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CRESTMORE, PAST AND PRESENT*

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When it came to be my turn, as retiring president of the Mineralogical Society of America, to deliver the customary parting address, it seemed quite natural to turn for my subject to Crestmore, since I have been in close touch with this remarkable mineral deposit for over thirty years. During this time, I have made repeated trips to this locality, which is a little west of Riverside, California, and only about sixty miles from my headquarters at U.C.L.A. These trips have been made alone or with successive classes of students from the University, and I feel that it has been, and still is, year in and year out, one of the most consistently profitable and rewarding sources of interesting mineralogical material anywhere in the world. Thinking back over these visits, I bring to mind one in particular which might well serve to "point a moral and adorn a tale." It was several years ago, when I encountered a small group of visitors to the quarry, among whom was a youngster of boy scout age, who was prowling in impatient fashion over the fragments of talus while his elders were busily collecting specimens. He was making most scornful remarks about "nothin' but ole quarry rock," just about the time that I was making an exciting find close by. To the boy, and to most of the general public I suppose, Crestmore is "just a quarry," since there is nothing particularly showy there apart from the beautifully blue calcite. But to a mineralogist, it is one of the seven wonders of the world, and a place worth all the "blood, sweat and tears" involved in what my students sometimes defined as "beating on boulders." After all, when you break open a rock, the exposed surface is something that has never before been seen by human eye, and occasionally that sight is highly rewarding. This is particularly so if the break happens to occur along a vein in which there is a cavity, for on the walls of this there may be a coating of beautifully developed crystals. The only trouble with a place like Crestmore is that with continuous excavation of rock, and only inter-

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* Address of the retiring President of the Mineralogical Society of America at the 41st annual meeting of the Society at Denver, Colorado, Nov. 1, 1960.

TABLE 1. NEW MINERALS FOUND AT CRESTMORE

Wilkeite	1914	Merwinite	1921	Parawollastonite	1935
Riversideite	1917	Foshagite	1925	Ellestadite	1937
Plazolite	1920	Tilleyite	1933	Nekoite	1955

NEW, BUT AS YET UNNAMED

Mineral Z	1953	Woodford's group	1940–41
10 Å hydrate	1959	(Minerals C, D, F, J, L, M and Q)	
Mg borate	1959		

mittent visits possible, many potential specimens go through the works and disappear. As Eakle commented, "the cement contains the calcined remains of many beautiful, rare, and perhaps new minerals." The title I have selected, "Crestmore, Past and Present," should perhaps have been extended by adding the word "future," because the locality seems as inexhaustible as the miraculous pitcher of Philemon and Baucis. I can vouch for the fact that in all my visits to Crestmore over this period of more than thirty years, I have practically never drawn a blank. I would take a class there, firmly resolved not to do any collecting, and then, in the course of showing a typical occurrence to a student, would encounter a specimen which was different, and warranted further examination in the laboratory. So much for the resolution! Of course, the cream has been skimmed, and most finds are of secondary interest, but not all, even now. The record of new minerals, for instance, with their dates of discovery as shown in Table 1, indicates that the end is not yet in sight, and there seems to be no reason to suppose that continued careful observation will not continue to produce results.

HISTORY

The earliest activity at Crestmore was the quarrying of limestone for lime-burning. This began some undetermined time before 1907, from some pits at the site of the present Commercial quarry on the east side of Sky Blue Hill. The old bins and lime works were in existence up to about 1940. They appear in a picture taken about 1928, shown in Fig. 2*a*.

A panorama taken from the west in about 1906 is shown in Fig. 1*a*. Perhaps if one of you is an old car fan he can date this picture from the automobile. This shows the original land surface, with Sky Blue Hill at the left and Chino Hill to the right. Quarrying for cement rock was started on the west side, mainly on Chino Hill, about 1907, and a plant was erected in 1909. At the same time, the Commercial quarry was being operated for road material as well as limestone, as was probably the high level North Star quarry on the northerly slope of Sky Blue Hill. This, as well as the workings on the west side, is shown in Fig. 1*b* probably taken in 1915 or before. Figure 1*c*, taken in March, 1917 from a slightly different angle, shows further progress in excavation. The record is somewhat vague here, since one statement is made that the high level quarry was the North Star, and that the Lone Star was started about 1917 between this and the Commercial quarry. It seems likely that this intermediate quarry is the one now called the Wet Weather quarry, and that the name Lone Star was applied to the North Star.

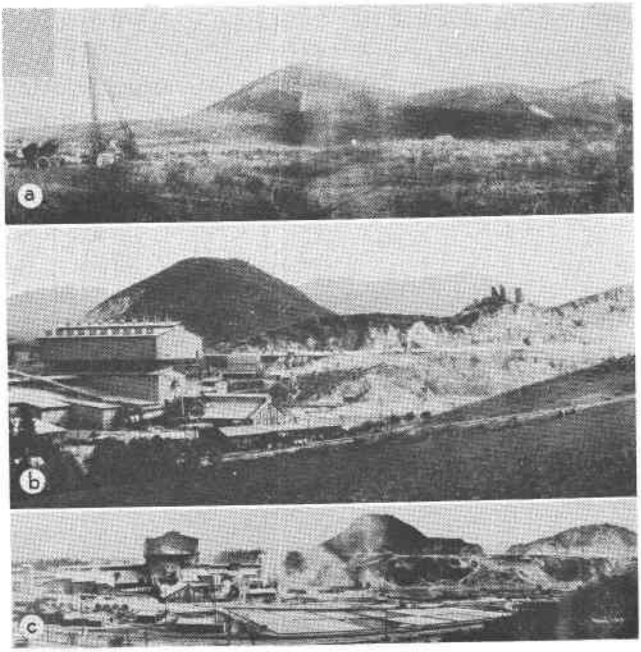

FIG. 1. Early views of Crestmore. (a) About 1907; (b) 1915; (c) 1917.

Two pictures taken from the air in 1928 show the general quarry pattern at that time. The first one (Fig. 2*a*), from the east, shows the old Commercial quarry face and in the foreground, the old lime kiln structures. This also shows the increased extent of quarrying on Chino Hill and its extension to the north. The second picture, (Fig. 2*b*) from the opposite direction, shows as well the high Lone Star quarry, the greatly deepened Wet Weather quarry, and a bit of the floor of the Commercial quarry.

In 1927 a shaft was started for underground mining, and excavation ultimately resulted in caving in of the surface and development of a glory hole between Chino and Sky Blue Hills. This is shown in a photograph taken in 1935 which shows the headframe of this shaft, and the beginning of a steep face on the west side of Sky Blue Hill (Fig. *3a*). Mine and open pit were both worked until about 1930, but from that date to 1939 the only production was from the mine. Late in 1940 some limestone was taken out on the east side, from the platform of the now abandoned Commercial quarry, and at this time the old lime kiln structures were removed. Then again, in 1946 and 1947 the Commercial quarry floor was cut into from the south, the excavation joining up with the 1940 workings, and forming the 910 foot level from which very extensive collections have been made in recent years. Since this time, and up to the present, all production has been from the underground workings, which now are down to a depth of some 550 feet below the surface. Figure *3b* shows the present Commercial quarry face and the 910 foot level.

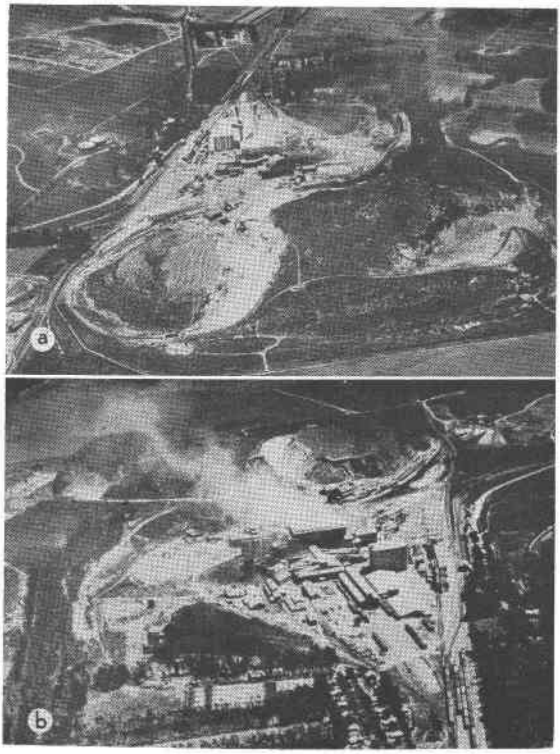

Fig. 2. Crestmore in 1928. (a) View from East, showing old Commercial quarry face, and old lime kiln structures. (b) View from West, showing the high Lone Star quarry and greatly deepened Wet Weather quarry.

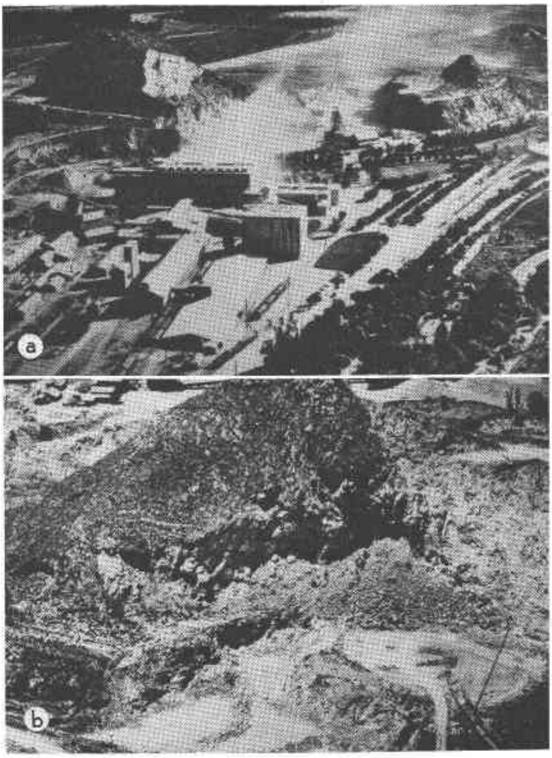

FIG. 3. (a) Crestmore in 1935; (b) 1956 (By permission, Geological Society of America).

GEOLOGY

The oldest rocks of the area are metasediments, in part crystalline, with some quartzite and other metamorphic types. These may be Mississippian or Triassic in age—there is no conclusive evidence, although comparisons have been made with the Mississippian Furnace limestone, and with the Triassic Bedford Canyon formation.

These rocks have been extensively invaded by quartz diorite which represents the northerly extension of the San Diego batholithic complex. Erosion has lowered the surface to the point where only patches of the metamorphics have been preserved, embedded in a matrix of the quartz diorite as roof pendants or "curtains." The Crestmore area represents one of these patches, which consists mainly of crystalline limestones or marbles, and a lesser amount of quartzite. The limestones are represented by two roughly lenticular bodies which dip in an easterly direction, as shown in Fig. 4. The upper, or Sky Blue limestone is about 500 feet in thickness, and is separated from the lower, slightly thinner Chino limestone, by an intrusive tongue of the quartz diorite. The Chino is in a somewhat irregular and wrinkled syncline, while the overlying Blue Sky has been somewhat bulged up by the intrusion of quartz monzonite porphyry which forms irregular or pipelike intrusions in the Blue Sky limestone or between it and the quartz diorite. At this time, or slightly later, there have also been intrusions of various pegmatites, mostly small.

The limestones are quite similar, consisting of layers of predazzite alternating with pure limestone, and with some layers of magnesium-poor rock. The Sky Blue series included some very large masses of almost pure blue calcite, and both it and the Chino are quite coarsely crystalline, although not solid enough to be marble such as could be used in building.

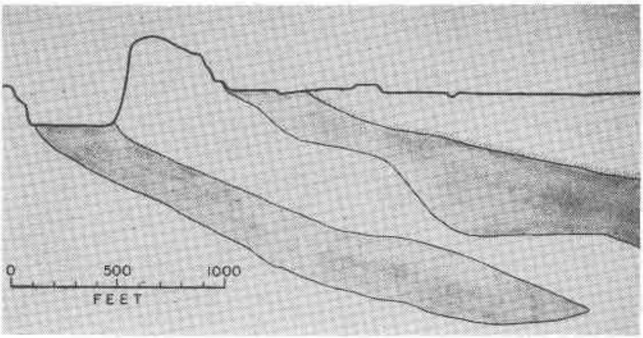

FIG. 4. Lenticular bodies of crystalline limestone at Crestmore. Upper—Sky Blue; Lower—Chino.

Contact effects of the quartz diorite are expressed by the presence of a relatively narrow, simple contact zone, presumably by the development, in its hotter stages, of the abundant periclase originally present in the predazzite, and by coarsening of the crystalline texture of the limestones.

Contact effects of the quartz monzonite porphyry are much more pronounced, and involve silication of thick zones in the limestone, perhaps development of the blue color in some of the calcite, and formation of a mixed or hybrid rock by absorption of limestone by the intrusive magma. The thick masses of contact rock show a zonal distribution of minerals from the intrusive contact to the untouched limestone, and it is in this region that many of the unusual minerals appear.

MINERALS

A great deal has been written about Crestmore and its minerals, but this afternoon I propose to bring only the more important portions to your attention. The initial papers were purely descriptive, and this term could probably be applied to most, but a few of the later ones have been more concerned with mineralogic history, origins and relationships. Before considering these you may be interested in a few statistics: The total number of named and identified minerals to date is 137, with an additional dozen or so which are so far unidentified, many of which are probably new. Of the named minerals, nine are new, as shown in Table I. Six of these have notyet been found elsewhere, and two more, riversideite and nekoite in only one or two other localities. I have listed parawollastonite as new, for it was on material from Crestmore that Peacock (1935) first recognized its monoclinic character, and suggested that the name wollastonite be used for the more common triclinic form. This puts Crestmore on a par with the two other great contact metamorphic assemblages—Franklin, New Jersey, and Långban, Sweden, each with essentially the same number of recognized species.

The attention of mineralogists was drawn to Crestmore as a contact metamorphic assemblage of considerable interest by A. S. Eakle (1914), at a meeting of the Geological Society of America. The abstract of this paper listed only a few of the minerals observed, including the rare mineral xanthophyllite, but was followed by a later, more complete presentation. In this year wilkeite, the first of the new minerals, was described by Eakle and Rogers (1914) and named in honor of the late R. M. Wilke, ardent mineral collector and dealer of Palo Alto. This was a good one to start off with, since it is a mineral of the apatite group with the unprecedented number of four acid radicals—phosphate, silicate, sulphate, carbonate. In this paper, they also mention the mineral okenite, which they describe as appearing as an alteration product of wilkeite.

A more complete paper by Eakle (1917) lists a total of 56 species, and describes two new minerals. These are crestmoreite and riversideite, both hydrous calcium silicates but with different percentages of water. Crestmoreite was described as an alteration product of wilkeite, taking the place of the earlier-named okenite. The mineral has since been shown to be tobermorite, always occurring with some residual wilkeite. Riversideite, occurring principally as white fibers interstitial to idocrase grains, and as veins in massive idocrase, is a doubtful but probably valid species. In this paper also, an occurrence of white needle-like grains was described as okenite, but this material has recently been shown by *x*-ray study to be nekoite, a new mineral.

In the next two years another seven species appeared, among them the rare mineral periclase (Rogers 1918), whose presence had been postulated as the original of the brucite granules, but which had not been found before. It appears as very occasional cores inside nests of brucite in the predazzite rock, confirming the earlier diagnosis. Here also plazolite, another new mineral, was described by Foshag (1920).

From 1921–1925 ten additional species were found, and of these three were new. Merwinite was described and named by Larsen and Foshag (1921). In the same year, Eakle (1921) determined jurupaite, which has since been considered to be a magnesium-rich xonotlite. A new mineral, foshagite, was described, also by Eakle (1925). It was later considered to be identical with hillebrandite (Berman 1937) but more recent work (Heller and Taylor 1956) has shown the validity of this material as a separate species.

During the period 1933–1937 twelve additions were made to the list, among them three more new species. The first of these was tilleyite, named by Larsen and Dunham (1933). Then Peacock (1935) determined the triclinic symmetry of one type of wollastonite crystals described by Eakle from Crestmore. He proposed that the name wollastonite be applied to this modification, and that the far less common monoclinic variety be called parawollastonite. Some of these truly monoclinic crystals are found among Eakle's Crestmore wollastonites, so that both modifications are present here. Then D. McConnell (1937) observed and named ellestadite, a wilkeite-like mineral with little or no phosphate radical present.

Rather extensive papers by Woodford and his associates (Woodford et al. 1941, Woodford 1943) added twenty-eight recognized species, most of them by their own observations. Besides these, they list at least eight unnamed species, some of them probably new, besides some others which have since been identified. These papers devote considerable attention to distribution of minerals throughout the quarries, and make incidental comments on the origin of several.

There is no published record of any additions to the list until 1949, when the mineral perovskite was noted, by the present author, Murdoch (1949), but a number of new occurrences were observed over the previous six years, in specimens from his personal collection and in material sent him by private collectors.

In the period 1951–55 eleven names were added, and among these was the new compound nekoite determined by Gard and Taylor (1955) from material Eakle had called okenite. Several of the observed species are rare, among them afwillite, scawtite, and bultfonteinite. Prior to these years, one probably new mineral was observed and partially described by the writer, and tentatively called mineral Z, but the results were not published, in absence of a reliable analysis. Qualitative tests indicated that this was a hydrated silicate carbonate of calcium.

Recently C. W. Burnham (1959) published a very complete paper on the detailed geology and paragenesis of minerals on Crestmore, and I have drawn freely on this in outlining the sequence of events and the characteristic features of the locality.

During the autumn and winter of 1959–60, I have had the privilege of working in the Harvard laboratory on an extensive collection of Crestmore material made by Col. C. M. Jenni. At the same time Alden Carpenter, a graduate student, has been working on his own collection of Crestmore specimens at the same place. The results of study here are by no means complete, but in the course of routine examination an additional eight named species have been added, including the rare minerals ettringite, szaibelyite, and huntite. In addition, a number of definite species have been observed which are so far not identified, and some of which are surely new.

The presence of such a great variety of minerals is due to the rather complex geologic history of the occurrence. This produced a fortunate combination of conditions which permitted the development of many uncommon compounds as well as of the usual species. There were a number of factors involved in this history, which started with the metamorphism of the original sediments, included the crystallization of the various igneous intrusions, continued with their successive contact effects, and ended with surface weathering and oxidation. The early, presumably regional, metamorphism of the sediments, and the final weathering, produced few minerals and no very interesting ones. Intrusion and crystallization of the igneous intrusives produced the normal suites of rock-forming minerals, and in the case of the quartz diorite, resulted in the development of a thin, normal contact zone with grossularite garnet, epidote and wollastonite. Early stages of the intrusion of this rock may well have been responsible for the formation of the original abundant periclase in the magnesium rich layers of the limestone. With dropping temperatures late hydrothermal agencies from the same source may have hydrated most of this periclase to the nests of foliated brucite that we see now. At the same time, some of the purer limestone may have received its blue color. There is as yet no adequate explanation for this color. The pegmatites may have been injected at about this time, but seemed to be responsible for very little mineralogic change.

The somewhat later intrusion of the quartz monzonite porphyry is responsible for the development of an extensive aureole of contact rock, some of it completely silicated. Burnham (1959) has observed a definite zoning in this aureole, starting next to the igneous rock with grossularite as the principal mineral, accompanied by minor wollastonite and diopside. The next zone is almost entirely idocrase, and the outermost mainly monticellite with a rather long list of minor constituents, such as chondrodite, clinohumite, merwinite, tilleyite, etc. This zoning shows a successive decrease in the ratio $Si+Al+Fe/Ca+Mg$ with increasing distance from the intrusive, and indicated that these elements were added metasomatically to an originally essentially pure limestone.

These zones are not always well defined, and are complicated by the irregular form of the intrusives. Further, we may find variations in them to produce local masses made up of idocrase-diopside-grossularite-spinel, monticellite-idocrase-wollastonite-diopside, or spurrite-merwinite-gehlenite. These may be solid silicate masses or may be interspersed with irregular patches of coarsely crystalline, often bright blue, calcite. In these calcite patches we sometimes find metallic sulphides, galena, bornite, chalcopyrite, disseminated in droplike pellets. Some of these are perfectly fresh, while others are altered to secondary carbonates or oxides. In a few cases the galena is surrounded in the neighboring matrix by minerals like wulfenite or mimetite.

Some of the massive garnet-wollastonite zone is composed of very fine, sugary grossularite, and fracture surfaces in this mass are often characterized by the presence of foshagite in "slip-fiber" form, like asbestos, or painted over with a thin coating of a brilliant blue mineral so far unidentified. This has tentatively been called mineral Y, and some of its characteristics determined, but not enough pure material is so far available for final determination though it appears to be a copper bearing calcium silicate hydrate. Mineral Y may occur alone on a surface, or in combination with foshagite, or less often as pellet-like aggregates of thin blades occurring in calcite just like the metallic sulphides.

The massive monticellite rock, brown in color, also is cut by narrow veins, rarely over one-eighth to one-quarter inch wide, filled with fibrous or platy white minerals. Usually these are massive, but occasionally small cavities allow the formation of crystals. Some of this vein filling is thaumasite, showing a cross fiber pattern and in the rare open spaces well developed terminated crystals. Much of it, however, is a platy mineral which I observed several years ago, and have tentatively called mineral Z. This occurs locally in the grossularite rock and the merwinite-spurrite rock as well as here, and normally appears as botryoidal groups of clustered blades. Rarely it develops freely, forming multiple or even more rarely, single thin crystals, reasonably suitable for single-crystal *x*-ray study. These crystals are so thin as to be practically invisible when viewed on edge, so that goniometric measurements are impossible. Optical properties, *x*-ray powder pattern, unit-cell dimensions and symmetry correspond closely to one of the calcium silicate hydrates (14 Å) described by Heller and Taylor (1956) and the qualitative chemical composition is essentially the same. A satisfactory chemical analysis had not been possible until last winter, when a more abundant supply became available from the Jenni and Carpenter collections at Harvard. Analysis of this material showed the presence of several per cent of B_2O_3 and CO_2, although these do not appear to affect the powder pattern. With the availability of this analysis, a reasonably complete description and naming of this mineral is in process. It has been suggested that it is somewhat similar in composition to Daubree's plombièrite, and so should be given this name, but his material was a gel, rather poorly described, and this is crystalline. In my opinion mineral Z is a definite and different substance, and deserves species rank and a name of its own. Some of the white crusts, in the merwinite-spurrite rock particularly, are very like mineral Z in appearance and gross chemical composition, but give a distinctly different *x*-ray powder pattern, corresponding to another of the calcium silicate hydrates of Heller and Taylor (with a prominent line at 10 Å), and appears to be free from admixture. The chemical analysis shows a different proportion of CaO to SiO_2 from mineral Z, so this also should be considered a mineral species.

In the spurrite-merwinite rocks, many of the veins are quite different from those just described, and are characterized by the presence of scawtite (sometimes accompanied by mineral Z), or afwillite (often with ettringite). Scawtite and afwillite are ordinarily in small, but well formed crystals. Ettringite is locally abundant, as tiny hexagonal prisms or as larger crystal grains without external form, and in the latter case often peppered through in poikelitic fashion, by afwillite. Analysis of the ettringite showed the presence of considerable Al_2O_3, SiO_2 and CO_2, and single photographs gave a unit cell with twice the *a* dimension of the published value for ettringite. Accordingly, this material was considered to be an allied but new mineral, and given the name woodfordite by Murdoch (1958). However, re-examination of the unit cell dimensions of ettringite showed the calculation of the *a* axis to be in error. The true value is double, thus making the cell size identical with woodfordite. It was then considered that the difference in composition was not enough to warrant making a new species, and that woodfordite should be considered as a variant of ettringite.

This group of vein minerals should probably be referred to a very late hydrothermal stage in the contact process. Further from the contact, with less complete silication, the invading minerals take the form of small grains disseminated in the calcite. These grains range in shape from smoothly rounded pellets to nearly perfect crystals. The commoner minerals involved are idocrase, diopside, wilkeite (less commonly with development of crystal faces), spinel, a colorless to gray monticellite (practically never showing crystal outlines). More rarely we find chondrodite, perovskite, and magnesioferrite.

In this sparsely mineralized region, wilkeite is usually more or less completely altered to the mineral called crestmoreite by Eakle. This has been shown to be tobermorite, practically all with residual wilkeite, even down to the submicroscopic state. The enveloping calcite is apparently entirely unaltered, but here again, as in the case of scawtite, afwillite, and mineral Z, the alteration is probably late hydrothermal in character.

In the Sky Blue limestone just below Burnham's locality N on the 910′ level of the Commercial quarry, there are various stringers of pegmatitic material carrying gray diopside, quartz, orthoclase and sporadic merwinite. Closely associated with these is a mass of mangesium-rich limestone carrying several borate minerals. One of these is ludwigite, occurring in small well formed black prismatic crystals. Another is a hydrous magnesium borate which appears to be a new species. It occurs as single prismatic individuals or clusters of prisms, colorless but usually with minute black flecks arranged in parallel position. Crystal outlines are usually poor, although good faces occur in the prism zone. The matrix is a mixture of rather coarse grains of calcite and dolomite. Late, probably hydrothermal action has reduced many of the borate crystals to white powdery szaibelyite and an unidentified magnesium carbonate. Chemical analysis shows hydroxyl as well as water of crystallization and a ratio MgO to BO_2 of five to one. A detailed description of this mineral is in progress. Closely accompanying this borate, we find feathery sprays of another unknown mineral, probably a borate, altered to white szaibelyite. This material needs further study.

Locally, notably in material from the Lone Star or Wet Weather quarries, galena and sphalerite are relatively abundant, and appear with their oxidation products anglesite and cerussite, hemimorphite and smithsonite. A perceptible cadmium content of the sphalerite is revealed by rare coatings of bright orange greenockite. After the closing down of these quarries, a good deal of this sort of material was available for a while from a dump ridge along the eastern boundary of the company's property. This dump unfortunately is now buried under sand from an extensive stripping operation.

I have tried to give you my impression of Crestmore as I have known it, a wonderful collecting ground and a place worthy of the enthusiasm of any ardent mineralogist. In closing, I wish to express my deep appreciation of the favors and courtesies extended to me over the years, by the Riverside Cement Company and its staff. Not only have they supplied me with invaluable pictures and information, but during all my visits to Crestmore I have had the most pleasant personal relationships in all my contacts there.

References

(In chronological order)

Eakle, A. S. (1914) Some contact metamorphic minerals in crystalline limestone at Crestmore, near Riverside, California: (*Abstr*) *Bull Geol. Soc. Am.* **25,** 125.

——— and Rogers, A. F. (1914) Wilkeite, a new mineral of the apatite group, and okenite, its alteration product, from Southern California: *Am. Jour. Sci.* (4) **37,** 262–267.

——— (1917) Minerals associated with crystalline limestone at Crestmore, Riverside County, California: *Calif. Univ. Dept. Geol. Sci. Bull* **10,** 327–360.

Rogers, A. F. (1918) An American occurrence of periclase and its bearing on the origin and history of calcite-brucite rocks: *Am. Jour. Sci.* **46,** 581–586.

Foshag, W. F. (1920) Plazolite, a new mineral: *Am. Mineral.* **5,** 183–185.

Larsen, E. S. and Foshag, W. F. (1921) Merwinite, a new calcium-magnesium orthosilicate from Crestmore, California: *Am. Mineral.* **6,** 143–148.

Eakle, A. S. (1921) Jurupaite, a new mineral: *Am. Mineral.* **6,** 107–109.

——— (1925) Foshasite, a new silicate from Crestmore, California: *Am. Mineral.* **12,** 97–99.

Vigfussen, V. A. (1931) The hydrated calcium silicates: I. the system CaO-SiO_2-H_2O. II. Hillebrandite and Foshagite: *Am. Jour. Sci.* (5) **21,** 67–78.

Larsen, E. S. and Dunham, K. C., Tilleyite (1933) a new mineral from the contact zone at Crestmore, California: *Am. Mineral.* **18,** 469–473.

Peacock, M. A. (1935) On Wollastonite and Parawollastonite: *Am. Jour. Sci.* **30,** 495–529.

McConnell, D. (1937) The substitution of SiO_4- and SO_4-groups for PO_4-groups in the apatite structure: ellestadite, the end member: *Am. Mineral.* **22,** 977–986.

Woodford, A. O., Crippen, R. A. and Garner, K. B. (1941) Section across Commercial Quarry, Crestmore, California: *Am. Mineral.* **26,** 351–381.

Woodford, A. O. (1943) Crestmore Minerals: *Calif. Jour. Mines and Geology Rept.* **XXXIX,** 333–365.

Murdoch, J. (1949) (abstr) Perovskite from California: *Bull Geol. Soc. Am.* **60,** 1911. (1951) *Am. Mineral.* **36,** 573–580.

Gard, J. A. and Taylor, H. F. W. (1956) Okenite and Nekoite (a new mineral): *Mineral Mag.* **31,** 5–20.

Murdoch, J. (1958) Woodfordite, a new mineral from Crestmore, California: (abstr) *Bull Geol. Soc. Am.* **69,** 1620–21.

Burnham, C. W. (1959) Contact metamorphism of magnesian limestones at Crestmore, California: *Bull Geol. Soc. Am.* **70,** 879–919.