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NEPHRITE JADE AND ASSOCIATED ROCKS

OF THE CAPE SAN MARTIN REGION, MONTEREY COUNTY, CALIFORNIA

By RICHARD A. CRIPPEN, JR.

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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.

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.

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

[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.

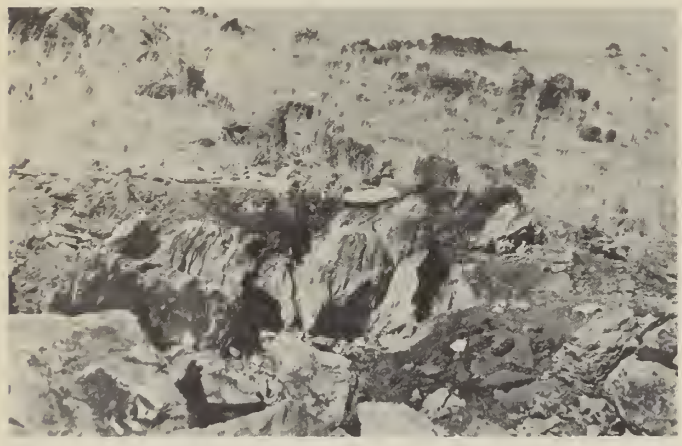

FIGURE 1. Site of first jade quarrying operation in California, 1949. The Janoko Brothers and Alston workings near Porterville, Tulare County. Face of working, left center, is green nephrite. Stock pile is to right. Outcrops on hillside are metasediments of the Kaweah series (Triassic) and serpentine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

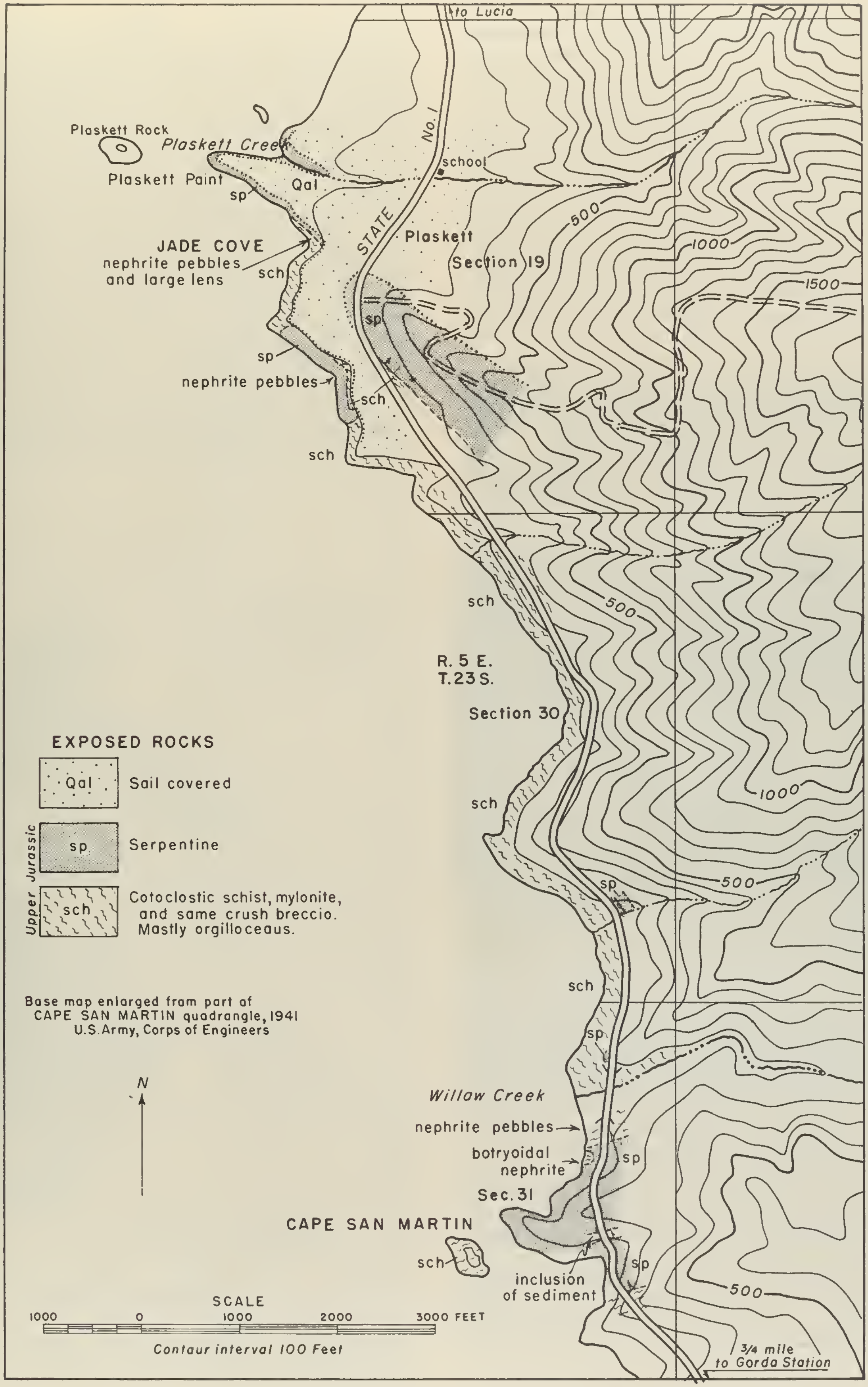

FIGURE 2. Topographic and geologic sketch map of the Plaskett-Cape San Martin region, Monterey County, California, showing nephrite localities.

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.

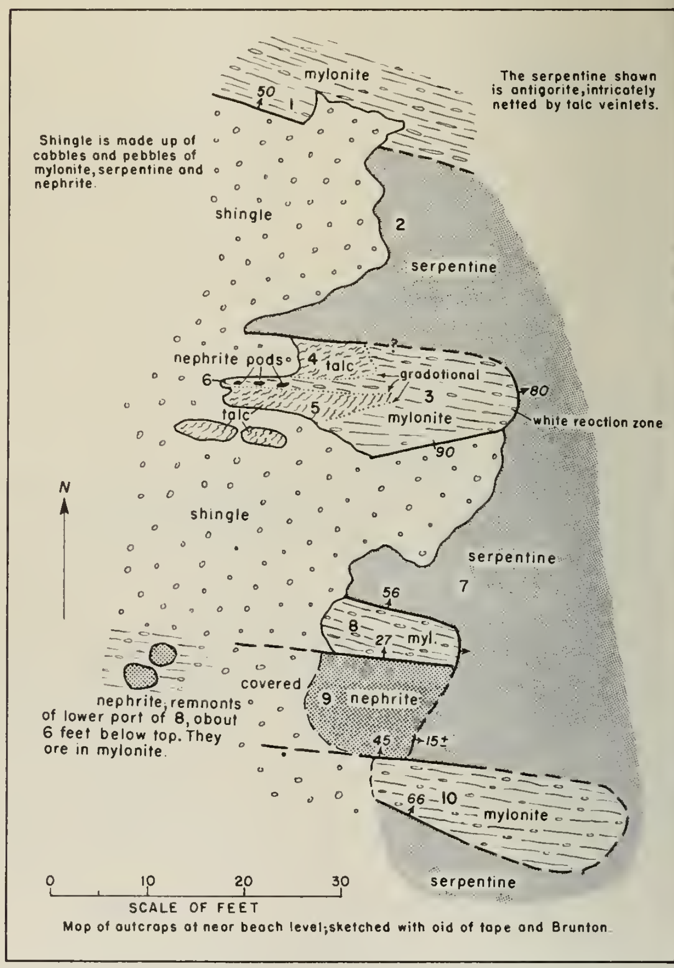

FIGURE 4. Geologic sketch map of part of Jade Cove showing large nephrite lens, small pods, and associated rocks.

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 visible in the steep north wall of Willow Creek gorge. The gorge of Willow Creek is cut in a zone marking an abrupt change in geologic structure. In the section to the north the principal schistosity approaches a horizontal attitude, whereas south of the creek the planar structures dip steeply in a northerly direction. About 250 feet south of Willow Creek bridge the schist is in contact with the large serpentine body which forms much of the promontory of Cape San Martin. This intrusive body is sectioned at two horizons: in the roadcut, and in the sea cliffs below. It appears to be of tabular form, about 1200 feet thick, dipping steeply northward and striking northeast. The schist of both footwall and hanging wall appears generally conformable in attitude, but there are local divergences of planar structures. In exposures near Willow Creek bridge the schist is hard, greenish-gray rock of such coarse schistosity as to resemble bedding. Closer examination reveals a structure in which sandy material is rolled out in a darker matrix of very fine grain, probably derived from argillaceous beds by cataclastic metamorphism. Although this rock is called schist for lack of a better name, it is a relatively competent rock, and subsequent dislocating forces have been largely absorbed by the serpentine which is greatly sheared.

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

In the sea cliff just within the northern face of the serpentine another argillaceous mass is found. It is 120 feet across between walls of serpentine and is roofed by serpentine. Near the mid-point of the exposure remnants of sedimentary bedding remain but most of the mass has been crushed and recrystallized to a massive, very fine-grained rock. A whitened zone also bounds this body. It is not certain whether these sedimentary masses were plucked and engulfed by the peridotite invasion or if they are remnants of interdigitations, but the first seems most plausible. It would appear that the peridotite invaded bedded sediments as a dike, producing thick zones of schist and other cataclastic rocks by the differential movement induced.

In the road cut near Alder Creek, 3½ miles to the south, graywacke, silty shale, and hard black shale strata compose a thick section. This series dips gently northeast showing only minor folding and faulting. The lithology of these sediments appears similar to that of the Cape San Martin road cut inclusion. From fragmentary bedding seen north of Willow Creek this same weak sedimentary series may well have been the parent rock of much of the Plaskett-Cape San Martin schists. More nearly typical Franciscan sequences, such as massive sandstone or graywacke and some shale, to sections predominantly shaly, no doubt are represented also in the bewildering lithologic variations. In places highly fissile schist 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 geologic map, figure 4. Camera facing south.

The specific gravity of a few specimens of nephrite averaged about 3.00 (Dana 2.96-3.1), sufficiently greater than that of serpentine (usually less than 2.65) to be perceived in the hand with a little practice. Beach pebbles 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 be separated readily.

Mylonite. The nature and origin of the gray schist and the identity of the whitish streaks and lenses is of particular interest. Two general types of the rock based 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, serpentines, and related "greenstones" used by the Maoris of Otago and 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.

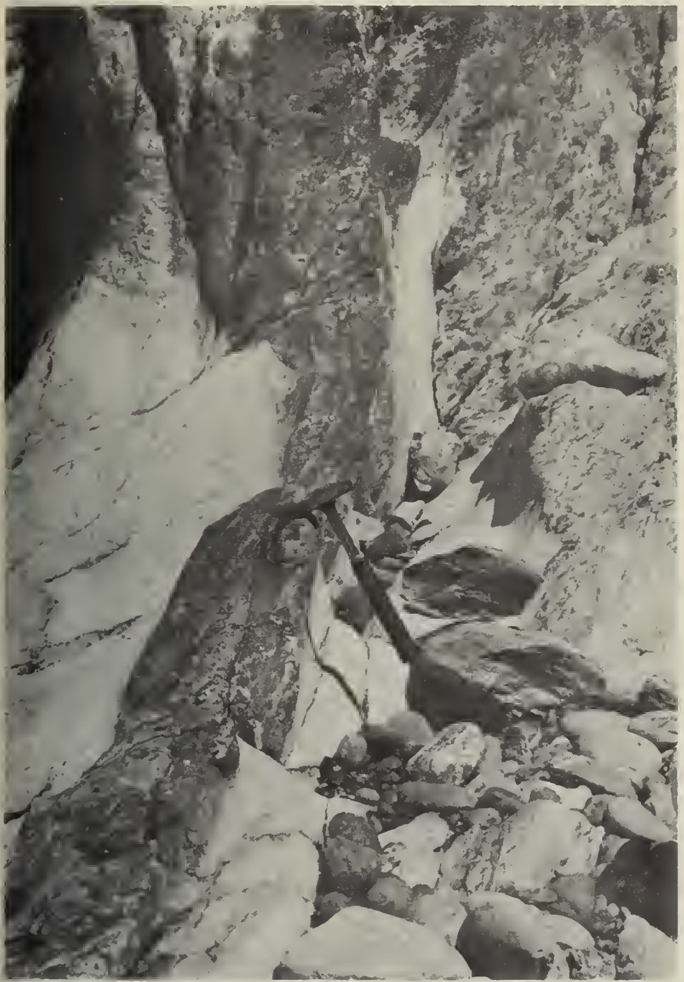

FIGURE 7. Outcrop number 3 in Jade Cove (see fig. 4) showing gradation of gray mylonite to white talc schist. Pick hangs on one of several small pods of nephrite.

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, C., 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

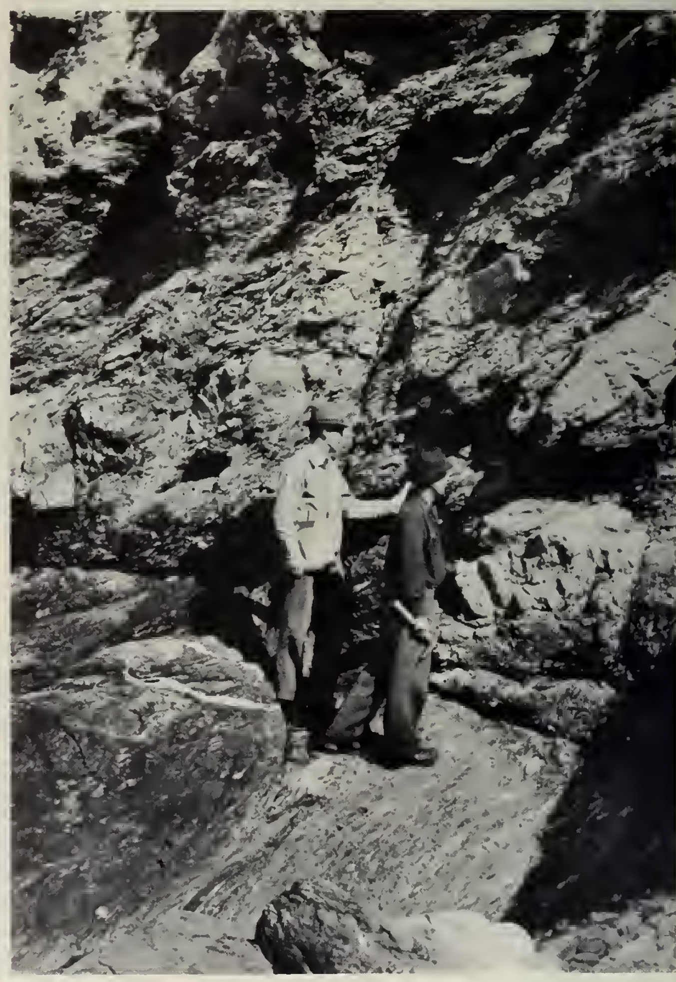

FIGURE 9. Seacliff in Jade Cove to south of mapped area. Large lenses of quartz-albite-tremolite rock in sheared mylonite. Foreground slope is black mylonite with white streaks and small lenses.

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

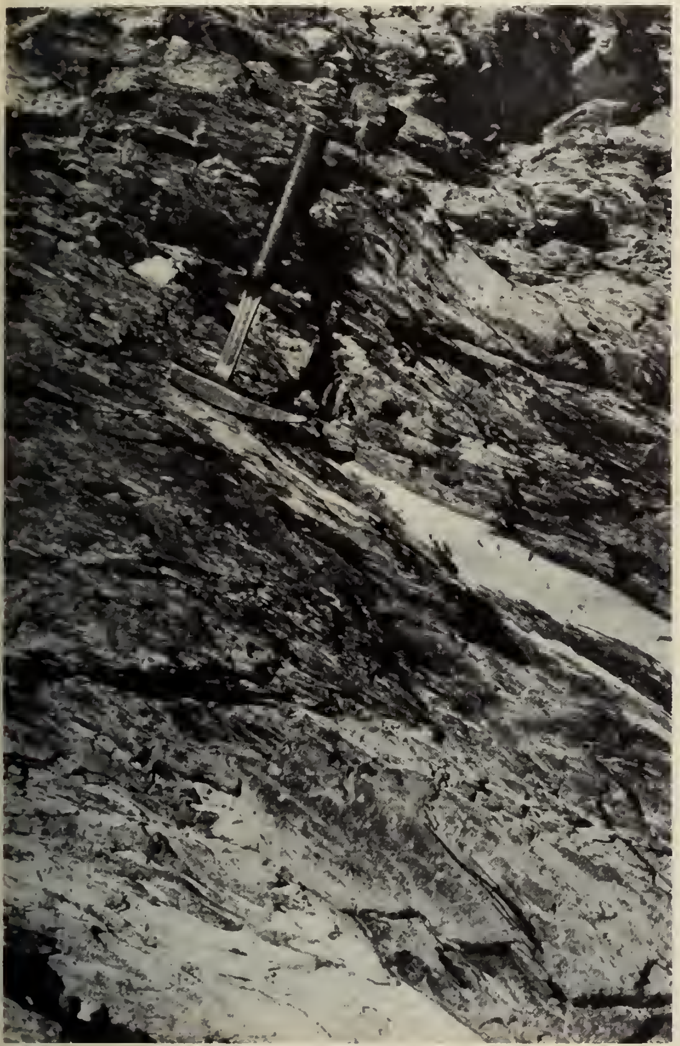

Figure 10. Mylonite at point of land just south of Jade Cove. White lens is talc, and a small lens of nephrite was found in place here. A serpentine body is nearby.

Cape San Martin

The Cape San Martin nephrite is part of a large mass of argillaceous rock enclosed in a great serpentine body. A whitened zone adjacent to the serpentine is seen at the south contact near beach level and also on the upper surface of the argillaceous mass (see fig. 11). It is in this white zone at the beach level that the unique development of botryoidal nephrite was found. It is sometimes buried by sand but it was well exposed when the photograph (fig. 12) was made. Massive gray-green nephrite forms a low shoulder of the inclusion near the botryoidal surface.

In the center of the included rock mass, unmistakable, although broken and confused interbedded black shale and graywacke is seen. This grades laterally into a massive gray rock of fine grain, evidently the product of 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 feldspar. The microstructure indicates cataclasis and there is some contorted and irregular dark banding, but parallelism 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 surfaces 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.

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

actinolite-tremolite was the only mineral possessing a form, as microfibrous nephrite, capable of crystallization in a medium undergoing complex intergranular movement, and subject to epizonal conditions of metamorphism.

The massive nephrite and the botryoidal type at Cape San Martin had a somewhat different manner of genesis from that at Jade Cove. At Cape San Martin the argillaceous mass was crushed, mixed, and largely recrystallized. At the same time perhaps, gradational replacement by massive nephrite took place locally near the serpentine contact, attended by forceful growth of the nephrite protuberances. The manner in which the nephrite has pressed into talc schist suggests crystallization of calcium and silica from the sedimentary rock and magnesium from the serpentine. Excess silica combined with magnesium to form talc.

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

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

Hydrogrossularite and Other Metamorphic Minerals of Cape San Martin. Mention has been made of the whitened zone bounding the sedimentary block of the roadcut exposure in serpentine. Similar occurrences were noted at the nephrite localities although the whitened zones there were altered to soft white material. In the road cut, the zone is a little over 1 foot in thickness and is sharply defined against serpentine, but grades indefinitely into the massive, greenish reconstituted sedimentary rock. The zone is light gray to white with darker streaking parallel to the contact.

The white part contains small vugs of crystals and calcite 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.

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