Weathering Crust of the Basement in Parametric Wells 50 Novournyak and 2000 Tuimazy in the South-Tatar Arch

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Abstract. The paper deals with allocation of the vertical profile of the weathering crust based on well logging in the Precambrian basement of the South-Tatar Arch in the Republic of Bashkortostan. Within the most elevated part of the basement in the region, crystalline rocks lie at depths of 1650-3000 m. Despite the fact that the weathered rocks are potential reservoirs, they were not objects of special studies in the Republic of Bashkortostan. One of the reasons is in poor study of core section. The exceptions are parameter wells '2000 Tuimazy' and '50 Novournyak', in which the core was taken out in several intervals of the weathering crust. Based on the comparison of logging data and rock material in these wells the areas were allocated of subsequent change of crystalline rocks under action of supergene factors from the initial disintegration of the initial substrate to the final products of its decomposition. In the well 50 Novournyak rocks alternated in the surface conditions are blocked by the most ancient sediments – Tyuryushevskian suite of the Lower Riphean. The authors believe that the basic pack of the suite presented with quartz-feldspathic sandstones and quartzites and visibly separated from the overlying sandstones according to logging completes a full profile of the weathering crust. In the well 2000 Tuimazy the weathering crust is overlapped by deposits of Koyvenkovskian horizon and is characterized by a greater degree of alternation and fragmentation of the initial substrate. Its formation in the gap between the Archean-Proterozoic and Lower Devonian was a multi-staged: with periods of complete or partial erosion, with the imposition of supergene processes in the previously formed areas. Despite some differences, the vertical profile of the weathering crust in both wells has similar logging characteristics. It is recommended to check signs identified on more wells drilled within the South-Tatar arch, and in the case of confirmation, they can be used to study the structure of the weathering crust in low coring or its absence.

Keywords: South-Tatar arch, basement, weathering crust, area, parametric well, crystalline rocks, logging data
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Currently, weathering crust of the basement of the ancient and young platforms is recognized as a promising oil exploration object. This geological formation is productive in many oil and gas regions of the globe, including in the northern edge of the Dnieper-Donets Basin, where the Precambrian basement weathering crust involves deposits of oil, gas and condensate on Yulievsky, Skvortsovsky, Khuhrinsky and other areas. Inflows of hydrocarbons derived from weathered rocks of pre-Jurassic basement of Western Siberia (Shaimsky, Krasnoleninsky arches) and Paleozoic – Kazakhstan (Oymasha field).

In the Republic of Bashkortostan K.R. Timergazin (Timergazin, 1951) first pointed out on the presence of weathering crust in wells of western areas, determining the genetic relationship of "chekanskian suite" rocks penetrated by well 1 Chekansky, alternated in surface conditions with biotite gneiss of the basement. Despite the fact that the weathered and disintegrated crystalline rocks are a potential reservoir, they were not objects of special studies in Bashkortostan. However, due to the reduction of hydrocarbon reserves in the Paleozoic complexes, identification of new promising horizons is relevant, among which may be weathering crust of the Precambrian basement of the South Tatar arch, where it lies at a depth of 1650-3000 m.

It is known that the formation of the weathering crust occurs in a complex set of effects on the crystalline rocks by supergene factors, among which physical and chemical ones are the most effective: the first is responsible for the mechanical destruction of the source rocks, the second provides the chemical transformation of rock-forming minerals.

In the process of weathering the degree of mechanical and chemical changes in rocks from the bottom up is increased, forming profile of the weathering crust. With long-term continental break, in a warm humid climate and relatively leveled terrain, modified weathering crust is developed, vertical zoning of which reflects the staging of processes from the initial disintegration of the source substrate to the end-products of its decomposition.

After B.B. Polynov (Polynov, 1934) and I.I. Ginzburg (Ginzburg, 1963; Ginzburg, Rukavishnikova, 1951), the works of which helped to form the doctrine of the weathering crust in an independent branch of geology in Russia; many researchers proposed scheme of the vertical profile of the weathering crust (Lapinskaya, Zhuravlev, 1967; Petrov, 1967; Sitdikova, Sidorova, 2011).

Despite some differences, its division into zones requires consistent transition from unmodified crystalline rock to its partial and then complete mechanical degradation, which is superimposed by processes of hydration, leaching, oxidation and hydrolysis. At that, presentation about changes of source rocks by supergene agents, structure of the weathering crust and mineral composition of the profile zones were based exclusively on the study of rock material.

Within the most hypsometrically elevated part of the South Tatar arch in Bashkortostan approximately 400 exploratory wells were drilled that penetrated the basement and its weathering crust to a depth of a few meters up to 20-120 m. In many wells (excluding parametric) core was selected only from the bottom zone, sometimes it was presented with 2-3 intervals, rarely – weathered differences. Certain information about the presence in section of rocks modified by supergene processes can be obtained from the slurry (in the case where it is characterized as a crystalline eluvium).

Poor study of rock material does not give even a general idea about the structure of the basement. However, in all drilled wells, the complex of geophysical studies, technical and methodological support was performed, and its representation has been steadily improving. Since the well logs reflect the petrophysical and petrochemical features of the section, it is possible to identify intervals with varying degrees of decompression, mechanical state of the rock and, in part, its chemical conversion.

The paper (Syngaevsky, Khafizov, 1999) according to field geophysics, supported by a core material, isolated logging facies corresponding to unmodified source rocks (zone "A"), and the successive zones of the weathering crust ("B", "C", "D" and "E") of the pre-Jurassic basement of the West Siberian Plain. Using the proposed signs, we attempted to characterize by well logs the vertical profile areas of the weathering crust in parametric wells drilled on the South Tatar arch – 50 Novournyak (NUN), and 2000 Tuymazy (TMZ), the most studied by a core (Fig. 1).

Source rocks of the upper part of the basement, which have been subjected to supergene changes, in both wells are presented by biotite plagio-gneisses, their microclinized differences and granite-gneisses, well-studied by cores and thin sections.

Biotite plagiogneisses are gray, greenish and pinkish-gray holocrystalline, inequigranular massive rocks with unclear gneissic texture (Fig 2a). The main rock-forming minerals are plagioclase (oligoclase-andesine, 55-75 %), quartz (10-30 %), biotite (3-7 %) and microcline (1-3 %, rarely occurred, in areas of cataclase is developed on plagioclase, replacing it in marginal portions of grains), the content of which varies considerably.

Individual core samples are presented microclinized biotite plagiogneisses, which have higher content of microcline (5-10 %); plagioclase is represented by albite-oligoclase and is 45-60 % of the rock. Structure of biotite plagiogneisses and their microclinized differences is porphyro-granoblastic, lepidoblastic and granoblastic. Accessory minerals are apatite, zircon, orthite, monocyte, rutile. Ore minerals are marked by magnetite and ilmenite.

Granite-gneisses, lifted out from well 50 NUN, are red-colored inequal-crystalline, strong, massive, poorly ungneissed rocks. Rock-forming minerals: microcline – 50-60 %, plagioclase (oligoclase) – 5-10 %, quartz – 15-30 %, biotite – 1-3 %. The accessory minerals are zircon, apatite, magnetite.

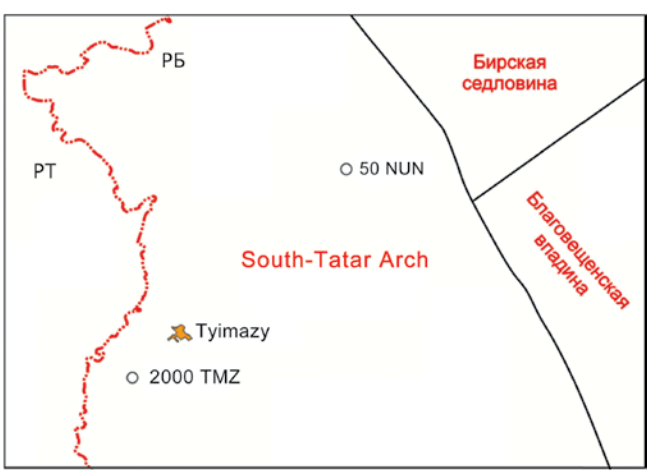

Fig. 1. Layout of the wells 50 NUN and 2000 TMZ.

The structure of the granite-gneiss is hetero-granoblastic, profirobalstic-clastic and blasto-clastic.

The characterized differences of plagiogneisses and granite-gneisses contain from 67.47 to 73.70 vol. % of silica, and are acidic rocks (Table 1). In the process of weathering by igneous and metamorphic rocks of the felsic composition hydromica-kaolinitic and kaolinitic types of crust are developed (Kazansky, 1969; Petrov, 1967).

Unchanged by supergene processes source rocks of the crystalline basement (area "A") are characterized by the values of apparent resistivity of the order of 625 Ohm*m (lower the section they may increase significantly). In well 50 NUN zone "A" is clearly recorded from a depth of 2462 meters by lateral logging, which is characterized by uniformly differentiated pattern, varying in the range of 550-7000 Ohm*m; neutron-gamma logging – values reach 7 cu; indications of microprobe reflecting solid rocks. Acoustic log curve is held close to 160 mcs/m, and induction – 90 Ohm*m (Fig. 3).

Core lifted out from intervals 2470.0-2472.0 and 2472.0-2475.0 m is represented by biotite plagiogneiss, red and pink, holocrystalline, inequigranular, massive, with unclear gneiss texture.

In well 2000 TMZ zone "A" begins at a depth of 1837.5 m; below, in the range 1837.5-1840 m, an increase of apparent resistivity from 625 to 1000 Ohm*m is observed, which, judging by the descriptions of the core, is due to the strong

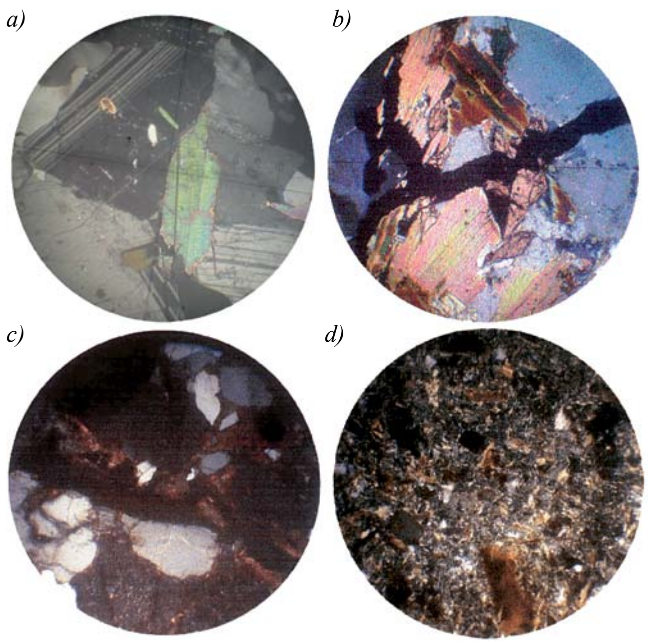

Fig. 2. Rocks of the weathering crust of the basement, a) Zone "A: – Biotite plagiogneiss. Well TMZ 2000, Int. 2051.6-2055.4 m. Sample 54. Zoom 58. Nicoli +. b) Zone "B" – Biotite plagiogneiss with an open crack. Well 50 NUN, depth 2455.6 m. Sample 336. Zoom 58. Nicoli +. c) Zone "C" – Conglomerate with fragments of biotite plagiogneiss, coarse grains of quartz, microcline and plagioclase cemented by kaolinite-hematite material. Well TMZ 2000, Int. 1811.3-1815.4 m. Sample 21. Zoom 58. Nicoli +. d) Zone "D" – Siltstone very clayish; composed of grains of quartz, microcline, weathered plagioclase and biotite flakes, chloritized. Well TMZ 2000, Int. 1780.0-1781.5 m. Sample 2. Zoom 58. Nicoli +.

silicification of plagiogneiss biotite (Fig. 4).

In zone "B" – the zone of initial disintegration, crystalline rocks are at the first stage of discontinuity. Under the influence of physical weathering factors, multidirectional fractures and microcracks are formed, the degree of manifestation of which increases from the bottom up. With the penetration of surface water through fractures containing oxygen, hydration and oxidation processes start. In the chemical composition of rocks the water content increases due to binding it with some minerals; through cracks reddish veins of iron hydroxides appear. But its initial appearance (color, texture, structure) as a whole remained.

In the well 50 NUN zone "B" corresponds to an interval 2462.0-2453.0 m. According to lateral logging it stands out as sharply differentiated curve against the background of values falling between 25000 and 100 Ohm*m and below, increasing the interval time of longitudinal waves travel between 150 and 200 mks/m; Apparent resistivity curve drops from 625 to 125 Ohm*m. In the bottom half of the interval by microprobe more solid rocks are recorded, but at a depth of 2458 m intervals differences between micronormal and microlateral probes are observed; Induction log from a depth of 2456 meters gradually lowers from 90 to 50 Ohm*m.

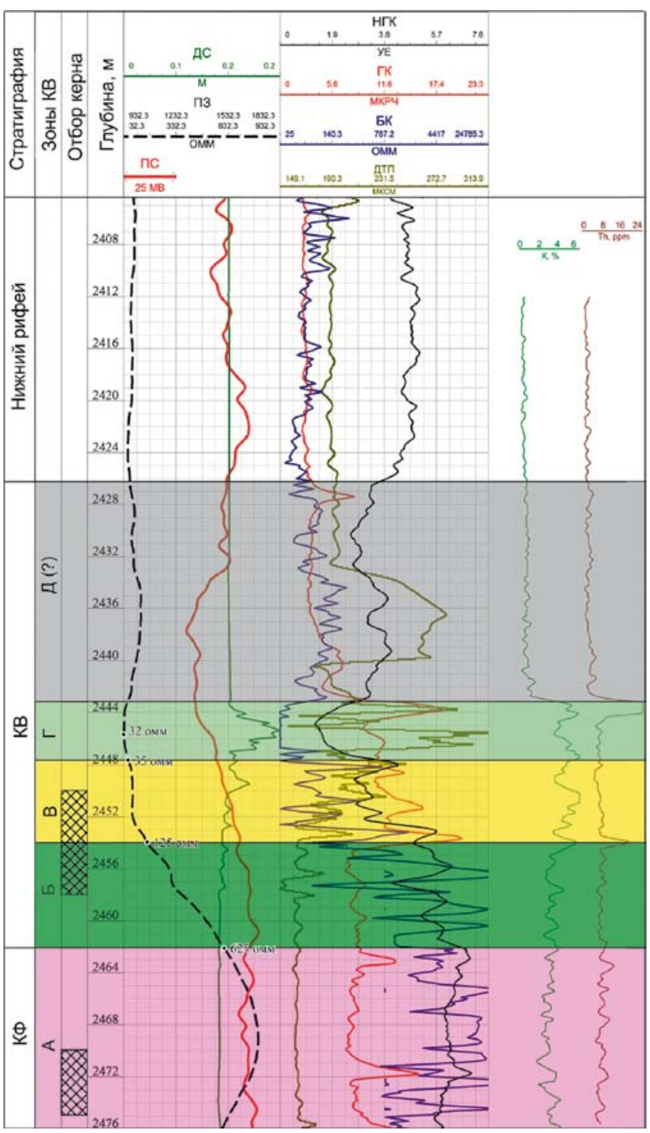

Fig. 3. The weathering crust of the basement in well 50 NUN (vertical well).

Rocks / Oxides	Biotite plagiogneiss	Microclinized biotite plagiogneiss	Granite-gneisses
SiO_2	67,47	70,50	73,70
TiO_2	0,41	0,30	0,15
Al_2O_3	16,34	15,59	13,30
Fe_2O_3	1,07	0,96	0,75
FeO	2,29	1,55	1,15
MgO	2,13	1,27	0,76
CaO	4,20	2,19	1,65
Na_2O	3,62	3,87	3,39
K_2O	1,54	2,81	4,37
Σ	99,07	99,04	99,22
Number of samples	15	44	9

Table 1. The chemical composition of the crystalline basement rocks for the well 2000 TMZ (average contents, vol. %).

From the middle part of the zone (2458.0-2455.0 m interval) biotite plagiogneiss is lifted out with pinkish-gray and reddish pink color, assorted, massive, fractured (Fig. 2b).

In the well 2000 TMZ zone "B" (in the core biotite and biotite microclinized plagiogneiss, weathered through cracks)

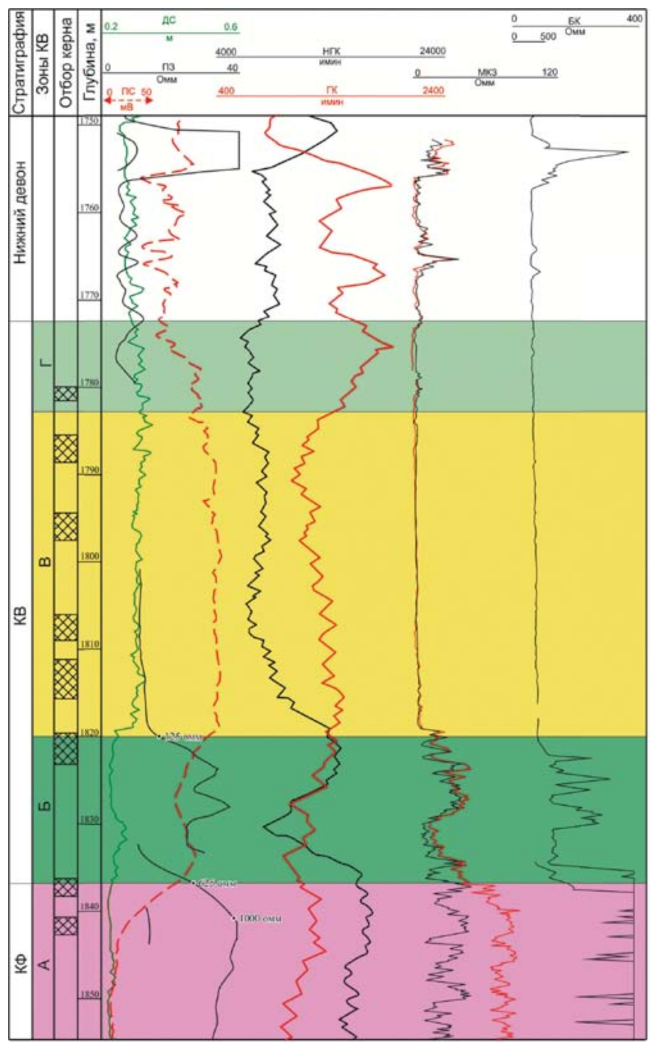

Fig. 4. The weathering crust of the basement in well 2000 TMZ (vertical well).

is recorded in the range of 1837.5-1820 m with gradual decrease in apparent resistivity values of 625 to 125 Ohm*m; in neutron gamma log – from 17000 to 14000 cu.

Zone "B" (zone of continuing disintegration and initial decomposition) has the most complex structure. At its base there are numerous multidirectional cracks that penetrate from the "B" zone, but up the section rocks are gradually becoming more mechanically weakened to a complete loss of continuity. The upper part of the zone is composed of breccia and breccia-conglomerate. The fragmentation of the rock increases reaction surface and provides an intensification of hydration and oxidation processes; decomposition (hydrolysis) of silicates and aluminosilicates continues.

Potassium, sodium, calcium are removed from feldspar that go into solution and, subject to leaching regime, are almost entirely (except for potassium, much of which is associated with clay material) removed from the weathering crust. Along plagioclases sericite, muscovite, albite (with decomposition of anorthite component, plagioclase becomes more acidic), hydromica are developed; as the final product of chemical decomposition kaolinite appears. Kaolinite is hydro-micaceous material that weakly cements fragments of crystalline rocks in the upper part of the zone. There is accumulation of iron hydroxides, giving fragments reddish color.

Changes in the physical state of rocks in the zone "B" (interval 2453-2447 m) in the well 50 NUN are reflected by step-down decrease of apparent resistivity from 125 to 35 Ohm*m and increase of the interval time of longitudinal waves travel from 180 to 240 mks/m. In the bottom half of the interval caliper log is held close to nominal value (155.6 mm), above – shows an increase in the well diameter, characteristic for coarse clastic rocks.

Raised core is represented by biotite plagiogneiss, pinkish-gray, holocrystalline, massive, highly fractured; partly rock has a mottled brownish-white color, sometimes it split up to large debris. In thin section, almost all plagioclase grains in varying degrees are pelitized, saussuritized, rarely sericitized; the presence of fine laminal kaolinite and hematite inclusions are identified; biotite is amorphized unevenly, often replaced by chlorite.

In the well 2000 TMZ zone "B" (interval 1820-1783 m) has a large fragmentation of rock compared to the well 50 NUN, which is evidenced by a significant increase in the borehole diameter. Samples of core from the bottom of the interval are represented by conglomerates from fragments of biotite plagiogneiss up to 5 cm; inter-clastic space is filled with a mixture of kaolinite and chlorite, strongly impregnated with iron oxides (Fig. 2c). The upper part of the zone is composed of assorted sandstones and siltstones from the angular and corroded grains of quartz, plagioclase and biotite, cemented by sericite-kaolin material.

Zone "C" is clay, has preferential predominance of the supergene hydrolysis process. It is most typical for the weathering crust and is present in all diagrams of the vertical profile.

Under the conditions of leaching regime a considerable clay starta can be accumulated, mineral composition of which is relatively homogeneous. As mentioned above, the product of weathering of acid metamorphic rocks (which are presented with plagiogneiss granite-gneiss penetrated within the studied area) is kaolinite. Kaolinite mass has undecomposed (more resistant to weathering) primary minerals – quartz grains, fragments of microcline, muscovite flakes, often occurring by lenses or interlayers.

In the section of well 50 NUN clay zone is not characterized by a core, but according to the well logging it is assumed in the range of 2443-2447 m, where the cavity is marked on caliper log (up to 225 mm) and a minimum in apparent resistivity – 32 Ohm*m; decrease in neutron gamma log is observed (up to 1.3 cu) and an increase in gamma log (in the upper part of the zone up to 21 mR/hr). Acoustic log diagram is sharply differentiated in the range of 180 to 310 mks/m.

Involvement of these spectral gamma logging, which allows dividing the section by the presence of natural radioactive elements, showed that high natural gamma radiation of the interval is due to, above all, potassium and thorium content. Potassium, which is released by weathered microcline and biotite, is partly removed from the weathering crust by aqueous solution, but a substantial part of it binds to clay and accumulates in the weathering crust (Alfimova, 2007; ... Mining Encyclopedia, 1986).

Uranium and thorium are present in dispersed form in the crystalline basement rocks, but the content of the first in the continental sediments is very low, because of the high mobility of its compounds under acidic and slightly alkaline environment of the weathering zone. Unlike uranium, "thorium does not go in aqueous solutions and concentrates in the biosphere in insoluble residues of destruction of its more primary discoveries ...", that is, in the weathering crust (Vernadsky, 1927).

In the impurities it contains such accessory minerals as orthite, zircon, xenotime, apatite, monazite; according to microdescriptions they are present in rock samples lifted from the crystalline basement in the wells 50 NUN and 2000 TMZ.

In the well 50 NUN average potassium content in unaltered rocks of the "A" zone is 3.3 %, gradually increasing in the "B" zone to 4.6 %; the maximum values (up to 6.5% or higher) were observed in zones "C" and "D".

As for thorium, its content in the depth interval 2462-2445 m (zones "B", "C" and lower part of the "D") with a few exceptions is held near the mark of 8 ppm, and only in the upper part of the latter there is a sharp increase in readings – to > 26 ppm. Thus, the data on the spectral gamma logging in the well 50 NUN suggest confinement of interval 2443-2447 m to zone "D" of the weathering crust.

In the well 2000 TMZ gamma spectrometry method was not used, but the interval 1783-1772.5 m, presumably corresponding to the area "D", is also characterized by high values of the natural gamma activity and an increase in caliper log. In the bottom part of the interval mudstones are penetrated; according to the microscopic description they are composed of the smallest scales of hydromuscovite and hydrochlorite with an admixture of amorphous clay material, as well as polymictic sandstones with a predominance of poorly decomposed feldspar debris, inequigranular, indistinctly laminated, impregnated with iron hydroxides (Fig. 2d).

Provided intensive drainage, well researched profile of the weathering crust is formed, which ends in the residual zone "E". It is composed of washed by clay material in varying degrees coarse-grained, poorly sorted sandstones with interbedded conglomerates and pebbles. The detrital material is represented by fragments of rocks and minerals, resistant to the effects of supergene factors. The most common residual minerals of the source rock are quartz and microcline, among mica – muscovite; other relics – zircon, rutile, magnetite.

Quartz is also found in new formations of the weathering crust: quartzite and ferruginous quartzite, chalcedony (Ginzburg, Rukavishnikova, 1951). Detritus is cemented mainly by silica or kaolinite. When gets dirty by iron hydroxides rock becomes yellowish-brown.

Zone "E" is very difficult to identify in the section of wells, because even in the presence of core material it is difficult to distinguish from the overlying clastic sediments of the pre-Devonian and Paleozoic; In addition, it is first subjected to erosion.

In the well 50 NUN on clay pack, corresponding to the "D" zone sediments of Tyuryushevskian formation of the Lower Riphean lie. However, the basal part (interval 2443-2427 m) on the characteristics of well logging clearly stands apart from overlying sandstones of the lower strata. This interval is characterized by increased gamma activity (maximum – 7-8 against 3.5 mR/hr), according to spectral gamma logging it is due to thorium and potassium content; significant decrease of the neutron gamma log curve, which is at a depth of 2427 m increased from 3.6 to 5 cu and gains other than the alleged "E" zone nature of the zone. By acoustic log in the middle of the interval 2443-2427 m a pack of about 7 m in thickness is allocated, which is characterized by a sharp increase in interval time to 280 against 180-190 mks/m in the top and bottom, suggesting the possible presence of porous-permeable rocks.

Core from the basal pack was not extracted; according to the slurry it is composed of sandstones with reddish-brown grains of quartzite. By the position in the section, increased natural radioactivity (due to the potassium and thorium), indirectly indicating the relationship with the underlying zone of the weathering crust, we can assume matching of this pack to the "E" zone.

Tyuryushevskian deposits were first allocated in 1966 in the section of well 2 TYuR. As the bottom of the suite was not penetrated (well is stopped in the first dozen meters from the assumed pack "E"), it was not accepted as a basement for the Lower Riphean. The well 50 NUN is the only one in the Republic of Bashkortostan, in which Tyuryushevskian suite is passed completely, including the problematic pack, markedly different from the main column according to well logging.

The weathering crust in the well 50 NUN has a thickness of 35 m (including the "E" zone) and complete vertical profile, zones of which stand out as clear logging characteristics. Its good preservation can be explained by the fact that it was sealed by most ancient sediments in the region of Tyuryushevskian suite of the Lower Riphean, so its age is pre-Riphean.

In the well 2000 TMZ weathered basement rocks overlap Royvenskian sediments, which makes its age pre-Devonian. It is obvious that between the Archean- Early Proterozoic and Early Devonian (2.7-0.4 billion years) the formation of weathering crust occurred in multiple stages; the most ancient crusts were repeatedly subjected to erosion as a whole or in part. Supergene processes are often superimposed on the previously-formed zone, changing the original appearance and eroding the boundaries between them. For example, in the Tuymazinsky well separation of the initial substrate has been recorded in the "B" zone, and the "C" zone is fully represented by coarse clastic rocks.

Well-modified and thick vertical profiles of the weathering crust in the wells 50 NUN and 2000 TMZ have allowed us to suggest that its formation occurred in a humid climate and elevated, stratified relief, providing intensive washing of the weathered crystalline rocks.

Conclusions

1. Comparison of the rock material and well logging data on the weathering crust in the wells 50 NUN and 2000 TMZ revealed that in spite of the different age and duration of the formation, the area of its vertical profile in both wells have similar logging characteristics.

2. Identified by logging signs are advisable to work out on a larger number of wells drilled within the South-Tatar arch, and if confirmed, they can be used to study the structure of the weathering crust in low core recovery, and even in its absence.

3. The use as benchmark surface of the top of zones uniquely set on well logs, have allowed us to perform correct structural buildings of the basement surface for the South-Tatar arch and for its weathering crust.

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