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# Experimental Study on Tanuma Shale Stability Using Drilling Fluids with Different Additives

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**Abstract:** Shale formation is represented as one of the challenge formations during drilling wells because it is a strong potential for wellbore instability. Tanuma formation in Iraqi oil fields (North Rumila) is located at a depth from 2102 m MD – 2126 m MD. It is considered one of the most problematic formations through drilling wells in North Rumila. Most problems of Tanuma shale are sloughing, swelling, caving, cementing problem and casing landing problem caused by the interaction of drilling fluid with the formation. This paper focuses on studying the chemical and minerals properties of Tanuma shale. In addition, study the effect of drilling fluids and additive salts by using different techniques; (XRD, XRF, reflected and transmitted microscope, scanning electron microscope and EDS) Also, the study includes experiments to observe and enhance the shale stability by using two types of drilling fluids, API and polymer type, with different additives. Four types of additives (KCl, NaCl,  $\text{CaCl}_2$  and Sodium silicate) in different concentrations (0.5, 1, 5 and 10) wt % and different immersion period (1, 24 and 72 hours) were used. The results show that adding 10 wt. % of sodium silicate to API drilling fluid results in a high percentage of shale recovery (77.99%). While, the maximum shale recovery was (79.76%) in polymer drilling fluid type gained by adding 10 wt % of sodium silicate.

## 1. Introduction

Shale is a fine-grained, clastic sedimentary rock collected of mud that is a mix of flakes of clay minerals and tiny fragments of other minerals. It is characterized by parallel layering or thin laminae or bedding less than one centimeter in thickness, called fissility[1]. Shales contain clay minerals and non-clay minerals, clay minerals can be grouped as Smectite, Vermiculite and Kaolin, Illite, and chlorite and Non-Clay minerals are quartz, feldspars [2]. Shale is recognized as one of the most suspicious rock types in petroleum engineering applications, it makes up over 75% of the drilled formations. Shale behavior is critical because its transition to an unstable situation may occur rather easily and quickly. The chemical properties of shale rock were playing a substantial effect on its behavior like the toughness and strength properties. It can be affected strongly by drilling fluid type. For example, the interaction of shale with drilling fluid, or movement of drilling mud into the shale matrix, may occur within a few hours, leading to tremendous practical problems, more than 70% of the wellbore problems are related to shale instability. The swelling is the measure of the reactivity of the fluids with shale samples [3]. Immersion (fracture development) tests were used in the last few years to evaluate and understand the contact between the drilling fluids and shale formations. Immersion tests were intended to directly evaluate and observe the rock-fluid interactions and fracture development when a piece of shale samples was immersed in the drilling fluids [4]. Tanuma formation in Iraqi oil fields (North Rumila) is located at a depth from (2102 m MD – 2126 m MD). It considered as one of the most problematic formations through drilling wells in North Rumila. Most problems of



Tanuma shale formation are sloughing, swelling, caving, cementing problem and casing landing problem caused by the interaction of drilling fluid with the formation. The description of Tanuma shale and the drilling fluids additive are mentioned in (table 1) and (table 2) respectively. This paper focuses on studying the properties of Tanuma shale as well as studying the effect of chemical interaction between the shale and salts additives in drilling fluid. The problems of shale formation are improved by using additives that have the ability to react with shale and reduce the reaction between water and shale formation.

**Table 1.** Description of Tanuma shale.

Depth	Description of Tanuma formation
<b>2102-2104m</b>	Shale (50%): Medium dark grey, olive grey, slightly hard, commonly fissile and slightly calcareous in place, occasionally thinly laminated. Limestone (50%): Mudstone to Wackestone, very light grey, yellowish grey, light olive grey, soft, firm in place, fine crystalline, earthy luster, argillaceous, no visible porosity, no oil show
<b>2104-2110m</b>	Shale (70%) Limestone (30%)
<b>2110-2120m</b>	Shale (100%)
<b>2120-2126m</b>	Shale (60%) Limestone (40%)

**Table 2.** Drilling Fluid Additives in Tanuma shale.

Products	Product Description	Product Function
<b>Soda Ash</b>	Sodium carbonate ( $\text{Na}_2\text{CO}_3$ )	Precipitate calcium in the water
<b>Caustic Soda</b>	Sodium Hydroxide ( $\text{NaOH}$ )	Alkalinity Source (pH)
<b>BARAZAN D</b>	Dispersion-enhanced xanthan biopolymer	Viscosifier / Hi-Vis
<b>PAC L</b>	Polyanionic Cellulose	Filtration Controller
<b>DEXTRID LTE</b>	Modified potato starch	Filtration Controller
<b>NaCl Salt</b>	Sodium Chloride	Shale inhibitor/weighting Material
<b>KCl</b>	Potassium Chloride	Shale/Clay inhibitor
<b>EZ MUD (PHPA)</b>	Polyacrylamide/Polyacrylate (PHPA)	Shale stabilizer/Encapsulator
<b>BAROTROL-PLUS</b>	Fine-grind blended hydrocarbon powder	Shale stabilizer
<b>GEM GP or GEM CP</b>	Poly-Alkaline glycol	Shale stabilizer, lubricity
<b>BAROLUBEGOLDSEAL</b>	Blend of surfactants and lubricants	Lubricant, reduce torque and drag and sticking shale problems.
<b>Barite API</b>	Ground Barium Sulphate	Weighting agent for slug
<b><math>\text{CaCO}_3</math> Fine</b>	Calcium Carbonate	Weighting & Bridging agent

## 2. Methodology (ANALYTICAL METHODS)

### A. Samples Preparation

Samples have been taken from Basra (North Rumila) at 2120 m depth. Two methods were used to clean the samples from hydrocarbons and drilling additives. First, soxhlet method to remove hydrocarbons from shale by using toluene, methanol, and benzene then heated in soxhlet device for three hours. The second method was using wet sieving to remove additive salts.

### B. Shale test

Forty-five samples of Tanuma shale have been studied by using different techniques, to investigate petrography and the effect of drilling fluid additives after and before the clean sample. Forty-five thin sections and polish thin sections were prepared to be examined by transmitted and reflected light microscope type BX51M /Olympus. Ten samples were examined using a scanning electron microscope and Energy dispersive X-ray spectroscopy (EDS). Mineral and chemical compositions of shale were examined by X-Ray Diffraction and XRF.

## 3. Experimental Procedure

In this work, 128 shale samples were immersed in two types of drilling fluids with different additives. Four types of salts (KCl, NaCl, CaCl<sub>2</sub> and Sodium silicate) with different concentration (0.5, 1, 5 and 10) wt % and different immersion period (1, 24 and 72) hours were used. Shale samples are prepared to soak with different drilling fluids [5]. The samples were studied by the microscope before and after immersion to determine the effect of the drilling fluids on the stability of the shale.

### Drilling fluid Preparation

Two types of drilling fluids were used in this paper WBM (API Manual) and PM. The drilling fluid was prepared then add additive with mixing for 2 minutes. Water-based mud was prepared by mixing water with the bentonite by using Hamilton Beach mixer for 20 min then the suspension is aged in a sealed container for 24 hours to ensure good hydration of bentonite after that the salts with concentrations of 0.5, 1, 5 and 10 wt % were added to WBM then mixed for 10 min. and Polymer based mud was prepared by mixing water with the bentonite by using Hamilton Beach Mixer for 20 min then the suspension is aged in a sealed container for 24 hours to ensure good hydration of bentonite then KCl, KOH, PAC Polymer, XC polymer were added. Each material was let to mix with the suspension for 2 minutes to ensure dispersion of particles into the drilling fluid matrix; finally, the whole mixture was mixed for 10 minutes after that the salts with concentrations of 0.5, 1, 5 and 10 wt % were added to PM then mixing for 10 min.

## 4. Results and Discussion

Various methods such as X-Ray Diffraction analysis, Reflected microscope and Scanning electron microscope and EDS used to detect the clay minerals in shale. Mineralogy analysis detected the quantities of compounds present in the shale. Clay and non-clay minerals were found in the shale samples. The clay minerals found in the shale indicates the degree of its hydration.

### The mineralogy of Tanuma shale

#### 1. Analysis of XRD and XRF

The mineralogical compositions of the samples were analyzed using X-ray diffraction. This is the method of analysis provides the mineralogy of shale; clay minerals composed mainly of kaolin and little Illite also found non-clay minerals quartz and calcite as shown in (figure 1). The chemical composition was measured before and after cleaning the samples, (table 3). The concentration of CaO,

$\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$  are changed after cleaning sample so those were referred to additive salts. The  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{MgO}$  referred to the main composition of shale.

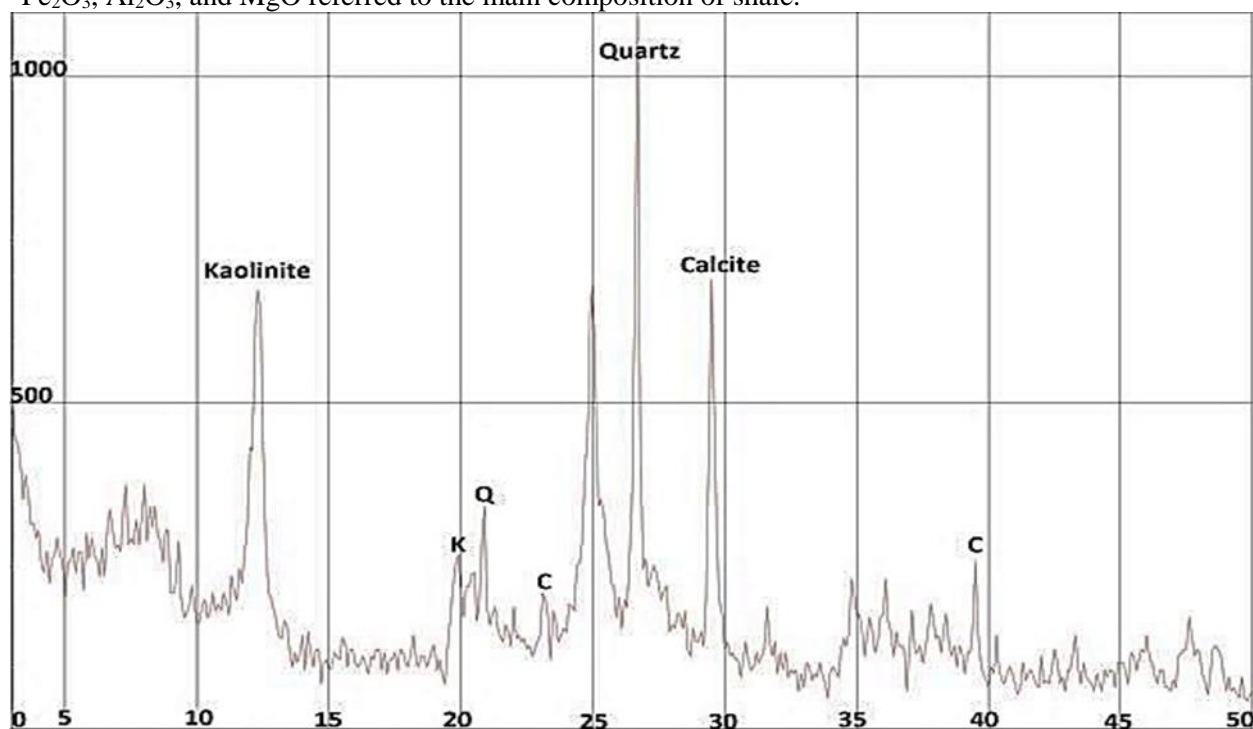


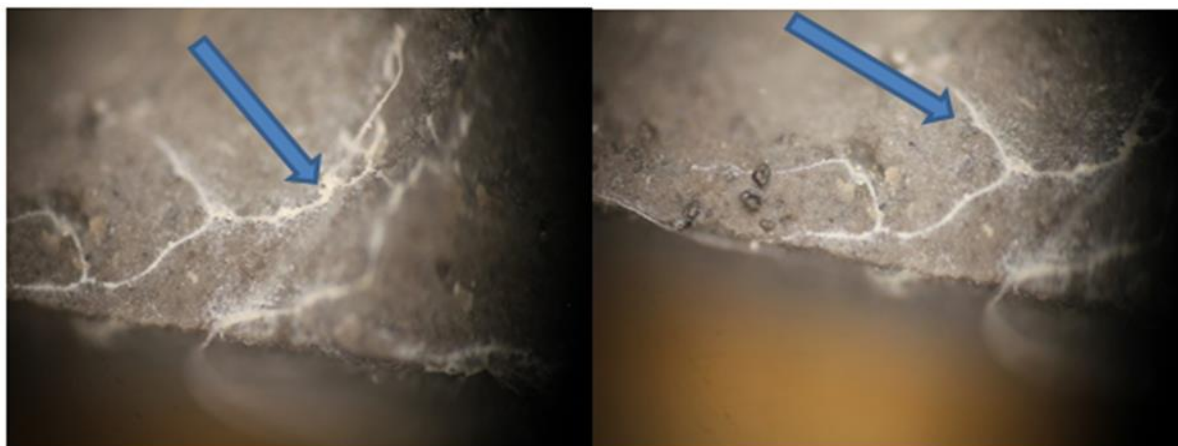
Figure 1. X-Ray Diffraction.

Table 3. X-Ray fluorescence.

Specimen	cleaning	$\text{SiO}_2$ %	$\text{Fe}_2\text{O}_3$ %	$\text{Al}_2\text{O}_3$ %	$\text{CaO}$ %	$\text{MgO}$ %	$\text{So}_3$ %	$\text{Na}_2\text{O}$ %	$\text{K}_2\text{O}$ %	Lol %
1	Before	40.67	10.33	16.85	10.2	0.8	0.510	0.91	3.42	14.64
2	After	47.96	10.22	17.9	5.93	0.86	0.440	0.25	2.98	11.79

## 2. Analysis of Reflected, transmitted microscope, SEM and EDS

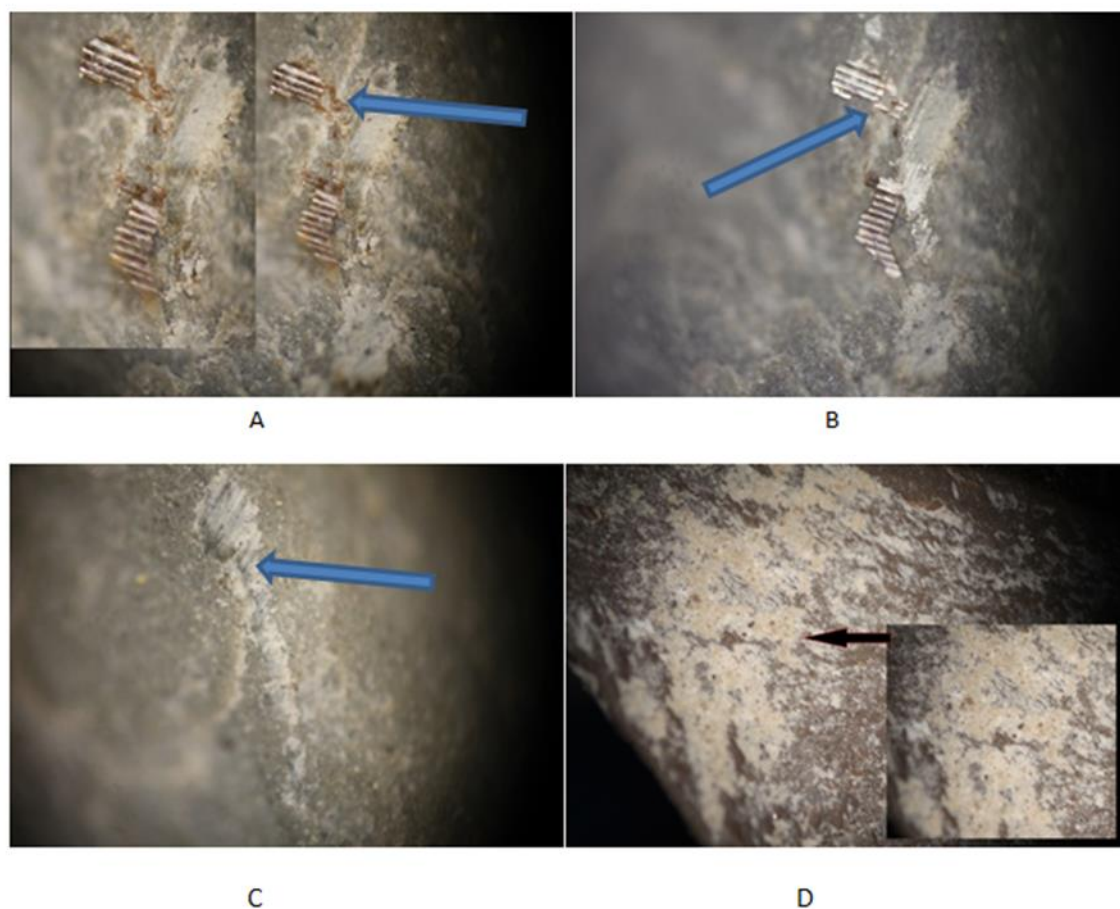
Before cleaning the shale, samples was found a lot of salt covered the surface and accumulation through caves, micro-fracture, and between sheets. The maximum accumulation at the edge and between sheets is illustrated in (Figure 2). The weakness of kaolin minerals is represented on the edge of the sheets so the cation exchange of ions occurs on the edge of the sheet [6].



**Figure 2.** Distribution Salts in the edge of the sheet.

Salts accumulation was at the edge due to sorption on shale surface, as well as cations exchange between salt in drilling fluids and shale as shown in (Figure 3 D).

Gypsum veinlet scattered on the surface of samples each veinlet twisted with another veinlet like a network [7] as illustrated in (figure 4). After cleaning shale samples, could recognize a small grains of magnetite distributed in shale and also, Biotite with red-brown color (figure 3 A), (figure 3 B) and (figure 7). Some of origin Biotite alteration due to an accumulation of salts on the surface of minerals (figures 3 C).



**Figure 3.** A: Mica, B: Mica by (Xn), C: Alteration Mica, D: coated salts.



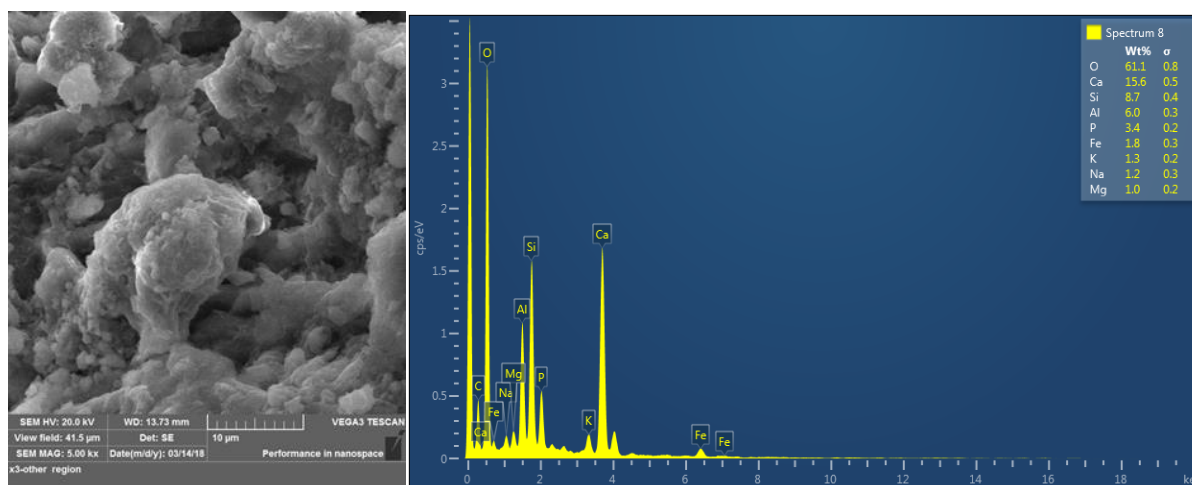


**Figure 4.** Distribution of veins.

Salts in drilling fluids had been affected on the parts of Mica [8]. The Scanning electron microscope and EDS were used to detect the major elements in shale and chemical element that distribution on the surface due to sorption and cation exchange. (Figure 5) shows a high concentration of  $\text{Si}^{+4}$  and  $\text{Al}^{+3}$ .

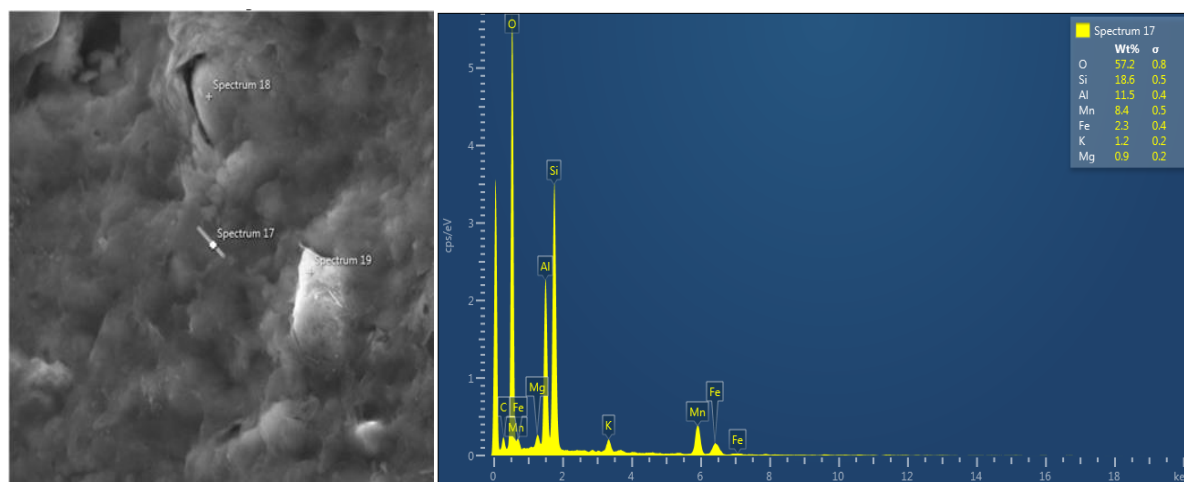
Clay minerals are hydrous aluminum phyllosilicates. The drilling fluids were used for Tanuma shale led to a high concentration of  $\text{Ca}^{+2}$  and  $\text{K}^{+}$ . As we know the attractive of kaolin with water is little but the cation concentric on the edge of the sheets often cation exchanges take place in the weak edge of the sheet.

(Figure 3 D) shows, samples before cleaning there are a lot of salts distributed on samples, as salt grains aggregated between sheets and on edge of the sheet, and covering clay grains completely.



**Figure 5.** SEM and EDS.

The grains of clay were covered by salts because of the reaction between the salts and clay minerals. Clay grains coated with salts and salt aggregate caused sheets separation and fractures. These causes reduce the stability of the shale. (Figure 6) shows the shale samples after cleaning. Note decreased the concentration of  $\text{Ca}^{+2}$ ,  $\text{Na}^{+}$ , and  $\text{K}^{+}$ .



**Figure 6.** SEM and EDS after cleaning.



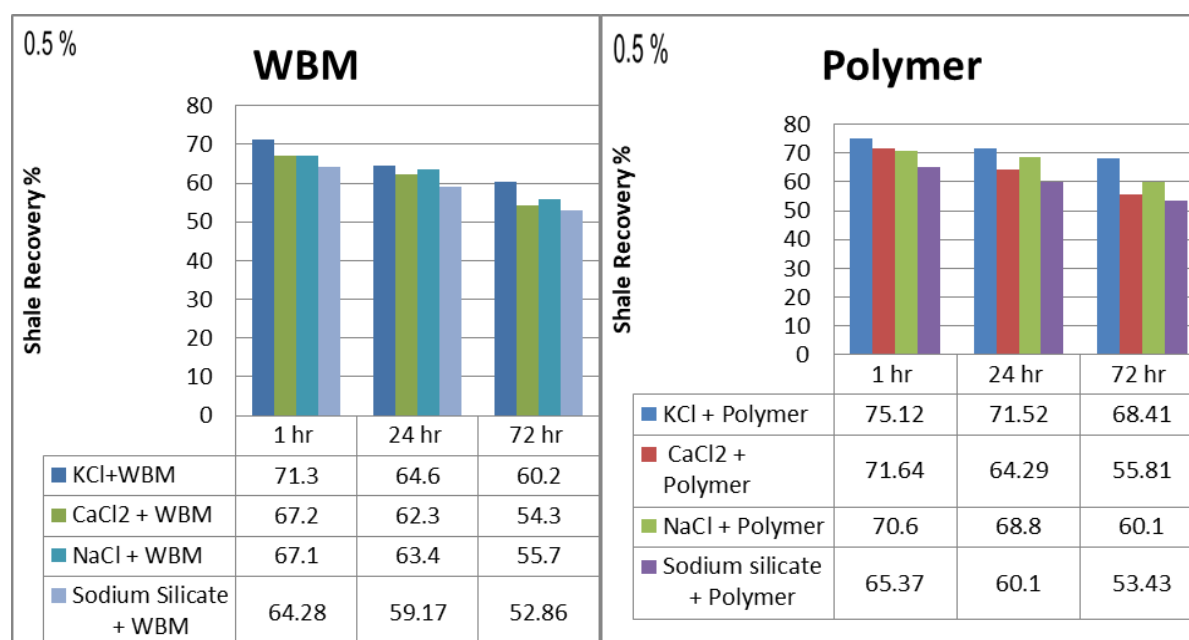
**Figure 7.** Shale samples after cleaning.

## Effect of drilling fluids on the Tanuma shale

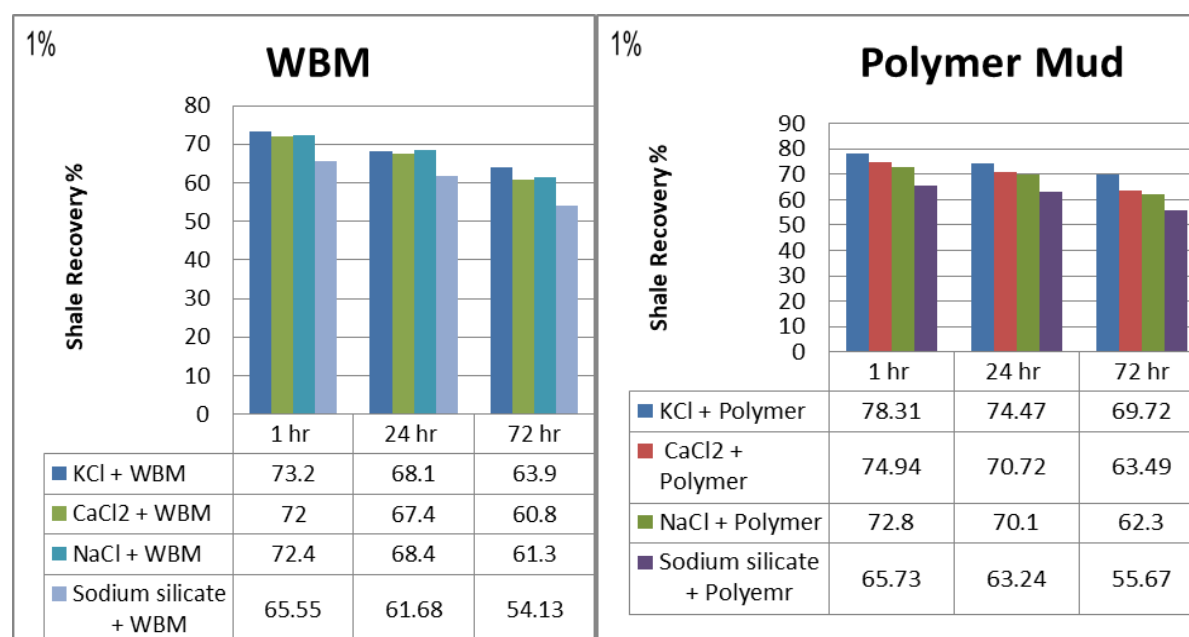
### 1. Immersion test

The recovery percentage values were calculated after immersion the samples in drilling fluid. These values were varied depending on the activity between the additive and shale samples. (Figure 8) shows the effect of 0.5% addition of different salt with water-based mud on the shale samples it can be seen that KCl salt gives the best recovery after 1 hour with a percentage of 70.1 %. After 72 hours the KCl recovery decreases to 60.2. In this point, the water got enough time to interact with shale samples and the KCl concentration is not enough to reduce the effect of water on shale samples. Increasing the concentration to (1, 5 and 10) wt % of KCl salt causes higher percentage recovery after one hour (73.2, 78.4, and 80.7) wt % in comparison with other salts. Using the same additives at the same concentration in the polymer mud, the recovery percentage increased as shown in (Figure 8). At 1 wt % concentration, the KCl salt gives the high recovery percentage in the water-based mud and polymer mud as shown in (figure 9).



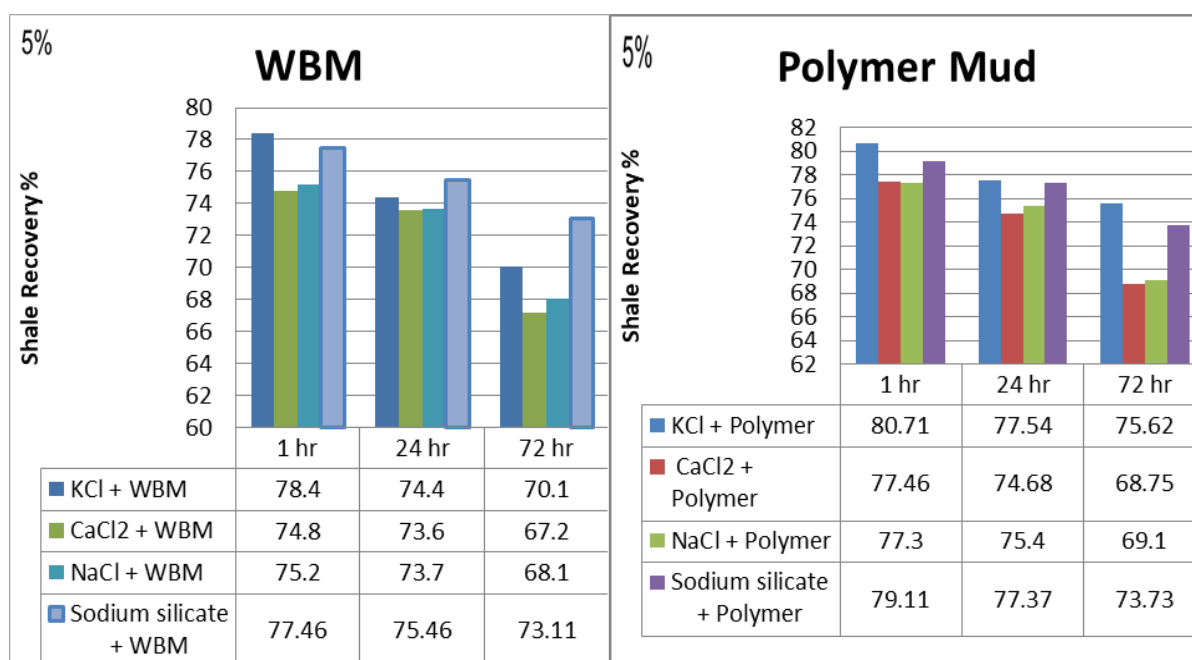


**Figure 8.** Recovery for WBM and Polymer Mud with concentration 0.5% Wt.

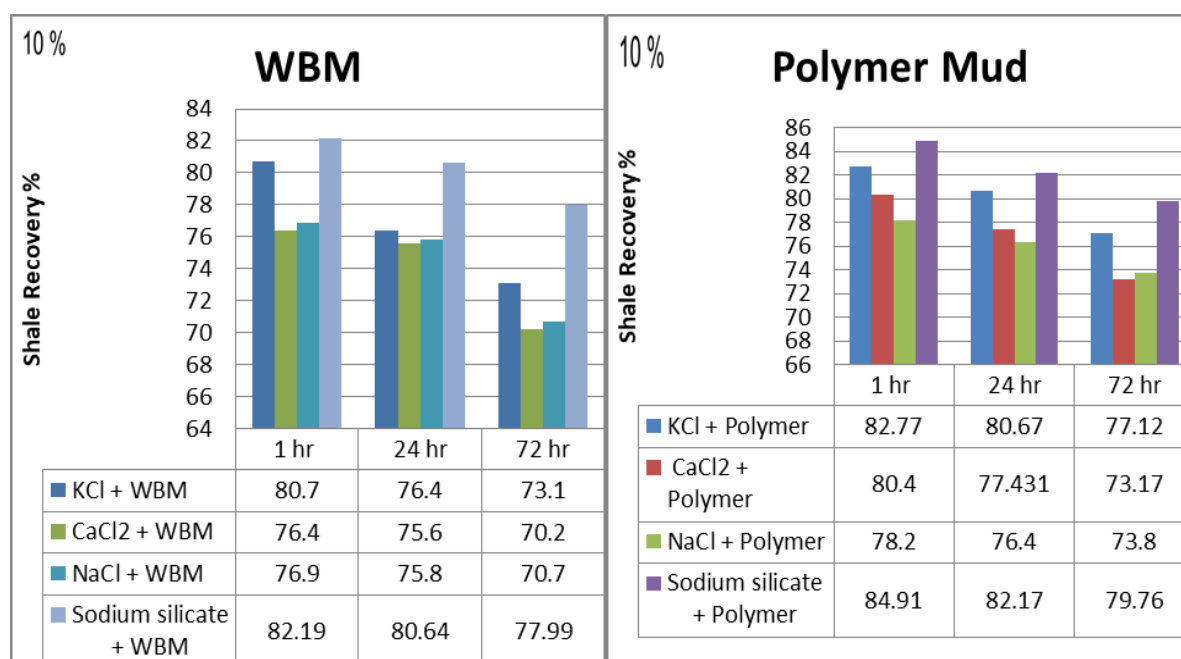


**Figure 9.** Recovery for WBM and Polymer Mud with concentration 1% Wt.

The effect of sodium silicate noticed at the concentration 5-10 wt %. The recovery percentage is high for sodium silicate at 5 and 10 wt % as shown in (figures 10) and (figure 11). Increasing the concentration of the salts will give a good recovery as noted in the tests.



**Figure 10.** Recovery for WBM and Polymer Mud with concentration 5% Wt.



**Figure 11.** Recovery for WBM and Polymer Mud with concentration 10% Wt.

KCl is considered as one of the best inhibitors for shale problems as noticed in results, the effect of KCl was very clear to increase the recovery percentage of shale samples.  $K^+$  has the ability to adsorb on the surface of shale and react with the ions on the surface of shale sheets. Due to replace of  $Si^{+4}$  with  $Al^{+3}$  in octahedral sheets and  $Al^{+3}$  changed with  $Mg^{+2}$  in tetrahedral sheets this will increase the negative charge and causes the attractive of the positive charge on the surface of shale. Therefore, the positive ions like  $K^+$ ,  $Ca^{+2}$ ,  $Na^+$ , and  $Si^{+4}$  were adsorbed on the surface of sheets. NaCl has a higher preliminary viscosity relative to KCl in the mud and it has lower water activity which gives rise to higher osmotic pressures. NaCl is represented a better equipped for reducing filtrate invasion for

drilling fluids to the shale [1]. The microscope shows the effect of samples immersion with KCl additives and other salts. (Figure 12) shows an accumulation of salts on the surface and edge of shale that's happened due to adsorb of the sheet of shale for  $K^+$ ,  $Na^+$  and  $Ca^{+2}$  ions are accumulated and the crystals of salts consisted of the samples and coated it as shown in (figure 13).



**Figure 12.** KCl accumulations on the surface.



**Figure 13.** Crystals of the salts on the surface of the shale.

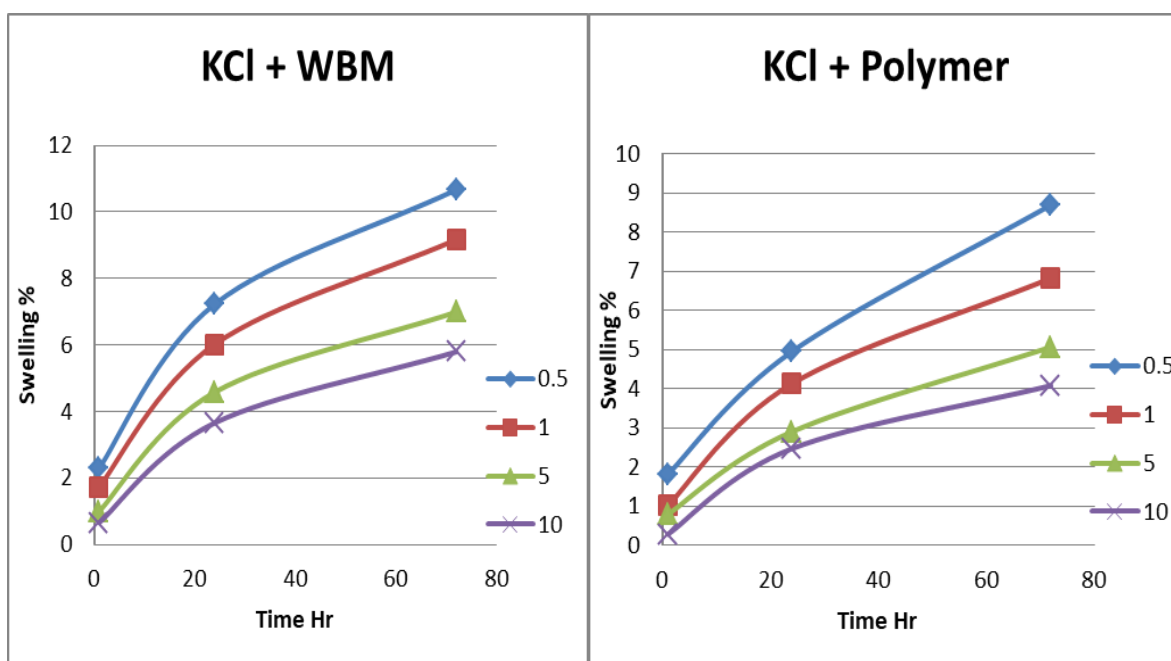
Silicate additive was used with drilling fluids. Soluble sodium silicate has the ability to invade the shale and react with available ions in the shale to consist insoluble precipitation. (Figure 14) shows the sodium silicate accumulation on the shale samples and sodium silicate invaded into the fracture and built a bridge between two sides then covered the shales to prevent any interaction with other fluids.



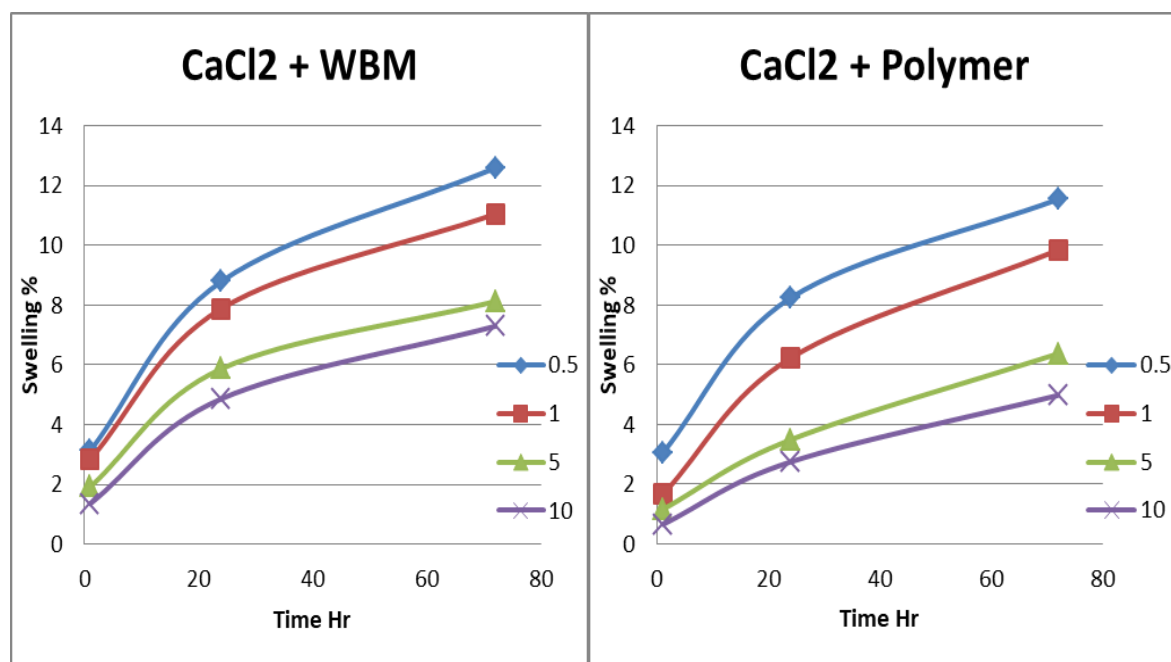
**Figure 14.** The Bridge of sodium silicate between the fractures.

## 2. Swelling Test

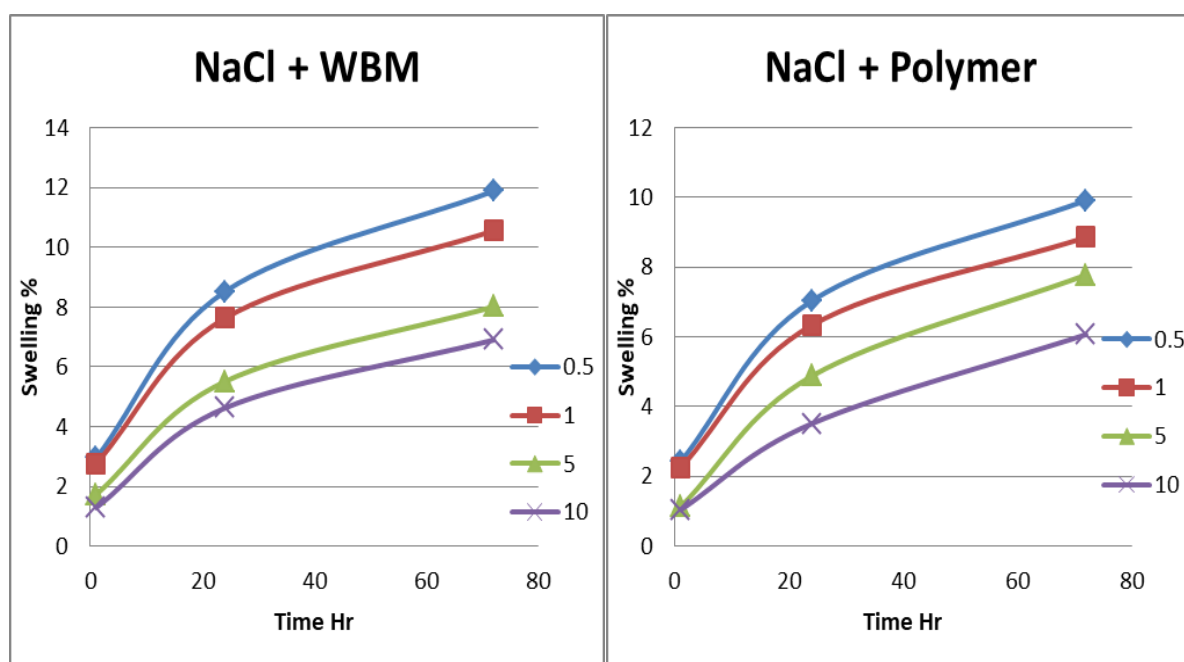
The samples were placed in the different drilling fluids to calculate the swelling percentage for Tanuma shale. As shown in (Figure 15), (figure 16), (figure 17) and (figure 18) the swelling affected by the salts concentration. Its percentage decreased by increasing the salts concentration. Sodium silicate with concentration 0.5 wt % gives a high swelling percentage while at 10 wt % concentration the swelling reduced to 3 percentages as shown in (figure 18).



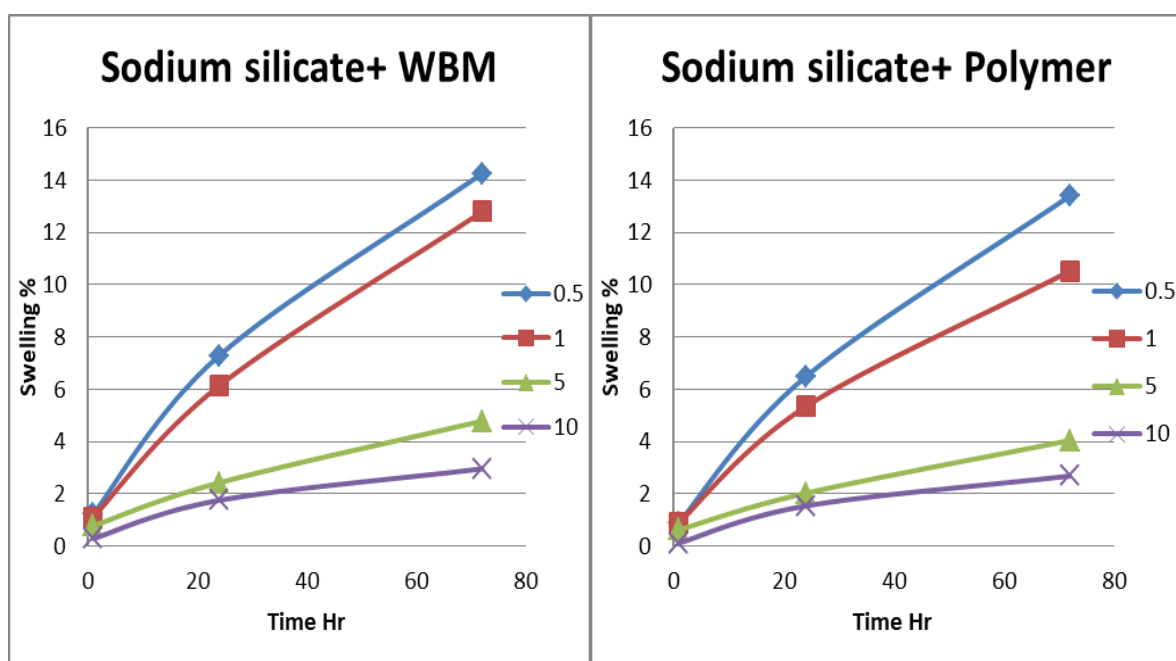
**Figure 15.** Swelling for WBM and Polymer Mud with KCl Salt.



**Figure 16.** Swelling for WBM and Polymer Mud with CaCl<sub>2</sub> Salt.



**Figure 17.** Swelling for WBM and Polymer Mud with NaCl Salt.



**Figure 18.** Swelling for WBM and Polymer Mud with Sodium silicate Salt.

As noticed in the swelling test of the Tanuma shale the swelling percentage is very low compared to other shale formations because of the swelling reactivity of the kaolin minerals very little. The quantity of swelling for Kaolin is very little compared with another clay mineral like Smectite. KCl can decrease the swelling in the shale formations. The results show the increasing of KCl concentration in the drilling fluids that lead to a decrease in the values of swelling as shown in (figure 15), indicating that KCl plays a role in inhibitor shale expansion. The results show the  $K^+$  is more effective comparing with  $Ca^{+2}$  and  $Na^+$  in decreasing the swelling of shale samples. Sodium silicate is normally preferred to use for formations those mainly containing swelling clay minerals such as shale.



It has the ability to attract the water and makes colloidal molecules then creating a large aggregation for suspending negative charge particles in the water. The swelling is reduced when using 5-10 wt % for Sodium silicate due to seal the fracture of samples and prevents further interaction with water as illustrated in (figure 14).

## 5. Conclusion

Tanuma shale composes mainly kaolin with a little amount of Illite. The concentrations of salts were accumulated on the surface of the shale sheet due to adsorb of salts on the surface of shale. The salts had differently affected on the shale samples depending on the ability of salts to adsorb on the surface of sheets. The appearance of veins on the shale surface of samples and twisted like a network represents gypsum veins. The microscope showed the distribution of salts on the surface of samples especially on the edge of shale that appeared the distribution of cations on the edge of kaolin mineral. Increasing the concentration of the salts will give a good recovery. The swelling was affected by the salts concentration, its percentage decreased by increasing the salts concentration. The high percentage recovery was found in the sodium silicate and KCL additives at concentration 5-10 % with polymer mud. One of the reasons causes of shale instability is related to the transportation of water/ions into or out of shale.

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