve only some part of tasks: according to thermometry to determine the annulus tightness, to define the lower interval of inflow and in some cases to determine separate producing beds according to hydrodynamic flow meter data. Due to high encroachment of products and low flow rate, the composition of inflow from the formation does not correspond to the composition of fluid within the borehole that stipulates low efficiency of applied sensors for compositions. The most reliable results in such cases are recorded by Induction resistivimeter.

The conditions for the application of hydrodynamic flow meters in injected wells are considered to be favourable. The tightness of annulus is recorded by thermometry method and the surveys by flowmeter allow to estimate each bed intake from simultaneously drilled ones. The information about the distribution of injected water through formations is effectively used for monitoring the encroachment of multiple layer pools. The intake profile in the interval of a separate formation-reservoir is of a less interest because in many cases it does not correspond to the profile of filtration water through the bed, it gives the picture of the state condition of nearby bottom hole zone.

Besides the above mentioned, there are various technologies of the usage of pulse neutron methods in cased as well as in open holes at various stimulation factors on a bed when oil bearing and flooded pools are delineated according to their phase permeability, independent of water salinity in a bed [5]. One of the perspective is the technology of induction log application in a bore hole where the interval of investigation is cased by reinforced fiberglass string. By changing in time the resistivity value in the interval of a given bed it is possible to determine with a high reliability the changing of the thickness of flooded pools and to determine the dynamics of changing of oil saturation factor while oil displacement by a formation water.

The dynamics of encroachment of producing wells products is widely used for monitoring the process of pools flooding. Initially it is necessary to determine that the appearance of water in a product of a well is the result of bed flooding after drilling. If after drilling there are several beds in a bore hole then it is necessary to define which one is flooding. This problem is solved by a comparison of sections of producing wells and of the nearest injection wells, taking into account the time of encroachment of producing well and the beginning of water injection into the injection well, the volume of injected water. It allows to follow the displacement front of movement through the area of a deposit.

DETERMINATION OF OIL AMOUNT RECOVERED FROM THE SECTIONS AND THE AREA OF RESERVOIRS DISTRIBUTION

The important element in solving the problems concerning the production logging is the feasibility of the deposit model which should demonstrate the basic regularities and specific features of reservoir and hydrocarbons laying. In accordance with the received model of the deposit there is composed a geologic base for monitoring the oil reserves recovery. When forming of geologic base it is included plotting of detailed schemes of correlation and geologic-statistical cross-sections with aim to divide multiple layer object into separate zonal intervals, the pools of which are connected hydrodynamically within the area of a pool but are rather isolated with each other in cross-section. For each zonal interval there is composed a map of the reservoirs distributions of latter differentiation into several groups of different conductivity value. The main task when monitoring of reserves recovery is to determine the oil amount recovered from each zone interval, from the area extent of bed with different conductivity. Total fund of producing wells is mechanized and hydrodynamic surveys while running the well are not carried out. So, the distribution of recovered oil between the reservoirs of the simultaneously drilled zonal intervals is usually done proportionally to beds conductivity. The error of such distribution in a given bore hole may be quite evident because the formation pressure value of a separate zonal interval, the state of bottom hole zone of a drilled bed and producing thickness of a pool are unknown. So, the most perspective should be considered the distribution of recovered oil in accordance with flooded area of a reservoir of each zonal interval. Using the composed geologic base it is possible to edge the area of flooded pools according to a combination of geophysical and oilfield data on maps of pools distribution of a separate zonal interval. Using the results of geophysical surveys flooding sweep through the pool thickness is determined, volume of flooded reservoir is computed and with taking into account the parameters specified when computing the initially recovered reserves, there is determined the amount of oil which could be recovered from that volume during the previous period of development through each zonal interval and from the area of the distribution of reservoirs with various conductivity value [1,3]. The obtained results should by compared with the amount of oil actually recovered from the deposit by producing wells during the whole period of development. The results obtained from the oilfield of Tatarstan Republic and Western Siberia demonstrate that discrepancy does not exceed 10 % thus the proposed method is acceptable for solving the problem under the study. The amount of oil which could be recovered from the obtained flooded volume, is regularly less than is recovered in reality. It can be explained because the edge of flooding area was considered on producing bore holes which were already achieved with the front of injected or formation water.

THE ANALYSIS OF RESERVES RECOVERY OF MULTIPLE LAYER POOLS WITH VARIOUS GEOLOGICAL STRUCTURE

The studied deposits of Povhovskoye and Vatyeganskoye oilfields of Kogalum oil producing regions in Western Siberia differ more from each other by geologic structure than by applied methods of development. The generalization of development experience on these or others large multiple layer zones of oil deposit demonstrate that the reserves production performance is mainly determined by their specific geological structure that should be taken into account when controlling and improving the system of development.

Povhovskoye field

The basic deposit is referred to the BV8 bed. These deposits are related to a sufficiently large north-east clinoform. The features of deposit structure are caused by its relation to the boundary between shelf and depressive-slope areas of a basin. Within the shelf boundary the formation have subhorizontal structure but depression-slope area is mainly characterized by mogacosolayed bedding. Correlation of sediments was carried out mainly according to forms of SP charts, variety of which through the borehole is determined by fractional composition of sandy-argillaceous sediments, i.e. paleohydrodynamic condition of sedimentation process. The sediments of separate facies were forming at different hydrodynamic modes that in a certain extent is demonstrated on the form of SP diagrams [2]. The results in determination of water flooded reservoirs according to geophysical surveys were used to follow the hydrodynamic link between correlated formation-reservoirs.

BV8 formation is divided into separate zone intervals which are heterogeneous at a certain extent in cross section as well as in the area of a deposit. But hydrodynamic link between the reservoirs within the zone interval is much higher than between the pools of adjacent zone intervals , i.e. in scale of development period each separate zone interval can be considered as a separate hydrodynamic system. One of the most important features of the construction of the development object is the specific slope of a delineated zone intervals with reference to the line of alignment in the direction from north-east to south-west (Fig.1). The reservoirs in the upper section of a zone interval at a certain part of the area are depositing parallel to the line of alignment. These sand stones were depositing in a shelf area of a basin during the process of vertical sedimentation on a horizontal paleosurface. The period of lateral increasing of sandy facies may correspond the break in sedimentation in shelf area and during that period there may occur faulting of rock wastes into the depression-slope area. As a confirmation of that it is possible to refer to the decreasing of the thickness of a pool and pinching out of the upper zone interval in north-east direction. At increasing of basin depth from shelf area along the slope of paleorelief there was increasing of argillaceous sediments of the section and when sinking of zone intervals there occurred reducing of a pool thickness and their facies displacement by argilliceous in south-west direction [6,7].

Eight zone intervals were delineated on the basis of results of detailed correlation in BV8 bed. It is very peculiar the regularity of distribution of development zones of pools of these zone intervals on the area of deposit. The pools of upper zone intervals are developed in the south part of a deposit, but the pools of lower zone intervals take the north part of the area. The pools of a maximum capacity are laying in the middle part of the area of spread zone intervals. To the south and north boundaries of zone intervals the pools thickness is reducing to 3-4 times. When reaching the North boundary the pool thickness is reduced due to its pinching-out. To the south boundary when sinking of zone interval there occurs the increasing of division factor and argillaceous due to facies displacement of pools by argilliceous. The pool sinking of a given zone interval is followed by the appearance of a pool in upper laid interval. Due to that specific features of geological structure it follows that the pools of adjacent zone intervals differ from each other according to sedimentation and in the cross section of a well they should differ by the parameters of a pool [4].

When selecting the system for BV8 bed development it was separated into two equal members by thickness. According to the given geological model there were distinguished two objects of development each of which was drilled on pattern well spacing 600 x 600 m with dividing of reservoir by injection well rows into XXII independent blocks of development. As a result multiple bed pool of a composite geological structure was drilled on a simple geometric spacing. Delineation of two objects of development was mainly endured by injection wells – in 70% of wells injection was carried out separately by two delineated members of BV8 bed. Very often when perforating the producing wells there were also drilled the majority of pay beds. As a result 60-70 % of recovered oil can be considered to be produced from the wells where there were perforated combined pools of several zonal intervals. Basing on the analyses of producing wells running at the initial step both objects were developed at the same rate. This conclusion contradicts with the studied features of the geological structure of a pool that is confirmed by the surveys at the tested area delineated within XV-XVIII blocks in the north part of a pool. After 2-3 years of production the area well spacing was densed by reducing the distance between wells up to 300 m. The test area consists of 556 wells.

The information about the state of reservoirs being water flooded was obtained from dynamics of products encroachment on 98 producing wells and of geophysical surveys [GIS] on 32 compaction wells, in the section of which are delineated some separate water flooded intervals of a pool. According to these data the area of the water flooding pool is delineated on the maps of the reservoirs distribution of each zonal interval (Fig 2). In all blocks of independent development the zonal intervals differ by sweep volume of water flooding on the area of a spreading pool, i.e. there occurs irregular recovery of reserves from the delineated zonal intervals (Table 1).

The basic reserves are located in the pools of 5-th and 6-th zonal intervals. According to blocks of development the flooding sweep on the area for 5-th zonal interval varies from 0,28 to 0,52; for the 6-th – from 0,12 to 0,39. As for zonal intervals with less reserves they have the less flooding sweep on the area. So, the 4-th zonal interval has the flooding sweep in XV block 0,18 and is decreasing up to 0,03 in XVI block ; as for 7-th zonal interval the flooding sweep is increasing from 0,05 in XV block up to 0,16 in XVIII block. The zonal intervals with value 0,04 and less are not included into the development, the reservoirs are depositing as a separate lens and are not influenced by the injection. Obviously, the delineated areas of zonal intervals of pools being flooded do not coincide in a plan. It indicates the weak hydrodynamic link between pools of adjacent zonal intervals that conform with conditions of sedimentation of deposits BV8 [3].

The coifficient of flooding sweep in the thickness is determined by the results of geophysical surveys, it's value mainly depends on the division factor and on the permeable heterogeneity of reservoir. According to the majority of zonal intervals the flooding sweep in thickness varies from 0,55 to 0,70 (Table 1).

Table 1

The characteristic of reserves recovery on zonal intervals of a tested section

Block №	Zonal Interval №	Pool Occurrance probability	Initial reserves share	Flooding sweep on area	Flooding sweep on thickness	Recovered from initial balance reserves
1	2	3	4	5	6	7
XV	4	0,97	0,19	0,18	0,95	0,20
	5	0,98	0,39	0,43	0,63	0,27
	6	0,94	0,31	0,12	0,41	0,07
	7	0,44	0,09	0,05	0,72	0,04
	8	0,08	0,02	-	-	-
XVI	4	0,66	0,13	0,03	1	0,04

	5	0,99	0,39	0,52	0,60	0,36
	6	0,94	0,28	0,24	0,56	0,15
	7	0,65	0,16	0,13	0,62	0,13
	8	0,21	0,04	-	-	-
XVII	4	0,33	0,03	-	-	-
	5	0,89	0,29	0,37	0,54	0,22
	6	0,99	0,40	0,39	0,74	0,26
	7	0,94	0,23	0,13	0,55	0,09
	8	0,33	0,04	-	-	-
XVIII	4	0,12	0,01	-	-	-
	5	0,84	0,30	0,28	0,54	0,16
	6	0,95	0,39	0,26	0,82	0,23
	7	0,87	0,29	0,16	0,58	0,13
	8	0,24	0,02	-	-	-

The oil volume recovered from each separate zonal interval of flooded areas prove that when drilling the pools of several zonal intervals the advancing front of injected water moves through the best bed , i.e. there occurs irregular production of reserves in pool section. Assume that in general in tested area it was recovered 0,14 from the initial balanced reserved, then recovery from initial reserves in different zonal intervals varies from 0,04 to 0,36 (Table 1). In blocks by advancing rates are developed the zonal intervals which are the basic in reserves. Irregular production of reserves in sections will require the conducting of a great volume of water isolating operations, the specific troubles may arise when isolating of the upper bed for further production of a pool in lower zonal intervals. Under such conditions the perspective one is considered to be the drilling of lateral boreholes. The selection of objects for drilling should be done with application of maps demonstrating the state of reservoirs being flooded in zonal intervals (Fig.2).

Thus, the utilization of new model of a deposit and the method of determination of oil amount recovered from each zonal interval made available to obtain quite new data of a specific recovery of deposit reserves of BV8 bed.

The oil field – Vatyeganskoye

This field is referred to dome-shaped high on Vartovsk pool roof. The basic pool according to reserves volume is located in AB1-3 beds. The sediments are presented by regular alternation of sand stones and argillites, the boundary between lithological differences are in parallel with alignment line (bench-mark) that proves the horizontal surface of paleorelief during sedimentation period. The modern form of bedding is stratified-parallel. Geological structure is characterized by a rather wide development of intrastratified washouts. Within cross-section of a deposit there are delineated three zonal intervals which are interrelated hydrodynamically but the strength of that relation within the zone of intrastratified washouts sharply differs along the area of pool spreading. The pools of all zonal intervals are developed on total area of a pool.

The average thickness of a pool of upper zonal interval AB-1 is 4,7 m. The pool is very often presented by two layers, the best one is of 4 meters thickness (Fig.3). In some separate sections of a pool the thickness is increasing up to 10-15 m due to partial washouts of underlying argillites (Fig.3 borehole № 480, 2126). In such part of the area the geologic structure is determined by a wide intrastratified washout and the result of that is the occurrence of the zone of pools agglomeration AB1+2 in latitude direction, the reservoirs thickness in that zone may approach up to 28 m. Actually, all drilled parts of a pool AB-1 are oil bearing.

Zonal interval AB-2 is of more complex structure. The thickness of a pool, its distribution are varied along the area ,and that is explained by the variation of intensity and the direction of bottom flow in the period of sedimentation. In the average part of a pool is delineated the band of meridional spreading where sedimentation occurred at very active performance of water environment. That band of a pool in the zonal interval is presented as a monoloth sandstone 12 m of thickness, and in the pool roof in the section of a total washout zone of underlying argillites there was founded the zone of agglomeration of pools AB2+3 when the total pool thickness approaches to 30 m (Fig.3. Wells № 2345-475 and wells 2122-2126). The pool thickness is reducing when moving from the studied band due to facies displacement, clayness and distribution of a section are increasing. In the south of a pool the structure is determined by the zone of agglomeration of the pools AB1+2. The factor of hydrodynamic link of the pools of zonal intervals AB-2 with the pools AB-3 are worse then with the pools of zonal interval AB-1.

In the basic area the pools of zonal interval AB-3 are water bearing, the initial oil reserves don't exceed 5 % of pool reserves AB1-3. Producing pools are delineated in the deposit roof and in reality are always underlying by bottom water.

Producing beds of zonal intervals AB-1 and AB-2 sufficiently differ by conductivity factor and consequently by their producing capacity. So, there was carried out their differentiation on the beds of high and low conductivity value. Zonal intervals AB-1 and AB-2 are very close in value of initial reserves but differ from each other by reserves volume in beds of high and low conductivity (Table 2). The beds of low and high conductivity value AB1 correspondingly have 0,43 and 0,12 but in the beds AB2 - 0,1 and 0,35 of balanced reserves of AB1-2 pool. Initially there was supposed to delineate two independent objects of development AB1 and AB2 and the system of area flooding at 9 points scheme of bore holes distribution. But the composed system of development is more complicated. The linear system of flooding is used alongside with area one in many of producing and injected wells where were simultaneously drilled AB1 and AB2 pools.

Table 2

Unique features of reserves recovery in beds AB1 and AB2
on cross-section of a pool

Bed	h, m	Q'	Q''	Q'+Q''	η_s	η_h	q1	q2
AB1	4,7	0,12	0,43	0,55	0,06	0,65	0,015 0,053	0,018
AB2	6	0,35	0,1	0,45	0,17	0,67	0,011	0,061

on the area of pool spreading of AB2 bed

Bed Conductivity	h, m	Q',Q''	η_s	η_h	q1/Q',Q''	q2/Q',Q''
Low	2,3	0,22	0,07	0,75	0,2	0,1
High	11	0,78	0,31	0,64	0,12	0,14

The volume of initial reserves in beds of high conductivity Q'; of low conductivity Q''. The volume of recovered oil from operating producing wells q1; from flooded pool q2; initial average thickness of a producing pool h; flooding sweep on area ηs ; on thickness η_h.

The advanced production of zonal interval AB2 is observed in accordance with the reserves distribution in bed of high and low conductivity basing on the results of analyses of pool water flooding conditions. So, the ratio of flooded area to initial producing one for the zonal intervals AB1 and

AB2 correspondingly are of 0,06 and 0,17 value (Table 2). The advanced production of reserves is observed in beds of more thickness; that is more peculiar for AB2 pool. In case of study only the zone of agglomerating of AB1+2 pools then ratio of flooded area to initial producing one is 0,24. That value is considerably more than the total value for AB2 bed. Flooding sweep through the pool thickness is 0,65-0,67. When distribution of a section is high, the best part of a reservoir bed is flooded at first.

In wells from pools of zonal intervals AB1 or AB2 which were the only one drilled, there was recovered correspondingly 0,015 and 0,011 from the initial reserves of deposit AB1-2. The recovered amount of oil at simultaneous drilling of pools of two zonal intervals compose 0,053 from initial ones, i.e. 67 % from the total amount of produced oil. The recovered reserves of flooded volume of a pool was determined according to each zonal interval. It was determined that from AB1 pool was recovered 0,018; from AB2 pool – 0,061 from the initial reserves recovery, i.e. at simultaneous drilling of zonal intervals AB1 and AB2 the upper one due to worse reservoir properties actually does not participate in bore hole operation; the lower one covers 94% of recovered oil.

Thus, the applied system of development does not provide simultaneous recovery of two zonal intervals. Actually the reserves are produced from down to up; the reserves of zonal interval AB1 will be put into active development after water flooding and isolation of pools AB2.

The analysis of reserves recovery was done according to pools with high and low conductivity of zonal interval AB2. In pools with low conductivity there is 22% of initial reserves of that zonal interval. The advanced rates of reserves production is observed in beds of high conductivity which are more influenced by injection into injected wells. It is very valuable to compare the amount of recovered oil from beds of different conductivity value when running of wells and the state of pool water flooding.

In accordance with the amount of reserves of flooded volume from beds of high and low conductivity there was recovered correspondingly 0,10 and 0,14 from initial reserves of zonal intervals AB2. From the producing wells from the bed with high conductivity value recovered 0,12 ; of low conductivity 0,20 from the initial reserves. So, the results of estimation of producing conditions of reserves from beds of high and low conductivity value recorded by two independent methods are effectively various between each other. It is very difficult to explain why while running the well the production is slower in beds of which high conductivity value. According to obtained flooded volumes, as it should be expected, the advanced recovery of reserves in beds with high conductivity is offered. Comparing the obtained data it is possible to make a conclusion about oil cross flow when oil development from beds with high conductivity to the bore hole located in zones with low conductivity. It is logically – the beds with high conductivity are more influenced by the injection and a half of oil volume recovered from wells drilled the beds with low conductivity, is received due to its cross flow from zones of beds spreading with high conductivity [1]. Such kind of regularity should be taken into account when improving the system of development.

CONCLUSIONS

1) Complex utilization of information obtained in the result of analyses of geophysical and geologic-oilfield data makes available to receive the actual picture about the process of water flooding of pools; unique features of oil reserves recovery from multiple layer deposits with complex structure and to choose the most perspective ways in improving the applied system of development.
2) The determination of flooding volume of a pool according to zonal intervals of the object under the development, delineated accordance with the selected model of a deposit, which takes into account the features of its geological structure, makes available to estimate the oil volume recovered from each separate zonal interval at simultaneous drilling.
3) The carried out investigations demonstrated that various zonal intervals of the development object differ with reference to pool features and conditions of pool depositing and at their simultaneous there is observed the irregular reserves production from the cross section of a deposit.
4) Comparison of oil amount recovered from the running well and with reference to the obtained value of flooded volume of a pool, to allows judge about the dynamics of reserves production on the area of pool spreading in the zonal interval. The unique feature is the presence of cross flow of oil within the process

of development from zones with high admittance into the wells in zones with less admittance and this fact should be taken into account when developing the system of water flooding.

5) The dynamics of recovery is main predetermined by the features of geological structure of a deposit according to the cross section and area of pools spreading and always should expect the advanced recovery of the best portion of reserves.

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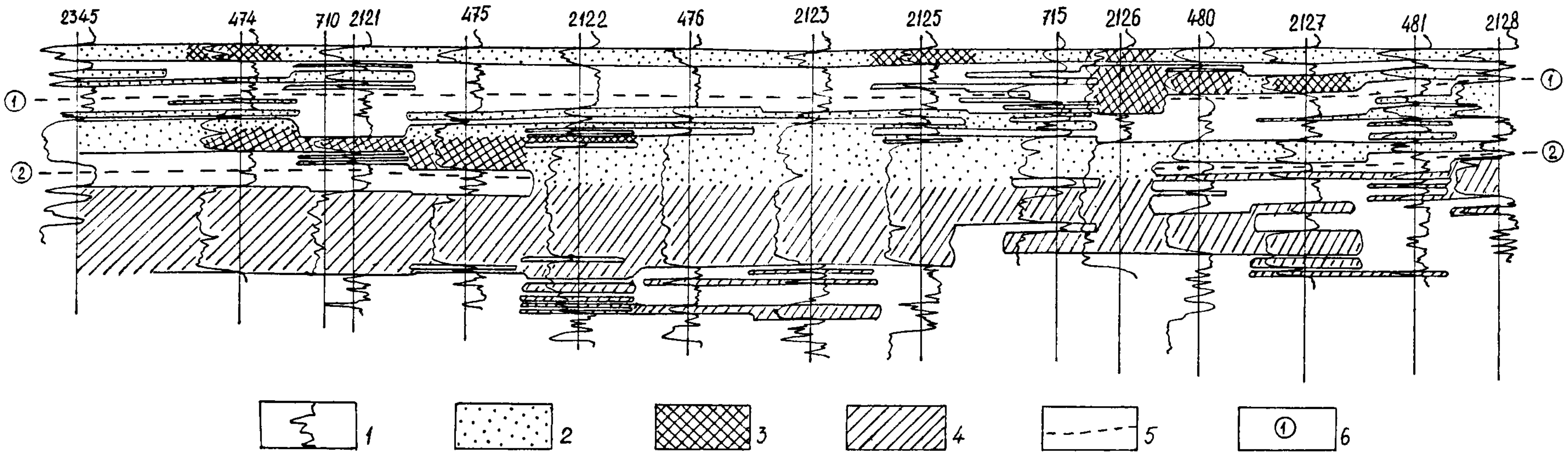

Fig.3. Correlation scheme and condition of reservoir water flooding of AB1-3 deposit of Vatyegansk field.

1 – SP curve; 2,3,4 – respectively oilbearing, waterflooded and watersaturated sandstone;
5,6 – bottom boundary and number of zone interval

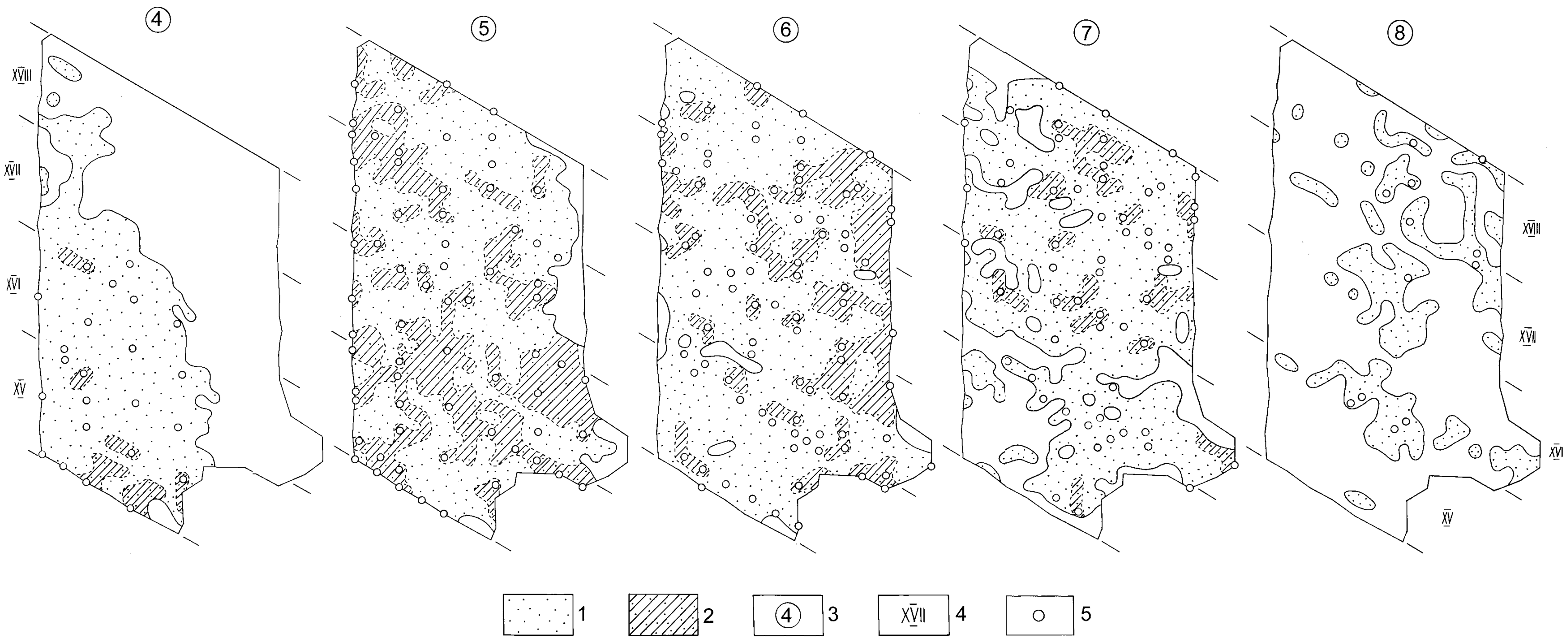

Fig.2. The condition of pools water flooding according to zonal intervals of objects under development.
1,2 - correspondingly oil bearing and flooded sandstone; 3 - number of zonal interval; 4 - number of block;
5 – injected wells

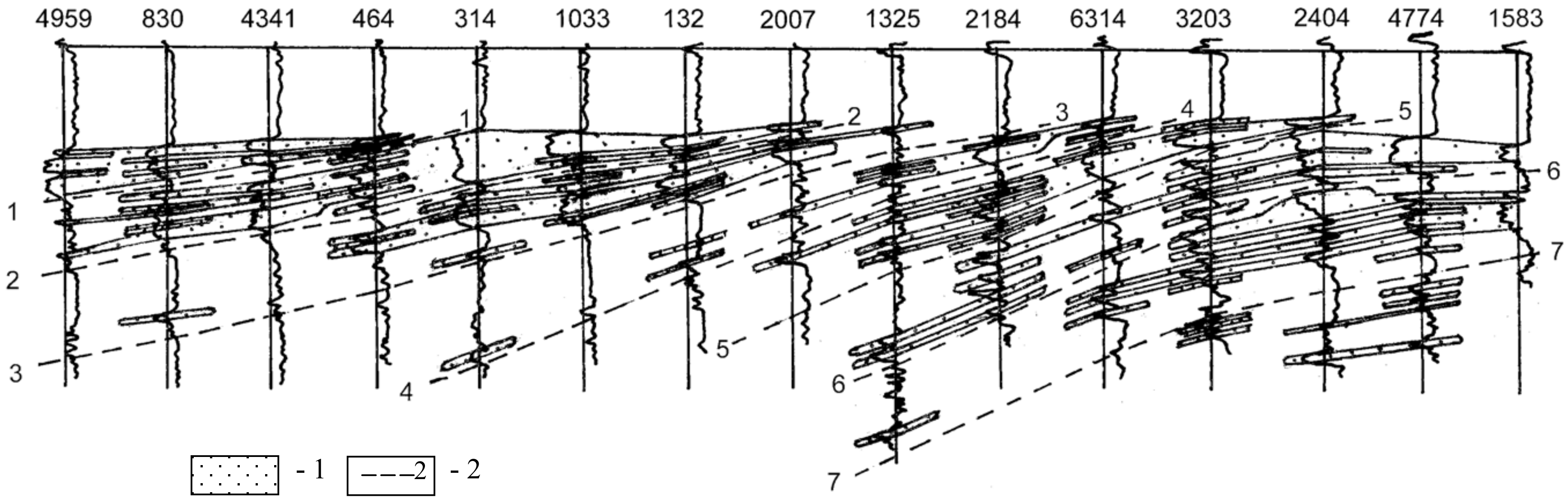

Fig.1. Meridian scheme of correlation of producing sediments according to SP in wells I-XXI blocks.

1 – pools; 2 – lower boundary and zonal interval number