Introduction to the Properties of Clay Minerals

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NOTES TO THE INSTRUCTOR

The concept of this laboratory originated in 1993 from the need to develop an environmental geology course. The overall objective of the course was to teach a broad understanding of earth processes and systems so that students could become informed consumers of scientific information. One portion of this course required an applied or environmental mineralogy component, with sufficient introductory material that a consistent background could be provided even if the course is taught by different instructors. Also, the laboratory needed to be simple, relatively inexpensive, easy to maintain and set up, capable of being completed within a two-hour period, and comprehensible for students with only minimal backgrounds in chemistry, since the course was not intended just for geology majors. Although this exercise was originally designed for an environmental geology course, it is applicable to many courses, including hydrology, mineralogy, sedimentology, geomorphology, physical geology, etc.

The resulting environmental mineralogy laboratory illustrates several important general mineralogical concepts. Although not always explicitly stated in the laboratory text, these concepts include cation sites and cation exchange, solid solution, charge neutrality of the chemical constituents in phases, and the effect of chemical composition on the physical properties of phases. Other concepts are more appropriate for clay mineralogy, such as the effect of salts on the behavior of clay swelling, plastic behavior of clays, and permeability.

Although this laboratory exercise is self-contained, it was not meant to stand alone. The laboratory leads not only to possible discussions of the scientific concepts given above, but also of how natural materials may be used to isolate or remediate chemical or nuclear waste. For example, courses may include discussion involving how to isolate low-level radioactive waste by using a clay containment system; we use an example near Chicago where low-level radioactive waste was to be sited within city limits. The discussion involves background information and past legal action, site conditions, a design of a proposed containment cell, national siting criteria, proposed performance objectives, and about 25 topics and questions to explore. This discussion is included here also, although with changes to names and details to protect the identity of the participants.

Special comments on the experiments and experimental procedures. It is noteworthy that the montmorillonite used in this laboratory must be of high purity. For example, cat liter and other similar sources are generally not of sufficient quality for these experiments. We use a high-purity montmorillonite[1] available commercially, but other sources may provide material of high quality.

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1. unmodified Supergel®, available from American Colloid Company, 1500 W. Shure Dr., Arlington Heights, IL 60004, USA. A gallon of unmodified Supergel® will last for years. American Colloid has provided these quantities free of charge as a service to the educational community. Please offer to purchase the material, however.

Part II of the laboratory considers the flow rate of water and Na-rich brines through a column of a montmorillonite + sand mixture. The times required for flow (Questions 8, 9 and 10) are dependent on the particle size of the sand used, the amount of montmorillonite added to the sand, and the quality of the montmorillonite used in the experiments. Pore sizes in the sand must be sufficiently small to trap some of the montmorillonite and to allow the montmorillonite to seal upon expanding. A sand with grain sizes ranging up to fine-medium has worked well, and a poorly sorted sand may be better than a well sorted sand. Also, Question 6 of Part II must be modified for the appropriate amount of added montmorillonite. The instructor should test the mixture so that the first experiment in which water drains through the column takes about 3-4 minutes (Question 10, Part II).

An important point in Question 7 of Part II is that montmorillonite must not form a layer on the top surface of the column. Clay is an effective sealant, and if a clay layer is allowed to form, water is impeded from flowing through the column. Decanting excess water above the column often prevents a clay layer from forming to seal the column surface. If your students need to send out for a pizza at this stage, it is probably because a clay layer has sealed the top surface of the column! Likewise, to prevent clay concentrations from forming, it is imperative that the student thoroughly mix the clay into the sand (for Question 6, Part II).

Sand obtained commercially may already contain clay. To check for clay material, place some sand in a large beaker with water and stir. If the resulting water appears cloudy, the sand contains a clay fraction, which must be washed from the sand before proceeding with the experiments. Successive stirring of the sand with clean water will remove the clay.

Anticipated results. Part I illustrates how cation exchange may affect the physical properties of the clay. Cation exchange takes place almost immediately upon stirring the montmorillonite in the saturated solutions of NaCl, $MgCl_2$, or $CaCl_2$. The wait time of 5 minutes is for the purpose of settling. The Na-exchanged clay, which contains H_2O in the interlayer also, does not settle to the same extent as the other exchanged montmorillonites. As more salt is removed by washing, the Na exchanged montmorillonite will disperse. This effect may be apparent within one or two washings. If the clay is washed sufficiently (four or five times), however, the use of a ultrahigh speed centrifuge will be required to bring the clay to the bottom of a container.

Part II examines the property of permeability through a sand column vs composition of the montmorillonite. Parallel experiments are done to isolate the effect of permeability of the sand column using pure water and then NaCl saturated solution, followed by the same fluids with a sand + Ca-exchanged montmorillonite column. The NaCl saturated solution (Part II, Question 4) takes substantially longer to flow through the sand column than pure water, presumably because of its different ability to wet the sand grains.

The student (Question 9, Part II) introduces NaCl saturated fluid into the column containing Ca exchanged montmorillonite, and this sets up a Na exchange. However, because of the salt present, the (now Na exchanged) montmorillonite does not disperse. Adding pure water in Question 10 washes the salt (excess Na and other cations having been exchanged from the clay) from the sand, thereby causing dispersion which closes the pore throats of the sand. Question 10 suggests that three washings are necessary, but this may vary and it may only be necessary to do two washings (less commonly, four washings). Variations in the number of needed washings are common, since the flow of water in the column cannot be controlled. In any case, if the students are waiting around watching a diminishing flow rate, then the point has been made.

Note that it takes only a small amount of montmorillonite to affect a considerable amount of sand. Also, brines passing through sands with some clay, followed by fresh water, clearly can greatly affect the permeability of the sands. Not only is this an important consideration in remediation work in the environmental industry, but it is also important in the petroleum industry and in the understanding of quick clays, stability problems, and many other engineering-related problems.

Question 11, which involves the introduction of methylene blue to the column, illustrates the ability of montmorillonite (+ sand) to adsorb other materials, and thus it acts as a "filter". The blue color is readily adsorbed in the top couple of centimeters of the column. Methylene blue is an organic molecule with an associated positive charge, and it is adsorbed quickly by the clay. An alternative experiment, in case class time is a concern, is to add the methylene blue directly to a beaker containing montmorillonite + water. The clay will adsorb the dye very quickly.

Additional classroom experiments. A short class demonstration to illustrate clay dispersion and swelling behavior are not included in this exercise, but it is appropriate for an introduction to the properties of clay minerals. Clay dispersion is best illustrated over several days so it is best to set up this demonstration in one class period and then to return to it at intervals up to a week.

Take two 150 ml. glass beakers and fill each about 3/4 with water. In one beaker add about 3 tablespoons of sand or soil (provided the soil does not have a significant clay component). In the other beaker, add a similar amount of montmorillonite (use the same montmorillonite as in the laboratory exercise). Stir the soil/water mix, but it is not necessary to stir the montmorillonite/water mix (if there is a time constraint, stir the montmorillonite very gently for a brief time). Allow both beakers to stand for two or more days. Larger beakers can be used with greater amounts of clay and water. Unlike the soil/water mix where the soil settles to the bottom of the beaker, the clay particles will disperse throughout the beaker of water. Materials generally do not behave this way! If the water is allowed to dry from the beaker with montmorillonite, the result will be a mass of hardened clay (clay + interlayer water) many times the volume of the initial 3 tablespoons.

SUGGESTIONS FOR THE LOW LEVEL RADIOACTIVE WASTE DISPOSAL DISCUSSION

The class may be divided into three groups, advocates for Nosean Mining Company, advocates for the citizens of the City of West End Chicago, and advocates for the NRC. The discussion leader can be the (impartial) judge. As judge, you may ask questions, but do not expect to render a "decision". The discussion should be considered "open-ended".

Topics and questions to explore:

Is there anything conceptually incongruous about disposal-site use for recreational use? Could recreational use actually accelerate deterioration of the cell? If snowmobile or motorcycle use are allowed, how could this affect the cell cover?

How may freezing and thawing affect cell cover integrity? How may drying and wetting affect the cell cover?

What may be the effect of borrowing animals, such as badgers, have on the integrity of the site? Consider both the effect on the cell cap and in the interior of the cell (void spaces). Does this suggest that such a site should be left unmonitored?

What are the negative effects of vegetation with extensive root systems? Are there any positive effects? Should vegetation grow in the disposal site without monitoring? Are there any effects from decomposing organic matter?

If monitoring is a wise idea, for how long should it be done? What are the criteria set forth by the NRC.

What is the "bath tub" effect? Does the engineering of this cell promote or lessen the possibility of the bath tub effect? What must be done to prevent the effect?

How would the designers of the cell determine if the cell fails? Do the leachate wells presently suggested test for failure? How would you design a cell to test for possible failure?

How may water run-off possibly affect the cell cover? How does erosion (e.g., wind, water, ice, etc.) in the Chicago area proceed? What will be the impact of raindrops during intense summer storms be on an unprotected clay cover? How may an extensive drought affect the cell integrity? Describe gully erosion, mass movement.

What site characteristics are at odds with the criteria set forth by the NRC? Discuss the criteria set forth regarding population, potential land use, and potential population increase.

What may be the effect of possible air pollution found in the Chicago area, such as acid rain (sulfuric acids)?

Although the cell contents will be artificially compacted during emplacement, how may additional natural compaction affect the cell integrity?

Discuss more ideal locations and climates for waste disposal. What would be considered "ideal" to you? What criteria did you use to decide on an ideal location?

What are the aesthetic objections for the West End Chicago site that might be offered by the citizens of the City and State? If the current siting proceeds, will the objectives of the City and State be met?

Should there be any criteria regarding slopes on the cell? How may this prove important?

For more advanced discussions:

Have the students design a waste disposal cell.

Discuss ways that geology may be used in the design of a "natural site" depository in conjunction with a well designed cell or cover.

How would low level waste disposal differ from high level waste disposal?

How would low level waste disposal differ from hazardous chemical waste disposal?

Discuss the rationale behind using a clay cover--Is such a cover to prevent all water from entering the cell or to limit water? How should the cell character differ or be related to liner characteristics?

What are slurry trenches and how may their use limit seepage? Discuss the purpose of redundant liners and leak detection systems.

Discuss possible biointrusion barriers to prevent burrowing animals or penetration of roots. Also consider the design of drains, swales, aprons, and infiltration barriers.

How would you design a marker to serve as a warning to future generations? Remember that the curses of the pharaohs were not particularly effective in stopping thieves and English language markers may be equally ineffective. Remember also that the limestone blocks on the pyramids, which represented quality building material, was stripped from the pyramids shortly after they were built.

What sort of performance assessments should be made on the site?