AGH DRILLING, OIL, GAS • Vol. 35 • No. 1 • 2018

http://dx.doi.org/10.7494/drill.2018.35.1.83

Andrzej Goc*, Patrycja Wojtasiak*,
Jarosław Piotrowski*, Maciej Stec*

THE INFLUENCE OF WATER ON VARIOUS CLAY ROCKS

1. INTRODUCTION

One of the challenges of any laboratory dealing with drilling fluids is the development of a mud that would be environmentally friendly and on the other hand inhibit the clay rocks at maximum. Due to their structure, age and origin clay rockshave different physical properties that have a huge impact on the drilling process. Each geological region in which drilling works are carried out is characterized by a specific stratigraphy determining the types of mud systems used for drilling through various geological bedding, including clay rocks layers.

While conducting researcheson the inhibitory properties of various types of drilling fluids with the use of OFITE's SWELLING METER the accurateness of behavior for various clay rocks under the influence of water was noticed. The mineralogical composition, geological age and depth of rocks determine the behavior of each type of clay rock under the influence of water.

When talking about clay rocks, rocks that are sensitive to hydration are usually meant but often the word is synonymous with: shale, marlstone, claystone, mudstone, etc.

2. CLAY ROCKS

According to the definition clay rock can be defined as a rock in which the grain composition is more than 50% of the clay fraction, so the fraction containing grains -below 2 μm or the rock which is built in more than 50% of clay minerals [1].

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* Exalo Drilling S.A., Centrum Zielona Góra, Poland

The clay minerals belong to sedimentary rocks with diversified structure. The clay minerals can be divided because of their:

1. Construction:
   - layer-type:
     - 2:1 layer type, e.g. mica, smectite,
     - 1:1 layer type, e.g. kaolinite,
     - 2:1:1 layer type, e.g. chlorite,
     - mixed layer type.
   - Inverted ribbons, e.g. palygorskite, sepiolite.
2. Mineralogical composition:
   - kaolinite rocks,
   - smectite rocks,
   - illite rocks,
   - vermiculite rocks,
   - palygorskite and sepiolite rocks.
3. Degree of compaction:
   - clayey sediments,
   - silt,
   - shale,
   - slate.
4. The environment of formation:
   - residual rocks,
   - clay rocks of lake origin,
   - clay rocks of river origin,
   - clay rocks of marine origin.

In drilling practice, it is rare to drill a hole in a homogeneous clay rock. It often contains various impurities like quartz, carbonates and other components in variable ratios. The structure of clays is more often mixed layer type than single layer type.

The clay rocks are sedimentary rocks.Their properties are determined by sedimentation environment, climatic conditions in which sedimentation took place, the possibility of discharginghydrolysis products or supplying the ions. The second factor influencing the properties of clays is their diagenesis. With the increase of the thickness of the overburden over the sedimentary layer, a simultaneous process of compaction, cementation, extrusion of water from pore and interlayer spaces, reduction of pore spaces and transformation of the mineral composition begins. With increasing thickness of overburden above clay sediments,simultaneous compaction and cementing process together with water squeezing from porous and inter-layers structures, reduction of porous spaces and mineral alterations begin. With the increasing depth of clayey sediments lithology changes from clay sediments through clays, claystone to shale while reduction of rock porosity from 90–70% to 4–3% [1, 8, 9]. Diagenesis is strongly influenced by tectonic movements which may cause upthrust or collapse of clay beddingfrom the same geological period and thus the clay rock samples from the same series may have different properties.

All the above-mentioned elements affect the properties of individual clay rocks and hence the correct selection of drilling mud system.

3. RESEARCH METHODOLOGY

One of the methods to check the behavior of clay in a drilling fluid environment or in water is a clay swelling test using LINEAR SWELLING METER. The OFITE device was used for the tests, which enables real-time monitoring of the sample behavior in water or drilling mud.

Regarding the samples of cuttings, attention was paid to the fact that it was subjected to the action of the mud and the image obtained as a result of the test may deviate from the rock sample not exposed to the drilling mud (taken during the coring). This is due to the fact that the sample of the cutting before the test was washed with water in order to get rid of residual drilling mud, thus losing the smallest fragments of the rock. However, on the other hand, we can observe a tendency in the behavior of a given rock in the water. It is often the only opportunity to take a sample because there is no access to the cores neither outcrops, as in the Miocene's London Clay or Oxford Clay.

The tests were aimed at collecting large sample chips (as far as possible), because cuttings were characterized by a short time of interaction with the mud and it was possible to wash it on a sieve, removing mud residue with a small amount of the finest rock particles.

All samples were dried for about 6 hours at 105°C. After drying, the samples were milled and then pressed at 6000 psi (41.37 MPa) for 30 minutes. The obtained rolls (Fig. 1) were placed in special cells, in which the volume increase of the compressed clay sample was measured for 20 hours at room temperature using the SWELLING METER equipment.

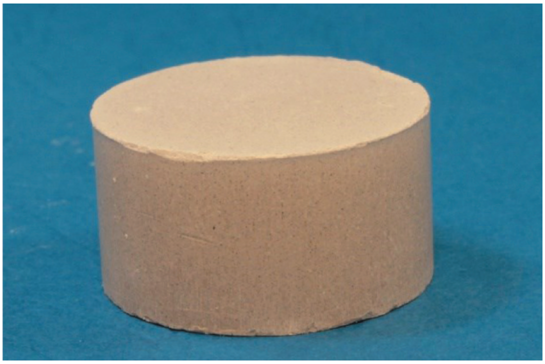

Fig. 1. Clay sample after pressing

In parallel to the swelling tests of rock samples, pieces of cuttings were placed in a beaker, flooding them with water, observing their behavior.

4. RESEARCHES

I. Bentopol (API bentonite)

The mud additive under the trade name Bentopol (ZGH "Zębiec") served as a swelling clay model with sodium montmorillonite content, minimum 70%. This material is characterized by the ability to form colloidal solutions, hence it can be used as a swelling clay model. Based on the conducted experiments with samples of bentonites containing sodium montmorillonite by various manufacturers, it was observed that the behavior of the samples in water is identical to that of Bentopol.

The behavior of a sample of swelling clay (smectite) in water can be seen in the following photographs, see Figure 2a–d.

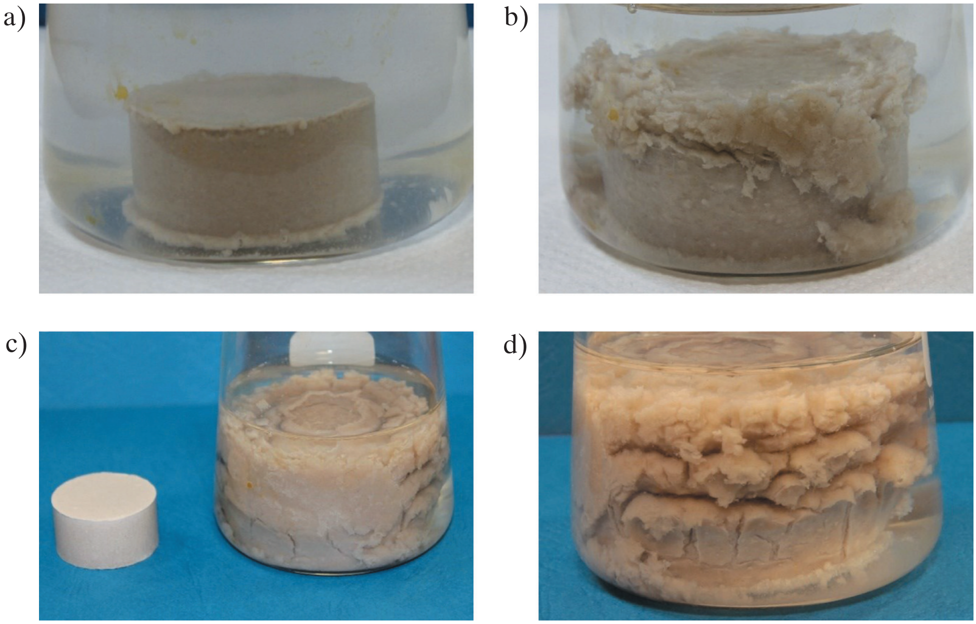

Fig. 2. Sample right after flooding with water (a); sample in the water after ~4.5 h (b); sample in the water after ~24 h (c and d)

Observing the shape of the plot for water swelling clay, it can be stated that the hydration of the clay samples takes place continuously until the upper limit of the swelling measurement by the instrument is reached. This behavior is correlated with the behavior of the sample in a beaker with water. The sample absorbs water, increasing the volume until the integrity of the sample becomes so poor that it undergoes disintegration forming a colloidal suspension.

In the first 3 hours of the test, the clay sample is getting quickly hydrated (Fig. 3). The hydration process then slows down, which results from the slower migration of water into the sample. Water migration takes place continuously.

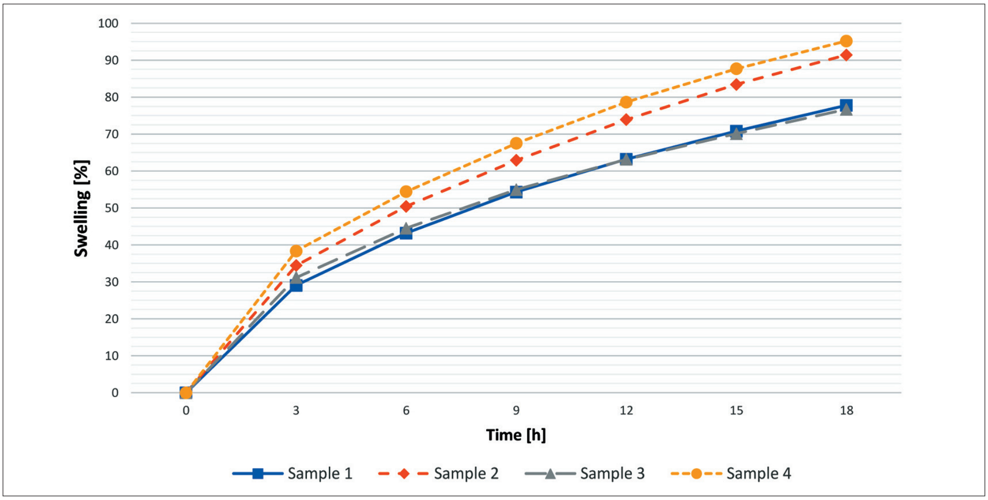

Fig. 3. The influence of water on Bentopol samples behavior (API bentonite)

II. Miocene Clay

A sample of Miocene Clay was obtained thanks to the kindness of IGNiG PIB Krosno Branch (Fig. 4).

Fig. 4. Sample of Miocene Clay

On the basis of the Polish stratigraphic table [3], the geological age of the sample is between 5.33 and 23.3 million years.It is a relatively young rock that was obtained from a quarry in the Carpathian Flysch area.

The Miocene Clay behaves differently under the influence of water comparing to the swelling clay, as illustrated in Figure 5. In the first three hours of water impact on the clay sample, the volume increases in the same way as in the case of swelling clay (Bentopol). In the interval between 3 and 6 hours, the increase rapidly drops. The volume increase practically surceases during the course of the test.

The behavior of a sample of Miocene Clay rock in water can be seen in Figure 6.

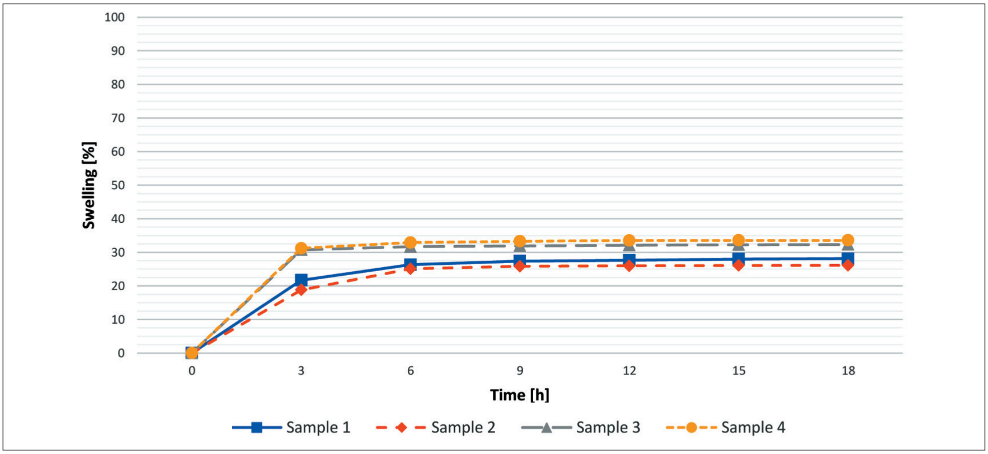

Fig. 5. The influence of water on MioceneClay behavior

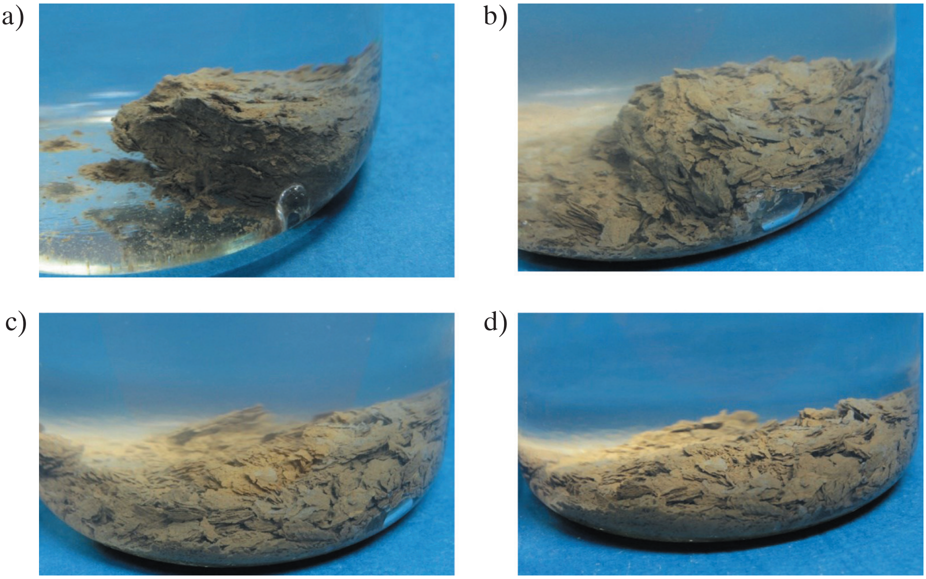

Fig. 6. Sample right after flooding with water (a); sample in the water after ~10–15 min (b); sample in the water after ~1 h (c); sample in the water after ~27 h (d)

Under the influence of water, the rock sample breaks down into fine laminae until the sample is completely disintegrated.

III. London Clay

A sample of the London Clay, Figure 7, was obtained thanks to the kindness of BDC Poland and Clear Solutions.

The rock sample belongs to the Paleogene period, the Eocene epoch, the Ypresian-stage, and London Clay is a local name. On the basis of the Polish stratigraphic table [4], the geological age of the sample is between 48.6 and 55.8 million years and it is an older rock from the Miocene Shale.

Fig. 7. London Clay sample

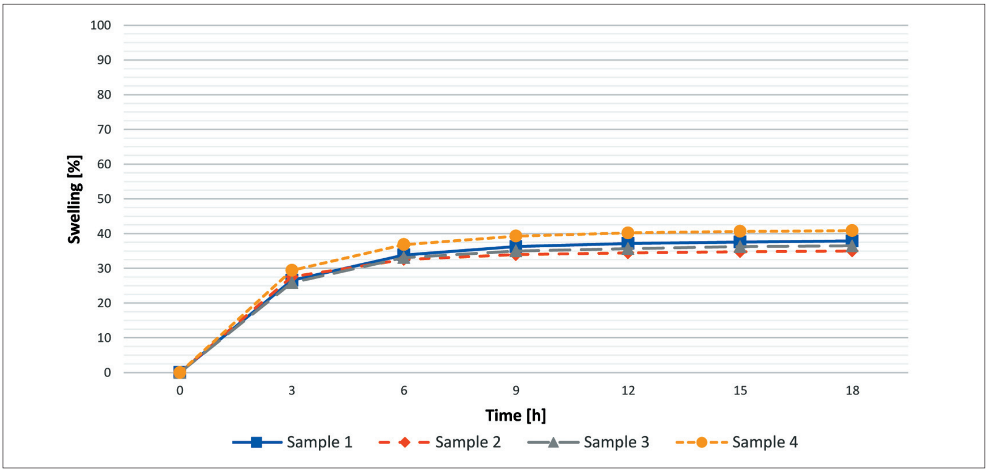

Fig. 8. The influence of water on London Clay behavior

A sample of London Clay rocks under the influence of water behaves like the Miocene Shale. In the first three hours of exposure of water to the rock sample, the volume increases in the same way as in the case of an swelling clay. In the interval between 3 and 9 hours, the increase rapidly drops (Fig. 8). In the further duration of the test, the volume increase decreases from 0.8–1.0% to the level of ~0.2–0.3% with a further decreasing tendency.The behavior of a London Clay rock sample in water can be seen in Figure 9.

Under the influence of water, the rock sample immediately disintegrates into very fine laminae. Practically after 5 minutes of contact with water, the rock has completely disintegrated. The rate of break up is higher than in the case of the Miocene Shale and the plates are smaller.

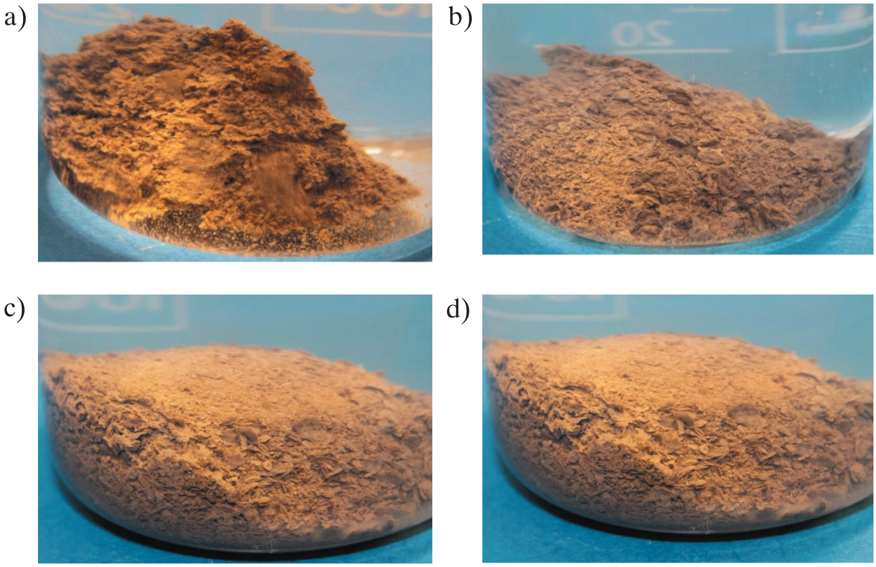

Fig. 9. Sample right after flooding with water (a); sample in the water after ~ 2 min (b); sample in the water after ~ 10 min (c); sample in the water after ~ 1 h (d)

IV. Oxford Clay

A sample of the rock, Figure 10, was obtained thanks to the kindness of BDC Poland. Based on the Polish stratigraphic table [4], the geological age of the sample is between 155.0 and 161.2 million years and it is older from the two above rocks.

Fig. 10. Oxford Clay sample

A sample of Oxford Clay rock under the influence of water behaves like the Miocene Shale and London Clay. In the first three hours of exposure of water to the rock sample, the volume increases in the same way as in the case of a swelling clay. In the interval between 3 and 9 hours, the increase rapidly drops (Fig. 11). The volume increase remains constant at ~ 0.2% during the entire test.The behavior of a London Clay rock sample in water can be seen in Figure 12.

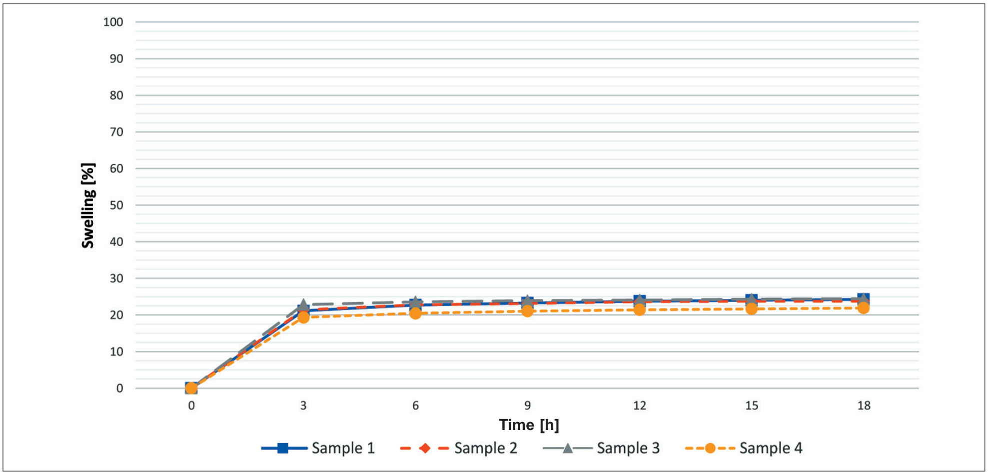

Fig. 11. The influence of water on Oxford Clay behavior

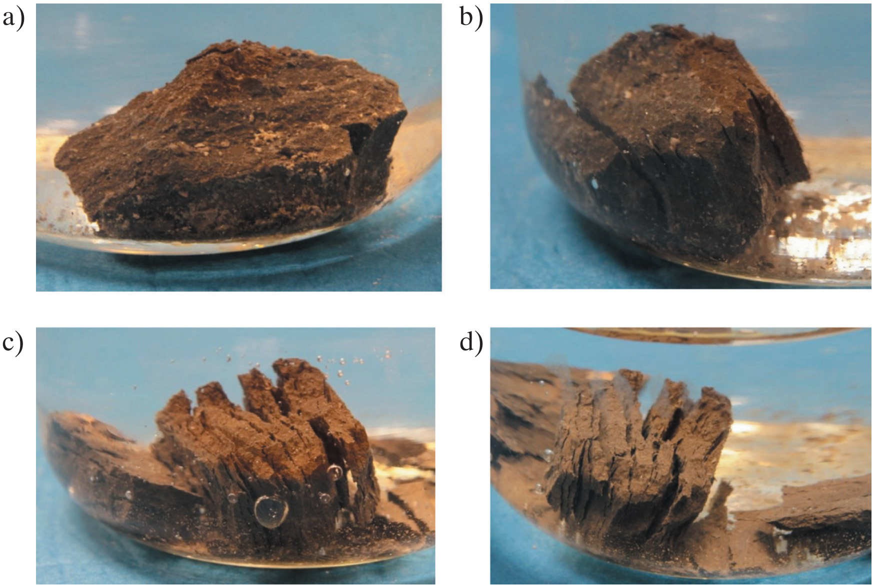

Fig. 12. Sample right after flooding with water (a); sample in the water after ~1 min (b); sample in the water after 1.5 h (c); sample in the water after 27 h (d)

Under the influence of water, the rock sample slowly disintegrates into "discs". The process of disintegration of the rock sample under the influence of water is much slower in comparison with Miocene Shale or London Clay. The difference in the number of laminae between Oxford Clay and the above-mentioned rocks is large. Small laminae are a minimum amount in relation to the size of the sample.

V. Upper Eocene

A sample of cuttings was obtained from the F-1 well, Figure 13, depth ~3500 m. StebnikUnit, Upper Eocene: coarse sandstones; gray sandstones; sandstones; dark gray mudstones, medium hard; with interbedding clayey shales and sandy mudstones [5].

Based on the Polish stratigraphic table [3], the geological age of the sample is between 33.9 and 55.8 million years. It is an older rock from the Miocene Shale and covers the London Clay age range.

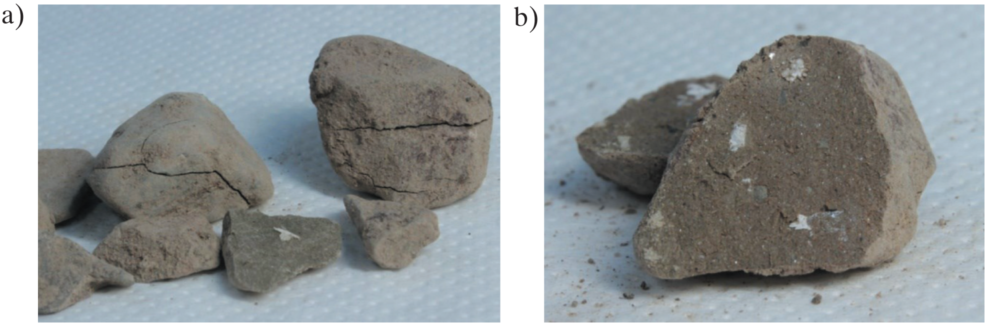

Fig. 13. Cuttings sample: 1 (a); 2 (b), Stebnik Unit, Upper Eocene

The cuttings from Upper Eocene from the F-1 well under the influence of water behaves similarly to the Miocene Shale, London Clay or Oxford Clay. In the first three hours of exposure of water to the sample of the material, the volume increases in the same way as in the case of swelling clay. In the interval between 3 and 6 hours, the increase rapidly decreases, and then the volume increase practically surceases (Fig. 14).

The behavior of the Upper Eocene rock sample in water can be seen in Figure 15.

Under the influence of water, single cracks appear on the rock sample, individual plates are separated, however, in the whole volume the rock sample does not change. There are also loose, very small laminae, which are a minor amount in relation to the size of the sample.

Compared to London Clay, the reactivity of the cuttings sample from the Upper Eocene is several times smaller. The difference in reactivity compared to the samples from the same geological age results from the placement depth of the sample.

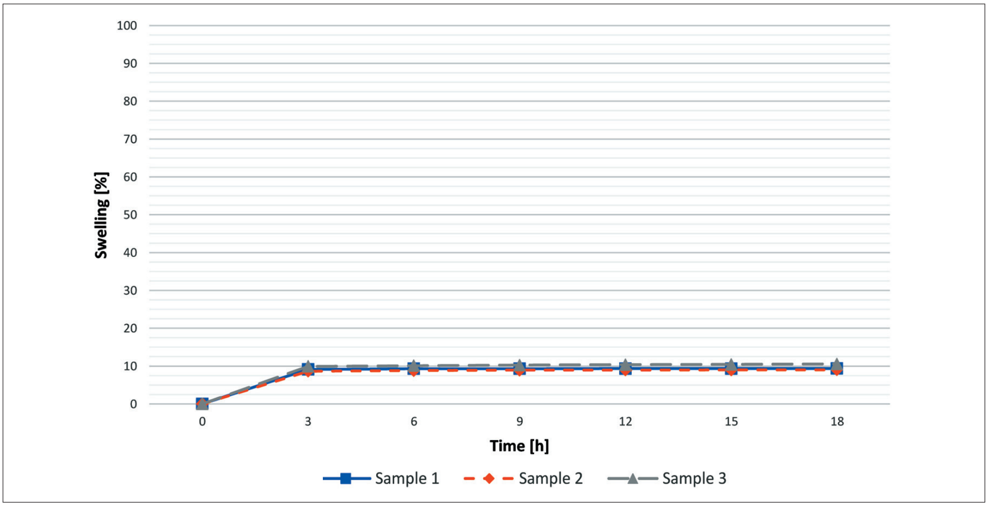

Fig. 14. The influence of water on Upper Eocene behavior

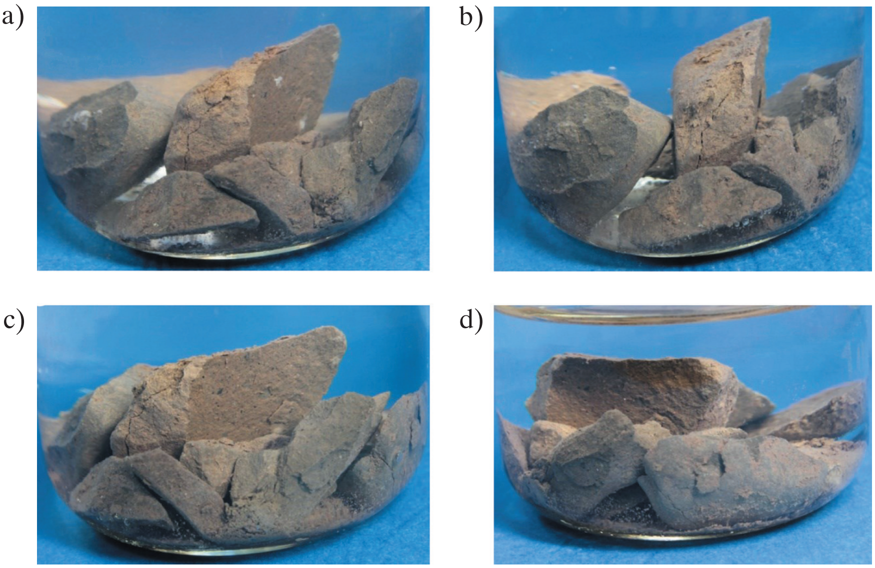

Fig. 15. Sample right after flooding with water (a); sample in the water after ~4 h (b); sample in the water after ~27 h (c); sample in the water after 7 days (d)

VI. Rhaetian

A sample of rock was obtained from the B-5H borehole, Figure 16, depth ~720 m. Rhaetian beddings belong to the Upper Triassic, which consist, going from bottom to top, from: variegated claystones; dolomitic claystones and clayey dolomites; platy variegated claystones and conglomerate variegated claystones and clays, gray or variegated claystones [6]. On the basis of the Polish stratigraphic table [4], the geological age of the rocks is between 199.6 and 203.6 million years.

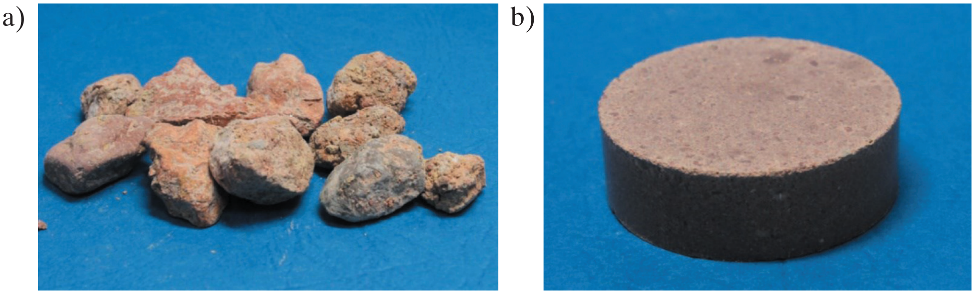

Fig. 16. Rhaetian rocks sample (a); milled and pressed Rhaetian sample disc (b)

The sample of the rock from the B-5H well under the influence of water behaves slightly differently than the Miocene Shale, London Clay or Oxford Clay. In the first three hours of exposure of water to the rock sample, the volume increases in the same way as in the case of swelling clay (Fig. 17). Then the volume increase drops (but does not stop) to the level of 0.5–1.0% for 3 hours.

The behavior of a sample of Rhaetian cuttings and a disc made of the rock in water can be seen in the Figure 18.

Under the influence of water, the rocks disintegrate into smaller fragments, however, in the entire volume the rock sample swells to a small extent. This is particularly evident in the behavior of the disc.

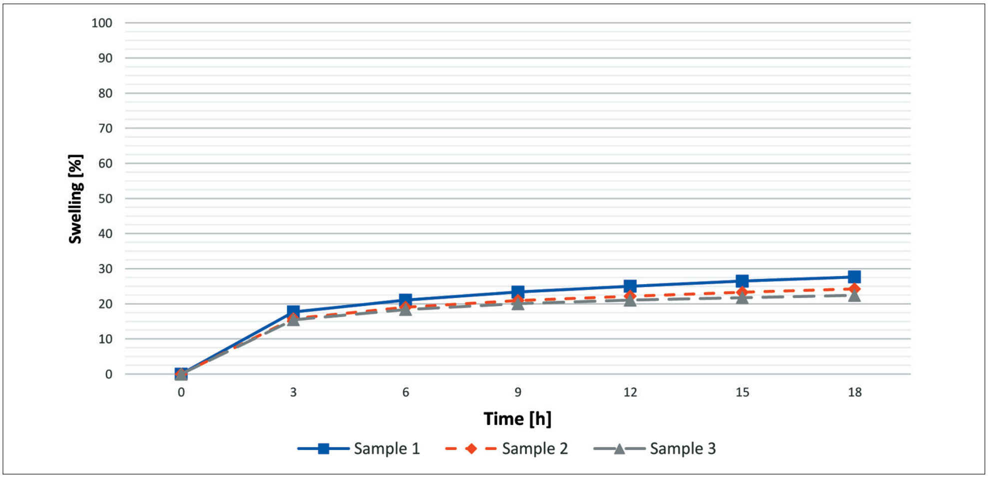

Fig. 17. The influence of water on Rhaetian behavior

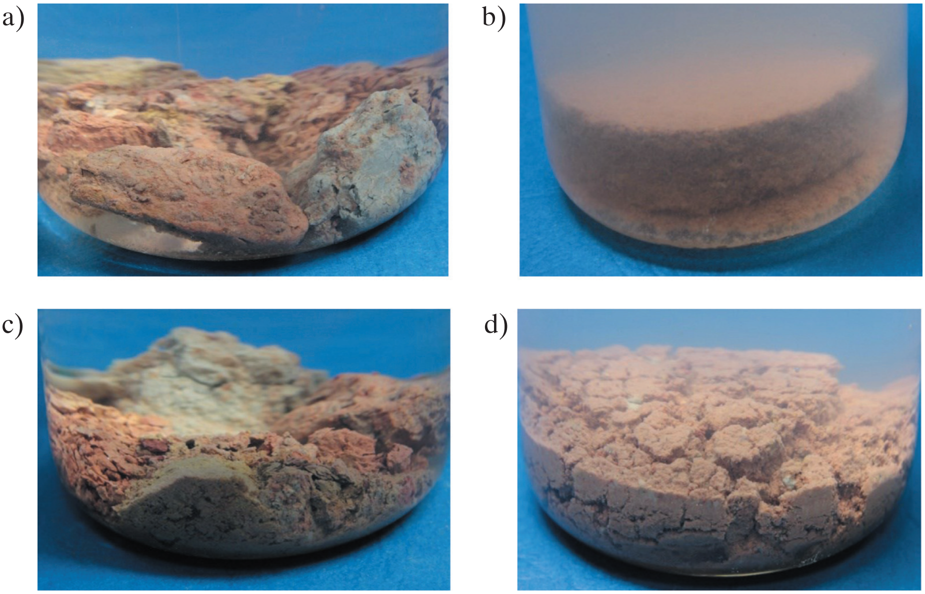

Fig. 18. Sample in the water after 3 min (a); sample right after flooding with water (b); sample in the water after 2.5 h (c); sample in the water after 5.5 h (d)

VII. Keuper

A sample of cuttings was obtained from the R-5H well, Figure 19, depth 1511–1881 m. Rock sample belongs to the Triassic period, the upper and partly middle epoch, stage: Rhaetian, Norian, Carnian, Ladinian. Keuper is the local name of the stage for extra-Carpathian Poland and Germany. Keuper, according to Dyjaczyński K.; Mamczur S. [6] is divided into two levels: lower Keuper consisting of mudstones, variegated claystones and sandstone and upper Keuper, divided into the lower gypsum series (claystones with gypsum and anhydrite interbedding), reed sandstone (sandstones, claystones, mudstones) and the upper gypsum series(claystones, marly claystones and dolomitic marls with many gypsum and anhydrite interbedding).

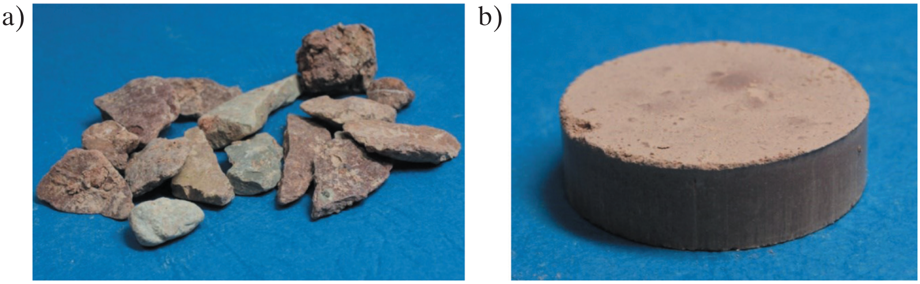

Fig. 19. Keuper rocks sample (a); milled and pressed Keuper sample (b)

Based on the Polish stratigraphic table [4], the sample's geological age ranges between 203.6 and 232.5 million years.

A sample of Keuper rock from the R-5H borehole under the influence of water behaves in a similar way as the Miocene Shale, London Clay or Oxford Clay. In the first three hours of exposure of water to the rock sample, the volume increases in the same way as in the case of an swelling clay. Then the volume increase drops (but does not stop) to the level of 0.2–0.3% for 3 hours (Fig. 20).

The behavior of a sample of Keuper rocks and a disc made of it in water can be seen in Figure 21.

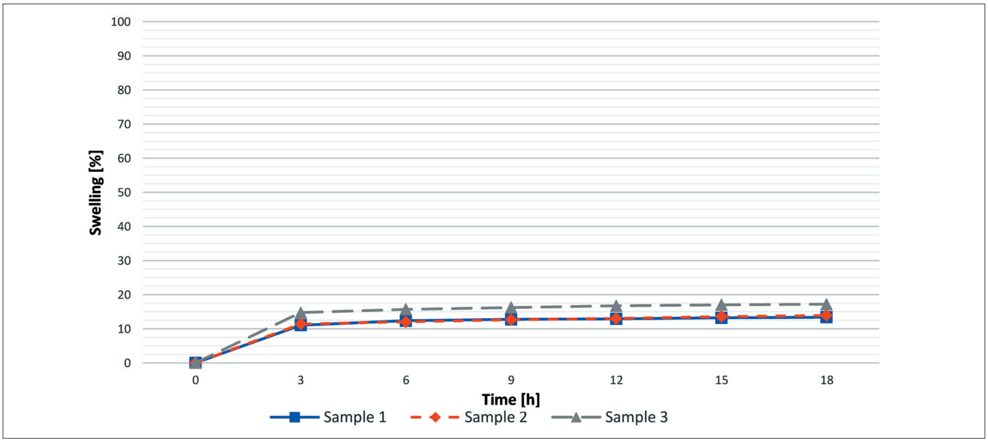

Fig. 20. The influence of water on Keuper behavior

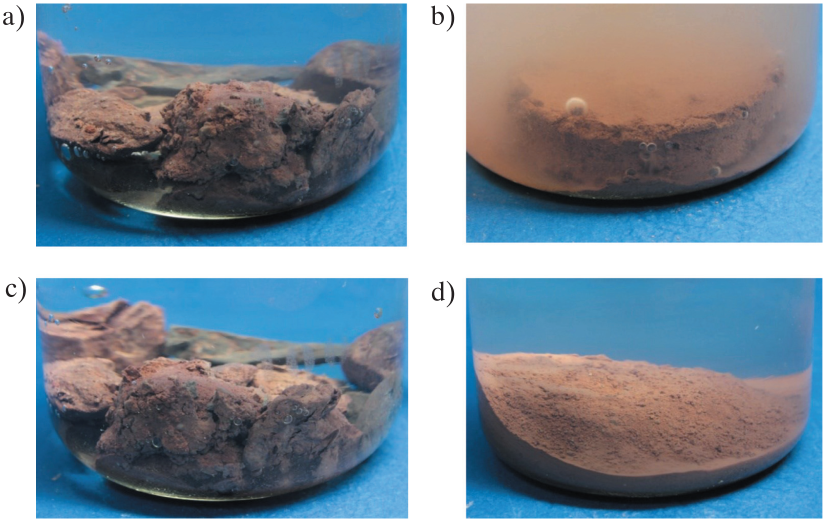

Fig. 21. Sample right after flooding with water (a); sample in the water after 1 min (b); samples in the water after 24 h (c and d)

Under the influence of water, the rocks do not break down into smaller fragments. The pellet slowly disintegrates. No increase in rock volume was observed. The behavior of discs in water is the same as Miocene, London Clay or Oxford Clay.

VIII. Red Pelite

A sample of Red Pelite was obtained from the G-10 well, Figure 22, depth 2928.5–2942 m. The beds of the Red Pelite are part of the Permian period, the upper epoch, the Zechstein unit, the Aller cyclothem (PZ4) [4, 6].

Fig. 22. Red Pelite rock sample

The Red Pelite is a very characteristic layer for the Zechstein deposits in the Polish Lowlands and it is a very plastic rock. The plasticity of this clay increases with the depth of deposition. During the drilling of this clay, no increase of the active clayey solid phase (MBT) in the drilling fluid is observed at all, and the only method to stabilize this rock is a drilling mud of appropriate density for a given drilling region. The Red Pelite is already in situ swollen. It lies between two impermeable layers and the water pressed out during the compaction could not be discharged anywhere. This also applies to the water formed during the dehydration of gypsum, which was originally pegmatite anhydrite.

Based on the Polish stratigraphic table [4], the sample's geological age ranges between 251 and 252 million years.

A sample of Red Pelite clay under the influence of water falls into smaller fragments without any visible increase in sample volume. In the first three hours of exposure of water to the clay sample, the volume of the sample increases. In the interval between 3 and 6 hours, the increase rapidly drops (Fig. 23). The volume increase practically surceases during the course of the test.

The behavior of a sample of Red Pelite cuttings and discs in water can be observed in Figure 24.

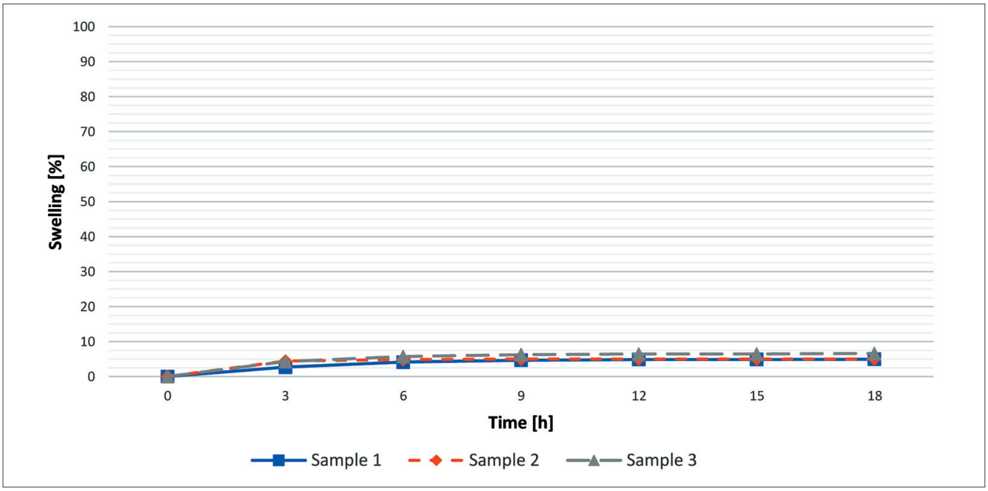

Fig. 23. The influence of water on Red Pelite behavior

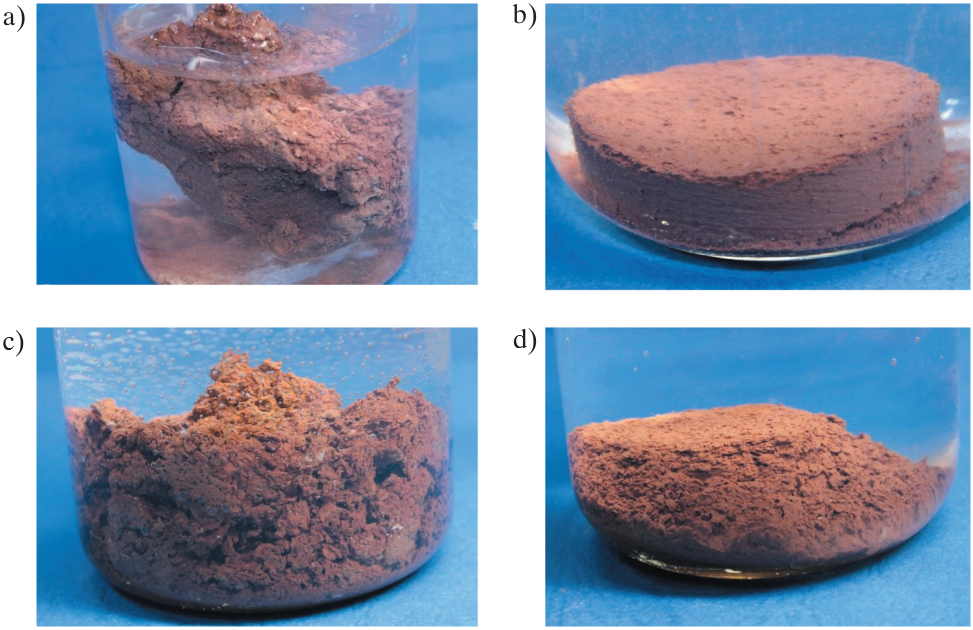

Fig. 24. Samples right after flooding with water (a and c);
samples in the water after 24 h (c and d)

Under the influence of water, the rock sample breaks down into small pieces, laminae. Larger fragments are cracked. The disc slowly breaks down into fragments of various sizes without the observed increase in rock volume. The behavior of the sample in water is the same as samples of the Keuper, Miocene Shale, London Clay or Oxford Clay.

IX. Silurian, Ludlow epoch

A sample of cuttings was obtained from the O-2 well, Figure 25, depth 1988–2004 m. The sample belongs to the Silurian period, the Ludlow epoch [4]: claystones, mudstones, clayey shalestones, shalestones.

Fig. 25. Silurian Ludlow cuttings sample

Based on the Polish stratigraphic table [4], the sample's geological age ranges between 418.7 and 422.9 million years.

The rock sample under the influence of water does not break down into smaller fragments. There are only few cracks. From the outer surface of the rock falls very small amount of some fine sediment. In the first three hours of exposure of water to the sample, its volume increases, which in the further course of the test practically surceases (Fig. 26).

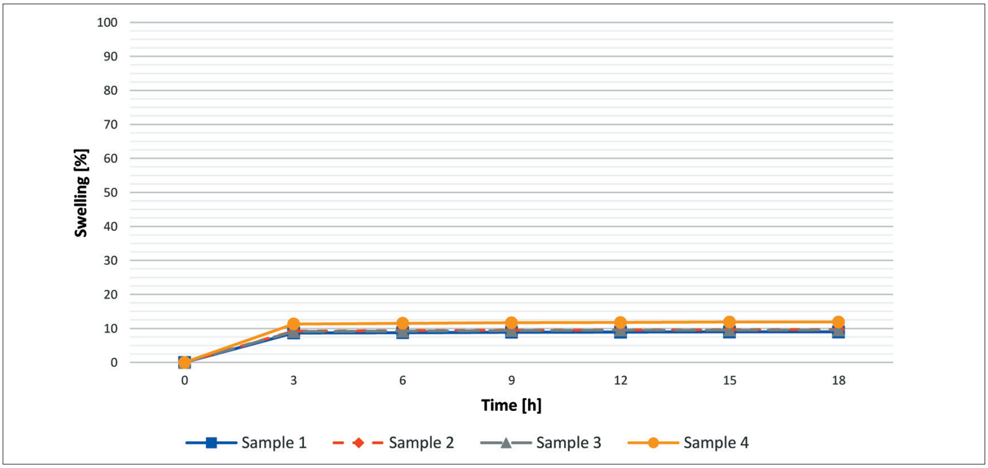

Fig. 26. The influence of water on Silurian, Ludlow epoch behavior

The behavior of rock in water can be seen in Figure 27. It was only observed that after removing rocks from the water and drying it, it was easier to break it than before the pieces were initially put into the water.

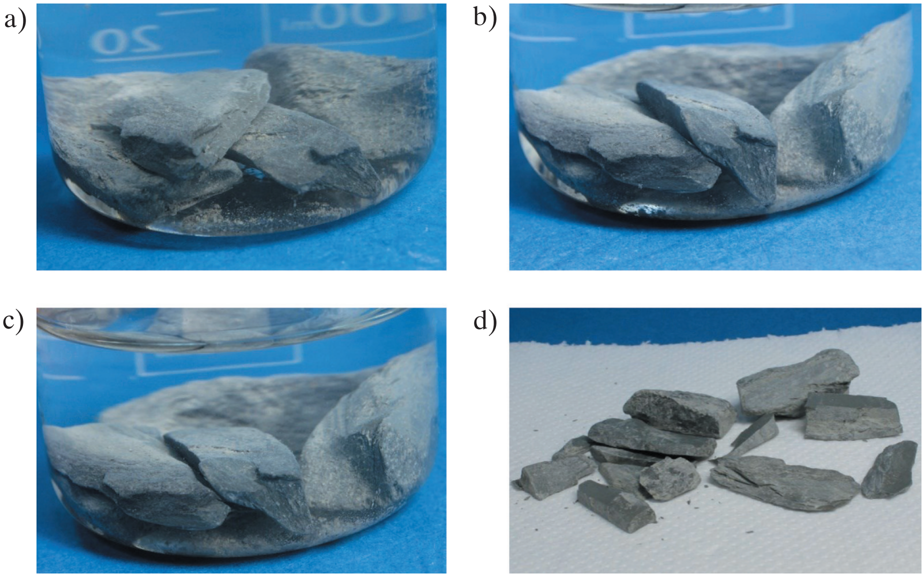

Fig. 27. Sample right after flooding with water (a); sample in the water after 8 days (b); sample in the water after 15 days (c); sample after taking out from the water (d)

X. Silurian, Llandovery epoch

A sample of cuttings was obtained from the L-3H well, Figure 28, depth ~2900 m. The sample is a part of the Silurian period, the Llandovery epoch [4]: claystones, mudstones, shale, shalestones.

Based on the Polish stratigraphic table [4], the sample's geological age is between 428.2 and 443.7 million years.

Fig. 28. Silurian-Llandovery rocks sample

Rock samples do not react with water. There are only few cracks. In the case of samples of this rock it is difficult to talk about the increase in the volume of the sample because it is negligible at the level of 0.1–2.5% (Fig. 29).

The behavior of the rock in water can be seen in the Figure 30. It was only observed that after removing rocks from the water and drying it, it was easier to break it comparing to the pieces that were not in the water.

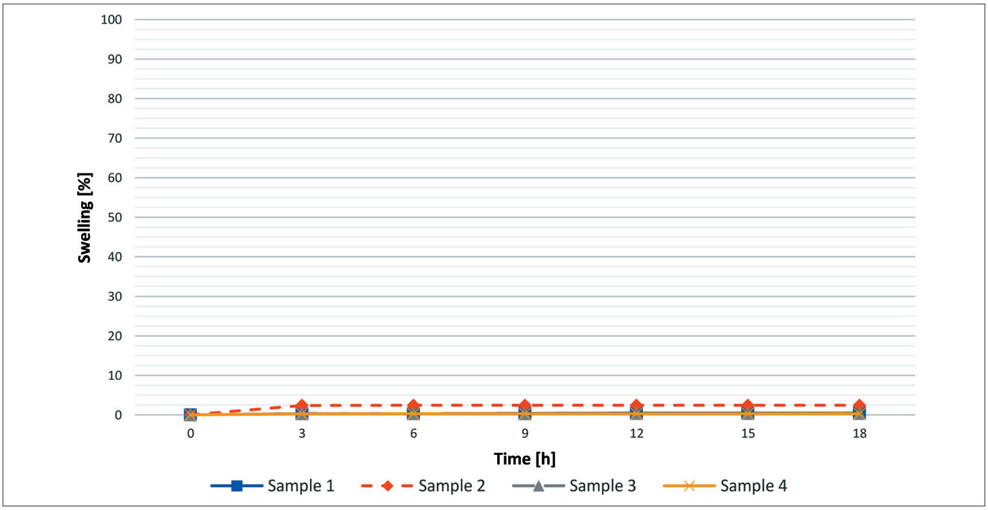

Fig. 29. The influence of water on Silurian, Llandovery epoch behavior

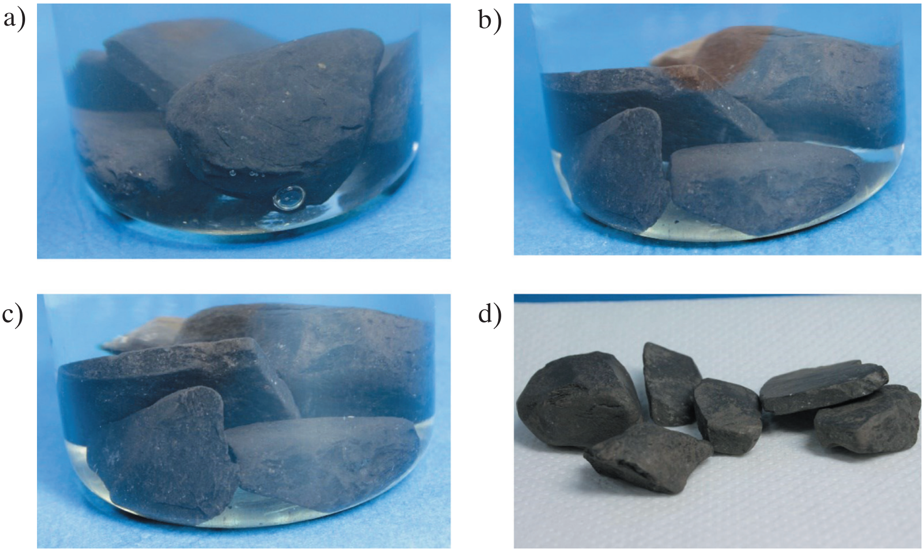

Fig. 30. Sample in the water after 48 h (a); sample in the water after 6 days (b); sample in the water after 8 days (c); sample after taking out from the water (d)

5. SUMMARY

The starting point for the studies on the interaction of clay rocks with water were tests on the inhibitive properties of drilling fluids. In the tests, a certain regularity was observed in the behavior of discs made of bentonite containing a minimum of 70% of sodium montmorillonite and discs prepared from raw Miocene Shale. This regularity can be seen in Figures 3 and 5. Continuing further research into the properties of various swelling inhibiting drilling fluids, it was found that the properties of clay rocks are an important element to pay particular attention to. The conducted research leads us to the following conclusions.

A. In all samples (apart from the sample of Silurian-Llandovery) in the first three hours there is the largest increase in the volume of the sample.

B. During rest of course of the test, the swelling slows down and there is a difference between the swelling shale, which main component is sodium montmorillonite, and non-swelling clays characterized by low cation exchange (CEC), e.g. illite, chlorite or kaolinite.

C. In the case of swelling clays, after three hours there is a slight slowdown in the volume increase of the sample until reaching the upper limit of measurement (practically until the sample breaks down).

D. In the second case(this concerns the Rhaetian), after three hours there is a significant slowdown in the volume increase of the sample, which indicates that the rock contains swelling and non-swelling clays. Since cuttings were exposed to the drilling fluid, the behavior of the sample in the water may be distorted.The true image would be given by a sample taken from the core. Confirmation of the behavior of the Rhaetian clay sample in water is the behavior of the rock during the drilling of the well, where with the poor inhibitive properties of the drilling fluid, the concentration of active parts of bentonite (CEC) is constantly increased in the mud at constant solid phase content.

E. In the third case, where the main component of the rock are clays characterized by low cation exchangeability, after three hours there is a slowdown in swelling growth, depending on the geological age and the depth from which the sample comes, almost to 0.

F. A special case is Red Pelite clay, which is plastic on the one hand and low swelling on the other. Its behavior results from the conditions in which it was formed. These are pieces of marine origin, deposited on the Younger Halite bed, and covered with the Pegmatite Anhydrite rocks where during the compaction the water could not be discharged anywhere. The drilling throughthis clay does not require any inhibition. The activity of this clay is regulated by the density of drilling mud.

G. The course of the Eocene Shale swelling plot in water conducted at the Drilling Oil and Gas Department at AGH UST in Krakow [10] with the help of HTHP Linear Swelling Meter M4600 by Grace Instrument coincides with the course of the Miocene Shale, London Clay or Oxford Clay graphs. The volume increase of the Eocene Shale sample in the tests performed ranged from 35% to 75%. With only the swelling diagram of the Eocene Shale sample, it can be concluded that the rock subjected to the influence of water will behave in the same way as the Miocene Shale or London Clay.

In Figure 31 the swelling of all samples that were used in the tests was summarized.

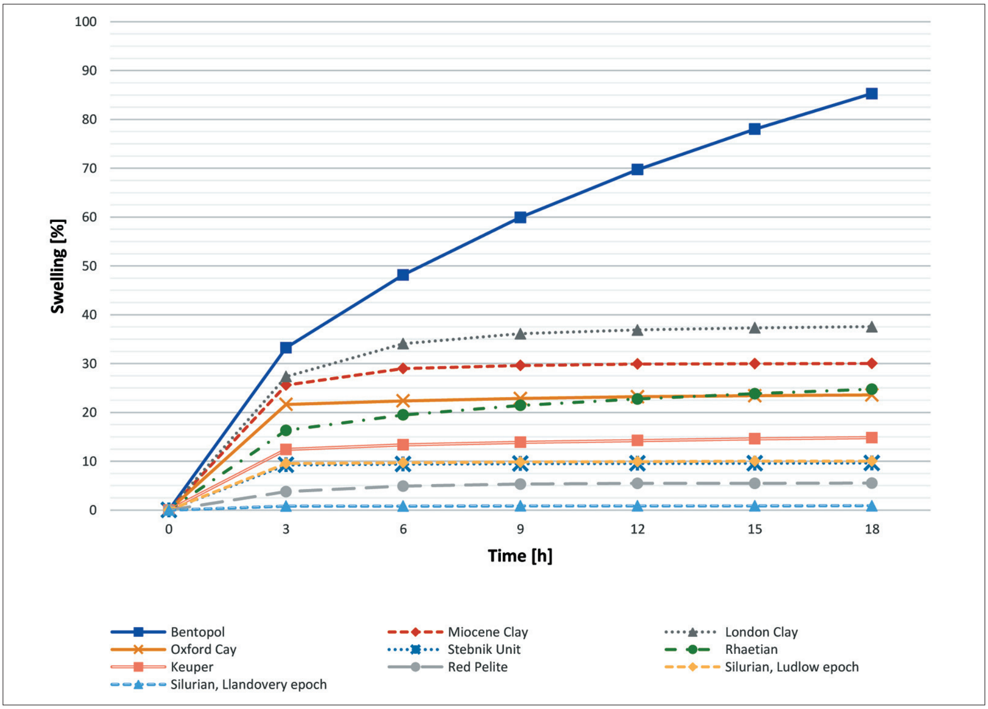

Fig. 31. The swelling of all samples

Knowledge of the behavior of clays from various geological layers in contact with water gives the opportunity to pay a special attention to the procedure when drilling wells, namely:

1. Filter cake

Due to the fact that the largest increase in the volume of the sample occurs in the first hours of contact of the rock with the drilling mud, it is particularly important to create a thin, flexible filter cake on the walls of the borehole. A good filter cake is an effective barrier against penetration of the drilling fluid filtrate into the rock. Any tearing off the cake from the wall of the well destroys this barrier, contributing to the loss of well stability. This problem concerns mainly clays characterized by a large increase in sample volume in water (Rhaetian) or easily disintegrating into small fragments (Miocene Shale or London Clay).

2. Rocks stability

As for rocks characterized by a low swelling at the level of 10–15%, the use of muds with high clay swelling inhibition capacity will not necessarily ensure stabilization of the wellbore walls. In this type of rocks, more attention should be paid to the drilling technique. Good practice should be the cooperation of people involved in drilling mud, people responsible for drilling technology and people involved in rock mechanics evaluation. Even the best drilling fluid will not prevent the clay rocks from destabilization if the bottom hole assembly (BHA) or hydraulic drilling parameters are poorly selected and designed.

3. Clays inhibition

Inhibition of clay rocks is particularly important when drilling clay rocks characterized by high volume growth. Inhibition prevents the cuttings from disintegration and makes the entry of the smallest grains into the drilling mud much more difficult. It also facilitates the cleaning of the drilling fluid from the excess of the solid phase.

4. Cooperation between various specialists while drilling

The drilling of clay rocks beds presents many difficulties, such as:

- stuck pipe,
- well falling,
- swelling and tendency to form “natural mud”.

It is therefore necessary to pay special attention to the cooperation between drilling crew and engineers, geologists, rock mechanics specialists and drilling fluids specialists and engineers. An example of such a good cooperation is drilling the Red Pelite clay. Such cooperation is especially important when drilling through mechanically unstable shale rocks. The drilling mud is only one of the elements of the entire drilling process and will not solve all problems if the BHA is wrongly chosen, the drilling hydraulic parameters for the drilled rocks are poorly planned or the stratigraphy and lithology of the hole are omitted.

REFERENCES

[1] Manecki A., Muszyński M. (Eds): *Przewodnik do petrografii.* Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2008.

[2] Bielewicz D.: *Płyny wiertnicze.* Wydawnictwa AGH, Kraków 2009.

[3] *Tablica stratygraficzna Polski, Karpaty.* Państwowy Instytut Geologiczny, Warszawa 2008.

[4] *Tablica stratygraficzna Polski, Polska pozakarpacka.* Państwowy Instytut Geologiczny, Warszawa 2008

[5] *Zapewnienie serwisu płuczkowego podczas realizacji otworu F-1.* PGNiG S.A.

[6] Dyjaczyński K., Mamczur S.: *Vademecum geologa dozoru – materiały szkoleniowo--instruktażowe.* Wydawnictwo ZZGNiG, Zielona Góra 1988.

[7] *Zapewnienie serwisu płuczkowego podczas realizacji otworu O-3.* PGNiG S.A.

[8] Kozłowski K., Łapot W.: *Petrografia skał osadowych.* Skrypt Uniwersytetu Śląskiego, nr 440, Katowice 1989.

[9] Środoń J.: *Minerały ilaste w procesach diagenezy.* Przegląd Geologiczny, vol. 44, nr 6, 1996.

[10] Wysocki S., Wójtowicz A., Gaczoł M.: *Influence of ionic hydration's inhibitors on swelling of clays and shales.* AGH Drilling, Oil, Gas, vol. 33, no. 2, 2016, pp. 471–482.