PLAINTIFF'S EXHIBIT
UC-879

MINERALOGY OF THE COALINGA ASBESTOS DEPOSIT

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SUMMARY

For the last four years, a major mineralogical study has been carried out on the Coalinga asbestos deposit to study the basic chemical and physical properties of the chrysotile asbestos ore, and to determine the distribution of minerals within the deposit and throughout the surrounding New Idria serpentinite body. The various milling operations used in the refining processes have also been studied in some detail, to determine the paths of the various ore and gangue minerals throughout the wet-processing circuit. The lack of definitive information in the literature about many of the fundamental properties of asbestos materials has made it necessary to conduct a number of basic mineralogical studies of the serpentine minerals.

NOMENCLATURE AND OCCURRENCE OF ASBESTOS

The word "asbestos is a commercial term for a group of fibrous silicate minerals that are both fire-proof and capable of being processed into flexible fibers. Although six different minerals are currently mined as "asbestos", the mineral chrysotile accounts for more than 95% of the world's production. Most commercial deposits of chrysotile asbestos are found as cross-fiber or slip-fiber veins within large bodies of serpentinite rock. The veins vary in size from fractions of a millimeter to several inches; their quantity and size determine the economic potential of the ore body.

The United States is not a major producer of asbestos. Canada, however, produces one million tons per year, an amount equalled only by the Soviet Union in recent years. In this country, small tonnages of asbestos are mined in northern Vermont, Arizona, and California. The size of the Coalinga asbestos deposit should add considerably to United States asbestos production in the future.

Chrysotile asbestos is the fibrous member of the serpentine group of minerals, which also includes the platy minerals, lizardite and antigorite. All members of this group have the same general formula, $Mg_3Si_2O_5(OH)_4$, with small amounts of nickel and iron substituting for magnesium. The serpentine structure, shown in Figure 1 of the text, consists of a unit magnesium hydroxide layer (brucite layer) connected to a unit silicon-oxygen layer (silicate layer) to form an infinite two-dimensional sheet. In the case of chrysotile, small differences in the unit dimensions of the two layers result in a curvature of the sheet with the brucite layer on the outside. Therefore, chrysotile occurs as tubular fibers of various lengths. The average fibril has an inner diameter of 110 Å and an outer diameter of 260 Å, or a wall thickness of about ten layers of the basic 1:1 serpentine sheet.

Although chrysotile is readily distinguished from other serpentine minerals by its tubular-fibrous habit (by electron microscopy), the similar morphologies of lizardite and antigorite preclude their differentiation by this technique alone. It is necessary to employ a combination of techniques, including film x-ray diffraction, electron diffraction, and electron microscopy, to make an unequivocal

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identification. No one technique is by itself completely satisfactory, especially where mixtures of two or more of the members are involved. In this respect, the present studies have shown that mixtures are the rule rather than the exception; all combinations of serpentine minerals have been encountered in the most highly purified samples and in the type specimens from around the world.

HISTORY OF THE COALINGA DEPOSIT

Late in 1957, Mr. J. H. Bright of our Exploration Department examined a group of asbestos claims, owned by the Condor syndicate, within the highly altered and sheared New Idria serpentinite, on the county line between Fresno and San Benito Counties, California. Bright noted that although the typical veins of cross-fiber chrysotile were not present in this ore, the entire southeastern third of the serpentinite body was made up of tough, leathery, sheet-like materials, intermixed with soft, friable, powdery agglomerates of asbesto-form material. The ore extended at least several tens of feet beneath the surface and appeared reasonably uniform over an area nearly of 15 square miles. Subsequent laboratory studies showed that this ore contained between 50 and 75% chrysotile in the form of very short fibers, matted together into small, pellet-like agglomerates. Most Canadian-type asbestos deposits contain only 5-10% usable fiber. The Condor asbestos ore, therefore, appeared to comparable with the Grade-7 Canadian asbestos, and thus appeared to be potentially useful in such products as wall-board, cement, shingles, and floor tile. This nearly unlimited supply of short-fiber asbestos prompted us, and several other companies, to acquire the mining rights to many square miles of ground within this body; by the end of 1959, Union Carbide was in control of more than 200 claims of what appeared to be the best asbestos ore, representing approximately 75% of the entire deposit.

All exploration activities were centered in the near-by town of Coalinga, and the asbestos deposits in the New Idria serpentinite shortly became known as the Coalinga asbestos deposits. At the present time, three major companies are mining ore from this deposit: Union Carbide, Atlas Corporation, and Coalinga Asbestos Corporation (a joint venture by Johns Manville Corporation and Kern County Land Company). The latter two process the ore by standard dry-lifting techniques at their mine-sites, while we haul the ore to King City for wet processing. In addition to the normal uses of short-fiber asbestos, mentioned above, the wet-processed asbestos has proved to be applicable to an entirely new spectrum of uses in the paper industry, water clarification, and other specialized businesses.

GEOLOGY OF THE DEPOSIT

The New Idria serpentinite occupies an area about 4 miles wide and 12 miles long. It resembles an elongated dome, flanked by upturned sandstones and shales. It forms resistant hills and ridges surrounded by lower, rounded hills. Most of the contacts between the serpentinite and the surrounding sediments are covered by landslides; however, where contacts are visible, they are often steeply dipping and are marked by high-angle faults or zones of extensive shearing, with little evidence of contact metamorphic phenomena. The serpentinite bears little

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resemblance to most of the other serpentinite bodies found throughout the world, since most of the mass has been highly sheared and pulverized, and consists of soft, friable sheets and clumps of asbesto-form material, admixed with a fine, talcose, asbestos powder. Hard, dense, competent masses of serpentinite rock, varying in size from fractions of an inch to several tens of feet in diameter, are scattered throughout the body, and stand out as resistant knobs or as "boulders" encased in softer, friable material.

The highest degree of shearing and fracturing appears to coincide with the areas of highest-grade asbestos, in the southeastern third of the body. The total depth of the serpentinite itself has been estimated from gravity surveys to be on the order of several thousand feet. The deepest drill hole (in the vicinity of the present Joe 5 pit) penetrated high-grade ore at a depth of 500 feet. The extremely incompetent nature of the asbestos ore, especially when it is wet, has resulted in numerous landslides in the past; portions of the serpentinite have filled former valley bottoms and have covered areas as large as several square miles. The crescent-shaped scarp shown in Figure 46 illustrates a recent slip, less than one mile from the present mine site.

MINERALOGY OF FRESH ASBESTOS ORE

Four main types of serpentine materials are distinguishable in the Coalinga asbestos ore: (1) hard, dense, dark-blue and green fragments of blocky serpentinite, ranging in size from fractions of an inch to boxcar dimensions; (2) large, tough, leathery sheets of matted chrysotile, up to several square feet in diameter; (3) small, brittle, bladed and platy fragments of green serpentine, up to several square inches in size; and (4) soft, friable, greenish-white agglomerates of flaky asbestos varying from about 1/4" to 1" in diameter, containing appreciable amounts of both the green-bladed material and the hard, dense serpentinite rock fragments.

The Coalinga ore consists predominantly of members of the serpentine group of minerals. Chrysotile itself is the major constituent of the soft, friable ore, and is the sole constituent of the leathery sheets and the green-bladed fragments. The hard, dense serpentinite "boulders" consist primarily of lizardite and antigorite, with varying amounts of short-fiber chrysotile, brucite, and magnetite. Minor quantities of calcite and traces of chromite and uvarovite garnet are also present. Talc has not been observed in the ore body. Chemical analyses of various purified fractions of chrysotile from the ore show only minor differences, although the green-bladed chrysotile appears to be somewhat enriched in iron compared with chrysotile from the leathery sheets. The longest fibers of chrysotile (up to several microns in length) have been found in the leathery sheets, while the chrysotile from the serpentinite rock is much shorter and stubbier. In contrast to the cross-fiber arrangement of most chrysotile asbestos ores, the chrysotile from this deposit occurs as a swirling mesh of disoriented fibers, as shown in Figures 49 and 50. Magnetite particles are also scattered throughout the sheets and imbedded in flakes.

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The greatest part of the gangue material in this ore consists of the hard, dense, serpentinite rock fragments, which are scattered throughout the soft, friable ore. In addition to lizardite and antigorite, these materials contain the bulk of the brucite, magnetite, and chromite found in the ore. Petrographically, they consist of dense aggregates of serpentine minerals, arranged in a breccia-like manner. Brucite is often intergrown with serpentine and frequently forms aggregates of alternating thin lamellae of each mineral. In most serpentinite fragments, two size ranges of magnetite are present, indicating two generations of crystallization. The larger particles probably formed when the mass crystallized from the parent magma, while the smaller grains probably were thrown down during the serpentinization process. Optical studies suggest that the composition of the parent olivine was approximately $(Mg_{1.82}Fe_{0.18})SiO_4$, similar to the olivine in most dunite bodies.

The results of chemical, electron probe, and x-ray diffraction analyses all confirm that the brucite in this ore is not pure $Mg(OH)_2$, but that it contains approximately 15 weight percent iron in solid solution, and has an approximate formula of: $(Mg_{10}Fe_2)(OH)_{24}$. The iron content of the brucite is a critical factor in the susceptibility of the ore to weathering, and exposure of brucite-rich ore to surface oxidation conditions invariably leads to marked discoloration of the ore.

MINERALOGY OF THE SURFACE WEATHERING ZONE

The surface weathering zone extends to a depth of 20-30 feet and is characterized by a reddish-brown color. Here, blocks and fragments of residual serpentinite have been transformed into soft, brown, crumbly masses; while the surrounding friable asbestos ore has been only slightly discolored. Surface coatings of white artinite ($Mg_2(OH)_2CO_3 \cdot 3H_2O$) and hydromagnesite ($Mg_4(OH)_2(CO_3)_3 \cdot 3H_2O$) are also common, the later mineral occuring as concentrations of white, pea-size concretions immediately above the water table. The weathered serpentinite "boulders" are enriched in pyroaurite ($Mg_6Fe_2CO_3(OH)_{16} \cdot 4H_2O$) and coalingite ($Mg_{10}Fe_2CO_3(OH)_{24} \cdot 2H_2O$), a new mineral discovered during the present study. Amorphous iron oxides are also abundant in the weathering zone, while brucite is almost absent. Field observations and laboratory experiments have shown that in the surface weathering zone, iron-rich brucite either dissolves, leaving behind a brown, amorphous residue of iron oxides, or transforms *in situ* into pyroaurite and/or coalingite by oxidation and carbonation. Further weathering destroys these minerals also, leaving behind more iron oxide. The dissolved magnesium later precipitates as hydromagnesite throughout the deposit. The generalized reactions involved, are shown schematically in Figure 54.

GENESIS OF THE DEPOSIT

Any consideration of the genesis of this unusual type of asbestos deposit must also include speculation on the formation and history of Alpine-type serpentinites, in general. These bodies are thought to have formed by the low-temperature hydration of pre-existing olivine- and pyroxene-rich ultramafic rocks (dunites and peridotites) to produce a mixture of serpentine and brucite. The process of serpentinization may therefore be represented by the following reaction:

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$$2Mg_2SiO_4 + 3H_2O = Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$$
Olivine — Water — Serpentine — Brucite

This reaction is accompanied by a considerable increase in volume (up to 40% and probably results from incremental additions of water from surrounding sedimentary rocks during the tectonic ascent of the ultramafic mass through the earth's crust. Serpentinization cannot proceed, in this manner, above 400°C and probably takes place between 100° and 300°C. Much, or all, of the expansion is probably accommodated during tectonism, and very likely assists in the diapiric ascent of the mass.

The New Idria serpentinite was probably formed in this same manner. The presence of serpentine and brucite indicates that the parent igneous rock consisted primarily of olivine. The composition of the minerals in the deposit suggest that the product serpentine actually contains less iron, and the product brucite, more iron that the parent olivine. The Coalinga asbestos deposit does not resemble most of the world's serpentinite bodies, and consists of a matrix of soft, friable, powdery asbesto-form material, surrounding fragments and blocks of hard, dense serpentinite. Only the Stragari deposit in southern Yugoslavia is known to be similar. The New Idria mass probably injected "cold" into the surrounding sediments. Its location close to the San Andrea fault zone probably accounts for its highly fractured and sheared appearance. The material present in the deposit today may be thought of as having been formed by the crushing and pulverization of hard, serpentinite blocks, much as a thick paste is ground and smeared out in a wet-ball mill or a mix-muller.

TYPICAL CHEMICAL COMPOSITION OF "CALIDRIA" ASBESTOS PRODUCTS

SiO_2	41.9%
MgO	41.8
FeO	0.6
Fe_2O_3	1.0
Al_2O_3	0.3
H_2O	13.3
CaO	0.1
NiO	0.1
Others	0.9
Total	100.0%

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