THE OCCURRENCE OF FINE GRAINED AUTHIGENIC FELDSPAR IN SHALES AND SILTS

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Introduction

The occurrence of secondary feldspar in sediments was reported as early as 1861 when Drian[1] and Lory[2] observed feldspar grains in limestones from the Alps. Since then secondary feldspar has been described by workers in different parts of the world and their findings have been reviewed by Boswell,[3] Twenhofel[4] and others. The more recent papers describing American occurrences are those by Daly,[5] Singewald,[6] Goldich[7] and Tester.[8] These investigators have demonstrated that small amounts of secondary feldspar are quite common and that they have a wide geologic and an equally wide geographic distribution.

Nearly all of the authigenic feldspar that has been described has been isolated from sandstones or from the insoluble residues of limestones and dolomites. In such rocks the observed grains vary from .008 mm. to 1.0 mm. in diameter. Many of the feldspar grains contain nuclear grains of detrital origin. For the present study the writers utilized x-rays to determine the composition of grains in shales and silts that are too fine-grained to be identified by their ordinary petrographic characteristics. It was found that orthoclase occurs in shales as grains less than a micron in diameter.

Materials and Methods Used

Samples from the Glenwood shale, the Decorah shale, and from shaley beds in the Oneota-Shakopee dolomites were studied and compared with clays and shales from other stratigraphic horizons. The Glenwood is a

[1] Drian, A., Notice sur les cristaux d'albite renfermes dans les calcaires magnesians des environs de Modane: *Soc. Geol. France, Bull.*, 2nd series, vol. **18,** p. 804, 1861.

[2] Lory, C., Comptes rendus d'une excursion geologique dans le Vallee d'Entremont (Savois); *Soc. Geol. France, Bull.*, 2nd series, vol. **18,** pp. 806–826, 1861.

[3] Boswell, P. G. H., *On the Mineralogy of Sedimentary Rocks.* T. Murby and Co., pp. 87–96, **1933.**

[4] Twenhofel, W. H., and others, *Treatise on Sedimentation*, 2nd Ed., pp. 591–596, **1932.**

[5] Daly, D. R., Low temperature formation of alkaline feldspars in limestones: *Proc. Nat. Acad. Sci.*, **III,** pp. 659–665, 1927.

[6] Singewald, J. T. Jr., and Milton, C., Authigenic feldspar in limestone at Glen Falls, New York: *Bull. Geol. Soc. Am.*, vol. **15,** pp. 463–468, 1929.

[7] Goldich, S. S., Authigenic feldspar in sandstones of southeastern Minnesota: *Jour. Sed. Petrol.*, vol. **4,** pp. 89–95, 1934.

[8] Tester, A. C., and Atwater, G. I., The occurrence of authigenic feldspar in sediments: *Jour. Sed. Petrol.*, vol. **4,** pp. 23–31, 1934.

thin sandy and silty shale, the Decorah is somewhat calcareous and contains layers of dolomitic limestone. The Oneota-Shakopee dolomites constitute the Prairie du Chien group of the basal Ordovician. The accompanying section of the Glenwood as exposed in the wall of the Mississippi River Valley at Minneapolis, Minnesota, is typical of the formation. Petrographic analyses of its various phases have been published by the junior author.[9]

Section of the Glenwood Shale at Minneapolis, Minn.

	Thickness in inches
1. Shale, calcareous	14
2. Shale, grayish green	4
3. Clay, soft, black, sticky	2
4. Shale, pale green, sandy	18
5. Sandstone, buff to white, clayey	20
6. Sandstone, ferruginous	12
7. Sandstone, ferruginous, banded	30
8. Sandstone, white	12
9. Sandstone, pale olive green	5

Outcrops of the Glenwood beds were sampled with special reference to layers with petrographic variations. In some instances an individual sample represented a layer no more than two or three inches in thickness. Beds numbered 4 and 5 of the Minneapolis section were studied most intensively.

Table 1

Diameter in mm.	Percent by Weight
1/2	2.28
1/4	8.44
1/8	2.67
1/16	48.81
1/32	5.96
1/64	0.34
1/128	2.26
1/256	3.69
1/512	25.02
less than 1/512	0.51
	99.98

In the procedure adopted a sample was disaggregated by placing it in a one per cent solution of sodium carbonate and agitating it in a soil dispersion machine. The shaking, combined with the peptizing effect of sodium carbonate produced a dispersed suspension. To remove all coarse detrital grains or aggregates the suspension was poured through a sieve

[9] Thiel, G. A., A petrographic analysis of the Glenwood beds: *Bull. Geol. Soc. Am.*, vol. **48**, pp. 113–121, 1937.

with meshes of 1/16 mm. (.061 mm.). It was then placed in a graduated liter cylinder and fractioned into various size grades by differential settling. Krumbein's method[10] for the analysis of fine-grained sediments was employed. The accompanying textural analysis shows the size range of the material in bed No. 4 (Table 1).

The mechanical analysis shows two distinct maxima. One, between $\frac{1}{8}$ and 1/16 mm. grain size, comprises about 48% of the sample. Another between 1/256 and 1/512 mm. contains 25% of the total. The first is about 83% quartz. The second is mostly feldspar. It contains no quartz.

The fraction with grains 1/32 mm. in diameter and finer was analyzed chemically (Dr. R. B. Ellestad, analyst, Rock Analysis Laboratory, Univ. of Minn.). It contains

SiO_2	56.29
Al_2O_3	19.22
Fe_2O_3 (total iron)	4.39
Na_2O	.19
K_2O	10.85
H_2O-	3.54
H_2O+	2.04
TiO_2	.64
CaO	.09
MgO	1.65
SO_3	.72
	99.62

If all the K_2O is in the feldspar, 66% of the material is potash feldspar. The total water content is 5.58% of which 2.04% is lost at 110°C. This is almost completely regained if the sample is left standing in the laboratory for several days. The SiO_2 and Al_2O_3 not necessary for the feldspar are in the molecular ratio of about 3.2 to 1.0. This points to minerals of the montmorillonite-beidellite series. Their presence would account also for the MgO and for the fact that the material is capable of absorbing water from the atmosphere. Allophane could also be present.

The fractions 1/32 mm. in diameter and finer were *x*-rayed.* In eight separate fractions ranging from 1/32 to 1/5000 mm. only orthoclase lines appeared in the *x*-ray films. Neither quartz, mica, kaolinite, nor montmorillonite were present in sufficient quantities to be detected. It might be pointed out at this time that *x*-ray methods are not very sensitive for the detection of montmorillonite when in a mixture with feldspar. Its lines are so diffused (including the well known line near the

[10] Krumbein, W. C., The mechanical analysis of fine-grained sediments: *Jour. Sed. Petrol.*, vol. **2**, pp. 140–149, 1932.

* Unfiltered Fe radiation. Radius of camera 57.3 mm. Thickness of rods 0.7 mm.

zero beam) that it is very doubtful that an amount less than 15 per cent can be noticed at all.

Since the limits of the colloidal state have been generally accepted to lie between 0.1μ and 0.2μ diameter, the sediment finer than the last fraction obtained by the Krumbein method is mainly of colloidal size. This very fine material which constituted no more than a small fraction of one per cent of the sample was divided into two fractions. When *x*-rayed the coarser one showed feldspar and mica, whereas the finer showed only diffused mica lines. The particles in the finest fraction were probably smaller than 1/10 micron in diameter.

Samples of the Decorah shale were subjected to similar treatment. Some channel samples that represent a vertical interval of five feet, contain sufficient orthoclase to produce *x*-ray patterns in which the feldspar lines are most conspicuous although quartz and mica lines are also present. When fractioned by the pipette method it was found that orthoclase predominates in the fractions from 1/32 to 1/512 mm. The 1/1024 fraction gave only mica patterns when *x*-rayed.

The basal Decorah is represented by 8 feet of thin bedded dolomite. The insoluble residues derived from the dolomite were fractioned by the pipette method and *x*-rayed. The fractions from 1/32 mm. to 1/128 mm. and smaller were predominantly orthoclase. Some mica and quartz were present. The latter seems to be absent, however, in material below 1/128. Some shale beds in the Shakopee formation also are composed largely of feldspar. Numerous thin layers of sandstone and sandy shale are interbedded with dolomite along the valley of the Willow River near Burkhardt, Wisconsin. A sample of green shale taken below the dam one mile northeast of the village was first treated with HCl to eliminate the carbonates. Only 5 per cent was soluble. The insoluble residue was *x*-rayed without further separation. The orthoclase pattern was most conspicuous. Lesser amounts of quartz and mica were also present. The residue was then washed and allowed to settle for one minute. The material that remained in suspension was then *x*-rayed. It produced an orthoclase pattern only.

Samples of Cretaceous shale from southwestern Minnesota were also *x*-rayed. The quartz pattern was always predominant in them.

Origin of Fine-grained Feldspar

In contradistinction to detrital minerals which were formed by the disintegration of older formations, authigenic minerals are those that have been formed at the same time as or subsequently to the laying down of the sediment. The authigenic feldspar in the limestones and dolomites of Europe have long been considered of sedimentary origin. There has been a tendency to ascribe the growth of feldspar to the action of marine waters on argillaceous material in the calcareous ooze on the floor of the sea. Grandjean[11] concluded that in all the occurrences of feldspar recorded by him the mineral had grown relatively rapidly during slow sedimentation and that the crystals probably ceased to grow after burial of the sediment.

Tester and Atwater[12] have recently suggested that noımal sedimentary processes of consolidation and cementation might also permit the growth of secondary feldspar. Their conclusions were based on a study of textural relations in thin sections of dolomitic rocks containing abundant authigenic feldspar.

Since much of the feldspar found in the silts and shales that were studied during this investigation is exceedingly fine-grained and remarkably free of other mineral grains one is not justified in postulating that it is of clastic origin. Fine-grained silts derived from the products of mechanical disintegration of igneous and metamorphic rocks are more or less siliceous. The Glenwood silt samples contain no quartz, however, in the fractions finer than 1/32 mm. Natural agents of sorting would scarcely separate quartz and feldspar of these dimensions, though clayey sediments of colloidal size may be sorted from finer silts. Another striking feature is the complete predominance of orthoclase. In detrital material plagioclase should be very common also. In view of the fact that much of the orthoclase is finer than 1/256 mm. it is hard to believe that it could have withstood the vicissitudes of weathering to which detrital material is subjected. It is much more likely that clayey material of colloidal dimensions and properties abstract potassium from solutions and form orthoclase under favorable conditions. Another alternative is to attribute the formation of the authigenic feldspar to hydrothermal activity.[13] A low-temperature form of orthoclase is known to occur in veins the temperature of formation of which is thought to be as low as 100°C. Increased temperatures due to deep burial of sediments might be sufficient therefore, to lead to the formation of feldspar. There is no evidence, however, that the early Paleozoic rocks overlapping on the pre-Cambrian shield in Minnesota have been buried to depths sufficiently great to raise their temperature appreciably. Furthermore, secondary feldspar has been reported from Cretaceous sandstones in Kansas, Nebraska and South Dakota where there is no evidence that either deep burial or volcanic emanations could have produced high temperatures for their formation.

[11] Grandjean, F. Propriétes optiques et genése du feldspath néogéne des sediments du bassin de Paris: *C. R. Acad. Sci., Paris*, vol. **148,** pp. 723–25, 1909.

[12] *Op. cit.*

[13] Gruner, J. W., Hydrothermal alteration of montmorillonite to feldspar at temperatures from 245°C. to 300°C.: *Am. Mineral.* vol. **21,** p. 515, 1936.