OCCURRENCE OF FELDSPAR REPLACING FOSSILS

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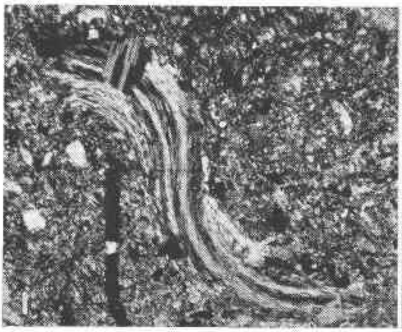
A study of some rock specimens from Provo River damsite No. 8 in Provo Canyon, Utah, brings to light an unusual occurrence of feldspar crystals in limestone, which in many instances are contained within skeletons of fossils. The obvious non-clastic derivation of the feldspar, together with the abundant evidence supporting authigenesis, suggests that the feldspar may be of this origin. The writer desires to extend his thanks and appreciation to Professors Paul F. Kerr and Phillip Krieger, and Dr. H. N. Coryell of the Columbia University faculty for their encouragement and advice during the preparation of this paper.

The sedimentary series in which the beds containing the feldspar is located, was mapped by the 40th Parallel Survey as Carboniferous.[1] The areal position of the bed indicates that it is within the Brazer formation of upper Mississippian age, but the identification of two genera of Bryozoa, *Strombopora* and *Rhombopora*, by Dr. H. N. Coryell, however, signifies that it might better be placed within the Pennsylvanian.

The bed containing the feldspar is approximately 7 ft. thick. Its strike is nearly due north-south and it dips 60° to the east. The exposure is in the bottom of the Provo gorge, about one quarter of a mile north of the Utah-Wasatch County line. At this point the Provo River flows southeastward and cuts obliquely across the strike just north of the exposure. Therefore the stream gravels cover the outcrop of the bed to the north, while to the south a thick mantle obscures the outcrop. Thus extensive observation of the bed along its trace is prevented in either direction.

The rock containing the feldspar is a dense black limestone with a few irregular fractures filled with calcite. Bedding laminae are essentially absent. A few megascopic brachiopods were present but an accurate identification of them could not be made. An occasional crinoid stem could also be seen with the unaided eye. On a polished surface of the rock many other small fossils were observed, but it was necessary to resort to the microscope to more definitely determine their character. Microscopically, the limestone consists of a matrix of fine grained carbonate with occasional coarsely crystalline calcite veinlets. Many fossils and fragments of fossils are imbedded in the matrix. The recognizable forms are brachiopods, crinoid arms and stems, pelecypods and bryozoa. Throughout are present many small quartz grains with sub-rounded outlines constituting about 2 per cent of the rock. They have a random distribution and are usually confined to the carbonate matrix between the fossils, and appear to be of clastic origin. Quartz also occurs as a fos-

[1] King Surveys, *Atlas Sheet No.* **50,** *U. S. Geol. Survey,* West of 100th Meridian.



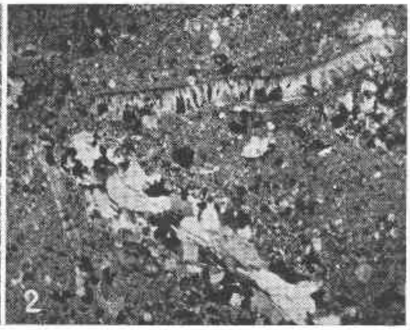


FIG. 1. Photomicrograph (×60) with crossed nicols. Shows a fossil fragment composed of fine carbonate which has been replaced by a well shaped feldspar crystal. Observe many irregularly shaped quartz grains of varying sizes distributed in the dense carbonate matrix. Quartz also appears replacing the fossils.

FIG. 2. Photomicrograph (×17) with crossed nicols. This shows part of a large elongate fossil (lower left center) almost completely replaced by quartz and feldspar. Immediately adjacent (upper center) is a fossil composed of carbonate which has been unaffected by replacement except for two minute quartz crystals (upper right).

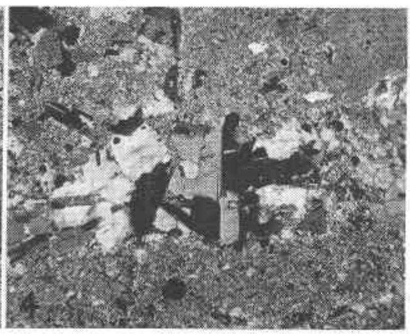


FIG. 3. Photomicrograph (×100) with crossed nicols. A large well formed feldspar crystal 0.23 mm. long has grown almost entirely in the matrix, only slightly replacing the crinoid arm (lower right center). Smaller crystals of feldspar and quartz can be seen throughout the illustration. Note the dolomite crystal which has developed within the large feldspar.

FIG. 4. Photomicrograph (×53) with crossed nicols. This feldspar crystal is 0.3 mm. in its greatest dimension and has replaced a fossil, whose outline in places has been obliterated by feldspar growth beyond its borders. The fossil extends from left to right across the center of the photomicrograph.

sil replacement. The anhedra are varied in size and generally have interlocking relations with one another.

Feldspar often accompanies the replacement of quartz, and apparently is contemporaneous in formation, and although predominantly anhedral in shape, there are a few instances where it is euhedral. Excellent albite twinning is present in all crystals. Figures 2 and 4 show fossils which have been replaced almost entirely by quartz and feldspar. In many cases (Fig. 2) the replacing material is confined within the fossil outlines. In an exceptional case (shown in Fig. 4) the feldspar has disregarded the outline of the fossil and has developed beyond it. Many fossils have been only partially replaced (Fig. 2).

The greatest amount of the feldspar is present in the fine carbonate matrix of the rock. In no case is quartz intimately associated with it here. The crystals are all exceptionally well formed, presenting good crystalline outlines, the largest of which is approximately 0.23 mm. in its greatest dimension (see Fig. 3). They range from this size down to minute submicroscopic crystals and are oriented at random and form no grouping whatsoever. Figure 1 shows a well formed crystal partly within and partly without the fossil. In many cases the feldspar and the quartz are replaced by dolomite, which is distinctly of later development (Fig. 3). The occasional carbonate veinlets which traverse the rock, cut feldspar and quartz alike, and are therefore considered to be of later development.

A fragment of the rock was dissolved in hydrochloric acid and the resulting residue was found to be about 20 per cent of the whole and consisted of black carbonaceous clay, quartz and feldspar. The solute was tested for sulphate and magnesium, which resulted negatively for sulphate, but considerable magnesium was found. With the aid of a binocular microscope, some excellent feldspar crystals were separated from the residue. These were found to be triclinic and elongated parallel to the *c*-axis. The forms (001) and (010) were well developed, while (110) and (101) were less frequent. Marked (001) cleavage was noted. The indices were determined as $\alpha = 1.5320$, $\beta = 1.5365$ and $\gamma = 1.5414$, which according to Rogers and Kerr[2] are the indices for a plagioclase of Ab_9An_1 composition. The expected large 2V was present, but could not be accurately measured because of the small size of the crystals. The crystals were clear and free of inclusions, but occasionally ragged edges were noted which are evidently due to the partial replacement by dolomite. Albite twinning was invariably present.

[2] Rogers and Kerr, *Thin-Section Mineralogy*, McGraw-Hill, 214 (1933).

Origin

An effort was made to discover a suitable hypothesis of origin which would account for the presence of these feldspar crystals in this apparently unaltered fossiliferous limestone. Hydrothermal introduction, or other high temperature source, was considered with rather discouraging results. So far as known, there is no igneous rock exposed within at least 15 miles of the point where the specimens were taken. The nearest known metaliferous mineralization is at least 10 miles away. A source for high temperatures other than burial would seem to be essentially lacking. The veinlets in the rock, which were evidently made during folding, contain carbonate only and appear to have been formed after the time of formation of the feldspar, and are therefore entirely unrelated to it. It is on this evidence that metamorphism during folding has not been seriously considered. The lack of veinlets, grouping or segregation of crystals of feldspar indicated that their position has not been controlled by secondary structures within the limestone. Minerals resulting from hydrothermal action on impure limestone are entirely absent, also the clastic quartz grains or feldspar crystals were not observed to be enlarged by secondary growth.

The rock in general presents an unaltered appearance with even the original carbon content relatively unaffected. Calcite is one of the more easily recrystallized minerals, but the character of the original carbonate of the rock remains unchanged even to the fine delicate structures of the unreplaced fossils (Fig. 2). The only direct evidence suggesting that introduction has taken place is the incongruity of non-clastic feldspar in a sedimentary rock, but since such an association has been observed before and an origin of authigenesis given, it seems reasonable and proper that this origin should be seriously considered for this occurrence.

A. Drian[3] in 1861 first described an occurrence of feldspars in dolomite of the Alpine Trias and suggested that sedimentary processes were responsible for their formation. Since then many occurrences of authigenic feldspars have been observed. It has been generally accepted that feldspars can, and do, form by this process, but the exact definition and description has varied somewhat with different authors. Several workers hold the view that feldspars form during deposition of the sediment or shortly after. Grandjean[4] went so far as to state that feldspars, thus

[3] Drian, A., Notice sur les cristaux d'albite renfermés dans les calcaires magnésiens des environs de Modane: *Bull. soc. géol. France*, ser. 2, **18**, 804–805 (1861).

Note. The information from the French publications cited was obtained from abstracts in *Mineralogy of Sedimentary Rocks* by P. G. H. Boswell. Thomas Murby & Co. 1933.

[4] Grandjean, F., Deuxième note sur le feldspath néogène des terrains sédimentaires non métamorphiques: *Bull. soc. franc. min.*, **33**, 92–97 (1910).

forming, cease to grow on the sea floor after burial. J. de Lapperent[5] suggests that organic acion was the "first cause" of the formation of this type of feldspar. Singewald and Melton[6] believe that a moderately high temperature, attained after burial, is the responsible factor. Reynolds[7] suggests that they may grow long after deposition and perhaps after consolidation through introduction of the alkalies by ground water and their absorption by clay material. Tester and Atwater[8] found feldspars being formed after dolomitization of limestones had begun.

Most of the authigenic feldspar found by these authors contained carbonaceous or other inclusions. Daly,[9] however, describes glass-clear feldspar and gives them an authigenic origin.

If it were not for the fact that the feldspar here described replaces fossils, and is present only as disseminated crystals in the lime matrix, little objection would be found in accounting for it through the process of authigenesis. The question arises then: can authigenic feldspars replace fossils during growth? An authigenically growing crystal in a lithified or partly lithified rock must replace the material in which it is imbedded. Therefore it does not appear unreasonable to assume that they could replace a fossil. All the constituents necessary to make up the feldspar are present within the rock. The alumina and silica are present as clay material and quartz grains. The calcium is abundantly present in the calcite. The soda may have been present in the connate water of the rock or it may have been introduced by ground water, as suggested by Reynolds.[10] Proof of either origin of the soda is lacking.

As to the exact temperature at which the feldspar formed, the writer is unable to state, but it certainly must have been moderate. Daly[11] states that feldspars have been made synthetically as low as 300°C., by K. Chrustschoff, using a considerable amount of time in the process. Daly also states that according to Doelter, feldspars can form at 100°C. and he further suggests that they may form as low as 70°C.

In the writer's opinion such an origin best explains the presence of the

[5] de Lapperent, J., Sur les cristaux de feldspaths développés dans les calcaires du Crétacé supérior pyrénéen: *Compt. rend. acad. sci. Paris*, **167**, 784–786 (1918).

[6] Singewald, J. T., and Melton, C., Authigenic feldspar in limestone at Glen Falls, New York: *Bull. Geol. Soc. Am.*, **40**, 463–468 (1929).

[7] Reynolds, D. L., Some new occurrences of authigenic feldspar: *Geol. Mag.*, 390–399 (1929).

[8] Tester, A. C., and Atwater, G. I., The occurrence of authigenic feldspar in sediments: *Jour. Sed. Petrology*, **4**, 23–32 (1934).

[9] Daly, R. A., Low temperature formation of alkaline feldspars in limestone: *Proc. Nat. Acad. Sci.*, **3**, 659–665 (1917).

[10] Reynolds, D. L., *Op. cit.*

[11] Daly, R. A., *Op. cit.*

feldspar in this limestone. It was obviously formed after deposition of the limestone and likely after consolidation, but before the folding, thereby eliminating a metamorphic consideration. The necessary chemical constituents were present in the original rock as a result of sedimentation with perhaps a little introduction of soda by ground water. The temperature was very low, perhaps near that of ground water. During growth some of the fossils were replaced by quartz as well as feldspar. Perhaps a more fitting explanation for the presence of the feldspar in this limestone, other than hydrothermal or authigenic origin, can be found. Up to the present time, however, no other satisfactory solution has presented itself.