

Laboratory Report

Cyprus Industrial Minerals Co.
Research Division

2435 Military Avenue
West Los Angeles, California
Telephone (213) 478-0462

Filing No 81-0237

References: K. Harris report
attached

Key Beaverhead ore particles

Date of Report 2/22/83

Date of Work Request / By 12/14/82 M. Kahn

Copies: Exploration
R.S. Lamar
~~T.R. Paul~~
B. Boudress
File

Reported By P. Colville/K. Harris

Approved By P. Colville PC

Status Complete

Subject Samples of hand picked particles logged as talc at the rig and under binocular microscope were sent for examination.

Objective Samples were studied by binocular microscope.

Particles from hole 4054 (25'-30', 30'-35', 40'-45') are nearly identical, pearly light greenish-grey, rounded, easily scratched with the fingernail, greasy to the feel and obviously talc. Xray diffraction studies show 95-98% talc. It is not immediately obvious from the few particles hand selected why GEB values were so low (64-73). However, a number of the particles were coated with yellow dust.

Particles from hole 4052 (130'-135', 145'-150', 155'-160') are irregular white fragments that resemble caliche. They break fairly easily. Some can be broken with the fingernail. The powder is not pearly or greasy like talc. Xray diffraction studies show the hardest white material to be cristobalite. The presence of chlorite and vermiculite in the assemblage may result in a ground powder that looks and feels like talc. Not all of the white particles were pure cristobalite. Some of the softest ones were chalky mixtures of calcite, cristobalite, vermiculite and chlorite.

There are sufficient differences so that the two minerals should be identifiable by the core loggers.

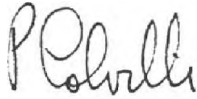
I am adding some pages out of Dana's mineralogy that give a quick test for MgO.

The cristobalite sample was checked by S.E.M. to see if it is an Opal C-T variety observed in the Tallahassee Creek rocks. The attached report shows that it is not Opal C-T. The massive cristobalite occurs with Al rather than Mg, and the photographs show some development of a clay mineral. This

PLAINTIFF'S
EXHIBIT
CAM-44

CYPRUS TA-Alfaro000365

was identified as vermiculite by Xray but may be a montmorillonite (beidellite). Mg was not detected in the samples selected.

A handwritten signature in cursive script, appearing to read "P. Colville".

P. Colville
PC/mh

BEAVERHEAD 1982 Hole # 4052

SAMPLE	GEB	LOI	TALC	CHLORITE	DOLOMITE	CALCITE	MICA	QUARTZ	FELDSPAR	OTHER
125				< 20		< 10		> 20	< 10	~20 cristobalite
										~20 vermiculite
130				< 20		> 50		< 10		~10 cristobalite
										~10 vermiculite
135				< 20		> 35		< 5	< 10	~20 cristobalite
										<10 vermiculite
140				< 10	< 5	> 35		< 20		~30 cristobalite
145				< 20		< 20		< 20		~30 cristobalite
										~10 vermiculite
150				< 20		< 5		> 20	< 15	~20 cristobalite
										~20 vermiculite
155				< 20				< 20		>40 cristobalite
										~20 vermiculite
160				< 20		< 20		< 5		~25 cristobalite
										~30 vermiculite
165				< 20		< 20		< 10		~20 cristobalite
										~30 vermiculite
170				< 5	< 5	< 10		< 20		~50 cristobalite
										~10 vermiculite

TTA-Alfa0000367

BEAVERHEAD 1982 Hole #B4054

SAMPLE	GEB	LOI	TALC	CHLORITE	DOLOMITE	CALCITE	MICA	QUARTZ	FELDSPAR	OTHER
10			< 5	> 50		< 5		< 40		
15			tr	> 58		tr		< 40		
20	56.8	7.42	> 80	< 10				< 10		
✓ 25	64.4	5.30	> 98					< 2		
✓ 30	67.1	5.02	> 95					< 5		
35	69.0	5.30	> 97	tr				< 2		
✓ 40	73.3	5.65	> 96	tr	< 2			tr		
45	69.5	6.73	> 89	< 5	< 5			tr		
50	55.7	7.06	> 78	< 20	tr			tr		
55	58.6	7.37	> 78	< 20	tr			tr		
60	67.0	7.80	> 74	< 20	< 5			tr		
65	61.0	8.22	> 73	< 20	< 5			< 2		
70	69.0	11.46	> 78	< 5	< 15			< 2		
75			< 30	< 5	> 43	< 10		< 2		< 10 magnesite
80	54.1	10.03	> 70	< 20	< 10					
85	69.4	17.64	> 65	< 20	< 15					
90			< 40	< 5	> 45	< 5		< 5		
95	56.0	8.45	> 75	< 20	< 5					
100			< 55	< 5	< 10			< 10	< 10	~ 10 serpentine
										(continued)

517. Salt of Phosphorus. — This flux gives for the most part reactions similar to those obtained with borax. The only cases enumerated here are those which are distinct, and hence those where the flux is a good test.

With *silicates* this flux forms a glass in which the bases of the silicate are dissolved, but the silica itself is left insoluble. It appears as a skeleton readily seen floating about in the melted bead.

The colors of the beads, and the metals to whose oxides these are due, are:

Color	Substance
Red.....	Chromium in O.F., hot — (fine green when cold).
Green.....	Chromium in O.F. and R.F., when cold — (red in O.F., hot). Molybdenum in R.F., dirty green, hot; fine green, cold — (yellow-green in O.F.).
	Uranium in R.F., cold; yellow-green, hot.
	Vanadium, chrome-green in R.F., cold — (brownish red, hot). In O.F., dark yellow, hot, paler on cooling.
Yellow.....	Molybdenum, yellowish green in O.F., hot, paler on cooling — (in R.F., dirty, green, hot; fine green, cold). Uranium in O.F., hot; yellowish green, cold — (in R.F., yellowish green, hot; green, cold).
	Vanadium in O.F., dark yellow, hot, paler on cooling — (in R.F., brownish red, hot; chrome-green, cold).
Violet.....	Titanium (TiO_2) in R.F., yellow, hot. (Also in O.F., yellow, hot; colorless, cold.)

CHARACTERISTIC REACTIONS OF THE IMPORTANT ELEMENTS AND OF SOME OF THEIR COMPOUNDS

518. The following list contains the most characteristic reactions, chiefly before the blowpipe and in some cases also in the wet way, of the different elements and their oxides. It is desirable for every student to gain familiarity with them by trial with as many minerals as possible. Many of them have already been briefly mentioned in the preceding pages. For a thoroughly full description of these and other characteristic tests (blowpipe and otherwise) reference should be made to the volume by Brush and Penfield referred to on p. 361.

It is to be remembered that while the reaction of a single substance may be perfectly distinct if alone, the presence of other substances may more or less entirely obscure these reactions; it is consequently obvious that in the actual examination of minerals precautions have to be taken, and special methods have to be devised, to overcome the difficulty arising from this cause. These will be gathered from the "pyrognostic characters" (Pyr.) given in connection with the description of each species in Part V of this work.

Aluminum. — The presence of aluminum in most infusible minerals, containing a considerable amount, may be detected by the blue color which they assume when, after being heated, they are moistened with cobalt solution and again ignited (*e.g.*, kyanite, andalusite, etc.). Very hard minerals (as corundum) must be first finely pulverized. The test is not conclusive with fusible minerals since a glass colored blue by cobalt oxide may be formed. It is to be noted that the infusible calamine (zinc silicate) also assumes a blue color when treated with cobalt nitrate. From solutions aluminum will be precipitated as a flocculent white or colorless precipitate on the addition of ammonium hydroxide in excess.

Antimony. — Antimonial minerals roasted on charcoal give dense white odorless fumes; metallic antimony and its sulphur compounds give in the open tube a white sublimate of oxide of antimony (see p. 365). Antimony sulphide (stibnite), also many sulphantimonites, give in a strong heat in the closed tube a sublimate of antimony oxysulphide, black when hot, brown-red when cold. Gives iodide test on plaster, orange to red. Sublimate disappears when subjected to ammonia fumes. See also p. 367.

In nitric acid, compounds containing antimony deposit white insoluble metantimonie acid.

Arsenic. — Arsenides, sulpharsenites, etc., give off fumes when roasted on charcoal, usually easily recognized by their peculiar garlic odor. In the open tube they give a white, volatile, crystalline sublimate of arsenic trioxide. In the closed tube arsenic sulphide gives a sublimate dark brown-red when hot, and red or reddish yellow when cold; arsenic and some arsenides yield a black to gray mirror of metallic arsenic in the closed tube. In arsenates the arsenic can be detected by the garlic odor yielded when a mixture of the powdered mineral with charcoal dust and sodium carbonate is heated (R.F.) on charcoal; or same mixture heated in closed tube will yield sublimate of metallic arsenic.

Barium. — A yellowish green coloration of the flame is given by all barium salts, except the silicates; an alkaline reaction is usually obtained after intense ignition.

In solution the presence of barium is proved by the heavy white precipitate (BaSO_4) formed upon the addition of dilute sulphuric acid.

Bismuth. — On charcoal alone, or better with soda, bismuth gives a very characteristic orange-yellow sublimate; brittle globules of the reduced metal are also obtained (with soda). Also when treated with 3 or 4 times the volume of a mixture in equal parts of potassium iodide and sulphur, and fused on charcoal, a beautiful red sublimate of bismuth iodide is obtained; near the mineral the coating is yellow; on plaster the iodide sublimate is chocolate-brown with underlying red. Changes to orange-yellow and red on exposure to ammonia fumes.

Boron. — Many compounds containing boron (borates, also the silicates, datolite, danburite, etc.) tinge the flame intense yellowish green, especially if moistened with sulphuric acid. For some silicates (as tourmaline) the best method is to mix the powdered mineral with one part powdered fluorite and two parts potassium bisulphate. The mixture is moistened and placed on platinum wire. At the moment of fusion the green color appears, but lasts but an instant.

A dilute hydrochloric acid solution containing boron gives a reddish brown color to turmeric paper which has been moistened with it and then dried at 100° ; the color changes to black when ammonia is poured on the paper.

Calcium. — Many calcium minerals (carbonates, sulphates, etc.) give an alkaline reaction on turmeric paper after being ignited. A yellowish red color is given to the flame by some compounds (e.g., calcite after moistening with HCl); the strontium flame is a much deeper red.

In weakly acid or alkaline solutions calcium is precipitated as oxalate by the addition of ammonium oxalate. Calcium sulphate is precipitated in concentrated solutions only on addition of sulphuric acid.

Cadmium. — On charcoal with soda, compounds of cadmium give a characteristic sublimate of the reddish brown oxide; on plaster the coating is greenish yellow with brown.

Carbonates. — All carbonates effervesce with dilute hydrochloric acid, yielding the odorless gas CO_2 (e.g., calcite); many require to be pulverized, and some need the addition of heat (dolomite, siderite). Carbonates of lead should be tested with nitric acid.

Chlorides. — If a small portion of a mineral containing chlorine (a chloride, also pyromorphite, etc.) is added to the bead of salt of phosphorus, saturated with copper oxide, the bead when heated is instantly surrounded with an intense purplish flame of copper chloride.

In solution chlorine gives with silver nitrate a white curdy precipitate of silver chloride which darkens in color on exposure to the light; it is insoluble in nitric acid, but entirely soluble in ammonia.

Chromium. — Chromium gives with borax a bead which (O.F.) is yellow to red (hot) and yellowish green (cold) and R.F. a fine emerald-green. With salt of phosphorus in O.F. the bead is dirty green (hot) and clear green (cold); in R.F. the same. Cf. vanadium beyond (also pp. 368, 369).

Cobalt. — A beautiful blue bead is obtained with borax in both flames from minerals containing cobalt. Where sulphur or arsenic is present the mineral should first be thoroughly roasted on charcoal.

Copper. — On charcoal, at least with soda, metallic copper can be reduced from most of its compounds. In the case of sulphides the powdered mineral should be roasted first in order to eliminate the major part of the sulphur before fusion with soda. With borax it gives (O.F.) a green bead when hot, becoming blue when cold; also (R.F.), if saturated, an opaque red bead containing Cu_2O and often Cu is obtained. Copper chloride, obtained by moistening the mineral with hydrochloric acid (in the case of sulphides the mineral should be previously roasted) yields a vivid azure-blue flame; copper oxide gives a green flame.

Most metallic compounds are soluble in nitric acid. Ammonia in excess produces an intense blue color in the solution.

Fluorine produces a form a vola then dipper will appear

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Iron. — when heated to brownish R.F. become the additior Ferric iron i cyanide is a ferricyanide.

Lead. — compounds; coating (Pb) disappears, t

In soluti delicacy is re water added

Lithium. resembling t the spectrosc

Magnesium color is obtai the addition produces a wi hydroxide or

Manganese. With soda (C relied upon, e

Mercury. mineral is be of metallic m is obtained.

Molybdenum stain (O.F.), : for a moment

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Nickel. — brown on cool nickel. A sol excess. If an a scarlet preci

Niobium (which slowly c tions with the

Nitrates. — acid they give

Phosphorus been moistene the presence of of metallic m hydrogen is giv

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Fluorine. — Heated in the closed tube with potassium bisulphate and powdered glass produces a white sublimate of SiO_2 . This sublimate and the hydrofluosilicic acid present form a volatile combination. But if the lower end of the tube is broken off and the open tube then dipped in a test tube of water so that the acid is removed, the deposit of SiO_2 which will appear when the tube is dried will be found to be no longer volatile.

Heated gently in a platinum crucible with sulphuric acid, many compounds (e.g., fluorite) give off hydrofluoric acid, which corrodes the exposed parts of a glass plate placed over it which has been coated with wax and then scratched.

Iron. — Minerals which contain even a small amount of iron yield a magnetic mass when heated in the reducing flame. With borax iron gives a bead (O.F.) which is yellow to brownish red (according to quantity) while hot, but is colorless to yellow on cooling; R.F. becomes bottle-green (see p. 368). Ferric iron is precipitated from a solution by the addition of ammonium hydroxide in excess as red-brown ferric hydroxide $\text{Fe}(\text{OH})_3$. Ferric iron in hydrochloric acid solution gives deep blue precipitate when potassium ferrocyanide is added; a similar test is obtained for ferrous iron by the addition of potassium ferricyanide.

Lead. — With soda on charcoal a malleable globule of metallic lead is obtained from lead compounds; the coating has a yellow color near the assay; the sulphide gives also a white coating (PbSO_4) farther off (p. 366). On being touched with the reducing flame the coating disappears, tingeing the flame azure-blue. On plaster, lead iodide coating is chrome-yellow.

In solutions dilute sulphuric acid gives a white precipitate of lead sulphate; when delicacy is required an excess of the acid is added, the solution evaporated to dryness, and water added; the lead sulphate, if present, will then be left as a residue.

Lithium. — Lithium gives an intense carmine-red to the outer flame, the color somewhat resembling that of the strontium flame but deeper; in very small quantities it is evident in the spectroscope.

Magnesium. — Moistened, after heating, with cobalt nitrate and again ignited, a pink color is obtained from some infusible compounds of magnesium (e.g. brucite). In solution the addition of ammonium hydroxide in large excess and a little hydrogen sodium phosphate produces a white granular precipitate of NH_4MgPO_4 . Elements precipitated by ammonium hydroxide or ammonium oxalate should be removed first.

Manganese. — With borax manganese gives a bead violet-red (O.F.), and colorless (R.F.). With soda (O.F.) it gives a bluish green bead; this reaction is very delicate and may be relied upon, even in presence of almost any other metal.

Mercury. — In the closed tube a sublimate of metallic mercury is yielded when the mineral is heated with dry sodium carbonate. In the open tube the sulphide gives a mirror of metallic mercury; in the closed tube a black lusterless sublimate of HgS , red when rubbed, is obtained.

Molybdenum. — On charcoal molybdenum sulphide gives near the assay a copper-red stain (O.F.), and beyond a white coating of the oxide; the former becomes azure-blue when for a moment touched with the R.F. The iodide coating on plaster is deep ultramarine blue. The salt of phosphorus bead (O.F.) is yellowish green (hot) and nearly colorless (cold); also (R.F.) a fine green. Molybdates are tested by putting powdered mineral in dry test tube with small scrap of paper, adding a few drops of water and an equal amount of concentrated sulphuric acid. Heat until acid fumes. Cool or add slowly drops of water and solution will assume deep blue color.

Nickel. — With borax, nickel oxide gives a bead which (O.F.) is violet when hot and red-brown on cooling; (R.F.) the glass becomes gray and turbid from the separation of metallic nickel. A solution of nickel becomes pale blue (cf. copper) on the addition of ammonia in excess. If an alcoholic solution of dimethylglyoxime is added to an ammoniacal solution a scarlet precipitate is formed.

Niobium (Columbium). — An acid solution boiled with metallic tin gives a blue color which slowly changes to brown on continued boiling and disappears on dilution. The reactions with the fluxes are not very satisfactory.

Nitrides. — These detonate when heated on charcoal. Heated in a tube with sulphuric acid they give off red fumes of nitrogen dioxide (NO_2).

Phosphorus. — Most phosphates impart a green color to the flame, especially after having been moistened with sulphuric acid, though this test may be rendered unsatisfactory by the presence of other coloring agents. If they are fused in the closed tube with a fragment of metallic magnesium or sodium, and afterward moistened with water, phosphureted hydrogen is given off, recognizable by its disagreeable odor.

A few drops of a nitric acid solution, containing phosphoric acid, produce in a solution of ammonium molybdate a pulverulent yellow precipitate of ammonium phosphomolybdate.

Potassium. — Potash imparts a violet color to the flame when alone. The flame is best observed through a blue glass filter which will eliminate the sodium flame color which will almost invariably be present. It is best detected in small quantities, or when soda or lithia is present, by the aid of the spectroscope. See also p. 364.

Selenium. — On charcoal selenium fuses easily, giving off brown fumes with a peculiar disagreeable organic odor; the sublimate on charcoal is volatile, and when heated (R.F.) gives a fine azure-blue flame. On plaster gives red to crimson volatile sublimate with characteristic odor.

Silicon. — A small fragment of a silicate in the salt of phosphorus bead leaves a skeleton of silica, the bases being dissolved.

Most silicates are insoluble in acids. The fine powder of such a silicate is fused with sodium carbonate and the mass then dissolved in hydrochloric acid and evaporated to dryness, the silica separates as a gelatinous mass and on evaporation to dryness is made insoluble. When strong hydrochloric acid and then water is added to the dry residue in the test tube, the bases are dissolved and the silica left behind.

Many silicates are directly soluble in hydrochloric acid, and the solution on evaporation will yield the characteristic silica jelly. Other silicates when treated with acid are decomposed, the bases present going into solution, but the silica separating and remaining suspended in the liquid. There are gradations between these three groups.

Silver. — On charcoal in O.F. silver gives a brown coating. A globule of metallic silver may generally be obtained by heating on charcoal in R.F., especially if soda is added. Under some circumstances it is desirable to have recourse to cupellation.

From a solution containing any salt of silver, the insoluble chloride is thrown down when hydrochloric acid is added. This precipitate is insoluble in acid or water, but entirely so in ammonia. It changes color on exposure to the light.

Strontium. — Compounds of strontium are usually recognized by the fine crimson-red which they give to the blowpipe flame; many yield an alkaline reaction after ignition (cf. barium). In concentrated and slightly diluted solutions strontium sulphate will be precipitated on the addition of sulphuric acid (cf. calcium and barium).

Sodium. — Compounds containing sodium give a strong and persistent yellow flame. Some compounds will give an alkaline reaction after ignition.

Sulphur, Sulphides, Sulphates. — In the closed tube some sulphides give off sulphur; in the open tube they yield sulphur dioxide, which has a characteristic odor and reddens a strip of moistened litmus paper. In small quantities, or in sulphates, sulphur is best detected by fusion on charcoal with soda and charcoal dust. The fused mass, when sodium sulphide has thus been formed, is placed on a clean silver coin and moistened; a distinct black stain on the silver is thus obtained (the precaution mentioned on p. 367 must be exercised).

A solution of a sulphate in hydrochloric acid gives with barium chloride a white insoluble precipitate of barium sulphate.

Tellurium. — Tellurides heated in the open tube give a white or grayish sublimate, fusible to colorless drops (p. 365). On charcoal they give a white coating and color the R.F. green. On plaster they give a dark brown volatile sublimate. A small amount dissolved in warm concentrated sulphuric acid yields a deep red solution. The color will disappear if acid is heated too hot or if on cooling, water is added.

Tin. — Minerals containing tin (e.g., cassiterite), when heated on charcoal with soda or potassium cyanide, yield metallic tin in minute globules and a white and difficultly volatile oxide coating is formed; the globules are malleable, but harder than silver. Dissolved in nitric acid, white insoluble stannic oxide separates out.

Titanium. — Titanium gives in the R.F. with salt of phosphorus a bead which is violet when cold. Fused with sodium carbonate and dissolved in hydrochloric acid, and heated with a piece of metallic tin, the liquid takes a violet color, especially after partial evaporation. A yellow to amber color results when hydrogen peroxide is added to a sulphuric acid solution.

Tungsten. — Tungsten oxide gives a blue color to the salt of phosphorus bead (R.F.). Fused and treated as titanium (see above) with the addition of zinc instead of tin, gives a fine blue color. The color changes to brown on continued reduction. The color does not disappear when the solution is diluted (cf. niobium).

Uranium. — Uranium compounds give to the salt of phosphorus bead (O.F.) a greenish yellow bead when cool; also (R.F.) a fine green on cooling (p. 369).

Vanadium. — With borax (O.F.) vanadates give a bead yellow (hot) changing to yellowish green and nearly colorless (cold); also (R.F.) dirty green (hot), fine green (cold). With salt of phosphorus (O.F.) a yellow to amber color (thus differing from chromium); also (R.F.) fine green (cold).

Zinc. — On yellow white heated become when heated at Zirconium. orange-yellow

519. Det general head depends mos cal character

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Zinc. — On charcoal in the reducing flame compounds of zinc give a coating which is yellow while hot and white on cooling, and moistened by the cobalt solution and again heated becomes a fine green. Note, however, that the zinc silicate (calamine) becomes blue when heated after moistening with cobalt solution.

Zirconium. — A dilute hydrochloric acid solution, containing zirconium, imparts an orange-yellow color to turmeric paper, moistened by the solution.

DETERMINATIVE MINERALOGY

519. Determinative Mineralogy may be properly considered under the general head of Chemical Mineralogy, since the determination of minerals depends mostly upon chemical tests. But crystallographic and all the physical characters have also to be carefully observed.

There is but one exhaustive way in which the identity of an unknown mineral may in all cases be fixed beyond question, and that is by the use of a complete set of determinative tables. By means of such tables the mineral in hand is referred successively from a general group into a more special one, until at last all other species have been eliminated, and the identity of the one given is beyond doubt.

A careful preliminary examination of the unknown mineral should, however, always be made before final recourse is had to the tables. This examination will often suffice to show what the mineral in hand is, and in any case it should not be omitted, since it is only in this way that a practical familiarity with the appearance and characters of minerals can be gained.

The student will naturally take note first of those characters which are at once obvious to the senses, that is: *crystalline form*, if distinct; *general structure, cleavage, fracture, luster, color (and streak), feel*; also, if the specimen is not too small, the apparent weight will suggest something as to the *specific gravity*. The characters named are of very unequal importance. Structure, if crystals are not present, and fracture are generally unessential except in distinguishing varieties; color and luster are essential with metallic, but generally very unimportant with nonmetallic minerals. *Streak* is of importance only with colored minerals and those of metallic luster (p. 271). Crystalline form and cleavage are of the highest importance, but may require careful study.

The first trial should be the determination of the *hardness* (for which end the pocket-knife is often sufficient in experienced hands). The second trial should be the determination of the *specific gravity*. Treatment of the powdered mineral with acids may come next; by this means (see pp. 359, 360) a carbonate is readily identified, and also other results obtained. Then should follow blowpipe trials, to ascertain the *fusibility*; the *color* given to the flame, if any; the character of the *sublimate* given off in the tubes and on charcoal; the metal reduced on the latter; the reactions with the *fluxes*, and other points as explained in the preceding pages.

How much the observer learns in the above way, in regard to the nature of his mineral, depends upon his knowledge of the characters of minerals in general, and upon his familiarity with the chemical behavior of the various elementary substances with reagents and before the blowpipe (pp. 359 to 369). If the results of such a preliminary examination are sufficiently definite to suggest that the mineral in hand is one of a small number of species, reference may be made to their full description in Part V of this work for the final decision.

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Status S.E.M. Complete

Subject Samples of Beaverhead particles logged at rig as having abundant talc.

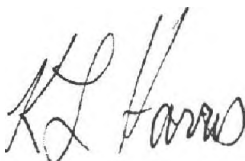
Objective S.E.M. examination to obtain micrographs and Xray analysis.

Results: Several hand picked particles were examined in S.E.M. and EDAX spectrums were taken.

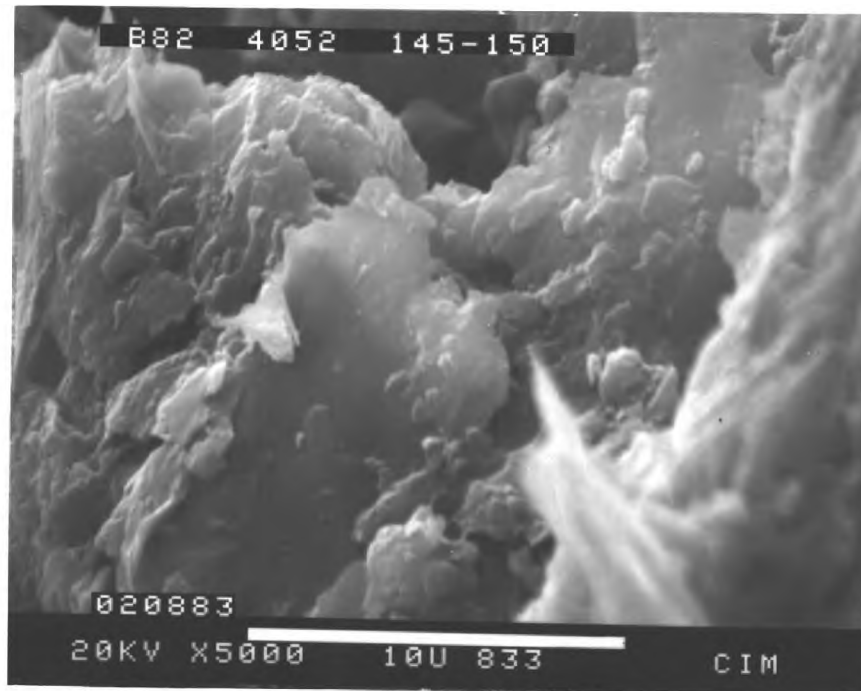
Micrographs were taken at X5000 and X10000 of samples from the 145'-150', and 155'-160' levels of hole No. 4052.

EDAX spectrums did not show the presence of Mg.

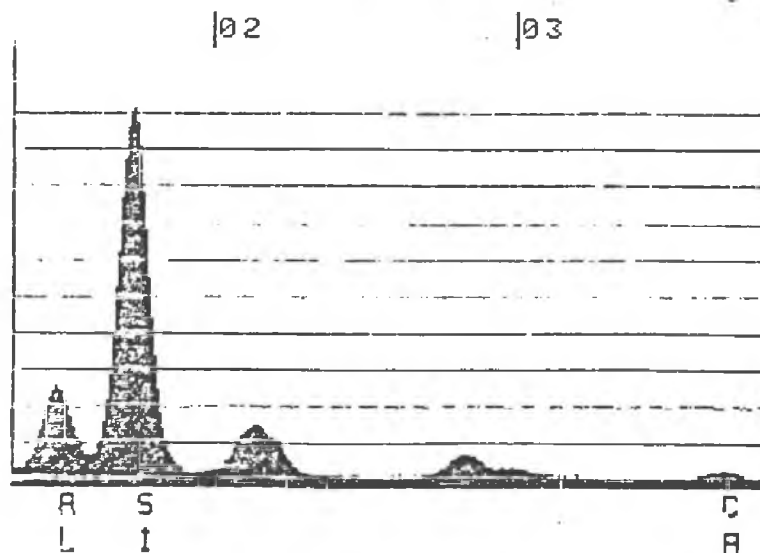
Micrographs and EDAX spectrum included.

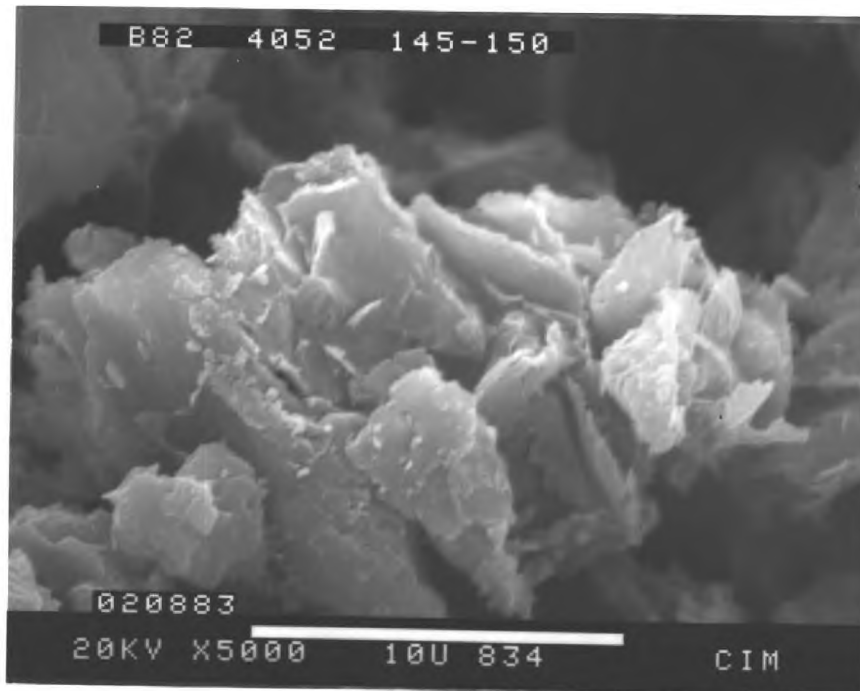


K. L. Harris
KLH/hks

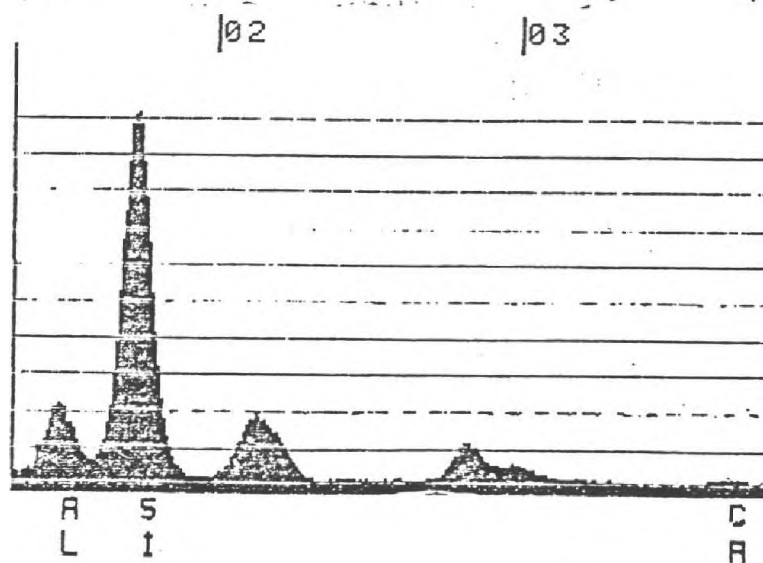


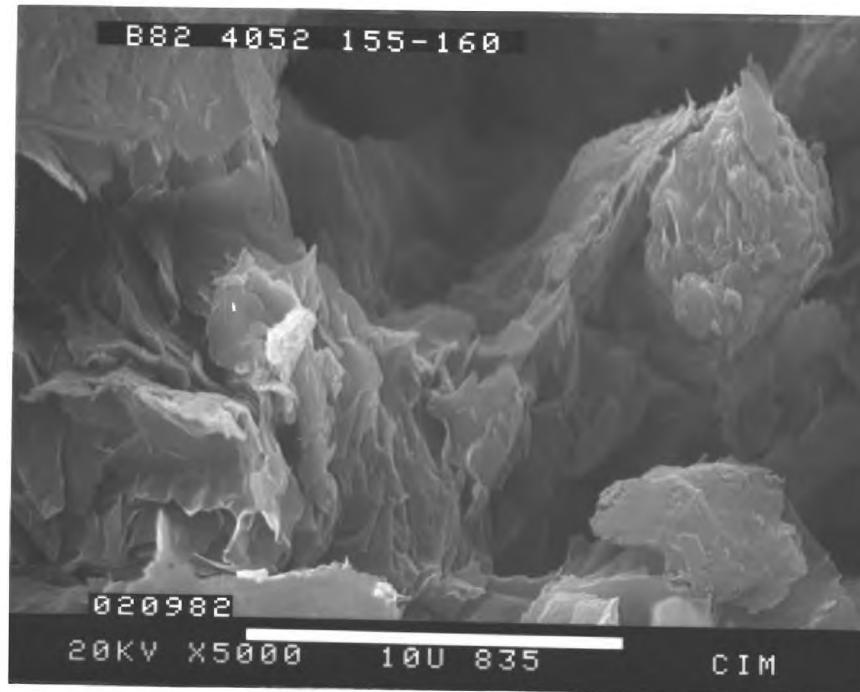
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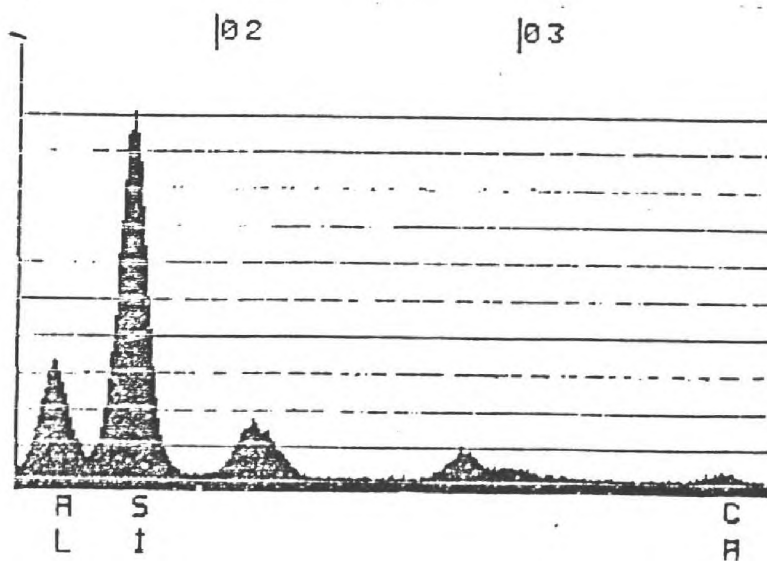


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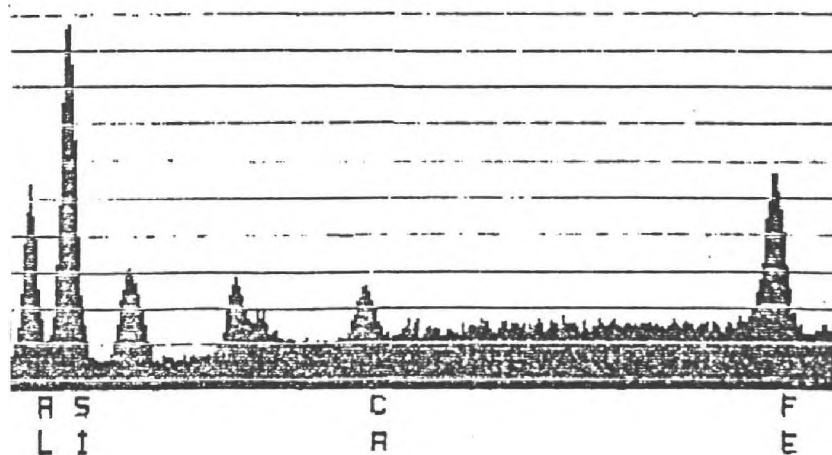


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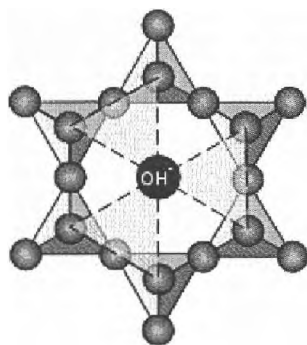
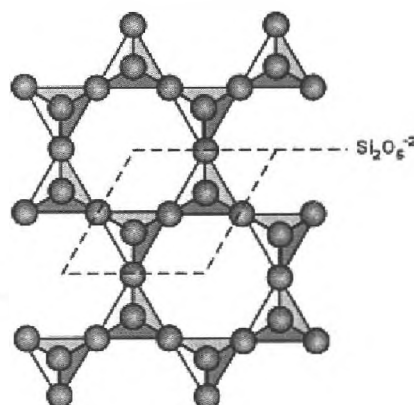
EENS 2110	Mineralogy
Tulane University	Prof. Stephen A. Nelson
Phyllosilicates (Micas, Chlorite, Talc, & Serpentine)	

This document last updated on 08-Nov-2010

Phyllosilicates (Sheet Silicates)

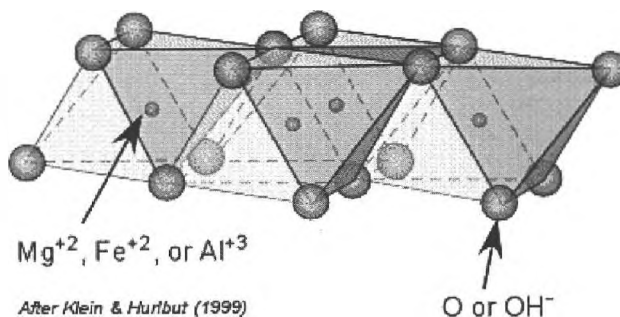
The phyllosilicates, or sheet silicates, are an important group of minerals that includes the micas, chlorite, serpentine, talc, and the clay minerals. Because of the special importance of the clay minerals as one of the primary products of chemical weathering and one of the more abundant constituents of sedimentary rocks, they will be discussed in more detail in the next lecture.

The basic structure of the phyllosilicates is based on interconnected six member rings of SiO_4^{-4} tetrahedra that extend outward in infinite sheets. Three out of the 4 oxygens from each tetrahedra are shared with other tetrahedra. This leads to a basic structural unit of $\text{Si}_2\text{O}_5^{-2}$.



Most phyllosilicates contain hydroxyl ion, OH^- , with the OH located at the center of the 6 membered rings, as shown here. Thus, the group becomes $\text{Si}_2\text{O}_5(\text{OH})^{-3}$. When other cations are bonded to the SiO_4 sheets, they share the apical oxygens and the (OH) ions which bond to the other cations in octahedral coordination. This forms a layer of cations, usually Fe^{+2} , Mg^{+2} , or Al^{+3} , that occur in octahedral coordination with the O and OH ions of the tetrahedral layer. As shown, here, the triangles become the faces of the octahedral groups that can bind to the tetrahedral layers.

The octahedral layers take on the structure of either Brucite $[\text{Mg}(\text{OH})_3]$, if the cations are +2 ions like Mg^{+2} or Fe^{+2} , or Gibbsite $[\text{Al}(\text{OH})_3]$, if the cations are +3 like Al^{+3} . In the brucite structure, all octahedral sites are occupied and all anions are OH^{-1} . In the Gibbsite structure every 3rd cation site is unoccupied and all anions are OH^{-1} .



Phyllosilicates

This gives rise to 2 groups of sheet silicates:

1. The **trioctahedral** sheet silicates where each O or OH ion is surrounded by 3 divalent cations, like Mg^{+2} or Fe^{+2} .
2. The **dioctahedral** sheet silicates where each O or OH ion is surrounded by 2 trivalent cations, usually Al^{+3} .

We can build the structures of the various sheet silicates by starting with the octahedral layers similar to the structures of brucite or gibbsite, as shown below.

The trioctahedral phyllosilicates are based on the structure where the octahedral layers are similar to brucite, where Mg^{+2} occupies the cation position.

Trioctahedral
Brucite $\text{Mg}(\text{OH})_3$



Dioctahedral
Gibbsite $\text{Al}(\text{OH})_3$

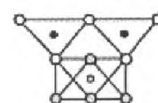
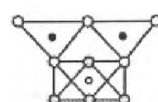


The dioctahedral phyllosilicates are based on the structure where the octahedral layers are similar to gibbsite, where Al^{+3} occupies the cation position.

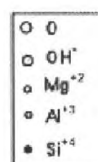
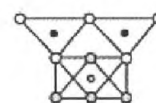
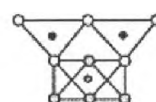
The octahedral sheets in both cases are held together by weak Van der Waals bonds.

If we start with the brucite and gibbsite structures shown above, and replace 2 of the OH ions with O, where the Oxygens are now the apical Oxygens of the tetrahedral sheets, then we get the structure of the serpentine mineral, Lizardite, if the octahedral layer is trioctahedral, containing Mg^{+2} . If the octahedral layer is dioctahedral, containing Al^{+3} , the structure of the clay mineral Kaolinite, is obtained.

Trioctahedral
Lizardite $\text{Mg}_2\text{Si}_2\text{O}_5(\text{OH})_4$



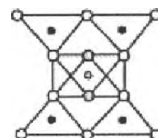
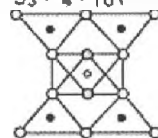
Dioctahedral
Kaolinite $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$



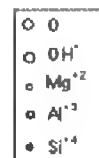
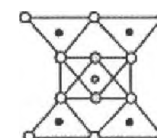
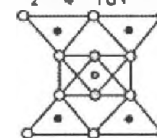
This leads to a tetrahedral - octahedral (T-O) structure, where each T-O layer is bonded to the top (or bottom) of another T-O layer by Van der Waals bonds.

If 2 more of the OH ions in the octahedral layer are replaced by O, and these O become the apical Oxygens for another tetrahedral layer, then this builds the trioctahedral phyllosilicate talc or the dioctahedral pyrophyllite. This becomes a T-O-T layer that can bond to other T-O-T layers by weak Van der Waals bonds.

Trioctahedral
Talc $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$

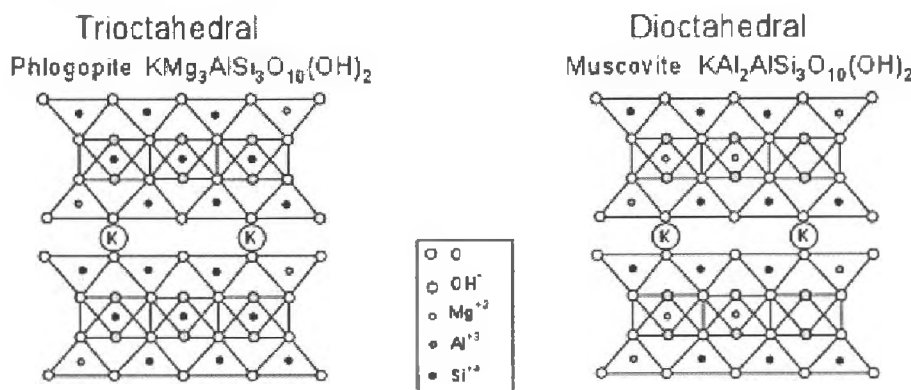


Dioctahedral
Pyrophyllite $\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$



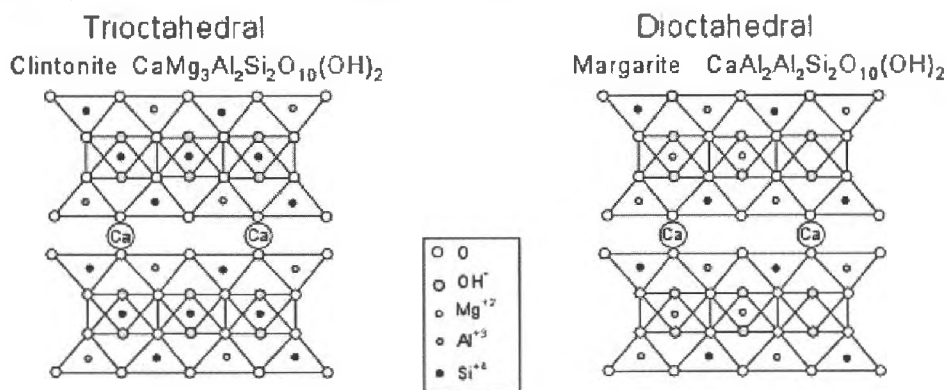
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If an Al^{+3} is substituted for every 4th Si^{+4} in the tetrahedral layer, this causes an excess -1 charge in each T-O-T layer. To satisfy the charge, K^{+1} or Na^{+1} can be bonded between 2 T-O-T sheets in 12-fold coordination.



For the trioctahedral sheet silicates this becomes Phlogopite (Mg-biotite), and for the dioctahedral sheet silicates this becomes Muscovite. This makes a T-O-T - T-O-T layer that, again can bind to another T-O-T - T-O-T layer by weak Van der Waals bonds. It is along these layers of weak bonding that the prominent {001} cleavage in the sheet silicates occurs.

Replacing 2 more Si^{+4} ions with Al^{+3} ions in the tetrahedral layer results in an excess -2 charge on a T-O-T layer, which is satisfied by replacing the K^{+1} with Ca^{+2} .



This results in the trioctahedral sheet silicate - Clintonite and the dioctahedral sheet silicate - Margarite.

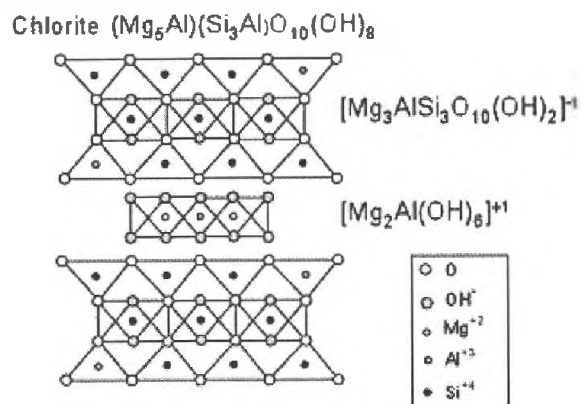
Because of the differences in charge balance between the trioctahedral and dioctahedral sheet silicates, there is little solid solution between the two groups. However, within the trioctahedral sheet silicates there is complete substitution of Fe^{+2} for Mg^{+2} and limited substitution of Mn^{+2} into the octahedral sites. Within the dioctahedral sheet silicates there is limited substitution of Fe^{+3} for Al^{+3} in octahedral sites. In addition, F^- or Cl^- can substitute for $(\text{OH})^-$ in the hydroxyl site. As previously discussed, substitution of F^{-1} stabilizes the mineral to higher pressures and temperatures.

Another group of phyllosilicates that is more of a mixture of structural types is the chlorite group. Although chlorite is complex in that the amount of Al that can substitute Mg and Si is

Phyllosilicates

variable, one way of looking at the chlorite structure is shown below.

Here, the chlorite structure is depicted as consisting of a brucite-like layer (with some Al) sandwiched between tetrahedral layers that are similar to phlogopite.



Another important sheet silicate structure is that of vermiculite. This is similar to the talc structure, discussed above, with layers of water molecules occurring between each T-O-T layer.

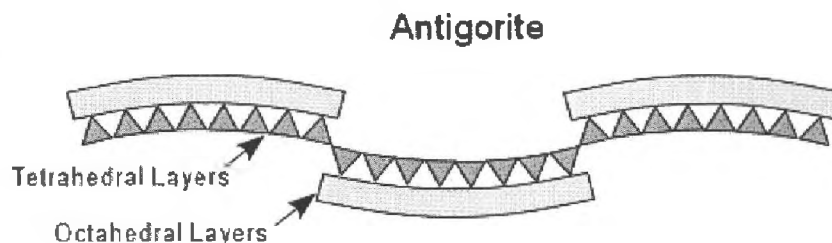
Similarly, insertion of layers of water molecules between the T-O-T sheets of pyrophyllite produces the structure of smectite clays. The vermiculite and smectite groups are therefore expanding type sheet silicates and as the water is incorporated into the structure the mineral increases its volume.

Although we have shown that the octahedral layers fit perfectly between the tetrahedral layers, this is an oversimplification. If the tetrahedral layers were stacked perfectly so that apical oxygens were to occur vertically aligned, then the structure would have hexagonal symmetry. But, because this is not the case, most of the phyllosilicates are monoclinic.

Serpentine Group

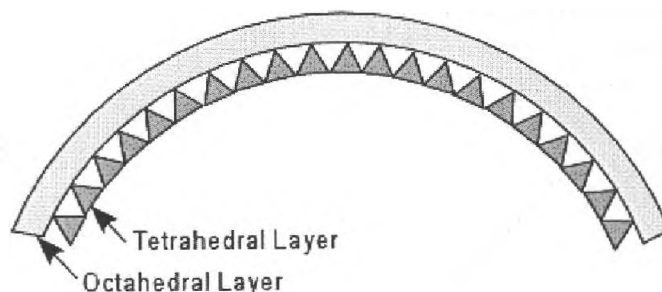
The serpentine group of minerals has the formula - $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$. Three varieties of serpentine are known. Antigorite and Lizardite are usually massive and fine grained, while Chrysotile is fibrous. As discussed above, the imperfect fit of the octahedral layers and the tetrahedral layers causes the crystal structure to have to bend.

In Antigorite the bending of the sheets is not continuous, but occurs in sets, similar to corrugations, as shown here.

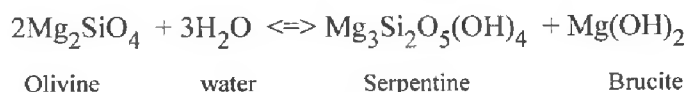


Chrisotile

In Chrisotile, the bending of the sheets is more continuous, resulting in continuous tubes that give the mineral its fibrous habit. The Chrisotile variety is commonly referred to as asbestos.



Occurrence - Serpentine is found as an alteration product of Mg-rich silicates like pyroxene and olivine. It results due to hydration. For example:



Thus, serpentine is commonly found pseudomorphed after olivines and pyroxenes in altered basic and ultrabasic igneous rocks, like altered peridotites, dunites, and sometimes basalts and gabbros. It is commonly associated with minerals like magnesite (MgCO_3), chromite, and magnetite. If the rock is made up almost entirely of serpentine, it is called a *serpentinite*.

Properties - Because the serpentines usually occur either as fine-grained aggregates or fibrous crystals, optical properties are difficult to determine. Most of the time, serpentine can be distinguished by its characteristic pseudomorphing of other crystals like olivines and pyroxenes. In hand specimen it generally tends to have a dark green color with a greasy luster. In thin section it is clear to pale green to pale yellow, but does not show pleochroism, shows a generally low relief compared to minerals like olivine and pyroxene with which it is associated, and show very low order interference colors due to its low birefringence.

Talc

Talc has the chemical formula - $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. It is probably best known for its low hardness. Although it has a micaceous structure, it is so easily deformed, that crystals are rarely seen.

Occurrence - Like serpentine, talc requires an environment rich in Mg. It is therefore found in low grade metamorphic rocks that originated as ultrabasic to basic igneous rocks. Rocks composed almost entirely of talc have a greasy feel and are referred to as *soapstone*.

Properties - Talc is most easily distinguished in hand specimen by its low hardness, greasy feel, and association with other Mg-bearing minerals. When crystals are present they show the characteristic micaceous cleavage on {001}. In thin section, talc is colorless, biaxial negative with a 2V of 0 to 30°. Like other sheet silicates, it shows the well developed {001} cleavage. Maximum interference colors, consistent with a birefringence of 0.05 is 3° yellow. Muscovite has a higher birefringence and higher 2V, properties which easily distinguish the 2 minerals.

Mica Group

The micas can be divided into the dioctahedral micas and the trioctahedral micas, as discussed above. Muscovite, Paragonite, and Margarite are the white micas, and represent the trioctahedral group, and Biotite and Clintonite (Xanthophyllite) the black or brown mica, represents the dioctahedral group. Muscovite and Biotite are the most common micas, but the Lithium- rich, pink mica, Lepidolite, $K(Li,Al)_2AlSi_3O_{10}(OH)_2$ is also common, being found mostly in pegmatites.

Muscovite

Muscovite, $KAl_3Si_3O_{10}(OH)_2$, and Paragonite, $NaAl_3Si_3O_{10}(OH)_2$, are two potential end members of the solid solution series involving K and Na. But, there is a large miscibility gap between the two end members with Muscovite being between 65% and 100% of K-rich end member, and Paragonite showing compositions between about 80% and 100% of the Na-rich end member.

Occurrence - Muscovite is common constituent of Al-rich medium grade metamorphic rocks where is found in Al-rich schists and contributes to the schistose foliation found in these rocks. Muscovite is also found in siliceous, Al-rich plutonic igneous rocks (muscovite granites), but has not been found as a constituent of volcanic rocks. In these rocks it is commonly found in association with alkali feldspar, quartz, and sometimes biotite, garnet, andalusite, sillimanite, or kyanite.

Properties - Muscovite is easily identified in hand specimen by its white to sometimes light brownish color and its perfect {001} cleavage. In thin section, the {001} cleavage is easily seen and it's high birefringence is exhibited by the large change in relief on rotation of the stage and it's 2nd to 4th order interference colors. It is clear and shows no pleochroism (which distinguishes it from Biotite), and it is biaxial negative with a 2V between 28 and 50°. One of the most diagnostic properties of the micas, including muscovite, is the mottled or birds-eye extinction exhibited by these minerals.

Biotite

Biotite is a solid solution between the end members Phlogopite $KMg_3AlSi_3O_{10}(OH)_2$ and Annite $KFe_3AlSi_3O_{10}(OH)_2$, although pure Annite does not occur in nature. In addition, small amounts of Na, Rb, Cs, and Ba may substitute for K, and like in other minerals, F can substitute for OH and increase the stability of Biotite to higher temperatures and pressures.

Occurrence - Nearly pure phlogopite is found in hydrous ultrabasic rocks like kimberlite, and is also found in metamorphosed dolomites. Biotite, with more Fe-rich compositions is common in dacitic, rhyolitic, and trachytic volcanic rocks, granitic plutonic rocks, and a wide variety of metamorphic rocks. In metamorphic rocks, biotite usually shows a preferred orientation with its {001} forms parallel to the schistose foliation.

Properties - In hand specimen, Biotite is brown to black and shows the perfect {001} micaceous cleavage. In thin section, it shows the perfect cleavage and mottled extinction

typical of all micas. It's most characteristic property is its pleochroism, showing yellow to brown to green colors. Hornblende shows similar pleochroic colors, but is distinguished from biotite by the differences in cleavage of the 2 minerals. Biotite is biaxial negative with a low 2V of 0° to 25°.

Chlorite Group

As discussed above, the Chlorite group has a structure that consists of phlogopite T-O-T layers sandwiching brucite-like octahedral layer. There is substantial substitution of Mg for Fe, and Al can substitute for (Mg, Fe) in both the octahedral sites, as well as for Si in the tetrahedral sites. Thus, chlorite can have a rather complicated formula - $(\text{Mg,Fe,Al})_3(\text{Si,Al})_4\text{O}_{10}(\text{OH})_6$.

Occurrence- Chlorite is a common mineral in low grade metamorphic rocks, where it occurs in association with minerals like actinolite, epidote, and biotite. It also forms as an alteration product of pyroxenes, amphiboles, biotite, and garnet in igneous as well a metamorphic rocks.

Properties - In hand specimen, chlorite is recognized by its green color, micaceous habit and cleavage, and association with other minerals like actinolite and epidote. In thin section, Chlorite shows low relief and low birefringence, with a characteristic midnight blue to black anomalous interference color. It shows some pleochroism in the range of green to pale yellow. It is easily distinguished from biotite by its lower relief and anomalous interference color.

Examples of questions on this material that could be asked on an exam

(note that properties that distinguish different minerals will be included in the laboratory exam)

1. What is the difference between the dioctahedral and trioctahedral sheet silicates?
2. What is the difference between antigorite and chrysotile?
3. State whether each of the following minerals would be most commonly found in igneous rocks, metamorphic rocks, or both igneous and metamorphic rocks: (a) Chlorite, (b) biotite, (c) muscovite, (d) talc, (e) serpentine,

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