PARAGENESIS OF THE MINERAL ASSEMBLAGE AT CRESTMORE, RIVERSIDE COUNTY, CALIFORNIA

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INTRODUCTION

For more than twenty years the Crestmore locality has excited the interest of mineralogists. This interest was first aroused when specimens of blue calcite with monticellite and xanthophyllite were sent to A. S. Eakle. The first publication appeared in 1914[1] and since then numerous papers have been published on the mineralogy of Crestmore by A. S. Eakle, W. F. Foshag, A. F. Rogers, and others.

Crestmore is situated on the extreme eastern lobe of the Jurupa Mountains about three miles west of Riverside, California. The Jurupa Mountains are an east-west range roughly eight miles long and three miles wide which parallels the front of the San Gabriel Mountains.

The cement plant, limestone quarries, and mine of the Riverside Cement Company are located at Crestmore. Quarrying operations were started some seventeen years ago. The rocks were at first used as road metal, burned lime for sugar refining, and for the manufacture of cement. With the increased demand for cement the quarrying operations were given over entirely to that purpose. At the present time the material is obtained by underground mining.

PURPOSE AND METHOD OF INVESTIGATION

Although much work has been done on the mineralogy of the limestones and associated rocks at Crestmore, never before has the geology been mapped and the mineralogy studied in its relation to the geology of the district for the purpose of determining the paragenesis of the minerals and their petrological associations. With this purpose in mind as a major objective, the work was conducted and resulted in the following related units:

1. Detailed geologic study of the Crestmore quarries and the eastern portion of the Jurupa Mountains.

[1] Eakle, A. S., and Rogers, A. F., Wilkeite, A New Mineral of the Apatite Group and Okenite, Its Alteration Product: *Am. Jour. Sci.*, vol. **27**, pp. 262–267, 1914.

2. Economic study of a typical Southern California limestone deposit.

3. Collection and determination of a large amount of mineralogical material by chemical analysis and optical methods.

4. Organization of this material into a catalogue of mineralogical associations.

Unfortunately some of the rare minerals described from this locality were entirely removed during the quarrying operations. Hence in preparing a catalogue of the mineral species it was necessary to take some of the data from the literature and in these cases the relationships and associations could not be precisely determined.

The map of the Crestmore quarries was made on the scale of 1″=100′ on a topographic map kindly furnished by the Riverside Cement Company. The hills to the west of the quarries were mapped on a portion of the U.S.G.S. San Bernardino Quadrangle, originally on the scale of 1″=1 mile photographically enlarged to 1 inch equals one-half mile. Locations were determined by means of a Brunton compass and a light plane table.

ACKNOWLEDGMENTS

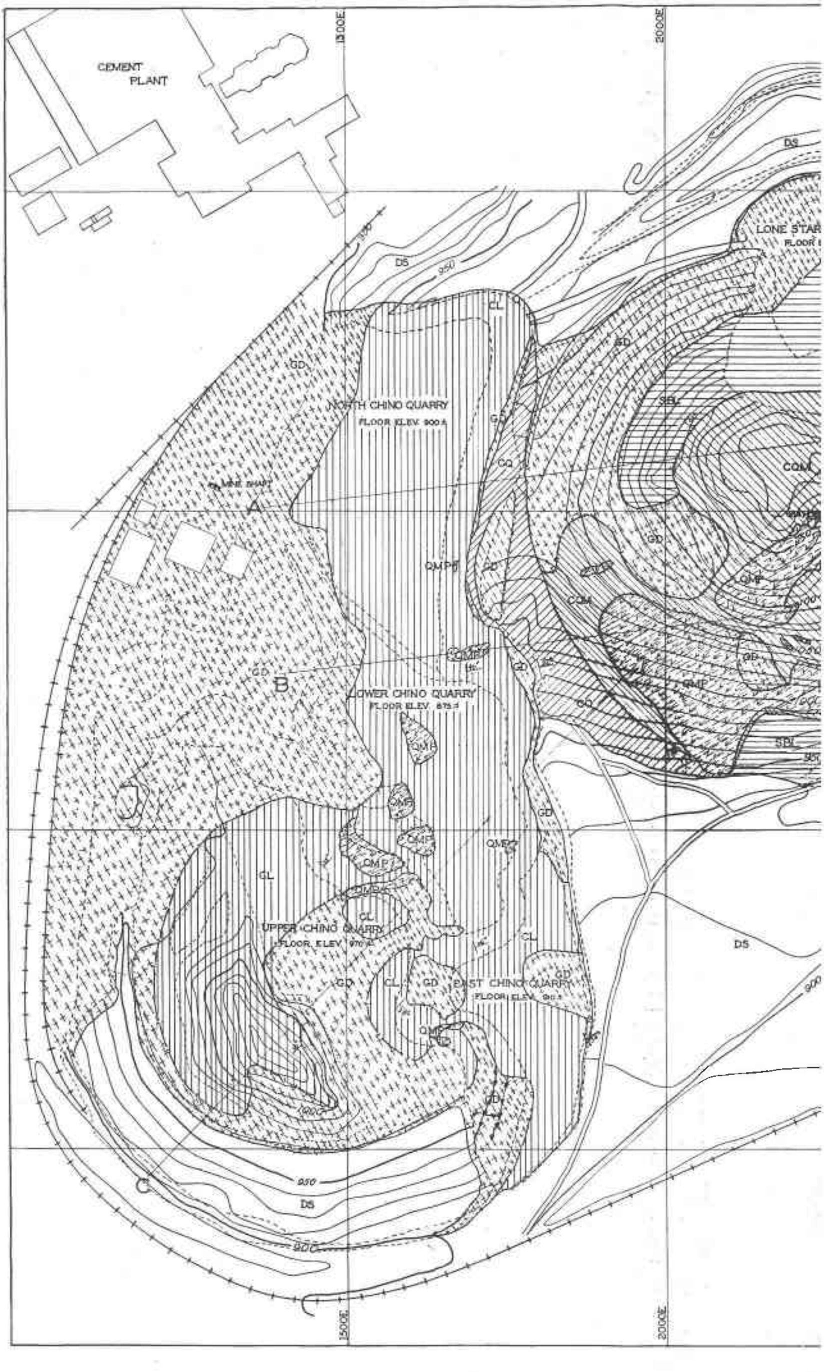
The writer wishes to thank the officials of the Riverside Cement Company, Mr. John Treanor, Mr. G. A. Beckett, and Mr. Earl MacDonald, for their permission to make a geologic map of the quarries. Messrs. Thomas Mullan and C. A. Robotham of the same organization were very helpful. Much credit is due Dr. René Engel, of the California Institute of Technology, under whose direction this work was conducted, for the help he has given.

GEOLOGY

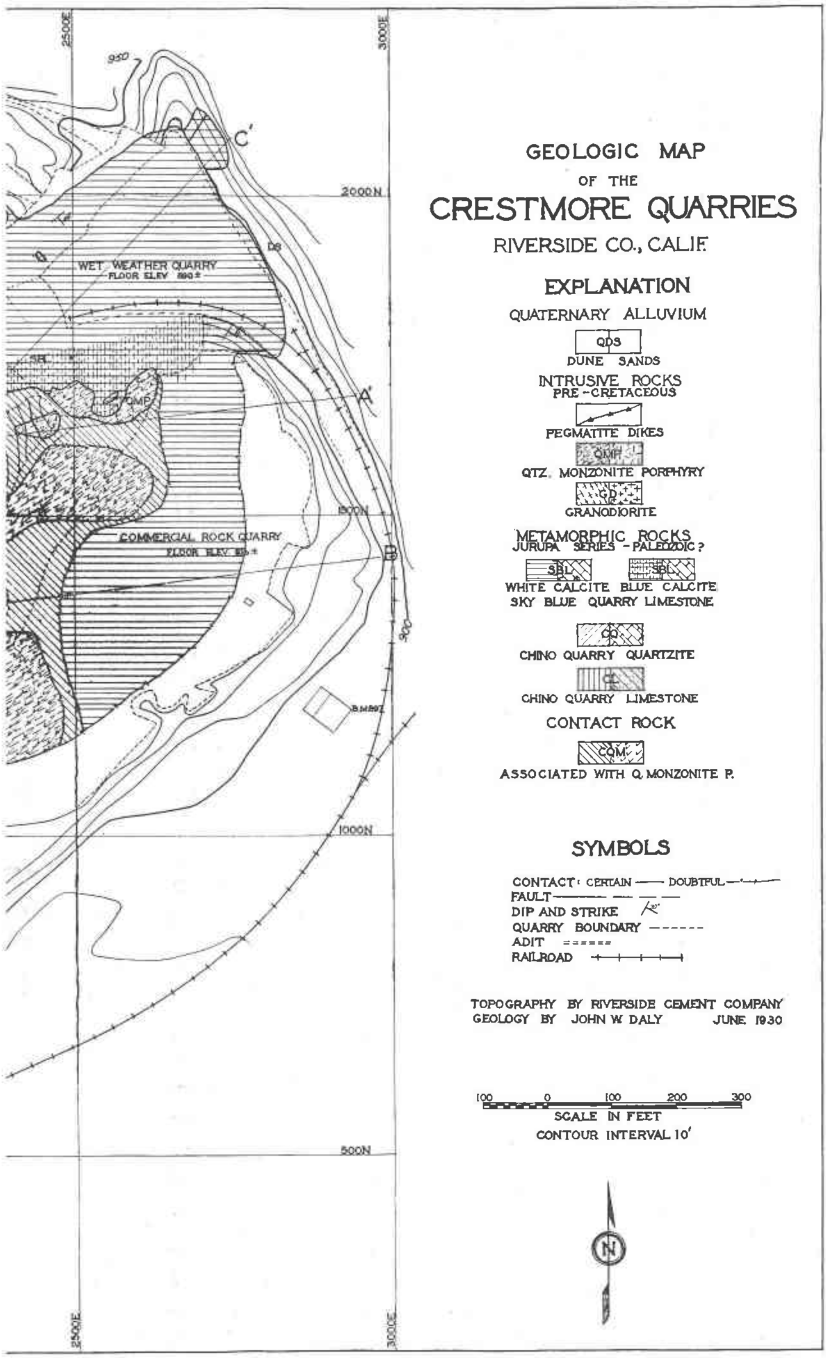
The geologic study of the district and the economic aspects of the Crestmore limestones will be the subject of another paper. However, it is entirely within the scope of the present paper and will add materially to its value to give here a brief resumé of the geology. A geologic and topographic map of the Crestmore quarries is shown on Plate 1.

Stratigraphy.

The oldest rocks of the Jurupa Mountains form a thick series of recrystallized sedimentaries for which the name, Jurupa Series, is proposed. The stratigraphically lower part of the section, consist-



CEMENT PLANT
1500E
2000E
DS
950
LONE STAR
GD
CL
NORTH CHINO QUARRY
FLOOR ELEV. 900 ft
SBL
CQ
COM
MINE SHAFT
A
QMP
B
LOWER CHINO QUARRY
FLOOR ELEV. 875 ft
UPPER CHINO QUARRY
EAST CHINO QUARRY
C
900



GEOLOGIC MAP
OF THE
CRESTMORE QUARRIES
RIVERSIDE CO., CALIF.
EXPLANATION
QUATERNARY ALLUVIUM
QDS
DUNE SANDS
INTRUSIVE ROCKS
PRE-CRETACEOUS
PEGMATITE DIKES
QMP
QTZ. MONZONITE PORPHYRY
GD
GRANODIORITE
METAMORPHIC ROCKS
JURUPA SERIES - PALEOZOIC ?
SBL
SBL
WHITE CALCITE BLUE CALCITE
SKY BLUE QUARRY LIMESTONE
CQ
CHINO QUARRY QUARTZITE
CL
CHINO QUARRY LIMESTONE
CONTACT ROCK
CQM
ASSOCIATED WITH Q. MONZONITE P.
SYMBOLS
CONTACT: CERTAIN DOUBTFUL
FAULT
DIP AND STRIKE
QUARRY BOUNDARY
ADIT
RAILROAD
TOPOGRAPHY BY RIVERSIDE CEMENT COMPANY
GEOLOGY BY JOHN W. DALY JUNE 1930
100 0 100 200 300
SCALE IN FEET
CONTOUR INTERVAL 10'
N
WET WEATHER QUARRY
FLOOR ELEV
COMMERCIAL ROCK QUARRY
FLOOR ELEV
C'
A'
B'
QMP
SBL
2500E
3000E
2000N
1500N
1000N
500N
950
900

ing of undifferentiated quartzites, schists and gneisses with small limestone lenses, will be referred to as the Undifferentiated Complex. Lying on this complex, with the same attitude and possibly conformably, are the limestones which are exploited for cement manufacture. These were differentiated on the large scale map of the Crestmore quarries (Plate 1) into the following units: (1) The lower, Chino Quarry limestone, (2) Overlying quartzite and schist beds, called the Chino Quarry quartzite, (3) The upper, or Sky Blue Quarry limestone. Granodiorite and quartz monzonite intrusions separate these lower members from the upper limestone. In mapping this last unit an effort was made to trace the limits of the development of the blue calcite. Because of the uncertain nature of the outcrops this distribution could not be carried through in detail but is indicated in a general way on the map (Plate 1).

The Undifferentiated Complex.

These rocks are best exposed in the hills about two miles northwest of Crestmore. The stratigraphic units are tabulated below in descending order:

1700 ft.	thin bedded quartzite interstratified with fissile mica schist.
850 ft.	coarse bedded quartzitic schists.
1050 ft.	biotite gneiss in part schistose.
100 ft.	hard, thick bedded, quartzite in part schistose.
3700 ft. +	

Granodiorite cuts off the base of the section and intrudes parts of it thus making it impossible to determine the true thickness of the section.

The Chino Quarry Limestone.

This limestone, the best exposure of which is in the Chino quarry, is white, medium to thin bedded, and medium to coarsely granular. Graphitic beds are found throughout the section but are more common near the base. Another conspicuous rock type is the calcite-brucite rock, or predazzite. Pseudo-isometric crystals of brucite occur in beds of medium grained, white limestone. Rogers[2]

[2] Rogers, A. F., An American Occurrence of Periclase and its Bearing on the Origin and History of Calcite-Brucite Rocks: *Am. Jour. Sci.*, vol. **46,** pp. 582–586, 1918. Periclase from Crestmore near Riverside, California, with a List of Minerals from this Locality: *Am. Mineral.*, vol. **14,** pp. 462–469, 1929.

has shown that these brucite crystals are pseudomorphs after periclase, remnants of which can still be found enclosed in the brucite. Associated minerals are chondrodite, spinel, magnetite and wilkeite.

The base of this limestone has been cut off by granodiorite so that the true section cannot be ascertained. The maximum exposed thickness is of the order of 470 feet. The total would undoubtedly be considerably greater.

The Chino Quarry Quartzite.

The structural relations between the Chino Quarry quartzite and the Chino Quarry limestone is not precise. They are in part separated by a sill-like intrusion of granodiorite. Where their contact is exposed they are apparently conformable, but the quartzite has a shallower dip than the underlying limestone. The top of the quartzite has been cut off by intrusions of granodiorite and quartz monzonite porphyry, except at the eastern end where it appears to be unconformably overlain by limestone, but the exposures are poor and this relation is not certain. The examination of diamond drill cores and the underground workings proves that the downward extension of these rocks is severed by intrusions about two hundred feet below the surface.

A total thickness of at least 75 feet is exposed. The formation consists of interstratified, thin bedded, quartzite and fissile mica schists.

The Sky Blue Quarry Limestone.

Except for the development of the blue calcite and the more intense metamorphism near some of the quartz monzonite dikes, this formation is lithologically similar to the Chino Quarry limestone. There is no evidence to show that the original sediments of these two units differed appreciably in chemical composition. This study has proven that any differences are directly related to the varying degrees of metamorphism to which each limestone has been subjected.

Igneous intrusions have separated the Sky Blue Quarry limestone from the underlying Chino Quarry quartzite so that their relations can only be inferred. The attitude of the formations differs appreciably. This may be due to distortion during intrusion, or possibly the intrusion followed a line of previous structural weakness, i.e., an unconformity or a fault.

Alluvium covers the top of the section but a thickness of over 500 feet is exposed in the quarries.

Other Outcrops.

In the Jensen quarry to the west and in several other parts of the area studied, outcrops of limestone are found. They are lithologically similar to the limestones described above but their structural relations are so obscure that their further discussion in this paper is not warranted.

Age and Suggested Correlation of the Jurupa Series.

Because of the isolated position of this range and the lack of fossils, correlation had to be based on lithologic similarity. On this basis, the Undifferentiated Complex is thought to be the equivalent of the Arrastre quartzite and the limestones equivalent to the Furnace limestone described by Vaughan[3] from the San Bernardino Mountains. Vaughan considered the Arrastre quartzite as lower Cambrian and the Furnace limestone as upper Cambrian and Ordovician. Later work by Woodford and Harriss[4] proves that at least the upper portion of the Furnace limestone is Mississippian (?). Since it is apparent that the age of similar rocks is not precisely known, the Jurupa Series has been assigned to the Paleozoic (?) era without attempting to relate it to any particular period or periods.

Quaternary Alluvium.

Undifferentiated dune sands, river sands, and fan deposits are grouped under this unit.

Igneous Rocks

In this region five distinct but related plutonic rock types are found. Apparently these types are the result of differentiation from a parent magma and range from hypersthene quartz diorite to pegmatites.

Hypersthene Quartz Diorite.

This oldest and most basic rock outcrops on the hills southwest

[3] Vaughan, F. E., Geology of the San Bernardino Mountains North of San Gorgonio Pass: *Bull. Dept. Geol., Univ. Calif.*, vol. **13**, pp. 319–412, 1922.

[4] Woodford, A. O., and Harriss, R. S., Geology of Blackhawk Canyon, San Bernardino Mountains, California: *Bull. Dept. Geol., Univ. Calif.*, vol. **17**, pp. 265–304, 1928.

of Crestmore. A microscopic determination shows the following: The texture is holocrystalline, medium grained, hypidiomorphic, inequigranular. The femic minerals are represented by slightly pleochroic hypersthene, hornblende, in part uralitic, and biotite. The feldspar is a basic andesine and shows slight zoning. Undulatory quartz was the last mineral to crystallize. Pyrite and apatite are the accessories. Near the periphery the rock shows textural and mineralogical differences. The texture is porphyritic. The phenocrysts are labradorite and the feldspar of the ground mass is andesine. Quartz is less abundant. These variations can be readily explained by the different rates of cooling that would obtain at the center and at the periphery of the mass.

Granodiorite.

It forms the bulk of the intrusive rocks in the area mapped. One of its most characteristic features is the presence of basic inclusions. These are roughly egg shaped, from two inches to one foot long, and are, to some extent, oriented with their long axes parallel to each other. The texture and the mineralogical constituents of these inclusions show their affinity with the peripheral phase of the hypersthene quartz diorite from which they were probably torn by the intruding granodiorite.

A holocrystalline, coarse to medium grained, hypidiomorphic, inequigranular texture is characteristic of the granodiorite. Most of the femic material is pleochroic hornblende. Chloritized biotite is present in lesser amounts. Sericitized oligoclase with subordinate amounts of orthoclase constitute the feldspathic elements. The abundant quartz shows undulatory extinction. The accessories are apatite, zircon and hematite.

Quartz Monzonite Porphyry.

Numerous intrusions of this rock cut the limestones in the Crestmore quarries and it is to solutions emanating from these intrusions that most of the rare minerals owe their genesis. The texture is holocrystalline porphyritic, hypidiomorphic, fine-grained, inequigranular. The feldspars are orthoclase and oligoclase both as phenocrysts and as constituents of the ground mass. They show alteration to calcite and sericite. Abundant quartz occurs in part in micropegmatitic intergrowth with the orthoclase. Scattered grains and aggregates of pale green augite constitute the femic material. Pleochroic grains and aggregates of titanite are common. Apatite and pyrite are the accessories.

The peripheries of the larger dikes and of many of the smaller ones exhibit marked endomorphic effects resulting from the assimilation of foreign material and from more rapid cooling. In a general way these effects are:

(1) Frequent development of porphyritic texture.

(2) An increase in the abundance of the ferromagnesium constituents and a change in their character. In this case we have diopside, diallage, augite, and grossularite.

(3) An increase in the amount and basicity of the plagioclase.

(4) In many cases a complete disappearance of quartz.

Granite Porphyry.

The granite porphyry outcrop, in the western portion of the Jurupa Mountains, is too far removed from the quarries to merit close consideration in this paper, but its occurrence is interesting in its relation to the igneous sequence.

The texture is holocrystalline, medium grained, porphyritic, hypidiomorphic, inequigranular. Microcline, oligoclase, orthoclase, quartz, biotite, rutile, magnetite and apatite are the minerals represented.

Pegmatite Dikes.

In the literature on the Crestmore quarries the statement that the pegmatite dikes are abundant and commonly traverse the limestone is often made. The writer's observations are at variance with this statement for very few of these dikes are seen and never in the limestone. It is possible, however, that the dikes mentioned in the literature were small and were removed during quarrying operations.

An abundance of pegmatite dikes occurs in the hills adjacent to the quarries. They vary in width from less than an inch to as much as twenty-five feet and some of them can be traced for miles. Many of these dikes show banding. The outer bands are made up of layers, one-half to one inch thick, composed of graphic intergrowths of quartz and albite. The inner zone, having a width of about one-tenth the total thickness of the dike, is composed of extremely coarse feldspar and quartz with the occasional development of black tourmaline and biotite. The composition of the feldspar varies between albite and microcline.

Age and Sequence of the Intrusive Rocks.

Intrusions of Jurassic age occur in the Santa Ana Mountains and in the Julian district. Vaughan[5] correlates the Cactus granite of the San Bernardino Mountains with the Jurassic granites of the Sierra Nevada but mentions an earlier intrusion which may belong to the Paleozoic. Since there is a possibility that the Jurupa Mountain intrusives might be earlier than Jurassic their age is designated merely as pre-Cretaceous.

The sequence of intrusions has followed the order: hypersthene quartz diorite, granodiorite, quartz monzonite porphyry, granite porphyry and pegmatite dikes. Their order and spatial relationship suggest differentiation from the same parent magma and that the intrusions followed closely in point of time.

Contact Rocks

Three distinct types of contact rock have been formed by the quartz monzonite porphyry intrusions. These are listed below in the order of their importance.

Garnet Contact Rock.

The face of the Commercial Rock quarry and the crest of Sky Blue Hill is made up almost entirely of this material. The greatest proportion of the rock is badly fractured massive grossularite. Other minerals, in the order of their importance, are diopside, diallage, calcite, wollastonite, augite and scapolite.

Vesuvianite Contact Rock.

At the corner of Lone Star, Wet Weather and Commercial Rock quarries a contact rock consisting chiefly of vesuvianite and calcite is developed. The proportions of these minerals vary greatly. In places the rock is nearly all vesuvianite, quite massive and glassy, at others the calcite and vesuvianite are approximately in equal amounts. The other extreme is found when the mass is almost all calcite with only a few grains of vesuvianite embedded in it. The calcite occurs as a soft, white mass of aggregates of extremely fine needles and some very small rhombohedrons. These forms probably represent rapid crystallization from a supersaturated solution. Diopside, garnet and wollastonite are the minerals commonly associated with this rock.

[5] Vaughan, F. E., *Op. cit.*, 1922.

In several places in the Wet Weather quarry this assemblage is found definitely confined to certain beds, thus indicating that the initial character of the limestone strata may have been one of the governing factors in its origin. It is interesting to note that in this case the calcite is quite coarsely crystalline.

Quartz and Garnet Contact Rock.

This rock is composed wholly of granular, vitreous quartz, and grossularite crystals and grains. It is found close to a small quartz monzonite porphyry dike near the outcrop of the Chino Quarry quartzite in the saddle north of the Chino quarry. This association indicates its derivation from an impure lime bearing sandstone.

MINERALOGY

It is impossible in this paper to include a complete catalogue of the minerals. Hence, the following descriptions are limited to new occurrences or to controversial subjects to which the author has new data to add.

Following this section the minerals are alphabetically tabulated in a manner which shows their petrologic distribution, their relative abundance and, to a large extent, their associations. For more detailed information the reader is referred to the abundant literature on this locality.

Sulphides: Eakle[6] states that the sulphides are associated with the pegmatite intrusives. The author has not found this to be the case. Where the association has been seen the sulphides are concentrated near the quartz monzonite porphyry. No sulphides are found as accessories in the pegmatites, but they are present as such in the quartz monzonite porphyry. In the author's opinion solutions from the quartz monzonite deposited the sulphide mineralization found in the quarries.

Monticellite: This mineral has been described by Eakle[7] from the blue calcite and later by Tilley[8] from the contact rock. Eakle suggested that the monticellite results from the metamorphism of the brucite limestone, while the diopside and vesuvianite were formed during the metamorphism of the pure beds. Thus he accounts for

[6] Eakle, A. S., Minerals Associated with Crystalline Linestone at Crestmore, Riverside County, California: *Bull. Dept. Geol., Univ. Calif.*, vol. **10**, pp. 327–360, 1917.

[7] *Op. cit.*, 1917.

[8] Tilley, C. E., On a Custerite-bearing Contact Rock from California: *Geol. Magazine*, pp. 371–372, **1928.**

the scarcity of monticellite and xanthophyllite. In an earlier paper Eakle[9] attributed the formation of these minerals to solution action accompanying the quartz monzonite porphyry intrusion. The writer's observations confirm the earlier statement by Eakle, for otherwise it would imply that the brucite limestone is limited in extent, while, on the contrary, it is quite common.

Diallage: Diallage is found in the endomorphic phases of the quartz monzonite porphyry, and in the garnetiferous contact rock.

Orthoclase: According to Eakle[10] orthoclase forms the larger portion of the pegmatite dikes. In the samples examined by the author no orthoclase was found in the pegmatites, only albite and microcline. It does occur, however, in the granodiorite, the granite porphyry and the quartz monzonite porphyry.

Oligoclase: This is the plagioclase feldspar of the granodiorite and also occurs in the enclaves in the granodiorite. It is a constituent mineral of the quartz monzonite porphyry, the hypersthene quartz diorite, the granite porphyry and the Undifferentiated Complex.

Labradorite: This has been described by Eakle[11] as one of the constituents of the granodiorite, along with oligoclase. No evidence has been found for two generations of plagioclase. The plagioclase is entirely oligoclase. Labradorite occurs as phenocrysts in the hypersthene quartz diorite and in some of the basic enclaves in the granodiorite. A few grains were found in the Undifferentiated Complex and the Chino Quarry quartzite.

Bytownite-Anorthite: Crystals of plagioclase of the bytownite-anorthite type were found in a small cavity at the border of one of the small quartz monzonite porphyry dikes in the lower Chino quarry. They were associated with pyrite, chalcopyrite and bornite.

Scapolite: A grey white scapolite with violet streaks has been mentioned by Eakle. The material collected by the author is white and composed of small radiating aggregates of extremely fine needles, so fine that to the unaided eye the material appears almost massive. It occurs in the contact rock associated with wollastonite, calcite, diopside, and grossularite, surrounding these minerals and filling spaces between them. The indices, $\omega = 1.567 \pm .005$, $\epsilon = 1.548$

[9] Eakle, A. S., Xanthophyllite in Crystalline Limestone: *Jour. Wash. Acad. Sci.*, vol. **6**, pp. 332–335, 1916.

[10] *Op. cit.*, 1917.

[11] *Op. cit.*, 1917.

$\pm.005$, measured on one sample would indicate, according to Winchell's[12] diagram marialite 60%, meionite 40%, or the species dipyrite. Another sample gave values $\omega=1.504\pm.005$, $\epsilon=1.550\pm.005$, which corresponds to the values of a mixture of 40% marialite, and 60% meionite, or the species mizzonite. This is an uncommon form of crystallization for scapolite. The fine crystallinity would suggest extremely rapid growth of crystals by rapid cooling of a supersaturated solution. However, the associated minerals are very coarse, so that this condition does not apply to all of them.

Clinozoisite: A pale, transparent to translucent, greenish grey variety occurs in shattered crystals and grains in a small contact mass associated with one of the smaller quartz monzonite porphyry dikes in the Chino quarry. The associated minerals are garnet and calcite. This undoubtedly results from the hydrothermal action of solutions from the quartz monzonite porphyry on the limestone.

Epidote: Small black crystals, up to three millimeters in length, were found disseminated in the white Chino limestone and associated with the deweylite and chrysotile, near a dike of quartz monzonite porphyry. A green epidote is abundant in some of the pegmatites as already noted by Eakle.

Xanthophyllite: This mineral was first described from this locality by Eakle[13] as disseminated in the blue calcite and associated with monticellite. The above occurrence was not found but small crystals and flakes were found in a locally developed, coarsely crystalline green calcite in the Chino Quarry limestone that was associated with a small dike of quartz monzonite porphyry.

Chrysotile and Deweylite: A massive green mineral was found in the white calcite of the Chino Quarry limestone in East Chino quarry, a few feet from a small quartz monzonite dike. An analysis was made by Mr. Thomas Mullan of the Riverside Cement Company and the following results were obtained:

SiO_2	40.88
$(Fe, Al)_2O_3$	1.27
CaO	5.91
MgO	37.52
H_2O	12.00
CO_2	2.50
	100.08

[12] Winchell, A. N., The Properties of Scapolite.: *Am. Mineral.*, vol. 9, pp. 108–112, 1924.

[13] *Op. cit.*, 1917.

Calcite grains could be seen in the material so $CaCO_3$ and $(Fe, Al)_2O_3$ were discarded and the other figures recalculated on the basis of 100 per cent.

	per cent	mol-numbers	ratios
SiO_2	45.20	.75	3
MgO	41.50	1.04	4
H_2O	13.30	.74	3

This gives the formula $3H_2O \cdot 4MgO \cdot 3SiO_2$, or $H_6Mg_4Si_3O_{13}$, which does not correspond with any of the known hydrous magnesium-silicate minerals. Grains of the material show indices as follows: A minimum of $1.528 \pm .005$, the maximum is $1.555 \pm .005$. If this were one mineral the birefringence would be 0.027, which is much too great in comparison with the observed birefringence. Thus it is thought that this represents a mixture of chrysotile and deweylite. A mixture of these minerals in the proportion 68.8% deweylite and 31.2% chrysotile would give an analysis corresponding to the above one. A thin section of the material proved that two minerals were present.

Rogers[14] describes deweylite replacing hydromagnesite in the calcite-brucite rock, and regards it as a supergene mineral. In view of its present relation to the quartz monzonite porphyry dike it seems that the genesis of these silicates can be assigned to the action of solutions emanating from this dike on previously formed minerals (epidote or diopside as suggested by their nearby occurrence) and thus in this case their origin would be hypogene.

Sepiolite: A white, fibrous mineral was found filling small veins in the calcite near the occurrence of the chrysotile and deweylite. The material is composed of finely interlocked fibers with the fibers oriented parallel to the vein walls. An analysis by Mr. Mullan gave the following results:

SiO_2	44.38
$(Fe, Al)_2O_3$	0.82
CaO	11.90
MgO	20.24
H_2O	13.09
CO_2	9.49
Total	99.92

The nature of the material made it impossible to free it, for analysis, from small grains of calcite so that $CaCO_3$ and $(Fe, Al)_2O_3$ were removed and the figures recalculated to 100 per cent.

[14] *Op. cit.*, 1918.

	per cent	mol-number	ratios
SiO_2	57.00	.95	3
MgO	26.00	.645	2
H_2O	17.00	.945	3

The above ratios correspond to the formula: $2MgO \cdot 3SiO_2 \cdot 3H_2O$. This probably represents a mineral between sepiolite and parasepiolite, but since the water content of sepiolite is variable the mineral has been called sepiolite. Optical properties are: $N_m = 1.510 \pm .005$, extinction parallel to the fibers, biaxial negative, birefringence low. It is unattacked by HCl. N_m for sepiolite is 1.52 and for parasepiolite 1.506. This mineral has intermediate optical properties as well as composition.

The proximity of this occurrence to the chrysotile and deweylite suggests that the sepiolite represents an alteration product of these minerals.

In the following table (Table 1) the minerals are listed in alphabetical order. At the right, in vertical columns, are entered the names of the predominate rock types of this locality. The petrologic distribution and to some extent the relative frequency of occurrence and the relative importance in a rock is indicated, for each mineral, by an appropriate letter. This gives a general conception of the mineral associations.

The purpose of this table is to summarize, in a general way, much of the data on the minerals of this locality. For more detailed information on any mineral the reader is referred to a paper by Rogers[15] in which a complete bibliography is given.

PARAGENESIS

The present record of the metamorphic history of the limestones shows no effect of the intrusion of hypersthene quartz diorite, the first member in the suite of intrusions which has altered these rocks. The spatial relations show that this intrusion was too far away to have had any effect other than recrystallization and fracturing resulting from heat and stresses produced during the injection of the magma.

The flow structure, so often found in the granodiorite near the contact with the sedimentaries, and the coarse crystallinity of the rock indicates that at the time of intrusion it was very viscous,

[15] Rogers, A. F., Periclase from Crestmore, near Riverside, California, with a List of Minerals from this Locality: *Am. Mineral.*, vol. **14**, pp. 12, 462–469, 1929.

and cooled slowly, likely under great pressure. Its contribution to the metamorphism of the limestone has been: (1) Recrystallization and further fracturing of the limestone. (2) The reduction of the carbonaceous material to graphite. (3) With a few exceptions the formation of the contact metamorphic minerals which are formed mostly under high pressure and temperature and without abundant mineralizers. This was accomplished in the following manner: (a) dissociation of magnesium carbonate to periclase; (b) by reaction in the impure limestone with the formation of spinel, magnetite, grossularite, wollastonite and diopside; (c) probably at a later stage chondrodite, wilkeite and phlogopite were formed by hydrous emanations from the magma containing phosphate, sulphate and halides. The hydration of the periclase to brucite took place, in part, during the cooling of this intrusion.

The contact metamorphic effects of the quartz monzonite porphyry were both endomorphic and exomorphic, but it is with the latter effects that we are principally concerned here, as the others have already been briefly discussed. As a consequence of this intrusion the limestones were further fractured and further recrystallized, especially near the borders of the dikes, until in some places the previous structures were eliminated. Chemical changes resulting from heat, pressure and the action of mineralizers were more general and more complex than those of the granodiorite. The most important of these changes from the standpoint of magnitude is the development of the garnetiferous contact rock. This development is particularly intense above the dikes where, we may assume, the action of the mineralizers would be concentrated. The total destruction in this mass of all previous structures and its coarse crystallinity indicates a complete reaction involving this material and slow cooling during subsequent recrystallization under rather uniform pressure. Thus by the solvent action on an impure limestone of the silicate solutions accompanying the quartz monzonite porphyry intrusion the formation of such minerals as grossularite, augite, diopside, diallage, wollastonite, scapolite, monticellite and bytownite-anorthite has been effected.

The manner in which the vesuvianite-calcite type of rock is confined to the outer margins of the contact mass suggests that its development was largely determined by physio-chemical relations in which a lower temperature and favorable concentrations in Al_2O_3 and SiO_2 were important factors.

Table 1

A—Accessory Mineral; C—Common; F—Frequent; M—Constituent Mineral; R—Rare

Minerals	Occurrence														Remarks
	Hypersthene Quartz Diorite	Granodiorite	Enclaves in the Granodiorite	Quartz Monzonite Porphyry	Endomorphic Phases of Q.M.P.	Granite Porphyry	Pegmatite Dikes	Schists and Gneisses	Quartzites	Chino Quarry Limestone	Chino Quarry Quartzite	Sky Blue Quarry Limestone	Contact Rocks	Miscellaneous and Uncertain	
Albite							M								
Andesine	M		M		M			F	F						
Anglesite													R	R	Alteration of galena
Apatite	A	A	A	A	A	A	A	A	A	R	A	R	R		
Apophyllite							R								In wollastonite near contact
Aragonite										F		F	F		In veinlets
Arsenopyrite												R			
Augite		M		M	M			C	C		C		M		
Axinite							R								Associated with garnet
Azurite													R		Occurs as stains
Biotite	M	M	M		M	M	M	M	M		M				
Bornite													R	R	In cavities near contact
Brucite										C		C			Alteration of periclase
Bytownite-Anorthite														R	In cavities near contact
Calcite	F	F	F	F	F	F	F	F	F	M	F	M	M	C	
Centrallasite							R								Replaces quartz
Cerusite														R	Alteration of galena
Custerite													R		
Chalcedony													R	R	
Chalcocite													R	R	In cavities near contact
Chalcopyrite													R	R	In cavities near contact
Chlorite	C	C	C		C		C	C	C		C				Alteration of biotite
Chondrodite										C		C			Disseminated in predazzite
Chrysotile										R					Small masses near monz. dike
Clinochlore													R		
Clinozoisite													R		Small masses near contact
Crestmoreite												R			Disseminated in blue calcite
Datolite							R								Massive
Deweylite										R		R			Small masses near monz. dike
Diallage					M								M		
Diopside					M								M		
Epidote							C			R					
Foshagite													R		In veins cutting vesuvianite
Galena												R		R	
Gehlenite												R			Associated with merwinite
Graphite										C		C			Disseminated
Grossularite					M			R		C		C	M		
Greenockite													R		Coating sphalerite
Hematite	C	C	C	C	C	C	C	C	C	C	C	C	C	C	Alteration of iron minerals
Hornblende	M	M	M				C								
Hydromagnesite										R		R			Alteration of brucite
Hypersthene	M		M												
Jurupaite												R			In cavities in limestone

TABLE 1 (*Continued*)

MINERALS	OCCURRENCE														REMARKS
	Hypersthene Quartz Diorite	Granodiorite	Enclaves in the Granodiorite	Quartz Monzonite Porphyry	Endomorphic Phases of Q.M.P.	Granite Porphyry	Pegmatite Dikes	Schists and Gneisses	Quartzites	Chino Quarry Limestone	Chino Quarry Quartzite	Sky Blue Quarry Limestone	Contact Rocks	Miscellaneous and Uncertain	
Kaolinite					C										Alteration of feldspar
Laumontite							R								Coating prehnite
Labradorite	M		M					F	F		F				
Limonite	C	C	C	C	C	C	C	C	C	C	C	C	C	C	Stains
Magnetite			A			A		C		F		F			Disseminated in the predazzite
Malachite										R			R		Stains
Merwinite												R			Large masses in blue calcite
Monticellite										R		R	R		
Microcline						M	M								
Muscovite					F			C	C		C				
Okenite							R			R		R	R		Alteration of apophyllite, wilkeite
Oligoclase	M	M	M	M	M	M	M		M	M					
Opal													F	F	
Orthoclase		M		M	M	M									
Periclase										R		R			Enclosed by brucite
Phlogopite										R					
Plazolite													R		
Prehnite							R								In cavities in feldspar
Pyrite	A			A	A				F	F	F	F			Disseminated in limestone
Quartz	M	M	M	M	M	M	M	M	M		M		R	C	
Riversideite													R		In veinlets in vesuvianite
Rutile						A		A							
Sepiolite										R					In veinlets in predazzite
Scapolite													M		
Sericite	C	C	C	C	C	C	C	C	C		C				
Sphalerite													R		
Spinel										C		C			Disseminated
Spurrite												R			Associated with merwinite
Tetrahedrite										R			R		In veinlets
Thaumasite												R	R		In veins and coating spurrite
Tilleyite												R			Associated with wollastonite
Titanite				A	A						A				
Tourmaline							C								
Uralite	C		C						R						
Vesuvianite												F	M		
Wilkeite										R		R	R		
Wollastonite							F	F		C		C	C		
Xanthophyllite										R		R			In blue and green calcite
Zircon		A	A		A	A									

Similar silicate solutions operating outside of the garnet and the vesuvianite zones and therefore probably at lower temperatures were responsible for the formation of the associated rare minerals merwinite, gehlenite, and spurrite. The fine granular and the acicular wollastonite were also formed in the outer portion of the contact zone.

After the crystallization of the garnet and vesuvianite contact rocks and following the high temperature reactions, but in part contemporaneous with them, hydrous solutions containing phosphates, halides and sulphates found easy access into the limestones and contact rocks along the bedding planes and numerous fractures. This probably represented the latter part of the pneumatolitic stage or the early part of the hydrothermal stage. By their action on the limestones and on the previously formed contact rocks they formed various hydrated minerals. It is thought that from reactions of this type minerals such as epidote, clinozoisite, wilkeite, chondrodite and custerite were produced. By further cooling crestmoreite, riversideite, foshagite, jurupaite and plazolite were formed. Crestmoreite, riversideite and foshagite are probably alterations of wilkeite.

Deweylite, chrysotile and sepiolite developed when the hydrothermal solutions acted probably on diopside and diallage or epidote of the contact zone. Xanthophyllite could have been formed either from preexisting silicates or from the impure limestone but under the conditions observed in the field it seems more probable that it too is an alteration of diopside or a closely related mineral. The reaction of the sulphated solutions on the spurrite resulted in thaumasite. Sulphide solutions deposited the sulphide minerals. It was in this stage of the hydrothermal action that the hydration of the periclase to brucite ended.

The metamorphic action of the pegmatite is similar in many respects to that of the quartz monzonite porphyry although not as intense and with the characteristic development of some borosilicate minerals. The first phase is characterized by the development in the pegmatite and in small adjacent contact zones of the common wollastonite, grossularite and the hydrous silicate epidote. This was followed shortly by apophyllite, prehnite, and the borosilicates, tourmaline, axinite and datolite. During the third stage apophyllite altered to okenite, prehnite to laumontite, and centrallasite replaced quartz. Eakle[16] mentions okenite as an alteration product of wilkeite, but whether this alteration took place during the hydrothermal stage related to the quartz monzonite porphyry or during that same stage of the pegmatites is unknown.

Other reactions that have occurred here are entirely supergene. The iron bearing minerals have yielded hematite and limonite, galena has altered to cerrusite and anglesite, the copper minerals to azurite and malachite. Circulating waters have deposited secondary quartz, chalcedony, opal, secondary calcite and aragonite. Rogers[17] described hydromagnesite as a supergene alteration product of brucite and deweylite as a supergene alteration of hydromagnesite.

SUMMARY

In recapitulating the results of these investigations the following points are emphasized:

Paleozoic(?) sandstones, shales and limestones have been intruded and recrystallized by a related series of pre-Cretaceous plutonic rocks in the order: hypersthene quartz diorite, granodiorite, quartz monzonite porphyry, granite porphyry and pegmatite dikes. Of these only the granodiorite, the quartz monzonite porphyry and the pegmatite dikes have been particularly effective metamorphic agents.

In the Crestmore quarries the principal effect of the granodiorite has been recrystallization and fusion. The more potent quartz monzonite developed large masses of contact rocks and most of the rare minerals found here. The action of the pegmatite has been similar but not as intense.

In the following the contact metamorphic minerals are listed below the rocks to which they owe their origin:

Granodiorite	*Qtz. Monzonite Porphyry*	*Pegmatites*
Graphite	Grossularite	Grossularite
Periclase	Augite	Wollastonite
Spinel	Diopside	Epidote
Magnetite	Diallage	Apophyllite
Grossularite	Wollastonite	Prehnite
Wollastonite	Scapolite	Tourmaline

16 Eakle, A. S., *op. cit.*, 1917. Jurupaite, a New Mineral: *Am. Mineral.*, vol. **6**, pp. 107–109, 1921.

17 Rogers, A. F., An American Occurrence of Periclase and Its Bearing on the Origin and History of Calcite-Brucite Rocks: *Am. Jour. Sci.*, vol. **46**, pp. 581–586, 1918.

Granodiorite	*Qtz. Monzonite Porphyry*	*Pegmatites*
Diopside	Monticellite	Axinite
Chondrodite	Bytownite-Anorthite	Datolite
Wilkeite	Vesuvianite	Okenite
Phlogopite	Merwinite	Laumontite
Brucite	Gehlenite	Centrallasite
	Spurrite	
	Epidote	
	Clinozoisite	
	Wilkeite	
	Chondrodite	
	Custerite	
	Riversideite	
	Crestmoreite	
	Foshagite	
	Jurupaite	
	Plazolite	
	Deweylite	
	Chrysotile	
	Sepiolite	
	Xanthophyllite	
	Thaumasite	
	Sulphides	
	Brucite	

It should be evident from the preceding pages and the above lists that the reactions which took place during and following these intrusions were not simple and complete; they were characterized by their extreme complexity and recurrence. Thus it is that many minerals are polygenetic, not only in that they have been generated by each successive intrusion but they have been formed during the same intrusion by derivation from different parent minerals due to variations in concentration, pressure and temperature that must have prevailed in a mass of this type and size. Not only is polygenesis evident but one finds that the same minerals yield various alteration products. For example: wollastonite, a mineral common to each intrusion, occurs as four distinct morphic types (a fact in itself of genetic significance) but as shown by Dunham[18] some of the alteration products of this mineral are tilleyite, gehlenite and vesuvianite. Gehlenite in turn yields grossularite. We know that all of the grossularite is not altered gehlenite and that all of the vesuvianite did not come from wol-

[18] Dunham, K. C., A Note on the Texture of the Crestmore Contact Rocks: *Am. Mineral.*, vol. **18**, pp. 11, 474, 1933.

lastonite. We are fairly certain of the intrusion which these reactions accompanied but not if they occurred during a later low temperature or a recurrent phase of the intrusion. These and many other questions can be answered only by further work.

The following graphically depicts some of the genetic sequences as they are known to date.

$MgCO_3$→Periclase→Brucite→Hydromagnesite
Epidote and/or Diopside→Chrysotile and Deweylite→Sepiolite
Wollastonite→Gehlenite→Grossularite
                    ↘Vesuvianite
                    Tilleyite
Wilkeite→Crestmoreite→Riversideite
Apophyllite→Okenite
Spurrite→Thaumasite
Prehnite→Laumontite
Quartz→Centrallasite

In studying the literature on Crestmore anent the paragensise of the minerals occurring there one finds confusing and conflicting statements. Some authors do not distinguish between the different contact zones related to the various intrusions, the phases of each intrusion and in one case the nature of the injected rock has been incorrectly determined. In short, the tendency has been to too greatly simplify the facts and to regard the evidence of special cases as representative of the whole. If we are to more fully understand the contact metamorphic phenomena demonstrated here it is necessary to take a broader view. It is hoped that this paper will serve as a step in the right direction.