Characteristics of hydro-magnesite of Salda Lake (Türkiye) and their implications on rocks of Jezerro Crater in Mars

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ABSTRACT: Hydro-magnesite formation in Salda Lake in Türkiye receive great attention as an example on Earth in relation to the early life traces in the Jezerro Crater of Mars. The authors investigated Salda Lake and sampled hydro-magnesite. The sampled stromatolites vary newly formed soft ones to quite hardened ones. Microscopic structures and X-Ray analyses of samples were used to characterize the minerological constitutents. Some samples were prepared from large pieces of stromatolites to determine physico-mechanical properties. The investigation results are presented and the implications of the outcomes from these investigations on the characteristics of rocks in Jezerro Crater in Mars are discussed.

Keywords: Salda Lake, hydro-magnesite, physico-mechanical properties, stromatolite, X-Ray analyses.

1 INTRODUCTION

This Hydro-magnesite are formed due to decomposition of ophiolites by living cyanobacteria and stromatolite formation is observed. This process is interpreted as evidence of traces of early life preserved in the geological formations. Hydro-magnesite formation in Salda Lake in Türkiye provides such an evidence in modern times. Therefore Salda Lake has received the great attention of NASA and many researchers worldwide. Jezerro Crater, which hosted a lake in the past is viewed a similar example to Salda Lake in Mars. NASA has recently sent the Mars Explorer Rover called Perseverance, which has been exploring Jezzero Crater and performing grinding, drilling and coring of rocks in Jezerro Crater.

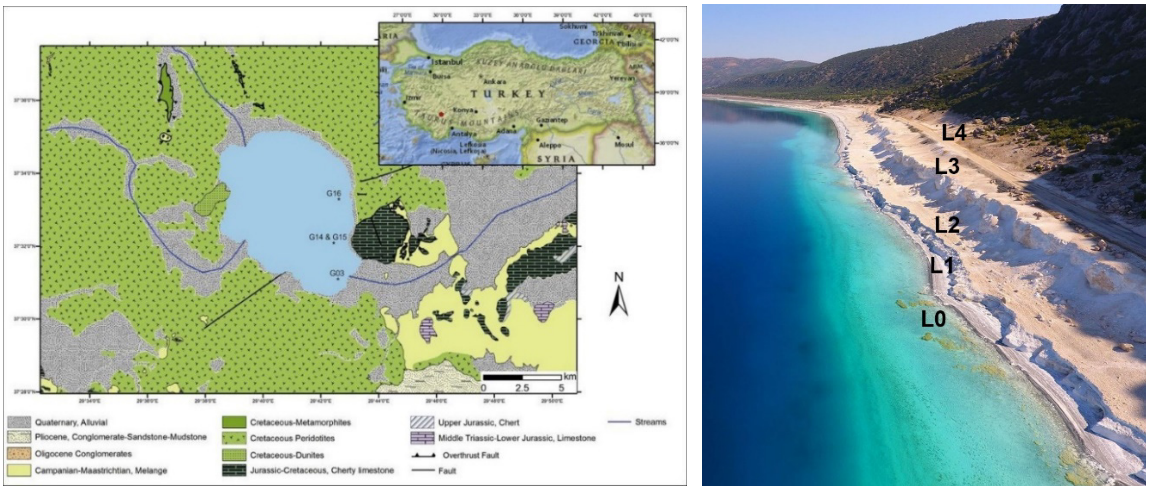
The authors had a chance to investigate Salda Lake and sampled hydro-magnesite from various stromatolites and exposed to different athmospheric and environmental conditions. The sampled stromatolites vary newly formed soft ones and quite hardened ones. Thin sections were prepared for evaluating microscopic structures and X-Ray analyses of samples were used to characterize the minerological constitutents. Some samples were prepared from large pieces of stromatolites to determine physical properties such as density, porosity, elastic wave velocity, mechanical properties such as Brazilian Tensile Strength (BTS), 3-Point Bending Tensile Strength and Uniaxial

Compression Strength (UCS) and elastic modulus. Experimental results indicated that the mechanical properties strongly depends upon the porosity of samples.

The investigations on the various characteristics of hydro-magnesite obtained from stromatolites of Salda Lake are presented and various interrelations as well as yield strength envelope of hyrdo-magnesite are evaluated. The implications of the outcomes from these investigations on the characteristics of rocks in Jezerro Crater in Mars are discussed. This study may be the first rock mechanics study on hydro-magnesites.

2 GEOGRAPHY AND GEOLOGY OF SALDA LAKE

Salda Lake is located within Burdur Province of Türkiye, which is also known as Lake District. It is a closed system and three creeks flow into the lake (Figure 1). The lake covers an area of 4,370 hectares, and its depth reaches 196 meters. The present level of the lake is approximately 10-12 m lower as inferred from the deposition of hydro-magnesites along the shores in Kayadibi location.



(a) Location and simplified geology (from Erentöz, 1974) (b) Kayadibi

Figure 1. (a) Location and simplified geology of the vicinity of Salda Lake and (b) a view of Kayadibi site.

The base of the lake consists of serpentinized ultramafic terrain consisting of mainly harzburgite. The area is tectonically and hydrothermally very active. Hydro-magnesite deposits are widely observed at Kocaadalar and Kayadibi localities with widespread stromatolites occurrences while the deposits cover the entire perimetry of the lake. The stromatolites are porous and their surfaces are cauliflower-like.

3 TECTONIC MOVEMENTS IN THE VICINITY OF SALDA LAKE

As noted from Figure 1(b), four erosion levels, at least, can be recognized. These erosion level changes can be related to water level fluctuations due to climatic changes, tectonic movements or both. During site investigations, one may easily note slicken-sided features in serpentinized ultramafic rocks at Doğanbaba, Salda and Sultanpınarı indicating uplift movements during the closure of Thetis Ocean in geologic past. One can also observe strike-slip faults in limestone as well as hydro-magnesite deposits along the roadway at Kayadibi locality (Figure 2). The strike-slip fault is noted in satellite images as well as in Figure 1(a). The dip direction and dip angle of the strike slip fault ranges between 210-230 and 70-85 degrees respectively while the rake angle of striations ranges between 5-30 degrees. The fault is inferred to be strike-slip with a normal component and it is probably youngest tectonic feature in the vicinity of Salda Lake. As a result of the tectonic movements, the hydro-magnesite deposits at higher elevations are expected to be older than those along the shoreline of Salda Lake. It is also expected that the hydro-magnesite deposits would harden due to water content lose.

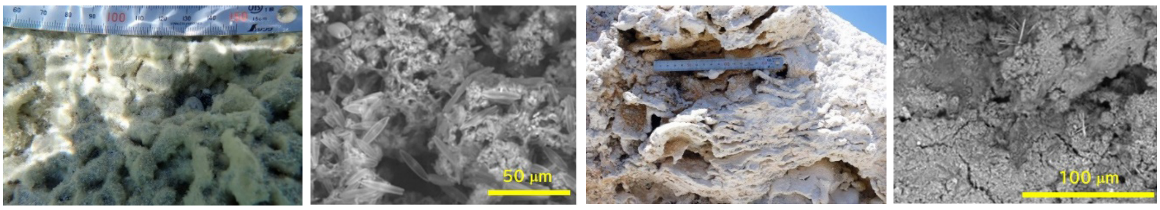
Figure 2. Striations in hydro-magnesite and limestone along the roadway at Kayadibi locality.

4 SAMPLING AND GEOCHEMICAL AND THIN SECTIONING ANALYSES

The authors have made sampling mainly at Kayadibi locality on hydro-magnesite stromatolites and deposits as shown in Figure 3. Sampling were directly done from stromatolites under water below the lake level, above the lake level for geochemical and thin sectioning analyses for the microscopic examination of composition and structure of formed hydro-magnesites. Furthermore, large rock hydro-magnesite blocks were gathered for physico-mechanical property testing samples. The samples were brought to Japan and geomechanical and thin sectioning analyses and physico-mechanical tests and furrther analyses and investigations. Geochemical analyses indicated that the samples consist of carbonates consisting of magnesium and calcium with small amaount of silica. Figure 4 shows some microscopic views of samples from stromatolites under and above water while Figure 5 shows the samples and thin sections of some samples used in physico-mechanical tests. Diatoms and needle-like crystal structure of hydro-magnesites are noted that formed hydro-magnesites has a very porous stucture. Hydro-magnesites are quite soft when they are under water.

(a) (b) (c)

Figure 3. Views of sampling locations (a) underwater; (b,c) above water level.



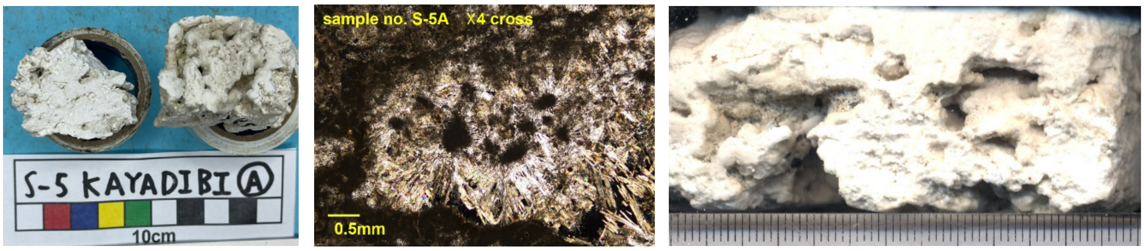
(a) Views of samples underwater (b) Views of samples above water level

Figure 4. Macroscopic and microscopic views of samples under water and above water level.

5 PHYSICO-MECHANICAL TESTS

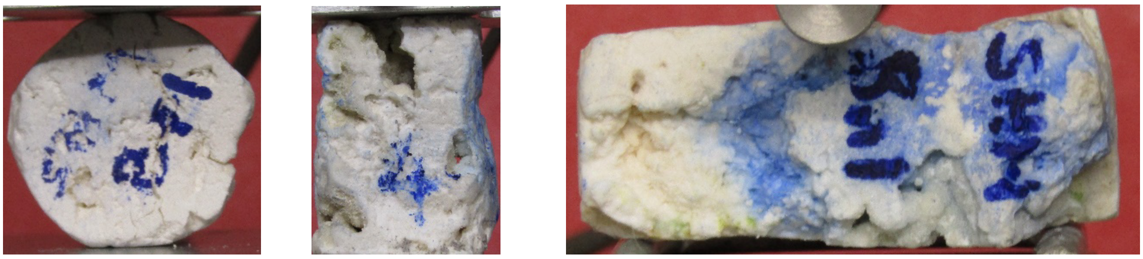
Experiments were carried out on samples prepared for Brazilian Tensile, Uniaxial Compression, 3-Point Bending tests according to the suggested aspect ratios of ISRM Suggested Methods (ISRM, 2007) while the sample sizes could not be in accordance with ISRM Suggested Methods due to limitations for sampling. Unit weight of samples were determined and the results are given in Table 1.

Figure 6 shows examples for Brazilian, 3-Point bending and Uniaxial compression experiments. In each testing group, samples exhibited stick-slip type behavior due to partial pore collapses.



(a) (b) (c)

Figure 5. (a) macroscopic and (b) microscopic views of Sample S-5 and a macroscopic view of a sample for physico-mechanical property tests.



(a) Brazilian (b) Uniaxial compression (c) 3-Point bending

Figure 6. Views of samples during mechanical tests.

5.1 Porosity

If the Salda Lake deposits is assumed to be made of purely hydro-magnesite, the likely porosity of samples may be computed from the following relation, provided that the unit weight of hydro-magnesite minerals is known:

$$n = \left(1 - \frac{\gamma_b}{\gamma_g}\right) x100 \quad (1)$$

where γ_b, γ_g are bulk unit weight and grain unit weight, respectively. Table 1 gives the unit weight of samples for mechanical tests to be presented in the following sub-sections. The unit weight of hydro-magnesite ranges between 21.6 and 22.0 kN/m^3 with a mean value of 21.8 kN/m^3. Thus, the porosity of Salda Lake hydro-magnesite deposits is likely to range between 41.3 and 65.6 %.

Table 1. Experimental results for uniaxial compression, Brazilian and 3-point bending tests.

Sample type	Lowest	Highest	Mean
Uniaxial Compression (UCS)	11.0	12.8	11.68
Brazilian (BTS)	7.5	11.3	9.88
3-Point Bending	9.54	11.6	10.8

5.2 Brazilian Tensile Tests

A number of Brazilian tests were carried out on Salda Lake hydro-magnesite samples. Figure 7 shows the displacement versus tensile stress responses. As noted from the figure, Brazilian tensile strength (BTS) values range between 281.23 kPa and 573.82 kPa with a mean of 437.08 kPa. As noted from these values, the hydro-magnesite samples are quite weak in terms of mechanical properties.

5.3 Uniaxial Compression Tests

A number of uniaxial compressive strength experiments were carried out and the strain-stress responses measured during experiments are shown in Figure 8. As noted from the figure, uniaxial compressive strength (UCS) values of Salda Lake hydro-magnesite samples range between 371.0 kPa and 906.4 kPa with a mean of 635.5 kPa. Similarly, the uniaxial compressive strength of hydro-magnesite samples is also quite weak. Nevertheless, the samples observed at higher elevations seem to have greater strength through some physical inspections. However, this aspect needs to be checked through mechanical tests.

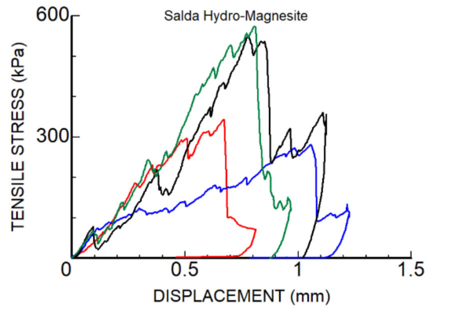


Figure 7. Displacement-stress responses in Brazilian tests.

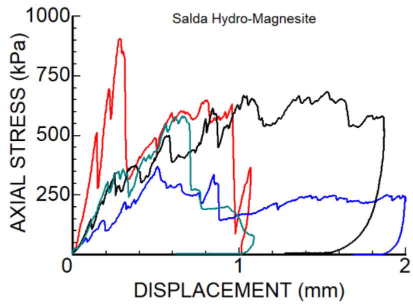


Figure 8. Strain-stress responses in uniaxial compression tests.

5.4 3-Point Bending Tests

Three 3-point bending tests were carried out and the displacement-stress responses measured during experiments are shown in Figure 9. As noted from the figure, bending strength values of Salda Lake hydro-magnesite samples range between 415.0 kPa and 657.9 kPa with a mean of 566.5 kPa. Tensile strength obtained from 3-point bending tests are always higher than that obtained from Brazilian tensile tests. This observation is in accordance with the previous experimental results by the authors (Aydan 2022).

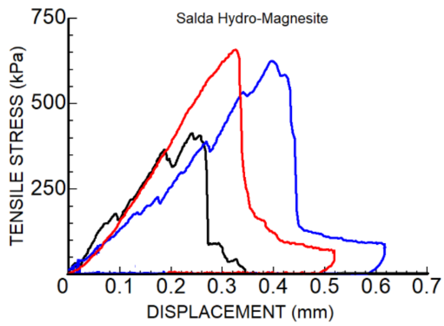


Figure 9. Displacement-stress responses in 3-point bending tests.

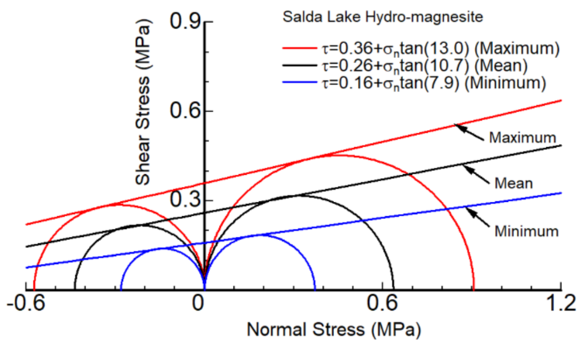


Figure 10. Mohr-Coulomb strength envelopes.

5.5 Mohr-Coulomb Strength Envelopes

Mohr-Coulomb failure criterion (e.g. Aydan 2020) was selected and the values of Mohr-Coulomb failure criterion for Salda Lake hydro-magnesite was evaluated by utilizing lower, mean and peak Brazilian tensile strength (BTS) and uniaxial compression strength (UCS) values and the results are shown in Figure 10. The cohesion for lower, mean and peak values are 0.16, 0.26 and 0.36 MPa and these values are quite similar to tensile strength values. Similarly, the friction angles for lower, mean and peak values of BTS and UCS are 7.9, 10.7 and 13.0 degrees. Although other failure criteria may be utilized, Mohr-Coulomb failure criterion is sufficient for engineering purposes.

6 IMPLICATIONS ON ROCKS AT JEZERRO CRATER

The outcomes from the investigations on the characteristics of rocks of Salda lake may have important implications on rocks explored by the persevrance rover in Jezerro Crater in Mars (Figure 11). Besides the exploration of some evidences of traces of early life preserved in rocks, abrasion (grinding), drilling and coring of rocks in Jezerro Crater will certainly yield their geo-mechanical characteristics. As the water had already been evaporated in Jezerro Crater as a result of erosion of the atmosphere of Mars due to weaking of its magnetic field, the rocks in Jezerro Crater would be almost in dry state. Due to large temperature differences as well as strong winds, they may be subjected to some weathering. If the deposits in Jezerro crater consists of hydro-magnesite, it is expected that hydro-magnesitic rocks would be quite harder. Some penetration tests with 3 mm-flat tip needle were performed on Salda Lake hydro-magnesite samples to check this hypothesis and the results are shown in Figure 12. As expected, the responses of penetration vs tip pressure differ as the rock harden with time.

Figure 11. Comparison of Salda Lake and Jezerro Crater (modified from NASA, 2019).

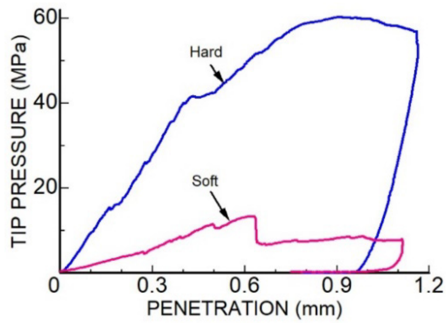


Figure 12. Penetration vs tip pressure responses of 3mm needle for hard and soft rocks.

Besides the similarity of the physico-mechanical properties of rocks in Jezerro Crater and Salda Lake, it is very likely that some geomorphological features such as toe erosion, cliff failures, rock falls and debris flow along the shoreline and adjacent slopes should be observed in Jezerro Crater. Furthermore, it is very likely that several shoreline erosion levels may be observed in order to confirm watery past of Mars.

7 CONCLUSIONS

Although this study is of first kind, the findings from physico-mechanical tests on rocks and observations in Salda Lake are of great importance for understanding traces of early life preserved in rocks and geo-mechanical characteristics of rocks through abrasion (grinding), drilling and coring of operations in Jezerro Crater of Mars. Furthermore, geomorphological observations described in this study in relation to shoreline changes due to the toe erosion, cliff failures and rock falls would definetly provide additional information for understanding the geologic and watery past of Jezerro Crater.

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