GENESIS OF KAOLINITE IN CRETACEOUS SHALES OF CENTRAL COLORADO

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ABSTRACT

The refractory shales of the Purgatoire and Dakota formations in central Colorado were studied to determine the genesis of the kaolinite. The compositions of the shales were similar, with variation only in relative amounts and grain size of the component minerals. The shales consist primarily of kaolinite, subangular to subrounded quartz, and hydromuscovite, with minor amounts of feldspar, montmorillonite, mixed-layer clays, and occasional traces of gypsum and zeolites.

An inverse relation between the kaolinite and hydromuscovite contents suggests that hydromuscovite was an intermediate mineral in the formation of the kaolonite. Derivation of vermicular kaolinite from feldspar and mica was evident from examination of thin sections. The thinly banded interfingered lenses of montmorillonite suggest a detrital origin rather than alteration *in situ* of a volcanic ash to bentonite.

Genesis of the kaolinite probably is similar to that proposed recently by Kesler for the Cretaceous clays of Georgia and South Carolina whereby feldspathic sands deposited in a near-shore environment were subsequently weathered to produce residual kaolinite. Winnowing of some of these clays and redeposition in downstream lagoons formed the fine-grained, carbonaceous, " flint " clays, whereas the plastic clays were formed by introduction of detrital montmorillonite.

INTRODUCTION

As part of a reconnaissance of the refractory clay deposits of Colorado by the Bureau of Mines, a mineralogical study was made of refractory shales of the Purgatoire formation and overlying Dakota formation. This paper presents a synopsis of the results of laboratory tests made on 57 samples to determine the mineralogical composition and genesis of the kaolinite in the shales. An information circular entitled " Refractory-Clay Deposits of Colorado " by J. N. Van Sant, soon to be published by the Federal Bureau of Mines, contains detailed descriptions of the various deposits from which the samples studied were obtained. Data on sample location and classification were abstracted from Van Sant's report. The sample numbers used also are identical for easy cross reference between the two reports.

Waagé (1953) gives the most recent and complete geological description of the various shale members of the Purgatoire and Dakota formations. His report includes a short discussion of the origin of the flint clays in these formations:

> Judging from the texture of the flint clay, it must have been deposited as a homogeneous, exceedingly fine sediment. Possibly it was deposited as colloidal material which recrystallized to form kaolinite, as has been postulated by Galpin (1912) for certain flint clays.

Kesler (1956), in describing the Cretaceous clay deposits in Georgia and South Carolina, suggests a mode of origin that seems to explain the genesis of the kaolinitic refractory shales of the Purgatoire and Dakota formations in Colorado.

METHODS OF INVESTIGATION

Samples

The shale samples used in the laboratory investigation were obtained from outcrops, test pits, open cuts, and underground mine exposures in Larimer, Boulder, Jefferson, Douglas, El Paso, Pueblo, and Huerfano Counties, Colo. The suite of 57 samples examined included four samples from the Lytle member and 30 samples from the Glencairn member of the Purgatoire formation, ten samples from the Dry Creek Canyon member of the Dakota formation and 13 samples from other shale lenses in the Dakota formation.

Preparation of Samples

Each sample was slaked for 24 hr in 500 ml of water, brought to pH 10 with sodium hydroxide, dispersed with 0.5 g of Calgon, and stirred with a high-speed mixer. The dispersed slurries were wet sieved on 60- and 200-mesh screens. The minus 200-mesh undersize of eight control samples was fractionated at 44, 16, 8, 4 and 2μ by the Andreasen pipette method. For the remaining 49 samples the undersize was fractionated at 2μ.

Quantitative Identification of Minerals

The mineral composition of the samples was quantitatively determined by differential thermal analysis (DTA) and x-ray diffraction (XRD) tests on the sized fractions from the various samples. Standard work curves for quantifying the results were established by analyzing mixtures of controlled proportions of quartz and kaolinite. This work was complemented by quantitative chemical analysis and microscopic examination of thin sections of eight control samples. The quantitative identification of quartz and kaolinite was determined to be accurate within ± 5 percent, whereas the other minerals present were quantified within ± 10 percent.

RESULTS

Purgatoire Formation

Four samples from the Lytle member and thirty samples from the Glencairn member were examined. The chemical analyses of representative samples from each of these members are given in Table 1.

TABLE 1.—CHEMICAL ANALYSES OF LYTLE AND GLENCAIRN SHALES

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI	Org. C
Lytle (160)	71.7	18.2	0.9	0.48	0.3	0.2	0.05	1.0	6.0	0.2
Glencairn (131)	62.0	23.0	1.4	0.75	0.4	0.6	0.05	0.5	9.8	1.3

The bulk mineral compositions, as determined by totalling the DTA and XRD analyses of each size fraction of the 34 samples from the Purgatoire formation, are given in Table 2. The sample locations are stated in Table 3.

TABLE 2.—BULK MINERAL COMPOSITION OF LYTLE AND GLENCAIRN SHALES GIVEN IN WEIGHT PERCENT

Sample Number	K	Q	HM	MT	ML	F	Z	G	C	AM
Lytle										
160	30	58	8	2	—	—	4	—	—	—
162	54	33	7	5	—	—	1	—	—	—
165	55	23	8	—	—	3	3	—	—	—
166	32	39	27	—	2	—	—	—	—	—
Glencairn										
131	45	35	9	3	4	tr.	—	3	—	—
132	20	18	19	35	—	5	tr.	—	—	—
133	45	29	6	10	—	10	3	—	—	—
167	34	43	5	12	—	6	—	—	—	—
168	82	9	6	—	—	—	—	—	—	—
169	17	28	12	43	—	—	—	—	—	—
170	84	6	6	4	—	—	—	—	—	—
172	86	6	6	—	2	—	—	—	—	—
173	77	3	4	10	—	3	3	—	—	—
174	61	16	8	5	4	3	1	—	—	—
175	32	39	7	3	—	tr.	—	—	19	—
176	74	18	8	—	—	—	—	—	—	—
177	38	31	10	14	—	6	1	—	—	—
178	48	37	2	10	—	—	3	—	—	—
179	87	11	—	—	—	—	2	—	—	—
180	76	7	5	7	—	5	—	—	—	—
181	81	8	2	9	—	—	—	—	—	—
182	80	10	7	—	—	3	—	—	—	—
183	75	17	8	—	—	—	—	—	—	—
184	65	17	8	—	—	tr.	tr.	—	—	—
185	64	32	—	—	—	—	—	—	—	4
186	75	10	6	3	—	4	2	—	—	—
187	75	6	8	10	—	—	1	—	—	—
188	86	5	3	6	—	—	—	—	—	—
189	80	15	5	—	—	—	—	—	—	—
190	45	30	3	12	—	3	4	—	—	—
191	30	53	16	1	—	—	tr.	—	—	—
192	58	19	5	6	—	1	1	—	—	—
4	55	29	8	5	—	3	tr.	—	—	—
5	40	20	12	21	—	3	4	—	—	—

Legend : K = kaolinite, Q = quartz, HM = hydromuscovite, MT = montmorillonite, ML = mixed-layer clay, F = feldspar, Z = zeolite, G = gypsum, C = carbon, AM = amorphous.

TABLE 3.—LOCATION AND DESCRIPTION OF SAMPLES OF PURGATOIRE FORMATION

Sample Number	County	Location	Type[1] of Clay
		Lytle member	
160	Larimer	SE1/4, sec. 20, T. 11 N., R. 69 W.[2]	SRSP
162	,,	NE1/4, sec. 24, T. 8 N., R. 70 W.	HSP
165	,,	SE1/4, sec. 32, T. 7 N., R. 69 W.	XP
166	,,	S1/2, sec. 24, T. 5 N., R. 70 W.	LSP
		Glencairn member	
131	El Paso	Sec. 15, T. 14 S., R. 67 W.	HP
132	,,	SE1/4, sec. 2, T. 16 S., R. 67 W.	LP
133	,,	Ditto	LP
167	Boulder	SW1/4, sec. 12, T. 1 N., R. 71 W.	LSP
168	,,	NW1/4NW1/4, sec. 31, T. 1 S., R. 70 W.	XP
169	Jefferson	SW1/4, sec. 6, T. 2 S., R. 70 W.	XP
170	,,	NW1/4, sec. 18, T. 2 S., R. 70 W.	XP
172	,,	SW1/4, sec. 16, T. 3 S., R. 70 W.	HP
173	,,	E1/2NW1/4, sec. 23, T. 4 S., R. 70 W.	XP
174	,,	SW1/4NE1/4, sec. 27, T. 6 S., R. 69 W.	HP
175	Douglas	S1/2, sec. 35, T. 6 S., R. 69 W.	SRP
176	,,	Ditto	HP
177	,,	,,	SRP
178	,,	,,	HP
179	,,	N1/2, sec. 2, T. 7 S., R. 69 W.	HP
180	,,	NE1/4, sec. 24, T. 7 S., R. 69 W.	HP
181	,,	Ditto	HP
182	Jefferson	SW1/4, sec. 14, T. 4 S., R. 70 W.	HP
183	,,	NE1/4NW1/4, sec. 8, T. 3 S., R. 70 W.	HP
184	,,	Ditto	HP
185	,,	Parts of sec. 10, 14, 15, T. 4 S., R. 70 W.	HP
186	,,	Ditto	HP
187	,,	SW1/4, sec. 29, T. 2 S., R. 70 W.	HP
188	Douglas	SW1/4, sec. 19, T. 7 S., R. 68 W.	HP
189	,,	SW1/4, sec. 19, T. 7 S., R. 68 W.	HP
190	,,	NW1/4, sec. 30, T. 7 S., R. 68 W.	SRP
191	,,	Ditto	SRP
192	,,	NW1/4SE1/4, sec. 30, T. 7 S., R. 68 W.	HP
4	Las Animas	NE1/4, sec. 22, T. 29 S., R. 55 W.	LRP
5	,,	E1/2, sec. 21, T. 28 S., R. 54 W.	XP

[1] Code: H = high-grade refractory PCE > 29; SR = semirefractory PCE 27–29; L = low-grade refractory PCE 20–26; X = not refractory PCE < 20; P = plastic; F = flint; SP = semiplastic.

[2] Sixth principal meridian unless otherwise identified.

An inverse relation between the kaolinite and the hydromuscovite content of the Glencairn shales suggests that the hydromuscovite was as an intermediate product in the weathering of feldspar fragments to kaolinite. In thin sections this relation was evident in the interleaved kaolinite and hydromuscovite derived from feldspar fragments. Although some kaolinite undoubtedly was carried into the depositional basin, these studies showed that the bulk of the kaolinite was residual and derived from feldspathic sands. A correlation could not be established between location of the samples in the basin and the kaolinite hydromuscovite contents.

The genesis of the kaolinite appears similar to that proposed by Kesler (1956) for the Cretaceous kaolins of Georgia and South Carolina—decomposition of detrital feldspar in coalescing deltas of coarse feldspathic sands. The decomposition of the feldspar probably took place while the deltas were exposed. Detailed study of the sedimentation pattern of the Colorado shales would be needed to confirm this supposition.

Identification of the zeolites was made by x-ray diffraction. Identification of mordenite-clinoptilolite was indicated by the presence, in a large number of diffractograms, of the prominent spacing of this mineral group (8.5–9.3 Å). The zeolites, however, were present in such small quantity that positive and varietal identification could not be made. These zeolites are significant in clay genesis, as they are recognized as intermediate products in the alteration of volcanic glass to bentonite. The interfingering relation of the montmorillonite in the clay, however, indicated a detrital origin for the montmorillonite in these beds.

Dakota Formation

Ten samples from the Dry Creek Canyon member and 13 samples from other shale lenses in the Dakota formation were examined. Representative chemical analyses from the Dry Creek Canyon horizon are given in Table 4.

TABLE 4.—CHEMICAL ANALYSES OF DRY CREEK CANYON SHALE

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI	Org. C
Dry Creek										
(134)	53.0	31.6	0.9	0.80	0.2	0.2	0.05	0.3	11.0	0.3
(141)	49.3	34.1	0.9	0.66	0.3	0.2	0.10	0.3	12.4	0.2

The bulk mineral compositions of the 23 Dakota shale samples, as determined by DTA and XRD studies, are given in Table 5 and the sample locations in Table 6.

As with the Purgatoire shales, the kaolinite versus hydromuscovite content in the Dry Creek Canyon and other Dakota shales showed an inverse relation.

In general, the feldspar fragments were larger in these shales than in the Glencairn shales, and the presence of hydromuscovite as an intermediate product in the weathering of feldspar to kaolinite was pronounced. The presence of randomly curved vermicular books of kaolinite in a fine-grained matrix of kaolinite indicated that some recrystallization of the kaolinite had occurred.

The mineral composition and textural relations of these shales were similar to those of the Glencairn, except that the Glencairn shales generally were finer grained. The genesis of the kaolinite in the two formations is believed to be the same.

TABLE 5.—BULK MINERAL COMPOSITION OF THE DRY CREEK CANYON AND OTHER DAKOTA SHALES, GIVEN IN WEIGHT PERCENT

Sample Number	K	Q	HM	MT	ML	F	Z	G	Classification
Dry Creek Canyon									
134	73	12	5	10	—	tr.	—	—	—
139	46	17	19	12	—	—	3	—	3 dolomite
140	71	11	8	6	—	—	4	—	—
141	75	10	5	—	9	tr.	1	—	—
142	82	5	4	9	—	—	—	—	—
143	86	13	—	—	—	—	tr.	—	—
144	40	34	16	6	—	—	2	—	—
145	88	5	2	—	—	2	3	—	—
146	79	5	5	—	10	1	tr.	—	—
147	88	4	7	—	—	—	1	—	—
Other Dakota Shales									
148	53	24	9	11	—	—	3	tr.	—
149	35	30	20	—	11	—	4	—	—
1	23	42	33	2	—	—	—	—	—
13	10	23	8	52	—	7	tr.	—	—
30	88	4	6	2	—	—	—	—	—
32	36	23	5	33	—	3	—	—	—
46	63	24	6	3	—	3	4	—	—
51	65	21	5	—	—	6	tr.	3	—
52	32	16	50	—	—	—	1	1	—
54	92	8	—	—	—	—	tr.	—	—
61	67	25	5	8	—	tr.	3	3	—
93	68	11	—	10	—	8	3	—	—
122	84	2	—	10	—	4	—	—	—
123	45	28	12	8	—	7	—	—	—

Legend: K = kaolinite, Q = quartz, HM = hydromuscovite, MT = montmorillonite, ML = mixed-layer clay, F = feldspar, Z = zeolite, G = gypsum.

SUMMARY AND CONCLUSIONS

The refractory shales of the Purgatoire and Dakota formations extending across central Colorado from Wyoming to New Mexico were studied to determine the genesis of the kaolinite. The mineral compositions of the 57 shale samples, as determined by DTA and XRD analyses, were similar. The Purgatoire shales were somewhat finer grained than the Dakota shales.

The shales consist primarily of kaolinite, subangular to subrounded quartz, and hydromuscovite, with minor amounts of feldspar, montmorillonite, mixed-layer clays, and occasional traces of gypsum and zeolite.

TABLE 6.—LOCATION AND DESCRIPTION OF SAMPLES OF DRY CREEK CANYON AND OTHER DAKOTA SHALES

Sample Number	County	Location	Type[1] of Clay
		Dry Creek Canyon member	
134	Fremont	SW1/4SW1/4, sec. 4, T. 18 S., R. 70 W.[2]	HP
139	Pueblo	SW1/4, sec. 26, T. 18 S., R. 67 W.	HP
140	,,	SE1/4, sec. 26, T. 18 S., R. 67 W.	HF
141	,,	Parts of sec. 25, T. 18 S., R. 67 W.	HF
142	,,	NE1/4, sec. 35, T. 18 S., R. 67 W.	HF
143	,,	SW1/4NW1/4, sec. 36, T. 18 S., R. 67 W.	HF
144	,,	SW1/4SW1/4, sec. 26, T. 22 S., R. 67 W.	SRP
145	,,	Ditto	HF
146	,,	NE1/4SE1/4, sec. 26, T. 22 S., R. 67 W.	HF
147	,,	S1/2, sec. 27, T. 24 S., R. 66 W.	HF
		Other Dakota members	
148	Huerfano	SE1/4, sec. 4, T. 25 S., R. 65 W.	LP
149	Pueblo	SE1/4NE1/4, sec. 31, T. 24 S., R. 65 W.	LP
1	Las Animas	N1/2, sec. 4, T. 30 S., R. 51 W.	SRP
13	Garfield	NW1/4, sec. 2, T. 6 S., R. 90 W.	XSP
30	Gunnison	SE1/4, sec. 34, T. 49 N., R. 3 E.[3]	HF
32	Mesa	NW1/4, sec. 9, T. 1 N., R. 3 W.[4]	XP
46	Delta	SE1/4, sec. 36, T. 14 S., R. 94 W.	HP
52	Montezuma	SE1/4, sec. 16, T. 37 N., R. 15 W.[3]	XP
54	San Miguel	NW1/4, sec. 6, T. 44 N., R. 9 W.[3]	HP
61	Park	NW1/4, sec. 13, T. 9 S., R. 7 W.	HP
93	Otero	SW1/4, sec. 17, T. 26 S., R. 54 W.	XP
122	Las Animas	NE1/4, sec. 34, T. 28 S., R. 53 W.	HP
123	,,	NE1/4, sec. 34, T. 28 S., R. 53 W.	SRP

[1] Code : H = high-grade refractory PCE $>$ 29 ; SR = semirefractory PCE 27–29 ; L = low-grade refractory PCE 20–26 ; X = not refractory PCE $<$ 20 ; P = plastic ; F = flint ; SP = semiplastic.
[2] Sixth principal meridian unless otherwise identified.
[3] New Mexico principal meridian.
[4] Ute principal meridian.

In thin section the derivation of vermicular kaolinite from feldspar and mica fragments was evident. An inverse relation between the kaolinite and hydromuscovite contents supports the observation that hydromuscovite was an intermediate mineral in the formation of the kaolinite.

The thinly laminated interfingering lenses of montmorillonite suggest a detrital origin. The small amounts of zeolites associated with the montmorillonite suggest that this clay mineral was formed originally by alteration of volcanic glass.

Genesis of the kaolinite probably is similar to that proposed recently by Kesler (1956) for the Cretaceous clays of Georgia and South Carolina, wherein feldspathic sands deposited in a near-shore environment were subsequently weathered to produce residual kaolinite. Winnowing of some Colorado clays and redeposition in downstream lagoons probably formed the fine-grained carbonaceous beds of flint clay. The plastic clay beds in the Purgatoire and Dakota formations presumably were formed by the addition of montmorillonite of detrital origin to the residual kaolinite clays.

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