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Chancellor of the University, and ex officio Director of the Survey

Raymond C. Moore, Ph.D., Sc.D.,
State Geologist and
Director of Research

John C. Frye, Ph.D.,
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FEBRUARY 28, 1949

CHEMICAL AND PETROGRAPHIC STUDIES OF THE FORT HAYS CHALK IN KANSAS

By

RUSSELL T. RUNNELS AND IRA M. DUBINS

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ABSTRACT

The chemical composition, petrographic character, and commercial usefulness of the Fort Hays chalk of Kansas are described in this report. The Fort Hays is the lower member of the Niobrara formation of Cretaceous age and crops out extensively in the north-central and central western part of the State. Samples were collected from Jewell, Smith, Osborne, Rooks, Ellis, Trego, Ness, Lane, Finney, and Hamilton Counties. Results of chemical and petrographic analyses show that the Fort Hays chalk is composed of fine-grained calcium carbonate except for scattered megafossils and limonite concretions. The average calcium carbonate content (excluding basal samples) is 94.2 percent, ranging from 98.2 percent to 88.7 percent. The grain size and the average calcium carbonate content did not vary significantly over the area studied. The chemical and petrographic properties compare favorably with whiting specifications for the paint, putty, rubber, and chemical industries.

INTRODUCTION

Purpose of the study. Chalk is the common source of pure, soft, fine-grained calcium carbonate called "whiting" used by paint, putty, rubber, and chemical manufacturers. Raw chalk of Cretaceous age is shipped from Europe and processed for whiting on the Atlantic coast. During the war much study was applied to grinding hard limestone as a substitute for chalk. A large deposit of Cretaceous chalk has been recognized in Kansas for almost a hundred years. The enormous tonnage available and wide range of commercial applications suggest a possible whiting industry for the State. The purpose of this study is to determine the chemical and petrographic properties of this chalk throughout its belt of outcrop for comparison with the chemical and physical specifications for commercial whiting.

Distribution. The Fort Hays chalk member of the Niobrara formation crops out over a wide area from north-central to western Kansas. The outcrop extends from the Kansas-Nebraska line in Jewell County southwestward to Finney County. A few isolated outcrops occur in Hamilton County adjacent to the Colorado-Kansas border. The distribution of the outcrops that were measured and sampled is shown in Figure 1.

Field sampling. The wide distribution of the Fort Hays and the nature of the intended analyses made it necessary to limit the amount of sampling. Where outcrops represented most of the member the section was measured and samples were taken from

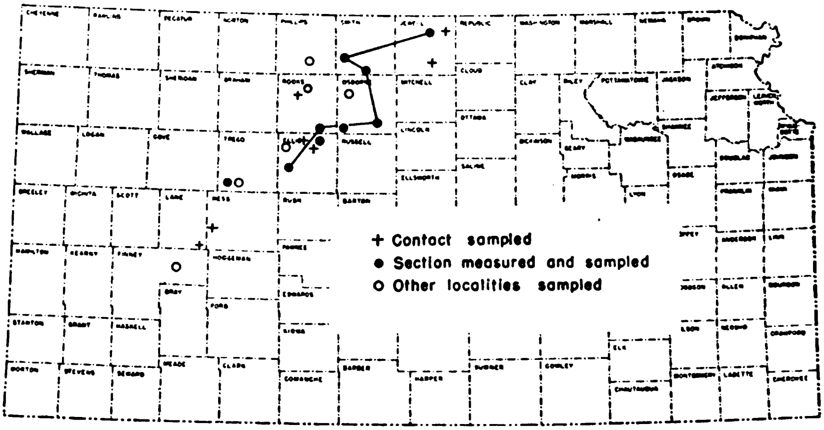

FIG. 1. Localities from which samples of Fort Hays chalk were selected for study.

(a) the basal bed just above the contact zone, (b) the top of the basal bed, (c) one-quarter the distance up the measured section, (d) one-half the distance, (e) three-fourths the distance, and (f) the top bed; if the top was weathered, the sample (f) was taken from the top consolidated bed. Other samples were taken without reference to stratigraphic position, and several samples were collected from the Codell sandstone and the Blue Hill shale member of the Carlile shale, immediately below the Fort Hays. In each case a fresh composite sample averaging about 10 pounds was taken in the field.

Table 1 gives the location of outcrops sampled and the abbreviation used for each.

Acknowledgments. Dr. R. M. Dreyer, Chairman of the Department of Geology, University of Kansas, supervised the petrographic work done by Dubins and reported here. An electron micrograph of chalk was obtained from Northwestern University by Dr. Dreyer. We express our thanks also to the many landowners and pit and quarry operators who aided us in this work and permitted us to examine outcrops on their property.

STRATIGRAPHY

The Fort Hays limestone is the lower member of the Niobrara formation (Moore, Frye, and Jewett, 1944, p. 152) of Cretaceous age. The Fort Hays member is recognized in the field primarily by its thick massive beds and small amount of shale. Chalky shale is the major constituent of the overlying Smoky Hill chalk. Underlying the Fort Hays limestone in most places is the Codell sandstone member of the Carlile shale. At some places the lenticular Codell sandstone is absent and the Blue Hill shale member of the Carlile is in contact with the Fort Hays limestone.

Thickness. The thickness of the Fort Hays limestone in Kansas is not uniform, the thinner parts lying to the north. According to A. R. Leonard (oral communication) the Fort Hays is 40 feet thick in the northern part of Jewell County. Landes and Keroher (1942, pp. 286, 289) report that the thickness in Phillips and Smith Counties ranges from 40 to 50 feet. Landes (1930, p. 18) states that the thickness of the Fort Hays in Osborne County is about 60 feet. Two miles south of Natoma in sec. 20, T. 10 S., R. 15 W., an incomplete section of the Fort Hays measures 61.5 feet. In Rooks County, a 56-foot section of the Fort Hays was measured. Bass (1926, p. 25) states that the Fort Hays in Ellis County is 56 feet thick. Landes and Keroher (1939, p. 289) report a thickness of almost 75 feet for the Fort Hays in Trego County. Moss (1932, pp. 19-21) found 70 to 80 feet of the Fort Hays in Ness County. Latta (1944, p. 159) reports that the Fort Hays ranges from 55 feet in the northwest corner of Finney County to 80 feet in the northeast corner. The thickness in Hamilton County is reported by Bass (1926, p. 62) and McLaughlin (1943, p. 135) to be about 61 feet. Thus, the Fort Hays in Kansas is variable in thickness in the southwest, constant but thinner in the central part of the State, and thins rapidly in the northern part.

Topographic expression. The typical outcrop of the Fort Hays consists of cream-colored chalk bluffs overlying barren blue slopes of the Carlile shale. At many places along its belt of outcrop in northern Kansas the Fort Hays gives rise to a prominent east-facing escarpment and where the Saline, Smoky Hill, and Solomon Rivers cross this belt their valley sides are typified by prominent bluffs. In several localities, especially near the eastern boundary of the Fort Hays, flat-topped buttes and small plateaus occur. The overlying Smoky Hill chalk member is thinner-bedded, contains more shale than the Fort Hays, and weathers more readily, giving rise to gentler slopes. Exposures of the Fort Hays may be seen in many road cuts, especially in Phillips, Smith, Mitchell, Ellis, Osborne, and Rooks Counties.

Slumping is common in the Fort Hays, and locally, massive chalk blocks are found as much as 50 feet below their normal stratigraphic position. In places, especially in southwestern Osborne County, small-scale faulting is widespread in the Fort Hays chalk. Twenhofel (1925, pp. 1060-1071) has suggested that the faulting results from adjustment of the Fort Hays to movement of the underlying shales. According to him the Cretaceous shales adjust themselves to irregularities of the Permian floor, or to sand lenses included in the Cretaceous. The more extensive the shales beneath the Fort Hays, the greater the adjustment, and the more intensive the faulting.

Means of recognition. The lower boundary of the Fort Hays is quite distinct. Either the Codell sandstone lentil of the Carlile or the noncalcareous Blue Hill shale member of the Carlile underlies the Fort Hays. The Codell sandstone is a friable, dirty-yellow to gray sandstone which is rarely calcareous. The Blue Hill shale is bluish black and noncalcareous.

Logan (1898, pp. 487, 493) found a paleontologic difference between the Fort Hays and the overlying beds of the Niobrara formation. *Inoceramus deformis* occurs in the Fort Hays and *Inoceramus grandis* in the Smoky Hill.

The contact between the Fort Hays and the Smoky Hill is gradational. Bass (1926, pp. 21-24) described in the Smoky Hill chalk a group of beds 13½ feet thick which he called "group B." The base of these beds was 8.5 feet above the contact of the Smoky Hill and Fort Hays. The first bed in this group was a soft, chalky shale containing a yellow band of bentonitic clay a quarter of an inch thick. The thickness of the shale bed was 3 to 4 inches. "Group B" also contained two similar bands of bentonitic clay about 3 feet apart, the lower of which is 7 feet above the lowest band of bentonitic clay. Moss (1932, p. 20) states:

> The contact between the Fort Hays limestone and the Smoky Hill chalk is transitional from predominating chalk beds to predominating chalky shale. The dividing point here used is the thin bentonite bed at the base of zone A of the Smoky Hill chalk. Although this is a few feet above any massive chalk beds, it is the only convenient and recognizable horizon at which to make a division.

According to Landes and Keroher (1939, p. 14) the top of the Fort Hays is at the top of the uppermost thick chalk beds several feet below the bentonitic seams in the Smoky Hill. However, since this horizon is not readily recognizable in all exposures, the two bentonite horizons lowest in the Smoky Hill chalk have been chosen by us to mark the boundary between the Fort Hays and the Smoky Hill. In Trego County, Landes and Keroher took the lowest bentonite stratum as the boundary between the Fort Hays and Smoky Hill. However, this bentonite stratum has not been mentioned in the reports on Hamilton, Osborne, and Phillips Counties, and it is not known whether it occurs in these counties or in Rooks, Smith, or Jewell.

According to Landes (1930, pp. 17-18) the proportion of massive chalk to chalky shale in the Smoky Hill runs about one to one, whereas in the Fort Hays the ratio is at least six to one. Landes also mentions that the Fort Hays is not as thin-bedded as the Smoky Hill. The Smoky Hill member of the Niobrara formation contains more limonitic concretions and it is much thicker, ranging from 450 to 700 feet in Logan County (Moore, Frye, and Jewett, 1944). The chalky shale near the base of the Smoky Hill (Bass, 1926, pp. 25-26) weathers to a deep-yellow or orange color.

It is not known whether or not the bentonitic layer in the lowest part of the Smoky Hill chalk is always present, and there seems to be a gradation from the Fort Hays into the Smoky Hill.

Texture. Milner (1940, pp. 399-400) defines chalk as a rather pure, white, yellow, or gray friable fine-textured foraminiferal limestone. It may be incoherent or well consolidated. The Fort Hays is commonly poorly coherent fine-grained chalk or chalky limestone. The texture is uniform except for widely scattered megafossils and limonite concretions. The concretions are as much as one-half inch in diameter and 2 inches in length.

Color. The color of the unweathered chalk ranges from a dirty yellow through grayish white to pure white. The unweathered chalk just above the Codell sandstone is a dirty yellow because of the large amount of limonite present. Higher in the section the chalk is purer and whiter with only scattered yellow spots caused by limonite concretions.

The color of the weathered surface of the Fort Hays chalk is tan, yellowish white, or white. The predominant color of the exposed surface is yellowish white. The yellowish tint in the chalk is caused by limonite. Locally, the lower 10 feet of the Fort Hays has a blue-gray color probably because of a high shale content. Locally, on a small scale, the Fort Hays is stained black on the surface to a depth of about 0.03 mm by manganese dioxide, and has black dendritic patterning on joint surfaces.

The color of the shale partings in the Fort Hays is also variable. The color of the shale ranges from black, blue, or green to buff.

Bedding. The Fort Hays is made up of massive beds of chalk and limestone separated by thin shale partings. The thickness of the individual chalk beds ranges from 5 inches to more than 7 feet and averages about 2½ feet. The shale partings range in thickness from 0.1 inch to 9 inches and average 2 inches. Some of the thin shale beds are chalky and grade into the chalky limestone. Many of the very thin shale partings are surface features only. In the few places where unweathered outcrops could be examined the overall thickness of many of the partings was no more than visible. In places, the shale partings are composed of two or more strata. In the western part of Osborne County, Landes (1930, p. 18) reports the presence of a shale bed containing mud cracks 25 feet above the base of the Fort Hays chalk.

ANALYSES

LOCATION OF OUTCROPS SAMPLED

Table 1 gives the locations of outcrops sampled and the abbreviation used for each locality.

The following abbreviations designate the height in the section at which the sample was taken. The numbers ending the abbreviation increase from the base to the top of the section, with 1 being the bed above the lower contact of the Fort Hays.

Sm-2-la ....sample taken at lower part of first, or lowest, bed.
Sm-2-1b ....sample taken at upper part of first, or lowest, bed.
Sm-2-¼........sample taken one-fourth distance up the measured section.
Sm-2-½, Sm-2-3/4 sample taken one-half, three-fourths distance up the measured section.

The letter "I" at the end of an abbreviation means that the sample analyzed consisted only of the coarser portion of the insoluble residue.

SAMPLE PREPARATION

Roughly one-fifth of the field sample was set aside for thin sections; the remainder was crushed in a jaw crusher to pass an 8-mesh screen. The crushed sample was divided, using a standard sample splitter, until two 100-gram samples were obtained. One was reserved for insoluble residues and heavy mineral separation; the other was reduced by further splitting to approximately 20 grams for making a chemical analysis.

PETROGRAPHY

INSOLUBLE RESIDUES

A weighed portion of each sample of chalk was digested in cold dilute hydrochloric acid (1:20) in order to determine the relative percentage of acid-insoluble material present. The results are summarized in Table 2, which also shows the percentage of insoluble grains larger and smaller than 0.002 mm, and the percentage of "heavy" and "light" grains in the large fraction. In general, the largest percentage of insoluble residue occurs at the base of the lowest chalk bed of the Fort Hays, and decreases rapidly to the top of the first bed. Higher in the section the aver-

TABLE 1.—*Location of outcrops sampled*

Locality	County	Sec.	T.S.	R.W.	Remarks
El-1	Ellis	11	13	20	6 miles west of Yocemento
El-2	Ellis	13	11	19	
El-3	Ellis	27	11	18	5 miles south of Rooks-Ellis border on route 183.
El-4	Ellis	36	11	19	
El-6	Ellis	3	13	18	
Fn-1	Finney	SW¼ NW¼ 22	22	30	
Ha-1	Hamilton	25	22	43	
Ha-2	Hamilton	3	22	43	
Jw-1	Jewell	NW¼ SW¼ 10	2	8	
Jw-2	Jewell	NW¼ 9	2	7	
Jw-3	Jewell	27	4	8	
Ln-1	Lane	28	20	27	
Ns-1	Ness	33	18	26	
Ob-1	Osborne	NW¼ 13	7	15	
Ob-2	Osborne	19, 20, 29, 30	10	15	
Ob-3	Osborne	31	9	12	
Ob-4	Osborne	19, 30	9	12	
Ph-1	Phillips	SE¼ SW¼ 36	4	18	
Ro-1	Rooks	35	10	17	just south of Ro-3
Ro-2	Rooks	SW¼ 15	7	18	
Ro-3	Rooks	26	10	17	
Ro-4A and B	Rooks	SW¼ 34	7	19	within 200 feet of one another
Sm-1	Smith	NE¼ 32	5	13	
Sm-2	Smith	SW¼ 36	4	15	Cedar quarry
Tr-1	Trego	NE¼ SE¼ 1	15	23	
Tr-2	Trego	4, 9, 5, 8	15	23	

age percentage of insoluble material is still less, but there is a gradual constant increase from the minimum near the center to the top of the section.

The geographical variation at two horizons in the lower part of the Fort Hays is shown in Figure 2. The data suggest that the purest chalk is in the southwest part of the outcrop area. However, samples from other levels show that the chalk of highest purity is present in the sections studied in Smith County. The purest chalk analyzed contains 98.04 percent acid-soluble material and occurs in bed 14 of the Sm-2 section.

Mineralogy of insoluble residue. "Heavy" and "light" fractions of the residues were separated by means of bromoform, and the minerals were identified. The heavy mineral suite is a restricted one, and consists predominantly of ilmenite, leucoxene, magnetite, tourmaline, zircon, muscovite, and biotite. Pyrite and limonite occur as authigenic or secondary minerals. Limonite is observed in scattered concretions as large as 2 inches in long diameter.

The light minerals consist chiefly of quartz, with minor quantities of feldspar and chalcedony or chert. Minerals lost in acid digestion include calcite and collophane. The calcite occurs as cement, as minute grains, and as fossils and fossil fragments. An electron micrograph of the grains indicates a roughly rectangular shape suggesting minute rhombohedrons. The diameters range from 0.2 to 0.55 microns.

THIN SECTIONS

All thin sections of the Fort Hays chalk are composed essentially of fine-grained calcite and of coarser calcite in foraminiferal tests and in fragments of larger shells. The matrix, or very fine material, comprises from 60 to 80 percent of the chalk. Embedded in the matrix are microfossils (which make up the next largest constituent), a few mineral grains, and grains of calcite which are either secondary or have been derived from *Inoceramus* shells.

Of the many types of microfossils present, *Gumbelina*, *Globerotalia*, *Globigerina*, and *Textularia* (Lalicker, 1947, oral communication) were identified. Most of the microfossils are made of calcite, and limonite is present in some. Microfossils comprise 17 to 34 percent of the chalk above the lowest bed.

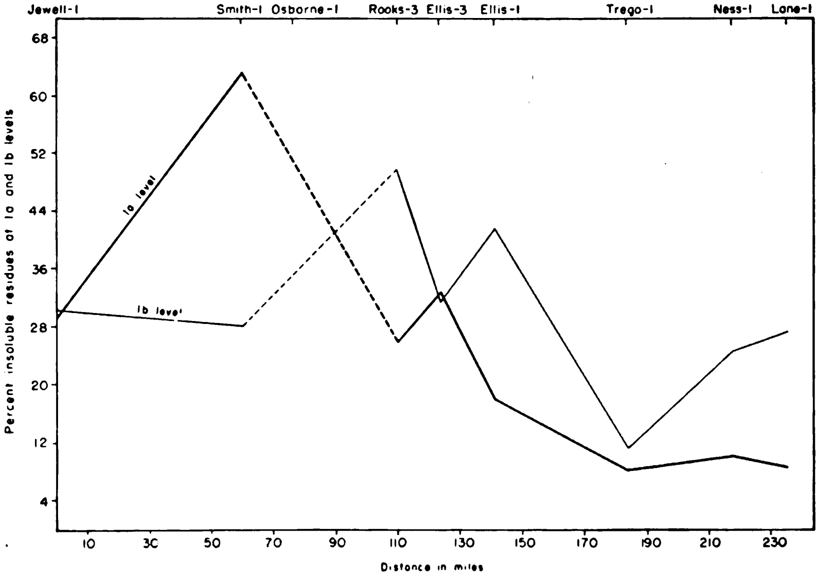

FIG. 2. Geographical variation of insoluble residues at two horizons in the lower part of the Fort Hays.

Limonite occurs as the massive form and as a fossil replacement ranging from 0.5 to 8 percent of the thin section, the average being about 2 percent. One thin section showed some cubic pseudomorphs of limonite. The limonite is opaque and is yellow-brown in reflected light.

Most of the quartz is too small to be distinguished from feldspar. The largest amount of quartz and feldspar occurs in thin sections of the chalk just above the lower contact of the Fort Hays. In beds higher in the section the percentage of quartz and feldspar ranges from less than 0.05 to about 1.7 percent. The grains are anhedral.

Microcline was observed in each of the three thin sections made of chalk collected just above the lower Fort Hays contact. The grains are anhedral and the amount was less than 0.1 percent. More microcline may be present, but does not show quadrille structure. In all the thin sections of chalk collected above the first bed, only 3 grains show the quadrille structure of microcline.

In 20 thin sections, three plagioclase grains showing polysynthetic twinning were seen. In only one grain could the extinction angle be measured. The extinction angle is 15 degrees, indicating that the plagioclase is albite or andesine. Most of the feldspar was unaltered, but a few grains were partially altered to sericite and kaolin.

TABLE 2.—*Insoluble residue of chalk samples, percent*

Sample no.[1]	Total	Total grains <.002mm	Total grains >.002mm	"Heavy"[2] grains >.002mm	"Light"[3] grains >.002mm
El-1-1a	17.40	12.53	4.87	0.22	4.65
El-1-1b	10.21	9.71	0.50	0.04	0.46
El-1-3					
El-1-¼	6.55	6.26	0.29	0.08	0.21
El-1-5					
El-1-½	4.38	4.29	0.09	0.02	0.07
El-1-7	3.60	3.53	0.07	0.01	0.06
El-1-¾					
El-1-11					
El-1-T	3.79	3.74	0.05	0.01	0.04
El-2-1a	15.3	12.9	2.4	0.07	2.33
El-2-1b	7.40	3.85	0.55	0.06	0.49
El-3-1a	32.1	20.00	12.1	0.3	11.8
El-3-1b	8.02	7.17	0.85	0.05	0.80
Jw-3-1a	38.03	16.44	21.59	0.13	21.46
Jw-3-1b	7.88	7.70	0.18	0.01	0.17
Jw-2-1a	29.33	14.65	14.68	0.31	14.37
Jw-2-1b	7.73	7.59	0.14	0.01	0.13
Jw-1-4a	4.09	4.05	0.04	0.02	0.02
Jw-1-¼					
Jw-1-6	2.92	2.79	0.13	0.03	0.10
Jw-1-½					
Jw-1-9	7.05	6.92	0.13	0.01	0.12
Jw-1-¾					
Jw-1-10	8.65	8.54	0.11	0.01	0.10
Jw-1-T					
Ns-1-1a	9.06	6.35	2.71	[illegible]	2.67
Ns-1-1b	85.74	5.31	0.43	[illegible]	0.40
Ln-1-1a	8.69	5.94	2.75	0.06	2.69
Ln-1-1b	6.67	5.64	1.03	0.05	0.98
Ha-1-1a	28.31	14.08	14.23	0.12	14.11
Ha-1-1b	11.56	9.82	1.74	0.06	1.68
Tr-1-1a	8.16	7.98	0.18	0.02	0.16
Tr-1-1b	2.95	2.85	0.10	0.01	0.09
Ob-2-1a	14.76	12.16	2.60	0.09	2.51
Ob-2-1b	6.77	6.59	0.18	0.06	0.12
Ob-3-1a	71.08	13.34	57.74	0.23	57.51
Ob-3-1b	9.03	8.51	0.52	0.07	0.45
Ob-4-7	2.62	2.53	0.09	0.02	0.07
Ob-4-½					

Ob-4-10 Ob-4-¾	7.10	7.04	0.06	0.003	0.057
Ob-4-14 Ob-4-T	4.40	4.35	0.05	0.005	0.045
Ro-3-1a	25.57	14.88	10.69	0.09	10.60
Ro-3-1b	12.55	9.16	3.39	0.06	3.33
Ro-3-A4	3.89	3.80	0.09	0.0003	0.0897
Ro-3-B4	5.16	5.04	0.12	0.03	0.09
Ro-3-5 Ro-3-¼	3.49	3.44	0.05	0.003	0.047
Ro-3-6	3.95	3.87	0.08	0.01	0.07
Ro-3-8	4.05	4.00	0.05	0.005	0.040
Ro-3-11 Ro-3-½	4.96	4.63	0.33	0.002	0.328
Ro-3-(16-19)[4] Ro-3-¾	3.63	3.59	0.04	0.02	0.02
Ro-3-22	7.50	7.48	0.02	0.007	0.014
Ro-3-24 Ro-3-T	6.54	6.52	0.02	0.01	0.01
Ro-3-25	6.65	6.60	0.05	0.003	0.047
Ro-3-26	7.46	7.44	0.02	0.002	0.018
Ro-4-B1a	69.62	12.63	56.99	0.16	56.83
Ro-4-B1b	5.78	5.67	0.11	0.006	0.105
Ro-4-A1a	51.46	16.10	35.36	0.70	34.66
Ro-4-A1b	28.4	10.9	17.5	0.5	17.0
Ph-1-1a	22.9	14.9	8.0	0.9	7.1
Ph-1-1b	6.79	6.48	0.31	0.06	0.25
Sm-1-1a	62.16	13.68	48.48	0.39	61.77
Sm-1-1b	7.27	6.96	0.31	0.03	0.28
Sm-1-2 Sm-1-¼	4.17	4.06	0.11	0.02	0.09
Sm-1-6 Sm-1-½	2.36	2.32	0.04	0.005	0.035
Sm-1-9 Sm1-¾	2.91	2.84	0.07	0.01	0.06
Sm-1-12 Sm-1-T	4.17	4.09	0.08	0.01	0.07
Sm-2-1a	72.45	16.87	55.58	0.63	54.95
Sm-2-1b	7.88	7.12	0.76	0.02	0.74
Sm-2-4 Sm-2-¼	10.12	9.92	0.20	0.02	0.18
Sm-2-9 Sm-2-½	4.59	4.50	0.09	0.05	0.04
Sm-2-14 Sm-2-¾	1.96	1.94	0.02	0.005	0.015
Sm-2-15 Sm-2-T	3.79	3.66	0.13	0.055	0.075

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[1] Complete location given in Table 1.
[2] Specific gravity greater than 2.85.
[3] Specific gravity less than 2.85.
[4] Composite.

TABLE 3.—*Petrographic analyses of chalk samples from thin sections*
(Figures are percentages)

Sample no.	Quartz feldspar	Limonite	Coarse calcite	Fossils	Calcite matrix	Biotite	Collophane	Chalcedony	Pyrite	Limonite or magnetite	Leucoxene
Sm-2-¼	Tr	2	4	34	60	Tr	Tr	Tr	Tr	Tr	
Sm-2-½	Tr	1	3	30	66	Tr	Tr	Tr		Tr	
Sm-2-¾	Tr	1	1	17	81	Tr	Tr			Tr	
Sm-2-T	Tr	2	2	17	79	Tr	Tr				Tr
Ro-3-A8	1	1	2	18	78	Tr	1				
Ro-3-(16-19)	Tr	1	1	30	68	Tr	Tr				
Ro-3-24	Tr	1	1	24	74	Tr					
Ro-3-26	Tr	1	Tr	16	83	1	1			1	
El-1-1a	8	4	1	13	73	Tr	Tr	Tr	Tr		
Ln-1-1a	4	2	4	19	71	Tr	Tr	Tr		Tr	
Jw-2-1b	Tr	3	2	24	70	Tr		Tr			
Sm-2-1b	1	4	3	31	60	Tr	Tr	Tr		Tr	
Ph-1-1b	1	3	3	31	61		Tr				
El-1-1b	1	3	3	17	76	Tr	Tr	Tr		Tr	
Ro-3-1b	2	3	1	18	76	Tr	Tr				
Ha-1-1b	2	2	3	30	63	Tr		Tr			
Ln-1-1b	1	8	4	28	59		Tr	Tr		Tr	
Tr-1-1b	Tr	3	3	27	67	Tr					
Ro-4-B1b	1	2	2	30	65		Tr			Tr	

Biotite is present in 85 percent of the thin sections in small amounts. Quantities range from 0.01 to 0.1 percent. Collophane is present in 80 percent of the samples in quantities ranging from about 0.1 to 0.5 percent. The grains are either isotropic or slightly anisotropic with extremely low birefringence. The color is a faint tan and the grains are irregular.

Chalcedony is present in 50 percent of the thin sections in amounts of 0.2 percent or less. It is colorless.

Plate 1A is a photomicrograph of typical chalk from Smith County, showing the matrix of fine-grained calcite and the scattered microfossils.

Petrographic analyses from thin sections are given in Table 3.

GEOCHEMISTRY

PROCEDURE

The fractions set aside for chemical analysis were ground with a porcelain mortar and pestle until they passed an 80-mesh screen. The analyses were made in sets of six samples on an oven dry basis. Loss on ignition, total sulfur, P_2O_5, SiO_2, Al_2O_3, Fe_2O_3,

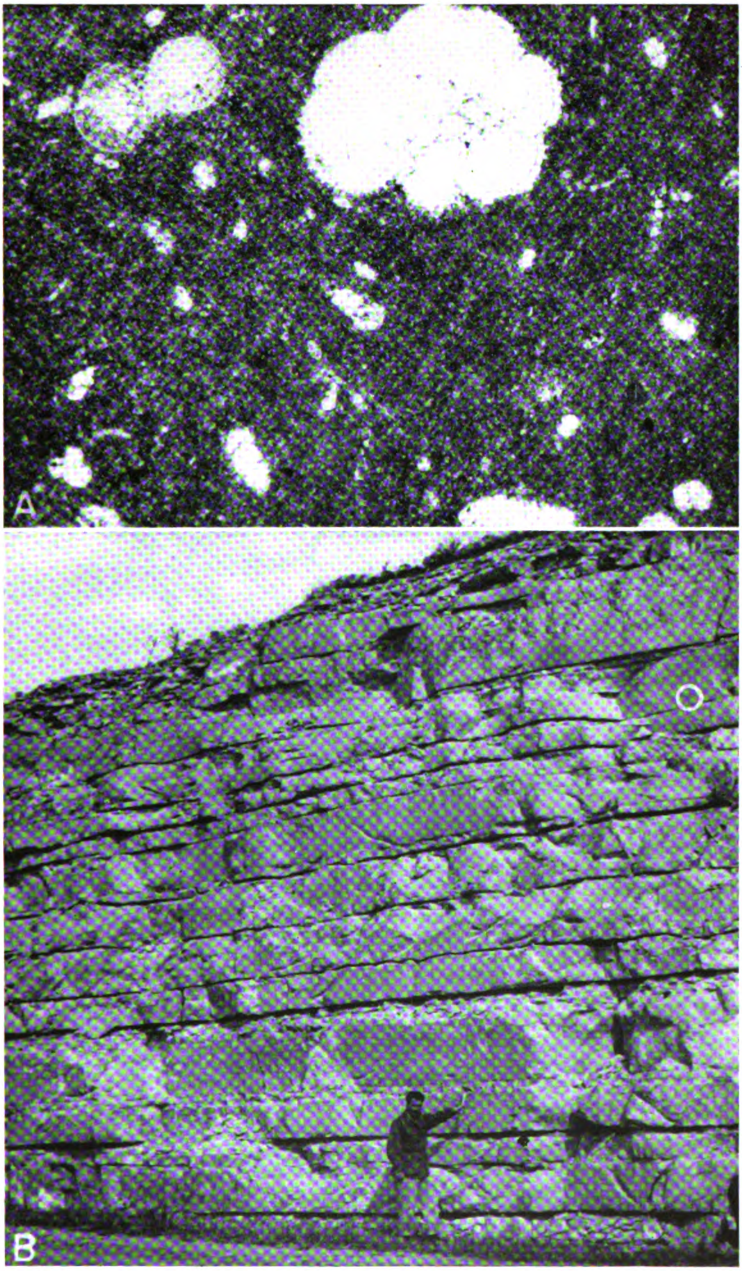

Plate 1. *A*, Photomicrograph of chalk thin section Sm-2-3/4 (Smith County, Kansas). Plane polarized light, X 45. Most of the thin section consists of fine-grained calcite. Microfossils and coarse grains of calcite compose essentially the coarser portion of the thin section. A grain of either quartz or feldspar, a grain of limonite, and a grain of magnetite or ilmenite are also present. *B*, Exposure of Fort Hays chalk in the SW¼ sec. 36, T. 4 S., R. 15 W., Smith County, Kansas. Circle shows stratigraphic position of photomicrograph above.

TiO_2, CaO, and MgO were determined by standard methods (Hillebrand and Lundell, 1946; Kolthoff and Sandel, 1946; Scott, 1939) with the exception of TiO_2, which was determined gravimetrically by a method worked out in the Survey laboratory by Runnels.

Determination of TiO_2.—Our method of determining TiO_2 utilizes cupferron (ammonium salt of beta nitrosophenylhydroxylamine) (Thornton, 1927, p. 90; Scott, 1939, p. 6, 466-469, 1035, 1099) to precipitate iron and titanium in the presence of aluminum. Any vanadium or zirconium present is included with the precipitate. (This method is used for material which contains appreciable titanium such as insoluble residues, clays, and shales.) The procedure is as follows. The weighed R_2O_3 precipitate is fused with $KHSO_4$ with care taken that *all* the precipitate is fused. (If the precipitate is large, it should be crushed in an agate mortar.) The fusion is cooled and dissolved in about 300 cc of HCl (or H_2SO_4). Cool in an ice bath until the temperature is 5° to 10° C. Then with stirring, slowly add a 4 to 6 percent water solution of cupferron until a white precipitate forms. (The precipitate soon vanishes.) Then add 10 percent excess. Allow the precipitate to settle and filter through medium ashless paper. Wash *well* with cool 1:9 HCl and permit drainage. The precipitate is then placed in tared crucibles, dried, and carefully ignited, allowing about 20 minutes at full heat after charring. Cool, weigh as Fe_2O_3 and TiO_2. (This form was used for the bulk of the chalk analyses.) Fuse this precipitate with $KHSO_4$. Dissolve with about 50 cc water and 10 to 15 cc HCl. Determine the iron with standard dichromate solution as given. Then subtract the weight of Fe_2O_3 from the total giving TiO_2 (+vanadium and zirconium if present) by difference.

Determination of sodium and potassium.—The J. Lawrence Smith method of determining sodium and potassium (Hillebrand and Lundell, 1946, p. 788) was used in the analysis of insoluble residues of chalk. Potassium was separated by chloroplatinic acid (Hillebrand and Lundell, 1946, pp. 519-520) with sodium being determined by difference.

SPECTROGRAPHIC ANALYSIS

A 1.5 meter Applied Research Laboratory spectrograph was used and the spectrograms visually inspected with an Applied Research Laboratory Comparitor. Selected samples were mixed

Table 4.—*Spectrographic analyses of selected chalk samples*

Sample no.*	Si	Fe	Al	Ti	P	Mn	Ca	Sr	Mg	Na	K	Ba	Li	Zr
BS-1a	vst	vst	st	st	**	**	vst	***	st	***	***	***	***	***
Sm-2-1b	st	st	st	**	**	**	vst	***	**	***	***	***	***	***
Sm-2-9	st	st	st	**	tr	**	vst	***	**	***	***	***	***	***
Sm-2-14	**	**	**	tr	***	**	vst	***	**	***	***	***	***	***
Sm-2-15	st	st	st	**	**	**	vst	***	**	***	***	***	***	***
Sm-1-13	st	**	**	tr	***	**	vst	***	**	***	***	***	***	***
El-1-5	**	**	**	tr	***	**	vst	***	**	***	***	***	***	***
El-4-9	st	st	st	**	tr	tr	vst	***	**	***	***	***	***	***
Tr-1-11	st	st	st	tr	tr	**	vst	***	**	***	***	***	***	***
Tr-1-15	st	st	st	tr	tr	**	vst	***	**	***	***	***	***	***
Ob-1-4	st	st	st	**	tr	**	vst	***	**	***	***	***	***	***
Ob-1-5	st	st	st	tr	tr	**	vst	***	**	***	***	***	***	***
J-2-1aI	vst	vst	st	vst	**	tr	**	***	**	***	***	***	***	***
Ha-1-1aI	vst	vst	st	vst	**	tr	**	***	**	***	***	***	***	***

*Complete location given in Table 1.
**Small but positive.
***May be present but not shown on spectograph.
vst Very strong.
st strong.
tr Very faint.

with an amalgam consisting of equal parts of graphite powder and chemically pure sodium fluoride to aid in volatilization. In each set of samples a blank of the reagents and the Bureau of Standards sample no. 1a of argillaceous limestone were included for comparison. The results of all spectrographic analyses are given in Table 4.

DISCUSSION OF DATA

The great extent of the Fort Hays made it impracticable to sample and analyze each bed. The petrographic and chemical data obtained, however, are judged sufficient to establish that the Fort Hays chalk is essentially the same throughout the area studied. For example, the calcium carbonate content of the chalk ranges from 88 to 98.2 percent (excluding basal samples). The 88-percent calcium carbonate chalk, however, has the same grain size and contains the same minerals and fossils as the purest chalk. This is true for all counties studied.

All samples studied show that the composition of the chalk is comparable to European chalk and suitable as a source of whiting. Deposits that do not meet the specifications for whiting can be beneficiated by standard methods. Examination of thin sec-

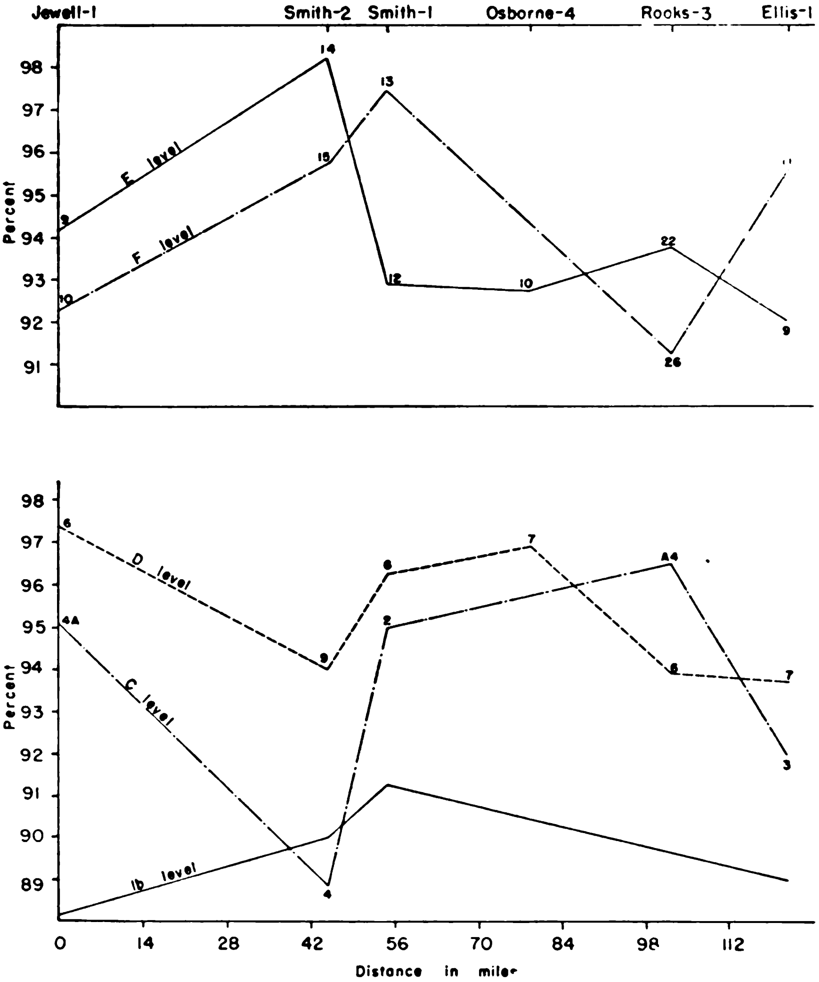

FIG. 3. Geographical variation of calcium carbonate content at specific levels.

tions and one photomicrograph show that 60 to 80 percent of the chalk is very fine grained. The actual grain size, as estimated from the magnification of the photomicrograph, is 0.3 microns by 0.3 microns to 0.3 microns by 0.55 microns. This size compares favorably with chemically precipitated chalk and would meet the specifications for whiting.

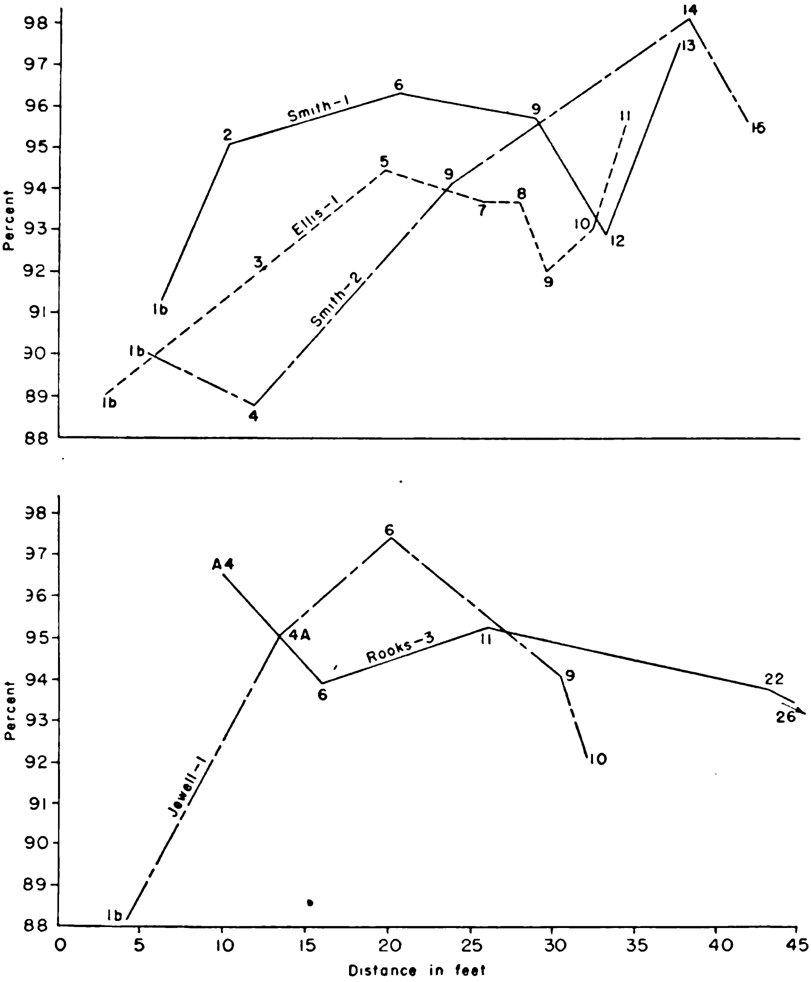

Fig. 4. Stratigraphic variation of calcium carbonate content.

The tables of analyses do not lend themselves to interpretations of any stratigraphic or geographic variation of chalk constituents. This, coupled with a range of calcium carbonate content in all the samples of only 10 percent, sharply reduced the possibilities for stratigraphic correlation within the Fort Hays member. This is illustrated by graphs of the stratigraphic and geographic variation of the calcium carbonate content plotted

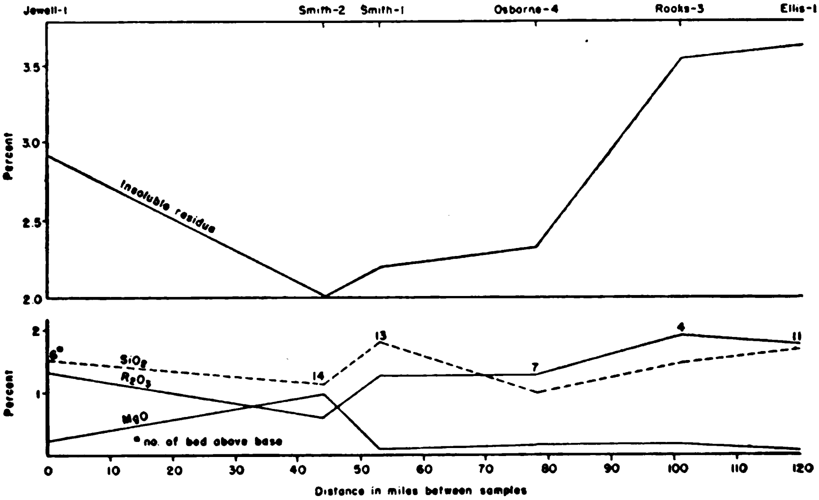

FIG. 5. Geographical variation of impurities in highest $CaCO_3$ samples.

from the chemical and petrographic analyses for measured sections (Fig. 6) that represent almost the total height of the Fort Hays. These graphs are shown in Figures 3 and 4.

In the El-1 and Sm-1 sections the calcium carbonate content increased from the base to the "c" level, then decreased at the "d" and "e" levels and increased at the "f" level, or top, with the greatest amount at this level. At Jw-1 the calcium carbonate increased to a maximum at the "c" level, at Ob-4 at the "d" level, and at Sm-2 at the "e" level. In the latter three sections there was a decrease in amount of calcium carbonate from the specified levels to the top of the section.

There is an increase in the calcium carbonate content in the 1 "b" and "c" levels toward the south. The "d", "e", and "f" levels show purer chalk in the central to north-central part of the area studied. The chalks of highest purity also are similar in composition. Thus, $CaCO_3$ ranges from 95.6 percent at El-1 to 98.2 percent at Sm-2. The SiO_2 ranges from 1.09 percent at Sm-2 to 1.53 percent at Ro-3, a difference of only 0.44 percent. The R_2O_3 shows the lowest percentage at Sm-2, 0.60 percent, and the highest at Ro-3, 1.97 percent, a difference of 1.37 percent. MgO, however, is highest at Sm-2 (1.08 percent) while only 0.17 percent at El-1. This is shown graphically in Figure 5.

The remaining constituents—R_2O_3 (Fe_2O_3, Al_2O_3, TiO_2), MgO, and SiO_2—are in various mineral impurities and are discussed in detail in the section on petrography. For example, SiO_2 occurs as quartz and as a constituent of various silicate minerals. The chemical analyses give only the total percentage of SiO_2. Fe_2O_3 occurs mainly in limonite. The MgO in the chemical analyses is derived mainly from magnesium carbonate.

Chemical analyses of the Fort Hays chalk are given in Table 5. Two analyses of the Codell sandstone and four analyses of insoluble residues are included for comparison. A selected number of samples were analyzed spectrographically (Table 4). No elements which had not been found in chemical or petrographic analyses were found by this method.

In summary, the following general statements can be made. (1) The central to north-central parts of the area studied have greater thicknesses of purer chalk. (2) The content of other constituents (SiO_2, R_2O_3, and MgO) generally is inversely proportional to the calcium carbonate content. (3) The decreasing calcium carbonate content at the top of the Fort Hays member might represent a qualitative method of identifying the transition between the Fort Hays and the Smoky Hill members of the Niobrara formation, although only a very limited number of analyses of the upper parts of the Fort Hays have been made.

CORRELATION BETWEEN PETROGRAPHIC AND CHEMICAL ANALYSES

Chemical analyses show that the amount of insoluble residue is largest at the base of the Fort Hays. Petrographic analyses show that the purest chalk generally lies between the "d" and "e" levels. The purest chalk bed is Sm-2-14 which contained 98.20 percent calcium carbonate.

In order to compare more closely the quantitative results of the petrographic and chemical analyses, the coarser parts of the insoluble residues of four of the most impure samples were analyzed. A routine chemical examination was made for SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, K_2O, and Na_2O. The calcium present was considered to be residual calcium salts not removed during separation of insoluble residues. The percentage of each mineral present in the coarse part was determined by counting the grains. The chemical oxide content was then calculated from the mineral

TABLE 5.—*Chemical analyses of Fort Hays chalk*

Sample no.[2]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	S	Igt. loss (140-1000°C)	$CaCo_3$ (calculated)	$MgCO_3$ (calculated)
El-4-9	3.79	1.47	1.97	52.04	......	***	0.01	40.69	92.80	......
El-6-0	2.30	0.47	1.48	53.43	0.17	***	***	41.23	95.27	0.36
El-1-1a	9.02	2.78	2.82	47.30	0.97	tr	tr	36.82	84.34	2.03
El-1-1b	6.59	1.14	1.77	49.84	0.52	tr	tr	39.78	88.87	1.09
El-1-3	3.46	1.90	1.56	51.53	0.81	tr	***	40.11	91.89	1.69
El-1-5	3.47	1.29[1]	1.12	52.88	......	***	***	40.43	94.29	......
El-1-7	2.38	1.57[1]	0.56	52.48	0.59	***	***	40.95	93.58	1.23
El-1-11	1.87	0.79[1]	1.00	53.56	0.17	***	***	41.59	95.51	0.36
El-2-1a	7.52	2.79	2.42[1]	48.53	0.38	0.10	***	38.07	86.54	0.79
El-2-1b	3.69	2.75[1,7]		51.76	0.38	0.20	***	40.70	92.30	0.79
El-3-1a	18.76	5.32[1]	4.18	39.02	0.29	***	***	30.95	69.58	0.61
El-3-1b	4.32	1.71[1]	1.41	51.53	0.23	***	***	40.29	91.89	0.48
El-4-0[2]	1.09	0.48[1]	0.43	54.63	0.13	***	0.13	42.34	97.41	0.27
El-4-5	2.12	0.62[1]	1.17	53.21	0.12	***	***	41.81	94.88	0.25
El-4-6	2.66	0.34	1.60[1]	52.63	......	***	0.02	41.79	93.86	......
El-4-7	4.99	2.91[1,7]		50.63	......	***	0.01	40.47	90.23	......
El-4-8	3.87	2.62[1,7]		51.64	......	***	0.10	40.70	92.08	......
Ha-2-6[3]	2.48	1.37[1,7]		53.56	0.43	***	***	41.73	95.51	0.90
Ha-2-7[3]	2.28	1.10[1,7]		54.00	0.32	***	***	42.04	96.29	0.67
Jw-1-1	5.14	2.14	2.72[1]	49.36	0.32	tr	0.22	38.65	88.02	0.67
Jw-1-4a	1.73	0.74	1.20[1]	53.23	0.65	tr	0.23	41.38	94.92	1.36
Jw-1-6	1.51	0.75	0.55[1]	54.54	0.20	***	0.01	41.56	97.25	0.42
Jw-1-9	3.63	1.28	1.34[1]	52.73	0.26	***	tr	40.64	94.03	0.47
Jw-1-10	4.62	1.00	2.51[1]	51.65	0.06	***	0.01	39.64	92.10	0.13
Jw-2-1a	18.84	6.48[1,7]		40.61		***	0.01	31.92	72.41	......
Jw-2-1b	3.70	3.60[1,7]		51.45		***	***	40.48	91.74	......
Jw-3-1a	25.04	6.48[1]	2.05	38.00	1.40	***	***	28.53	67.76	......
Jw-3-1a	3.35	1.44[1]	1.12	51.52	***	0.04	***	40.26	91.87	......
Sm-1-1a	47.95	6.53	2.60[1]	22.73	0.62	***	***	16.87	40.53	1.30
Ns-1-2[3]	2.90	1.50	0.70[1]	51.21	1.47	***	***	41.85	91.32	3.08
Ns-1-3[3]	3.25	1.52	0.56[1]	52.17	0.74	***	***	41.69	93.03	1.55
Ln-1-1a	5.27	0.67	1.54[1]	51.01	0.30	0.14	***	40.02	90.96	0.63
Ln-1-1b	3.55	0.97	1.82[1]	51.78	0.11	0.13	***	41.11	92.33	0.23
Fn-1-0[1,3]	3.48	0.92	0.43[1]	52.34		0.07	***	41.07	93.99	......
Fn-1-1[3,4]	3.38	1.17	0.51[1]	53.31	0.34	***	***	41.76	95.06	0.71
Fn-0-0[3,5]	1.41	1.68[1]	0.40	54.27	......	......	......	42.43	96.77	......
Ha-1-1a	20.18	6.57[1]	2.05	38.93	1.16	***	***	31.85	69.42	2.43
Ha-1-1b	6.47	2.31[1]	0.78	50.81	0.95	***	***	39.13	90.60	1.99
Ob-3-1a	50.54	7.66[1]	6.02	18.13	0.22	tr	***	14.35	32.33	0.46
Ob-3-1b	4.63	2.32[1]	1.87	50.74	0.25	tr	***	40.06	90.48	0.52
Ob-4-7	1.00	0.49[1]	0.79	54.26	0.22	tr	***	42.67	96.75	0.46
Ob-4-10	4.38	1.40[1]	1.03	51.92	0.16	***	***	40.95	92.58	0.33
Ro-3-A4	1.52	1.03[1]	0.94	54.00	0.23	***	***	42.11	96.29	0.48
Ro-3-1a	16.71	4.64[1]	1.60	41.84	Lost	0.10	***	32.95	74.61	
Ro-3-6	1.93	1.27[1]	1.79	52.61	0.40	***	***	42.02	93.81	0.84
Ro-3-11	2.13	0.79[1]	1.03	53.41	0.13	***	***	41.55	95.24	0.27
Ro-3-22	1.70	3.12[1]	2.57	52.51	0.26	***	***	40.74	93.63	0.54
Ro-3-26	4.08	2.88[1]	1.21	51.07	Lost	0.07	***	40.15	91.07	......
Ro-4-A1a	46.36	4.80	3.17[1]	23.45	0.45	0.56	***	19.03	41.82	0.94
Ro-1-1	3.14	1.78[1]		51.85	0.68	tr	***	41.64	92.46	1.42
Ro-1-2w	2.53	1.76	1.32[1]	50.98	0.07	0.19	0.10	41.24	90.87	1.41
Ro-1-4w	2.15	0.67	1.35[1]	52.16	0.58	0.06	tr	41.89	93.02	1.21

Ro-1-5w	2.97	0.72	1.73[1]	51.37	0.82	0.10	tr	41.46	91.60	1.72
Ro-1-6w	4.00	0.75	2.33[1]	50.45	0.81	0.16	0.02	40.65	89.96	1.71
Ro-4-a1b	4.32	0.42	3.64[1]	50.15	0.13	0.09	***	39.39	89.43	0.27
Tr-1-11	2.84	2.32[1]	0.76	....	2.23	***	***	41.28	....	......
Tr-1-15	1.66	0.29[1]	0.64	53.45	0.19	***	tr	41.61	95.31	0.40
Tr-2-1	2.82	1.41[1]		52.91	0.49	***	***	41.48	94.35	0.87
Sm-1-1b	3.37	1.74	1.77[1]	51.88	0.79	***	***	40.87	92.51	1.65
Sm-1-2	1.68	0.82	1.14[1]	53.25	0.03	***	***	42.49	94.95	0.06
Sm-1-6	1.02	0.49	0.48[1]	53.91	0.25	***	***	42.91	96.13	0.52
Sm-1-9	1.38	0.57	1.09[1]	53.58	0.30	***	***	42.62	95.54	0.62
Sm-1-12	1.58	1.05	0.85[1]	52.02	1.29	***	***	42.22	92.76	2.70
Sm-1-13	1.78	0.63	0.65[1]	54.62	0.10	tr	tr	41.30	97.39	0.21
Sm-2-1a	56.01	3.66	1.50[1]	16.10	2.73	tr	***	13.29	28.71	5.71
Sm-2-1b	4.10	1.71	0.66[1]	50.39	2.63	tr	***	40.52	89.85	5.50
Sm-2-4	5.84	1.74	0.65[1]	49.75	1.38	tr	***	39.86	88.71	2.89
Sm-2-9	2.51	0.64	0.53[1]	52.65	1.05	tr	***	41.75	93.38	2.20
Sm-2-14	1.09	0.50	0.10[1]	55.01	1.08	tr	***	42.96	98.09	2.26
Sm-2-15	2.43	1.20	0.46[1]	53.64	1.11	tr	***	42.01	95.65	2.32
Ph-1-1a	14.27	3.48[1]	2.37	43.97	0.26	***	***	35.15	78.41	0.54
Ph-1-1b	3.05	0.85[1]	1.80	52.60	0.36	***	***	41.08	93.79	0.75
Ob-1-2[3]	2.47	2.26[7] [1]		53.34	0.32	***	***	41.56	95.11	0.67
Ob-1-3	3.14	1.91[1]		52.73	0.18	***	***	41.46	94.03	0.38
Ob-1-4	3.43	3.92[1]		51.67	0.40	***	***	40.78	92.14	0.84
Ob-1-5	0.93	0.96[1]		54.63	0.30	***	***	42.73	97.41	0.63
Ob-2-1a	6.55	2.29	2.94[1]	48.13	0.12	***	***	37.63	85.82	0.25
Ob-2-1b	2.53	0.83	1.90[1]	52.59	0.14	***	***	40.72	93.78	0.29
Sm-1-1aI[10]	90.20	3.76	1.87	0.45	0.40			0.46		
Jw-2-1aI[11]	87.68	4.06	1.16	0.30	0.39			0.60		
Ro-4-A1aI[12]	90.40	2.38	1.98	0.42	0.29			0.61		
Ha-1-1aI[13]	85.92	5.09	0.62	0.30	0.32			0.72		
J-3-ss[6] [14]	76.01	12.35	3.83	1.35	2.16	0.08		2.57		
Os-3-ss[6] [15]	72.70	12.56	4.22	1.87	2.23	0.08		2.77		

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[1] Includes TiO_2.

[2] Composite samples of beds 3 and 4.

[3] Above lowest visible bed: Lower Fort Hays contact not seen.

[4] Spot samples from upper part of quarry.

[5] Composite of quarry analyzed by R. Thompson in 1943.

[6] Codell sandstone.

[7] And Fe_2O_3.

[8] Complete location given in Table 1.

[10] TiO_2, 0.67; K_2O, 1.91; Na_2O, 0.58; determined by difference from 100 percent.

[11] TiO_2, 1.02; K_2O, 2.73; Na_2O, 2.06; determined by difference from 100 percent.

[12] TiO_2, 0.87; K_2O, 3.05; Na_2O, Nil; determined by difference from 100 percent.

[13] TiO_2, 2.79; K_2O, 0.93; Na_2O, 3.79; determined by difference from 100 percent.

[14] TiO_2, 1.02; SO_3, 0.04.

[15] TiO_2, 1:55; SO_3, 0.04.

*** nil.

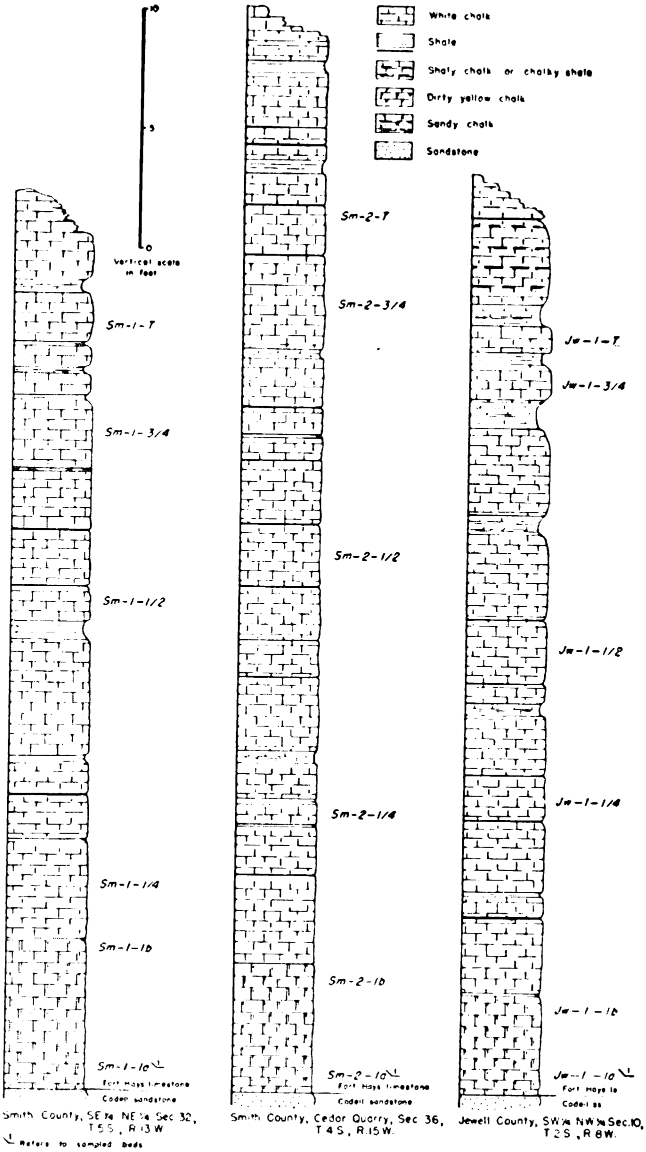
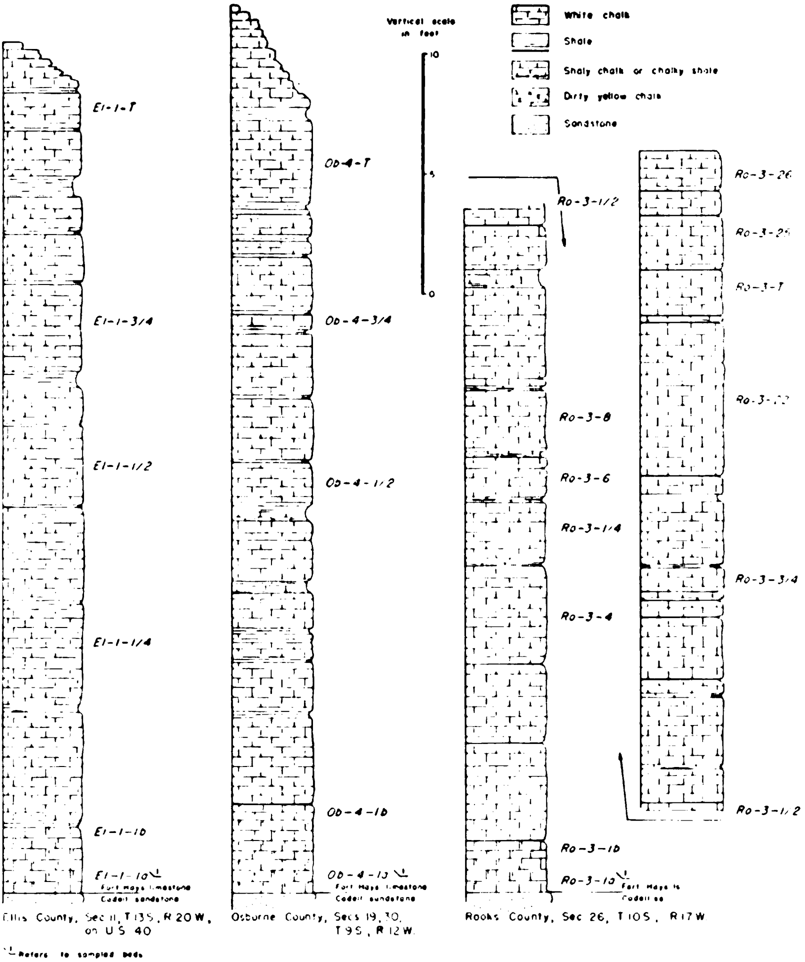


FIG. 6. Stratigraphic sections

content. Table 6 lists the oxide content determined by both chemical and petrographic analyses.

The silica content determined petrographically and chemically agrees closely. The amount of alumina is generally higher in the petrographic analyses. The amount of TiO_2 is consistently higher in the chemical analyses. The amount of K_2O is slightly higher on the average in the petrographic analyses, whereas the amount of Na_2O is slightly higher on the average in the chemical analyses.



of Fort Hays chalk.

Table 6.—*Correlation of petrographic and chemical analyses of the coarser portion of insoluble residues*

	SiO_2		Al_2O_3		TiO_2		K_2O		Na_2O		CaO	
	Chem.[1]	Petr.[2]	Chem.	Petr.	Chem.	Petr.	Chem.	Petr.	Chem.	Petr.	Chem.	Petr.
Jw-2-1a	87.68	85.68	4.06	6.07	1.02	0.54	2.73	3.04	2.06	1.59	0.30	....
Sm-1-1a	90.20	93.17	3.76	2.88	0.67	0.19	1.91	2.30	0.58	0.44	0.15	....
Ro-4-A1a	90.40	91.11	2.38	3.63	0.87	0.07	3.05	3.00	0.00	0.00	0.42	....
Ha-1-1a	85.92	84.90	5.09	8.08	2.79	0.00	0.93	1.41	3.79	3.73	0.30	....

[1] Chem.—chemical analysis.
[2] Petr.—petrographic analysis.

A possible cause for the larger amount of TiO_2 determined chemically is that some of the ilmenite may have been called magnetite in the petrographic analysis.

An explanation which can be offered for the larger amount of alumina in the petrographic analyses is the assumption that the determination of the feldspars was too high. However, the fact that the K_2O is only slightly higher and the Na_2O slightly lower in the petrographic analyses casts doubt on the above assumption.

In general, however, there is good agreement between the chemical compositions determined by both methods of analyses.

UTILIZATION

Whiting

Bowles (1942, p. 3) states: "Whiting is finely ground, pulverized, powdered or chemically precipitated calcium carbonate of good white color." The United States Bureau of Mines defines precipitated whiting as being prepared by reaction of milk of lime with carbon dioxide, or by some similar chemical reaction (precipitated chalk). Chalk whiting is prepared from crude chalk by mechanical settling. Most of the whiting plants are in eastern coastal States.

The uses of whiting are listed below (Lamar and Willman, 1938, p. 44).

As a constituent of
- calcimine and cold water paints
- paints (inert extender)
- putty
- ceramic glazes, enamels, and bodies
- cigarette papers
- white ink
- dressing for white shoes

- picture frame moldings
- dolls
- wire insulation
- metal polish
- dyes
- toothpaste
- fireworks

As a filler in
- rubber
- oilcloth
- window shades
- linoleum
- asphalt (may be off-color whiting)
- magazines and book paper (precipitated calcium carbonate)

For
- compounding rubber goods (bootwear, heels, hard rubber objects, white rubber, stock molded rubber goods, sponge rubber, hose, belts, mats, and electric cable insulation)
- facing molds and cores in brass casting
- a coating on glazed paper
- neutralizing in fermentation processes
- making buff brick from red-burning clay
- manufacturing citric acid
- dusting unburned brick to prevent sticking in the kiln.

Whiting is used in the following industries: structural iron, ship-building, locomotive works, file manufacture, explosives, medicines, leather, printing, shoe manufacture, roofing cement, and chemical manufacture.

Fifty percent of the imported chalk and whiting is used by the paint industry, 35 percent by the rubber industry, and 10 percent by the putty trade. Additional uses of whiting listed by Bowles (1942, p. 5) are in soap, dentifrices, sealing wax, acoustic tile, roofing, calking compounds, insecticides, gypsum plaster, cosmetics, and paper plastics.

Specifications for chalk to be used in whiting.—The specifications for whiting vary considerably depending on the use. Specifications are lacking except in a few instances. Generally the color, fineness, and freedom from grit are important in determining the quality. However, some standard methods to determine certain specific properties have been established. Sales are based largely on samples.

Particle size (Wilson and Skinner, 1937, pp. 39-40) plays an important role in such properties as tint, brightness, hiding power, and oil absorption of paint pigments and fillers. The fineness of the filler in the rubber industry determines the smoothness of the finished product and to some extent the amount of latex necessary. It has been reported (Wilson and Skinner, 1937, pp. 39-40) that rubber has been given high tensile, tear, and abrasion resistance by precipitated calcium carbonate so fine that 98 percent is less than 0.4 microns in diameter. Chalk grains studied by us range from 0.2 to 0.55 microns. Precipitated whiting made from this chalk would have a smaller grain size. Abrasion and rapid wear of the internal structure of rubber particles subject to movement and stress is caused by coarse gritty particles. Fillers in cosmetics and dentifrices require a fine smooth texture. Tables 7 and 8 give the chemical requirements for the rubber industry and ceramic whiting.

Chalk whiting for cold water paints and calcimine is governed by a number of factors (Bowles, 1942, p. 4), depending upon the use of the finished product. In general, particle size, shape, and distribution, texture, chemical reactivity, oil absorption, color, and specific gravity are the prime factors.

For putty, the chemical specifications are 95 percent calcium carbonate or higher, with impurities plus tinting compound not to exceed 5 percent. The various properties of the different types of putty call for a number of physical specifications of which fineness of grain size, freedom from grit, and oil absorption are the most important.

Chemically precipitated whiting and various finely ground natural whitings are used as fillers, to increase opacity, and to improve printing quality in paper. The only definite specification given (Bowles, 1942, p. 5) is that fineness of grain size is important.

Many other uses of whiting have been listed but specifications are so varied that in most cases the suitability of the whit-

TABLE 7.—*Chemical requirements of whiting for the rubber industry*
(Figures are percentages) (Wilson and Skinner, 1937, p. 31)

Co.	Max. CaO	Min $CaCO_3$	Ignition Loss	Insoluble Content in HCl	SiO_2 and Al_2O_3	Fe_2O_3 Al_2O_3 and MgO	SiO_2	MgO	Moisture
B	....	....	42-44	0.05-1.5	....	....	....	....	0.1-0.5
C	....	97.5	2	....	....	0.25	0.90	....	0.25
D	50	....	40	....	5.0	....	....	3.0	0.25

TABLE 8.—*Specifications for ceramic whiting*
(Figures are percentages) (Wilson and Skinner, 1937, p. 31)

	Total Carbonates	$CaCO_3$	$MgCO_3$	Fe_2O_3	SiO_2	SO_3
Class 1:						
Minimum	97	96	....	....	....	....
Maximum	....	....	1	0.25	2.0	0.1
Class 2:						
Minimum	97	89	....	....	....	....
Maximum	....	....	8	0.25	2.0	0.1

ing is best determined by submitting samples to the prospective customer.

OTHER USES OF CHALK

The following discussion of the uses of chalk has been adapted from Lamar and Willman (1938).

Ground chalk is used for dusting coal mines to prevent explosions. The chemical requirements are high calcium carbonate and low silica content. All the chalk must pass a 20-mesh sieve, and 50 percent must pass a 200-mesh sieve. A light-colored powder, free from grit, is desired.

Ground chalk is employed for asphalt filler. All must pass a no. 30 sieve, not less than 95 percent should pass a no. 80 sieve, and not less than 65 percent should pass a no. 200 sieve. A more finely ground filler is used with asphalt for other purposes.

Chalk may be used for agricultural limestone or "agstone" as it is more familiarly known. The neutralization of soil acids and acid clays, releasing of some plant food elements from some soil minerals, the supplying of nutrients for plant use in the form of calcium, the favoring of the growth of vegetables, the improving of the type of decay of organic matter in the soil, and the conversion of toxic aluminum compounds soluble under acid conditions to insoluble compounds are but a few of the functions performed by the addition of calcium carbonate to soil. The requirements for agricultural limestone are a calcium carbonate equivalent of at least 80 percent. The physical requirements (1946) are 25 percent passing 100 mesh and 95 percent passing 8 mesh.

Chalk may be used as a filler and conditioner in fertilizers. Weight is added to fertilizers by fillers and the caking of fertilizers is reduced by conditioners. If there is superphosphate present, the chalk neutralizes any "free" phosphoric acid present. The general chemical specification for fertilizer manufacture is a reasonably pure chalk. The general physical specification is a fineness of 20 to 80 mesh.

Chalk may be used in making mineral feeds for stock. The general chemical requirements in Kansas (personal communication, Kansas State Board of Agriculture, 1947) are a calcium carbonate content of 80 percent (20 percent calcium) and less than 0.03 percent fluorine. The general physical specification is fineness of 200 mesh or finer.

Fort Hays chalk has been used locally as building material. By selection of beds, blocks from pure white to buff color can be produced with a minimum of equipment. There are two primary objections to using Fort Hays chalk as a building stone: (1) iron concretions cause staining and (2) the chalk has low tensile strength, so that blocks chip easily. Both these objections are overcome by cutting relatively small blocks. Thus all iron concretions can be discarded with a minimum loss and the small block will "case harden" more quickly. (Freshly cut limestone or chalk hardens on the surface from exposure to air). The small blocks make very attractive buildings and enormous tonnages of easily accessible chalk are available.

Chalk can be used in Portland cement. The general chemical specifications are less than 2 percent magnesium carbonate, less than 1 or 1.5 percent total sulfur, and less than 0.5 percent P_2O_5. (J. H. Griffith, Lonestar Cement Corp., personal communication, 1947). The general physical requirements are ability to pulverize easily and 100-mesh size. The tolerance of Fe_2O_3 in white Portland cement is very low. Basal Fort Hays is utilized for Portland cement at Superior, Nebraska, and at Boulder, Colorado. It was used also at Yocemento, Ellis County, Kansas.

Lime is made by burning limestone or chalk at a temperature which drives off the carbon dioxide. The technology of the manufacture of lime is dependent on the chemical and physical properties of the raw stone and the manner in which it is burned. Lime produced from the Fort Hays chalk meets all specifications listed below.

Chalk or limestone for nonhydraulic limes must contain more than 91 percent calcium carbonate, less than 6 percent magnesium carbonate, and less than 3 percent other constituents. For hydraulic limes, the carbonates must be between 91 and 97 percent with 3 to 9 percent other constituents. The physical requirements are clean dry fragments from 6 to 10 inches if burned in vertical kilns, and 0.5 to 1.5 inches if burned in rotary kilns.

Other uses of lime include building material, such as plaster, mortar, brick, and stucco; in many chemical processes; in the purification of water; and in the treatment of sewage.

COMPARISON WITH OTHER CHALKS

In the United States, chalk also occurs in Alabama, Arkansas, Colorado, Iowa, Mississippi, Nebraska, South Dakota, Tennessee, Texas, and Wyoming. Except for the basal part of the Fort Hays, the lowest calcium carbonate content in the Fort Hays is 88 percent, the highest is 98.1 percent, averaging (excluding the base) 94.2 percent. The chalk in Alabama is reported (Bowles, 1942, p. 6) to have a maximum of 85 percent calcium carbonate. In Mississippi the best chalk is reported (Bowles, 1942) to contain only 70 to 84 percent total carbonate, the magnesium content usually being less than 1 percent. Bowles (1942) states that chalk in Arkansas contains as much as 93 percent calcium carbonate, and 3 to 12 percent magnesium carbonate. The Iowa chalk ranges from 86 to 95 percent total carbonates and is low in magnesium (Bowles, 1942). As far as is known the chalk in Iowa has not been developed commercially. The Nebraska chalk is in the Niobrara formation and has a calcium carbonate content ranging from 67 to 96 percent (Bowles, 1942), and 1.5 percent or less magnesium carbonate. As far as is known, the Niobrara chalk has not been developed commercially except for use in cement. The Texas chalk (Bowles, 1942) has 70 to 90 percent calcium carbonate and contains flint nodules. South Dakota chalk (Wilson and Skinner, 1937, p. 146) contains from 69 to 98 percent calcium carbonate, 1.5 to 5.3 percent clay, 0.0 to 4.0 percent free silica, and 0.56 to 7.00 percent ferric oxide. The chalk is similar to the deposits of the same formation in Nebraska and Kansas, but has a darker color due to the presence of carbonaceous matter. This latter characteristic may limit its use for whiting. The chalks of Tennessee and Wyoming do not occur extensively and according to Bowles (1942, p. 15) show little possibility of commercial development.

France and the United Kingdom have been the leading exporters of crude chalk to the United States. The chalk in France (Cayeaux, 1935, p. 38) contains 90 to 98 percent carbonates, usually less than 1 percent clay, 0.5 percent silica except when the chalk contains siliceous spicules, and 0.04 .to 2.82 percent P_2O_5. The lower English chalk is the most impure, containing 88 to 94 percent calcium carbonate, and averaging 89 to 90 percent. The middle chalk contains 93 to 98 percent calcium carbonate. The purest English chalk is in the upper chalk which contains 95 to 99 percent calcium carbonate (Tarr, 1925, p. 258). The chalk from Europe is, on the average, whiter than the Fort Hays and has a slightly higher calcium carbonate content.

CONCLUSIONS

The data obtained from this study shows that, in general, the Fort Hays chalk can meet, or be processed to meet, the requirements for whiting in the paint, rubber, putty, and chemical industries. The study also shows that the Fort Hays chalk is generally uniform in its properties throughout the area of outcrop in Kansas.

In addition to quality and quantity of raw materials, the development of a new industry is governed by many economic factors such as distance from existing markets, development of new markets, and distribution of competitors. A whiting industry in Kansas would have all the necessary raw materials, including water. The existing markets and the distribution of competitors are such that the possibilities for such an industry in the near future would be entirely within reason. A detailed study of the physical properties of Fort Hays chalk, supplementing the data given in this report, is being planned by the State Geological Survey.

OCCURRENCE BY COUNTIES

ELLIS COUNTY

The Fort Hays chalk crops out extensively north of a diagonal line across Ellis County from northeast to southwest. The calcium carbonate content of the chalk (33 feet thick) in sec. 11, T. 13 S., R. 20 W., 6 miles west of Yocemento on U. S. Highway 40 ranged from 89.0 percent for the upper part of the base to 94.4 percent for the fifth bed above the base.

There are additional outcrops along the Union Pacific Railroad in this area. A 2-foot bed was sampled in a quarry producing building blocks in sec. 3, T. 13 S., R. 18 W., on Kansas Highway

183 north of Hays. This bed is very white and contained 95.4 percent calcium carbonate.

There are extensive outcrops, as much as 56 feet thick, bordering Saline River Valley, but the distance to rail facilities and lack of roads limits their economic value.

FINNEY COUNTY

The Fort Hays chalk crops out only in the northeast corner of the county. The chalk in a small building block quarry located in the SW¼ NW¼ sec. 22, T. 22 S., R. 30 W., was sampled in 1943 and 1947 by the Kansas State Geological Survey. The earlier sample is a composite of the quarry face which shows a calcium carbonate content of 96.9 percent. Spot samples taken in 1947 reveal 93.5 and 95.2 percent calcium carbonate. In general, the chalk from this quarry is of exceptional whiteness. The quarry has moderate reserves and is 20 miles from the nearest railroad at Garden City. This distance is not prohibitive, however, in view of the general lack of limestone in the southwest part of the State. The building blocks are very white and contain relatively few concretions. This area could well supply chalk for whiting, lime, and building stone for Garden City, Dodge City, and other towns to the southwest.

HAMILTON COUNTY

The Fort Hays chalk crops out in Hamilton County north of Arkansas River near the Colorado line. In general, the outcrops are few in number and isolated. Two samples were taken in sec. 3, T. 22 S., R. 43 W. The calcium carbonate content is 95.6 and 96.4 percent; the color is a bluish gray.

JEWELL COUNTY

The Fort Hays chalk crops out diagonally across the county from northeast to southwest. The greatest thickness observed was 39 feet in a quarry face in the NW¼ SW¼ sec. 10, T. 2 S., R. 8 W., approximately 8 miles north of Mankato. Analyses of the chalk show the calcium carbonate to range from 90.1 to 97.4 percent. The highest calcium carbonate content occurs in the sixth bed above the base which is 3 feet 8 inches thick. This quarry is on a county road with Mankato the nearest shipping point. The remainder of the Fort Hays outcrops in Jewell County are thinner, with usually only the basal part remaining.

LANE COUNTY

Samples from the basal bed of the Fort Hays chalk were collected in sec. 28, T. 20 S., R. 27 W. As far as could be determined there are no extensive outcrops of the Fort Hays chalk in this county.

NESS COUNTY

As far as could be determined only minor outcrops of the Fort Hays chalk occur in Ness County. The chalk crops out generally in the northeast corner to north of Ness City and along the western edge of the county. Samples from the basal part were collected in sec. 33, T. 18 S., R. 26 W.

OSBORNE COUNTY

The Fort Hays crops out in the western half of Osborne County.

An extensive outcrop occurs south of Alton along the South Solomon River bluffs in the NW¼ sec. 13, T. 7 S., R. 15 W. Approximately 40 feet of chalk is present in this locality. The calcium carbonate content of four white beds in a small quarry face ranges from 92.3 to 97.6 percent. This locality has large reserves and is readily accessible to U. S. Highway 24 and the railroad through Alton.

A 33-foot section was observed in a road cut on Highway 281 in secs. 19 and 30, T. 9 S., R. 12 W. The thicker beds show white on a fresh surface and beds no. 7 and 10 contain 92.7 and 96.9 percent calcium carbonate, respectively. Similar chalk was observed in other road cuts in the same area.

In the southwest corner of the county south of Natoma in secs. 19, 20, 29, and 30, T. 10 S., R. 15 W., an outcrop similar to the one on Highway 281 was observed but not measured because of local faults.

PHILLIPS COUNTY

A few outcrops of the Fort Hays chalk are present on the North Solomon River bluffs on Highway 183. Basal samples were collected in the SE¼ SW¼ sec. 36, T. 4 S., R. 18 W. The relatively small outcrops, the distance from roads, and the closeness of such favorably situated quarries as the one at Cedar make development of the Fort Hays chalk in Phillips County improbable.

ROOKS COUNTY

Both Solomon River and Paradise Creek provide east-west areas through Rooks County along which the Fort Hays crops out extensively. In a road cut south of Codell in sec. 26, T. 10 S., R. 17 W. a 56-foot section of chalk was measured. The calcium carbonate content of the 26 beds of chalk in the exposure ranges from 96.4 percent in bed 4 to 91.1 percent in bed 26. Several of the white beds were not analyzed, however. This location has large reserves. There is a gravel road to Codell and the Union Pacific Railroad runs through Codell.

There are numerous outcrops of the Fort Hays chalk along South Solomon River Valley from Webster to the eastern border of Rooks County. These outcrops were not sampled, but further study may reveal suitable chalk for commercial development.

SMITH COUNTY

Fort Hays chalk crops out as bluffs on North Solomon River from west of the town of Cedar to the town of Portis just across the Smith County Line in Osborne County.

A small quarry in the SW¼ sec. 36, T. 4 S., R. 15 W., 3 miles west of Cedar on Kansas Highway 9, produces chalk for whiting. The section measures 43.5 feet in this area. Plate 2B shows this section as viewed from the road. Bed 14 shows 98.2 percent calcium carbonate and was the purest chalk studied. Bed 15 shows 95.8 percent. These two beds provide the working face of the quarry where the chalk is hand-picked and averages 97 percent calcium carbonate with 99.1 percent total carbonates. A section in the NE¼ sec. 32, T. 5 S., R. 13 W. measures 38 feet; the top bed (13) has a calcium carbonate content of 97.5 percent.

This entire area is suitable for quarry sites and a Missouri Pacific Railroad line passes through Cedar, Gaylord, and Portis.

TREGO COUNTY

Chalk of the Niobrara formation crops out over a large part of Trego County. The Fort Hays-Carlile contact crops out along Smoky Hill River from the eastern border of Trego County to the junction of Hackberry Creek with Smoky Hill River.

An incomplete section in the NE¼ SE¼ sec. 1, T. 15 S., R. 23 W. measures 55 feet. Bed 15 contains 95.4 percent calcium carbonate. A 52-foot section in the NW¼ sec. 30, T. 14 S., R. 24

W., at the junction of Hackberry Creek with Smoky Hill River was measured by John C. Frye.

There are large tonnages of chalk available in Trego County, but the distance from transportation makes the economic utilization unfavorable at present. The nearest railroads are the Union Pacific at Wakeeny and a Missouri Pacific branch line at Ransom.

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