SPECIAL PUBLICATION 49

CALIFORNIA JADE

A COLLECTION OF REPRINTS

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CALIFORNIA DIVISION OF MINES AND GEOLOGY

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Nephrite Jade and Associated Rocks of the Cape San Martin Region, Monterey County, California
by Richard A. Crippen, Jr., 1951.

Nephrite in Marin County, California
by Charles W. Chesterman, 1951.

Jadeite of San Benito County, California
by H.S. Yoder and Charles W. Chesterman, 1951.

Intrusive Ultrabasic Rocks and Their Metamorphic Relationships at Leech Lake Mountain, Mendocino County, California
by Charles W. Chesterman, 1963.

Nephrite Jade in Mariposa County, California
by James R. Evans, 1966.

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INTRODUCTION

Diamonds are said to be forever, but there are very few gemstone materials about which there has developed throughout the ages such a curious lore as there has about jade. In California, this lore has attracted statewide attention, principally because deposits containing the jade minerals, jadeite and nephrite, occur at several places throughout the state and because gem or lapidary quality jade has been recovered in substantial amounts from several of these localities.

Many dense, fine-grained, green-colored rocks have mistakenly been called jade; but, from a gemological point of view, jade is a name given to the massive, gem-quality varieties of the two rock-forming minerals nephrite and jadeite. Nephrite is an amphibole, a silicate of calcium and magnesium that usually contains a small amount of iron. Jadeite, on the other hand, is a pyroxene and is a silicate of sodium and aluminum; usually, however, it contains variable amounts of two other pyroxene minerals, diopside (silicate of calcium and magnesium) and acmite (silicate of sodium and iron), which, when present in sufficient amounts, produce a dark green variety of jade called chloromelanite.

It is true that nephrite and jadeite resemble each other very closely, but they can be distinguished by their different physical and chemical properties. Not only is jadeite harder than nephrite but it has a higher specific gravity. In general, the specific gravity of jadeite is 3.32 and that of nephrite is 2.98.

Both of these minerals have a wide range of colors and color shades. Jade ranges in color from pure white, through every possible shade of green to amethyst, mauve, violet and light blue, yellow, orange and diverse tints of brown, red, and black. Because the colors in nephrite and jadeite usually are distributed unevenly, descriptive terms such as mutton fat, spinach green, and onion green have been employed to describe jade.

Successful use of jadeite or nephrite as gem quality jade depends upon several important properties, such as desirable color, color pattern, and a certain degree of translucency. Because of this, the amount of jadeite and nephrite that is of gem quality is rather small in comparison to the amounts of these materials that are of mineralogical significance only.

The occurrences of nephrite and jadeite, especially nephrite, are comparatively widespread and common in California. Most deposits of these interesting gemstone materials have been found only in or adjacent to bodies of serpentine, an association that seems to be characteristic of nephrite and jadeite occurrences throughout the world. Exceptions to this, however, are the unusual occurrences of nephrite associated with magnetite, epidote, chlorite and garnet in irregular contact metamorphic zones between granitic rocks and dolomitic limestone, near Victorville in San Bernardino County and in the western part of the Eagle Mountains in Riverside County.

Many of the occurrences of nephrite and jadeite in California are well known to individuals and groups of amateur mineralogists but the several reports that follow, which have been prepared and published by the Division of Mines and Geology, describe in detail a few of the best known and most significant occurrences of nephrite and jadeite in California.

C. W. Chesterman
San Francisco, 1973

NEPHRITE JADE AND ASSOCIATED ROCKS OF THE CAPE SAN MARTIN REGION, MONTEREY COUNTY, CALIFORNIA

Reprinted from Special Report 10-A (May 1951)

By Richard A. Crippen, Jr.*

OUTLINE OF REPORT

Illustrations

ABSTRACT

Pebbles and boulders of nephrite found in the shingle of beaches near Cape San Martin, in southern Monterey County, California, are adjacent to bedrock occurrences of nephrite in the sea cliffs. Gray schists, massive recrystallized rock and mylonites predominate; these have been derived mainly from shale, sandstone, calcareous graywacke, and siltstone of upper (?) Franciscan (Upper Jurassic) age. Many intrusions of peridotite, now serpentine, have further affected the schists, and the nephrite in place is always near such bodies of serpentine.

Two modes of genesis are demonstrated, but in all cases, the nephrite was evidently derived from portions of the cataclastic rocks by chemical reconstitution under the stress of differential movement. Magnesia metasomatism from the periodotite was essential to the process, which took place under epizonal temperature and pressure.

INTRODUCTION

Within the past few years jade has become familiar to many persons in California who delight in the hobby of polishing stones. This is largely due to the accessibility and local abundance of this rare mineral variety among the boulders and pebbles of certain small beaches in southern Monterey County; to the discovery of jade in Tulare County in minable quantity; to another occurrence in Marin County; and to large amounts of the very rare jade species, jadeite, found recently in southern San Benito County and in Mendocino County. Some of the mystic appeal of jade may have been lost now that it is not exclusively a product of faraway places, but the intrinsic qualities of jade, so revered by the Chinese, now have meaning for many Americans.

* Supervising Geological Draftsman, California Division of Mines. Manuscript submitted for publication August, 1950.

Because wondrously carved objects expressing the artistry of Chinese jade workers may be found in nearly every part of the world in museums and Chinese stores, we are likely to associate jade primarily with China.

However, in the late Stone Age before man learned to use metals for weapons and tools, the green stone we now call jade was widely used for axes, chisels, spear points, and other objects, which were fashioned by grinding. Other stones were used also, but the advantages of jade over other materials were discovered independently, it would appear, in nearly every continent, as jade artifacts have been found in China, Europe, Siberia, Alaska, Mexico, Central and South America, and New Zealand.

The peculiar properties of jade—extreme toughness, hardness usually greater than steel, and workability by grinding and sharpening on the slightly harder common sandstone—made it well fitted for use as tools. The characteristic shape of many of the jade pebbles of streams, beaches, and gravel deposits, are thin-edged slabs or lenses, which no doubt facilitated adaptation, as the stone cannot be broken or chipped to shape as can flint. Late Stone Age people made other objects of jade too, such as symbolic and ornamental pieces, indicating an early perception of the beauty of the smooth green stone.

Although it is probable that stream pebbles and float were the principal source of jade for these early artisans, deposits in place have been known in several parts of the world, including China, Alaska, Siberia, New Zealand, and Europe.

Only two jade artifacts have been reported in the United States; a celt or chisel found in New Mexico evidently came from Old Mexico, and a jade axe found in Washington is presumed to have been brought from Alaska.[1]

For this reason the finding of jade in the United States appeared unlikely, and its discovery in Wyoming and California sometime after 1935 was of unusual interest to both mineralogists and archaeologists. Our native Stone Age Americans had learned to shape axes and chisels by grinding, and the apparent fact that the Wyoming jade was not so utilized, is remarkable.

ACKNOWLEDGMENTS

This study of the Monterey County nephrite was suggested by Dr. Olaf P. Jenkins, Chief of the Division of Mines. For helpful discussion and petrographic assistance, the writer is indebted to Charles Chesterman and Lauren Wright, Associate Geologists, Division of Mines, and to Garn Rynearson, Geologist, U. S. Geological Survey. Also gratefully acknowledged is the help given by Dr. Frank J. Turner and Dr. Adolph Pabst of the University of California.

The author first visited the localities by the invitation and guidance of Orlin J. Bell, then president of the Federation of Mineralogical Societies of California, and members of several of these societies donated specimens and information about localities.

[1] Heizer, Robert F., personal communication.

JADE IN THE UNITED STATES

Nephrite jade has been discovered in four places in the United States. Three are in California and the other near Lander, Wyoming. Some of the Wyoming jade is of fine quality and color, perhaps superior to any yet found in California.

The California deposits include those of the coast of southern Monterey County, described in this paper; a discovery (1949) near Porterville, Tulare County; and another near Petaluma, Marin County, found by M. Vonsen. Although the bedrock exposures of nephrite in Monterey County are excellent for geologic observation, the material found in place is not of choice color. The best pieces found have been loose boulders and pebbles, some of which have produced attractive polished gems of fine quality.

Specimens of the Porterville material sent to the Division of Mines early in 1949 were identified as nephrite; in October 1949, the deposit was being mined by the discoverers, Frank Janoko and C. V. Alston of Porterville. At the time more than a ton had been blasted from the lens and several tons were in sight. It is variable in quality but is largely of good green color and is very translucent, making excellent gem stones.

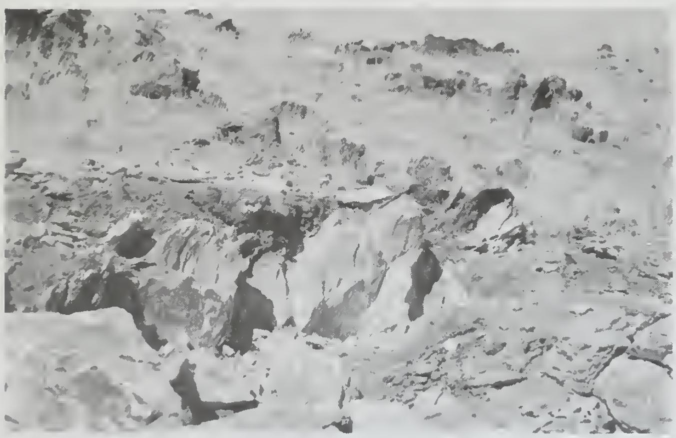


FIGURE 1. Site of first jade quarrying operation in California, 1949. The Janoko Brothers and Alston workings near Porterville, Tulare County. Face of working, left center, is green nephrite. Stock pile is to right. Outcrops on hillside are metasediments of the Kaweah series (Triassic) and serpentine of large sill enclosing the jade lens.

Of great interest is the jadeite discovered during 1949 and 1950 in Mendocino and San Benito Counties. Numerous stream pebbles and boulders have been found in both places; the jadeite ranges from opaque dark green to white, translucent material with green spots and streaks. In San Benito County, Charles W. Chesterman has found jadeite in bedrock association with schists and serpentine.[2] This occurrence in place is one of the few places known in the world where jadeite and accompanying rock types can be studied.

Other deposits in place will no doubt be found, as beach and stream pebbles from several northern California localities have been identified as nephrite and jadeite by the Division of Mines.

[2] Chesterman, Charles W., Jadeite in San Benito County, California: Lapidary Jour., vol. 4, pp. 204, 208, 1950.

NEPHRITE AND JADEITE

The term jade in this report includes nephrite and jadeite. Although both species are represented in artifacts of China, Europe, and Mexico, the known sources of nephrite are numerous whereas jadeite is extremely rare, having been found in quantity in Burma only. The Burmese deposits have been mined since late in the eighteenth century and it is likely that much of the Chinese jade-working since 1800 is in jadeite. Before that time the ancient nephrite mines of Chinese Turkestan evidently supplied most of the material. Some say that nephrite is called "true jade" by the Chinese, others that color and cutting quality are the only value criteria, regardless of variety. It is seldom practical to distinguish nephrite and jadeite in carved and polished pieces, but their mineral properties differ sufficiently when tests can be made. Some shade of green is typical of most nephrite and jadeite, but both greenish-black and nearly colorless varieties and more rarely, red, mauve, and brown jade is seen. Most valuable is the precious jade of brilliant translucent green, compared by the Chinese to the green of young rice shoots. It is said that such material is found only in small patches within white jadeite.

Nephrite is not classed as a separate mineral species, but as a compact-fibrous variety of the actinolite-tremolite series of the amphibole group. Tremolite is calcium-magnesium silicate ($Ca_2Mg_5Si_8O_{22}(OH)_2$), usually white or grayish. Actinolite differs from tremolite in that part of the magnesium is replaced by ferrous iron, giving the actinolite a green color. The two minerals form an isomorphous series, intermixing in almost any proportion, and hence grading from colorless to dark green. They are quite common metamorphic minerals, found usually in crystals or fibrous masses. The finely fibrous type is the asbestos of many familiar uses (not to be confused with chrysotile, the fibrous serpentine).

In the asbestiform type, individual fibers, each a crystal, may be separated from the bundles with ease, and the ultimate practical separation at times will produce microscopic filaments. Nephrite of identical composition chemically, on the other hand, is one of the toughest, most nearly unbreakable minerals. At least a part of the explanation is revealed by the petrographic microscope with which one may observe the structure of nephrite. As seen in polarized light, thin sections or grains of nephrite are a complex intergrowth of bundles of filament-like crystals in a random felted arrangement. This remarkable microstructure is characteristic of good quality nephrite, which together with its optical properties usually provides quick and certain identification. Much jadeite possesses a similar microstructure, but in other optical properties it differs from nephrite. Nephrite of good cutting quality, the dense horny type, has this intricate felted structure, and a hardness of 6 to 6.5.

NEPHRITE OF MONTEREY COUNTY

Nephrite occurs in bedrock at several places in the seaworn cliffs within a 2-mile stretch of coast in southern Monterey County. The region is midway between Monterey and Morro Bay, about 60 miles from either town. The Army Engineers map of the Cape San Martin quadrangle covers the area and shows State Highway 1.

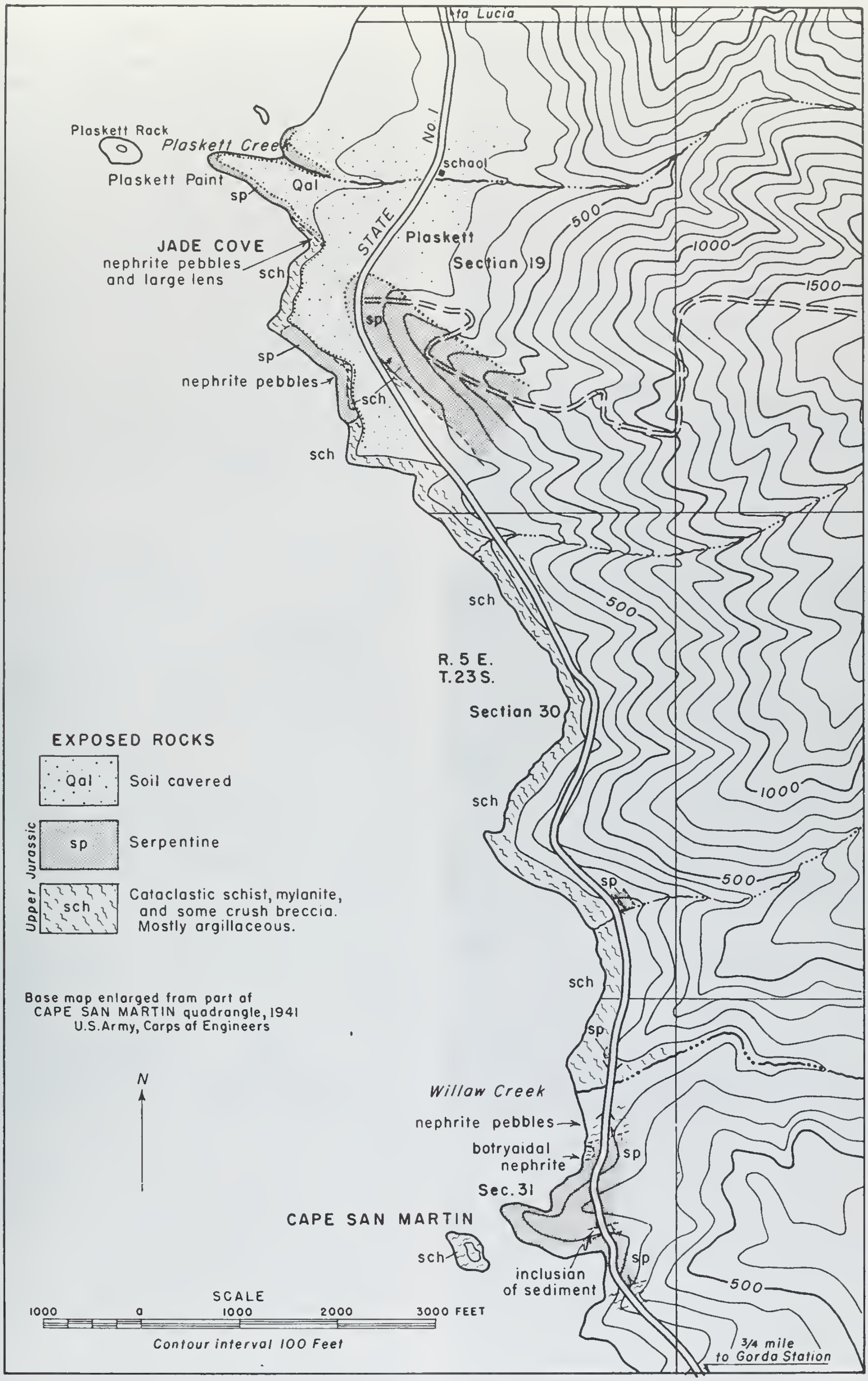


FIGURE 2. Topographic and geologic sketch map of the Plaskett-Cape San Martin region, Monterey County, California, showing nephrite localities.

The older U.S. Geological Survey map of the same area was made long before the highway was constructed. The principal deposits in place are those near Plaskett (a ghost town except for a country school) in section 19, and at Willow Creek, section 31, both in T.23S., R.5E. Cape San Martin promontory stands out just south of Willow Creek near a huge offshore sea stack. The small but instructive nephrite occurrence is in the sea cliff just north of the cape. The Plaskett locality of greatest interest is in the cove south of an unnamed slender promontory which points to another great sea stack 300 yards out to sea. The sea stack, a creek, and the old settlement bear the name of Plaskett so the promontory might well be called Plaskett Point and for convenience the name will be used in this paper. Furthermore, as the first discovery of nephrite in place in California was in the cove mentioned, it seems most fitting to call it Jade Cove.

The Jade Cove nephrite discovery was made by E. S. Parmalee of Palo Alto during his search for the source of the nephrite pebbles which local residents had found occasionally on the beaches nearby. The precise location was not disclosed by the finder nor by Rogers,[3] who reported it in 1941. It was rediscovered in 1947 and the locality is now widely known among the members of

FIGURE 3. Sedimentary sequence near Alder Creek. Hard black shale with sparse sericite in partings, silty shale and highly calcareous graywacke. Probably upper Franciscan.

amateur mineral and lapidary societies of the state. The narrow pebble beach in Jade Cove is reached by a fair trail down the cliff. Some excellent nephrite has been found here ranging from small pebbles to beach worn boulders. Many of the pebbles are nephrite, but few are of desirable color and translucency. A very large block of nephrite in bedrock is exposed here as well as numerous small pods and lenses of mediocre nephrite.

The next cove to the south has produced some nice jade, but it is less accessible. It can be visited at low tide, either by a difficult climb down the cliff or over the tumbled sea-cliff boulders from the point of land south of Jade Cove.

Most accessible is the beach at Willow Creek and although nephrite pebbles are rather scarce, some good ones have been found. An easy trail leads to the beach from the south end of Willow Creek bridge.

[3] Rogers, A. F., Nephrite jade from Monterey County, California: (abstract) Am. Mineralogist, vol. 26, p. 202, 1941.

Geology

The rocks of the seaward slope of the Santa Lucia Range within the Cape San Martin quadrangle are assigned to the Upper Jurassic Franciscan group. Members of this group, such as arkosic sandstone and graywacke, shale, chert, basalt, and serpentine are seen in typical exposures in the roadcuts and outcrops both to the north and south of the Plaskett-Cape San Martin region. In the Plaskett-Cape San Martin region, however, these types, with the exception of serpentine, are rare, and a peculiar gray schist of considerable variability is found. Overlying the schist at Plaskett is a sill-like body of serpentine which forms a prominent jutting spur of the mountainside and also underlies Plaskett Point. The sill strikes N. 45 W., dips about 35°-40° NE., and is more than 300 feet thick, where it is exposed in the roadcut. There its lower contact with the schist is well-defined, and is parallel to the schistosity. Irregular blocks and masses of serpentine are found in the schist in several rather widely separated places along the seacliffs to the south. Evidently these bodies are parts of minor offshoots of the large intrusions.

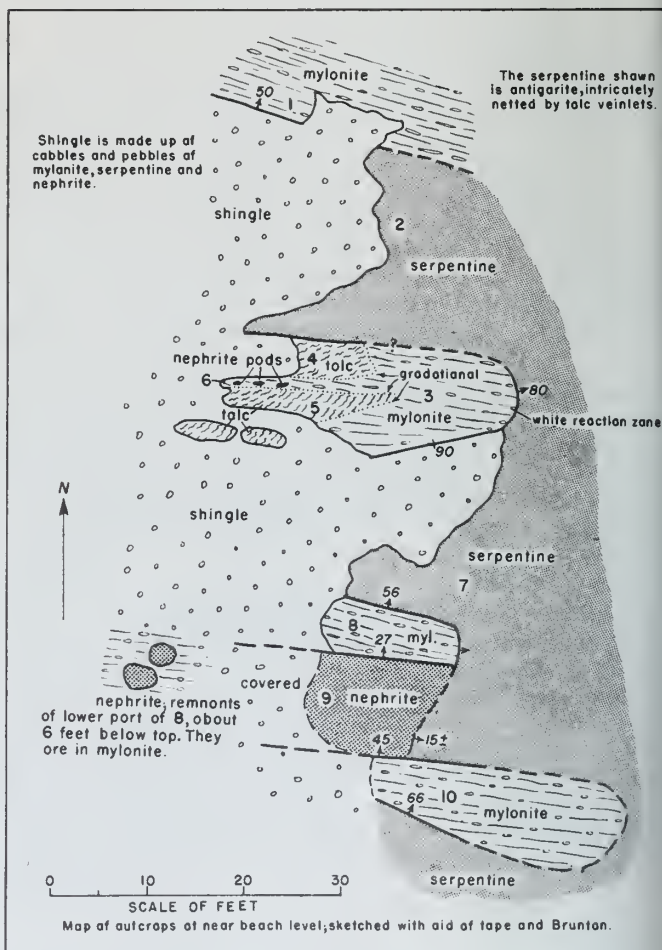


FIGURE 4. Geologic sketch map of part of Jade Cove showing large nephrite lens, small pods, and associated rocks.

One and one half miles south from Plaskett to Willow Creek the schist, owing to gentle northeast dip, increases in thickness to a maximum of at least 500 feet risible in the steep north wall of Willow Creek gorge. The gorge of Willow Creek is cut in a zone marking an ıbrupt change in geologic structure. In the section to the ıorth the principal schistosity approaches a horizontal ttitude, whereas south of the creek the planar structures lip steeply in a northerly direction. About 250 feet south of Willow Creek bridge the schist is in contact with the arge serpentine body which forms much of the promonory of Cape San Martin. This intrusive body is sectioned t two horizons: in the roadcut, and in the sea cliffs beow. It appears to be of tabular form, about 1200 feet hick, dipping steeply northward and striking northeast. The schist of both footwall and hanging wall appears enerally conformable in attitude, but there are local ivergences of planar structures. In exposures near Wilow Creek bridge the schist is hard, greenish-gray rock f such coarse schistosity as to resemble bedding. Closer xamination reveals a structure in which sandy material s rolled out in a darker matrix of very fine grain, probbly derived from argillaceous beds by cataclastic metanorphism. Although this rock is called schist for lack of better name, it is a relatively competent rock, and subseuent dislocating forces have been largely absorbed by he serpentine which is greatly sheared.

Within the serpentine body in the roadcut there is block of sedimentary material, 75 feet wide in the secion exposed. Its southern boundary is a white reaction one against sheared serpentine; the northern contact is overed. Most of the block is fine-grained graywacke inerbedded with hard black silty shale lying nearly horiontal but broken by vertical joints and small dislocaions. From the serpentine contact for several feet invards the bedding has been obliterated and blended into nassive rock which grades from the outer whitened zone nto greenish-gray material.

In the sea cliff just within the northern face of the erpentine another argillaceous mass is found. It is 120 eet across between walls of serpentine and is roofed by erpentine. Near the mid-point of the exposure remnants f sedimentary bedding remain but most of the mass has een crushed and recrystallized to a massive, very finerained rock. A whitened zone also bounds this body. It s not certain whether these sedimentary masses were lucked and engulfed by the peridotite invasion or if they re remnants of interdigitations, but the first seems most lausible. It would appear that the peridotite invaded edded sediments as a dike, producing thick zones of chist and other cataclastic rocks by the differential movenent induced.

In the road cut near Alder Creek, 3½ miles to the outh, graywacke, silty shale, and hard black shale strata ompose a thick section. This series dips gently northeast howing only minor folding and faulting. The lithology f these sediments appears similar to that of the Cape San Martin road cut inclusion. From fragmentary bedling seen north of Willow Creek this same weak sedinentary series may well have been the parent rock of nuch of the Plaskett-Cape San Martin schists. More nearly typical Franciscan sequences, such as massive andstone or graywacke and some shale, to sections predominantly shaly, no doubt are represented also in the bewildering lithologic variations. In places highly fissile chist appears to grade into massive recrystallized rock, and every possible intermediate phase seems represented along the road cuts. Occasional crush breccia of sandy fragments in argillite indicate the sedimentary origin but usually none of the minerals can be determined by hand lens in these very fine-grained rocks.

The very extensive development of such cataclastic rocks in the region north of Willow Creek can hardly be assigned to effects of peridotite intrusion alone. It is more readily believable that they are a product of great differential movement between underlying and overlying competent rocks. There is evidence also that the Plaskett peridotite intrusion followed rather than instigated the production of some of the schists. Both processes, however, probably took place during the Diablan orogeny which Taliaferro [4] believes closed the Jurassic period, as the lithology of the sediments seen in the region resembles the upper Franciscan and Knoxville types.[5]

FIGURE 5. Jade Cove. Cliff in background is mylonite rock, overlain by serpentine near top of picture. Numbered outcrops are shown on geologic map, figure 4. Camera facing north.

The uplift of the Santa Lucia Range according to Taliaferro [6] involved elevation by horizontal compression and development of thrust faults dipping inward on both sides of the range, and it is to a low angle thrust that the schists of the region north of Willow Creek are most logically ascribed.

[4] Taliaferro, N. L., Geologic history and structure of the central Coast Ranges California: California Div. Mines Bull. 118, pp. 127-128, 1943.
[5] Taliaferro, N. L., op. cit., p. 126.
[6] Taliaferro, N. L., op. cit.

Plaskett and Jade Cove

The Plaskett region is also called Pacific Valley; however, the gently sloping land surface is a wave-cut terrace, not a valley. At the widest point it is about half a mile from the sea cliffs to the mountain side, one of the very few areas of flat land along this stretch of coast. The rocky shelves and narrow beaches which are exposed at low tide along the near vertical cliffs are accessible at several places: by trail down the north bank of Plaskett Creek, by trail into Jade Cove, and by a rather easy descent at the south side of the point of land to the south of Jade Cove.

Although the writer did find a single pebble of nephrite at the mouth of Plaskett Creek, it is not a favorable spot for jade collecting. Plaskett Creek has cut its bed along the northern and upper side of the serpentine sill which forms Plaskett Point and the little cove formed at the mouth of Plaskett Creek is in the serpentine. Certain folded layers of light-gray microcrystalline rock and unusual colors and structures in the serpentine probably indicate nearness to the upper contact.

The trail into Jade Cove ends on a shelf of boulders and angular rock masses broken from the cliff. Traversing the foot of the cliff to the southeast one comes upon a small pebble beach, and the nephrite in bedrock. The nephrite occurrences are included in an 80-foot stretch of beach and outcrops which are shown on the geologic map (fig. 2) and in the accompanying photographs. Outcrops and special features both on the map and in the photographs are numbered. In this zone an interfingering of serpentine into the schist, accentuated by some dislocation, is apparent. The schist contact (no. 1) with serpentine (2) is a planar structure which seems more in the nature of a compressional feature than a fault. Serpentine no. 2 evidently terminates a short way to the west under pebble and boulder cover as the fault 50 feet to the west is in schist. A layer of green actinolite asbestos elongated horizontally lies in the plane of movement at the fault. At the blunt end of wedgelike outcrop no. 3, a whitened zone grades into the gray schist at the serpentine contact. Much of this outcrop has been replaced by talc, and pods of nephrite lie in the gray schist layer between the talc zones. The dark schist grades into talc schist without a break in structure. Evidently the talc schist was derived by magnesia metasomatism, the magnesia coming from serpentinization of the peridotite.

Another example of replacement of sediments by talc is seen on the point of land just south of Jade Cove. A large mass of talc forms a shoulder of the cliff here in which are many fragments of black argillaceous material. An isolated body of serpentine intrudes the schist close by, and a small nephrite lens was dug from the schist near this serpentine.

The schist fingers numbers 8 and 10 showed no alteration to talc, and the huge lens of nephrite (no. 9) lies sharply defined in schist. It is not gradational at the upper end in the serpentine. While the surface exposure of this lens of nephrite is 10 feet wide, the actual thickness is less due to its inclination. However, the dips indicate increasing thickness downward. Its total length is uncertain as its seaward portion is largely covered by boulders and the other end dips at low angle under the serpentine. The color is fair—a dull jade green—similar to that of many of the nephrite pebbles found here.

Quite commonly a flaky or schistose structure is seen in the Jade Cove nephrite. Parts of such specimens often are easily scratched but other parts are harder than steel. The softer parts prove to be the same mineral, but the fibers are seen to be a little coarser and more nearly parallel than felted when studied microscopically. In descriptions of similar material in New Zealand, Turner[7] has applied the term seminephrite.

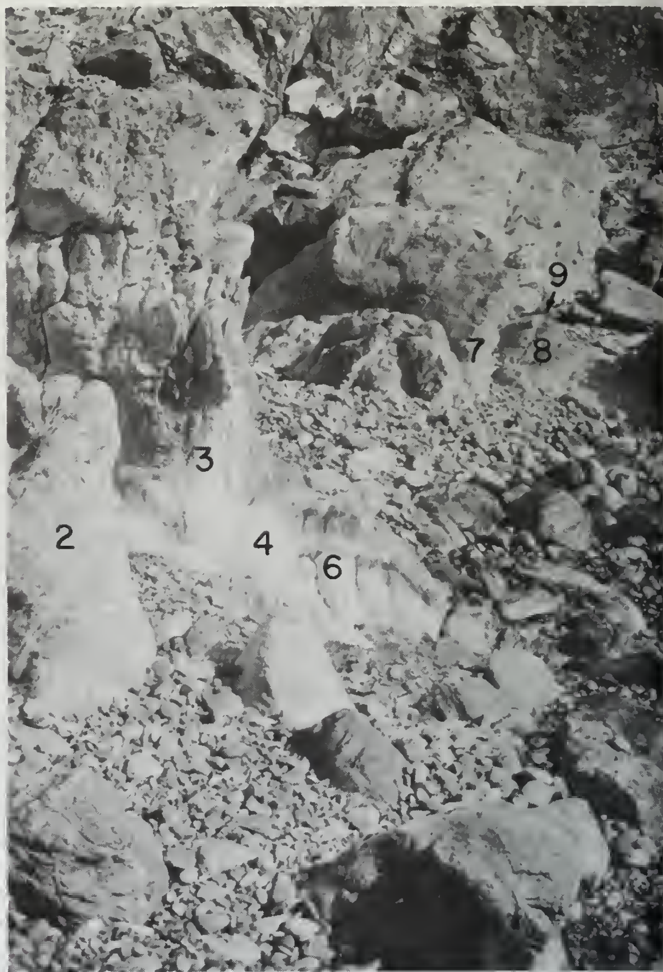


FIGURE 6. Jade Cove. Numbered outcrops are shown on geologi[c] map, figure 4. Camera facing south.

The specific gravity of a few specimens of nephrit[e] averaged about 3.00 (Dana 2.96-3.1), sufficiently greate[r] than that of serpentine (usually less than 2.65) to b[e] perceived in the hand with a little practice. Beach peb[b]les of serpentine and nephrite may look much alike but using this rough test and the greater hardness and toughness of nephrite of good cutting quality, they may b[e] separated readily.

Mylonite. The nature and origin of the gray schis[t] and the identity of the whitish streaks and lenses is o[f] particular interest. Two general types of the rock base[d] on texture and inclusions are recognized at Jade Cove In outcrops no. 3, 8, and 10 the whitish lenses are small

[7] Turner, F. J., Geological investigations of the nephrites, ser[pentines], pentines, and related "greenstones" used by the Maoris of Otago an[d] South Canterbury: Royal Soc. New Zealand, Trans. and Proc., vol 65, pt. 2, p. 190, 1935.

mostly 1 inch to 2 inches long, and the gray matrix, although appearing schistose, is not conspicuously fissile. In the photograph of the sea cliff a short distance south of the mapped zone (fig. 9) this type of schist forms the surface on which the men are standing. The second type of schist is seen in the cliff above. It is coarsely and irregularly laminated and sheared and contains large, rather angular masses of light-gray rock resembling chert. Some of the masses are shown in the photograph.

FIGURE 7. Outcrop number 3 in Jade Cove (see fig. 4) showing gradation of gray mylonite to white talc schist. Pick hangs on one of several small pods of nephrite.

This rock, found only in Jade Cove, is an uncommon metamorphic type. It is hard, cryptocrystalline, usually massive, and is composed principally of albite, quartz, and tremolite.

The albite-quartz-tremolite rock may have been derived by cataclastic metamorphism and reconstitution of a lens of graywacke in the manner noted by Turner.[8] Thin sections of a somewhat schistose sample showed dark flow lines and parallelism of structure suggestive of cataclastic origin. Untwinned albite, enclosing minute tremolite needles, and quartz make up a mosaic of intergrown grains. There is an occasional wisp of chlorite and some calcite.

[8] Turner, F. J., Evolution of the metamorphic rocks: Geol. Soc. America Mem. 30, p. 117, 1948.

Otherwise the second type of schist is as black and argillaceous as the rock below. Most of the rocks of Jade Cove are so very fine-grained that little can be discerned with a hand lens, but differences in texture and color are noticeable. Microscopic study of thin sections indicates nearly all are of cataclastic derivation and have been recrystallized to various degrees. The black schist of the first type with its many small whitish lenses and streakings is of particular interest both as a rock of unusual type and as it is related to the genesis of the nephrite.

In general the black schist is a type of mylonite, a term applied to rocks in which the original mineral grains have been milled and pulverized to exceeding fineness, with only slight recrystallization. The name mylonite was first applied to "certain laminated or schistose appearing rocks associated with thrust faults" by Lapworth.[9]

Similar rocks in California were described by Waters and Campbell [10] and by Alf.[11]

Mention is made by Rieche [12] of mylonites among the rocks studied in the Lucia quadrangle which adjoins the Cape San Martin quadrangle on the north.

Thin sections of the Jade Cove mylonites display the microstructural features which, by definition, characterize such rocks. These are: (1) a parallel structure evidenced by fluidal lines of dark unresolvable material, (2) a nearly complete pulverization of the original rock grains, (3) the survival of a few porphyroclasts and fragments of plagioclase and quartz, (4) firm coherence in the resulting mylonite, and (5) crystallization of new minerals in general attaining only partial development.

Mylonitized rocks are diagnostic of the operation of differential forces producing extreme movement, and which are in combination with a penetrative crushing component. This component may be produced by the load of overlying rock as with low angle thrusts, and perhaps also by the horizontal compression involved in the mechanics of some steep strike faults of great movement, such as the San Andreas fault. The coherence typical of mylonites may be attributed to the retention of molecular bonds during pulverization more than to recrystallization, as suggested by Lapworth.[13] Another concept is that of induration or welding of the pulverized material by pressure after movement ceased. Many of the rocks of the Plaskett and Cape San Martin region, herein called schists, are probably mylonites, but only those near nephrite localities have been studied microscopically.

Petrography. It has been pointed out that the Jade Cove mylonites and the other cataclastic schists of the region were derived from mechanically weak sedimentary rocks consisting of thinly interbedded graywacke, silty shale, and shale. The initial crushing of these beds evidently produced a crush breccia in which angular fragments of sandy material were intercalated in the more plastic shale. The shale, already of slaty fineness of grain,

[9] Lapworth, G., The Highland controversy in British geology: its causes, course, and consequences: Nature, vol. 32, pp. 558-559, 1885.

[10] Waters, A. C., and Campbell, C. D., Mylonites from the San Andreas fault zone: Am. Jour. Sci., 5th ser., vol. 29, pp. 473-503, 1935.

[11] Alf, Raymond M., Mylonites in the eastern San Gabriel Mountains: California Div. Mines Rept. 39, pp. 145-151, 1943.

[12] Reiche, Parry, Geology of the Lucia quadrangle, California: Univ. California Dept. Geol. Sci., Bull., vol. 24, p. 135, 1937.

[13] Op. cit.

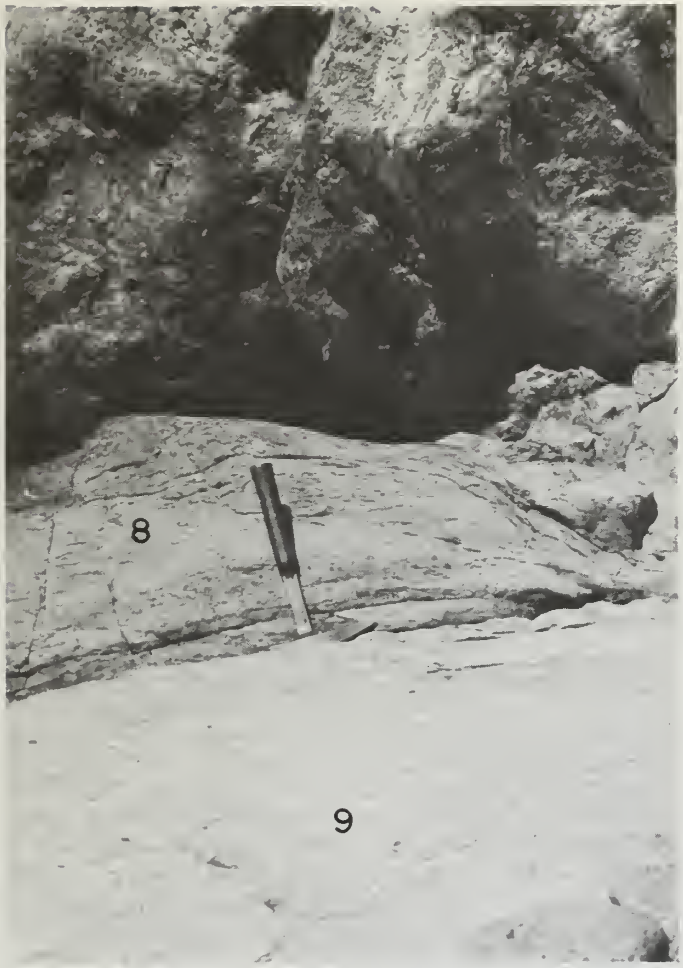


FIGURE 8. Large nephrite lens in Jade Cove. The flat, nearly horizontal surface is 10 feet wide. Actual thickness of the jade mass is 6 to 7 feet near surface but may be thicker downward as indicated by dips of upper and lower sides. Pick leans against mylonite which overlies jade.

thus became the matrix in which the fragments were confined, the initial stage in the production of the Jade Cove mylonites. These sandy fragments composed largely of quartz and plagioclase grains with fine interstitial material were rolled and flattened within the flowing black argillaceous matrix. The process might be compared to rolling a sack of sand under foot, for although the brittle grains were reduced by friction there was little intermixing with the black matrix. Boundaries of the lenses are sharp and the schistosity of the matrix flows around them. In thin section, the schistosity is not evidenced by parallelism of elongated minerals but by dark fluidal lines of unresolvable material. These flow parallel to lens boundaries and curve around relict grains of feldspar and quartz which have survived by insulation from one another in the plastic black portion. This portion in thin section is seen to be colorless to turbid brownish, unresolvable and isotropic. Very slight recrystallization is indicated by low birefringence of some vaguely elongated forms.

The white lenses seldom show parallel structures or fluidal black lines. Most of the material is colorless but some is clouded and contains pale brownish clots, and nearly opaque spots. It is largely isotropic but porphyroclasts and grains of quartz and twinned plagioclase are nearly always present. The feldspar is like that seen in sections of the graywacke; because it has low angles of extinction, it is probably oligoclase. Recrystallization varies in degree in different lenses and in areas of the same lens. Pleochroic green chlorite in wisps is the only colored mineral. More common are small aggregates of clear untwinned and interlocked albite, many of which contain tremolite needles. There are some quartz grains among the albite aggregates and the assembly is like that of the massive albite-quartz-tremolite rock described previously.

Tremolite-actinolite is the most common new mineral, usually in finely fibrous bundles dispersed in the cloudy isotropic material. Little or none is seen in some lenses, in others the little groups of fibers nearly coalesce. A small lens showing this partial crystallization in thin section was examined in the portion from which the slice was sawed, and it appeared to be gray-green nephrite of poor quality. The next step in metamorphism, complete recrystallization as nephrite, was studied in a thin section of a lens dug from the mylonite. This lens which was about 2 inches in diameter and half an inch thick, had a hard black coating. Under the microscope, this material was seen to be dark and isotropic like the mylonite matrix but

FIGURE 9. Seacliff in Jade Cove to south of mapped area. Large lenses of quartz-albite-tremolite rock in sheared mylonite. Foreground slope is black mylonite with white streaks and small lenses.

; pervaded by nephrite. A gray to black color or dark mot-ling and streaking is common in Jade Cove nephrite, and n much of the nephrite, it is probably caused by inclusion f an argillaceous substance.

IGURE 10. Mylonite at point of land just south of Jade Cove. White ns is talc, and a small lens of nephrite was found in place here. A serpentine body is nearby.

Cape San Martin

The Cape San Martin nephrite is part of a large nass of argillaceous rock enclosed in a great serpentine ody. A whitened zone adjacent to the serpentine is seen t the south contact near beach level and also on the pper surface of the argillaceous mass (see fig. 11). It is n this white zone at the beach level that the unique de-elopment of botryoidal nephrite was found. It is some-mes buried by sand but it was well exposed when the hotograph (fig. 12) was made. Massive gray-green ephrite forms a low shoulder of the inclusion near the otryoidal surface.

In the center of the included rock mass, unmistak-ble, although broken and confused interbedded black hale and graywacke is seen. This grades laterally into massive gray rock of fine grain, evidently the product f cataclastic mixing and recrystallization.

A thin section of the shale-graywacke part showed the usual angular oligoclase and quartz grains and muddy, nearly isotropic material containing some chlorite and areas of intergrown quartz and albite. Numerous patches of calcite appear to replace both quartz and feld-spar. The microstructure indicates cataclasis and there is some contorted and irregular dark banding, but parallel-ism is lacking.

Botryoidal Nephrite. Nearest to the serpentine and facing it is the peculiar botryoidal nephrite. The surface is made up of protuberances, rounded but irregularly shaped, each one an individual, like grains of corn on a cob. They seem to have grown outward, are closely packed together, are rooted in a common layer, and are readily split apart.

Thin layers of talc separate some individuals and both talc and finely fibrous white tremolite are pressed into the valleys between protuberances.

Magnetite as minute grains speckles some surfaces but it is not present within the nephrite. The nephrite, a very light shade of grayish-green is nearly colorless by transmitted light. Hardness tests made on smooth sur-faces of heads and shanks of the protuberances show a range from 5 to 6½. This variation and a microstructure of felted and parallel fibers and occasional prisms of tremolite would classify it as seminephrite in part.

FIGURE 11. The Cape San Martin nephrite occurrence. White face of ledge (lower center) is botryoidal pale green nephrite.

The base on which the nephrite seems to have grown is massive, darker gray-green nephrite; the rounded heads grew outward into a zone of talc schist. Portions of the schist when broken away have the impress of the botryoidal nephrite surface, and the talc is compressed and contorted.

Origin of the Monterey County Nephrite

The nephrite found in bedrock at Jade Cove is evidently a replacement of lenticular bodies of pulverized clastic material, originally graywacke, confined in argillaceous mylonite. Serpentine, which is always adjacent to or near nephrite occurrences is quite obviously essential to the process. At Cape San Martin the massive and the botryoidal nephrite appear to be replacements in the peripheral reaction zone bounding a large mass of dynamothermally altered argillaceous and sandy material enclosed in serpentine.

Thus two distinctive environments have produced nephrite in these localities, which in their derivation from sediments demonstrate an origin not heretofore recognized in nephrite deposits. Of other deposits, those of New Zealand alone seem to have been studied relative to origin. Most recent are the investigations of Turner, 1935,[14] and of Hutton, 1936.[15]

Among the numerous hypotheses of origin which have been advanced regarding the New Zealand nephrite, Turner [16] considers the replacement of olivine by tremolite and the uralitization of pyroxene as probable steps. The presence of residual hornblende which grades into tremolite in some of the tremolite rocks studied by Turner led to his suggestion of the derivation of nephrite in such rocks from hornblendite.

Two of the California nephrite occurrences, one near Porterville and another in Marin County, may possibly have had such an origin. Chromite grains are scattered through much of the Porterville nephrite. The complete absence of chromite in the Monterey nephrite and the rather clear evidence of derivation from sediments requires a different hypothesis of origin.

Mechanical Factors. In the interpretation of evidence seen in Jade Cove the mechanical factor probably is of first importance. Common forms of actinolite are frequently encountered in the Coast Ranges in schists and at contracts of serpentine with sedimentary rocks. In these and other associations actinolite-tremolite apparently reflects differing mechanical environments in both orientation and size of its crystals.

A clue to the problem may be in the behavior of some of the white lenses during mylonitization. Although the brittle particles once composing them were milled to near colloidal fineness the material remained largely immiscible with the argillaceous matrix. The matrix in thin section is seen to flow around the lenses. The interior of many of the lenses shows circular or elliptical traces which could be produced by rolling. In rolling, the outward form remaining lenticular, there would be set up a complex intergranular movement within the lenses. The continuance of this peculiar state into the phase of recrystallization might provide the condition for development of a microstructure like that of nephrite.

Chemical Factors. Only a few general observations about the chemistry of the process can be made because there are so many unknown factors.

The nephrite found here was derived from sedimentary material and this would be possible only by both addition and subtraction of certain elements. In this sense then the bulk composition of the original material means but little.

Analogous to this idea is the suggestion of Turner [17] regarding the origin of glaucophane schists and associated metamorphic rocks in the Franciscan group of rocks. "To sum up it would seem that neither special physical conditions nor special bulk chemical composition of the rocks affected has been shown to be essential for development of glaucophane schists. Perhaps the controlling factor is the composition of the pore solutions (especially as regards concentration of iron and soda ions) permeating the rock during metamorphism."

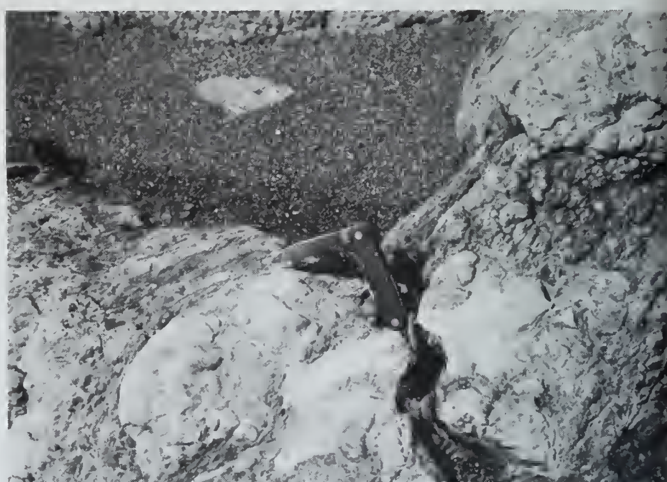


FIGURE 12. Close-up of botryoidal nephrite. White areas are thin sheets of fibrous tremolite.

Replacement of certain lenses by nephrite and only slight development of fibrous actinolite-tremolite in others is ascribable perhaps to varying accessibility to the solutions. Passage of solutions would be along planes of schistosity in the relatively impermeable mylonite. This stage of replacement—the reaction of alkaline solutions on the finely divided siliceous lens material—may be explained in part by the solution principle. This process of metamorphic differentiation has been recognized by several investigators and is discussed by Turner.[18] Briefly it sets forth that in dynamothermal metamorphism of various rock types new minerals or assemblages are created which are more stable under the condition of stress and temperature. Furthermore, it is believed that in the convergence toward these certain minerals, chemical ions which are in excess or unwanted in the process migrate in solution. From this a conclusion might be drawn that

[14] Turner, F. J., Geological investigations of nephrites, serpentines and related "greenstones" used by the Maoris of Otago and South Canterbury: Royal Soc. New Zealand, Trans. and Proc., vol. 65, pt. 2, pp. 187-198, 1935.
[15] Hutton, C. O., Basic and ultrabasic rocks in northwest Otago: Royal Soc. New Zealand, Trans., and Proc., vol. 66, pp. 237-238, 1937.
[16] Turner, F. J., op. cit.

[17] Turner, F. J., Evolution of the metamorphic rocks: Geol. Soc. America, Mem. 30, p. 100, 1948.
[18] Turner, F. J., op. cit., pp. 143-145, 1948.

IGURE 13. View of east side of Cape San Martin roadcut, showing hitened reaction zone (rodingite?). Graywacke and shale to left, sheared serpentine to right.

ctinolite-tremolite was the only mineral possessing a orm, as microfibrous nephrite, capable of crystallization n a medium undergoing complex intergranular movenent, and subject to epizonal conditions of metaorphism.

The massive nephrite and the botryoidal type at 'ape San Martin had a somewhat different manner of enesis from that at Jade Cove. At Cape San Martin he argillaceous mass was crushed, mixed, and largely ecrystallized. At the same time perhaps, gradational relacement by massive nephrite took place locally near the erpentine contact, attended by forceful growth of the ephrite protuberances. The manner in which the nephrite as pressed into talc schist suggests crystallization of calium and silica from the sedimentary rock and magnesium rom the serpentine. Excess silica combined with magesium to form talc.

Although these botryoidal forms hardly can be ssociated with dynamic movement, the requisite condiion for felted microstructure within them may have een provided by their own growth.

It is probable that serpentine, which is always near he nephrite, was the source of pore solutions carrying nagnesia, but sufficient calcium probably was available n the sedimentary material.

Hydrogrossularite and Other Metamorphic Minerals f Cape San Martin. Mention has been made of the vhitened zone bounding the sedimentary block of the oadcut exposure in serpentine. Similar occurrences were oted at the nephrite localities although the whitened ones there were altered to soft white material. In the oad cut, the zone is a little over 1 foot in thickness and s sharply defined against serpentine, but grades indefiitely into the massive, greenish reconstituted sedimenary rock. The zone is light gray to white with darker treaking parallel to the contact.

The white part contains small vugs of crystals and alcite fillings and proves to be typical massive prehnite which grades into the fine-grained, gray material. The gray material is essentially a hydrous calcium aluminum silicate, with hardness of 6, specific gravity of 2.96, and easy fusibility to greenish glass without intumescence. In thin sections and as grains in oil, the mineral is colorless and structureless. Quite unlike prehnite it shows neither cleavage nor elongation. It is partly isotropic but much has an indefinite birefringence reaching an estimated $\gamma - \alpha$ of .010.

In manner of occurrence and in properties this material is rather like the rock called rodingite reported from New Zealand by Turner [19] and others, and from northern California by Wells, and Cater.[20]

The mineral, if it can be called such, is perhaps in part a lower grade member of the hydrogarnet group which includes hydrogrossular, hibschite, and plazolite, according to Yoder.[21]

Rodingite, as described, contains at times zoisite, prehnite, and pyroxene; it has been found as dikes in serpentine. The dikes are considered by Turner [22] to have been derived from dioritic and gabbroic rocks by lime metasomatism, the lime being of magmatic origin from peridotite, either as residual solutions or set free by serpentinization of calcium-bearing pyroxene.

By similar metasomatic action non-calcareous sediments may be converted to grossularite, diopside, vesuvianite, etc., at peridotite contacts.[23] Not far from the road cut and also deep within the serpentine body exposed in the roadcut, there is a mass of calc-silicate rock composed of grossularite, pyroxene, and idocrase. The idocrase is in stringers and in vugs lined with brilliant green crystals as much as 3 millimeters in length. The grossularite is pale greenish, massive, isotropic, and n is greater than 1.73. A pale brown cleavable mineral grades into the

FIGURE 14. Lenses of white rock (rodingite?) in sheared serpentine.

grossularite; its indices and extinction angles are in the range of diopside. This mass is irregular in shape and seems to be an inclusion rather than part of a dike.

Other kinds of massive garnet-rock found on Willow Creek beach as boulders and pebbles are of several

[19] Turner, F. J., Evolution of the metamorphic rocks: Geol. Soc. America Mem. 30, p. 119, 1948.

[20] Wells, Francis, and Cater, F. W., Jr., Chromite deposits of Siskiyou County, California: California Div. Mines Bull. 134, pt. 1, chap. 2, pp. 77-127, 1950.

[21] Yoder, Hattan S., Jr., Stability relations of grossularite: Jour. Geol., vol. 58, p. 243, 1950.

[22] Turner, F. J., Evolution of the metamorphic rocks: Geol. Soc. America, Mem. 30, p. 119, 1948.

[23] Turner, op. cit.

colors. Grains of a greenish-gray specimen were isotropic with *n* both above and below 1.73. Others are mixtures of garnet having *n* near 1.72 to above 1.73 and some fibrous or bladed minerals. The blades have not been certainly identified, but those in a pinkish-gray garnet-rock are pyroxene, near jadeite in refringence and extinction angles. In a tough, white cryptocrystalline type, the bladed mineral resembles anthophyllite in optical properties.

The garnet part of these rocks and the first mentioned greenish types perhaps should be given the name hydrogrossular as defined by Hutton.[24]

Like grossularite the composition is calcium aluminum silicate but also contains water in varying amount. The calcium is usually ascribed to lime metasomatism of aluminous silicates.

The hydrogrossular of Cape San Martin, however, like the rodingite, could have been derived by simple reconstitution of the pulverized and mixed sediments, shale and graywacke. The graywacke contains considerable calcite in the rodingite bounded inclusion; and in the similar graywacke of Alder Creek, far from serpentine, calcite is so large a constituent that the rock effervesces with acid like solid calcite. Likewise, the assumption that ample calcium was available in the sediments for the formation of the nephrite in Jade Cove and Cape San Martin seems most probable. The dearth of calcium compounds in general near the serpentine would seem to preclude lime metasomatism as an active process in this region.

[24] Hutton, C. O., Hydrogrossular, a new mineral of the garnet-hydrogarnet series: Royal Soc. New Zealand, Trans. and Proc., vol. 73, pt. 3, pp. 174-180, 1943.

BIBLIOGRAPHY

Alf, Raymond M., Mylonites in the eastern San Gabriel Mountains: California Div. Mines, Rept. 39, pp. 145-151, 1943.

Anderson, Eskil, Asbestos and jade occurrences in the Kohuk River region, Alaska: Terr. of Alaska, Dept. Mines, Pamph. 3, 1945.

Anonymous, The jade rush: Mineralogist, vol. 13, no. 12, pp. 514-515, 1945. (Notes on Wyoming nephrite discovery.)

Branham, Allan, A new discovery of jade that resembles the Fraser River material: Rocks and Minerals, vol. 21, p. 838, 1946. (The Wyoming discovery.)

Chesterman, Charles W., Jadeite in San Benito County, California: Lapidary Jour., vol. 4, pp. 204, 208, 1950.

Henley, R. F., Jade in California: Rocks and Minerals, vol. 22, no. 12, pp. 1114-1115, 1947 (notes on Monterey County nephrite).

Hutton, C. O., Basic and ultrabasic rocks in northwest Otago: Royal Soc. New Zealand, Trans. and Proc., vol. 66, pp. 231-254, 1937.

Hutton, C. O., Hydrogrossular, a new mineral of the garnet-hydrogarnet series: Royal Soc. New Zealand, Trans. and Proc., vol. 73, pt. 3, pp. 174-180, 1943.

Lapworth, G., The Highland controversy in British geology: its causes, course, and consequences: Nature, vol. 32, pp. 558-559, 1885.

Petar, Alice V., Jade: U. S. Bur. Mines Inf. Circ. 6844, 16 pp., 1936.

Reiche, Parry, Geology of the Lucia quadrangle, California: Univ. California, Dept. Geol. Sci. Bull., vol. 24, pp. 115-168, 1937.

Rogers, A. F., Nephrite jade from Monterey County, California: (abstract) Am. Mineralogist, vol. 26, p. 202, 1941.

Taliaferro, N. L., Geologic history and structure of the central Coast Ranges of California: California Div. Mines, Bull. 118, pp. 119-163, 1943.

Turner, F. J., Evolution of the metamorphic rocks: Geol. Soc. America, Mem. 30, 1948.

Turner, F. J., Geological investigations of the nephrites, serpentines, and related "greenstones" used by the Maoris of Otago and South Canterbury: Royal Soc. New Zealand, Trans. and Proc., vol. 65, pt. 2, pp. 187-210, 1935.

Turner, F. J., The metamorphic and intrusive rocks of southern Westland: New Zealand Inst., Trans. and Proc., vol. 63, pt. 2, pp. 178-236, 1933.

Tyrell, G. W., The principles of petrology, 2d ed., London, Methuen and Co., 1929.

Waters, A. C., and Campbell, C. D., Mylonites from the San Andreas fault zone: Am. Jour. Sci., 5th ser., vol. 29, pp. 473-503, 1935.

Wells, Francis, and Cater, Fred W., Jr., Chromite deposits of Siskiyou County, California: California Div. Mines, Bull. 134, pt. 1, chap. 2, pp. 77-127, 1950.

Yoder, Hattan S., Jr., Stability relations of grossularite: Jour. Geol., vol. 58, pp. 221-253, 1950.

NEPHRITE IN MARIN COUNTY, CALIFORNIA
Reprinted from Special Report 10-B (July 1951)

y Charles W. Chesterman*

OUTLINE OF REPORT

ABSTRACT

The first known occurrence of nephrite north of San Francisco ay is in Marin County where it occurs as veins and lenses of varying ngth and thickness in massive and sheared serpentine. The nephrite ries in color from pale olive-green through light bluish-green to rk bluish-green. In places it is intergrown with white fibrous emolite and forms all gradations from tremolite through semiephrite to nephrite. Veins of nephrite cut narrow veins containing mixture of actinolite, talc, and chrysotile. Four stages in mineralation are recognized: (1) formation of serpentine, (2) fracturing nd shearing of serpentine with deposition of veins of fibrous serentine and veins of mixed actinolite, talc, and chrysotile, (3) depotion of nephrite and fibrous tremolite, and (4) post-nephrite eformation and shearing.

INTRODUCTION

Nephrite occurs in Marin County on the east side of lassa Hill, on the Vonsen Ranch, about 5 miles southest of Petaluma, California. It was found by M. Vonsen nd the writer in January 1950 while examining the eology of Massa Hill. Although the presence of nephrite n Monterey County has been known for several years, this s probably the first record of the occurrence of this maerial north of San Francisco Bay.

Massa Hill is a prominent landmark among low olling hills, as it rises 842 feet above sea level. The western part, the largest portion of the hill, lies in sec. 23, T. 5 N., R. 8 W., M.D.B.&M. However, that portion of the hill wnich contains the known occurrences of nephrite is in sec. 19, T. 5 N., R. 7 W., M.D.B.&M.

Two geological maps of the area were prepared, a small scale map of Massa Hill and vicinity (fig.1), and a large scale map of the nephrite deposits (fig. 2). The small area which includes the nephrite deposits was mapped with a plane table and telescopic alidade at a scale of 20 feet to the inch to show in detail the relationship between the nephrite and the serpentine.

In order to correlate various field data, laboratory studies were made of 43 rock specimens. The petrographic work was supplemented by spectrographic analysis and x-ray examinations of the nephrite, tremolite, and the various serpentine minerals.

The nephrite at Massa Hill ranges in color from pale olive green through pale bluish green to dark bluish green. Cabachons cut from dark bluish-green nephrite from locality A are pleasing stones of unusual color. Stones cut from the central translucent portion of a dark bluish-green zone of a lens-vein from locality B are also beautiful and show unusual colors.

Acknowledgments. The writer wishes to thank Mr. M. Vonsen of Petaluma for many suggestions and aid during the course of the field investigation and for reading the manuscript. Special thanks should go to Dr. W. T. Schaller of the U. S. Geological Survey, Dr. A. Pabst of the University of California, and Dr. Hatten S. Yoder, Jr. of the Geophysical Laboratory for their helpful suggestions and x-ray determination of the nephrite, tremolite, and serpentine minerals.

GEOLOGY

Massa Hill, for the most part, is made up of schists, serpentine, and sedimentary rocks of the Franciscan group[1] Albite-clinozoisite-muscovite schist is exposed on the top central part of the hill. This rock ranges in color from dark gray to grayish-brown and forms very few conspicuous outcrops. At the top of Massa Hill it is coarsegrained and contains considerably more quartz than it does near the serpentine-schist contact. Locally, the schist is highly quartzose as indicated by the number of large, angular boulders of milky-white quartz which weather out of the schist. At the nephrite deposits where the schist is in contact with the serpentine, the schist is mediumgrained and exhibits a fairly well developed flaser structure. As seen under the microscope, the quartz and albite appear as rounded grains and as fine granular aggregates. The albite shows no twinning. Clinozoisite is colorless, occurs in stumpy prismatic crystals and granular aggregates of angular crystals, and constitutes approximately 30 percent of the rock. Fine-grained, almost colorless muscovite forms wispy plates and shredlike flakes wrapped around the grains of quartz, albite, and clinozoisite. Glaucophane is present in very small amounts.

* Associate mining geologist, California Division of Mines.
lanuscript submitted for publication February, 1951.

[1] Weaver, C. E., Geology and mineral deposits of an area north of San Francisco Bay, California: California Div. Mines Bull. 149, 1949.

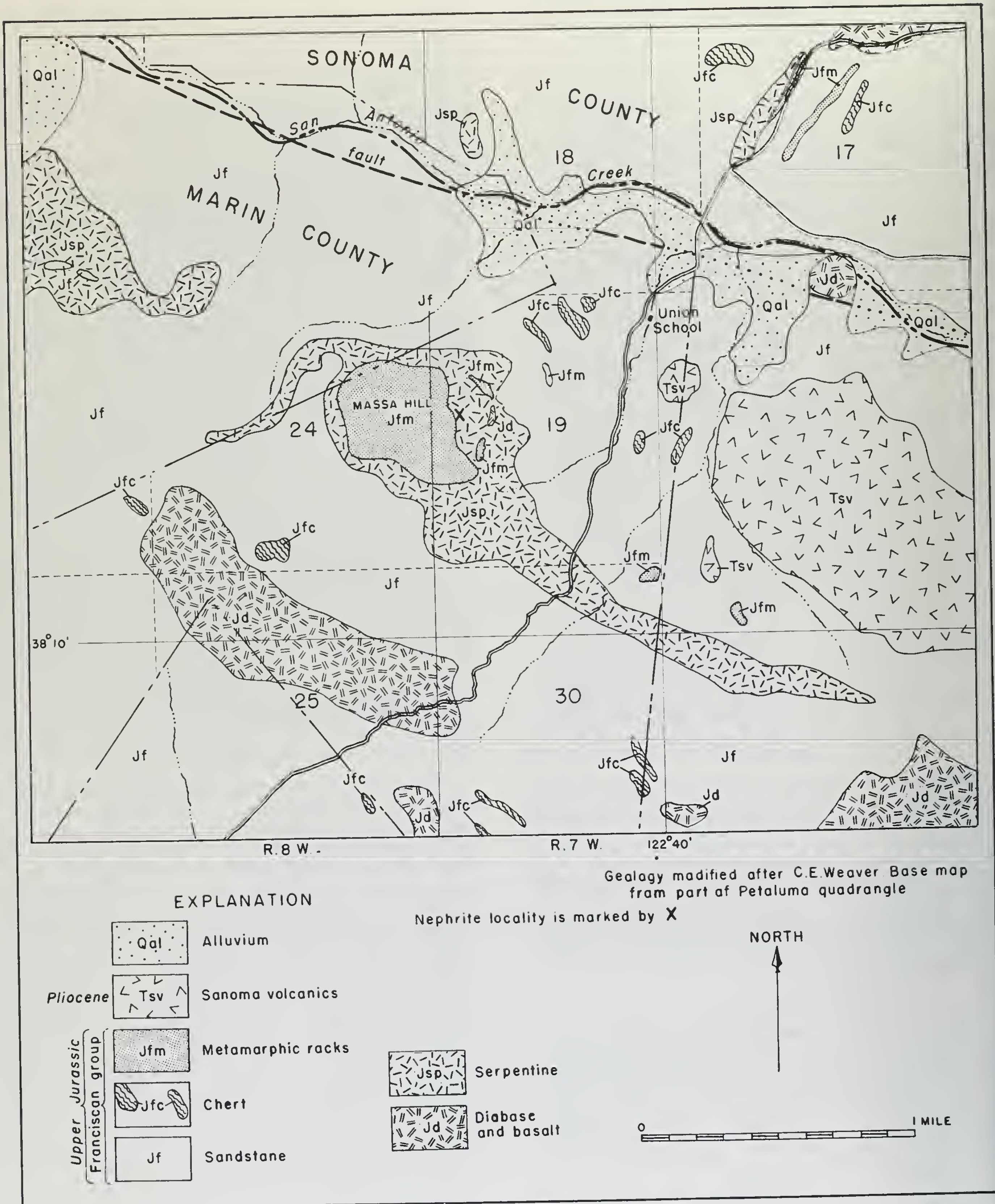


FIGURE 1. Geologic map of Massa Hill region, Marin County, California, showing nephrite locality.

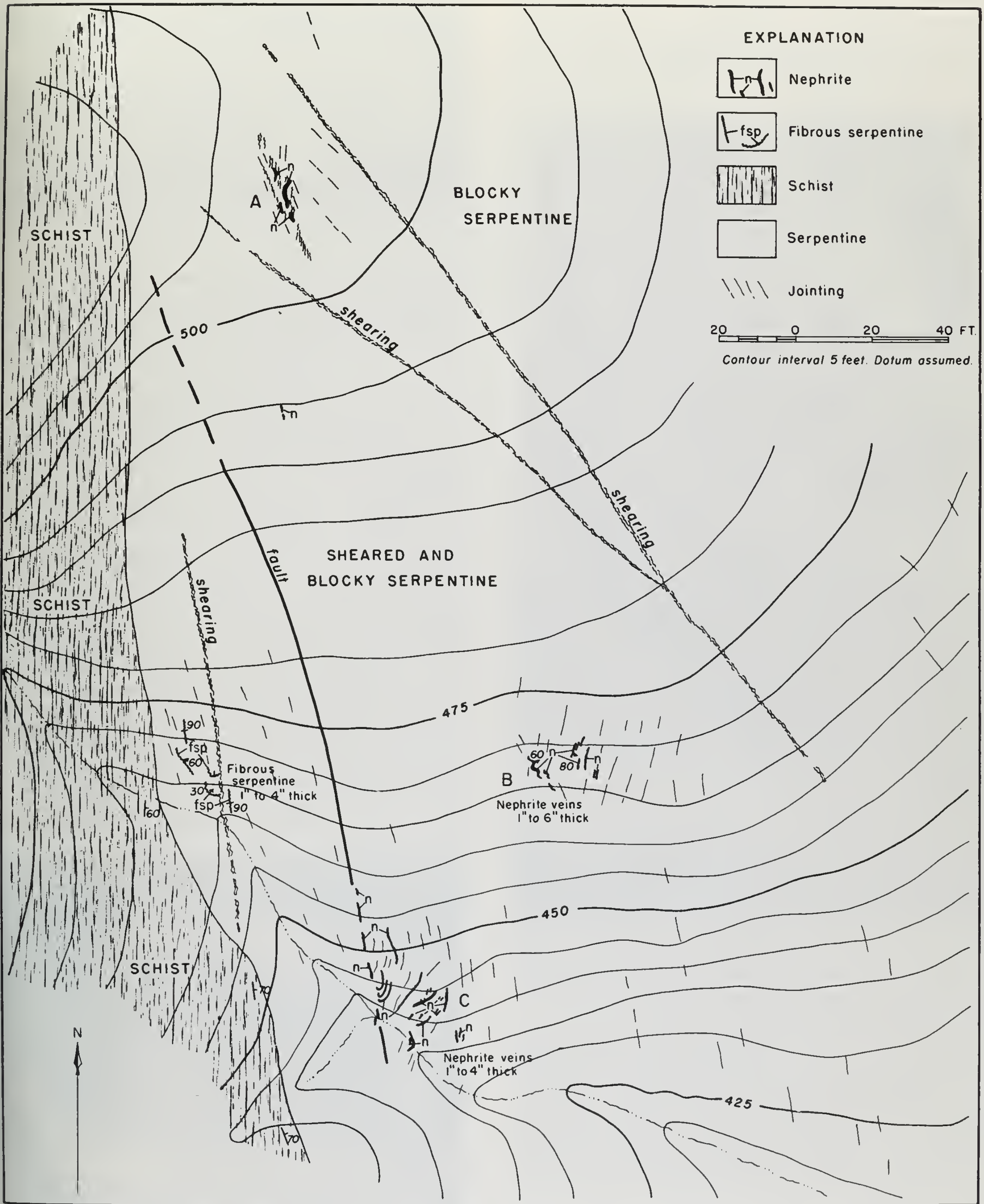


FIGURE 2. Geologic map of the nephrite deposits of Massa Hill, Marin County, California.

It is bluish violet in color and usually occurs closely associated with the muscovite. The schist represents a metamorphosed phase of the Franciscan sandstone. This is emphasized by the presence of slightly metamorphosed chert lenses in the schist.

FIGURE 3. Small lenses of nephrite removed from sheared serpentine at locality A. Nephrite has light-greenish exterior and dark bluish-green core. Pencil is 6 inches long.

Serpentine forms a large part of Massa Hill, especially the lower part where it completely encircles the hill and extends toward the southeast as a narrow belt for several miles. The serpentine ranges in color from brownish green through light green to light bluish green. In some places it is massive and only slightly sheared but in many places is found highly sheared and crushed. It is strongly foliated, has a scaly structure, and is traversed by numerous slickensided surfaces and an occasional network of narrow chrysotile veins.

Still lower down Massa Hill there are extensive areas underlain by sandstone and other sedimentary rocks of the Franciscan group. The sandstone is dark gray in color. It ranges in grain size from 0.5 millimeter to 1 millimeter. It is arkosic and contains, in addition to quartz, oligoclase, orthoclase, biotite, magnetite, and zircon, small rounded and splintery fragments of black shale and angular grains of serpentine and chert. An occasional lenticular mass of conglomerate may be found. Radiolarian chert which is present in lenses, is banded and ranges in color from deep chocolate brown to pale greenish gray.

Scattered throughout the sandstone are bodies of glaucophane schist, which are dark in color and locally contain albite, epidote, and chlorite. There are also several lenslike bodies of an epidote-albite-hornblende rock. This rock is dark in color, fine- to medium-grained, and consists almost entirely of hornblende, epidote, and albite. Locally it contains pale red garnets. It is enclosed in serpentine and forms several prominent outcrops on the east side of Massa Hill.

Also enclosed in the serpentine is a small, irregular intrusive body of diabase, dark green in color and moderately fine-grained. When viewed under the microscope it is seen to have a fairly well developed diabasic texture. The feldspar is intermediate andesine and occurs in unaltered lath-shaped crystals which form a mesh that encloses angular augite crystals. The augite is partly altered to chlorite. Enclosed within the feldspar laths are needles of pale green hornblende. Chlorite is the only secondary mineral, occurring as pale green shreds and wispy plates.

NEPHRITE DEPOSITS

Modes of Occurrence: The nephrite at Massa Hill has three distinct modes of occurrence, each mode being characterized by a set of distinct physical and structural relations.

Locality A: Thick, short lenses in sheared serpentine.
Locality B: Contorted lens-veins and veins in sheared and massive serpentine.
Locality C: Veins in massive and sheared serpentine.

At locality A the nephrite is found in thick, short lenses which range from less than ¼ inch to a foot or more in length (fig. 3). The ratio of length to thickness is approximately 2:1. The lenses are composite in structure, having a core of deep bluish-green nephrite and a rim of pale bluish green nephrite (fig. 4). The core is somewhat more translucent than the rim which is variable in thickness. The serpentine enclosing the lenses is highly sheared, light greenish brown in color, and forms a scaly shell around each lens. Small amounts of serpentine and white, fibrous tremolite occur as inclusions in the nephrite. Although there is a distinct color difference between the rim and core of each lens, and also a differ-

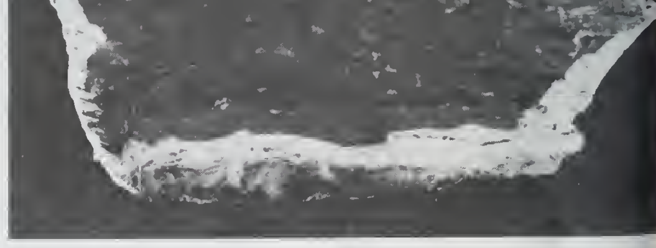
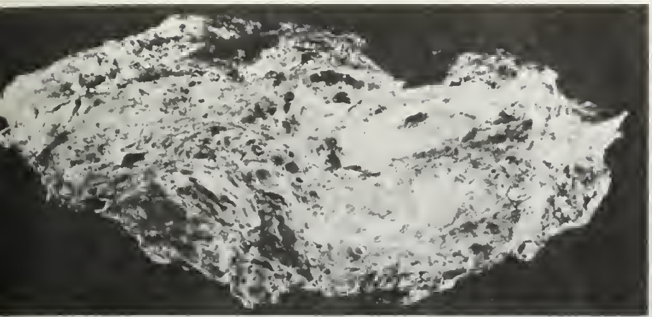
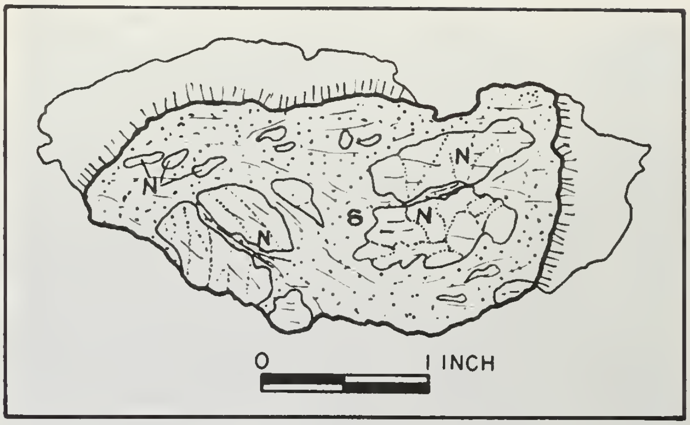


FIGURE 4. Polished surface of a portion of a lens of nephrite from locality A. Note dark interior and irregular rim. Natural size.



...URE 5A. Sheared serpentine (S) from locality A enclosing small lenslike bodies of pale bluish-green nephrite (N).



B. Drawing of specimen shown in fig. 5A.

...ce in the kind of included material found in each part ... the lens, there is no discernible difference in the ...phrite. Under the microscope a color difference may ... noted but the fine fibrous nature of the nephrite is ...ntinuous from rim to core of the lens.

At locality B the occurrence of nephrite is especially ...teresting. Here are veins of nephrite cutting hard, dark ...een serpentine, and irregular and highly contorted lens-...ins in sheared serpentine (fig. 6). The narrow veins ...rely exceed 1 inch in width and can be traced for several ...et. The highly contorted lens-veins, (fig. 8) on the other ...nd, range in thickness from ¼ inch to 6 inches. In both ...e narrow and contorted veins, however, the nephrite ...nges in color from light bluish green to deep bluish ...een. Here, as at locality A, there is a zoned condition in ...hich the central portion of the vein is darker in color ...an the rim (fig. 9). Although there appears to be a ...arp boundary between the zones, they are gradational ... indicated under the microscope where continuity in ...e appearance of the fine fibrous nephrite from one zone ...to the other may be seen with a slight difference in ...lor. The cause of this apparent color zoning is not ...own. The fact that the core is more translucent than ...e rim suggests a difference due to degree of crystalliza-...on and orientation of the fibers. At locality B there are ...so veins containing a mixture of actinolite, talc, and ...rysotile cutting the serpentine (fig. 10). These veins ...ry in width from ⅛ inch to 1 inch. They are cut by veins ... nephrite which tend to narrow down slightly where ...ey cut the other veins (fig. 11).

The nephrite at locality C occurs as straight veins ...d as vein fillings in a shear zone (fig. 12). The veins ...nge in width from ¼ inch to more than 1 inch. The ...rpentine that enclosed them is massive and sheared. The ...assive serpentine is dark green in color whereas the ...eared serpentine ranges in color from pale to dark blu-...n green. The nephrite in the straight veins is pale olive ...een in color and closely resembles a dense, fibrous ser-...ntine in structure. A section across one of the straight ...ins shows the following (fig. 13): massive serpentine ...all followed by a narrow, irregular zone of white, fibrous ...emolite. This is followed by three bands of long, fibrous, ...le olive-green nephrite which are separated by narrow, ...scontinuous zones of dark green serpentine. Separating ...e third nephrite band from the serpentine wall is an-...her narrow, irregular zone of white, fibrous tremolite. ... all veins the nephrite and tremolite are cross-fibered, ...d the fibers make an angle of 70° with the serpentine ...alls.

The nephrite in the sheared serpentine zone seems to contain far more fibrous tremolite than that in the massive serpentine. In the shear zones, the tremolite and nephrite are intergrown so that the fibrous tremolite appears to be only a modification of the nephrite. The tremolite is silky white when shredded, but in the unshredded state, it has a pale-green satiny appearance. Spectrographic examination of the nephrite and fibrous tremolite indicates no apparent difference between them. Also, x-ray studies indicate that the fibrous material is tremolite and not chrysotile.

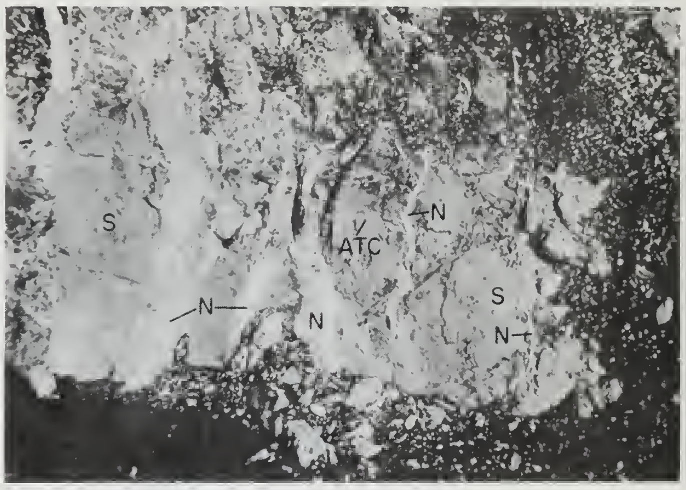


FIGURE 6. Veins of pale-greenish nephrite (N) cutting serpentine (S) and vein of mixed actinolite, talc, and chrysotile (ATC). From locality B. Pencil (vertical position) is 6 inches long.

In the strong shear zone at locality C, a peculiar form of nephrite forms discontinuous veins traceable for at least 30 feet. The veins vary in width from 1 inch to 6 inches and seem to include, in places, considerable amounts of sheared serpentine. The nephrite is variable in color, ranging from pale greenish white to light olive green. It is coarsely to finely fibrous and cuts narrow veins containing a mixture of actinolite, talc, and chrysotile. Butting up against the shear zone are several *en echelon* veins of nephrite curved so as to resemble drag folds.

Relations of Nephrite Deposits to Shear Zones in the Serpentine. All veins of nephrite and fibrous tremolite are in or near shear zones in the serpentine. In the small

FIGURE 7A. Composite vein of nephrite (N) with border of fibrous tremolite (T) cutting massive serpentine (S) from locality B. Pencil is 6 inches long.

B. Drawing of vein shown in fig. 7A.

area that includes the nephrite deposits the serpentine is cut by at least four prominent shear zones. Although the serpentine between the two outer shears is crushed and sheared, it contains local blocks and areas that are well jointed and less sheared. No nephrite has been found outside this major shear zone, nor has any been found in the schist where the shear zones are in contact with the schist. Although several of the shear zones within the major zone are several tens of feet in length, none of the nephrite veins found exceeds 5 feet in length.

FIGURE 8. Contorted lens-vein of light-greenish nephrite. Removed from sheared serpentine at locality B. Natural size.

MINERALOGY

Microscopic Features of the Nephrite. In thin section the nephrite is seen to be almost colorless. It ranges in structure from fine interlacing fibers to coarse fibrous. There are all gradations from nephrite to fibrous tremolite, with semi-nephrite as an intermediate type. Semi-nephrite may be considered merely as a more coarsely crystalline, dense, compact facies of nephrite. The fibers possess positive elongation and show wavy, approximately parallel extinction. The coarse fibrous semi-nephrite shows sweeping extinction. The fine and coarse fibrous nephrites have a refractive index for gamma equal to 1.624. Indices for alpha and beta were not determined.

Chemical Properties of the Nephrite, Tremolite, and Serpentine. Spectrographic analysis of nephrite, fibrous tremolite, and the various forms of serpentine were made with the following results:

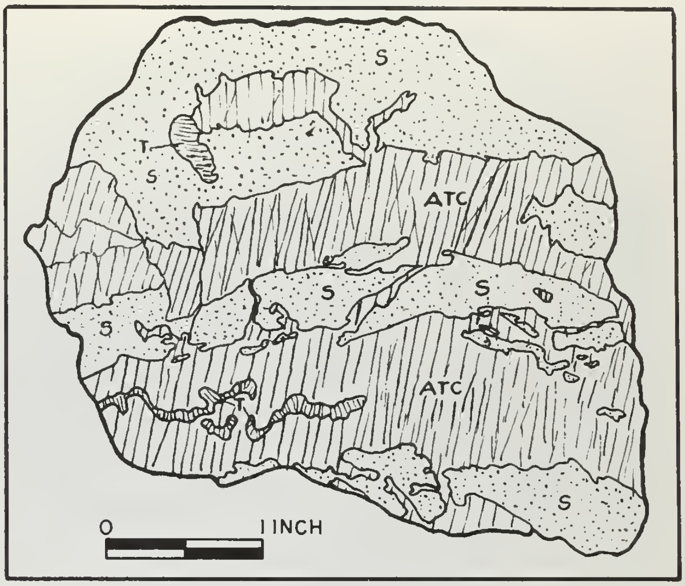
Element	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Silicon	L	L	L	L	L	L	L	L
Aluminum	S	S	S	Tr.	Tr.	Nil	S	Tr.
Chromium	Nil	Nil	Nil	Nil	Tr.	Nil	Tr.	Tr.
Iron	Tr.	Tr.	Tr.	Tr.	Tr.	Nil	Tr.	Tr.
Magnesium	M	M	M	M	M	M	M	M
Calcium	M	M	M	M	M	S	S	S
Sodium	Tr.	Tr.	Tr.	Nil	S	Nil	Tr.	Nil

L = Large amount, M = Moderate amount, S = Small amount, Tr = Trace, and Nil = None.

1. Bluish-green nephrite from locality A.
2. Bluish-green nephrite from locality B.
3. Bluish-green nephrite from locality C.
4. Fibrous tremolite from locality B.
5. Altered nephrite from locality B.
6. Sheared serpentine from locality A.
7. Sheared serpentine from locality B.
8. Sheared serpentine from locality C.

FIGURE 9. Composite vein of nephrite showing narrow contorted zone of dark, bluish-green nephrite in light bluish-green nephrite. The rounded and elongated inclusions in the central part are the same as the exterior portion of the vein. From locality B. Natural size.

'IGURE 10A. Polished surface showing veins composed of a mixture f actinolite, talc, and chrysotile (ATC) containing fibrous tremolite (T) in sheared serpentine (S) from locality B.



B. Drawing of specimen shown in fig. 10A.

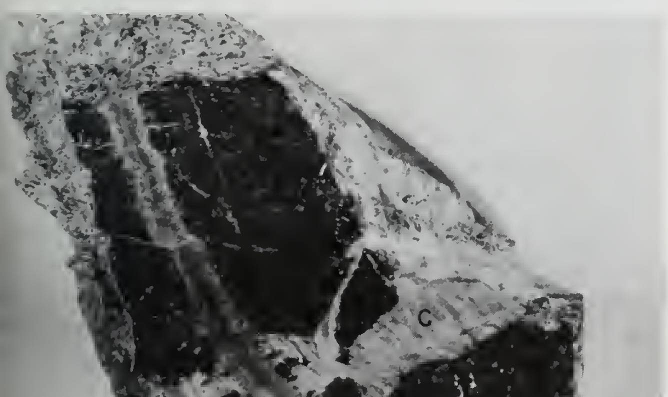
The nephrite and massive serpentine contain alum-
num, although the amount present in the serpentine is ess than in the nephrite. Chromium and iron are present n the nephrite and both of these elements might have omething to do with coloring the mineral. Although no uantitative chemical analyses were made of the nephrite, -ray studies indicate that it is a monoclinic amphibole vith a composition corresponding to $Ca_2Mg_5Si_8O_{22}(OH)_2$.

ORIGIN

The nephrite was deposited as lenses, lens-veins, and eins in massive and sheared serpentine. The sequence of vents as inferred from field and laboratory studies is as ollows:

1. Formation of serpentine from peridotite or some other ultrabasic rock.
2. Fracturing of serpentine and filling of these fractures with a mixture of actinolite, talc and chrysotile.
3. Further fracturing and shearing of serpentine and veins.
4. Deposition of nephrite and fibrous tremolite as veins and lenses in massive and sheared serpentine.
5. Post-nephrite shearing and deformation.

At localities B and C there are exposed narrow veins of nephrite cutting veins containing a mixture of actinolite, talc and chrysotile (fig. 11). The contacts between the two types of veins and the enclosing walls of serpentine are sharp. Not only are the contacts sharp, but the walls of the veins are parallel, especially at locality C where they are straight for several feet. At locality B the walls of the veins are also parallel, but curve and may be found in the form of the letter S.



'IGURE 11A. Polished surface showing veins of nephrite (N) cutting veins composed of a mixture of actinolite, talc, and chrysotile (ATC) in sheared serpentine from locality B. Natural size.

B. Drawing of specimen shown in fig. 11A.

FIGURE 12. Vein of pale olive-green nephrite from locality C. The three bands of nephrite are separated by thin, discontinuous selvages of dark green serpentine. Natural size.

FIGURE 13. Photomicrograph showing vein of nephrite (N) cutting vein of fibrous serpentine (C), all enclosed in sheared serpentine. From locality B. Plain light. Magnification 100X.

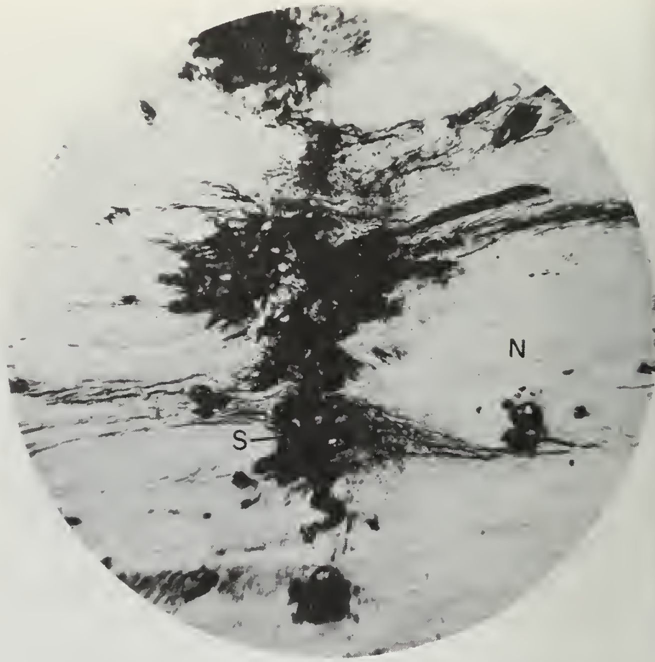
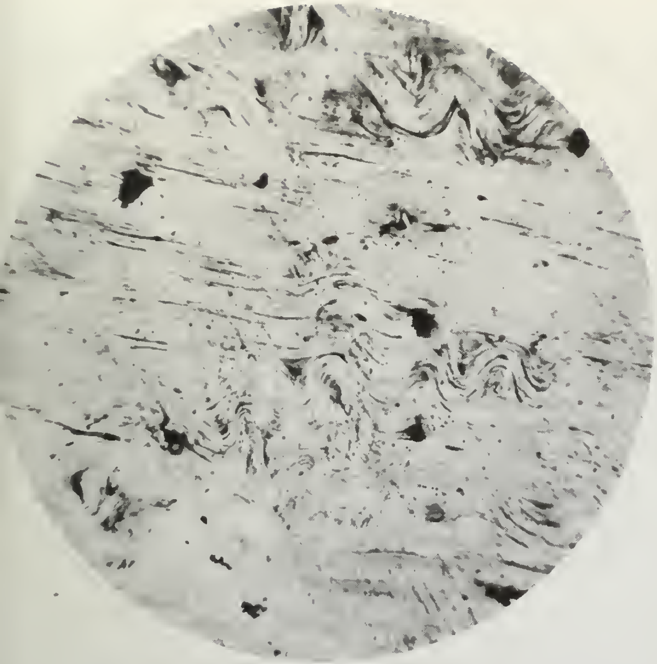


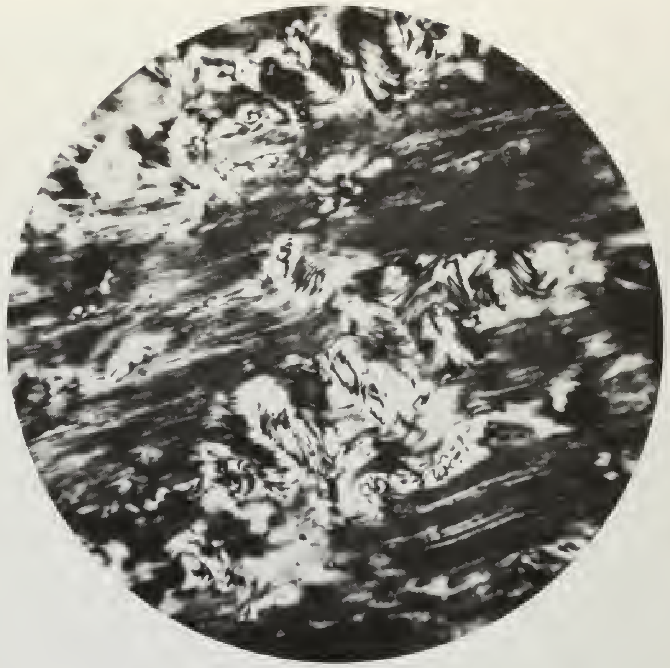
FIGURE 14. Photomicrograph of nephrite (N) with irregular inclusions of serpentine (S). From locality B. Plain light. Magnification 100X.

A thin section across a $\frac{1}{2}$-inch nephrite vein which includes the serpentine walls, shows some interesting features. The serpentine has the typical mesh structure and appears to consist almost wholly of antigorite. The nephrite, however, is colorless and has much higher relief than the serpentine. It is made up of many small interlacing and radiating fibers. The contact between the nephrite and the serpentine is sharp and distinct. Small, irregular bodies of serpentine occur in the nephrite as though they were detached from the walls when the nephrite was deposited. Branching off from the main nephrite vein in the section are several thin, ramifying veinlets of nephrite which follow fractures in the serpentine. Scattered at random through the nephrite are small, divergent, fanlike clusters of tremolite fibers. These clusters of tremolite are intergrown with the nephrite and appear to represent a size modification of the nephrite.

At locality A, however, the field relations are different. Here the nephrite occurs as distinct lenses in the sheared serpentine (fig. 5). The lenses are thick, short, and range in size from 1 inch to 12 inches in length. Scattered throughout the sheared serpentine are small lenslike bodies of pale-green nephrite. They are the result of post-nephrite shearing and have their longest axes in more or less parallel alignment with the axes of the larger lenses and the general trend of the shear zone. The larger lenses also show the effects of shearing for several were found that showed slickenside surfaces when broken.



IGURE 15*A*. Photomicrograph of nephrite from locality B. Plain light. Magnification 100X.

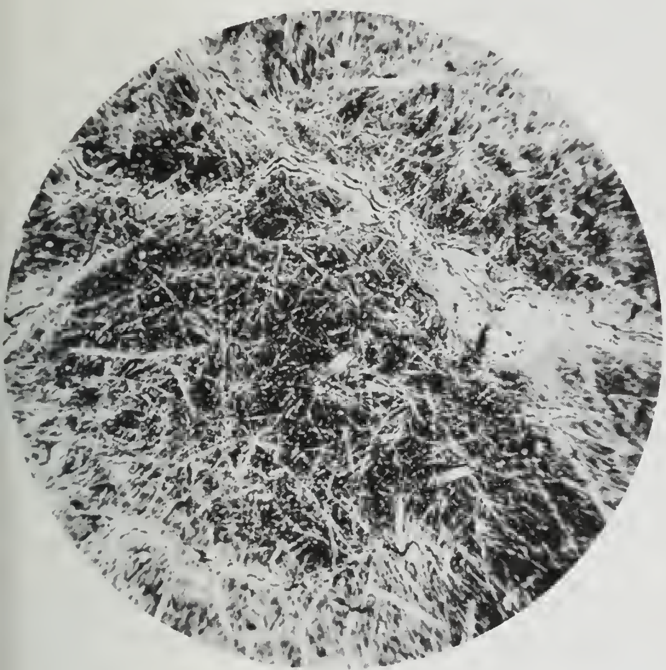


B. Photomicrograph of nephrite from locality B. Crossed nicols. Magnification 100X.

These surfaces made an angle of 45° to 60° with the long axis of the lens, and are sufficiently polished to resemble polished shear surfaces commonly developed in serpentine.

Source of Solutions Forming Nephrite. Where the solutions that were responsible for the formation of nephrite came from is not known. The small body of diabase about 500 feet south of the nephrite deposits is intrusive into the serpentine. Because of a lack of nephrite in the immediate vicinity of the diabase where the serpentine is jointed and sheared, it appears unlikely that the diabase contributed any material for the nephrite veins. An alternative source would be late solutions given off by the serpentine. Inasmuch as the material making up the veins of mixed actinolite, talc, and chrysotile was introduced during the emplacement of the serpentine, there is reason to believe that much, if not all, of the material for the nephrite also came from the serpentine.

It is clear that nephrite at Massa Hill was deposited from solutions in veins and along shear zones in serpentine following emplacement of the serpentine. The solutions responsible for the formation of the nephrite and fibrous tremolite probably came from the serpentine and not from the diabase.



'IGURE 16. Photomicrograph of nephrite from locality C. Plain light. Magnification 100X.

JADEITE OF SAN BENITO COUNTY, CALIFORNIA †
Reprinted from Special Report 10-C (September 1951)

By H.S. Yoder* and Charles W. Chesterman**

OUTLINE OF REPORT

INTRODUCTION

In view of the considerable interest in jadeite, it is desirable to present some of the preliminary results of field studies made in San Benito County, California, during the summer of 1950. Laboratory work in progress will be included in a complete report at a later date.

The mineral which most nearly approximates the ideal formula for jadeite, $NaAl(SiO_3)_2$, is known from only four other areas:[1] Burma, Japan, Central America, and Celebes.[2] In Burma the jadeite is found in serpentine associated with albite and nepheline; in Japan, in serpentine with albite and quartz; in Celebes, rimming an aegirine-rich pyroxene in a lawsonite-albite-sericite quartzite. The California deposits are the first occurrences in place of jadeite which have been found in the western hemisphere.

The first report of jadeite in California was made by Mielenz[3] in his study of the geology of the southwestern part of San Benito County. He described a quartz-albite-jadeite schist containing lawsonite, glaucophane, garnet, and muscovite. Although this work has not been published, reference was made to his discovery by Taliaferro.[4] In 1950 Bolander,[5] unaware of Mielenz's work, reported the discovery of jadeite in boulders in Clear Creek, San Benito County, about 6 miles east of the area mentioned by Mielenz. Shortly thereafter, discoveries of jadeite in place were announced by several prospectors who had been working the area. Several deposits found in other counties have since been made known to the Division of Mines through the generous cooperation of both amateur and professional mineral prospectors.

† Manuscript submitted for publication January 25, 1951.
* Petrologist, Geophysical Laboratory, Carnegie Institution of Washington.
** Associate mining geologist, California Division of Mines.
[1] Yoder, H. S., Jadeite problem: Am. Jour. Sci., vol. 248, pp. 225-248, 312-334, 1950.
[2] de Roever, W. P., Igneous and metamorphic rocks in eastern central Celebes: Geological explorations in the Island of Celebes under the leadership of H. A. Brouwer, North-Holland Publishing Co., Amsterdam, pp. 65-173, 1947.
[3] Mielenz, R. C., Geology of the southwestern part of San Benito County, California: Univ. California, unpublished thesis, p. 59, 1936.
[4] Taliaferro, N. L., Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 109-219, 1943.
[5] Bolander, L. Ph., Jr., First jadeite discovery in America: Mineralogist, vol. 18, pp. 186, 188, 1950.

GENERAL GEOLOGY

The general geology of the area in San Benito County in which the jadeite is found has been described by Eckel and Myers.[6] The jadeite outcrops lie in an oval body of serpentine, 4 by 12 miles, which is rimmed by Franciscan sandstone and Upper Cretaceous Panoche formation (fig. 1). The major portion of the area is barren of vegetation and subject to frequent rock slides, but most of the outcrops of jadeite are obscured by manzanita, spine grass, briar, and poison oak. The area may be reached by secondary roads maintained by the county; however, the roads may be impassable after a heavy rain.

Eight large exposures of jadeite were found in the canyon of Clear Creek (New Idria quadrangle: N ½ sec. 12, T. 18 S., R. 11 E.) and there are, no doubt, many more. Six of these bodies, completely surrounded by highly sheared and brecciated serpentine, are lens shaped and do not exceed 50 by 200 feet in outcrop. The seventh, a veinlike body, was found at the contact of the serpentine with an enclosed mass of schist. The existence of an eighth body is inferred from the few large masses of float at the contact of another enclosed block of schist with the serpentine, and from the presence of jadeite in the schist near the contact. The locations of the jadeite bodies are given in figure 2. Detailed collections of specimens were made across the jadeite bodies where possible. Although an effort was made to secure representative samples, some outcrops did not yield samples, even to heavy sledging.

Lens-shaped Jadeite Body. One of the six lenslike bodies which were examined in detail is shown in figure 3. The serpentine which completely surrounds this body is sheared into lenticular masses (elongated discoids) whose longest dimension averages about 6-8 inches. Occasional portions of the serpentine may be massive or may be brecciated into small blocks. Each dark-green lenticular mass (antigorite) is usually bounded by an apple-green slickensided surface (chrysotile). In close proximity to a jadeite body the serpentine is extremely sheared, darker in color, the surface dull, and appears to have been altered. Many sinuous, threadlike white streaks (garnet) apparently formed in the alteration process.

The contact zone, not more than 2 feet wide (fig. 4), was weathered out except at one point. The only unweathered contact rock observed is light brown in color, fine-grained, heavy, hard, and tough. The bulk of this rock appears to be grossularite, lawsonite, pumpellyite, and a green amphibole. This type gives way to natrolite and jadeite. An abrupt change in color marks the contact with a rock composed only of jadeite. The jadeite in the contact zone is no doubt quite variable in composition. In many places the contact zone is probably much narrower and may even be absent.

[6] Eckel, E. B., and Myers, W. B., Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California: California Jour. Mines and Geology, vol. 42, pp. 81-124, 1946.

FIGURE 1. Photograph of typical serpentine outcrop.

The jadeite rock crops out as isolated knobs; although most of it is massive, it is in places blocky, sheet jointed, or cavernous. The most striking feature is the banded character (fig. 5) produced by alternating light- and dark-green layers a fraction of an inch to an inch in thickness. Individual bands, although contorted in a gentle way only, cannot be traced from outcrop to outcrop. Enclosed by the jadeite mass are blobs of natrolite, pectolite, and albite, knots of black talcous material, and small irregular masses of thickly banded shaley rock.

Preliminary work indicates that much of this jadeite contains a considerable amount of the diopside molecule.

Probably many more masses of jadeite will be found in the serpentine, judging by the large number of jadeite boulders in Clear Creek. Most of the jadeite boulders in Clear Creek, some of which are as large as five feet in diameter, probably retain their original shape as bounded in the serpentine; masses of jadeite of similar size and shape probably will be found in place as isolated masses randomly distributed throughout the serpentine.

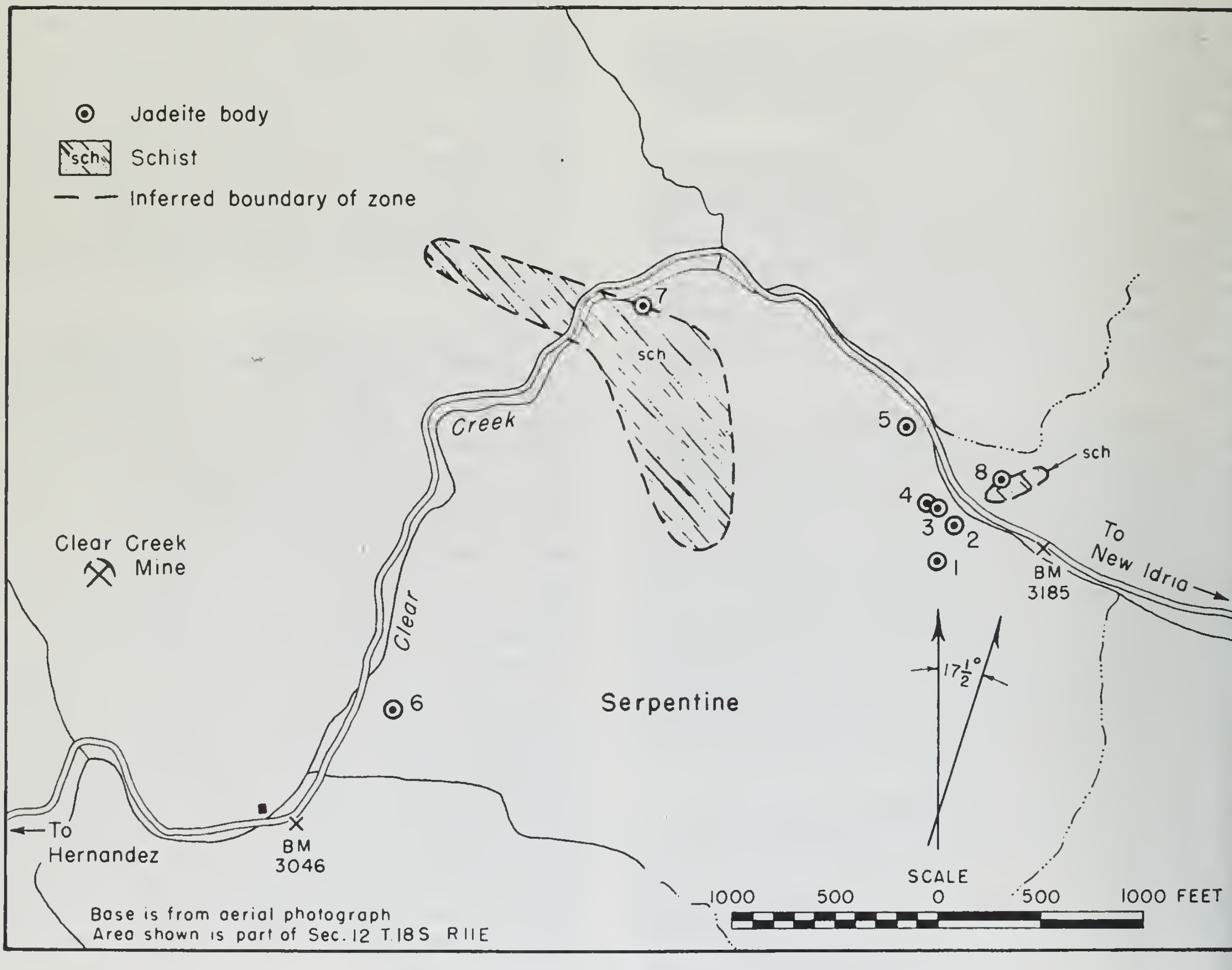


FIGURE 2. Map showing location of jadeite bodies in Clear Creek, San Benito County, California.

Many mono- and bi-mineralic bodies, of which jadeite is only one representative, lie in the serpentine. Masses of comparable size, but mainly of grossularite, diopside, natrolite, tremolite, idocrase, or albite, are not uncommon in the serpentine area. All of the bodies, including those of jadeite, exhibit cavities. In the jadeite it could not be ascertained whether these had been filled and weathered out or whether they were original open cavities.

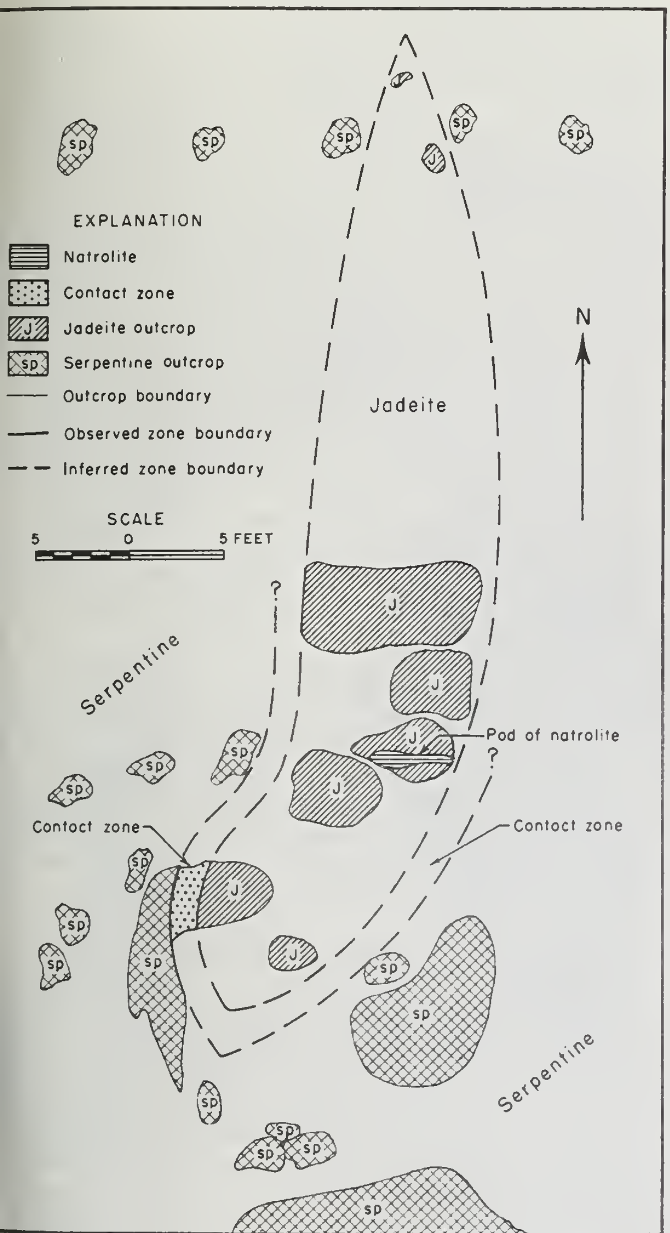


FIGURE 3. Sketch of outcrops and inferred boundary of lens-shaped jadeite body.

Veinlike Jadeite Body. At the contact of a block of schist in the serpentine lies a different type of jadeite body (fig. 6), a vein traceable for about 50 feet. At one end it appears to be terminated by large masses of jadeite, similar to the first type, which pinch and swell along the continuation of the trend of the vein. A multiplicity of veinlets, roughly paralleling the main vein, lie in the schist. One large branch of the main vein cuts across the schist; no branches were observed to enter the serpentine. Near the contact the sheared serpentine becomes black in color and the surface of the individual serpentine lenticular mass appears glassy. The contact zone against serpentine consists of approximately 3 inches of hard mixed rock of chlorite and contorted and broken ribbons of diopside. Next is found a zone 1 inch thick consisting of chlorite. This soft material is traversed by irregular cracks from which jadeite crystals appear to have grown out into the chlorite.

FIGURE 4. Photograph of contact zone sketched in figure 3 showing contact zone (C) composed of grossularite, lawsonite, pumpellyite, and green amphibole lying between jadeite (J) and sheared serpentine (S).

The jadeite vein is mostly from 6 to 8 inches wide but pinches to 2 inches in places. It is dark green at the borders and becomes white and coarser grained at the center. There are patches of the white jadeite in the dark-green jadeite and some natural sections give the impression that the white material has been brecciated. Preliminary X-ray work indicates that the white jadeite is exceptionally rich in the jadeite molecule. Considerable analcite and some albite occur in the vein.

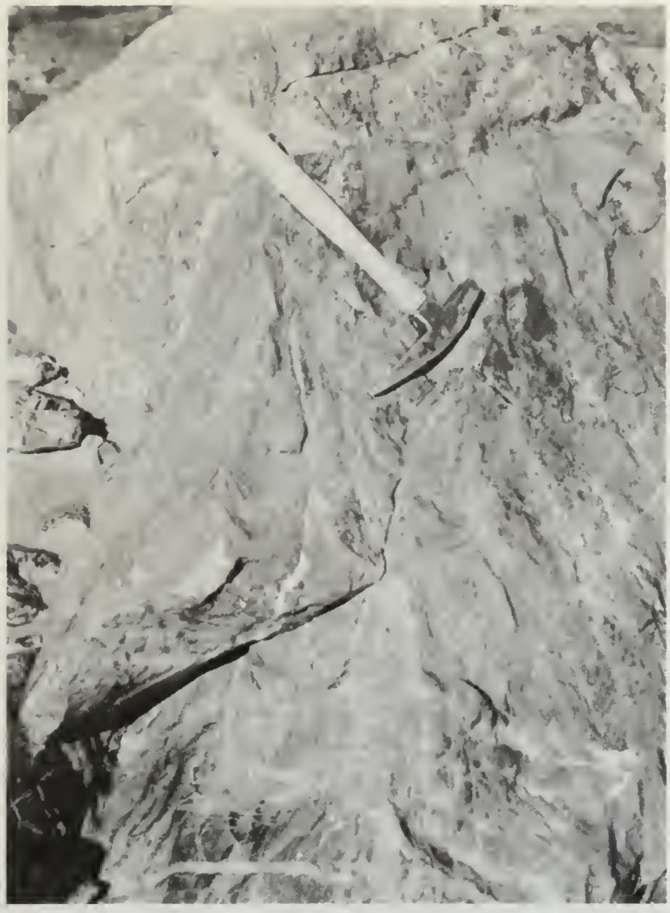


FIGURE 5. Photograph of banded jadeite boulder.

It is not clear from the field data how many stages of jadeite growth took place or what the significance of the apparent brecciation may be. For example, the white jadeite, occupying the center of the vein, is considered to be later than the dark-green jadeite at the vein walls, yet dark-green jadeite encloses patches of white jadeite. There is evidence in one of the lenslike bodies that the green jadeite was crushed and sheared into a flaser structure before the white jadeite was deposited. Further complications were observed in the jadeite masses terminating the vein.

The contact on the albite-actinolite-sericite schist side is marked by soft clayey material; the alteration zone extends for several feet. The veinlets which parallel and cross the schistosity also contain white jadeite and analcite. The main vein and its branches are displaced slightly by many faults which are lined or filled with analcite.

The mass of dark-green jadeite terminating the vein is traversed by many small sharply bounded veinlets of white jadeite and albite. The veins of white jadeite may be as much as 1 inch in width and bear cross-cutting relations with each other in much the same way as the many chrysotile veins cut each other in some serpentines. The crystals usually grow with their long dimension perpendicular to the vein walls but sometimes occur in sprays.

The jadeite masses, similar to those of the first type, are thinly banded and enclose small lenses of neighboring schist. Other contacts of the serpentine with enclose blocks of schist were examined for similar jadeite bodie but in one other place only was there evidence for th possible existence of a veinlike body.

Mode of Formation. From the field data collected the following mode of origin has been inferred:

1. Serpentine was either emplaced in the solid state or forme by alteration of a previously emplaced pyroxenite.

2. The blocks of schist in the serpentine are either residu country rock or inclusions from depth.

3. Deformation took place either during or after the emplace ment of the serpentine. The serpentine acted as a plastic body an the schist as a brittle body. The former is predominantly slipped an sheared, and brecciated only rarely when massive; the latter i highly faulted.

4. The most intense fracturing, shearing, and brecciation, a well as the greatest development of open space, took place at th contact of the serpentine and schist. Many other granulated zone unrelated to schist, formed in the serpentine.

5. Fluids entered the most highly brecciated, fractured, an sheared zones. These fluids were probably residual from the proces which gave rise to the serpentine. This idea is favored in that it i readily supported by laboratory data and there are no other so-calle igneous bodies in the area with which the fluids may be associate

6. The fluids gave rise to many mono- and bi-mineralic bodie in the serpentine of which the jadeite is only one representative.

7. The fluids are presumed to have deposited a diopsidic pyro ene at first and then an almost pure jadeite in the later stages.

8. During the final stages or following consolidation, the jad ite bodies were fractured and faulted to a minor degree. The frac tures and faults were then lined or filled with analcite.

From the field evidence, then, it may be tentativel stated that the jadeite formed either during or after th emplacement of the serpentine and that the fluids fro which it was deposited were most likely residual from th process which gave rise to the serpentine.

Jadeite has in the past been considered a high pressure mineral, that is, a mineral which can form onl under very high pressures. Recent laboratory experi ments [7] led to the conclusion that jadeite was stable no only at low temperatures but even at atmospheric pres sure. The occurrence of jadeite in a vein associated wit serpentine supports the view that jadeite does not requir high pressures for its formation and that it is stable a moderate (less than 500° C.) temperatures.

ECONOMIC IMPORTANCE

The jadeite deposits studied in San Benito County California, will probably not yield high-quality gem ma terial but will be a source of attractive and interesting specimens for collecting and polishing. There is littl doubt that many more deposits of jadeite will be found within the serpentine belt of California. Although similar in color to most serpentine, the toughness and density of jadeite should be adequate clues to the keen prospector.

Other localities in California for which reports of jadeite have been verified by the Division of Mines are as follows:

Williams Creek, Mendocino County	Stream boulders
Valley Ford, Sonoma County	Glaucophane schist
Paso Robles, San Luis Obispo County	Stream boulders
Eel River, near Mina, Mendocino County	Stream boulders

[7] Yoder, op. cit.
Yoder, H. S., and Weir, C. E., Change of free energy with pressure of the reaction nepheline + albite = 2 jadeite: Am. Jour. Sci. (in press), 1951.

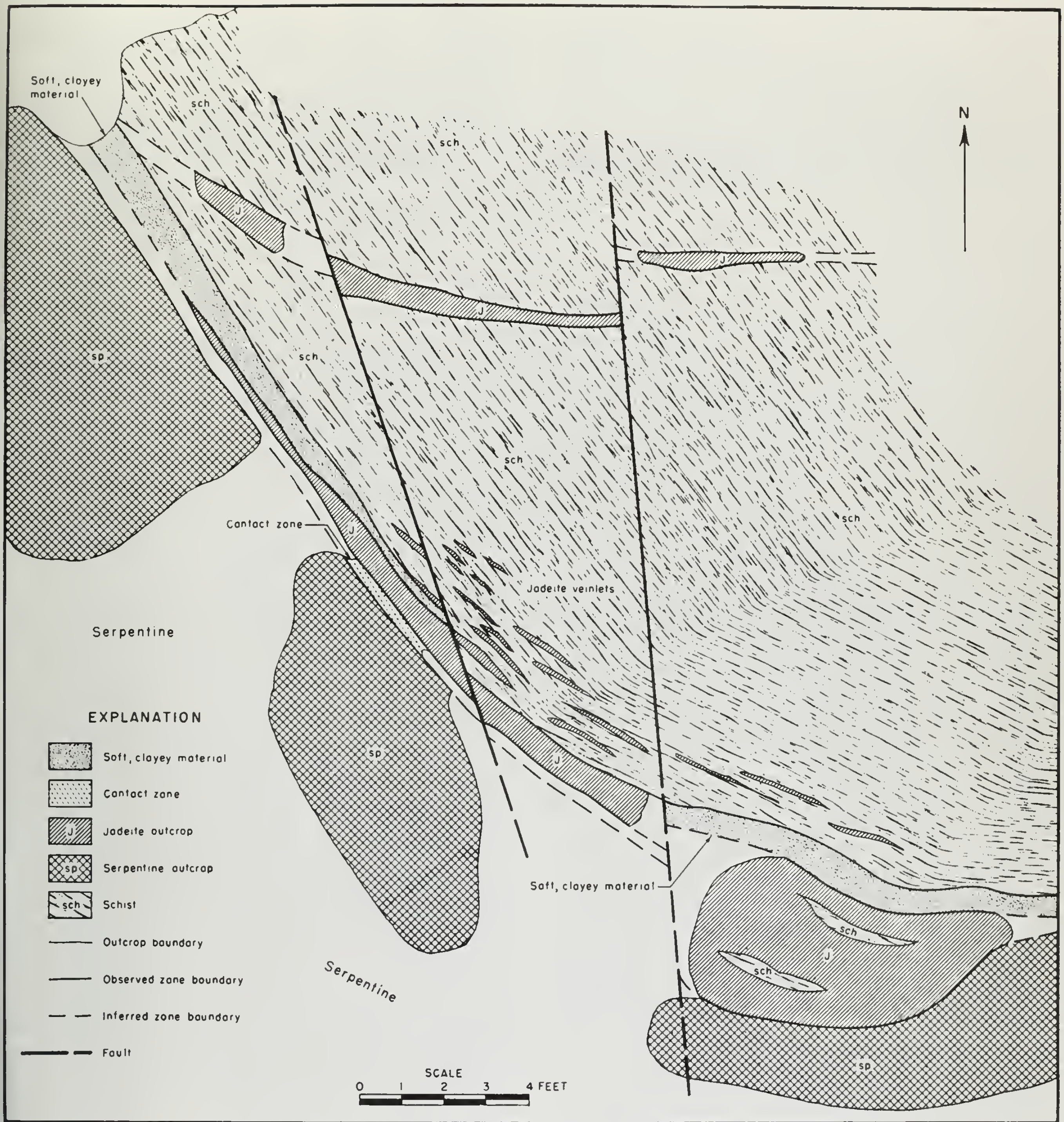


FIGURE 6. Sketch of outcrops of jadeite vein at contact of serpentine with enclosed block of schist.

REFERENCES

Bolander, L. Ph., Jr., First jadeite discovery in America: Mineralogist, vol. 18, pp. 186, 188, 1950.

Chesterman, Charles W., Jadeite in San Benito County, California: Lapidary Jour., pp. 204, 208, 1950.

de Roever, W. P., Igneous and metamorphic rocks in eastern central Celebes: Geological explorations in the Island of Celebes under the leadership of H. A. Brouwer, North-Holland Publishing Co., Amsterdam, pp. 65-173, 1947.

Eckel, E. B., and Myers, W. B., Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California: California Jour. Mines and Geology, vol. 42, pp. 81-124, 1946.

Mielenz, R. C., Geology of the southwestern part of San Benito County, California: Univ. California, unpublished thesis, p. 59, 1936.

Taliaferro, N. L., Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 109-219, 1943.

Yoder, H. S., Jadeite problem: Am. Jour. Sci., vol. 248, pp. 225-248, 312-334, 1950.

Yoder, H. S., and Weir, C. E., Change of free energy with pressure of the reaction nepheline + albite = 2 jadeite: Am. Jour. Sci. (in press), 1951.

INTRUSIVE ULTRABASIC ROCKS AND THEIR METAMORPHIC RELATIONSHIPS AT LEECH LAKE MOUNTAIN, MENDOCINO COUNTY, CALIFORNIA*

Reprinted from Special Report 82 (1963)

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ABSTRACT

Intrusive contacts between sills af serpentinite and tuffaceaus graywackes af the Franciscan Farmatian are excellently expased at Leech Lake Mauntain. Expasures af such contacts are exceedingly rare in Califarnia. This ane was studied in detail, in the field and in the labaratary.

The ultrabasic rack was emplaced as a liquid peridotitic magma, nat as serpentinite. A metamarphic effect af the intrusion was the farmatian af much jadeitic pyraxene and smaller amaunts af blue sodic amphibole in the graywacke. This mineral assemblage indicates a grade af metamarphism in the glaucaphane schist facies, althaugh glaucaphane itself is scarce. The intrusion was accampanied by a hydrothermal phase which 1) partly serpentinized the graywacke immediately at the contact; 2) farmed veins of nephrite, jadeitic pyroxene, hydrograssular, and vesuvianite in the serpentinite, and 3) farmed manamineralic veinlets af pectalite, xanotlite, and calcite in the graywacke.

Diabase sills were intruded between beds af chert befare the ultrabasic sills were emplaced. Lacally the diabase was intruded by the later peridatite; at these cantacts the peridotite was altered ta nephrite, and the diabase was altered to a chlorite - serpentine - kaersutite - actinalite - pumpellyite rack. The hydrathermal phase that accompanied the intrusion af the peridatite affected all af the diabase: the feldspar was altered in part to pumpellyite; the titaniferaus augite was altered ta chlarite, pale-green actinolite, and blue amphibale (crassite); and the ilmenite and sphene were altered ta leucaxene.

* Revised from the Report of the International Geological Congress, XXI Session, Norden, 1960, (Part XIII, Petrographic Provinces, Igneous and Metamorphic Rocks) Copenhagen, Denmark, pages 208-215.

INTRODUCTION

Leech Lake Mountain is in the central part of the northern Coast Ranges of California in northern Mendocino County, about 175 miles north of San Francisco. The area is accessible by trail from the Eel River Ranger Station which is 11 miles south of Leech Lake Mountain and 13 miles east of Covelo.

An area of approximately five square miles around Leech Lake Mountain was mapped on a scale of 1000 feet to the inch on an enlarged portion of the U.S. Geological Survey Covelo quadrangle (1953 edition).

To Dr. J. R. McNitt of the California Division of Mines and Geology and Dr. F. J. Turner, Professor of Geology at the University of California, Berkeley, I am indebted for helpful discussions relating to the structure and petrology of the area, and to Dr. Ian Campbell, Chief, California Division of Mines and Geology, for a critical reading of the manuscript.

GEOLOGY OF LEECH LAKE MOUNTAIN

The rocks at Leech Lake Mountain consist of interbedded graywackes, siltstones, and cherts; sills of diabase and serpentinite; and flows of basalt. The only fossils found were a few radiolaria in the chert, and fairly well preserved *Buchia piochii* (Gabb) in the graywacke. The entire sequence is considered to be part of the Franciscan Formation (Upper Jurassic to Lower Cretaceous) which covers extensive areas in this part of California.

Figure 1.

Graywacke, ranging from massive to well bedded, is the most abundant rock type exposed in the area. Even in the massive graywacke, crude bedding is suggested by parallel rows of dark, flat fragments of shale. The graywacke, where it is distant from the serpentinite bodies and apparently unaltered, is medium gray in color; near the serpentinite contact, where it has been altered, the graywacke ranges in color from dark bluish-gray to a very light gray.

The unaltered graywacke is a dense rock consisting of about 60 percent of fragments which range from 0.5 mm to 1 cm in size. They consist of basalt, plagioclase (An35-40), black shale, augite, hornblende, and minor amounts of quartz. These fragments are enclosed in a fine-grained matrix of argillaceous material, sericite, chlorite, and devitrified volcanic ash.

Interbedded with the graywacke are thin beds of siltstone which have a smaller average grain size, and contain a higher percentage of argillaceous material and devitrified volcanic ash than does the graywacke.

Chert, composed largely of crystalline quartz with crisscrossing veinlets of microcrystalline quartz and clear chalcedony, occurs in lenses composed of well-layered beds. Its color ranges from yellowish-gray through grayish-green; brown; and red to black. Radiolarian tests and spicules are rare, but are most abundant in a red ferruginous chert.

Diabase sills occur in several parts of the area studied. They are localized primarily in two areas which are about one mile apart. On Leech Lake Mountain, at least six diabase sills were mapped in a northeast-trending zone about a mile long and a quarter of a mile wide. The sills range in thickness from six feet to 30 feet and in color from dark grayish-green to grayish-black. They are separated from each other by beds of well-layered chert. The second area, about one mile south of Leech Lake Mountain contains fewer sills, but these appear to be similar to those at the Leech Lake Mountain area.

In thin section, the diabase displays an ophitic texture. Deep pink titaniferous augite occurs in conspicuous prismatic crystals which are largely altered to pale-green chlorite and actinolite, and rarely to strongly pleochroic blue crossite. Plagioclase (average composition about An 50) is altered to pumpellyite and prehnite. Granular sphene, leucoxene, apatite, and ilmenite are abundant accessory minerals.

Greenstone and basalt occur as small plug-like bodies in the graywacke and as thin flows associated with the diabase. The greenstone is dark brownish-green in color, fine-grained, and extensively fractured. Where it has been intruded by peridotite, the greenstone has been converted to a dense hornfelsic rock containing abundant actinolite, some chlorite, and green diopsidic pyroxene.

Sills of peridotite, now fully converted to serpentine rock, intrude the other rocks. The serpentinite is green, bluish-green, and brownish-green in color. The most common variety is massive, coarsely crystalline, and contains bastite. Picrite is common, especially in local areas within the bastite serpentinite. Chrysotile is present but not common. Chromite and magnetite occur in small grains, scattered sparsely throughout the serpentinite.

Small veins of white, tough rodingite are scattered throughout the serpentinite. These are composed of colorless vesuvianite, colorless hydrogrossular, prehnite, zoisite, and talc. The largest body of rodingite exhibits a coarse pegmatitic texture and appears to have been formed through hydrothermal alteration of a gabbro pegmatite. A similar origin was suggested by Grange (1927) and Bloxam (1954) for rodingite bodies in New Zealand and Scotland respectively.

Other bodies of rodingite appear to have an entirely different origin. They have almost the same mineralogy as the rodingite body just described, but contain in addition angular grains of feldspar which are largely replaced by a pale-green fibrous pyroxene; clusters of graphitic material derived from carbonaceous shale fragments; and a pyroxene composed of 70 percent diopside, 20 percent jadeite, and 10 percent acmite.

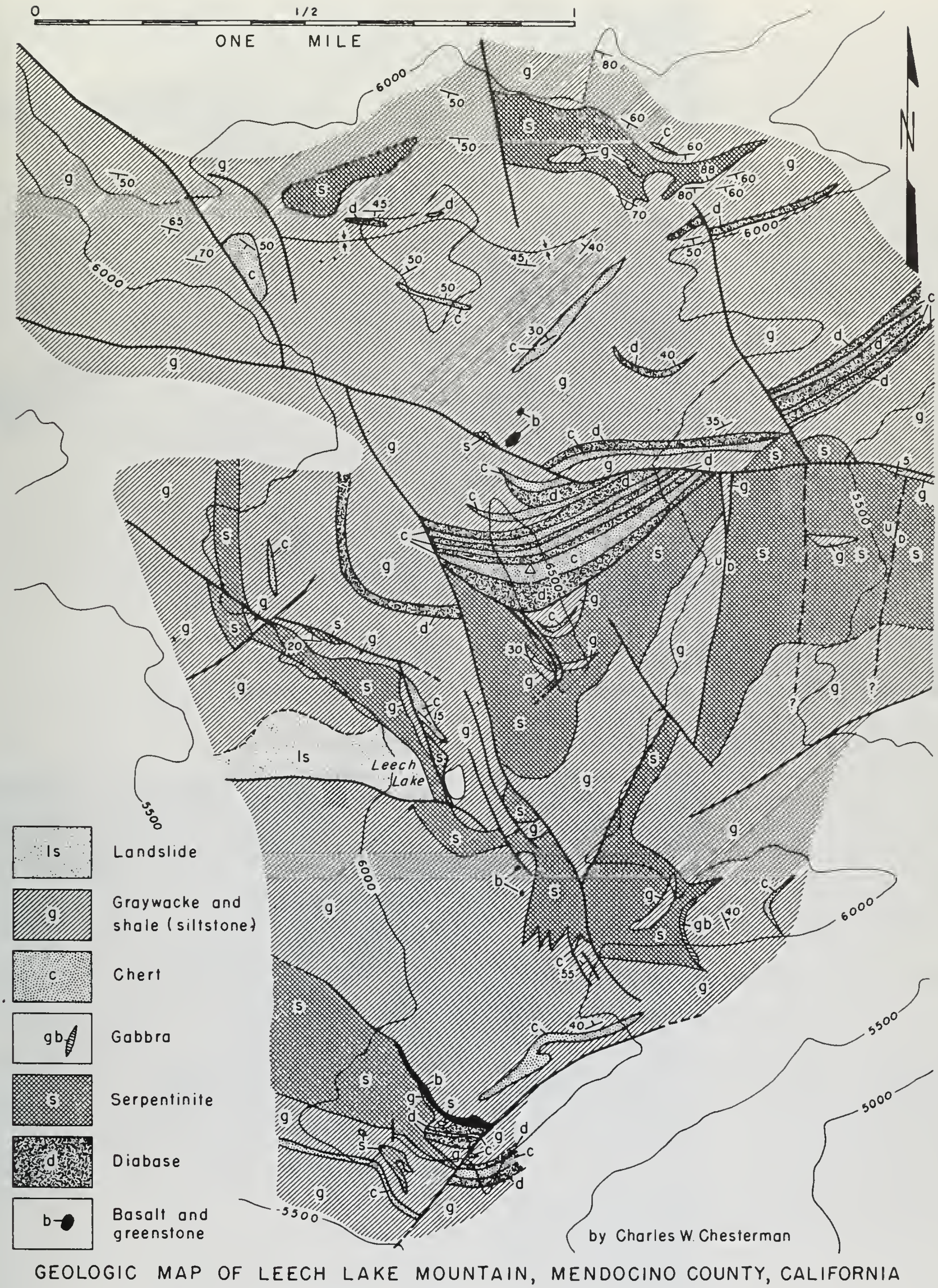
0
1/2
1
ONE MILE
N
ls Landslide
g Graywacke and shale (siltstone)
c Chert
gb Gabbra
s Serpentinite
d Diabase
b Basalt and greenstone
Leech Lake
6000
5500
5000
by Charles W. Chesterman
GEOLOGIC MAP OF LEECH LAKE MOUNTAIN, MENDOCINO COUNTY, CALIFORNIA

Figure 2.

Photo 1. Contact between serpentinite (s) and graywacke (g). White contact zone (c) and veinlets in serpentinite are composed of nephrite, diopsidic-jadeite, hydrogrossular and vesuvianite. Scale is indicated by 5-inch long pencil.

The presence of quartz grains, altered feldspar, and the clusters of graphitic material indicate that the rodingite was derived from graywacke which had been engulfed in the peridotite during its emplacement. Bodies of this type of rodingite are usually less than four inches thick. Most of them contain a contact zone of serpentinized graywacke which is less than one inch wide. Under the microscope, this serpentinized graywacke is fine-grained and appears to consist largely of a pale-green, very low birefringent matrix material—some chlorite, and some antigorite—all enclosing the grains of altered feldspar and fragments of shale.

CONTACT METAMORPHISM OF THE GRAYWACKE

Contact relationships between the graywacke, chert, greenstone, and diabase, and the ultrabasic rocks that intruded them are unusually well exposed and clearly defined at Leech Lake Mountain, offering a rare opportunity to study the mineralogical and structural contact effects.

Ideally, the effects of metamorphism of the graywacke by the ultrabasic intrusion should be studied in samples taken at regular intervals away from the contact along a bed that meets the contact at right angles. At Leech Lake Mountain, this sampling technique was impossible, because the intrusive contacts are conformable with the adjacent bedding. Therefore, samples were taken in the next best way: at regular intervals perpendicular to the bedding and the contact, across the bedding of a single massive bed of graywacke about 15 feet thick.

Fifteen feet from the serpentinite contact, the graywacke is medium-gray in color and shows slight foliation parallel to the bedding. It contains angular fragments of plagioclase (An 35-40) which are partially altered to sericite; blue-green hornblende; finely fibrous, pale blue-green actinolite; basalt fragments in which the ferro-magnesian minerals are altered to pale-green chlorite; and shale. The matrix is composed of argillaceous material and devitrified volcanic ash.

Three feet from the serpentinite contact, the graywacke is medium-gray in color and shows the same foliation as it does 15 feet from the contact. The mineralogical composition of the graywacke three feet from the contact, however, shows a marked change: actinolite persists but a pale yellowish-green pyroxene of aegiritic composition has developed at the expense of the argillaceous matrix material. The shale fragments have disappeared and in their place are spongelike clusters of black grains (probably graphite).

One foot from the serpentinite contact, the graywacke is light-gray in color and still displays a clastic texture. The angular fragments of feldspar (An 35-40) are partially altered to sericite, and altered fragments of basalt and black shale are recognizable. Actinolite is even less abundant than at three feet from the contact; aegirite is still present; and blue pleochroic amphibole (glaucophane) is present, apparently derived from clasts of pale bluish-green hornblende.

Six inches from the serpentinite contact, the graywacke is lighter still in color than that one foot from the contact. A prominent set of joints has developed, normal to the contact. Feldspar is scarce, and altered largely to minute scales of sericite. The pyroxene is diopsidic jadeite (di_{60} ja_{40}), and occurs in colorless, needle-like crystals that seem to have developed best in open cavities which later were filled with calcite. The fragments of basalt are completely destroyed; many are altered to clusters of radiating needles of diopsidic jadeite. The matrix material is recrystallized, and also contains abundant diopsidic jadeite. No blue amphibole could be found. Small, well-developed crystals of green garnet, radiating rosettes of thomsonite, some pale-green antigorite, and colorless prehnite are also present. Both the thomsonite and prehnite occur as late fracture fillings.

A metamorphic zone of mottled light-green and greenish-white material, ranging in width from a fraction of an inch to as much as 18 inches, is developed at the contact of the graywacke with the serpentinite. This material, which has a specific gravity of about 3.3, is composed of minerals derived from both the serpentinite and the graywacke, and contains in addition incompletely altered fragments of graywacke and serpentinite. The bulk mineralogy, which varies greatly from place to place in the zone, includes nephrite, diopsidic-jadeite (di_{80} ja_{20}), vesuvianite, hydrogrossular, prehnite, thomsonite, chrysotile, antigorite, and garnet. Veins that consist principally of nephrite, diopsidic jadeite, and minor amounts of vesuvianite and hydrogrossular, branch into the serpentinite from the metamorphic zone. These veins, which range from 1 mm to 30 mm in width, form a network that extends into the serpentinite as far as three feet from the contact. Veins of this composition have not been found in the graywacke; instead, one finds monomineralic veins of pectolite, xonotlite, and calcite. The pectolite veins are common but are short and few extend farther than two feet into the graywacke.

In general, the veins in the serpentinite are relatively high in calcium and magnesium, but are low in aluminum; those in the graywacke are higher in calcium, but lack aluminum and magnesium.

The distribution of the minerals in the contact zone appears to be controlled by bulk composition: vesuvianite and hydrogrossular, minerals high in calcium and aluminum, tend to be localized in the graywacke side of the contact zone; nephrite and pyroxene occur generally in the serpentinite side of the contact zone.

METAMORPHISM OF THE CHERT AND DIABASE

The chert, at its contacts with serpentinite and diabase, is a dense, fine-grained rock in which the silica has recrystallized to fine-grained quartz. Both aegirite and pale bluish-green amphibole are present. The aegi-

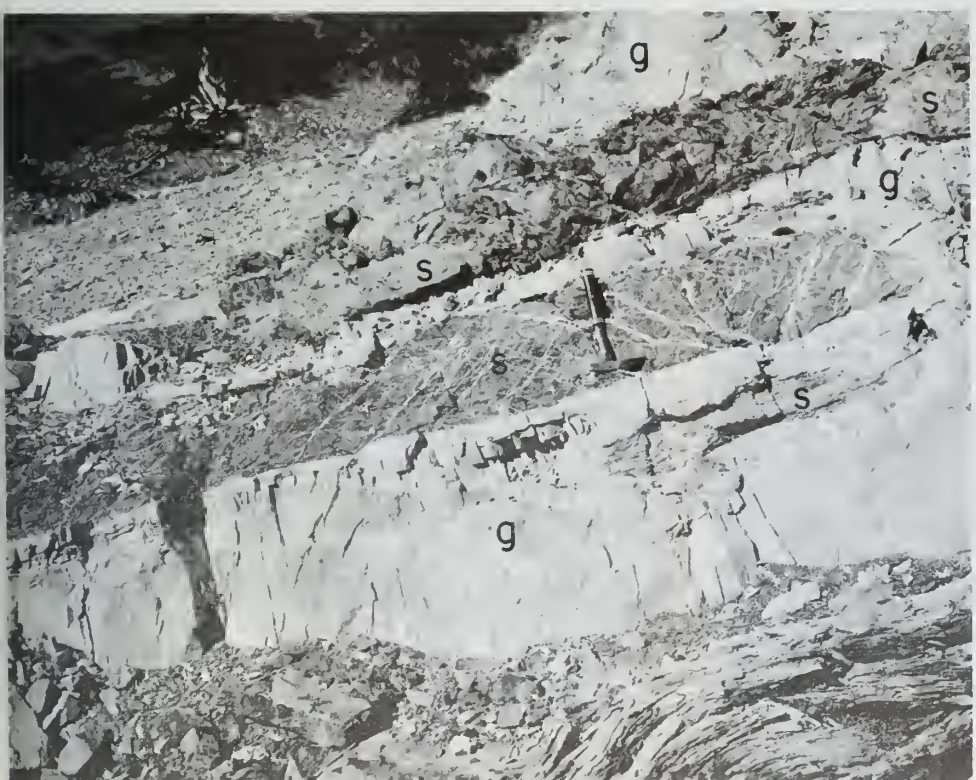

Photo 2. Apophyses of serpentinite (s) in graywacke (g). White veinlets in middle apophysis are composed of nephrite and diopsidic-jadeite, and are fillings along shear joints. The blunt end of the middle apophysis appears to be just an edge of the apophysis.

rite is more abundant than the amphibole and occurs in rosettes of yellowish-green crystals. The red iron oxide which is common to most cherts in this area is recrystallized to hematite.

The contact metamorphic effects of the peridotite upon the diabase, however, are more evident and intense than are those upon the chert. Titaniferous augite is completely altered to pale-green chlorite, a pale-green amphibole, and serpentine minerals. Feldspar is completely altered to a fine-grained mixture of pumpellyite and a colorless, low-birefringent material. Of all the minerals originally present in the diabase, apatite is least affected. It remains as typically cross-fractured needles, and is best preserved where it occurs in a matrix of fine-grained chlorite. The ilmenite and sphene are altered to leucoxene.

Of considerable interest is an uncommon, deep-brown, strongly pleochroic amphibole, which appears to be idioblastic where it replaces the original pyroxene, but is in xenoblastic crystals where it replaces the chloritic matrix material. From its optical qualities (negative, $2V = 75\text{-}80°$, $Z \wedge C = 16°$, $X =$ pale yellowish-brown, $Y =$ reddish-brown, $Z =$ dark red-brown) and association, this mineral is referred to as kaersutite. An amphibole of similar properties and occurrence has been decribed by Bloxam (1955, p. 322).

A contact zone, rarely more than a few inches wide, is developed at the diabase-serpentinite contact. This zone consists essentially of pale-greenish nephrite, some pale-green serpentine minerals (mainly chrysotile) and talc. Very narrow veins of the same mineralogy extend from the contact zone into the diabase and serpentinite. Much of the nephrite in this zone, and in the veins, apparently formed through endomorphic effects on the peridotite at the time of its emplacement.

MODE OF EMPLACEMENT OF THE PERIDOTITE

From the mineralogical and field evidence mentioned above, it is concluded that the serpentinite was originally emplaced as a liquid magma of peridotitic composition and not as a cold intrusion of serpentinite. Intrusive contacts are common along the margins of all serpentinite bodies in this area. The upper contact of the largest sill on Leech Lake Mountain contains several small apophyses of bastite serpentinite ranging in thickness from 12 inches to four feet. The smaller apophyses effected a lower degree of metamorphism on the enclosing graywacke than did the larger serpentinite bodies. At its contact with the apophyses, the graywacke is bleached light-gray and is cut by tension joints normal to the contact. The apophyses are cut by a conjugate system of shear joints which are filled with veins of nephrite and diopsidic jadeite. The mineralogy of the graywacke at its contact with the apophyses is the same as that of the graywacke in contact with the larger serpentinite bodies.

The graywacke at and near the larger serpentinite bodies is not strongly deformed and contorted but is prominently jointed parallel to the bedding. The serpentinite is not sheared intensely at the contact. It is believed, therefore, that the original peridotite was sufficiently mobile to be forcefully emplaced along bedding planes in the graywacke and that the graywacke was indurated, yet sufficiently plastic to allow the peridotite access.

GRADE OF METAMORPHISM

The graywacke has undergone progressive contact metamorphism, with progressively higher grades being found towards the contact with the intruding peridotite. The mineral assemblage in the altered graywacke at the contact consists of diopsidic jadeite, scarce glaucophane (and/or crossite), antigorite, and chlorite. Although this assemblage is not necessarily characteristic of the glaucophane schist facies, the presence of considerable diopsidic jadeite and scarce glaucophane indicates that the grade of metamorphism has progressed beyond the greenschist facies and is transitional into the glaucophane schist facies. Metamorphic conditions within the glaucophane schist facies—namely low temperature and high pressure (Turner, 1958, p. 226; Bloxam, 1956, p. 496)—would surely account for the formation of the diopsidic jadeite.

REFERENCES

Bloxam, T. W., 1954, Rodingite from the Girvan-Ballantrae complex, Ayrshire, Mineralogical Magazine, vol. 30, no. 227, pp. 525-528.

Bloxam, T. W., 1955, The origin of the Girvan-Ballantrae Beerbachites, Geol. Mag., vol. 92, no. 4, pp. 329-337.

Bloxam, T. W., 1956, Jadeite-bearing metagraywackes in California, Am. Min., vol. 41, pp. 488-496.

Fyfe, W. S., Turner, F. J., Verhoogen, J., 1958, Metamorphic reactions and metamorphic facies, Geol. Soc. America, Memoir 73, pp. 224-228.

Grange, L. F., 1927, On the "rodingite" of Nelson: Trans. New Zealand Inst., vol. 59, pp. 160-166.

NEPHRITE JADE IN MARIPOSA COUNTY
Reprinted from *Mineral Information Service* (September 1966)

By James R. Evans
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Since the discovery of jade in the Mother Lode area (announced in this magazine, February 1964), many prospectors, miners, and would-be miners have scanned the area of the jade outcrops. Although many of the outcrops are on public land, and hence fall within the jurisdiction of the mining laws, some are on private land, and almost all of them are accessible only by crossing either private land or land already in use by private individuals. We can not stress strongly enough the necessity for obtaining permission to enter private land or privately used land.

It is illegal to trespass; *in the Mother Lode, where men of mountain temperament are the rule, not the exception, it can be downright dangerous. Prospectors, please, for your own well-being*—GET PERMISSION!

Nephrite jade * was found in Mariposa County during September of 1962 by Oliver E. Bowen of this Division who was mapping the geology of the Coulterville and El Portal 15-minute quadrangles. The first jade discovered was in David Gulch, 2½ miles NNE of Bagby, a small hamlet on the Merced River. Since the first discovery a dozen other localities have been found; most of them lie between David Gulch and the Merced River, within 2 miles of Bagby, but a few are about 6 miles to the northwest, nearly to Coulterville. Some of these were also found by Mr. Bowen; others by this writer, also of the California Division of Mines and Geology, who is mapping the Coulterville-Bagby area geologically; and still others by Walter McLean, George Matlock, and other residents of Mariposa County. The discoveries indicate a new jade province roughly 13 square miles in extent.

The hard, dense, green material at the discovery site is in steeply east-dipping bodies as much as 5 feet thick and about 50 feet long. Lenticular bodies a few inches thick and a few feet in maximum length also may be seen. None have been explored in depth for more than 10 or 15 feet. Nephrite jade also occurs as stream-worn boulders. The larger masses form prominent outcrops all of which look quite different from the surrounding rocks. Many of the masses weather dark brown. Others have a light-colored talc or serpentine-rich shell around them. All are associated with serpentinized rocks and with various kinds of intrusive igneous rocks—mostly dikes.

Nephrite jade-bearing material is locally unflawed, but it also occurs as flawed and unattractive mixtures of nephrite, talc, serpentine, and magnetite. It is possible to differentiate them because talc- and serpentine-rich rocks can be scratched with the point of a geology pick, whereas nearly pure nephrite rock cannot. Part of the material takes a fine polish, is very attractive and comes in several shades of green. Extremely high-quality material is scarce.

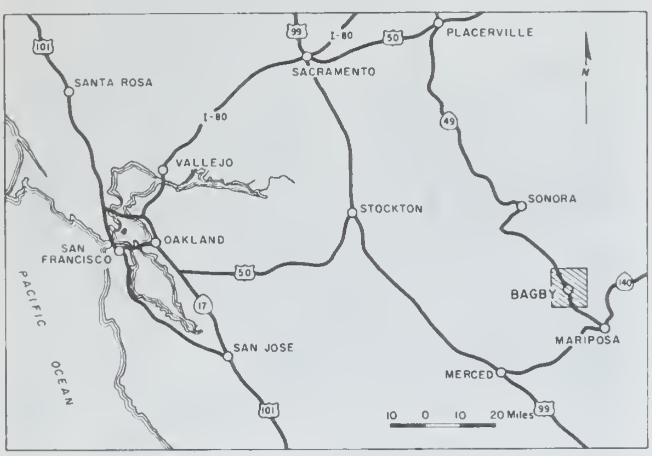
Laboratory identification of the nephrite was made initially in the Division of Mines and Geology laboratory in San Francisco by means of a petrographic microscope and by x-ray diffraction methods. Laboratory studies are continuing at the Division in San Francisco and at the University of California at Davis. Although the various deposits have not as yet been studied extensively, it is known that the jade is nephrite and that it consists of microscopic needles of monoclinic tremolite-actinolite. Needles are commonly oriented in a semiparallel fashion. Grains and clusters of magnetite are present locally, and make up as much as 20 percent of some specimens. The best quality jade, however, generally contains less than 1 percent magnetite as disseminated grains.

Talc nephrite jaderock near the discovery shaft, Mandarin-Empire deposit. View is north.

* See section on nomenclature of jade in this magazine.

One sample of jade at the Mandarin-Empire deposit was found to be cut by veinlets of anthophyllite. The veinlets appear very dark green in reflected light, but transparent in transmitted light through cut slabs 1/16 inch thick. The largest veinlet was 3/8 inch wide and about 3 inches long. Mineral identification was made from this veinlet, and probably the other veinlets are the same. Unusual as it seems, the calcium-poor amphibole may prove to be common as a late stage mineral.

As the Mariposa jade province lies in the Mother Lode gold belt, it has been walked over by miners and prospectors—even the Chinese—for more than 100 years. It at first seemed odd to me that no one was curious enough to test or even take samples of the jade outcrops to see what they were. Most miners, of course, were interested mainly in gold or other metallic minerals. I think the remarkable resemblance of the jade outcrops to the "Gravestone or Tombstone Slates" common in part of the southern Mother Lode area was the main reason that they ignored the jade outcrops. "Gravestone or Tombstone Slate" was a term used at an early date in the mining camps to describe steep, slab-like rocks that project upward from smooth grassland areas. The outcrops are brown, occur in discontinuous rows, and in dim, or by moon, light resemble headstones in a graveyard. H. F. Turner in a geologic report published 1896 (pp. 670 and 672) showed photos of outcrops 4 miles SW of Crimea House near the road from Crimea House toward Don Pedro Reservoir, Tuolumne County. The rocks are usually not slate but schistose green volcanic flows and tuffs commonly called greenstone.



Index map of Bagby area.

GEOLOGY OF SOME NEPHRITE JADE-BEARING AREAS

The jade discovery was deemed important enough to warrant further study. Accordingly, in late 1964 and intermittently through 1965, detailed geologic maps on scales of 1″ = 10′ and 1″ = 50′ of two jade-bearing areas were prepared. These were not the only occurrences, but they offered the best potential for geologic and economic study as various rock types were in place and well exposed. The geologic map of the Coulterville-Bagby area is on a scale of 1″ = 1000′, and when completed will show the location of all jade outcrops.

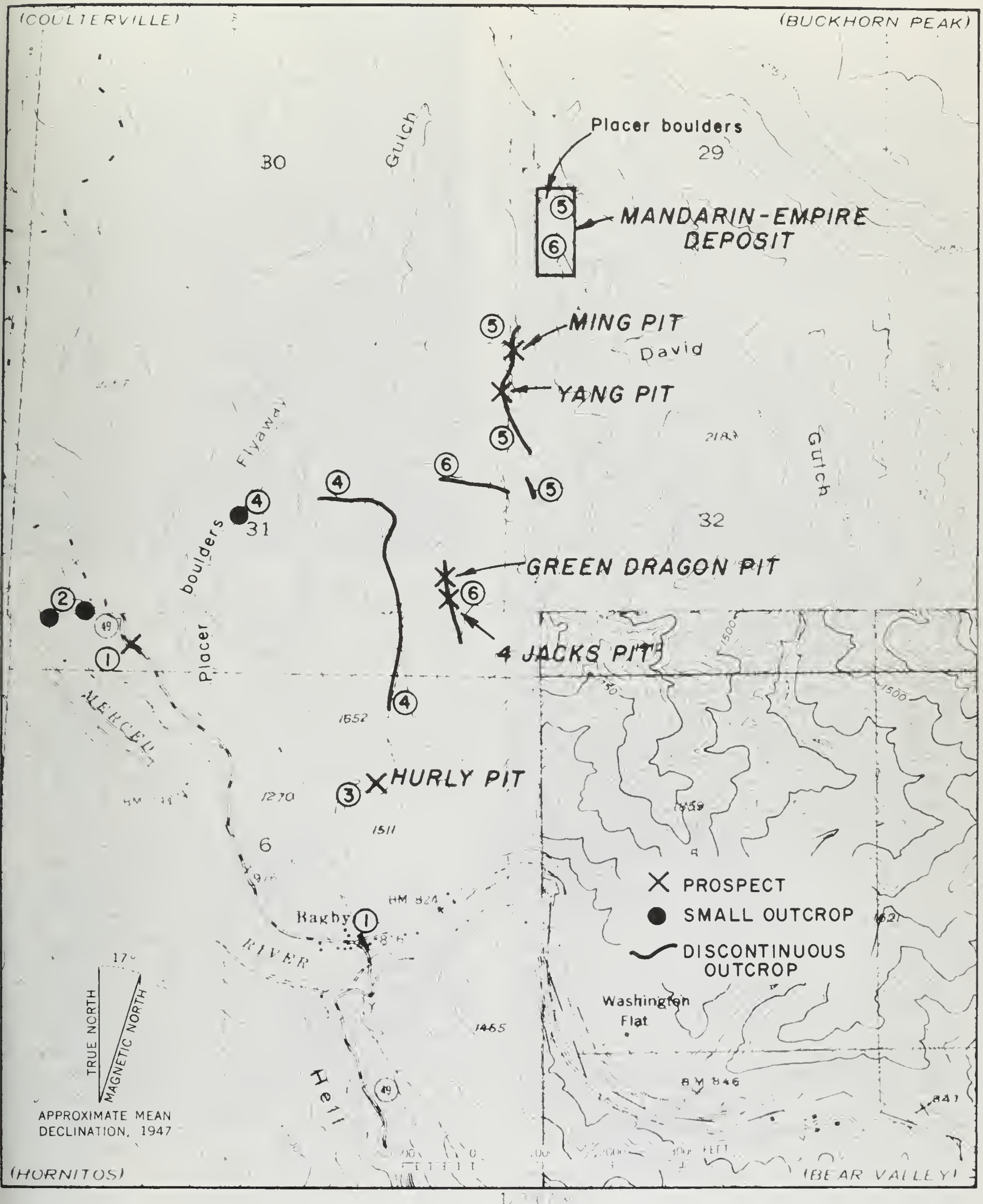
A physical, spectrochemical, and petrologic study of the jade and adjacent rocks is now underway. These laboratory studies, plus the geologic mapping, will provide clues, and hopefully answers, to the problems of jade formation. In addition, more data can be gathered which will help with mining, marketing, and prospecting the jade.

Although the study is only partially complete, certain things are known about the jade and its field occurrence. It is found mainly in irregularly shaped, discontinuous bodies of steeply east-dipping, talc-rich rock in six different geologic environments, which are:

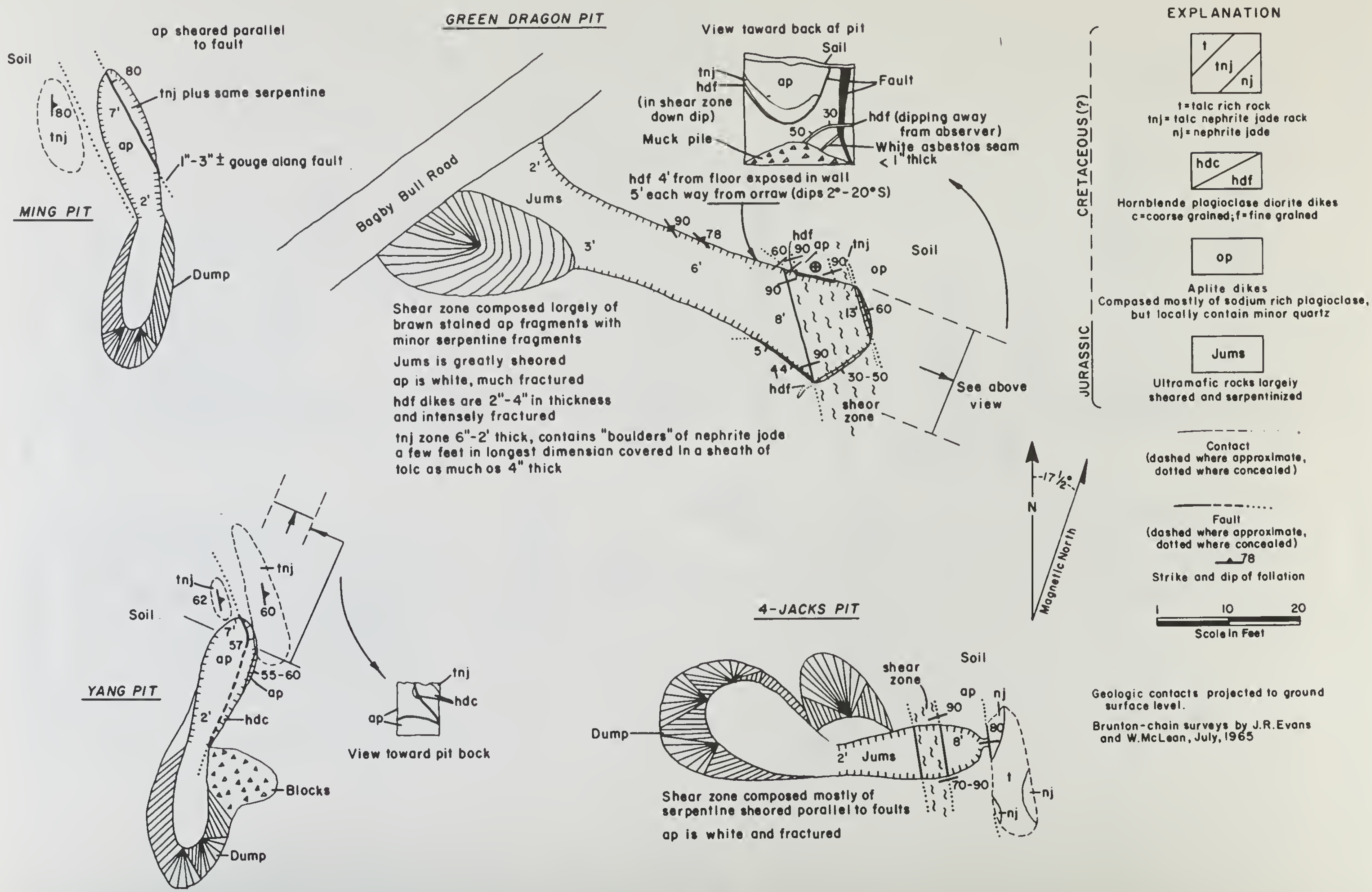
1. Entirely within sheared serpentine rock masses as in the SW¼ of Sec. 31 about 100 feet SW of Highway 49.
2. In contact with volcanic flows and pyroclastic rocks within serpentine as in the SW¼ of Sec. 31 a few to several hundred feet SW of Highway 49 along the south slope of a west trending ridge.
3. In contact with slate within serpentine as in the NE¼ of Sec. 6 about ½ mile N of Bagby.
4. In intrusive contact zones between gabbroic rock and serpentine as in the E½ of Sec. 31, and the NE¼ of Sec. 6.
5. In intrusive contact zones between hornblende-plagioclase diorite dikes and serpentine as at the Mandarin-Empire deposit and in the area about a quarter of a mile to the SSW.
6. Against aplite dikes in shear zones between serpentine and slate, and in shear zones between serpentine and dikes, as at the Mandarin-Empire deposit, the Ming-Yang deposits, and close by areas. At present, it appears that all contacts of jade against the aplite dikes in this environment are faults, but some may prove to be intrusive. The dikes are composed almost entirely of sodium-rich plagioclase. Some specimens are porphyritic and contain minor amounts of quartz.

As widely varied as these environments are, it is clear that serpentine is vital to the formation of jade. Even the present limited knowledge indicates that jade formed through metasomatic alteration of the serpentine by addition of calcium, silica, and possibly iron, by intrusion of the gabbroic and dioritic rocks. Water * needed for the formation of tremolite-actinolite could readily be obtained from the hydrous serpentine. The significance, if any, of the aplite dike intrusions in formation of the jade is not yet known.

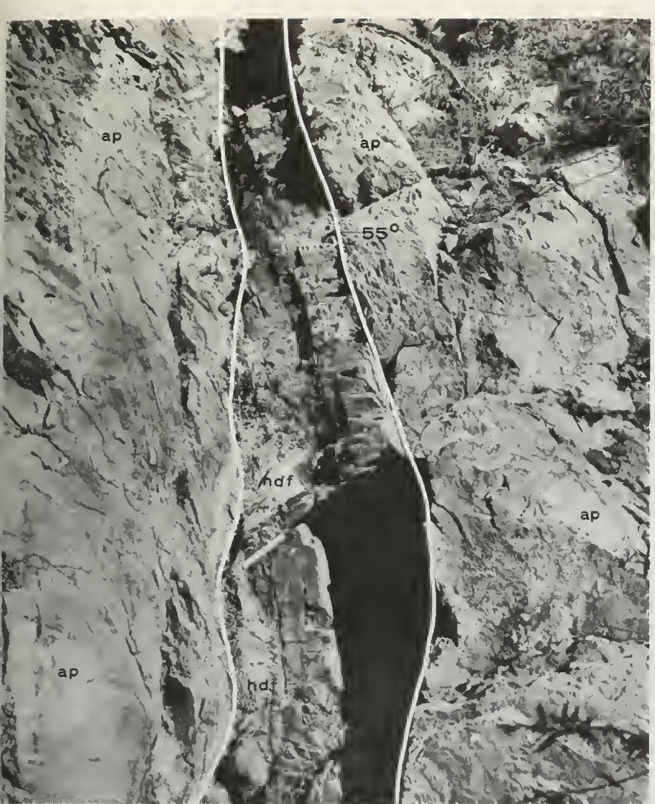
* See section on Chemical, Physical, and Optical Properties of Nephrite (Tremolite-Actinolite) Jade.



Topographic map of the Bagby area showing locations of talc nephrite rock and nephrite in geologic environments.



Geologic maps of the Ming, Yang, Green Dragon, and 4-Jacks pits, Mariposa County.



Fine-grained hornblende diorite dike (hdf) cutting an aplite dike (ap) in David Gulch at the Mandarin-Empire deposit.

Part of some jade-bearing rocks are rich in talc, which accounts for the ease with which some outcrops may be scratched. The amount, and exact time of formation, of the talc are not yet known, but it did form after the jade at lower temperatures and pressures.

ECONOMIC ASPECTS

Mining Mariposa Jade

Mariposa jade occurs in outcrops, and as alluvial boulders which have weathered from outcrops and moved downslope usually for only a short distance. Boulders have not moved far because of their size and weight. They weigh from about a ton to several tons, and are as much as 7 feet in longest dimension. There are boulders in David Gulch, Flyaway Gulch, and Scotch Gulch. Most of the known jade outcrops are outlined on the maps accompanying this article.

Extracting jade from the outcrop is not extremely difficult, but it should be done carefully. Since it occurs as discontinuous and irregular shaped bodies in talc-rich ledges, once a body of jade is well exposed, it can be pried from the ledge with an iron bar. At present, the best way to extract the jade appears to be by making an access trench into the talc-rich ledge at right angles to the strike (see geologic map of the Green Dragon and 4-Jacks pits). To date, blasting within a few feet of the jade has presented no problems and should do no damage. After the jade-bearing zone or suspected jade-bearing zone is reached and any bodies pried out, the excavation should continue at least 15 feet past the base of the zone at pit level. At the end of the access trench, a mining trench should be excavated along the strike of the ledge on the upper or hanging wall side, leaving enough room at the trench junctions to allow ready access for any needed heavy equipment. On the other hand, if the foot wall or lower side is worked, the miner must remove those of the steeply dipping bodies that are inclined toward him. This creates a dangerous situation, because the jade bodies could give way suddenly and fall on the men working the bars and prys. It is much safer for dips of roughly 50° to 75° to mine the jade in the first described manner and simply pry or slide the jade bodies out of the outcrop and down into the trench. For shallower or steeper dips the miner must use his own judgment as to which is the better side of the zone to work.

An access and mining trench width of 10 to 15 feet should prove ample for all types of heavy equipment that might be used. A low gradient is necessary toward the trench entrance, together with a ditch to drain water from the trench after a heavy rain.

Jade bodies, either extracted or alluvial, can be loaded without blasting by a skip loader, crane, or DC7 Caterpillar onto a 4-wheel drive truck, or sawed into smaller pieces by a drag or circular saw and then loaded. Boulders cannot be blasted even with 40 percent dynamite, as they will either shatter into irregular pieces, or develop cracks along the semi-parallel fibrous intergrowths.

A 4-wheel drive, heavy-duty truck is needed for moving large pieces because roads into or near the known Mariposa jade deposits are unimproved, narrow, and locally steep. In the winter they are muddy after heavy rains and nearly impassable for several days, even with 4-wheel drive. Jade could be mined in the spring or summer months and a stockpile made at some convenient location.

A drag saw has been specially designed that can be used in the field or elsewhere. It should be mounted on a heavy duty wooden platform or on a slab of cement under cover of some type, preferably a wooden shed. The advantage of the drag saw over a circular saw is that it can cut through a large boulder with one smooth cut. It is noisy, however, and requires continuous oiling. In addition, just the proper amount of weight must be applied on the counter balance at the

Diamond drag saw designed by George Matlack and A. C. Brill. The frame is made of I-beam steel. Power from a 3/4 hp electric motor drives the 4-foot blade. The blade has twelve 2-inch metal segments in which heavy duty commercial diamonds are soldered. The blade has an 8-inch throw, and makes a cut 40 inches long and about two-tenths of an inch wide. Clyde Call (left) and George Matlack (right) are placing the saw in operation.

end of the saw so that it will not bind into, or ride up with the cut. About two-tenths of an inch of jade is lost per cut on the drag saw, but nearly one-tenth of an inch is lost on a circular saw. If the boulder is too thick to cut clear through with a circular saw, it can be carefully split by driving iron wedges into a saw cut with a double jack. A jagged surface of whatever thickness was left unsawed will result, however. A useful combination is a drag saw and a 24-inch table mounted circular diamond saw. Large pieces can be sawed by the drag saw, and the cut pieces then trimmed or sliced by the circular saw.

Evaluating and Prospecting Mariposa Jade

Field characteristics that should be considered in deciding whether a jade mass is worth processing are hardness, toughness, color, uniformity of color, and the presence of cracks. High quality material cannot be scratched with the blade of a pocket knife. Softer, less desirable masses generally are mixtures of nephrite, talc, serpentine, and magnetite and can be scratched with the knife blade. Many jade bodies that have an enclosing shell of soft weathered material several inches thick must be sawed into slabs for adequate hardness tests.

The best grades of Mariposa jade are various shades of green. All grades contain some magnetite. A few fine grains of black magnetite can enhance the overall appearance of the jade, but too much magnetite detracts from the appearance. An attractive "Kelly" green jade found at the Green Dragon Pit is variegated by white stringlets of a presently unidentified mineral, possibly white tremolite. If the jade is cut very thin, say to ⅛th of an inch thick, and held up to the light, it is faint green to green and translucent, with a few dark specks of magnetite. It is colorless to faint green in very thin slices (0.025 mm) cut for examination under the microscope.

In some cut slabs a rough color zonation can be seen. The center of the slab is green and grades outward through light green to white with brown edges. In this type of material the discolored areas have proven to be rich in talc and magnetite, and of poor quality.

Bodies of jade, particularly at the ground surface, are commonly cracked and discolored along the fractures and away from them for an inch or two. Material between the discolored areas, however, can be good quality jade. Jade can best be evaluated only after sawing. It is preferable to saw large unwieldy bodies of jade near the outcrop, because if it is found to be poor, there will be no need of moving the boulder to a plant or shop. An edge or end of many bodies can be sawed with a small gasoline driven saw for preliminary evaluation. Inasmuch as many large masses have an irregularly shaped central area of high quality material, the best method of evaluation is to saw them in half.

Some bodies of cracked, discolored, or talc-rich material at the ground surface probably will prove to be entirely of poor quality after cutting. If so, it may still be possible to find good jade a few or several feet below the ground surface, where the rock has not been subjected to such rigorous weathering processes. Jade bodies are irregularly shaped and discontinuous along the strike and there is every reason to believe they will continue this way in depth. Any zone worth examining on the surface is also worth exploring at depth, at least for a few tens of feet.

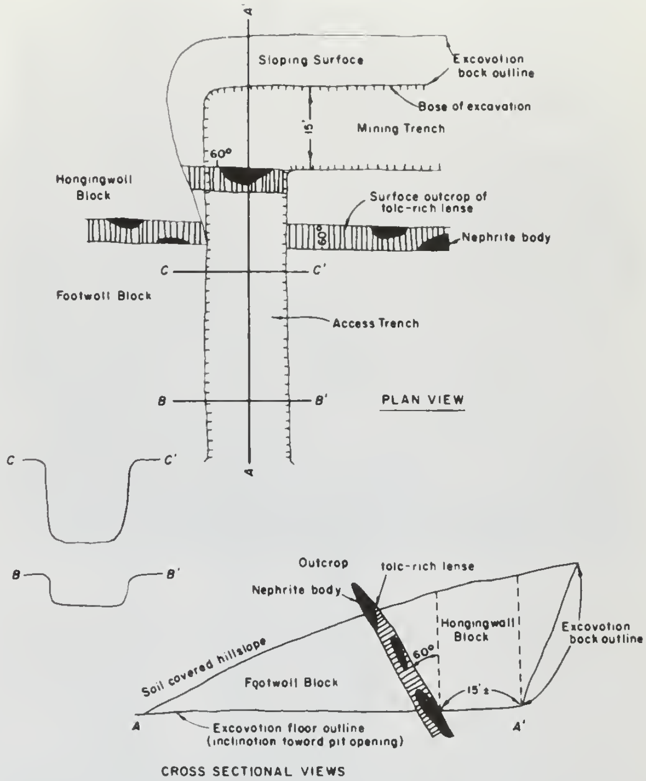
It is not difficult to distinguish jade or talc-rich zones from the "Gravestone" or "Tombstone" slate mentioned in the early part of this article, even though both may weather brown. Jade is quite difficult, or even impossible, to break off in the outcrop, whereas greenstone or slate will break much more readily. Slate has a marked cleavage and is brown to black. Volcanic rocks are coarser grained, have a granular or porphyritic texture, a rougher surface, and are gray or green.

As previously mentioned, serpentine is necessary for jade development and prospectors should search areas underlain by it. Geological relationships in the serpentine belt from Kanaka Creek in Tuolumne County to Mormon Bar in Mariposa County are so similar to those at the known jade province that the whole belt should be prospected. Part of the land may be privately owned, but much of it is on public domain and open for prospecting.

Marketing

Most Mariposa jade is sold by the pound, prices ranging from $5 to $10 or more per pound. Prices received for jade from other U. S. and foreign sources are similar, although unusual, or special quality material occasionally sells as high as several hundred dollars a gram. Mariposa jade cut in slabs 3/16 of an inch thick sells for $0.50 to $0.75 per square inch. Carving material is available in bulk lots at negotiated prices. Custom cuts or shapes, and unusual or large orders are also filled at negotiated prices.

At present, Mariposa jade is marketed in Mariposa by two groups of claim holders; Clyde Call and George Matlock, P. O. Box 301, owners of the Mandarin-Empire deposit in David Gulch, and John Fulham, Ray Jepperson, Walter McLean, Harry Odgers, and Allan Grant, P. O. Box 627, owners of the Ming-Yang deposit in Charcoal Flat.



Sketch showing suggested method of mining jade.

NOMENCLATURE OF JADE AND A COMPARISON OF OTHER MINERALS CALLED JADE

Early people of North America may have been the first to find jade as jadeite. Foshag (1954, and 1955 a and b) indicates that jadeite was used as long ago as 2,200 years by the ancient Mayans as tools for hard stone carvings, and for ornaments. Nephrite jade (tremolite-actinolite) is of course known from Chinese cultures dating back 3,000 years or more. The Chinese valued jade highly and made many beautiful art objects from it. A small amount of jadeite is also known to have come from China.

The Aztecs also highly prized jade (jadeite) which they called Chalchihuitl. Spanish explorers in the early 16th century took note of the valuable Chalchihuitl; Fr. Bernardino de Sahagun mentioned it by name in his work on Aztec culture in 1530. Sahagun, however, thought Chalchihuitl was emerald. Molina (1555) also defined the mineral as emerald in his Mexican dictionary. The particular value the Aztecs placed on

Table 1. Comparison of microfibrous or microgranular compact forms of minerals which have been called jade.

All varieties are transparent or translucent to subtranslucent. Only nephrite (tremolite-actinolite) and jadeite can properly be jade. All varieties except serpentine, chrysoprase, chert, phrase, and plasma are typical of contact metamorphic and metasomatic zones developed between carbonate and intrusive rocks. Serpentine is a common alteration product of iron-magnesium-rich ultrabasic rocks. Chrysoprase typically occurs as veinlets and as cavity fillings in serpentine. Chert is a sedimentary rock and occurs in beds one inch or less to as much as several feet in thickness. Beds may have great lateral extent or may lens out rapidly in several feet. Phrase and plasma occur in vugs and as cavity fillings in many types of rocks.

MINERAL	COLOR	HARDNESS	SPECIFIC GRAVITY (APPROX.)	LUSTER	CHEMICAL COMPOSITION	SOME SIMPLE DISTINGUISHING TESTS	DERIVATION OF NAME	CRYSTAL SYSTEM AND CLASS
"Nephrite" Tremolite	White to green	5–6	2.90–3.07	Vitreous	$Ca_2Mg_5(Si_8O_{22})(OH)_2$	Not soluble in HCl (see wollastonite); difficultlyfusible under blowpipe; some specimens distinguished from jadeite by hardness.	Nephrite from the Greek word for kidney, as it was once thought to aid or prevent diseases of that organ.	Monoclinic; prismatic
"Nephrite" Actinolite	Green	5–6	3.07–3.32	Vitreous	$Ca(Mg,Fe)_5(Si_8O_{22})(OH)_2$	In some specimens, from tremolite by color, and specific gravity; difficultly fusible under blowpipe; not soluble in HCl.	Tremolite for Tremola Valley, south side of St. Gottard, Switzerland Actinolite from Greek words, ray and stone because commonly found in radiating crystals.	Monoclinic; prismatic
Jadeite	White to green	6–7	3.24–3.43	Vitreous	$Na(Al,Fe)(Si_2O_6)$	Not soluble in HCl; fuses at 2½ to transparent glass under blowpipe (see tremolite-actinolite).	From Spanish *Piedra de yjada*, loin stone, because it was thought to prevent nephritic colic.	Monoclinic; prismatic
Serpentine	Light to dark green	2–4	2.55–2.61	Greasy, waxlike, or dull rough	$(Mg,Fe)_6(Si_4O_{10})(OH)_8$	Low in scale of hardness; greasy luster; infusible; soluble in HCl	For green serpent-like mottling or discoloration on massive specimens.	Monoclinic; prismatic
Diopside	White to green	5–6	3.22–3.38	Vitreous	$Ca(Mg,Fe)Si_2O_6$	Fusible at 4 to green glass; insoluble in HCl.	From Latin words *di*, two, and *opsis*, appearance—vertical prism zone can be oriented two ways.	Monoclinic; prismatic
Epidote	Yellowish green to green	6–7	3.38–3.49	Vitreous	$Ca_2(Al,Fe)Al_2O(SiO_4)(Si_2O_7)(OH)$	Partially soluble in HCl; fusible at 3–4 to black slag which is not fusible under blowpipe.	From Greek *epidosis*, increase—because in many crystalline specimens the base of the rhomboidal prism has one side longer than the other.	Monoclinic; prismatic
Vesuvianite (Idocrase) var. Californite	Brown to green	6–7	3.33–3.43	Vitreous to resinous	$Ca_{10}(MgFe)_2Al_4(Si_2O_7)_2(SiO_4)_5(OH)_4$	Fusible at 3 to a greenish brown glass; from garnets by specific gravity; partially decomposed by HCl, after fusing completely soluble.	Mt. Vesuvius, Italy, where mineral occurs in ejected lava blocks—later idocrase, because crystal forms resemble those of other minerals; from Greek, *eidos* appearance, and *krasis*, a mixture.	Tetragonal; ditetragonal-dipyramidal
Garnets Grossularite, and hydrogrossularite	White to green	6½–7½	3.59	Vitreous to resinous	$Ca_3Al_2Si_3O_{12}$, and $Ca_3Al_2Si_2O_8(SiO_4)_{1-n}(OH)_{4n}$	Grossularite fuses at 3 to glass; andradite at 3½; uvarovite at 6 (nearly infusible); all fused globules soluble in HCl except uvarovite; andradite globule magnetic; hydrogrossular soluble in HCl without heating; distinguished from each other, and other minerals by specific gravity.	Garnet is possibly from Latin, *granutus*, pomegranate, because its color is similar to the fruit pulp color. Grossularite from botanical name, *grossularia*, for pale green gooseberry. Andradite for Portuguese mineralogist, J. B. d'Andrada, melanite, from Greek word for black. Uvarovite for Count S. S. Uvarov, past President of St. Petersburg (Leningrad) Academy, Russia.	Isometric; hexoctahedral
Andradite var. melanite	Green melanite dark brown or black (from Ti)		3.86		$Ca_3Fe_2Si_3O_{12}$ (Melanite $Ca_3(Fe,Ti)_2Si_3O_{12}$)			
Uvarovite	Green (from Cr)		3.90		$Ca_3Cr_2Si_3O_{12}$			
Wollastonite	White	4½–5	2.87–3.09	Vitreous	$Ca(SiO_3)$	Soluble in HCl; fusible at 4 to white glassy globule; from jadeite by hardness.	After W. H. Wollaston, British chemist and mineralogist.	Triclinic; pinacoidal
Chrysoprase	Green (from Ni)	6½	2.57–2.64	Waxy to subvitreous	SiO_2+nH_2O+nNi	Uneven or conchoidal fracture; brittle, and may be cracked; infusible; insoluble in HCl; soluble in HF.	From the Greek words meaning gold and leek green.	Hexagonal -R, trigonal, trapezohedral
Phrase and plasma	Various shades of green	6½	2.57–2.64	Waxy to subvitreous	SiO_2+H_2O+ finely disseminated crystals of green silicate minerals such as chlorite	Both species infusible; insoluble in HCl, soluble in HF; plasma nearly opaque; smooth to conchoidal fracture; phrase usually more translucent than plasma.	Phrase from the Greek word meaning leek green; plasma from Greek for form.	Hexagonal -R, trigonal, trapezohedral
Chert	Green	6½	2.57–2.64	Dull to subvitreous	SiO_2+nH_2O	As above; dull luster may be diagnostic	Old local English term for rock, taken into geologic literature because of common use.	Hexagonal -R, trigonal, trapezohedral

their Chalchiuitl is shown in the following quote from Chief Moctezuma as recorded by Bernal Diaz del Castillo, 1632 and given in Foshag (1955), "I will also give you (Cortez) some very valuable stones, which you will send to him (King of Spain) in my name; they are Chalchihuitles and are not to be given to anyone else but only to him, your great Prince. Each is worth two loads of gold."

Chalchihuitl was valued for its medicinal properties as well as an ornament. It was mixed with herbs (in powdered form?) and served for head fractures, gout, fever, or what-have-you, according to Martinus de la Cruz and Juannes Badianus (1552).

Spanish explorers felt Chalchihuitl was particularly effective for kidney or liver ailments, and they also brought much carved material to Europe where it was highly prized. A Seville physician, Nicolas Monardes, called it *piedra de yjada*, or loin stone, in his book about New World medicines published in 1569. The French translation of the terms used by Monardes is *pierre de ejade*, which was later simplified through mistake or common usage to jade. The Latin translation of the terms was *lapis nephriticus* and was the basis for the mineral species name nephrite first used in print by the German mineralogist A. B. Werner in 1780.

The supply of jade from Mexico was soon insufficient to meet the demand and a shortage resulted. As trade routes were opened to the near and far east in the early 17th century, jade was brought to Europe from China, Persia, and India to meet the demand. During the late 17th century, the 18th, and 19th centuries, so much jade was brought in from China that people soon forgot, or ignored the material from Mexico. As a result the word jade nearly always brought to mind thoughts of the Orient.

In 1846, A. Damour, a French mineralogist and chemist, studied the Chinese material and called it *jade nephritique*. In 1863, Damour again examined the Chinese material and this time found a second variety which he called jadeite. Thus demonstrating that two varieties of jade came from China, although the majority was probably jade nephritique (nephrite jade). It was not until 1881 that Damour examined the Chalchihuitl from Mexico. He identified it as jadeite.

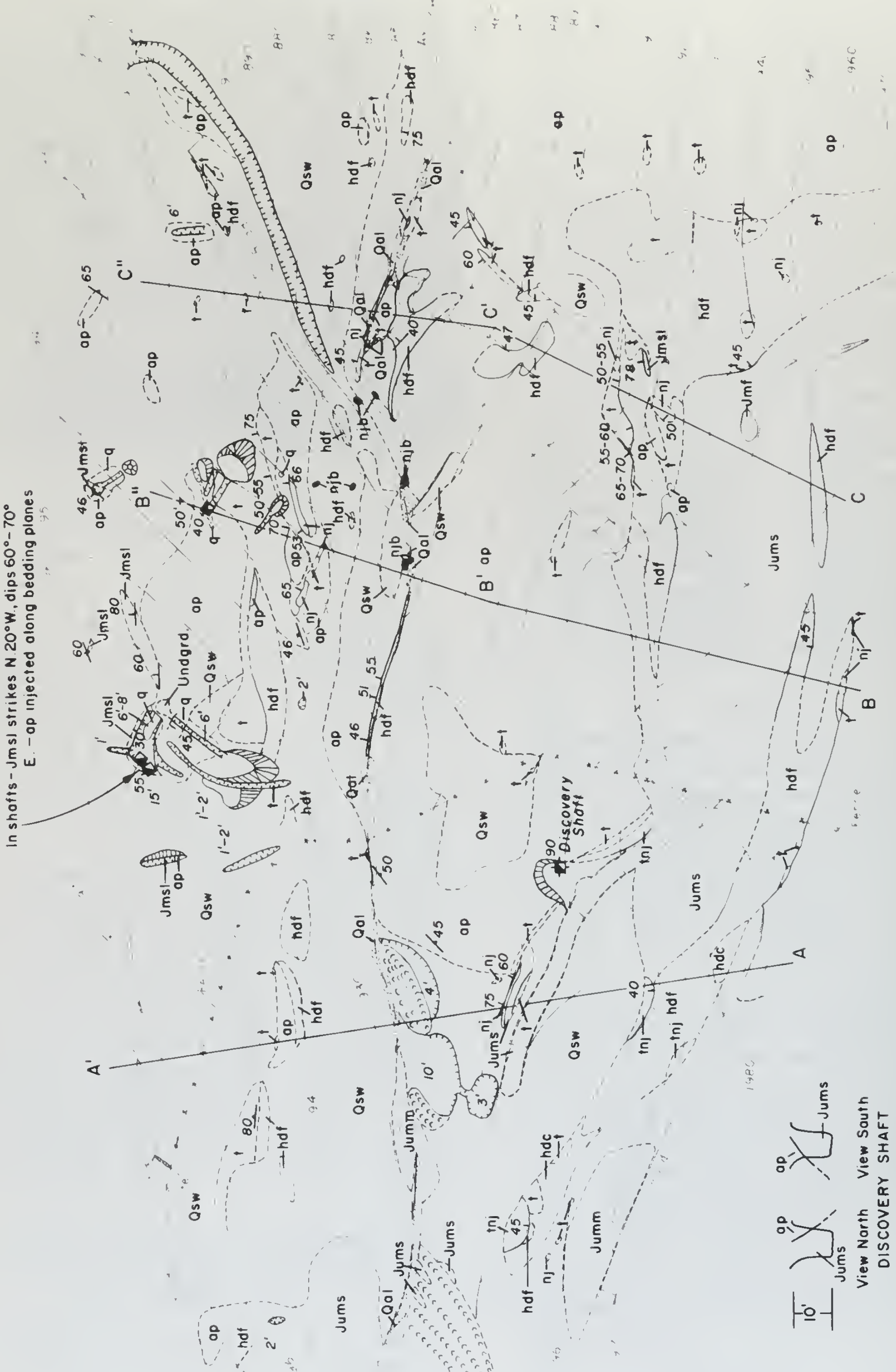
Through historical use since the work of Damour the term jade has been reserved for the microfibrous or microgranular compact forms of nephrite and jadeite, even though it often takes a mineralogist to distinguish between them. The critical reader will note that when nephrite (tremolite-actinolite) or jadeite occur in coarse clusters of individual crystals that can be distinguished by eye they are not termed jade.

Thirty-inch circular diamond saw designed and built by Allen Grant (shown in photo) and John Fulham, Mariposa. It is driven by a 1 hp motor and makes a 1/10-inch cut. The saw is in operation at the Diltz mine near Mariposa.

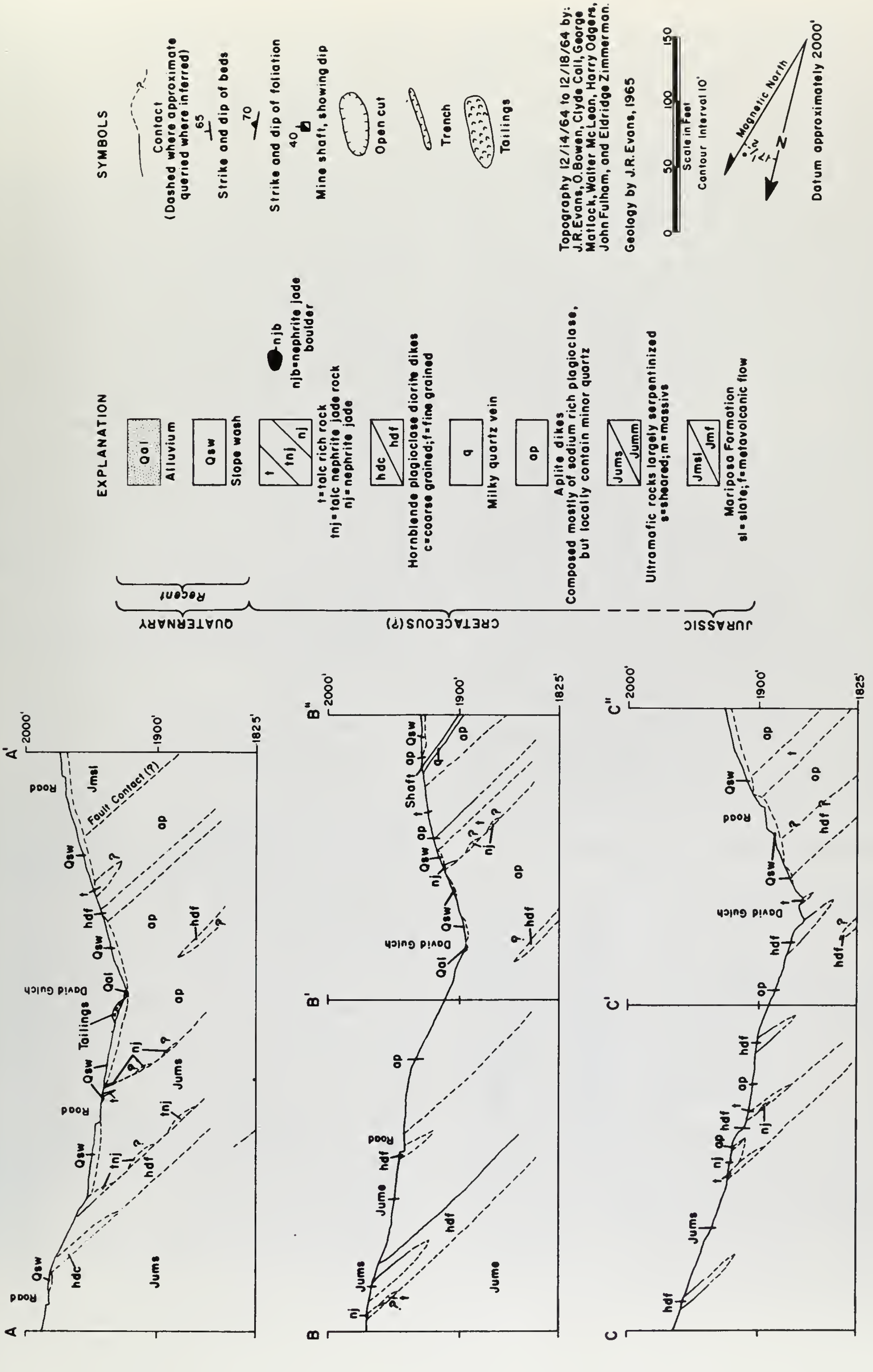
Therefore, only a certain textural form of these minerals qualifies them as jade. Much jade is impure mineralogically. For example, minor amounts of other minerals such as magnetite and anthophyllite are known to occur with Mariposa jade. Nevertheless, the bulk of mineral material called jade should be either nephrite or jadeite. Unfortunately, it has become common practice to call any massive green or white mineral which can be polished a variety of jade. Often a geographic prefix is added to the name, such as California Jade (californite) or Happy Camp Jade which is found in Siskiyou County near Happy Camp. Most of this material is really an attractive variety of vesuvianite (idocrase). Often it is difficult for the mineralogist, as well as the layman, to tell the compact forms of jade and other green minerals apart. To aid in this distinction Table 1 has been prepared. It may be necessary to use sophisticated laboratory techniques involving chemical analysis or to use x-ray equipment properly to identify a mineral as jadeite jade or nephrite jade.

SOME CHEMICAL, PHYSICAL AND OPTICAL PROPERTIES OF NEPHRITE (TREMOLITE-ACTINOLITE) JADE

Tremolite, actinolite, and rare ferroactinolite are members of an isomorphous mineral series. Tremolite is the calcium- and magnesium-rich silicate end member and ferroactinolite the calcium- and iron-rich silicate end member. Actinolite is a silicate containing



Geologic map of the Mandarin – Empire deposit, Mariposa County


EXPLANATION
QUATERNARY
Recent
Qal Alluvium
Qsw Slope wash
CRETACEOUS(?)
t tnj nj
t=talc rich rock
tnj=talc nephrite jade rock
nj=nephrite jade
njb
njb=nephrite jade boulder
hdc hdf
Hornblende plagioclase diorite dikes
c=coarse grained; f=fine grained
q
Milky quartz vein
ap
Aplite dikes
Composed mostly of sodium rich plagioclase, but locally contain minor quartz
JURASSIC
Jums Jumm
Ultramafic rocks largely serpentinized
s=sheared; m=massive
Jmsl Jmf
Mariposa Formation
sl=slate; f=metavolcanic flow
SYMBOLS
Contact
(Dashed where approximate queried where inferred)
Strike and dip of beds
Strike and dip of foliation
Mine shaft, showing dip
Open cut
Trench
Tailings
Topography 12/14/64 to 12/18/64 by: J.R.Evans, O.Bowen, Clyde Call, George Matlock, Walter McLean, Harry Odgers, John Fulham, and Eldridge Zimmerman.
Geology by J.R.Evans, 1965
0 50 100 150
Scale in Feet
Contour Interval 10'
Magnetic North
Datum approximately 2000'
A A' 2000' 1900' 1825'
Road Qsw hdc Jums tnj hdf Tailings Qal David Gulch ap Jmsl Fault Contact (?) nj
B B' B" 2000' 1900' 1825'
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C C' C" 2000' 1900' 1825'
hdf Jums nj ap David Gulch Qsw Road t

calcium, magnesium, and iron. As previously discussed, when tremolite and actinolite occur in tough compact forms that take an attractive polish they are called nephrite jade. Ferroactinolite is very rare, and has not been found as jade.

There has been, and still is, a difference of opinion as to the distinction between the above members of the series. I favor the definition used by Deer, Howie, and Zuessman (1963, p. 250) which is based on the theoretical molecular percent of ferroactinolite. On this basis, tremolite has 0-20 mole percent of the ferroactinolite composition, and actinolite has from 20–80 mole percent. The mole percents are closely equivalent to 0–5.75 percent, 5.75–22.95, and 22.95–28.80 percent elemental iron (Fe). The 28.80 percent represents the maximum theoretical amount of iron in pure ferroactinolite.

The analyses in Table 2 show the chemistry of two tremolite and two actinolite samples. The iron oxide value is the most important property for distinction between tremolite and actinolite. Note that replacement of magnesium (Mg) by ferrous (Fe^{+2}) iron (as in FeO) can easily be as much as 50 percent, and even more. Generally only a minor amount of silicon(Si) is replaced by aluminum (Al), but there may be a continuous replacement of Mg, Fe^{+2}, and Si by Al; i.e. $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$ can go to $Ca_2(Mg,Fe)_3$-$Al_4Si_6O_{22}(OH)_2$. Ferric (Fe^{+3}) iron (as in Fe_2O_3) is a minor constituent of tremolite, but increases to as much as 5 or 6 percent in ferroactinolite. Sodium (Na), and potassium (K) are sometimes present in tremolite, but more often in actinolite. Titanium (Ti), chromium (Cr), manganese (Mn), and flourine (F) are sometimes present in either mineral, but only in minor amounts. Note also the percentage of water contained in both minerals. This feature is shown by the two hydroxyl ions (OH^-) in the chemical formula of both minerals. These ions are an integral part of the structure, and water must be available for mineral formation.

Table 2. Chemical analyses of tremolite and actinolite.

	Samples			
Constituent	1	2	3	4
SiO_2	59.45	58.59	55.26	51.40
TiO_2	-	-	0.04	0.74
Al_2O_3	0.49	0.10	2.23	3.88
Fe_2O_3	0.00	-	1.19	3.90
FeO	0.07	-	5.12	14.91
Cr_2O_3	-	-	0.32	-
MnO	0.38	-	0.31	0.33
MgO	25.19	24.78	20.41	11.22
CaO	11.88	13.95	12.07	10.17
Na_2O	-	0.12	0.59	1.67
K_2O	-	0.10	0.10	0.09
H_2O	2.27	2.31	1.81	1.90
F	-	none	0.31	-

1. *Tremolite* from a tremolite-calcite skarn, Balmat, New York, analyzed by H. B. Wink (in Weeks, 1956).
2. *Tremolite* from Ham Island, Alaska, analyzed by Allen and Clement (in Posnjak and Bowen, 1931).
3. *Actinolite* from Chester, Vermont, analyzed by J. C. Maxwell (in Weeks, 1956).
4. *Actinolite* from albite-stilpnomelane-actionlite schist, Lake Wakatipu area, New Zealand, analyzed by C. O. Hutton (in Hutton, 1940).

If in coarse, euhedral crystals, tremolite and actinolite can be determined as belonging to the monoclinic crystal system, prismatic class. Nearly always crystals are elongate or pencil-like and terminated by two faces of a first-order prism. They can have perfect [110] cleavage at 56°, and when crystals are broken at right angles to the cleavage a splintery fracture is developed. Unfortunately, crystals are so fine grained and fibrous in nephrite jade that a microscope is needed just to determine outlines of crystals, let alone detailed crystallographic data. Hardness of the two minerals is from 5 to 6 on the Mohs scale. Specific gravity of tremolite is from about 2.90 to 3.07, and for actinolite, 3.07 to 3.32. This property is a very useful one for distinction between the two members. Both minerals have a vitreous luster. Tremolite is white, although only one or two percent iron will give it a green cast in hand specimen. With increasing iron content the green color deepens.

If fibers are not too minute, microscopic examination of thin mineral slices (0.025mm) will show the following properties with increasing iron content:

1) An increase in refractive indices (n_x, n_y, n_z);
2) A decrease in birefringence (n_z-n_x);
3) A decrease in the angle of Z to C;
4) A decrease in the optic axes angle 2V.

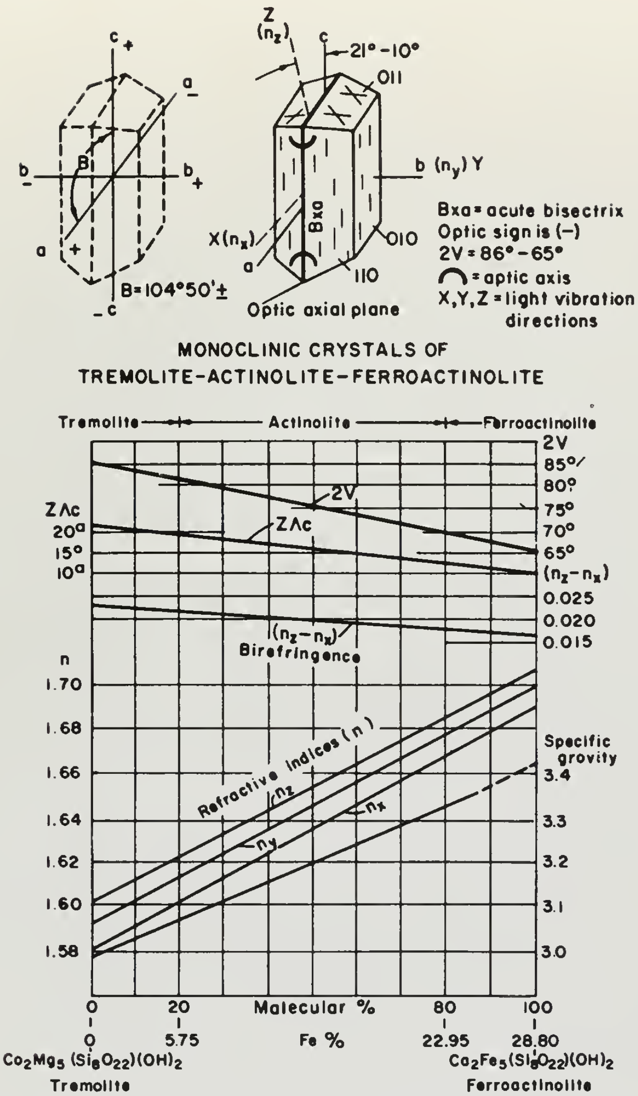
An accompanying figure is a graphical representation of the optical properties. Tremolite is colorless in thin slices, but actinolite shows pleochroic colors from pale yellow through yellow-green to green. The colors in actinolite become stronger with increasing iron content.

SELECTED REFERENCES

Damour, A., 1846, Analyses du jade oriental: Ann. Chem. Phys., 3rd series, vol. 16, pp. 469–474.

————————, ——, 1863, Notice et analyse sur lo jade verte; Reunion de cettes motiére minerol a la fomille wernites: Compt. Rend., vol. 56, pp. 861–865.

————————, ——, 1881, Nouvelles analyses sur la jodeite et sur quelques roches sodiféres: Bull. Soc. Minérol France, vol. 4, pp. 156–160.



Crystallographic and optic orientation diagrams of jade minerals.

Deer, W. A., Howie, R. A., and Zussman, J., 1963, Rock forming minerals, vol. 2, Chain silicates. John Wiley and Sons Inc., New York N. Y., 379 p.

Diaz del Castillo, Bernal, 1632, (ms. about 1532), Historia verdadera de la conquista de la Nueva Espana. Trans. A. P. Maudslay. Hakluyt Soc., London (1901).

Foshag, W. F., 1954, Mineral studies on Guatemalan jade; ms. *in* Instituto Anthropologia Historia Guatemala.

————, ———, and Leslie, Robert, 1955, Jadeite from Manzanal, Guatemala: Am. Antiquity, vol. 21, pp. 81–83.

————, ———, 1955, Chalchihuitl—a study in jade: Am. Mineralogist, vol. 40, pp. 1062–1070.

Hutton, C. O., 1940, Metamorphism in the Lake Wakatipu region, western Otago, New Zealand: Rept. Sci. and Ind. Res. N. Z., Geol. Mem. No. 5.

Martinus de la Cruz, and Badianus, Juannes, 1552, Badianus manuscript (Codex Barberini). Trans. Emily Walcott Emmart, Baltimore (1940).

Molina, Alonso de, 1555, Vocabulario en lingua Castellana y Mexicana. Mexico. Madrid. (1944).

Monardes, Nicol, 1569, Primera y segunda y tercera parte de la historia medicinal de las casas que se traen de las Indias Occidentales que sirven en medicina. Seville. See also Joyful News from the Newe Worlde, by Monardes; written in both Spanish and English. English ed. by John Frampton, merchant, London (1577); ed. Sir Stephan Gaselee, London (1925).

Posnjak, E., and Bowen, N. L., 1931, the role of water in tremolite: Amer. Jour. Sci., 5th ser., vol. 22, pp. 203–214.

Sahagun, Fr. Bernardino de, 1530, Historia general de las casas de Nueva Espana. Mexico (1938).

Turner, Henry W., 1896, Further contributions to the geology of the Sierra Nevada: U. S. Geological Survey Ann. Rept., Part I,d, pp. 523–762.

Weeks, W. F., 1956, Heats of formation of metamorphic minerals in the system $CaO—MgO—SiO_2—H_2O$ and their petrological significances; Jour. Geology, vol. 64, pp. 456–472.

Werner, Abr. G., 1780, In Cronstedt's Mineralogie (1758), translation by Werner.

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