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The Major Types of the Weathering Crust of the Eastern Russian Plate and Its Mineralogical and Geochemical Features

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Abstract

The long continental period in the East of the Russian plate (the upper Proterozoic – the middle Devonian) caused the formation of a weathering crust on the crystalline basement rocks. In pre-Devonian time, due to the washing-out and the subsequent processes of redeposition of substance, two types of weathering crust were formed: displaced and non-displaced. The widespread weathering crust of the crystalline basement of the East of the Russian plate is a unique object for studying the mineral formation processes of ancient weathering. Complex mineralogical and geochemical studies of the weathering crust are of practical value for the creation of a full picture of the development of the deep horizons of the earth crust and a forecast of mineral deposits.

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Keywords: weathering crust; crystalline basement; Tatar arch.

1. Introduction

For a significant part of the Paleozoic period up to the Devonian and the beginning of formation of a sediment cover, the East of the Russian Plate turned into continent due to the rise of the basement, within which weathering developed (Troepolskii and Ellern, 1956).

The extensive development of a weathering crust of the crystalline basement was considered for the first time in works of T.A. Lapynskaya, E.G. Zhuravlev B.S. (1967), Sitdikov B.S. (1968) and others. The ancient weathering crusts are distributed within shields and elevations of pre-Cambrian crystalline basement of ancient platforms, for example Baltic and Ukrainian shields, West Siberian and Siberian platforms and others (Meshcherskii et al, 2003; Nikitina, 1968). The weathering crust of the basement carries important information that can be used for climatic,

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tectonic and geographical reconstruction of the past of Earth's crust. Moreover, it can be connected with deposits of various minerals. Rocks of the weathering crust have a higher filtration rate, higher capacitive properties and oil evidences that allows referring them to nonconventional reservoir zones of big depths (Sidorova and Sitdikova, 2014).

2. Geological overview

The object of research is the geological core material of the numerous deep wells drilled within the territory of the Tatar arch – a large structure of the Russian plate in geological and tectonic relation (Figure 1). Currently, about 900 deep wells within the Tatar arch have penetrated the weathering crust to a different extends, varying from 10 to 60 m in 150 wells (Gatiyatullin and Baranov, 2013).

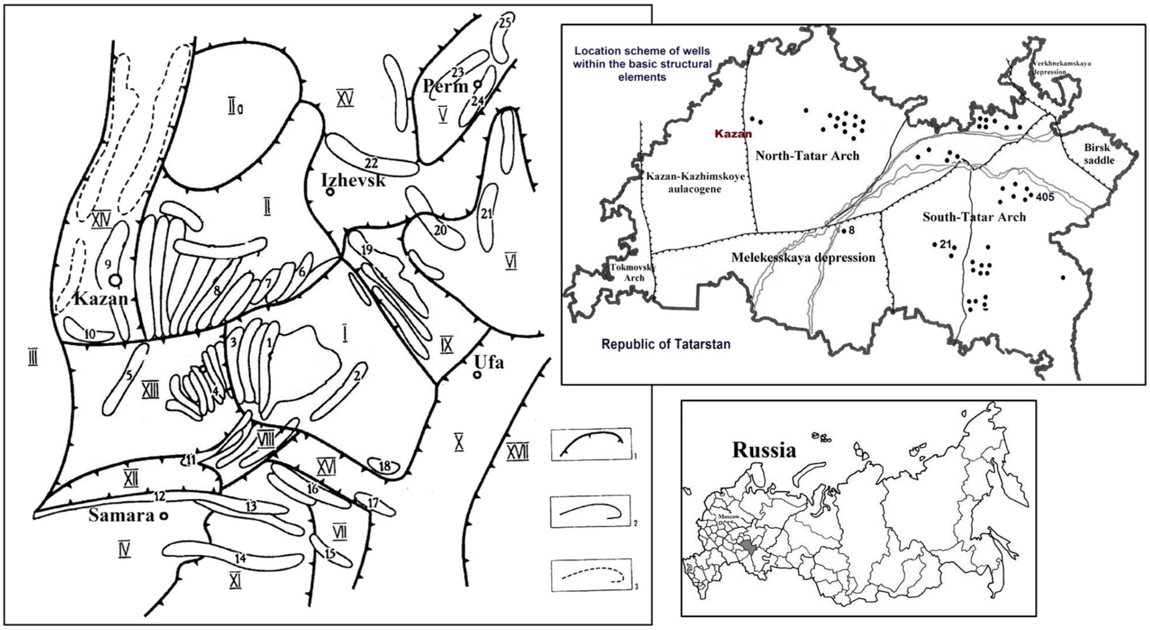

Fig. 1. Tectonic scheme of the Volga-Ural anticlines **-** *large positive structure of the Russian plate* (Voitovich and Gatiyatullin, 2003**)** and location scheme of wells. 1 - boundaries of large tectonic structures of the first order. Arches: I – South-Tatar; II - North-Tatar; III – Tokmovsky; IV – Zhigulevsko-Pugachevsky; V – Permian; VI – Bashkir; VII – East Orenburg protrusion. Saddles: VIII – Sokskaya; IX – Birsk; X – South-eastern slope of the platform. Depressions, large deflections: XI – Buzulukskaya; XII – Stavropol; XIII – Melekesskaya; XIV – Kazan-Kirov; XV – Verkhnekamskaya; XVI – Abdullinsky; XVII – Belskaya. 2 - boundaries of structures of the second order; 3 - boundaries of structural forms of the Vyatskyi shaft.

Administratively, the studied area is located within one of the main oil-producing regions of Russia – the Republic of Tatarstan where hydrocarbon deposits of sedimentary cover are actively developed. The structure of the Tatar arch has two levels: the lower one is represented by crystalline rocks of the basement, the upper one is represented by deposits of a sedimentary cover. The weathering crust on the basement occupies an intermediate position and is covered by sedimentary rocks of Devonian, Carboniferous, Permian and Cenozoic age of a thickness from 1,500 to 2,500 m. The basement of the Tatar arch is characterized by a complex geological structure with strong tectonic dissection formed by a system of blocks, faults of different order and length. The Tatar arch consists of the South and North-Tatar arch. The sedimentary cover of the South-Tatar arch includes major hydrocarbon deposits – the Romashkino field and its satellites. According to the stratigraphic schemes, basement rocks are divided into two complexes differing in the degree of methamorphism: the upper Archean – lower Proterozoic granulite-gneiss complex and the Proterozoic schist-gneiss complex. The main differences of rocks subjected to weathering are represented by gneiss and crystalline schist rocks, including two formations allocated by the quantitative relation of rock-forming minerals: mafite-siliceous and aluminous-highly aluminous formations (The crystalline basement, 1996). Features of the weathering crust are determined by the time of its formation, climate, composition of original rocks of the crystalline basement, geological and tectonic position, intensive development of different weathering processes and actions of secondary superimposed processes.

3. Results and discussion

The formation period of the weathering crust of the territory's crystalline basement is defined by an interval from the Upper Proterozoic to the Middle Devonian. Since the exact time of formation is not established, several types of weathering crust are identified in accordance with the age of covering sedimentary rocks: Riphean-Vendian, pre-Eifelian, pre-Givetian and pre-Frasnian. The most common ones are the pre-Givetian and pre-Frasnian weathering crusts, the least developed one is the Riphean – Vendian. Different climatic conditions during the formation of these types of weathering crust are marked by significant warming in Givetian and Frasnian times. In the coldest period, the Riphean – Vendian-weathering crust was formed (Lapinskaya and Zhuravlev, 1967). Thus, the formation of the weathering crust of the Tatar arch proceeded in different periods of geological time.

In pre-Devonian time, due to the washing-out and the subsequent processes of redeposition of substance, two types of weathering crust were formed: displaced and non-displaced (residual). The following three types of weathering crust are distinguished by morphology: areal, linear-fractural, and fractural-areal. As a result, the thickness of areal crust with the reduced weathering profile varies for different sites of the Tatar arch: from 1,0-5,0 m in the central parts to 20.0-25.0 m on the periphery of the Southern Tatar arch. Development of the linear type of the weathering crust with a thickness more than 50.0 m is also indicative for this region and is connected with zones of basement faults of various degree (Lapinskaya and Zhuravlev, 1967; Sitdikov, 1968).

The main criteria for selection of the weathering crust in well sections are a transition from unchanged rocks of the crystalline basement to weathered rocks with increased rate of alteration up to the profile, as well as mineralogical and geochemical zoning of weathering profiles. Analysis of available data shows that weathering crust of the areal type with significant zoning is mainly developed in the studied area. The weathering crust of linear type has no clear zoning.

Data of our research testifies that weathering crust formation proceeded because of a consecutive change of weathering processes: disintegration, hydration, leaching, hydrolysis, and oxidation. Therefore, the zonal distribution of the crust is established. From the bottom up, the profile of weathering zones varies in mineral and chemical composition: disintegration, cementation, hydration, leaching, oxidation and a zone of secondary hydration (Sitdikova and Sidorova, 2014). Another feature of the core formation of this region is the development of an incomplete core profile which is in most cases presented only by the lower zones. The intensity of weathering processes and the formation of clay minerals increases from the lower to the upper zones of the profile.

The profile of the weathering crust penetrated by well No.21 (interval 1705,5-1720,4 m), located within the central part of the South-Tatar arch, refers to an incomplete residual type of areal of weathering crust with a thickness of 9.5 m according to the well core data. Rocks of the crystalline basement subjected to weathering are presented by garnet-biotitic gneisses (Figure 2a, b). The weathering profile includes two zones: disintegration and hydration leaching. According to the content of clay minerals, the rocks belong to the illite-kaolinite association (Figure 3a, f). The content of illite decreases up the profile and does not exceed 5-10% in the hydration-leaching zone. The final stage of the clay mineral transformation due to weathering is kaolinite. It determines its leading role in composition of clay component of the weathering crust both in this weathering profile and in the majority of studied profiles of the Tatar arch.

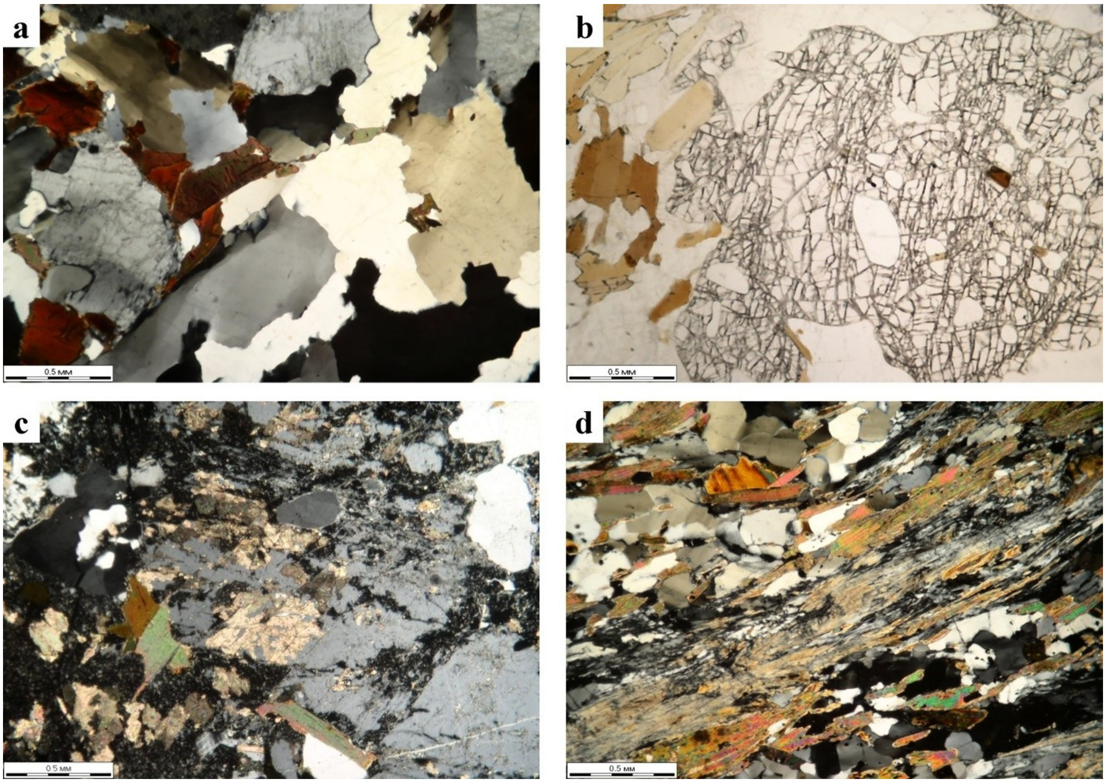

Fig. 2. *Optical micrographs (microscope Leica DM/LP).* a) Quartz with wavy extinction in garnet-biotite gneiss. Well №21, 1714,7-1720,4 m, Nicole +; b) Fractured grain of garnet in garnet-biotite gneiss. Well №21, 1714,7-1720,4 m, Nicole II; c) Biotite-plagioclase gneiss, development of kaolinite after plagioclase. Well №8, 1867,3-1868,7 m, Nicole +; d) Quartz-sillimanite-biotite schist. Well №405, 1798,1-1802,1 m, Nicole +.

The weathering profile studied in well No.8 (interval 1860.3-1868.7 m) located within the western slope of the South-Tatar arch (wing of Melekesskaya depression) is an incomplete residual profile of areal crust. The thickness is 8.4 m, according to the core data. Weathering process goes on with biotite-plagioclase gneisses (Figure 2c) and forms a profile with a selection of two zones: disintegration and hydration-leaching. This profile differs from the previous one by the development of kaolinite association of clay minerals, starting with a disintegration zone and an increased rate of crystallinity of kaolinite during transition to the hydration-leaching zone (Figure 3 b, e).

The geochemical zoning of the profile of areal weathering crust has common patterns in migration of individual components (Table 1). According to x-ray fluorescent spectral analysis (X-ray fluorescence spectrometer S2 Ranger Bruker) upward the profile, hydration and leaching zones have accumulated alumina and titanium oxide, increased content of impurity elements, with carry-over of silica, alkali and alkaline earth metals.

The calculated values of geochemical indexes are: The chemical Index of Alteration

$$CIA=[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]\times 100,$$

Chemical Index of Weathering

$$CIW=[Al_2O_3/(Al_2O_3+CaO+Na_2O)]\times 100,$$

and Plagioclase Index of Alteration

$$PIA=[(Al_2O_3-K_2O)/(Al_2O_3+CaO+Na_2O-K_2O)]$$

are increased during transition from disintegration zone to hydration-leaching zone, confirming the increased rate of weathered rocks up the profile and showing the formation of this weathering crust in warm climates (Fedo et al, 1995; Nesbitt and Young, 1982; Harnois L., 1988; Price and Velbel, 2003).

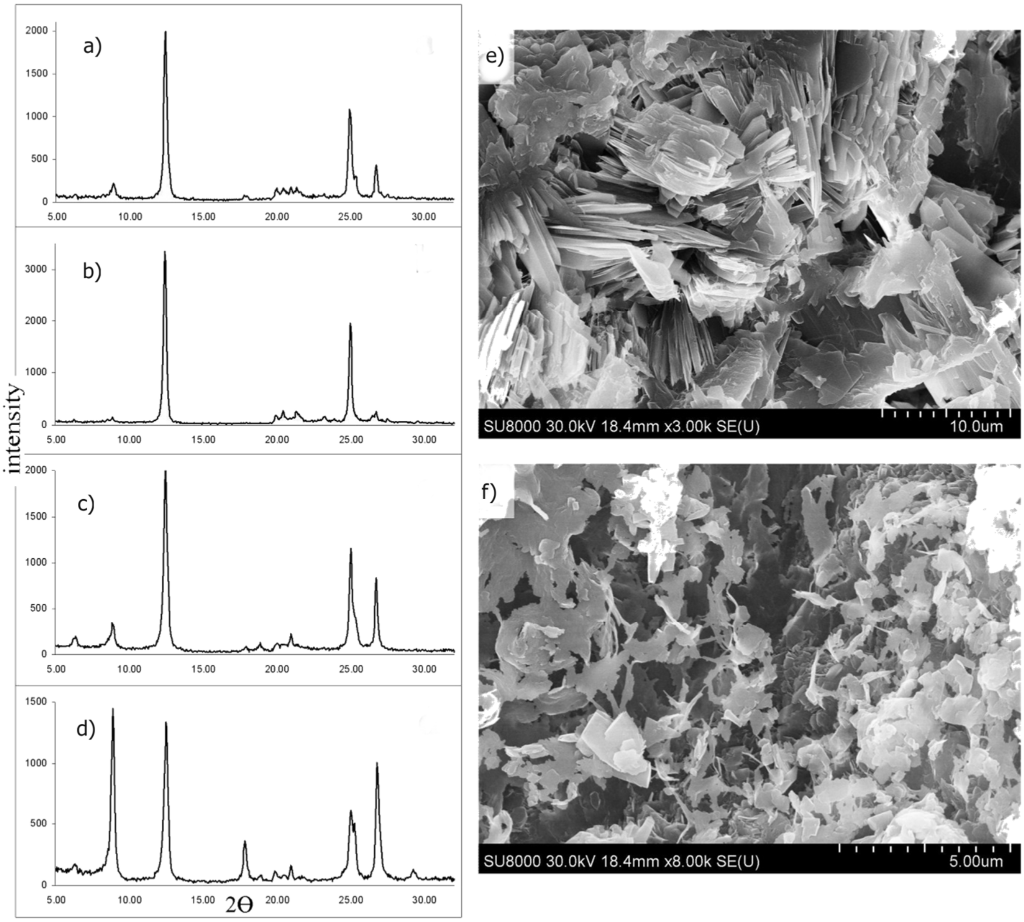

Fig. 3. *XRD patterns of air-dried samples (diffractometer DRON-3M, CuKα):* a) Illite-kaolinite association, well №21, 1705,5-1707,7 m; b) Kaolinite association, well №8, 1860,3-1867,3 m; c) Chlorite-illite-kaolinite association, well №405, 1793,9-1798,1 m; d) Chlorite-kaolinite-illite association, well №405, 1805-1807,7 m. *Photographs (scanning electron microscope Hitachi SU8000, Zelinsky Institute of Organic Chemistry, Moscow):* f) Aggregates of mica and kaolinite in the pore space, disintegration zone, well №8, 1867,3-1868,7 m; e) Formation of clay minerals – kaolinite, chlorite, mixed-layer mica, well №22, 1734,2 m.

An example of the linear type of weathering crust is the profile of well No. 405, drilled on the side of the Kamsky-Kinelsky system of deflections in an area of tectonic faults. The thickness of the weathering crust developed on crystalline schist (Figure 2d) is 49.8 m according to the core data. The actual thickness of such weathering profile is difficult to define due to the small deepening of wells at the basement rocks. The main associations of clay minerals in this profile are chlorite-illite-kaolinite, mixed (mica-smectite)-kaolinite and chlorite-kaolinite-illite interstratified along the profile (Figure 3c, d).

The weathering of the crystalline basement rocks and the consequent formation of clay minerals lead to changes in the physical properties of rocks, which is reflected in the increase of total (25-30%) and efficient (5-15%) porosity (Sidorova and Sitdikova, 2013). The establishment of oil ingress from rocks of the weathering crust of the Tatar arch (Gatiyatullin and Baranov, 2013) allows us to attribute this geological formation to unconventional reservoir zones of deep horizons.

4. Conclusions

Several types of weathering crust of the Eastern Russian Plate (Tatar arch) were allocated by age, morphology, degree of preservation, structure, mineral and geochemical composition based on the published data and results of the research conducted. The classification of the studied weathering profiles with these criteria allows to set up the most promising areas for the development of the ancient weathering crusts within the Tatar arch.

Table 1. Chemical composition of the weathering crust.

Component %	**Well №21**				**Well №8**		
	sample 2	sample 4	sample 5	sample 131	sample 1	sample 2	sample 5
	hydration and leaching zone			*disintegration zone*	*hydration and leaching zone*		*disintegration zone*
SiO_2	63.62	68.66	60.80	71.07	68.18	70.05	74.86
TiO_2	1.99	0.76	0.90	0.51	0.96	0.51	0.17
Al_2O_3	19.65	19.27	15.00	11.13	24.27	16.48	12.84
Fe_2O_3	5.90	1.57	11.89	6.41	0.40	1.72	1.66
MnO	0.01	0.01	0.04	0.04	0.00	0.04	0.02
MgO	2.48	2.39	3.82	2.70	0.00	0.00	1.46
CaO	0.25	0.00	0.19	1.21	0.00	4.11	4.35
Na_2O	2.30	2.74	1.85	1.96	4.52	0.00	2.24
K_2O	1.12	2.39	3.35	3.44	0.00	5.46	1.44
P_2O_5	0.19	0.15	0.00	0.00	0.00	0.00	0.00
LOI	2.50	2.06	2.17	1.53	1.68	1.63	0.97
Total	100	100	100	100	100	100	100
CIA	*79.7*	*74.1*	*68.1*	*54.9*	*76.6*	*55.2*	*49.4*
CIW	*83.8*	*82.3*	*81.5*	*67.2*	*76.5*	*68.8*	*52.5*
PIA	*83.0*	*80.1*	*77.0*	*57.7*	*76.6*	*58.6*	*49.3*

0.00 - component content is less than 0.005 wt.%.

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