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# COMPRESSION BEHAVIOUR OF HIGHLY EXPANSIVE CLAYS STABILISED WITH A GREEN STABILISER OF MAGNESIUM CHLORIDE

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**ABSTRACT:** The presence of expansive clays underlying infrastructures has been responsible for damages to the structures in many cases all over the world when the moisture content of these problematic soils changes. One of the effective methods to alleviate the swell potential of expansive clays is to stabilize them with an additive such as lime, cement, resins, chemicals and so on. In this study, the use of magnesium chloride ($MgCl_2$) as a green stabilizer to improve the geotechnical properties of the treated clays has been investigated by conducting several laboratory tests. Currently, $MgCl_2$ is mainly used as an anti-icing materials in pavement industry; however, it has been recently received more attention as a stabilizer for clayey soils. Firstly, the effect of $MgCl_2$ on the consistency limits of the treated clayey soils was studied in this study. Next, the swell pressure and free swell strain of the treated samples were measured and the results compared with one of the untreated samples. Overall, the results state that even a small dose of $MgCl_2$ can be used as a stabilizer for expansive clays to improve the geotechnical properties considerably and to mitigate their swell potential effectively.

*Keywords: Clay, Laboratory test, Swell pressure, Magnesium chloride, Expansive, Stabilisation*

## 1. INTRODUCTION

Expansive clayey soils with high potential of swelling are mostly found in arid and semi-arid regions all over the world. These soils are highly susceptible to the variation of their water content and cause huge problems to pavements, embankments, drinking water networks, irrigation open canals, railways, mining structures (e.g. overland conveyors), and light residential buildings for excessive settlement and expansion. Globally, billions of dollars have been spent on either financial losses or treatment work of these problematic soils every year [1-3]. Generally speaking, the cost of damage to the structures due to shrinkage and swelling of expansive clays is even greater than the cumulative cost of damage caused by all natural disasters such as hurricanes, volcanic eruptions, earthquakes, floods, and tornadoes [4, 5].

The damage to structures can be eliminated or significantly mitigated by stabilization of expansive clays prior to construction of the structures on problematic soils. The stabilizer agents can be used to improve the engineering properties and to reduce the swelling and shrinkage potential of expansive clays. Based on the usage frequency of the stabilizers and the popularity of them amongst engineers, they may be categorized into two major groups: Traditional and non-traditional stabilizers.

Traditional stabilizers comprising cement, hydrated lime, zeolite, industrial waste, fly ash and gypsum are frequently used in industrial projects and extensive case studies as well as laboratory tests have been performed on the ability of these additives to improve the compressibility of soft clayey soils and alleviate the swelling pressures [6-13].

Lime as the most popular type of stabilizers is used generally as one of the forms of hydrated dolomitic lime [$Ca(OH)_2$. $Mg(OH)_2$], dolomitic quicklime [CaO.MgO], hydrated lime ($Ca(OH)_2$ and quick lime (CaO). Among aforementioned types of lime, hydrated lime is preferably used in the construction industry because there is no need for extra water for hydration process. Moreover, it can produce a considerable amount of free calcium which is essential for the stabilization of expansive clays.

Another traditional stabilizer is cement which is mostly used as Portland cement. Similar to lime, calcium oxide is produced in hydration process of cement which is the basis of the stabilization of the clayey soils. Adding cement and lime as the stabilizer agents to the expansive clays with an adequate amount of water produces $Ca^{2+}$ ions. Free calcium ions replace monovalent ions which reduce the interlayer electrochemical forces and increase the particle packing. This cation exchange improves the soil properties of the treated clay such as increasing the soil density, workability and shear strength and reducing the soil plasticity, dispersive properties and expansion potential [14, 15].

It is well established that pozzolanic reaction of clayey soil and cement/lime improves the engineering properties of the treated clays and alleviate the sensitivity of the expansive clays. Nevertheless, the usage of these traditional stabilizers (i.e. lime and Portland cement) is decreasing recently due to the increase of awareness of environmental issues and waste disposal difficulties as well as an increase in cost and treatment procedure.

On the other hand, there are a number of non-traditional chemical stabilizers which are increasingly being investigated for their effectiveness in treating expansive clays for the past two decades [15-18]. Chemical stabilizers as an alternative to the traditional calcium-based stabilizers are comprised of combinations of liquid polymers, resins, ions, silicates, acids, and lignin derivatives [16, 17]. These chemical stabilizers are normally concentrated liquids diluted with water or powder dissolved in water and then sprayed on the problematic clayey soils (e.g. expansive clays) prior to compaction. Polymers are also very effective to mitigate the swelling potential by developing bonds between clay minerals and polymers. Non-traditional stabilizers not only reduce the cost of transportation but also are easy to be employed as only small amounts of chemicals are required and the process of applying them to the problematic soils is practical. Chemical stabilizers are also highly effective for high sulfate soils in comparison to calcium-based stabilizers (i.e. cement and calcium) as some traditional stabilizers have no major effect on soils with a high amount of sulfate and even distress excessive heave called sulfate-induced heave [19, 20].

Bischofite with the chemical name of “Magnesium Chloride Hexahydrate” ($MgCl_2.6H_20$) is one of the non-traditional stabilizers which has recently been the center of focus of researchers. Bischofite is normally used for dust control and also for decreasing coarse particle scattering and preventing ice formation in road and pavement industry [21]. In comparison to calcium-based stabilizers such as cement which produces a large amount of green-house gas, Magnesium chloride is a sea salt which has been recognized as a green stabilizer worldwide as it has no harm to plants and animals as well as no corrosion to asphalt or concrete pavements and vehicles [22]. In Europe, the ordinary salt (NaCl) is replaced by $MgCl_2$ almost completely as the regular salt is ineffective at a very low temperature and cause a lot of damages to trees and asphalt every year. On the other hand, magnesium chloride has more prolong effectiveness as an ice melter with little damage to pavements and vegetation. It caused magnesium chloride as a popular environmentally friendly ice melter in countries experiencing cold winters.

As the use of magnesium chloride is becoming more common especially in pavement industry, its potential to mitigate the swelling potential of expansive soils is getting more attention amongst researchers. There is quite limited research on the performance of treated clays with $MgCl_2$ in the literature [16, 18]. Nevertheless, more research is still required to investigate the effect of $MgCl_2$ on the swelling pressure of expansive clays with different mineralogies.

To the best of authors’ knowledge, there is also a lack of study on the free swell of the treated clays with $MgCl_2$. This investigation is important to understand the behavior of the stabilized clay when subjected to excavation loadings in future. In this paper, the effect of magnesium chloride on the mitigation of the expansion potential of a highly plastic clayey soil from Australia is investigated.

Accordingly, the following questions are addressed in this study:

a) What is the effect of magnesium chloride on the plasticity of the high plastic clayey soils?
b) What is the effectiveness of various percentage of magnesium chloride in mitigating the swell pressure of expansive clays?
c) What is the effect of magnesium chloride on the free swell of the treated clayey soils in comparison with the untreated soil?

## 2. MATERIALS AND TEST PROGRAM

### 2.1. Materials

The expansive clayey samples used in this research were collected from the southern part of Perth, Western Australia (Fig.1). Due to the color of the studied soil, it is referred herein as the ‘black clay’. To characterize the soil sample, soil classification tests including soil classification (ASTM D2487), organic content, moisture content (ASTM D2216), Atterberg limits (i.e. liquid limit, plastic limit and plasticity index (ASTM D4318) were performed [23]. According to the Unified Soil Classification System, the black clay can be classified as a high plasticity clay (CH). The liquid limit ($w_L$) and plasticity limit ($w_P$) of the black clay are measured to be 82% and 35% respectively. The in-situ water content of the samples were measured immediately after collection and was 40% [24]. The laboratory tests also state that the shear strength of the black clay is highly dependent on the initial water content [25]. The particle size distribution (PSD) curves of the studied soil are illustrated in Fig. 2; the PSD tests were performed on three samples (sample no.1-3). Based on the particle density test performed on the studied sample using a hydro-pycnometer, the specific gravity is measured to be 2.6 (ASTM D854). As shown, 84% of the soil consisted of fine materials of which a hefty percentage (68%) is clay. Based on X-ray diffraction (XRD) test results, smectite is the dominant clay mineral of the black clay [3].

There are several methods to indicate the swell potential of an expansive soil based on only the physical properties. One of the simplest methods proposed by Building Research Establishment (BRE) is to use plasticity index [26]. According to this method, the potential for volume change of a soil with a plasticity index greater than 35% is classified as very high, between 22% and 48% as high, between 12% and 32% as medium, and less than 18% as low. For the studied soil, the plasticity index of 47% makes the potential for volume change of the black clay be categorized as 'very high'. Another method for assessing the swell potential is to employ the soil activity chart proposed by Van Der Merwe [27]. In this method, the expansiveness of a soil is analyzed by both the plasticity index and the clay content of the soil. As can be seen in Fig. 3, the black clay is placed into the high expansion category based on the soil classification and the results of consistency tests.

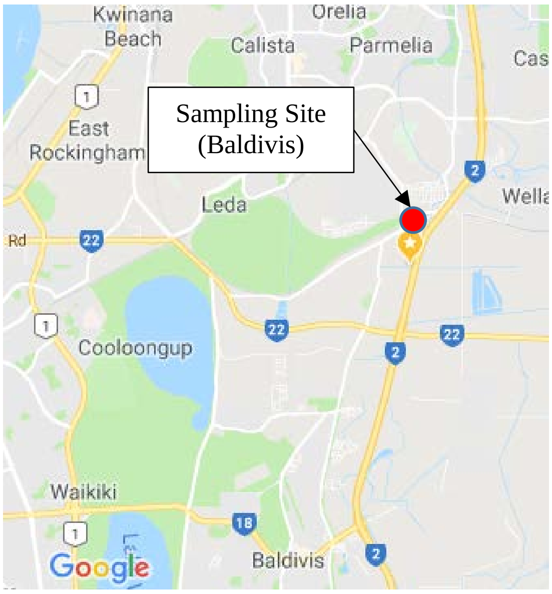


Fig. 1 Sampling site, Baldivis Western Australia (Google maps 2018) [28]

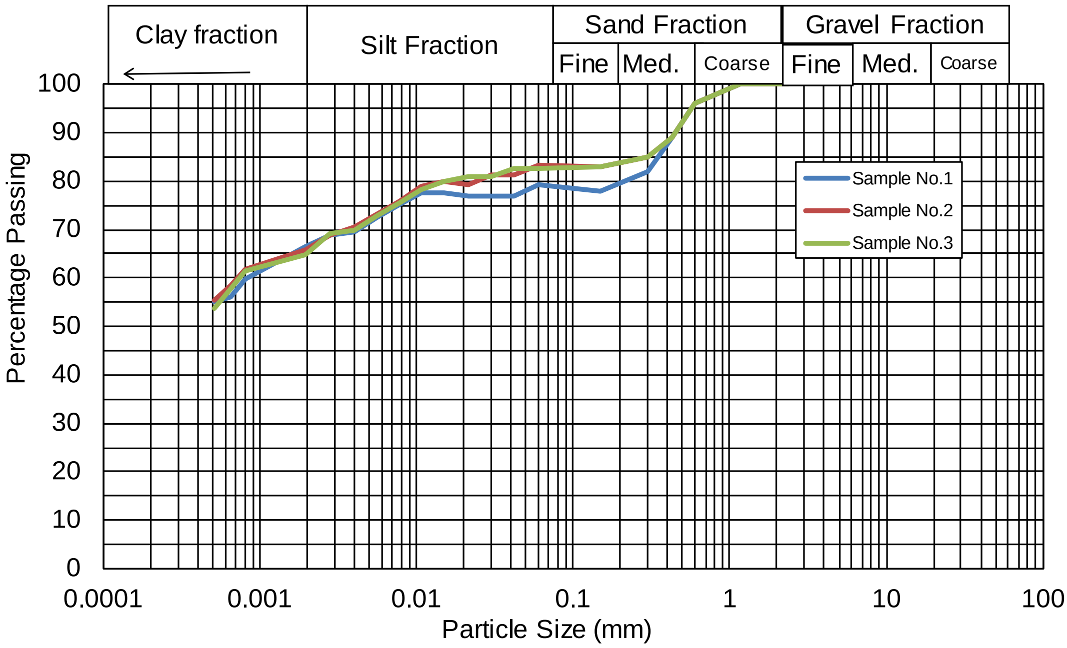


Fig. 2 Particle size distribution curves of the black clay

Bischofite (Magnesium chloride, $MgCl_2$) has been used effectively as a de-icing material in winter for road maintenance in many countries all over the world such as the U.S., Canada, Russia, Netherlands, Belgium, France, Scandinavia, the U.K., and Germany. $MgCl_2$ can be found in the forms of flake, powder, and liquid.

The salt used in this study was in the form of flake with white color and a chemical formula of ($MgCl_2.6H_2O$), Magnesium Chloride Hexahydrate, and a purity of 98 – 100%.

## 2.2. Sample Preparation

Samples were prepared in accordance with the sample preparation procedure proposed for remolded samples [29]. Initially, the collected samples were oven-dried at 105°C ± 5 until the constant weight achieved. The dried samples were then ground and sieved using a 2 mm nominal opening size to obtain a uniform soil powder before using them in the laboratory tests. Different percentages of $MgCl_2$ (2, 4, 6, 8, 10, and 12%) were added to distilled water to make a $MgCl_2$ solution. The quantity of water was measured for all samples to simulate the in-situ water content. Then samples were kneaded manually until a homogeneous mixture formed. A measured weight of the wet clay relating to the in-situ soil unit weight (1.67 g/cm$^3$) was then placed into the oedometer ring and compacted to reach the in-situ density. The specimen was fully covered with multiple cling foils and cured for 24 hours in a temperature-controlled room (22°C ± 2) to reach a uniform moisture distribution prior to conducting the laboratory tests.

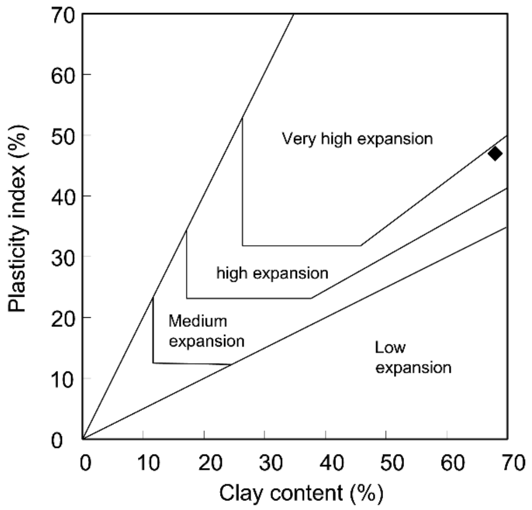


Fig. 3 Activity chart for expansive clays (redrawn from [5])

### 2.3. Test Procedure

An automotive one-dimensional consolidation apparatus was used for measuring the swelling pressure and free expansion of the treated and the untreated clays. The swell tests were carried out on 64 mm x 25.4 mm (diameter x height) specimens with two porous stones and filter papers on top and bottom of the specimens. To reduce the friction between the specimen and the consolidation ring, a thin layer of silicone grease was used. Zero-deformation method and free swell tests were used to investigate the effect of stabilization agent on the compressibility and the swell pressure of the studied expansive clays [1].

A small amount of seating pressure, 3 kPa, was applied on the specimen in zero-deformation test prior to filling the cell with water. As swelling starts, consolidation pressure is increased continuously to prevent the specimen from any expansion. The maximum pressure applied to the specimen to avoid any swelling (zero deformation), is called the swell pressure. This procedure was undertaken for all various percentage of $MgCl_2$ for the treated samples and the untreated one (zero percent of magnesium chloride).

In free swell tests, a specimen was allowed to swell completely under no seating pressure. The vertical displacement was measured by LVDT.

## 3. RESULTS AND DISCUSSION

### 3.1. Atterberg Limits

Index tests including liquid limit and plastic limit were conducted on the untreated clayey sample (zero percent of $MgCl_2$) and the treated samples with various percentage of magnesium chloride ( 2 to 12%) based on ASTM D4318. The results of consistency limits are presented in Fig. 4. As seen, the index parameters are decreasing with the increase of the stabilizer dose. Moreover, the index parameters virtually flatten when the stabilizer dose is greater than 8%. The results state that the use of $MgCl_2$ as the stabilizer is significantly effective for reducing both the liquid limit and the plastic limit; however, the liquid limit decreases in a great extent in comparison with the plastic limit. The reason for the decrease of index parameters can be explained by a reduction in the thickness of Defuse Double Layer (DDL) because of the influence of $MgCl_2$ on the cation exchange.

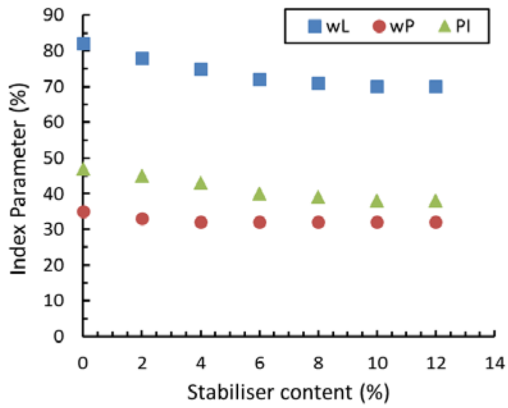


Figure 4. Variation of the index parameters with the stabilizer content

### 3.2. Swell Pressure

Based on the activity chart, the studied clay is classified as a soil with very high potential for expansion. Likewise, according to another classification, the clayey soil with the plasticity index greater than 35% can also be considered as a soil with very high potential for expansion [30]. The results for measuring the swell pressure with the zero-deformation technique are plotted in Fig. 5. The results are replotted on a semi-logarithmic plane in Fig. 6. As seen, the curves can be divided into three distinct stages of initial swelling, primary swelling, and secondary swelling. The swell pressure increases gradually in the initial phase; the swell pressure then rises considerably with elapsed test time after this stage. Moreover, the swell pressure reaches nearly the final value at the primary swell stage. As seen in Fig. 6, the primary phase which is responsible for the main portion of the value of swell pressure, begins after approximately 40 – 60 minutes of the start of inundation. Moreover, after about 16 – 24 hours, 90 per cent of the swell pressure occurs in all of the stabilizer contents. Results depict that the swell pressure of the untreated sample is 83 kPa; however, the swell pressure of the treated samples reduces considerably with the use of the stabilizer even with a low dose of $MgCl_2$ (i.e. 2%). In fact, the swell pressure plunges to 16 kPa, one-fifth of the initial value, with 8% of $MgCl_2$. The swell pressure remains almost constant with the increase of stabilizer content from 8% to 12% from 16 kPa to 14.2 kPa.

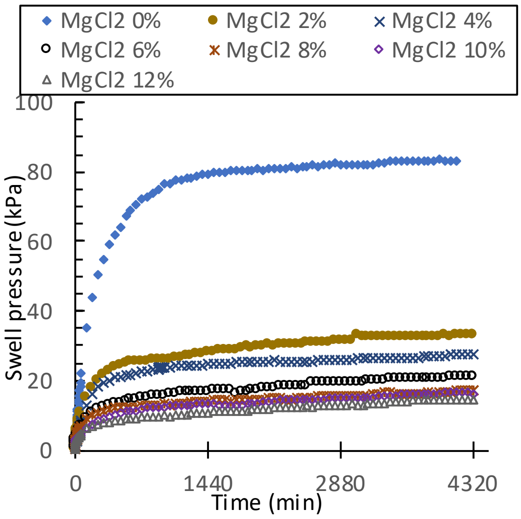


Fig. 5 Variation of the swell pressure against test time for various stabilizer content

### 3.3. Free Swell

The swell displacements against test time of the treated and the untreated samples were measured directly to determine the free swell strain. A soil specimen of 25.4 mm height and 64 mm diameter was placed between two porous stones and filter papers were used in the free swell tests. Then, the sample soaked to swell freely; no seating stress was applied during the free swell tests. Vertical displacement was measured with test time and the swell strain was calculated correspondingly. Fig. 7 shows the swell strain vs elapsed test time on a semi-logarithmic scale. Similarly to the results of zero-deformation swell, all free swell curves can be divided into three distinctive stages. A schematic of the free swell curve is presented in Fig. 8 to define these stages. At the initial swelling stage, the vertical displacement increases gradually with time for the first 40 – 60 min. Then, it increases sharply and reaches approximately 90% of the total swell strain in the second stage which referred to as the primary swelling stage. Finally, the vertical displacement levels with time when the elapsed time is greater than 4 days. Recording the vertical displacement continued until no further displacement observed. As the main clay mineral of the studied soil is smectite [3], it is expected that the swelling displacement continues in the secondary stage; the secondary swell strain is approximately 5 – 10% of the total swell for the studied clay. Overall, the secondary swell strain decreases when the $MgCl_2$ content increases.

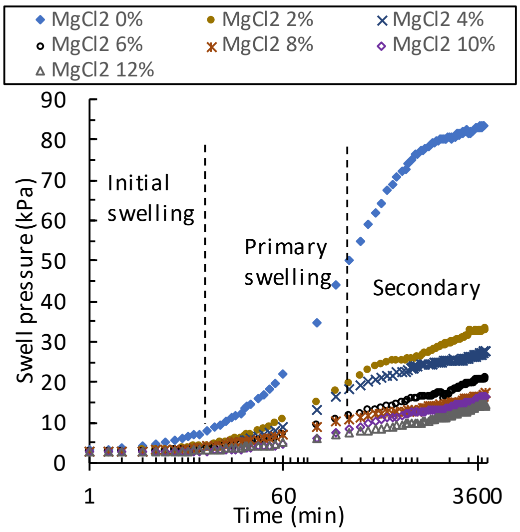


Fig. 6 Variation of the swell pressure against test time for various stabilizer content in a semi-logarithmic plane

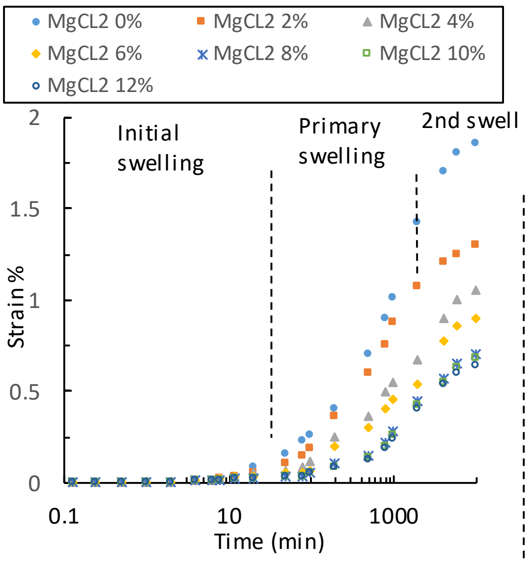


Fig. 7 Variation of the swell strain against time for various stabilizer contents

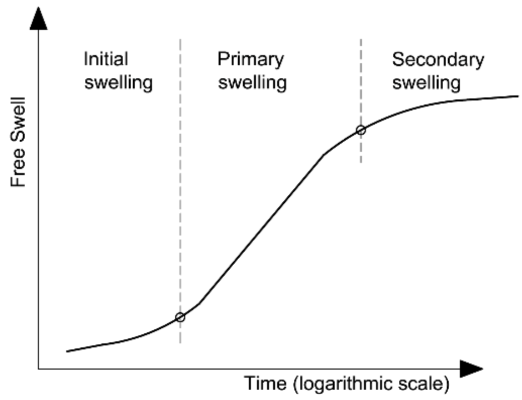


Fig. 8 A schematic of swell pressure with time (redrawn from [31])

## 4. CONCLUSIONS

In this study, the following conclusions were drawn:

i. Adding $MgCl_2$ as a stabilizer to the clayey soil decreases the consistency limits (i.e. liquid limit and plastic limit). However, the tendency is decreasing for both of consistency limits, the decreasing effect is greater for the liquid limit rather than the plastic limit.
ii. The swell strain of the treated samples with $MgCl_2$ is decreasing considerably to one-fifth of the initial value of the untreated sample. The swell strain remains nearly constant for the $MgCl_2$ content higher than 8%.
iii. Zero-deformation test results show that the swell pressure of the treated expansive clays decreases from 83 kPa to 16 kPa with the use of 8% of $MgCl_2$ as the stabilizer. The tendency is decreasing with the increase of additive content; however, the use of higher values of $MgCl_2$ (> 8%) slightly alleviates the swell potential of the treated samples in comparison with the sample treated with 8% of $MgCl_2$.
iv. The zero-deformation test and the free swell test results show that the swell curves can be divided into three separate stages of initial, primary and secondary swelling. However, the swell displacement mainly occurs in the primary stage, a 5-10 % of the total displacement happens in the secondary stage because of the existence of smectite in the clay mineralogy.

## 5. ACKNOWLEDGEMENTS

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