CIRCULAR 144

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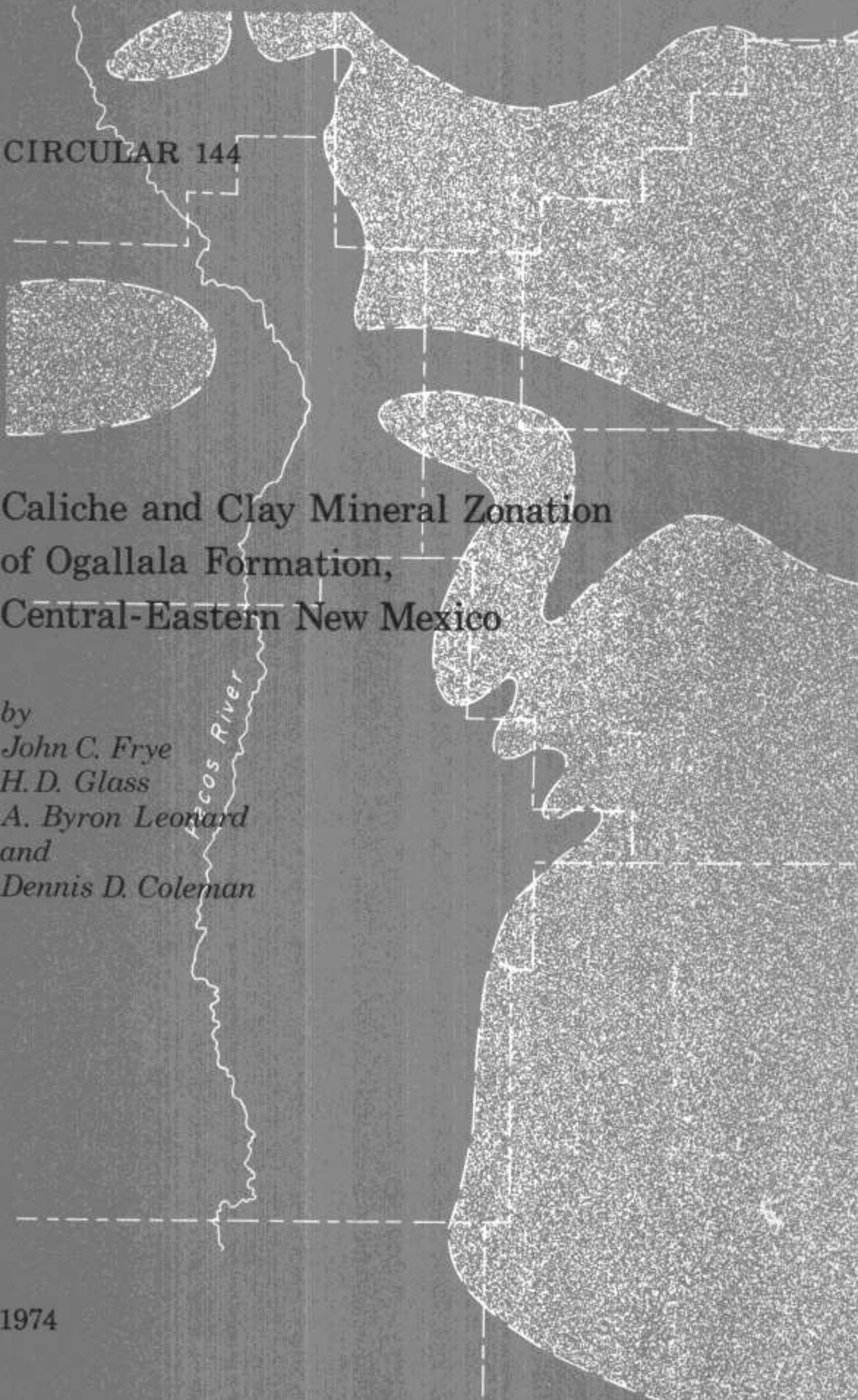

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ABSTRACT

Clay mineral compositions permit the zonation of the Ogallala Formation (Pliocene) in central-eastern New Mexico. The clay mineral assemblage of the lowest part is dominated by montmorillonite (Zone I); above is a zone of progressive upward increase of attapulgite (Zone 2); and above this, a thin zone dominated by sepiolite and attapulgite (Zone 3). Zones 1 through 3 are interpreted as representing progressive desiccation through Pliocene time. At the top of the formation, above Zone 3, are two thin zones characterized by abundant carbonate. Zone 4 is again dominated by montmorillonite with lesser amounts of illite and kaolinite, but no attapulgite or sepiolite. Zone 5 at the top, the pisolitic limestone, contains weathered montmorillonite, illite, kaolinite, and locally chlorite. These uppermost zones are interpreted as representing the modifying effects of Pleistocene events. Caliche, displaying a wide range of physical appearance, occurs on Pleistocene deposits of several ages, and in the capping zone of the Ogallala. These caliches were studied by their clay mineral assemblages, and by radiocarbon dating. Radiocarbon dates on Pleistocene caliches ranged from 11,250 to 31,700 B.P.; on the pisolitic limestone (Zone 5), at the top of the Ogallala Formation, from 27,160 to 35,000 **B.P.;** and on caliches from 2 to 10 ft below the top of the Ogallala (Zones 2-4), from 30,880 to 43,100 B.P. The radiocarbon dates are apparent ages and do not indicate the time of initial deposition of the caliche. The dates reflect modifications of the calcium carbonate by events during late Pleistocene and Holocene time.

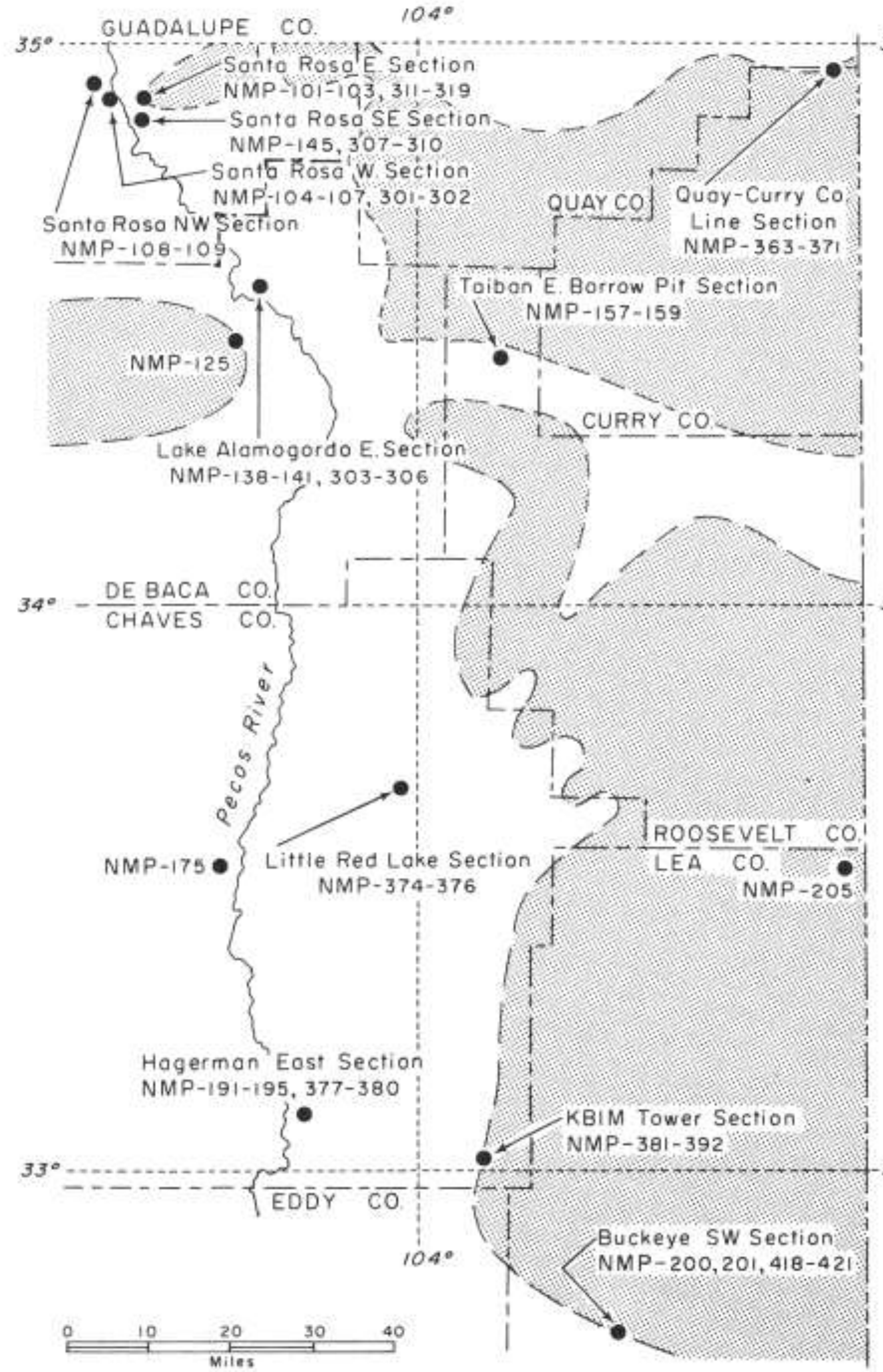

FIGURE 1 — Map showing localities sampled. The stippled areas show the generalized distribution of the major areas of Ogallala Formation. Sample numbers (NMP-) are listed in table 1, and locations are given in the Appendix. Radiocarbon dates are given in table 2.

INTRODUCTION

The Ogallala Formation (Pliocene) is widespread in the central and southern Great Plains, comprising the deposits at or near the surface in much of central-eastern New Mexico. The uppermost part of the formation generally consists of a zone containing a very high percentage of calcium carbonate, variously called "cap rock", "lime rock", and caliche. This capping zone of carbonate has its thickest development in central-western Texas and eastern New Mexico, becoming thinner northward across western Kansas, eastern Colorado, and western Nebraska. The origin of this conspicuous, widespread, and distinctive rock has been controversial (Lovelace, 1972, p. 53); first considered to be caused by percolating water by Haworth (1897, p. 270); attributed to deposition in a widespread lake (Elias, 1931, p. 138; Price and others, 1946); considered to be a caliche resulting from surficial processes of soil formation (Gould and Lonsdale, 1926; and Smith, 1940); and described as the complex product of multiple generations of soil formation, brecciation of the caliche zone, and of recementation (Swineford and others, 1958; Frye and Leonard, 1972).

Recently, studies of caliche and its origin have been made in the adjacent High Plains of Texas and eastern New Mexico by Reeves (1970), and chemical data on eastern New Mexico caliche has been presented by Aristarain (1970). Studies of caliche, and radiocarbon dating of caliches, have been made in the Rio Grande valley to the west of this area by Gile and others (1966 and 1970), and by Ruhe (1967).

Several weeks of field work in central-eastern New Mexico by Frye and Leonard during the summers of 1971 and 1972 led to a regional study of clay minerals in Pleistocene deposits, collection of data on clay minerals in the Ogallala Formation (Glass and others, 1973), and review of the late Cenozoic stratigraphy and molluscan paleontology of the region (Leonard and Frye, 1974). During the course of this work, questions arose concerning the origin, age, and clay mineral content of the extensive caliche deposit. During the summer of 1973, six previously studied sections of Ogallala Formation were sampled with emphasis on the predominantly carbonate zone in the uppermost 10 ft. Caliche samples were also collected from several other Ogallala localities, and from Pleistocene sections for comparative purposes. The geographic distribution of all localities and samples used in this report are shown in fig. 1.

Clay mineral compositions were determined by the same methods used in the previous study (Glass and others, 1973). Carbonate was removed from caliche samples by slow dissolution in 5 percent acetic acid at room temperature, followed by repeated rinsing of the clay residue, then preparation for X-ray analysis. The results of all X-ray analyses are given in table 1, and location data for all samples are given in the Appendix. Radiocarbon age determinations were made in the laboratories of the Illinois State Geological Survey on 16 caliche samples, and the results are given in table 2.

ZONATION OF OGALLALA FORMATION

The Ogallala Formation in this part of New Mexico (Leonard and Frye, 1974) is relatively thin when compared with sections farther east in Texas (Frye and Leonard, 1959); the sections sampled for this study ranged in thickness from less than 10 ft to slightly more than 100 ft. The data as a basis for the recognition of 5 distinctive clay mineral zones in the Ogallala and their stratigraphic relationships, were largely based on 5 sections: Buckeye SW, KBIM Tower, Quay-Curry County Line, Santa Rosa E., and Santa Rosa SE. Clay mineral data are presented for these sections in table 1, and are graphically presented for 3 of them — the KBIM Tower Section (fig. 2), the Quay-Curry County Line Section (fig. 3), and Santa Rosa E. Section (fig. 4). Based on these 5 sections, with supplemental data from the Santa Rosa NW, and Little Red Lake Sections, and from several isolated samples (covering a region 165 miles north-south and 90 miles east-west) a composite clay mineral zonation of the Ogallala of the region is presented in

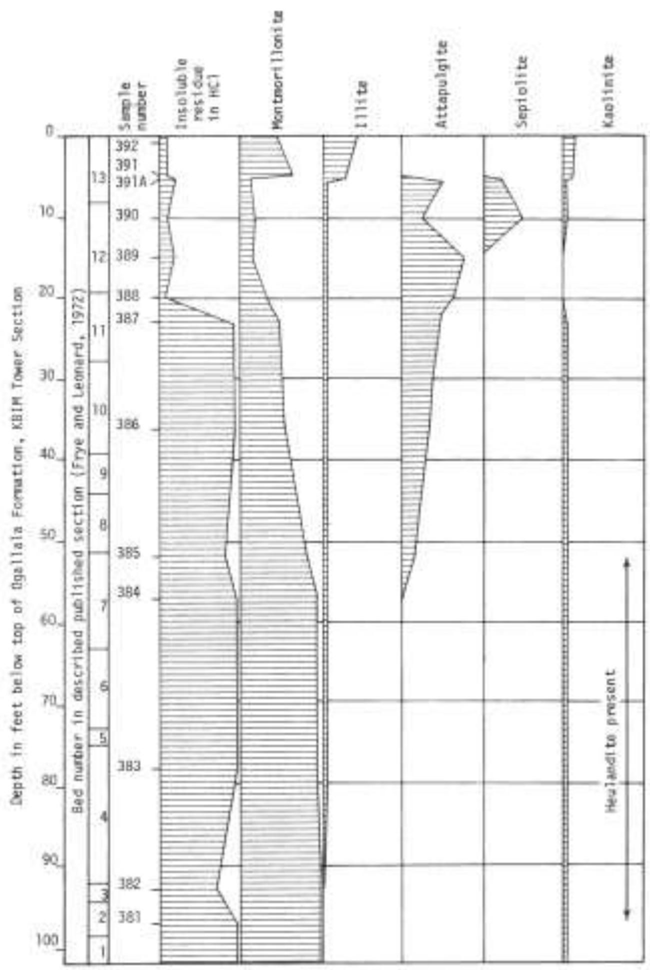

FIGURE 2 — Clay mineral compositions, and solubility data for the Ogallala Formation at the KBIM Tower Section; NW¼ SW¼ sec. 18, T. 15 S., R. 31 E., Chaves County. The clay minerals are shown as percentage of the total clay mineral assemblage, and solubility in HCl is percent soluble of total sample.

TABLE 1 – *Quantitative X-ray Analyses of Clay Minerals* (by H. D. Glass, Illinois State Geological Survey laboratories)

Sample No.	Lithology	Distance below top of section (ft)	% clay minerals (estimates are in parentheses): Montmorillonite	Illite	Kaolinite and Chlorite	Attapulgite	Sepiolite	Remarks	Ogallala clay mineral zone, or age, and % soluble
BUCKEYE SOUTHWEST SECTION									
NMP-421	pisolitic ls	0.3	20	58	22				5
420	platy caliche	3	14	(5)	2	79			2?
419	cem. sand	6	15	(5)	2	42	36		3
201	sand	15	10	(5)		85		opal	2
418	sand	25	15	(5)		80			2
200	sand	35	23	(5)		72		opal	2
HAGERMAN EAST SECTION									
NMP-377	platy caliche	0.3	38	(5)	7	50			Kansan
195	platy caliche	0.3	35	(5)	8	52			Kansan
378	massive cal.	3	14	(5)	3	78			Kansan
379	sand	6	54	(5)	3	38			Kansan
380	sand	9	66	(5)	4	25			Kansan
193	sand	12	82	13	5	tr			Kansan
194	sand	12.5	70	22	8	?		gypsum	Kansan
191	sand	30	83	14	3				Kansan
192	Permian sh	35	76	19	5			gypsum	Permian
KBIM TOWER SECTION									
NMP-392	pisolitic ls	0.3	44	42	14				5 92.30
391	dense caliche	5	63	26	11				4 91.25
391A	soft caliche	5.3	13	(5)	3	52	27		3 83.70
390	cem. sand	10	16	(5)	3	26	50		3 91.76
389	cem. sand	15	15	(5)		80			2 88.47
388	cem. sand	20	31	(5)		64			2 94.47
387	sand	23	48	(5)	3	44			2 5.72
386	sand	36	56	(5)	3	36		heulandite?	2 5.65
385	sand	52	83	(5)	1	11		heulandite	2 17.65
384	sand	57	95	5				heulandite	1 2.85
383	sand	78	95	5				heulandite	1 2.68
382	sand	93	98	2				heulandite	1 28.25
381	sand	97	98	2				heulandite	1 2.46
LAKE ALAMOGORDO EAST SECTION									
NMP-306	platy caliche	0.1	46	38	16				Woodfordian
305	platy caliche	0.5	47	37	16			chlorite	Woodfordian
304	soft caliche	2	8	(5)	2	20	65	gypsum	Pleistocene
140	pisolitic ls	3.5	45	41	14			chlorite	5
139	sand	8	52	22	4	22			2
138	sand	15.5	33	36	4	27			2
LITTLE RED LAKE SECTION									
NMP-376	pisolitic ls	0.3	36	48	16			chlorite	5
375	sand	14		amorphous					1
374	sand	26	82	12	4				1
QUAY-CURRY CO. LINE SECTION									
371	pisolitic ls	0.3	48	43	9				5
371A	banded cal.	0.5	83	11	6				4
370	massive cal.	8	75	16	9				4
369	cem. sand	12	11	(5)		84			2
368	sand	18	51	(5)	3	41			2
367	sand	30	56	(5)	3	36			2
366	sand	44	82	(5)	5	8			2
365	sand	63	91	5	4				1
364	sand	75	90	6	4				1
363	Triassic sts	96	44	56	?				Triassic

(table 1, continued) Sample No.	Lithology	Distance below top of section (ft)	% clay minerals (estimates are in parentheses) Montmorillonite	Illite	Kaolinite and Chlorite	Attapulgite	Sepiolite	Remarks	Ogallala clay mineral zone, or age, and % soluble
SANTA ROSA EAST SECTION									
NMP-311	pisolitic ls	0.3	46	36	18			chlorite	5
101	pisolitic ls	0.3	43	38	19			chlorite	5
312	dense caliche	2	42	37	21			chlorite	5
313	massive cal.	4	10	(5)	2	27	56		3
102	massive cal.	5	3	(5)	3	34	55		3
314	cem. sand	6		amorphous		tr	tr		3
315	cem. sand	8	53	(5)	2	40			2
103	cem. sand	10	53	(5)	2	40			2
316	cem. sand	10	47	(5)	3	45			2
317	sand	12	34	(5)	4	57			2
318	sand	16	21	(5)	4	70			2
319	sand	17	40	(5)	4	51			2
322A	Triassic ss	35	41	43	16			chlorite	Triassic
322B	Triassic sh	35	29	57	14			chlorite	Triassic
SANTA ROSA NORTHWEST SECTION									
NMP-108	pisolitic ls	0.3	14	55	31			chlorite	5
109	massive cal.	5	17	(5)	23	55			2
SANTA ROSA SOUTHEAST SECTION									
NMP-307	pisolitic ls	0.3	38	40	22			chlorite	5
145	pisolitic ls	0.3	36	47	17			chlorite	5
308	massive cal.	5	10	(5)	3	82			2
309	cem. sand	10	41	(5)	2	52			2
307	cem. sand	28	76	19	5				1
SANTA ROSA WEST SECTION									
NMP-301	pond marl	0.5	37	46	17				Woodfordian
107	pond marl	0.5	38	42	20				Woodfordian
302	sand	3		gypsum sand					Woodfordian
106	sand	3	24	52	24			gypsum	Woodfordian
105	sand	10	52	32	16			gypsum	Woodfordian
104	sand	13	63	27	10			gypsum	Woodfordian
TAIBAN EAST BORROW PIT SECTION									
NMP-159	platy caliche	0.5	63	27	10			chlorite	Kansan
158	grey sand	9	87	10	3				Kansan
157	red sand	17	74	22	4				Kansan
INDIVIDUAL SAMPLES									
NMP-125	banded cal.	0.5	71	18	11				4
175	pisolitic ls.	0.3	53	33	14			chlorite	5
205	soil caliche		57	36	7				Woodfordian

fig. 5. At depths greater than about 50 ft below the top of the formation the clay mineral assemblage consists predominantly of montmorillonite, ranging from 76 to 98-percent, with very minor amounts of kaolinite and illite, and locally accompanied by identifiable amounts of heulandite. This lowest zone is low in carbonate minerals, and will be referred to as the montmorillonite zone, or Zone 1. At about 50 ft below the top, small amounts of attapulgite (palygorskite) appear, and increase upward to about 10 ft below the top, locally reaching a maximum of about 85 percent of the clay mineral assemblage. As illite and kaolinite remain essentially constant at very small percentages, and as attapulgite increases upward at the expense of montmorillonite, this zone (from about 50 to about 10 ft) will be called the attapulgite zone, or Zone 2. Calcium carbonate increases sharply in the upper part of this zone. Opal, with a disordered tridymite structure (Mitchell and Tufts, 1973), commonly occurs in the middle and upper part of the attapulgite zone, as well as in the overlying sepiolite zone. The occurrence of opal only in association with attapulgite suggests that the opal is genetically related to the alteration of montmorillonite to these fibrous clay minerals.

Next above the attapulgite zone is an interval characterized by the presence of sepiolite in association with attapulgite (Zone 3). In this unit sepiolite generally exceeds attapulgite in amount, and the sum of the two may reach a maximum of about 85 percent of the clay mineral assemblage. Only in Zone 3 has the mineral sepiolite been detected. This zone is only 2 to 4 ft thick, contains small amounts of illite and kaolinite, and commonly the lowest percentage of montmorillonite found in the Ogallala Formation (table 1 and fig. 5). This zone generally contains a high percentage of calcium carbonate, ranging up to more than 90 percent. In contrast to the sepiolite-rich Woodfordian pond deposits which may contain authigenic dolomite (Glass and others, 1973), the mineral has not been detected in Zones 2 and 3 of the Ogallala. Opal, which locally occurs in the middle and upper part of the attapulgite zone, terminates upward in the sepiolite zone. Zones 1, 2, and 3 present an upward sequence of progressive clay mineral change through Pliocene time.

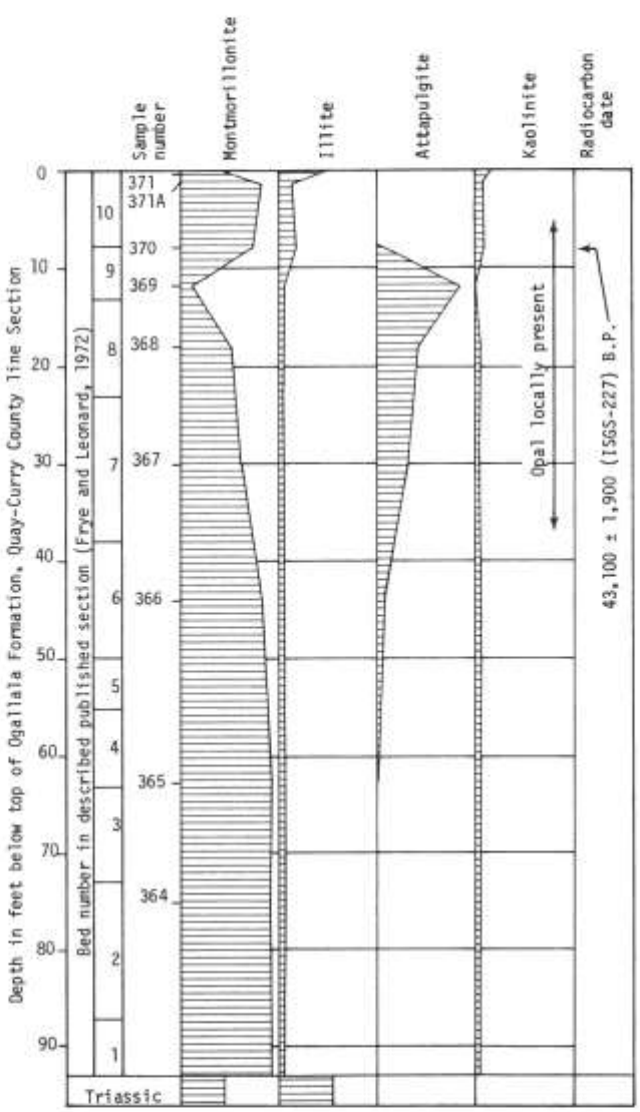

FIGURE 3 — Clay mineral compositions of the Ogallala Formation at the Quay-Curry County Line Section; SW¼ SE¼ SE¼ sec. 34, T. 9 N., R. 36 E., Quay County.

Sepiolite and attapulgite terminate sharply at the top of the sepiolite zone (Zone 3), commonly 4 to 6 ft below the top of the formation. Above is a zone 2 to 4 ft thick, characterized by a sharp increase in well-crystallized montmorillonite to an average of about 75 percent of the clay mineral assemblage, accompanied by an increase in illite (15 percent), and in kaolinite (10 percent). This thin zone is referred to as the montmorillonite-illite zone, or Zone 4.

The uppermost clay mineral zone, Zone 5, generally coinciding with the pisolitic limestone, is rarely more than 2 1/2 ft thick. The clay mineral composition is characterized by a decrease in montmorillonite, and a corresponding increase in illite and kaolinite, and generally the presence of chlorite. In contrast with the well-crystallized montmorillonite of Zone 4, the montmorillonite of Zone 5 is always weathered, and is characterized by poorly defined X-ray diffraction peaks (Glass and others, 1973). This rock is predominantly calcium carbonate, having a unique and distinctive appearance (Swineford and others, 1958) because of its contained pisolites, many of which have been brecciated and recemented. This uppermost zone has also been observed at several isolated localities in the region where only the pisolitic limestone was sampled.

All five of the Ogallala sections studied in detail are underlain by Triassic rocks. The striking contrast in clay mineral composition of Zone 1, the lowest zone of the Ogallala, with the composition of the underlying Triassic is shown graphically by the Quay-Curry County Line Section (fig. 3 and table 1), and the Santa Rosa E. Section (fig. 4 and table 1). The Triassic rocks at these and other localities show that the clay mineral assemblage commonly contains 50 percent or more illite, 45 percent or less montmorillonite, and locally kaolinite, chlorite, and corrensite. In contrast, as much as 98 percent montmorillonite, with little or no illite or kaolinite, occurs in Zone 1 of the Ogallala (figs. 2, 3 and table 1).

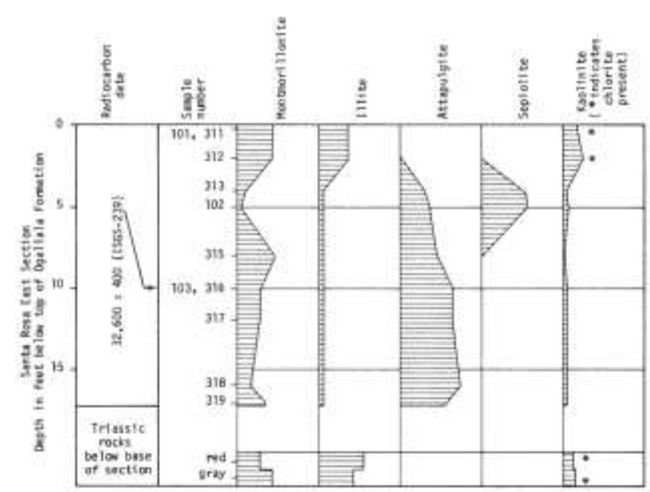

FIGURE 4 — Clay mineral compositions of the Ogallala Formation at the Santa Rosa East Section; NE¼ NE¼ sec. 4, T. 8 N., R. 22 E., Guadalupe County.

TABLE 2 – *Radiocarbon Age Determinations of Carbonate Samples from Central-eastern New Mexico*
(by Dennis D. Coleman, Illinois State Geological Survey laboratories)

Laboratory No.	Apparent date	Sample No.	Formation or deposit	Stratigraphic section, or location of sample
ISGS-148	16,010 ± 180	NMP-205	Wisconsinan soil caliche	NE¼ SE¼ sec. 14, T. 9 S., R. 37 E., Lea Co.
ISGS-200	29,470 ± 360	NMP-140	Ogallala Fm., pisolitic lm.	Lake Alamogordo E. Section (1)
ISGS-201	27,160 ± 540	NMP-108	Ogallala Fm., pisolitic lm.	Santa Rosa NW Section (2)
ISGS-203	41,500 ± 1,200	NMP-109	Ogallala Fm., 5 ft below top	Santa Rosa NW Section (2)
ISGS-205	32,160 ± 430	NMP-145	Ogallala Fm., pisolitic lm.	Santa Rosa SE Section (3)
ISGS-207	35,000 ± 850	NMP-175	Ogallala Fm., pisolitic lm.	NE¼ SE¼ SE¼ sec. 8, T. 9 S., R. 25 E., Chaves Co.
ISGS-212	30,880 ± 400	NMP-125	Ogallala Fm., 2 ft below top	SW¼ NW¼ NW¼ sec. 20, T. 3 N., R. 25 E., DeBaca Co.
ISGS-213	27,400 ± 500	NMP-159	Top of Kansan deposits	Taiban E. Borrow Pit Section (4)
ISGS-214	24,100 ± 300	NMP-301	Top of Wisconsinan terrace	Santa Rosa W. Section (5)
ISGS-216	20,490 ± 230	NMP-305	Pleistocene deposit	Lake Alamogordo E. Section (1)
ISGS-221	11,250 ± 150	NMP-306	Top, Pleistocene deposit	Lake Alamogordo E. Section (1)
ISGS-227	43,100 ± 1,900	NMP-370	Ogallala Fm., 8 ft below top	Quay-Curry County Line Section (6)
ISGS-228	26,190 ± 220	NMP-377	Top of Kansan deposit	Hagerman E. Section (7)
ISGS-232	31,700 ± 570	NMP-378	Kansan dep., 3 ft below top	Hagerman E. Section (7)
ISGS-239	32,600 ± 400	NMP-316	Ogallala Fm., 10 ft below top	Santa Rosa E. Section (8)
ISGS-240	33,680 ± 300	NMP-308	Ogallala Fm., 5 ft below top	Santa Rosa SE Section (3)

(1) NE¼ SE¼ SE¼ sec. 36, T. 5 N., R. 25 E., DeBaca Co.
(2) NW cor., sec. 36, T. 9 N., R. 20 E., Guadalupe Co.
(3) SE¼ sec. 22, T. 8 N., R. 22 E., Guadalupe Co. (Leonard and Frye, 1974)
(4) SE¼ SE¼ sec. 36, T. 3 N., R. 29 E., Roosevelt Co. (Leonard and Frye, 1974)
(5) S½ sec. 3, T. 8 N., R. 21 E., Guadalupe Co. (Leonard and Frye, 1974)
(6) SW¼ SE¼ SE¼ sec. 34, T. 9 N., R. 36 E., Quay Co. (Frye and Leonard, 1972)
(7) SW¼ SW¼ NW¼ sec. 17, T. 14 S., R. 27 E., Chaves Co.
(8) NE¼ NE¼ sec. 4, T. 8 N., R. 22 E., Guadalupe Co.

The clay mineral zones identified in the Ogallala Formation are consistent and persistent throughout central-eastern New Mexico. These mineral zones constitute a basis for regional stratigraphic correlation, for interpretation of Pliocene ecology, and for interpretation of the origin of the thick carbonate zone at the top of the formation.

CLAY MINERALS OF PLEISTOCENE DEPOSITS

A description of clay minerals in Pleistocene deposits of this region has been presented recently (Glass and others, 1973). To furnish an adequate background for this study of caliche development, several Pleistocene sections were sampled for additional study. The widespread Kansan deposits, and the strongly developed caliche zone at the top, are typified by the Taiban East Borrow Pit Section, and the Hagerman East Section (table 1 and fig. 6). The Kansan deposits are characterized by high percentages of montmorillonite, accompanied by moderate amounts of illite, and the presence of kaolinite. Kansan deposits occur above Permian rocks in extensive areas; the similarity of the two clay mineral assemblages suggests a sediment source relationship. At the Hagerman East Section, the upper part of the Kansan deposits is characterized by a zone of attapulgite, not found farther north.

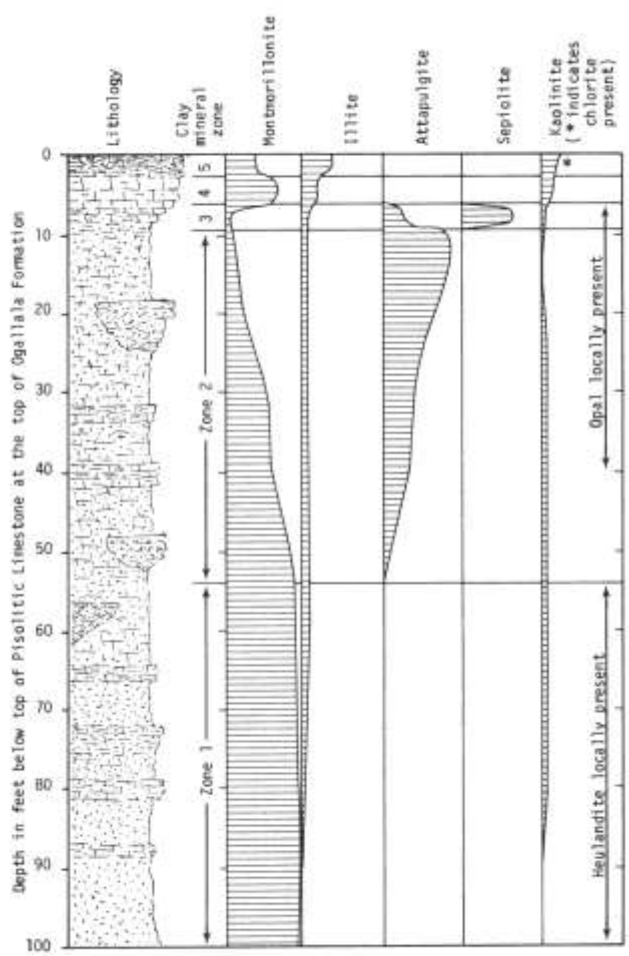

FIGURE 5 – Generalized composite clay mineral compositions of the Ogallala Formation in central-eastern New Mexico. Lithology is generalized for the region.

Younger Pleistocene terrace and pond deposits, generally lacking prominent caliche zones at the top, fall either into the category of a detrital clay mineral assemblage of montmorillonite, illite, and kaolinite, or into the category of the High Plains pond deposits characterized by sepiolite (Glass and others, 1973). However, two young (radiocarbon dated) Pleistocene sections contain unusual caliche zones at the top; their clay mineral sequences will be briefly described.

The Santa Rosa West Section (table I) contains a clay mineral assemblage (Glass and others, 1973) typical of the Wisconsinan terrace deposits along the Pecos River valley across the region — 63 percent montmorillonite where unweathered (NMP-104), moderate illite, kaolinite, and abundant gypsum, particularly in the upper part. The Santa Rosa West Section is capped at the top with a truly unique layer of calcium carbonate at the level of a terrace. This carbonate layer, containing abundant imprints of plant stems that form nuclei of deposition (fig. 7a), appears to be a pond marl. This carbonate layer contains about equal amounts of weathered montmorillonite and illite with lesser amounts of kaolinite — approximately the same clay mineral assemblage as occurs in the Ogallala pisolitic limestone, and surface sands of the High Plains.

Another exceptional Wisconsinan sequence is the Lake Alamogordo East Section (table 1). Above the Ogallala pisolitic limestone is a sequence of 3 1/2 ft of Pleistocene deposits. The lower part of the sequence is a soft calcareous deposit containing an abundance of sepiolite and some attapulgite among the clay minerals. However, 3 ft above the top of the pisolitic limestone, a zone of platy caliche is characterized by a high percentage of montmorillonite and illite, and a lesser content of kaolinite and chlorite — essentially the same clay mineral assemblage as in the pisolitic limestone below. Half a foot higher, at the top of the section, a hard, dense, platy caliche with an identical clay mineral assemblage occurs as the capping layer.

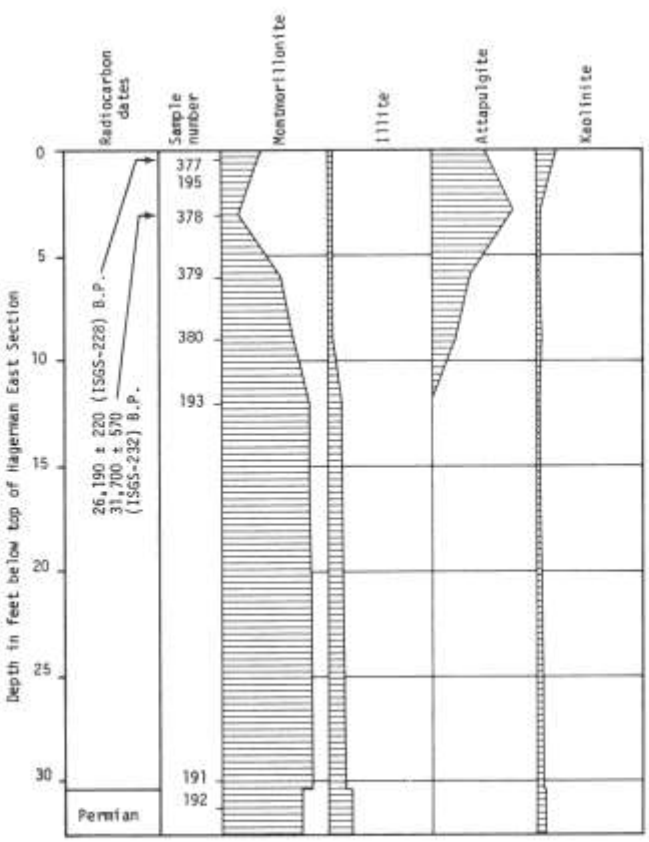

FIGURE 6 — Clay mineral compositions of the Kansan deposits at the Hagerman East Section; SW¼ SW¼ SW¼ sec. 17, T. 14 S., R. 27 E., Chaves County.

CLIMATIC HISTORY OF OGALLALA FORMATION

Because the deposition of caliche is genetically related to climate, examining the climatic history of Pliocene time in the southern Great Plains, as interpreted from the Ogallala Formation, is desirable. Based on the succession

FIGURE 7 — Caliches in central-eastern New Mexico. A) Marl at top of Santa Rosa West Section (dated 24,100 ± 300, ISGS-214 B.P.) that caps a Wisconsinan terrace of Pecos valley (NMP-301; S½ sec. 3, T. 8 N., R. 21 E., Guadalupe County). Note abundant imprints of plant stems and lack of any evidence of secondary precipitation. B) Pisolitic limestone (NMP-371) at top of Ogallala Formation at the Quay-Curry County Line Section (SW¼ SE¼ SE¼ sec. 34, T. 9 N., R. 36 E., Quay County).

of fossil remains of plants and mollusks, and using supplemental data from the lithology of the sediments, a climatic history of the Ogallala of western Texas to western Kansas has been presented (Frye and Leonard, 1957). Their interpretation was a history of slowly but progressively decreasing precipitation during at least the last half of Ogallala time, probably accompanied by increasing temperature. The clay mineral succession described here from eastern New Mexico may be interpreted in much the same way. The sediments of Zone 1 (montmorillonite zone) are detrital stream deposits, with small amounts of calcium carbonate. Above Zone 1 is a zone of progressively upward-increasing attapulgite (Zone 2) overlain by thin sepioliteattapulgite zone (Zone 3). Generally, the fibrous clay minerals attapulgite and sepiolite are developed mostly in situ by diagenetic processes, and do not represent transport from a remote source area. Therefore, the environment of their development is an index to local conditions. Because an alkaline environment is necessary for the development of attapulgite, this zone represents progressive decrease in precipitation (and/or increasing temperature) causing an increase in alkalinity in the surface waters. The thin sepiolite Zone 3 above the attapulgite Zone 2 represents further progression of the same trend. Furthermore, if the fibrous clay minerals are formed, at least in part, by alteration of detrital montmorillonite in the sediments, some resulting excess silica may be the source of the opal that occurs locally in the upper part of the attapulgite zone and the sepiolite zone.

The physiographic relationships of the Wisconsinan deposits of the region may aid in interpretation of magnesium concentration and sepiolite development. Those pond deposits near the level of the High Plains surface, and those associated with the highly permeable terrace deposits of Pecos valley, do not contain sepiolite. Those pond and lake deposits of the region that do contain abundant sepiolite are in relative lowland areas, such as the floor of abandoned Portales valley, and southern Lea County, south of the Ogallala escarpment. As these lowland ponds probably were water-table ponds in Woodfordian time, the episode of progressive desiccation caused them to be areas of ground-water discharge. Thus, the more soluble constituents such as magnesium were concentrated and a sepiolite-forming environment was produced. Applying this analogy to Zone 3 of the Ogallala suggests that progressive desiccation caused loss of ground water by upward movement by evapotranspiration for a short period, produced a magnesium-rich environment conducive to formation of attapulgite and sepiolite. Under wet conditions of downward-moving water, or the condition of lowered water table that exists today, sepiolite has not formed. Under well-drained conditions, such as represented by the permeable terrace deposits, magnesium is removed and authigenic kaolinite has formed.

The parallelism of climatic history interpreted from the fossil zones in western Texas and the clay mineral zones in eastern New Mexico is striking. Unfortunately, the lack of adequate fossil assemblages in eastern New Mexico and lack of clay mineral data from western Texas prevents a positive correlation of the sequences developed in the Ogallala from the two areas.

The top 4 to 6 ft of the Ogallala containing the thin but distinct clay mineral Zones 4 and 5, and dominated by abundant calcium carbonate, does not logically follow this progressive climatic history. Although the accumulation of a thick caliche deposit could be considered as the climax to the climatic history of the Ogallala, clay minerals indicating in situ diagenetic development are not present in the dense caliche of the top 6 ft.

The uppermost 4 to 6 ft of the Ogallala commonly consists of 90 percent or more of calcium carbonate. The uppermost 1 to 2 1/2 ft, where not removed by erosion, have been called pisolitic limestone (Swineford and others, 1958) because of the dense pisolites, commonly broken and recemented during several generations (fig. 7b) of brecciation and recementation. The clay mineral content of Zone 5 consists of detrital minerals resembling the Weathered clay minerals common in eolian surficial sands and late Pleistocene terraces (Glass and others, 1973); the clay minerals also contain chlorite which could not have persisted unweathered in surficial deposits since even middle Pleistocene time, and which is not present in any of the clay mineral zones below. This unexpected relationship prompted radiocarbon dates on this top layer, pisolitic limestone (table 2).

The 2- to 5-ft thick Zone 4 between the pisolitic limestone (Zone 5) and the top of the sepiolite (Zone 3), consists of dense, platy to massive caliche, 80 to 90 percent calcium carbonate, with a clay mineral assemblage of dominantly unweathered montmorillonite, with lesser illite and kaolinite — but no chlorite. The clay mineral assemblage resembles the high montmorillonite Pleistocene deposits of the region. This zone is sharply terminated at the top of the sepiolite (Zone 3). The clay minerals of Zones 4 and 5 clearly do not display the degree of weathering expected in a soil profile that had been at the surface since late Pliocene time, or even in a profile that had been at the surface since Kansan time (Glass and others, 1973). Therefore, they must represent added increments of Pleistocene clay minerals.

CALICHE

The term caliche has been applied to a wide variety of deposits of calcium carbonate and other salts that originated in many ways. In the United States the term caliche has been applied to deposits of calcium carbonate in the C-horizon of soil profiles, to efflorescence deposits of calcium carbonate and other salts in deserts, and to precipitates of calcium carbonate on surfaces of pre-existing rocks in a form commonly called travertine. In the context of this paper we include all 3 forms of deposit in the term caliche. Furthermore, we also include shallow pond deposits of calcium carbonate (marl) precipitated around plant stems, and complex deposits that involve not only the first 3 modes of origin, but also brecciation of older deposits followed by recementation.

Calcium carbonate is a readily soluble material. When water penetrating the surface has a pH below 7 because of organic acids in the solum, or constituents dissolved from the atmosphere, calcium carbonate may be dissolved and moved in solution. For these reasons, a deposit of caliche probably will not long remain unmodified at or near the land surface.

The pedocal soils, those soils containing accumulations of calcium carbonate at some depth below the soil surface, are characteristic of semiarid or moderately arid climates. The calcium is derived from carbonate minerals in the surface horizons, or by the breakdown of calcium-containing minerals such as feldspar, and is then precipitated as calcium carbonate when the solution moves downward in the solum. Also, some carbonate and clay minerals were probably added by eolian transport.

With the single exception of the vesicular pond marl at the Santa Rosa West Section (NMP-301), all the caliche deposits analyzed, dated, and described in this report were deposited by some variation of this process. Even the pond marl was produced by climatic effects because evaporation of the waters of the shallow pond was the prime cause of precipitation of calcium carbonate around the plant stems.

Validity of Radiocarbon Dates on Caliche

Numerous workers have reported radiocarbon ages determined on caliche deposits from throughout the world. However, these dates may not represent the true ages of the materials being studied. Williams and Polach (1971) compared dates on organic material to dates on associated caliche. They concluded that the ages determined on one-cycle soil caliche were from 500 to 7000 years too old.

One of the problems in interpreting caliche dates is in determining the initial C^{12}/C^{14} ratio of the carbonate material. For a radiocarbon date to be accurate, the initial C^{12}/C^{14} ratio must be equal to that of atmospheric CO_2. If the bicarbonate from which the carbonate was precipitated was partly derived from solution of older carbonates, the initial C^{12}/C^{14} ratio would be much higher than that for atmospheric CO_2, and the result would be an apparent radiocarbon age greater than the true age of the precipitate.

Williams and Polach (1971) have given the following equation for solution of limestone.

$$H_2O + CO_2 + CaCO_3 \rightarrow Ca^{++} + 2HCO_3^{-}$$

The equation shows that half of the carbon in the dissolved bicarbonate comes from the CO_2 and half from the $CaCO_3$. If the CO_2 is from the atmosphere and the $CaCO_3$ is "dead" (much older than 50,000 radiocarbon years, thus containing no detectable C^{14}), the radiocarbon age of the precipitated bicarbonate would be 5570 radiocarbon years (one C^{14} half-life) too old. If the dissolved $CaCO_3$ were not dead, the apparent age would be closer to the true age — the case in a pond or near-surface deposit where precipitation and resolution could take place.

Under these circumstances, the maximum error would be 5570 radiocarbon years. We have assumed, however, that the material dated was deposited entirely from solution. If some undissolved, dead $CaCO_3$ were mixed with the precipitated $CaCO_3$, the error would be much greater

For example, consider a sample of $CaCO_3$ that was precipitated 20,000 years ago: If the original bicarbonate solution obtained half of its carbon from dissolved, dead carbonate, the apparent age would be 25,570. If, however, the sample is a 50/50 mixture of precipitated $CaCO_3$ and detrital, dead $CaCO_3$, the apparent age would be 31,140 an error of 11,140 radiocarbon years. Some deposits probably contain even less than 50 percent precipitated $CaCO_3$, thus even larger errors could be encountered. A radiocarbon date on caliche therefore, should be regarded as the maximum age of the precipitated $CaCO_3$. If multiple cycles of solution and recrystallization have occurred, however, the date can represent only the maximum possible age for the last cycle of deposition.

Another problem 'encountered when dating caliche is surface contamination of modern carbon. Broecker and Orr (1958) have shown that errors resulting from exchange of CO_2 between the atmosphere and the surface layer of $CaCO_3$, followed by diffusion of carbonate ions into the lattice, are generally negligible. Surface recrystallization in solutions containing CO_2 obtained from the atmosphere, however, would produce significant error. For example, a sample of dead $CaCO_3$ which was contaminated with only 0.5 percent modern, pre-bomb (pertaining to advent of introduction of man-made C^{14} into atmosphere via nuclear devices) carbonate would give an apparent age of about 42,000 radiocarbon years B.P. If post-bomb CO_2 is considered, ages as young as 37,000 years could theoretically be obtained with only 0.5 percent contamination. This problem would not be as severe with younger samples, however. A sample 20,000 radiocarbon years, contaminated by 0.5 percent modern, pre-bomb carbon, would have an apparent age of 19,570. A total of 2 percent modern contamination would give an apparent age of 18,390.

The probability of modern contamination having occurred can be more easily evaluated than the initial C^{12}/C^{14}ratio. Extremely dense, nonpermeable materials are not likely to have had any recent contact with meteoric waters, except on the surface. Porous materials, however, could have been contaminated either by percolation of rainwater into the outcrop or by movement of ground water through the units.

Pleistocene Caliche

In the Pleistocene deposits in central-eastern New Mexico are at least 5 categories of caliche development. The first is represented by a single locality of caliche developed on the top of Wisconsinan pond deposits at the Lake Alamogordo East Section. Here the deposit immediately above the Ogallala pisolitic limestone contains a clay mineral composition (NMP-304) indicating a pond comparable to the High Plains ponds because the environment was conducive to the diagenetic development of sepiolite. This pond deposit was capped by caliche (NMP-305; 20,490 ± 230, ISGS-216) that developed just above the soft marl containing sepiolite. A thin layer of sediment that accumulated above this deposit and forms the surface layer reflects an episode of surface precipitation (NMP-306; 11,250 ± 150, ISGS-221); its clay mineral assemblage is similar to that of weathered Woodfordian terrace deposits of the Pecos River valley. Second is the soil caliche developed in Wisconsinan deposits (NMP-205; 16,010 ± 180, ISGS148). Third is the pond marl, the capping layer of a terrace at the Santa Rosa West Section (NMP-301; 24,100 ± 300, ISGS-214). The origin of this deposit was in a shallow pond — as shown by the abundant molds of plant stems (fig. 7a) and the lack of visible evidence of extensive solution or reprecipitation. The molds of plant stems are filled with loose, red-tan sand. This is the only locality in eastern New Mexico where we have observed a deposit of this type.

Fourth is the caliche that has developed in the upper part of the Kansan alluvial deposits. This caliche occurs as the Cca-horizon of a soil profile below a thick B-horizon (Glass and others, 1973). Where the A- and B-horizons have been removed by erosion, the caliche occurs as a dense, platy deposit at the surface (fig. 6). The fifth category of Pleistocene caliche is the cemented zone at the top of the extensive pediment veneers of the Pecos valley, especially well developed on the west side of the valley in Chaves County (Frye and Leonard, 1972), where a poorly sorted limestone gravel of the pediment veneer has been dissolved, cusped, and recemented. This type was well described by Bretz and Horberg (1949) who incorrectly assigned the middle Pleistocene pediment veneer to the Ogallala Formation. A possible sixth category of caliche on Pleistocene deposits occurs on a few small erosional remnants that may represent deposits of Nebraskan age (Leonard and Frye, 1974) at isolated localities in Chaves, DeBaca, Eddy, and Lea Counties. These deposits superficially resemble the pisolitic limestone and the underlying few feet of massive and platy caliche at the top of the Ogallala Formation, but, because of their physiographic setting and the character of the sediments below the caliche, are not correlated with the Ogallala. Because they have not been analyzed or studied in detail, their age and correlation are not firmly established.

If any radiocarbon dates for Pleistocene caliches can be used as a basis for determining the true age of the deposit, they will be helpful in interpretating the significance of the apparent ages determined on the Ogallala capping caliches. Thus, an examination of the Pleistocene dates from youngest to oldest is in order.

The youngest apparent age determined is 11,250 ± 150 (ISGS-221) on the uppermost, or surficial part of the platy caliche at the Lake Alamogordo East Section. However, half a foot below, a date of 20,490 ± 230 (ISGS-216) was determined on platy caliche in apparently conformable stratigraphic relations, and containing the same clay mineral assemblage (table 1). This uppermost unit of platy caliche that yielded these 2 dates is gradationally underlain by less than 3 ft of soft marl with a high sepiolite content, suggesting a pond deposit. The massive marl, in turn, rests on Ogallala pisolitic limestone with a determined date of 29,470 ± 360 (ISGS-200) — all 3 dates in a vertical distance of 3 1/2 ft. The 3 dates cannot reasonably reflect the age of initial deposition of the deposits involved. If the platy caliche dated 20,490 represents the concluding episode of pond deposition, and the date is one half-life, or a fraction of one half-life, older than the true age, the date would be within the range of the pond deposits of the Pecos valley area (Glass and others, 1973; Leonard and Frye, 1974). If such is the case, presumably the surface caliche only half a foot higher (11,250 ± 150) must be contaminated with very young carbon.

Soil caliche that developed as nodules up to ^{3}4 inch in diameter in the Cca-horizon of a soil developed in a High Plains pond deposit was dated 16,010 ± 180 (ISGS-148). At a locality a few miles away, mollusks from a similar pond deposit were dated 13,690 ± 160 (ISGS-147), but a younger profile occurs in eolian sands overlying the solum (Glass and others, 1973). The form of the nodules indicates only one cycle of caliche accumulation, but the range of years during which accumulation occurred is not known.

The vesicular pond marl at the Santa Rosa West Section dated 24,100 ± 300 (ISGS-214) has the physical appearance of a one-cycle deposit that has not been significantly modified by subsequent solution or precipitation. Furthermore, if the determined date is one half-life too old, the age approaches the range of the dates determined on mollusk shells from pond deposits associated with the Woodfordian terraces (Leonard and Frye, 1974) of the Pecos valley.

Three samples of caliche from Kansan deposits were radiocarbon dated. At the Taiban East Borrow Pit Section in the Kansan deposits below the floor of abandoned Portales valley, the capping layer of caliche was dated 27,400 ± 500 (ISGS-213), overlapping the young end of the range of dates determined on the Ogallala pisolitic limestone. More than 90 miles to the south, at the Hagerman East Section (fig. 6) in the Pecos valley, the uppermost layer of Kansan caliche was dated 26,190 ± 220 (ISGS-228), and a caliche sample 3 ft below the top of the section was dated 31,700 ± 570 (ISGS-232). These dates on Kansan caliche are not significantly different from the dates obtained from the upper part of the capping caliche of the Ogallala Formation. Clearly they reflect the same late Pleistocene and Holocene modifications that are reflected by the Ogallala capping caliche. At a few places in eastern New Mexico (Glass and others, 1973) soil caliche in Kansan deposits has been studied where it is below 3 ft, or more, of leached, clayey, red-brown B-horizon — in contrast to the localities dated where the initial A- and B-horizons have been stripped from the caliche surface. Possibly soil caliches protected by such deeply developed B-horizons will yield significantly older radiocarbon dates. Unfortunately, however, caliche from such a situation was not sampled for dating, although the clay mineral composition has been described (Glass and others, 1973).

The Ogallala Capping Caliche

Within the context of the clay mineral zonation of the Ogallala Formation, the sequence of Pleistocene caliches and their radiocarbon dates, and the derived climatic history of Pliocene and Pleistocene time, an interpretation is made of the development of the carbonate zone at the top of the Ogallala Formation. The uppermost alluvial sediments of the Ogallala were deposited sometime between 2 and 3 million years B.P., but the carbonate deposits that cap the sequence have yielded radiocarbon dates (table 2) ranging from 27,160 ± 540 (ISGS-201), to 43,100 ± 1,900 (ISGS-227). These dates confirm the conclusion reached on the basis of the clay mineral data that the capping carbonate zone was extensively modified during Pleistocene and Holocene time.

At the end of the period of Pliocene deposition, resulting in a widespread plain of alluviation, soil development proceeded in the sediments immediately underlying the surface. The climatic trend indicates that the climate during this initial episode of soil formation was semiarid to arid, and that the soil developed on the surface of the Ogallala alluvial plain must have been a pedocal profile, and may have developed a thick caliche zone in the solum before the first pluvial of the Pleistocene. Although a climatic history for Pleistocene time has been suggested for the southern Great Plains (Frye and Leonard, 1957), data from eastern-central New Mexico are meager for the interval from the end of Ogallala deposition until the major episode of Kansan alluvial sedimentation (Leonard and Frye, 1974), and the stabilization of extensive Kansan pediment veneers. Also, the available data do not furnish a reliable indication of Illinoian climate. As a result, the history of the capping carbonate zone prior to Wisconsinan time is largely by extrapolation from western Texas.

The depth of the Ogallala climax soil prior to Nebraskan time is unknown. However, cobbles of abraded, indurated caliche have been observed in the basal deposits of the Blanco Formation (Nebraskan) in western Texas, where the Blanco occurs below the eroded top of the Ogallala, demonstrating that a significant caliche zone existed on the High Plains surface prior to Nebraskan time. In the Kansan gravels, topographically below the Ogallala of east-central New Mexico, are many abraded cobbles and pebbles of dense, pisolitic caliche, indicating that caliche development has reached an advanced stage by Kansan time.

Four radiocarbon dates (table 2) were determined on samples of Ogallala pisolitic limestone. The apparent ages range from approximately 27,000 to 35,000 radiocarbon years B.P. The pisolitic limestone at the Lake Alamogordo East Section, with an apparent age of 29,470 ± 360 radiocarbon years B.P. (NMP-140, ISGS-200), is overlain by a Pleistocene caliche with a date of 20,490 ± 230 (NMP-305, ISGS-216). These dates might be interpreted to indicate that the climatic event causing deposition of the Pleistocene caliche at Lake Alamogordo East is responsible for recementing of the fractured pisolitic limestone throughout the area. If only one event had occurred, all samples of pisolitic limestone would not likely give the same apparent age, because the age would depend on the extent of fracturing and permeability controlling the amount of younger material added. Although possibly all these ages are the result of modern contamination, the pisolitic limestone is hard and dense and is not likely to have had significant amounts of modern water passing through it, except by way of fractures and joints. Possibly — or even probably other caliche-forming events have also affected the Ogallala cap rock during the last 50,000 years.

Two samples were dated from Ogallala Zone 4. The first, from DeBaca County, had an apparent radiocarbon age of 30,880 ± 400 (NMP-125, ISGS-212). This sample was from a position stratigraphically 2 to 4 ft below the pisolitic limestone, but was at the surface at the location where collected. The sample was, therefore, probably subjected to some modern contamination. The second sample from Zone 4 was from the Quay-Curry County Line Section and had an apparent age of 43,000 ± 1,900 (NMP-370, ISGS-227). This sample was from the lower part of Zone 4, where overlain by Zone 5. For this reason, the material is less likely to have been contaminated with modern carbon than the previous sample. As the amount of brecciation caused by dessication decreases with depth, the available space for precipitation also decreases, and the apparent age would be greater than near the surface.

In an attempt to determine the depth to which late Pleistocene caliche deposition had occurred, 3 samples from Zone 2 were dated. We anticipated these samples would give infinite dates of greater than 50,000 radiocarbon years B.P. (the limit of our dating capabilities). The caliche generally increases in permeability with depth, and therefore is more susceptible to modern infiltration by rainwater, solution, and reprecipitation near the outcrop surface. Therefore, these dates probably reflect modern contamination more than the late Pleistocene episode of deposition. The youngest of these 3 dates (32,600 ± 400, ISGS-239; NMP-316) was on a sample 10 ft below the surface, but was a permeable, carbonate-cemented sand. The next youngest date (33,680 ± 300, ISGS-240; NMP-308) was only 5 ft below the top of the formation, but was determined on a massive, moderately soft caliche, with a minor amount of sand. The oldest of the 3 dates (41,500 ± 1,200, ISGS-203; NMP-109) was also 5 ft below the top of the pisolitic limestone, but the rock dated was more dense and hard, with less apparent permeability than the other sample from the same depth. The oldest date determined (43,000 ± 1,900, ISGS-227; NMP-370), although from clay mineral Zone 4, was from 8 ft below the top of the formation and was determined on a dense caliche. To determine the depth of late Pleistocene deposition by radiocarbon dating, using samples from a core may be necessary, because of the probability of modern contamination on the outcrop. Even then, the sampling location should be carefully chosen to minimize the possibility of ground water flowing through the porous lower zones of caliche.

CONCLUSIONS

When these data are considered in conjunction with the clay mineral zones, lithology of the rocks, and the physiographic setting, some conclusions may be drawn. Above the sharp cutoff at the top of the sepiolite zone (Zone 3) of the Ogallala (4 to 6 ft below the top), the montmorillonite-illite Zone 4 is hardly distinguishable from the clay mineral assemblage in the unweathered Kansan deposits of the Portales valley region, and from the unweathered Wisconsinan terraces of Pecos valley. The clay minerals of the uppermost Zone 5, the pisolitic limestone, however, are similar to those of the weathered Wisconsinan terraces, and the weathered eolian sands locally overlying the Ogallala, except that chlorite may locally be present. The presence of scattered grains of quartz, with diameters exceeding 2 mm, removes the possibility that the deposit is entirely a superimposed thin layer of loess. Furthermore, the physiographic setting of the capping caliche at the top of prominent escarpments, and as the top of the highest uplands of the region, indicates that stream-carried sediments could not have been added to the sequence after the completion of deposition of the Ogallala Formation (Pliocene).

The repeated episodes of wet and dry climates through Pleistocene time have caused some solution, downward movement, and reprecipitation of carbonate in repetitive episodes. Even in the physiographic setting of the prominent Ogallala escarpments some small quantities of fine sediment from the topographically lower Pleistocene deposits could have been deposited by wind action, thus accounting for the source of the clay mineral Zones 4 and 5 in the top 4 to 6 ft. As the indigenous Ogallala clay minerals have been weathered through repeated climatic cycles since Pliocene time they have been destroyed, or rendered non-identifiable by X-ray analysis. Even the feldspar has been essentially removed by weathering in the top few feet of the Ogallala capping caliche, although present in the uppermost layer of Kansan caliche. Eolian deposition also may have contributed some carbonate material that was incorporated into the capping caliche.

These considerations suggest that the top 4 to 6 ft of the capping caliche of the Ogallala Formation (the thin clay mineral Zones 4 and 5) was developed to its present form and composition by events of the Quaternary. Some indigenous materials, such as the coarse grains of quartz, have been incorporated from the original Pliocene sediments, but the clay minerals and the lithologic characteristics of the carbonate deposit reflect the Pleistocene and Holocene history.

Appendix follows

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APPENDIX

Location of samples and described sections listed and described in this report are given below. Field descriptions are in field notes on file at the New Mexico Bureau of Mines & Mineral Resources, Socorro, New Mexico. Clay mineral compositions of some of these, and other samples from the region, are described by Glass, and others (1973), and several of the described stratigraphic sections have been published by Frye and Leonard (1972), and by Leonard and Frye (1974).

NMP-101	NE¼ NE¼ sec. 4, T. 8 N., R. 22 E., Guadalupe Co. (Santa Rose E. Section).
NMP-102	do.
NMP-103	do.
NMP-104	S½ sec. 3, T. 8 N., R. 21 E., Guadalupe Co. (Santa Rosa W. Section).
NMP-105	do.
NMP-106	do.
NMP-107	do.
NMP-108	NW cor. sec. 36, T. 9 N., R. 20 E., Guadalupe Co. (Santa Rosa NW Section).
NMP-109	do.
NMP-125	SW¼ NW¼ NW¼ sec. 20, T. 13 N., R. 25 E., DeBaca Co.
NMP-138	NE¼ SE¼ SE¼ sec. 36, T. 5 N., R. 25 E., DeBaca Co. (Lake Alamogordo E. Section).
NMP-139	do.
NMP-140	do.
NMP-145	SE¼ sec. 22, T. 8 N., R. 22 E., Guadalupe Co. (Santa Rosa SE Section).
NMP-157	SE¼ SE¼ sec. 36, T. 3 N., R. 20 E., Roosevelt Co. (Taiban E. Borrow Pit Section).
NMP-158	do.
NMP-159	do.
NMP-175	NE¼ SE¼ SE¼ sec. 8, T. 9 S., R. 25 E., Chaves Co.
NMP-191	SW¼ SW¼ NW¼ sec. 17, T. 14 S., R. 27 E., Chaves Co. (Hagerman E. Section).
NMP-192	do.
NMP-193	do.
NMP-194	do.
NMP-195	do.
NMP-200	SW¼ SE¼ sec. 18, T. 18 S., R. 34 E., Lea Co. (Buckeye SW Section).
NMP-201	do.
NMP-205	NE¼ SE¼ sec. 14, T. 9 S., R. 37 E., Lea Co.
NMP-301	S½ sec. 3, T. 8 N., R. 21 E., Guadalupe Co. (Santa Rosa W. Section).
NMP-302	do.
NMP-304	NE¼ SE¼ SE¼ sec. 36, T. 5 N., R. 25 E., DeBaca Co. (Lake Alamogordo E. Section).
NMP-305	do.
NMP-306	do.
NMP-307	SE¼ sec. 22, T. 8 N., R. 22 E., Guadalupe Co. (Santa Rosa SE Section).
NMP-308	do.
NMP-309	do.
NMP-310	do.
NMP-311	NE¼ NE¼ sec. 4, T. 8 N., R. 22 E., Guadalupe Co. (Santa Rosa E. Section).
NMP-312	do.
NMP-313	do.
NMP-314	do.
NMP-315	do.
NMP-316	do.
NMP-317	do.
NMP-318	do.
NMP-319	do.
NMP-322A	do.
NMP-322B	do.
NMP-363	SW¼ SE¼ SE¼ sec. 34, T. 9 N., R. 36 E., Quay Co. (Quay-Curry Co. Line Section).
NMP-364	do.
NMP-365	do.
NMP-366	do.
NMP-367	do.
NMP-368	do.
NMP-369	do.
NMP-370	do.
NMP-371	do.
NMP-371A	do.
NMP-374	SE¼ SW¼ sec. 25, T. 7 S., R. 28 E., Chaves Co. (Little Red Lake Section).
NMP-375	do.
NMP-376	do.
NMP-377	SW¼ SW¼ NW¼ sec. 17, T. 14 S., R. 27 E., Chaves Co. (Hagerman E. Section).
NMP-378	do.
NMP-379	do.
NMP-380	do.
NMP-381	NW¼ SW¼ sec. 18, T. 15 S., R. 31 E., Chaves Co. (KBIM Tower Section).
NMP-382	do.
NMP-383	do.
NMP-384	do.
NMP-385	do.
NMP-386	do.
NMP-387	do.
NMP-388	do.
NMP-389	do.
NMP-390	do.
NMP-391	do.
NMP-391A	do.
NMP-392	do.
NMP-418	SW¼ SE¼ sec. 18, T. 18 S., R. 34 E., Lea Co. (Buckeye SW Section).
NMP-419	do.
NMP-420	do.
NMP-421	do.