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Clay Mineralogy Sedimentary Petrology Soil Forensics X-Ray Diffraction

XRD Analysis of Soil Samples Associated With a Proposed County Leach Field, Nevada City, California

A STUDY CONDUCTED FOR

Cascade Shores Alliance for Land Safety (CSALS)

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SUMMARY

The clay mineralogy of 2 soil sample associated with a proposed county leach field was investigated to understand textural and mineralogical factors that might affect leach field performance and potential elevated risks of landscape instability. The proposed leach field would occupy a hummocky area that developed as a result of Holocene- to Recent soil slumping. The leach field is bordered to the south southeast by a significant escarpment that results from historic erosion and hydraulic mining of gold-bearing gravels. Soil sample #1 (T6 10-14-in depth) consists of a mixture of cristobalite (silica), halloysite, hematite, gibbsite, and titanium oxides (anatase and rutile), with minor quartz (another form of silica). The presence of gibbsite, halloysite (both hydrated and de-hydrated halloysite are present), and hematite indicate a long history of intense weathering. The sand fraction of this soil consists of silica-cemented halloysitic/hematitic claystone fragments that resisted prolonged ultrasonic dispersion treatments. The soil material is generally well aggregated and appears relatively permeable. In part due to the stabilization of clay fragments by iron oxide and silica cements.

Sample #2 was obtained from the near-surface exposure of the cliff face of the hydraulic mining area that borders the proposed leach field about 400-ft southeast of Sample #1. This sample is composed of mottled orange and white kaolinitic claystone with moderate amounts of disordered smectite, muscovite, and goethite. Cristobalite and gibbsite are not present and quartz is the major silica phase in the soil. Although the sample mineralogy is dominated by kaolinite, smectite and interstratified illite/smectite make up between 15-20% of the fine soil fraction. The occurrence of these swelling clays and the fine texture of the mottled claystone stratigraphic unit contribute to significant restriction of water flow across this layer. Surface water seepage along the cliff face where this impermeable layer is exposed in outcrop is well documented in photographs taken 1 May 2018. The distribution of this highly restrictive layer should be mapped to understand its impact on the proposed leach field as disposed fluids will likely flow laterally across this unit and could adversely affect hydrologic factors contributing to landscape instability and reactivation of ancient landslide deposits.

INTRODUCTION

Changing land use and residential development in the Nevada City area have resulted in home construction in areas that exhibit classic hummocky topography associated with historic and ancient landslide events. Rotated slump blocks with small sag ponds bordering significant escarpments are evidence of subsidence along rotational fault planes that disrupted normal soil drainage. Such features occur south and southwest of a rural residential area outside Nevada City, California, in an area presently under consideration for development as a waste water disposal area (Figures 1 & 2). The proposed disposal of large volumes of water in an area of historic landscape instability is potentially disconcerting in an area with poorly characterized hydrogeologic character. This preliminary study was undertaken to attempt to identify soil factors that might impact fluid disposal and the hydrogeology of the area. Two samples were studied, one from the area of the proposed leach field, and another located several hundred feet south of the proposed disposal site at the margin of an active slope failure. The significant escarpment associated with this slope failure is a remnant feature of historic hydraulic gold mining activites.

METHODS

The samples were collected from a depth of approximately 1-ft and sealed in water-tight plastic bags for shipping. The #1 T6 sample was air dry; however, the #2 – Cliff Face sample was extremely wet and consisted of a muddy slurry with clasts of mottled claystone. Approximately 25-30-g of soil from each sample was disaggregated in distilled water using a Branson Model 6510 ultrasonic cleaning tank. The soil was dispersed using repeated ultrasonic treatments with ca 200-ml distilled water and a 10 minute sonic treatment, stirring the slurry several times during treatment to ensure suspension of fine soil particles. The dispersed fine suspension was poured through a 63-micron screen and collected in a 1-l beaker. The dispeersio process was repeated 4-5 times, or until the beaker was filled. The collected suspended material was separated into 3 size fractions by a combination of gravity settling and centrifuge treatment, ultimately obtaining a 63-15-, 15-2-, and <2-μm separation. Slides of the <2- and 15-2-μm separates were made for X-ray diffraction (XRD) analysis after Mg-saturation of the <2-μm clays. A combination of air-dry, glycol-solvated, and heat treatments were used to characterize the clay components of the various size fractions. XRD analysis was accomplished using an automated Philips XRG 3100 diffractometer equipped with a Cu X-ray tube and a focusing monochromator. Patterns obtained during analysis were interpreted using calculated diffractograms generated using NEWMOD (Reynolds, 1996).

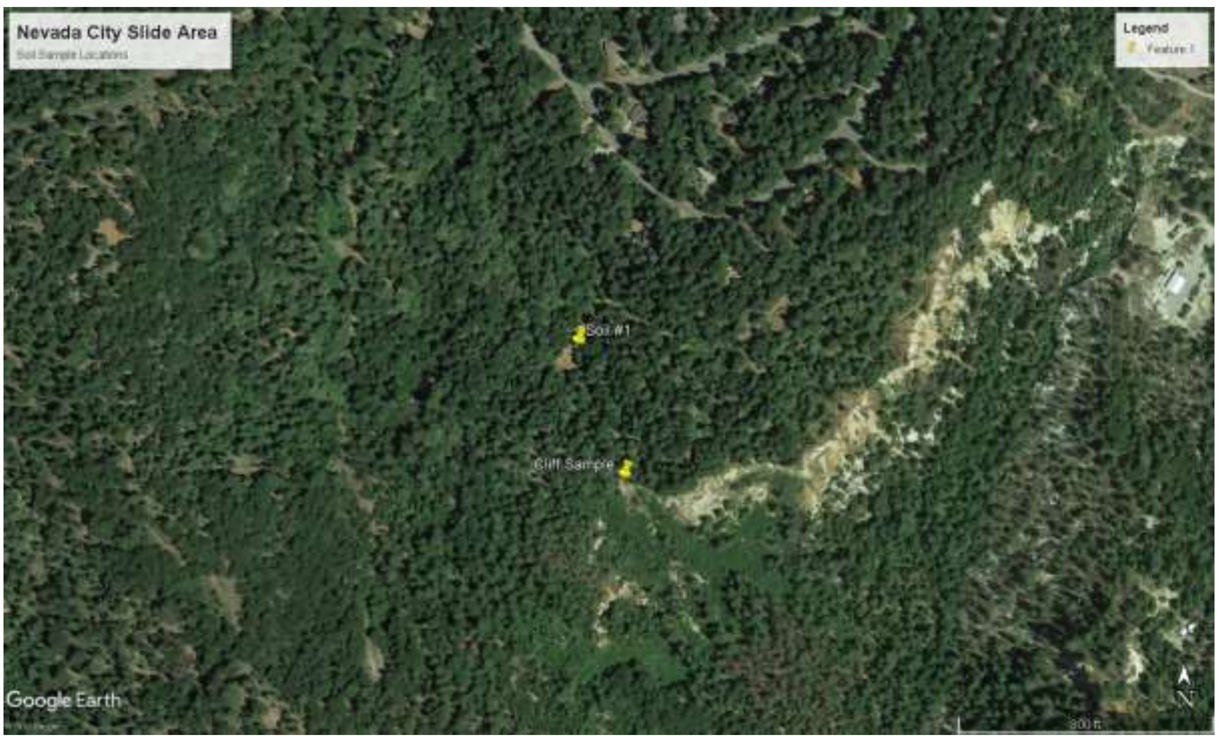

Figure 1. Google Earth aerial photo the proposed leach field area and the location of the 2 soil samples investigated in this study. Sample #1-T6 was taken from a shallow soil pit from the perimeter of the proposed leach field site. The Cliff Face sample (#2) was taken at the head of an escarpment that falls away to the south and is characterized by surface water seepage on top of a moderately thick clay-rich stratigraphic unit. Seepage of water into the test hole during sampling at this location resulted in the bagging of a wet, fluidized sample. The valley that occupies the southeast corner of the photo was severely modified by hydraulic gold mining activity during the late 1800's. The proposed leach field site shows hummocky topography and includes near-by sag ponds that formed in response to historic landslide activity (rotational slumping).

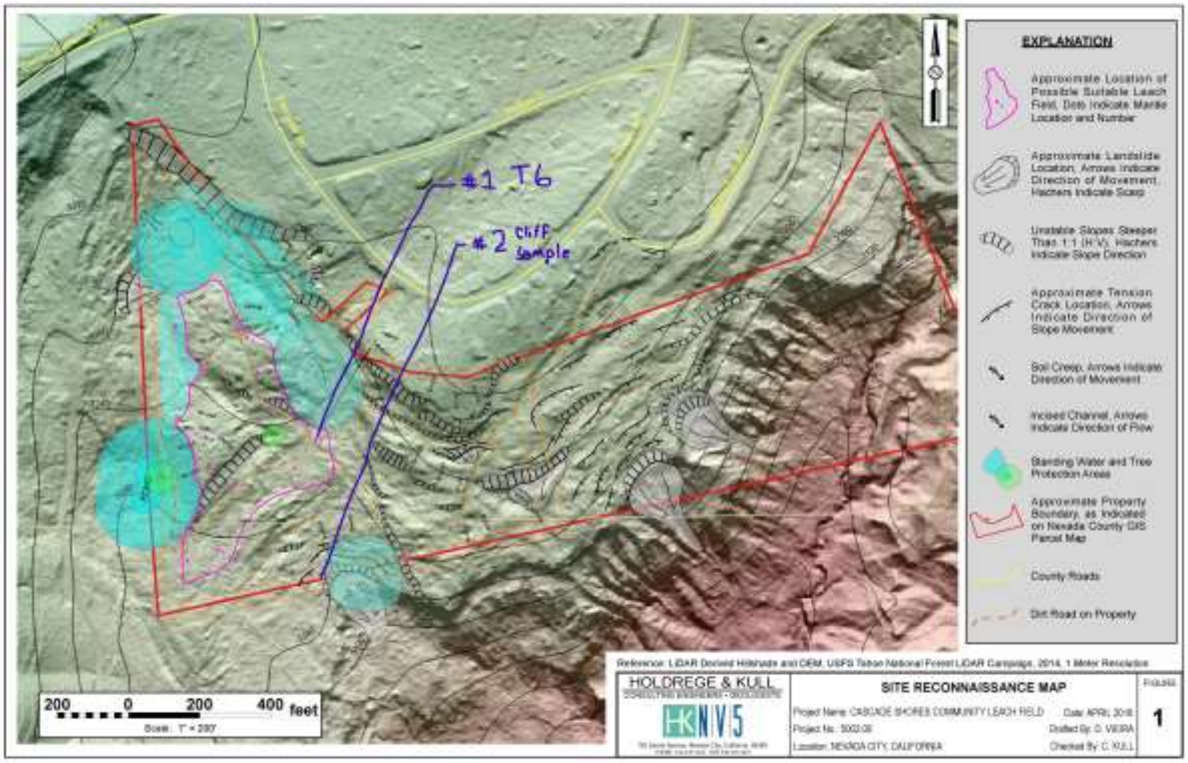

Figure 2. LIDAR imagery of the proposed leach field area, showing sample location and important hydrogeologic features (i.e., scarps, springs, sag ponds, active failures, and surface drainage patterns; after Holdredge and Kuhl, 2018). LIDAR imagery is useful as it “sees” through vegetation and allows recognition of landscape features that may be missed by normal aerial photography. LIDAR imagery is an indispensable tool for mapping and monitoring natural hazards in areas with complex topography.

RESULTS

Clay Mineralogy

The <2-μm fraction of the #1-T6 soil sample shows the presence of cristobalite (silica), halloysite, gibbsite, hematite, anatase, rutile, and quartz (Figure 3). Halloysite is the dominant phyllosilicate and occurs in both hydrated (1.0-nm) and dehydrated (0.75-nm) forms. Hydrated halloysite collapses irreversibly with mild heating; hence the intensification of the 0.75-nm peak in Figure 3 in the heat-treated clays. Water-sensitive smectite clays are not present in the T6 sample and the presence of gibbsite and Ti-oxides (anatase and rutile) indicates soil mineralogy affected by prolonged weathering. Cristobalite may be associated with pedogenic silica cementation resulting from such prolonged weathering and is common in some subtropical/tropical laterites near the groundwater interface. The presence of abundant cristobalite in this sample may indicate that the surface soil represents recycled ancient lateritic material modified by more recent landscape instability. This sample was difficult to disperse owing to the silica-cemented nature of soil aggregates. It is likely that this soil will have relatively good permeability for leach field applications; however, other soil strata may have different mineralogical character that could adversely impact soil hydrology.

The cliff sample (soil #2) exhibits clay-rich texture and is strongly kaolinitic (Figure 4, Table 1). The clay mineral assemblage of this sample includes kaolinite, smectite, interstratified illite/smectite, illite (muscovite), goethite, and quartz. Calculated models that exhibit similar pattern characteristics suggest the following mineral abundances: Kaolinite, 67%; illite, 18%; smectite, 10%; interstratified illite/smectite, 5%. Although smectitic clays are not a major component of the sample, their presence in this extremely fine-grained mudstone sample adversely affects soil permeability. The wet nature of this sample – even in a drought year – indicates that lateral flow of subsurface water occurs at the top of this stratigraphic unit. Numerous seeps and springs occur along the outcrop pattern of this clay-rich unit. The kaolinitic character of this mudstone unit suggests affinities to the Ione Formation, which includes river-deposited sands and associated overbank clays and other clay-rich depositional environments.

It is unclear whether this impermeable clay extends beneath the T6 soil sample in the area of the proposed waste water disposal site. If this clay rich layer is laterally extensive, it will have a profound effect on groundwater hydrology. Lateral flow of concentrated wastewater could affect natural seeps and result in pollution of surface water. Fluid concentration along this aquitard may increase the risk of soil instability in overlying saturated soils. Laterally-migrating soil water will eventually find vertical passage along faults and fractures in the restrictive layer and may lubricate large-scale structural features in the ancient slump-affected landscape. Further study of the soil hydrology of the proposed waste water disposal site is warranted before large scale development to understand the environmental impact of large-scale fluid additions into this sensitive landscape.

CONCLUSIONS

Mineralogical analysis of 2 soil samples from the area of a proposed waste water disposal leach field indicates that soil materials of very different character occur in close proximity on the landscape. The surface soil at the leach field at the T6 location exhibits highly weathered character with low activity clays, gibbsite, and iron oxides. This material may be eroded remnants of a very old landscape that once was widespread prior to recent natural and man-made erosion. This material may have “rafted” to its present position as its associated slump block moved downslope during repeated episodes of landslide activity. Sample #2, located at a cliff exposure associated with recent slope failure of the outer edge of a larger-scale slump upon which the leach field is proposed, exposes deeper strata of this large slump block. The clay-rich sedimentary layer exposed at the cliff face exhibits extremely poor permeability, in part due to modest smectite content, but mostly arising from the extremely fine-grained nature of the kaolinitic mudstone. Widespread evidence of seepage at this stratigraphic boundary along the cliff face indicates that the mudstone unit is laterally extensive and probably underlies the proposed leach field site. The depth of this restrictive aquitard layer is presently unknown, but should be ascertained by soil boring to understand the hydrologic behavior of the poorly consolidated soils that occur at the leach field. Laterally extensive hydrologic barriers may force waste water to the surface before soil neutralization is complete and result in contamination of surface waters. Abnormal soil saturation due to concentration of effluent above impermeable soil layers may increase the potential for landslide reactivation by raising soil water pore pressure and reducing soil strength.

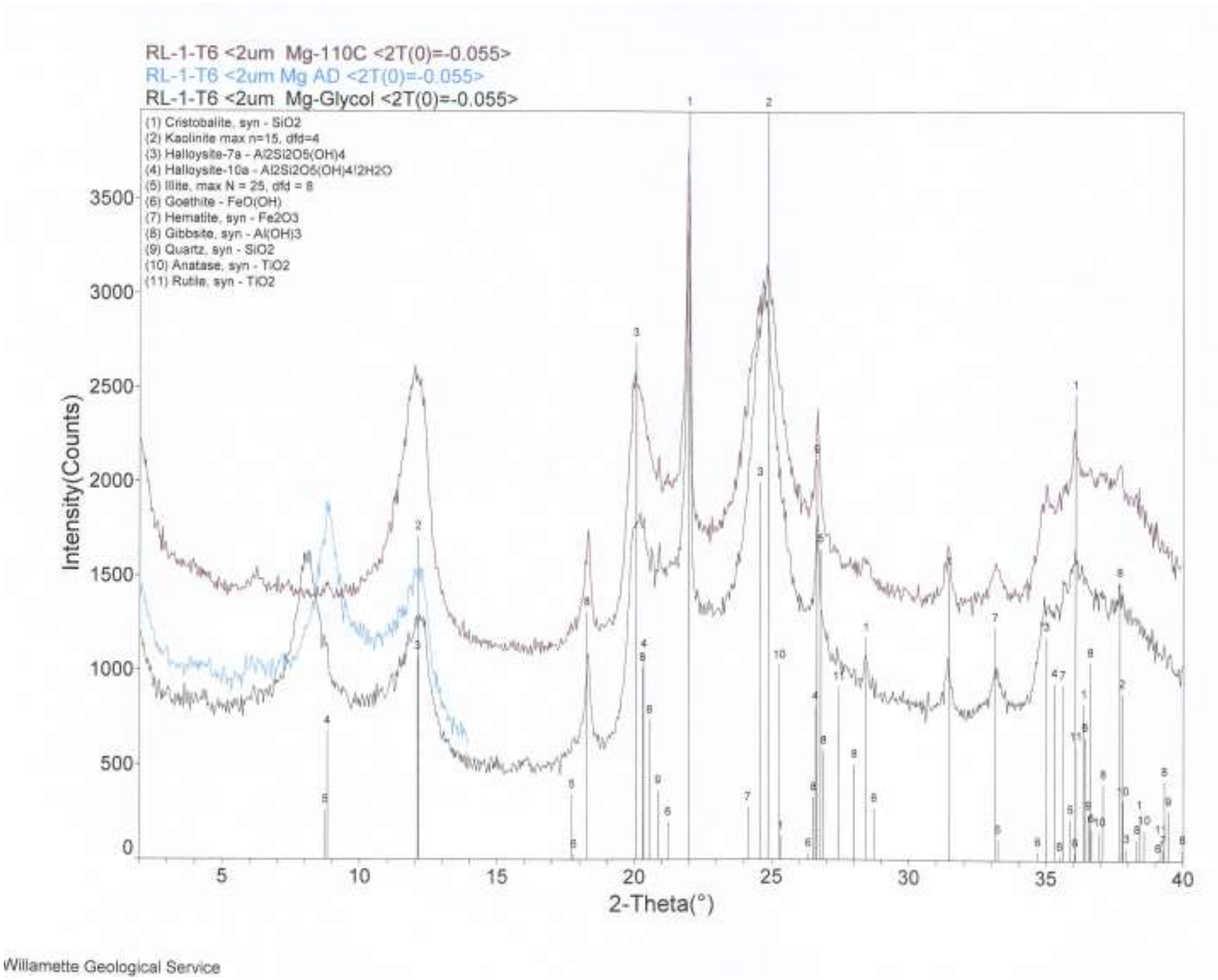

Figure 1. XRD pattern of the <2-µm fraction of the #1-T6 soil, showing the presence of hydrated and dehydrated halloysite, gibbsite, cristobalite, hematite, and various Ti-oxides. Traces of chloritic intergrade minerals and illite also occur. This clay mineral assemblage is characteristic of deeply weathered lateritic soils, where cristobalite often occurs as pedogenic cement that is concentrated by fluid concentration at ground water tables.

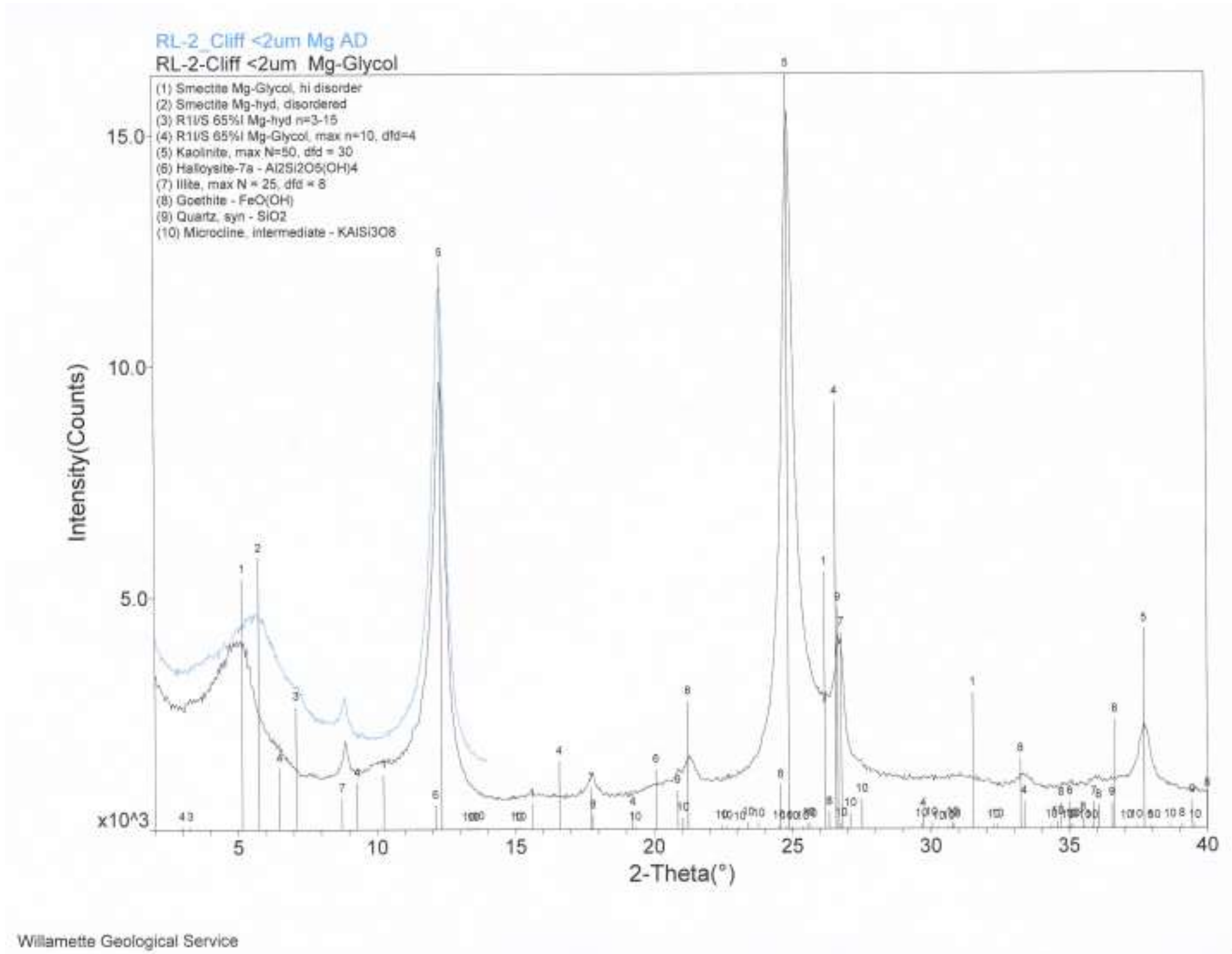

Figure 2. XRD pattern of the <2-µm fraction of the #2-Cliff Face soil, showing the presence of kaolinite, smectite, mixed-layer interstratified illite/smectite, illite, goethite, and quartz. This soil is fine-textured and exhibits low permeability. Vertically migrating fluids concentrate and flow laterally along the top of this clay-rich unit. Although water-sensitive smectitic clays comprise only 15% of the clay fraction, they are likely uniformly distributed through the mudstone and adversely affect interparticle porosity and mudstone permeability.

Table 1. Results of XRD analysis of the <2-μm fraction of soil samples, Nevada City, CA, study.

Sample Description	SM %	R1 IL/SM %	CH/VM %	ILL %	KAO %	HALL %	CR %	QTZ %	KSP %	HM %	GOE %	GIB %	Other %
#1 – T6	0	0	1	1	5	56	20	2	0	5	0	5	5
#2 – Cliff Sample	10	5	0	17	64	0	0	1	0	0	3	0	0

Mineral key: SM = smectite, R1 IL/SM = short-range ordered interstratified illite/smectite, CH/VM = mixed-layer chlorite/vermiculite, ILL = illite, KAO = kaolinite, HALL = halloysite (combined hydrated and de-hydrated forms), CR – cristobalite, QTZ = quartz, KSP = microcline, HM = hematite, GOE = goethite, GIB = gibbsite, Other = Ti-oxides, amorphous soil components.

Reactivation of slump block movement in the area of the proposed leach field would likely cascade to adjacent upslope residential areas, as toe support is removed and gravity continues to move unstable terrane to lower elevation. Such reactivation would pose substantial risks to property owners and could lead to costly litigation.

The interpretations expressed in this report are based on very limited data from a very small sample population. Subsequent analyses may augment or refute some of the conclusions of this report. Willamette Geological Service assumes no liability for the correctness or application of interpretations made in this report. If you have any further questions, don't hesitate to contact me.

Respectfully submitted,

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