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Professional Paper 186—K

THE STRATIGRAPHY OF THE UPPER CRETACEOUS ROCKS NORTH OF THE ARKANSAS RIVER IN EASTERN COLORADO

BY

C. H. DANE, W. G. PIERCE, AND J. B. REESIDE, JR.

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Explanation of letter symbols on plate 64 (p. 212)

Kd, Dakota sandstone; Kgr, Graneros shale; Kgn, Greenhorn limestone; Kcl, Carlile shale; Kn, Niobrara formation; Kps, Sharon Springs member of the Pierre shale; Kp, Pierre shale above the Sharon Springs member (black dots marked Kpt indicate location of tepee buttes): Tu, Tertiary deposits; Qal, alluvium (shown only along the Arkansas River).

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THE STRATIGRAPHY OF THE UPPER CRETACEOUS ROCKS NORTH OF THE ARKANSAS RIVER IN EASTERN COLORADO

By C. H. Dane, W. G. Pierce, and J. B. Reeside, Jr.

ABSTRACT

A comparison of the stratigraphic sections of the rocks of Benton age in western Kansas and the southern foothill region of eastern Colorado indicates the probability that the lower members of the Greenhorn of Kansas merge westward into the upper part of the Graneros shale of the foothills, the Greenhorn of the type locality being much thinner than that of western Kansas and the Graneros of the type locality being much thicker than the Graneros of western Kansas. The Greenhorn of Prowers County, Colo., north of the Arkansas River, has, however, the thickness of the Kansas Greenhorn, and the member subdivisions of the Greenhorn made in Kansas can also be recognized in Prowers County. The Carlile shale, which overlies the Greenhorn, contains at the top the persistent but variable Codell sandstone member. This member, which contains the Carlile fauna, is believed to have been deposited in shallow water under conditions that were maintained for a considerable period of time. The faunal discontinuity between the Carlile and the overlying Niobrara formation is believed to represent a time lapse, although no evidence was seen to indicate subaerial erosion of the Carlile.

In the foothill region of Colorado the Niobrara consists of the Timpas limestone member and the overlying Apishapa shale member. The Timpas includes in its upper part limy shales and thin limestone beds which, in Kansas, have been excluded from the basal Hays limestone member. The Hays limestone member appears to be a more satisfactory lithologic and faunal unit, and the name is therefore extended into that part of Colorado east of the foothills and north of the Arkansas River. Similarly, the name "Smoky Hill" is extended from the chalk member of that name in Kansas to the marl member overlying the Hays limestone in eastern Colorado.

The basal portion of the overlying Pierre shale consists of black shale nearly devoid of fossils, to which the name "Sharon Springs member" is extended from the type locality in Wallace County, Kans. The overlying portion of the Pierre shale was not sufficiently studied to warrant the establishment of member names, although the "rusty zone", "tepee zone", and "transition zone" of previous authors are recognized.

The known invertebrate faunas of the several formations are briefly described, and the fauna of the overlying Fox Hills sandstone is also discussed because of its close relationship to the fauna of the "transition zone" of the Pierre shale.

INTRODUCTION

During parts of the summers of 1931 and 1932 C. H. Dane and W. G. Pierce spent about 8 months on a reconnaissance examination of a large area of the High Plains of eastern Colorado north of the Arkansas River. A few additional observations on the lower part of the Upper Cretaceous section in the southern foothills region were made by C. H. Dane in the fall of 1933. The invertebrate faunas collected during this reconnaissance have been studied by J. B. Reeside, Jr., who has also contributed many hitherto unpublished data. Although detailed work has been done in several areas in this region, no summary of the stratigraphy has been published for many years, and it has therefore seemed appropriate to publish the data gathered in the present study and to correlate them with the previous work. Because of the large size of the area traversed, it was not possible to make a rigorous examination of any specific problem, though considerable information was obtained concerning the lower portion of the Upper Cretaceous.

The location of the area within which most of the observations here recorded were made is shown on the index map (fig. 9), which also shows the location of some areas covered by previous reports.

The geologic map (pl. 64) shows the areas of outcrop of the principal stratigraphic divisions with reference to the major geographic and cultural features of the region. The base was taken from the United States Geological Survey map of Colorado compiled in 1922, with minor modifications of land lines, drainage, and culture observed by the writers in the field or suggested by more recently compiled maps. The mapping was done wholly by sketching, either on county maps or on so-called military maps of the Colorado State Highway Commission, which show towns, railroads, and graded roads with considerable accuracy.

The formations exposed are of Upper Cretaceous and Tertiary age. The Cretaceous rocks were laid down in the widespread seas that covered much of the western interior of the United States at that time. During the period in which the earlier deposits accumulated there was some differential warping of the crust, but subsidence later became more pronounced in an area centering somewhat north of Denver. During the epoch of subsidence a basin was formed which filled with sediments as it subsided, the later Cretaceous rocks thus having a much greater thickness toward the central part of the basin. Toward the end of the Cretaceous and early in the Tertiary the rising Rocky Mountains shed great quantities of debris eastward to form a series of nonmarine deposits. Although the

seas had withdrawn, the basin continued to subside until deposition ceased, probably in early Eocene time. The latest structural movements accompanying the rise of the Rocky Mountains completed the outline of the sedimentary basin and made it a structural basin as well. There ensued a period in which erosion was predominant, and the main outlines of the present areal geology of the Cretaceous rocks were formed by the beveling of the inclined strata. Somewhat later, in middle and late Tertiary time, gravelly debris was

FIGURE 9.—Index map showing location of area in eastern Colorado considered in this report (shown by short-dashed lines) and of some areas described in previous reports, including folios of the Geologic Atlas of the United States (cross-lined) and reports of the Colorado and Kansas Geological Surveys (dotted).

swept out from the mountains by streams, and widespread though comparatively thin deposits of gravel and sand were laid down. The great plain thus built up sloped gently eastward, its materials concealing the underlying Cretaceous rocks far east of the mountain front. Renewed erosion in still later epochs has cut away much of this plain and exposed the underlying rocks, but large areas of it still remain, and beneath these areas the Cretaceous rocks are wholly concealed. Even where the present surface has been cut below the level of the High Plains deposits, there are extensive areas where the Cretaceous rocks are concealed by relatively late terrace deposits at several levels, surface wash, and sand dunes, and the alluvial deposits of the larger streams. For the greater part also the Cretaceous rocks are soft and easily erodible, and even where not concealed by younger deposits they may be weathered into smooth ungullied sod-covered slopes in which the details of the lithology cannot be determined. No attempt has been made to indicate on the map the distribution of terraces, wash, or eolian deposits, which in places conceal the Tertiary as well as the Cretaceous rocks. The extent of the present alluvial plain of the Arkansas River is shown only approximately.

EARLIER WORK

The first comprehensive studies of the Cretaceous stratigraphy of the Arkansas Valley were begun by G. K. Gilbert in 1893 with the mapping of the Pueblo quadrangle.[1] Mapping of the Apishapa quadrangle[2] was begun in the following year, and a subsequent reconnaissance of the more easterly portion of the valley led to the publication in 1896 of Gilbert's report on the underground water of the Arkansas Valley in eastern Colorado.[3] The description of the Denver Basin,[4] a more northerly area of the foothills and adjoining plains, was published at about the same time, though based on field work of the preceding decade. In the succeeding years several other folios[5] were issued that followed closely the outlines of the stratigraphy laid down by Gilbert and that dealt with areas of the southern foothills and adjoining plains. In 1906 Darton's broader study[6] of the geology and underground water of the Arkansas Valley was published. With the appearance of the Castle Rock folio[7] in 1915 and the Colorado Springs folio[8] in 1916 the earlier phase of the geologic study of the region came to an end, and most of the larger features of the geology had been outlined. Several detailed reports on areas in the Arkansas Valley in Colorado have since appeared, and some features of the stratigraphic relations have been touched upon in other papers. In recent years several detailed studies have been made of the Upper Cretaceous rocks in western Kansas.[9] In these studies finer division of the Cretaceous beds has been made than in

[1] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), 1897.

[2] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), 1912.

[3] Gilbert, G. K., U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 351–601, 1896.

[4] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 1896.

[5] U. S. Geol. Survey Geol. Atlas, Elmoro folio (no. 58), 1899; Walsenberg folio (no. 68), 1900; Spanish Peaks folio (no. 71), 1901; Nepesta folio (no. 135), 1906.

[6] Darton, N. H., Geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Prof. Paper 52, 1906.

[7] U. S. Geol. Survey Geol. Atlas, Castle Rock folio (no. 198), 1915.

[8] U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (no. 203), 1916.

[9] Bass, N. W., Geologic investigations in western Kansas, pt. 2, Geology of Hamilton County: Kansas Geol. Survey Bull. 11, 1926. Elias, M. K., The geology of Wallace County, Kans.: Kansas Geol. Survey Bull. 18, 1931.

Fossils probably from the lower part of the Fox Hills sandstone—Continued

	Locality
Lucina occidentalis Morton	3
Sphaeriola cordata Meek and Hayden	2
Cardium whitei Dall	3, 5
Tellina sp	5
Mactra sp	7
Dentalium sp	5, 8
Lunatia sp	8
Pyrifusus newberryi Meek and Hayden	8
Baculites grandis Hall and Meek	1
Discoscaphites sp	2, 8

1. 15736, Leyden Gulch.
2. 15831, near center sec. 23, T. 5 S., R. 58 W.
3. 15866, center sec. 1, T. 1 S., R. 58 W.
4. 15868, SE¼ sec. 36, T. 1 N., R. 58 W.
5. 15869, NE¼ sec. 25, T. 1 S., R. 58 W.
6. 15870, SW¼ sec. 31, T. 1 S., R. 57 W.
7. 15874, SW¼ sec. 31, T. 1 S., R. 57 W.
8. 15964, NW¼SW¼ sec. 14, T. 13 S., R. 59 W., along road and bank of Horse Creek.

Fossils from the Fox Hills sandstone

	Locality
Nucula larimerensis Reeside	5, 9, 12
Nucula planimarginata Meek and Hayden	6, 7, 9, 10, 11, 12, 18
Nucula sp	13, 20
Yoldia evansi Meek and Hayden	8
Yoldia sp	17
Arca n. sp	2
Gervillia subtortuosa Meek and Hayden	2
Pteria nebrascana Evans and Shumard	14, 20
Ostrea glabra Meek and Hayden	15
Unio? sp	15
Anomia sp	7, 20
Mytilus? sp	20
Crenella elegantula Meek and Hayden	19, 20
Pholadomya n. sp	8, 14, 20
Tancredia americana Meek and Hayden	7
Lucina occidentalis Morton	16
Sphaeriola cordata Meek and Hayden	2, 14
Cardium whitei Dall	6, 7, 9, 10, 11, 13, 14, 15, 17, 18, 20
Protocardia subquadrata Evans and Shumard	6, 14, 20
Dosiniopsis nebrascensis Meek and Hayden	2
Dosiniopsis? sp	13, 14
Tellina scitula Meek and Hayden	14, 20
Tellina equilateralis Meek and Hayden	15
Sanguinolaria? sp	20
Mactra gracilis Meek and Hayden	1
Mactra formosa Meek and Hayden	7, 11, 13

Fossils from the Fox Hills sandstone—Continued

	Locality
Mactra sp	2, 6?, 14, 17
Dentalium gracile Hall and Meek	2, 6, 9, 10, 14, 18, 20
Dentalium sp	11
Lunatia concinna Meek and Hayden	9, 10
Lunatia subcrassa Meek and Hayden	7, 17
Turritella? sp	17
Melania? sp	15
Fusus? sp	10, 14
Fasciolaria (Piestochilus) culbertsoni Meek and Hayden	7, 13
Fasciolaria (Piestochilus) scarboroughi Meek and Hayden	7
Haminea sp	13, 17
Cinulia sp	20
Baculites ovatus Say?	3
Baculites sp	1?
Discoscaphites conradi (Morton)	14?, 20
Sphenodiscus (Coahuilites) cf. *S. (C.) pleurisepta* Conrad	4
Sphenodiscus lenticularis (Owen)	3, 9
Sphenodiscus sp	13
Belemnitella bulbosa Meek and Hayden	8
Mesojassoides gigantea Oman	20
Lamna sp	15, 17
Crocodile tooth	15
Rolled leaves and wood	20

1. 15737, Leyden Gulch.
2. 15748, east side of Fountain Creek, north of Colorado Springs, half a mile south of Pikeview station.
3. 15749, Fountain Creek, west of south end of the south lake of the two below Pikeview station.
4. 15835, northeast corner sec. 29, T. 4 S., R. 58 W.
5. 15817, sec. 33, T. 6 S., R. 57 W.
6. 15819, same locality as 15817, but higher.
7. 15821, NE¼ sec. 1, T. 7 S., R. 58 W.
8. 15824, sec. 32 or 33, T. 6 S., R. 57 W.
9. 15829, sec. 8, T. 7 S., R. 57 W., south of Beaver Creek.
10. 15833, southwest corner sec. 23, T. 5 S., R. 58 W.
11. 15837, SW¼ sec. 3, T. 5 S., R. 58 W.
12. 15839, north-central part of sec. 28, T. 8 S., R. 57 W.
13. 15840, northeast corner sec. 13, T. 8 S., R. 57 W.
14. 15846, SW¼NW¼ sec. 11, T. 5 N., R. 59 W.
15. 15865, SE¼ sec. 31, T 1 S., R. 59 W.
16. 15867, SE¼ sec. 35, T. 1 N., R. 58 W.
17. 15871, center sec. 27, T. 2 S., R. 58 W.
18. 15872, N½ sec. 12, T. 2 S., R. 58 W.
19. 15873, same locality as 15872, float.
20. 16306, 500 feet south of northeast corner sec. 27, T. 1 S., R. 58 W.

the rocks of equivalent age in eastern Colorado. Although the observations recorded in this paper were made in reconnaissance, they show that some of the smaller units set up in Kansas can be recognized also in eastern Colorado. Much of the area offers small promise of results to be obtained from detailed work, but in places exposures are sufficient to justify more careful stratigraphic study than has yet been carried out.

THE FORMATIONS

In the area shown on plate 64 the Upper Cretaceous rocks include the formations from the Dakota sandstone to the lower part of the Pierre shale. West and north of the mapped area the higher part of the Pierre shale is present, overlain by the Fox Hills sandstone, the Laramie formation, and the Dawson arkose. The uppermost beds of the Pierre shale and higher Cretaceous rocks are not discussed at length in this paper, but certain observations, particularly the record of fossil collections, are given.

The stratigraphic divisions of the Upper Cretaceous rocks described in this paper are as follows:

- Fox Hill sandstone.
- Pierre shale:
  - Transition zone.
  - Tepee zone.
  - Rusty zone.
  - Sharon Springs shale member (barren zone).
- Niobrara formation: (Foothill region, Colo.)
  - Smoky Hill marl member. } Apishapa shale member.
  - Hays limestone member. } Timpas limestone member.
- Carlile shale:
  - Codell sandstone member.
  - Blue Hill shale member.
  - Fairport chalky shale member.
- Greenhorn limestone.
- Graneros shale.
- Dakota sandstone.

DAKOTA SANDSTONE

The Dakota sandstone, which is the basal formation of the Upper Cretaceous series of this region, crops out in a narrow strip adjacent to the alluvial plain along the north side of the Arkansas River and extends from the northwestern part of T. 23 S., R. 51 W., to the southwestern part of T. 22 S., R. 47 W. Only the upper part of the formation is exposed. In the exposures observed by the writers it consists principally of buff and white, uniformly fine-grained, cross-bedded sandstone, with weathered surfaces pitted. As much as 40 feet of sandstone of this type is exposed at one locality, but elsewhere the exposed thickness is much less. The total thickness is somewhat variable but probably does not exceed 100 feet.[10] Where a more nearly complete section is exposed south of the Arkansas River it is described as a hard massive or quartzitic sandstone.[11] Carbonaceous and lignitic layers and fossil leaves of Upper Cretaceous age are found locally in the sandstone.

GRANEROS SHALE

Exposures of the next overlying formation, the Graneros shale, occur in a narrow belt north of the Arkansas River and extending from a point south of Fort Lyon on the east to a point south of Wiley on the west, and also east of Holly in a small area near the Kansas-Colorado State line.

The Graneros shale was defined by Gilbert[12] as a laminated argillaceous shale from 200 to 210 feet thick, the lowest formation of the Benton group. It was named from a creek in the northern part of the Walsenburg quadrangle.

The formation consists predominantly of dark-gray to black fissile noncalcareous shale. Because it is soft and easily erodible and because of the widespread deposition of terrace sands along the Arkansas River, exposures are so small and scattered that little information on the details of lithology, thickness, and stratigraphic relations can be obtained in this area.

The basal part of the Graneros is exposed at various places from sec. 4, T. 23 S., R. 51 W., eastward to the southwestern part of T. 22 S., R. 49 W. The basal Graneros in this area consists of well-bedded nonsandy shale, with thin bentonite beds at places. Although the basal contact was everywhere concealed, there seems to be an abrupt change in lithology from the cross-bedded sandstone of the underlying Dakota sandstone. In other areas there is a transition zone of sandy shale at the base of the Graneros. In Hamilton County, Kans., the basal 8 or 10 feet of the formation contains lenses of impure sandstone and sandy shale and layers of iron concretions 2 to 8 inches in diameter.[13] South of the Arkansas River, in the La Junta area,[14] several feet of alternating shales and sandstones at the top of the Dakota form a transition to the overlying Graneros, and similar transitional relations have been observed in the vicinity of Pueblo[15] and of Colorado Springs.[16]

[10] Duce, J. T., Geology of parts of Las Animas, Otero, and Bent Counties; Colorado Geol. Survey Bull. 27, pt. 3, pp. 89–90, 1924.

[11] Darton, N. H., Geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Prof. Paper 52, pp. 25–27, 1906.

[12] Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 564, 570, 1896.

[13] Bass, N. W., Geologic investigations in western Kansas, pt. 2, Geology of Hamilton County: Kansas Geol. Survey Bull. 11, p. 72, 1926.

[14] Patton, H. B., Underground water possibilities for stock and domestic purposes in the La Junta area, Colo.: Colorado Geol. Survey Bull. 27, pt. 1, p. 14, 1924.

[15] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

[16] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (no. 203), p. 8, 1916.

In Hamilton County, Kans.,[17] the Graneros shale is from 60 to 65 feet thick. It is believed to have about the same thickness in the extreme eastern portion of the Arkansas Valley in Colorado, where, in addition, the same divisions of the overlying Greenhorn limestone may be recognized as in Hamilton County. In the northeastern part of Bent County, Colo., however, the Graneros shale is estimated by the writers to be about 200 feet thick, and although the overlying Greenhorn limestone is there incompletely exposed, it seems to be much thinner than in western Kansas. This relation suggests that the Graneros has thickened westward at the expense of the Greenhorn. In the western part of Bent County and in Otero County[18] the Graneros has a thickness of about 200 feet, and farther west[19] it is from 200 to 220 feet thick. In a section measured by the writers at Colorado City, west of Colorado Springs, the Graneros shale is 210 feet thick.

Lithologic subdivisions of the Graneros were not distinguishable in the small scattered exposures observed within the area covered by this report. In the region of La Junta and farther west in the Arkansas Valley[20] the middle portion of the Graneros includes nearly black shales which contrast with somewhat lighter colored shales above and below. The subdivision into a nearly black middle portion and lighter-colored upper and lower portions is also recorded farther south in the vicinity of Walsenburg and Trinidad.[21] The thickness in those localities is given as 200 to 210 feet. This is also about the thickness of the Graneros exposed at a locality about 10 miles northwest of Vermejo Park, on the east flank of the Sangre de Cristo Range, in New Mexico near its northern boundary. A calcareous concretionary zone occurs at 30 to 40 feet above the base, and a thin calcareous sandstone or sandy limestone occurs 45 to 50 feet below the top. In the Apishapa quadrangle[22] a bed of impure, sparingly fossiliferous limestone 12 to 14 inches thick lies from 65 to 75 feet above the base, and a 6-inch bed of hard sandstone occurs a few feet above the limestone. At 80 feet above the base of a section of Graneros measured by the writers at Colorado City, west of Colorado Springs, there is a prominent thin-bedded sandstone 1 foot thick with 2 feet 6 inches of gray sandy shale below it. Over the western part of the area described in this report and a considerable region to the west and south the Graneros seems to maintain a fairly uniform thickness, and it is likely that a few individual beds in it may be recognized and traced over large areas.

Bentonite beds from a fraction of an inch to a few inches thick occur at several horizons within the Graneros. Although they afford a potentially useful means of detailed correlation, the inadequacy of exposures over much of the portion of eastern Colorado here discussed makes it unlikely that such detailed correlation can be effected without very careful recording of the formation where it is penetrated by wells. Southwest of Las Animas a bed of bentonite 3 feet thick[23] occurs about 85 feet above the base of the Graneros and has been recorded as "talc" in several wells drilled for water in the La Junta region. No beds of equal thickness are known elsewhere in this region. Beds of similar thickness have, however, been recorded in the lower part of the Benton[24] shale of northeastern Colorado, which is the equivalent of the Graneros shale and the overlying Greenhorn and Carlile formations of the Arkansas Valley.

The fauna of the Graneros shale is scanty and imperfectly known. A small simple oyster somewhat larger and more regular in form than *Ostrea congesta* is abundant in sandy limestone near the top of the Graneros shale in the region of the Apishapa quadrangle.[25] Gilbert, during his work in the Arkansas Valley, collected from the lower part of the Graneros the following fossils, largely unnamed species: Corals, several species; pelecypods, *Leda* sp., *Arca* sp., *Inoceramus* aff. *I. bellvuensis* Reeside, *Pteria* sp., *Pecten* sp., *Lucina* sp., *Dosinopsis* sp.; scaphopod, *Dentalium* sp; gastropods, *Turritella whitei* Stanton, *Mesostoma occidentalis* Stanton, *Cinulia?* sp., *Actaeon propinquus* Stanton; cephalopods, a nautiloid, *Mammites* sp., *Metacalycoceras* sp., *Borissjakoceras* sp., *Turrilites* sp. Bass[26] reported *Ostrea* n. sp., small simple type, and *Inoceramus*, n. sp. related to *I. fragilis* Hall and Meek from western Kansas.

A section of the Benton shale was measured by the writers along the south fork of Bear Creek 1.3 miles south of the place where the main road from Mount Morrison to Denver crosses the Dakota sandstone hogback. About 10 feet above the top of the Dakota sandstone and thus in beds equivalent to the Graneros shale the writers collected *Holcolepis pulchellus* Cockerell and *Leucichthyops vagans* Cockerell, species originally described from the Mowry shale. Several other small lots of fossils were collected at horizons 250 to 300 feet

[17] Bass, N. W., op. cit., p. 72.

[18] Patton, H. B., op. cit., p. 14.

[19] Gilbert, G. K., op. cit. (Pueblo folio), p. 3. Fisher, C. A., U. S. Geol. Survey Geol. Atlas, Nepesta folio (no. 135), p. 2, 1906.

[20] Patton, H. B., op. cit., p. 14. Gilbert, G. K., op. cit. (Pueblo folio), p. 3. Fisher, C. A., op. cit., p. 2. Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), p. 5, 1912.

[21] U. S. Geol. Survey Geol. Atlas, Walsenburg folio (no. 68), p. 1, 1900; Elmoro folio (no. 58), p. 1, 1899.

[22] Stose, G. W., op. cit., p. 5.

[23] Patton, H. B., op. cit., pp. 14–15.

[24] Mather, K. F., Gilluly, James, and Lusk, R. G., Geology and oil and gas prospects of northeastern Colorado: U. S. Geol. Survey Bull. 796, pp. 81–83, 1928.

[25] Stose, G. W., op. cit., p. 6.

[26] Bass, N. W., op. cit., p. 73.

Fossils from the "transition zone" of the Pierre shale—Contd.

	Locality
Anchura? sp	31?
Haminea subcylindrica (Meek)	3
Cinulia (*Oligoptycha*) *concinna* Hall and Meek	3, 32
Baculites grandis Hall and Meek	2, 11, 12, 17, 20, 24, 25, 29?, 31
Baculites sp	7, 17, 28, 34, 35, 36, 37, 38, 40?
Discoscaphites conradi (Morton)	30, 39
Discoscaphites cheyennensis (Owen)	3
Discoscaphites mandanensis (Morton)	5, 17, 22
Discoscaphites cf. *D. abyssinus* (Morton)	20
Discoscaphites cf. *D. nicolleti* (Morton)	22
Discoscaphites sp	4, 6, 7, 8, 9, 11, 16, 18, 20, 22?, 23, 27
Acanthoscaphites sp	33?, 35, 37?
Sphenodiscus lenticularis (Owen)	6
Belemnitella bulbosa Meek and Hayden	26
Decapod crustacean, undetermined	4

1. 15802, north tributary of Fountain Creek, north of Colorado Springs.
2. 15806, SW¼ sec. 35, T. 13 S., R. 58 W.
3. 15814, 15.1 miles north of Limon on Brush road.
4. 15815, 15.1 miles north of Limon on Brush road, above 15814.
5. 15816, 21.3 miles from Limon, just east of road bridge across Beaver Creek on road to Agate.
6. 15825, NE¼ sec. 24, T. 2 S., R. 55 W.
7. 15826, 9.1 miles north of Last Chance store.
8. 15827, NE¼ sec. 15, T. 3, S., R. 56 W.
9. 15828, SW¼ sec. 5, T. 2 S., R. 55 W.
10. 15830, NW¼ sec. 6, T. 10 S., R. 55 W.
11. 15832, SE¼ sec. 36, T. 9 S., R. 55 W.
12. 15834, NW¼ sec. 30, T. 9 S., R. 55 W.
13. 15804, one-eighth mile north of southeast corner sec. 3, T. 14 S., R. 58 W.
14. 15838, SW¼ sec. 33, T. 3 S., R. 58 W.
15. 15842, northeast corner sec. 1, T. 2 S., R. 58 W.
16. 15844, SW¼ sec. 7, T. 2 S., R. 53 W.
17. 15845, SW¼ sec. 29, T. 11 S., R. 56 W., East Rush Creek.
18. 15848, NW¼ sec. 6, T. 2 N., R. 55 W.
19. 15849, southwest corner sec. 1, T. 5 N., R. 59 W.
20. 15850, center sec. 4, T. 13 S., R. 57 W., Rush Creek.
21. 15851, NE¼ sec. 30, T. 13 S., R. 58 W., Little Horse Creek.
22. 15852, S½ sec. 20, T. 13 S., R. 58 W.
23. 15853, N½ sec. 26, T. 12 S., R. 56 W.
24. 15856, S½ sec. 7, T. 14 S., R. 57 W.
25. 15857, NW¼ sec. 13, T. 14 S., R. 58 W., Horse Creek.
26. 15875, SW¼ sec. 16, T. 8 N., R. 57 W.
27. 15876, E½ sec. 4, T. 8 N., R. 55 W., South Pawnee Creek.
28. 15956, SW¼ sec. 31, T. 13 S., R. 66 W., Monument Creek north of Colorado Springs.
29. 15961, center SW¼ sec. 30, T. 13 S., R. 66 W.
30. 15969, SE¼ sec. 3, T. 1 N., R. 43 W., 3 miles east of Wray.
31. 15971, NW¼ sec. 6, T. 2 S., R. 42 W.
32. 16307, SE¼ sec. 5, T. 3 S., R. 57 W.
33. 15955, SW¼ sec. 21, T. 14 S., R. 66 W., 2 miles southeast of Colorado Springs.
34. 15957, NW¼ sec. 31, T. 13 S., R. 66 W., Monument Creek, north of Colorado Springs.
35. 15958, NW¼ sec. 31, T. 13 S., R. 66 W.
36. 15960, NW¼ sec. 31, T. 13 S., R. 66 W.
37. 15970, near center sec. 21, T. 2 S., R. 43 W.
38. 15805, NW¼ sec. 2, T. 14 S., R. 58 W., bank of Horse Creek 250 feet east of bridge.
39. 15836, NE¼ sec. 13, T. 9 S., R. 56 W.
40. 15803, line between secs. 3 and 10, T. 14 S., R. 58 W.
41. 15807, E½ sec. 33, T. 13 S., R. 58 W.

FOX HILLS SANDSTONE

The Fox Hills sandstone, which overlies the Pierre shale, outcrops north and northwest of the area shown on plate 64. Its geographic distribution and some features of its stratigraphic relations with the Pierre shale are briefly discussed in another paper[88] dealing with the later Cretaceous formations of the Denver Basin. Because of the faunal relationships between the transition zone of the Pierre shale and the Fox Hills sandstone it is desirable to include in this paper a summary of identifications of fossils collected from the Fox Hills.

As used by the writers the name "Fox Hills sandstone" is applied to a unit ranging from 200 to a little more than 300 feet in thickness, consisting in the lower part of buff or brown sandstone and sandy shale that contains large gray to brown hard sandy concretions and in the upper part chiefly of soft sand or poorly consolidated white sandstone. In general this is also the way the Fox Hills of eastern Colorado was restricted by the Rocky Mountain Association of Petroleum Geologists in 1932.[89]

Because the contact of the Fox Hills sandstone and the Pierre shale is transitional in many places and because the zones of large concretions at the base of the Fox Hills were not traced in detail over the complete area from which collections were made, the fossils collected from the Fox Hills sandstone are shown in two lists. The first shows species in lots whose position is somewhat doubtful; that is, they may possibly belong to the transition zone of the Pierre shale, though the writers believe them more likely to represent Fox Hills horizons; the second shows the species in lots assigned with confidence.

The fauna contains many species that appear first in sandy rocks at various horizons in the Montana group of other areas, though such species as *Baculites grandis* Hall and Meek, *Discoscaphites conradi* (Morton), and *Sphenodiscus lenticularis* (Owen) always indicate a very late Cretaceous horizon wherever found. Some of the lots—for example, collection 15865—show a definite admixture of nonmarine elements, a not unusual occurrence in the Fox Hills.

Fossils probably from the lower part of the Fox Hills sandstone

	Locality
Solemya bilix White	3
Solemya? sp	8
Pteria nebrascana Evans and Shumard	5, 6
Volsella cf. *V. meeki* (Evans and Shumard)	4
Crenella elegantula Meek and Hayden	5
Pholadomya n. sp	3

[88] Dane, C. H., and Pierce, W. G., Dawson and Laramie formations in southeastern part of Denver Basin, Colo.: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 10, pp. 1308–1328, 1936.

[89] Lovering, T. S., Aurand, H. A., Lavington, C. S., and Wilson, J. H., Fox Hills formation, northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 16, no. 7, pp. 702–703, 1932.

FAUNA

The fossils collected from the Pierre shale by the writers are listed below. The first list contains fossils from the beds between the transition zone and the base of the "tepee zone", with the exception of collections 15752, 15753, 15757, 15864, and 15962, which came from the lower part of the formation. The second list includes fossils from the transition zone in the uppermost part of the Pierre.

Fossils from the Pierre shale below the transition zone

	Locality
Cliona sp., borings	31
Inoceramus barabini Morton	3, 21, 24
Inoceramus sagensis Owen	5, 6, 7, 8, 9, 11, 12, 13, 15, 16, 18, 22, 26, 31
Inoceramus sp	14, 20, 28, 29, 30, 31
Ostrea cf. *O. congesta* Conrad	24, 28
Anomia sp, probably new	11
Lucina occidentalis Morton	9, 10, 15, 17, 23, 25, 26, 28, 30
Lucina subcrassa Meek and Hayden	25
Lucina sp	19, 31
Mactra gracilis Meek and Hayden	4, 30
Mactra canonensis Meek	1, 2, 4
Dentalium gracile Hall and Meek	11, 30
Lunatia dakotensis Henderson	30
Aporrhais sp	25
Fasciolaria sp	25
Anchura sp	16, 29?
Baculites compressus Say	9, 31
Baculites ovatus Say	2, 7, 25, 30
Baculites ovatus Say var. *haresi* Reeside	5, 26
Baculites sp	11, 12, 16, 27, 28, 29
Exiteloceras? sp	25
Didymoceras cf. *D. beecheri* Hyatt	26
Parapachydiscus complexus (Meek)	29
Acanthoscaphites nodosus (Owen) typical form	31
Acanthoscaphites nodosus (Owen) var	1, 9, 10, 20, 28
Acanthoscaphites quadrangularis (Meek)	24, 27
Acanthoscaphites sp	15, 18, 22
Placenticeras meeki Boehm	11
Hypsodon? radiatulus Cockerell	6

1. 15732, Leyden Gulch, north of Golden, about 5,000 feet above the base of the Pierre.
2. 15733, Leyden Gulch, nearly the same as 15732.
3. 15734, Leyden Gulch, nearly the same as 15732.
4. 15735, Leyden Gulch, nearly the same as 15732.
5. 15752, opposite Piñon station, 6.2 miles north of Eden on Pueblo-Colorado Springs highway.
6. 15753, west of Pueblo, north of Arkansas River, east of Dry Creek Valley.
7. 15757, northeast corner sec. 18, T. 16 S., R. 66 W., south of Little Fountain Creek, southwest of Colorado Springs.
8. 15759, SE¼ sec. 15, T. 15 S., R. 65 W., at bridge on abandoned railroad grade.
9. 15750, near center of sec. 3, T. 17 S., R. 65 W., 1 mile southeast of Little Buttes.* [87]
10. 15809, NW¼ sec. 19, T. 15 S., R. 57 W.
11. 15810, secs. 14 and 23, T. 17 S., R. 55 W.
12. 15812, NE¼ sec. 27, T. 15 S., R. 55 W.
13. 15841, along highway, sec. 3, T. 11 S., R. 54 W.

[87] Collections made from the core rock of tepee buttes are indicated by asterisks.

Fossils from the Pierre shale below the transition zone—Contd.

14. 15843, SW¼ sec. 36, T. 13 S., R. 56 W.
15. 15847, NE¼ sec. 30, T. 13 S., R. 56 W.
16. 15854, NW¼ sec. 26, T. 14 S., R. 55 W.
17. 15855, SW¼ sec. 14, T. 14 S., R. 57 W.
18. 15858, NE¼ sec. 36, T. 10 S., R. 53 W.
19. 15859, NE¼ sec. 34, T. 10 S., R. 52 W.
20. 15860, SE¼ sec. 30, T. 10 S., R. 51 W.
21. 15861, NE¼ sec. 26, T. 8 S., R. 50 W.
22. 15862, SE¼ sec. 35, T. 9 S., R. 51 W.
23. 15863, SE¼ sec. 28, T. 11 S., R. 52 W.
24. 15864, NW¼ sec. 22, T. 13 S., R. 51 W.
25. 15755, 3.1 miles north of Belle Plaine, which is 2.7 miles east of Fountain Creek at Pueblo.
26. 15756, same locality as 15755, 40 feet higher.
27. 15808, sec. 1, T. 21 S., R. 59 W., 5.3 miles north of Olney Springs.*
28. 15813, 2.6 miles south of Karval.
29. 15962, NE¼ sec. 34, T. 14 S., R. 67 W., 500 feet above base of Pierre.
30. 15963, SW¼ sec. 20, T. 14 S., R. 66 W., brick pit southeast of Colorado Springs.
31. 16072, NW¼NE¼ sec. 1, T. 13 S., R. 47 W.*

Fossils from the "transition zone" of the Pierre shale

	Locality
Robulus sp	5, 10, 20, 27
Serpula? sp	20
Lingula sp	3, 8
Solemya bilix White	3
Nucula planimarginata Meek and Hayden	3, 4, 8, 13
Nucula larimerensis Reeside	17?, 18
Nucula sp	6, 20, 22?, 26, 27
Yoldia scitula Meek and Hayden	28
Yoldia evansi Meek and Hayden	3, 4, 5, 6, 15, 19, 28
Yoldia sp	18?
Perissonota? sp	4
Inoceramus sagensis Owen	20, 22, 28, 31, 36
Inoceramus altus Meek?	39
Inoceramus fibrosus (Meek and Hayden)	4, 6, 7, 9, 10, 11, 12, 16, 17, 18, 22, 25, 30, 31
Inoceramus sp	9, 27, 38
Pteria nebrascana Evans and Shumard	26, 32
Pteria sp	20
Pecten nebrascensis Meek and Hayden	28
Lima n. sp., several	4
Crenella elegantula Meek and Hayden	14
Pholadomya n. sp	14
Cuspidaria ventricosa Meek and Hayden	4, 8
Veniella humilis Meek and Hayden	19
Eriphyla gregaria Meek and Hayden?	3
Lucina occidentalis Morton	10, 23, 27, 30
Lucina sp	3, 6, 19, 26?
Protocardia subquadrata Evans and Shumard	4, 15, 17
Tellina scitula Meek and Hayden	19
Mactra gracilis Meek and Hayden	1, 2, 11, 13, 22, 28, 34, 35, 36, 38, 40, 41
Mactra canonensis Meek	33
Mactra sp	14?, 17
Dentalium gracile Hall and Meek	20, 27?
Dentalium sp	4
Lunatia dakotensis Henderson	3, 9?, 20, 33
Lunatia sp	27, 37?
Turritella sp., probably new	3
Fasciolaria? cf. *F. cheyennensis* Meek and Hayden	4?, 20

above the base of the Benton in this section. These lots include the species in the following list:

Globigerina sp.
Globotruncana sp.
Inoceramus sp.
Ostrea sp.
Ptychodus sp.

GREENHORN LIMESTONE

The Greenhorn limestone was differentiated as a formation by Gilbert.[27] It was so named from Greenhorn station, 14 miles south of Pueblo, and Greenhorn Creek. The formation as described by Gilbert is from 25 to 40 feet thick and consists of alternating beds of fine-grained, compact, pale bluish-gray limestone and light-gray laminated calcareous shale. The Greenhorn as recognized in western Kansas, however, has a thickness of 100 to 130 feet and includes three recognizable members in some places and four in others. It seems desirable to compare the exposures of the formation along the north side of the Arkansas Valley in Colorado with the thicker and divisible section of western Kansas.

In Hamilton County, Kans., which adjoins Colorado, Bass [28] recognized three members of the Greenhorn—the Bridge Creek limestone member at the top, the intermediate Hartland shale member, and the basal Lincoln limestone member. The Bridge Creek member consists of an alternation of limy shale and chalky limestone having a thickness of 74 feet, four-fifths of which consists of shale. It merges into the overlying Carlile shale with no apparent lithologic change but is separable from the Carlile faunally. Below the Bridge Creek member is a unit of calcareous shale, the Hartland shale member. This is 23 feet thick and almost devoid of limestone but contains, like the Bridge Creek member, many layers of bentonitic clay. The Lincoln limestone member, although consisting predominantly of calcareous shale, contains numerous thin beds of hard finely banded gray limestone that weathers brown. These beds are most abundant near the top and base of the member, which is 35 feet thick.

These divisions of the Greenhorn may also be recognized north of the Arkansas River in eastern Prowers County, Colo. The Bridge Creek member is exposed along the west side of Cheyenne Creek from the NW¼ sec. 8, T. 23 S., R. 41 W., northward to the NE¼ sec. 6 of the same township. A partial and approximate section follows:

[27] Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 564–565, 570, 1896.

[28] Bass, N. W., op. cit., pp. 66–70.

Partial section of Bridge Creek member of Greenhorn limestone on west side of Cheyenne Creek in Prowers County, Colo.

	Ft.	in.
Limestone, gray; weathers into hard yellowish-gray irregular flat slabs; numerous *Inoceramus labiatus*		6
Concealed	1	6
Limestone, gray, with *Inoceramus labiatus*		6
Concealed	2	
Limestone, gray, with *Inoceramus labiatus*	2	6
Concealed	3	6
Limestone, gray		6
Concealed	3	8
Limestone, gray		4
Concealed	1	
Limestone, gray		4
Concealed	5	6
Limestone, gray, with *Inoceramus labiatus*		8
Concealed	1	6
Limestone, gray, with *Inoceramus labiatus*		8
Concealed	2	
Limestone, gray, with *Inoceramus labiatus*		8
Concealed	5	6
(Above this point the section is approximate.)		
Limestone, gray, bedded		6
Shale, chalky, poorly exposed	1	8
Limestone, chalky, thin-bedded		5
Shale, chalky, poorly exposed	1	
Limestone, white, chalky		3
Shale, chalky, thin-bedded, with a few hard white and gray limestone lenses less than half an inch thick	2	11
Bentonite		5
Limestone, gray; weathers white; single bed, with vertical joints from 2 to 8 inches apart; upper part somewhat chalky		6
Shale, chalky, paper-bedded	1	10
Limestone, gray; weathers white; single bed, with vertical joints from 2 to 8 inches apart		4
Shale, chalky, well bedded, with a few layers of gray crystalline limestone one-sixteenth inch thick	1	5
Limestone, gray; weathers white; in lenses as much as 2 inches thick and 6 inches long		2
Shale, chalky, well bedded, with one zone of limestone lenses 2 inches thick below the water level of a dug pool.		
Total measured	44	3

This section when plotted can be correlated at least approximately with the lower part of the section of the Bridge Creek member published by Bass.[29] The 5-inch bentonite bed resting on 6 inches of limestone can be correlated with a similar bed near the base of the Hamilton County section, and a zone of abundant fossils 30 to 40 feet higher appears in both sections. Many of the intermediate limestone beds also seem to match. Unfortunately the exposures along Cheyenne Creek were not sufficiently good to permit the recognition of other bentonite beds. However, near the southeast corner of the SW¼ sec. 12, T. 23 S., R. 41 W., a bed of bentonite 5½ inches thick crops out above a bed of limestone 6 inches thick and below chalky shale. This

[29] Idem, fig. 21.

may well be the bed measured in the section west of Cheyenne Creek, given above.

In the SE¼ sec. 12, T. 23 S., R. 42 W., somewhat more than 40 feet of soft chalky shale is exposed. These beds contain scattered limestone lenses as much as 2 inches thick but no continuous beds of limestone. They represent the Hartland shale member. Below them in the NE¼ sec. 18 and NW¼ sec. 17, T. 23 S., R. 41 W., the basal part of the Greenhorn is exposed above the Graneros shales. The beds include chiefly calcareous shales, but also hard crystalline limestone beds as much as 2 inches thick, which weather into hard yellowish and brownish plates. The limestone beds constitute only about 10 percent of the exposed rocks but because of their resistance to erosion are conspicuous on the outcrop. These lowest exposures of the Greenhorn correspond in lithology and probably also in thickness with the Lincoln limestone member as recognized in western Kansas.

In the SW¼ sec. 11, T. 23 S., R. 42 W., exposures of the uppermost part of the Greenhorn limestone include beds of gray limestone and chalky marl. Part of the limestone, however, occurs as flat but rounded lenses or concretionary lenses from 6 to 12 inches thick.

The upper part of the Greenhorn limestone is also exposed in the NW¼ sec. 18 and the W½ sec. 7, T. 22 S., R. 44 W. It consists of alternating beds of chalky marl and gray limestone, and the limestone beds have a thickness of 6 to 12 inches and carry numerous specimens of *Inoceramus labiatus*. There are also some lenses of hard gray crystalline limestone largely composed of fossil shells. In somewhat lower Greenhorn exposures in this vicinity there are less numerous impressions of *Inoceramus labiatus* and other fossils, and the limestones are less platy in habit, breaking rather into irregular chunks. Exposures of the lower part of the Greenhorn that might include possible equivalents of the Hartland shale member and Lincoln limestone member were not observed. In the north-central part of sec. 7, T. 22 S., R. 44 W., a partial section of the top of the Greenhorn limestone and basal part of the overlying Fairport chalky shale member of the Carlile shale was measured, as follows:

Partial section of top of Greenhorn limestone and base of Carlile shale in sec. 7, T. 22 S., R. 44 W.

	Ft.	in.
Fairport chalky shale member of Carlile shale:		
Chalky shale.		
Limestone, gray, with *Inoceramus*		3
Chalky shale	2	3
Limestone, gray		3
Chalky shale	2	6
Limestone, white, hard; breaks in curving plates and flat slabs; in part weathering to yellowish gray		5

Partial section of top of Greenhorn limestone and base of Carlile shale in sec. 7, T. 22 S., R. 44 W.—Continued

	Ft.	in
Fairport chalky shale member of Carlile shale.—Contd.		
Chalky shale, white, thin-bedded	3	
Chalk, white; breaks into thin chips		4
Partial thickness	9	
Greenhorn limestone:		
Limestone, light gray, dense, in part weathering to yellowish gray, less fossiliferous than lower beds; breaks along vertical joints into flat and irregular vertical plates		10
Chalky marl, gray, in part thin-bedded gray limestone; numerous *Inoceramus* and oyster shell fragments	3	10
Limestone, gray		4
Chalky marl, poorly exposed		10
Limestone, gray, dense; breaks into numerous irregular flat slabby plates and chips; in part stained rusty yellow; *Inoceramus labiatus*		5
Chalky marl, soft, poorly exposed	1	2
Limestone, gray; breaks into thin flat chips in lower 2 inches; *Inoceramus labiatus*		6
Chalky marl, in part flaky and paper-bedded	1	1
Limestone, gray; weathers very light gray; dense, with an irregular lower surface. Contains abundant *Inoceramus labiatus*		7
Chalky marl, flaky and paper-bedded in part	1	1
Limestone, chalky, gray; breaks into irregular flat chips		3
Chalky marl, yellowish gray, flaky and paper-bedded in part	1+	
Partial thickness	11	11
Total measured	20	11

No precise correlation can be made of this partial section with the partial section measured along Cheyenne Creek. The lower part may include some beds equivalent to the upper part of the Cheyenne Creek section, or it may include only beds higher than the top of the section measured on Cheyenne Creek.

The thickness and lithology of the Greenhorn in the region north of Lamar are very imperfectly known, but there is some suggestion that a thickness comparable with that farther east may be present and that the underlying Graneros has also a small thickness like that of western Kansas.

Somewhat farther west, 1½ miles north of McClave, a section was measured of the upper part of the Greenhorn, possibly including some of the lowest part of the Fairport chalky shale member of the Carlile shale:

Section of upper part of Greenhorn limestone 1½ miles north of McClave

	Ft.	in.
Shale, marly	5+	
Limestone		4
Shale, calcareous, tan	5	
Limestone, gray		2
Shale, calcareous	1	1
Limestone, gray, with *Inoceramus labiatus*		3

indicates contemporaneously favorable life conditions of some sort for them.

It seems possible that such favorable conditions might be provided by submarine springs of low volume but relatively high concentration in calcium carbonate. It has already been pointed out by Gilbert[85] that springs of sufficient volume to build a tufalike core would produce a concentric structure in the cores, which has not been found. On the other hand, a spring or seep of low volume on the sea floor might simply provide an abundance of mineral salts in solution, which would produce locally a favorable site for the growth of many kinds of organisms. A feature of the distribution of the buttes, which might be construed as favoring the hypothesis of submarine springs, is their tendency to alinement in rows. The lines of buttes in various places trend in diverse directions, so that this tendency to alinement does not produce any discernible systematic arrangement of the tepees as a whole, but locally the alinement is pronounced and should be explained by any satisfactory theory of their origin, as should also the tendency of the buttes to occur in groups or clusters.

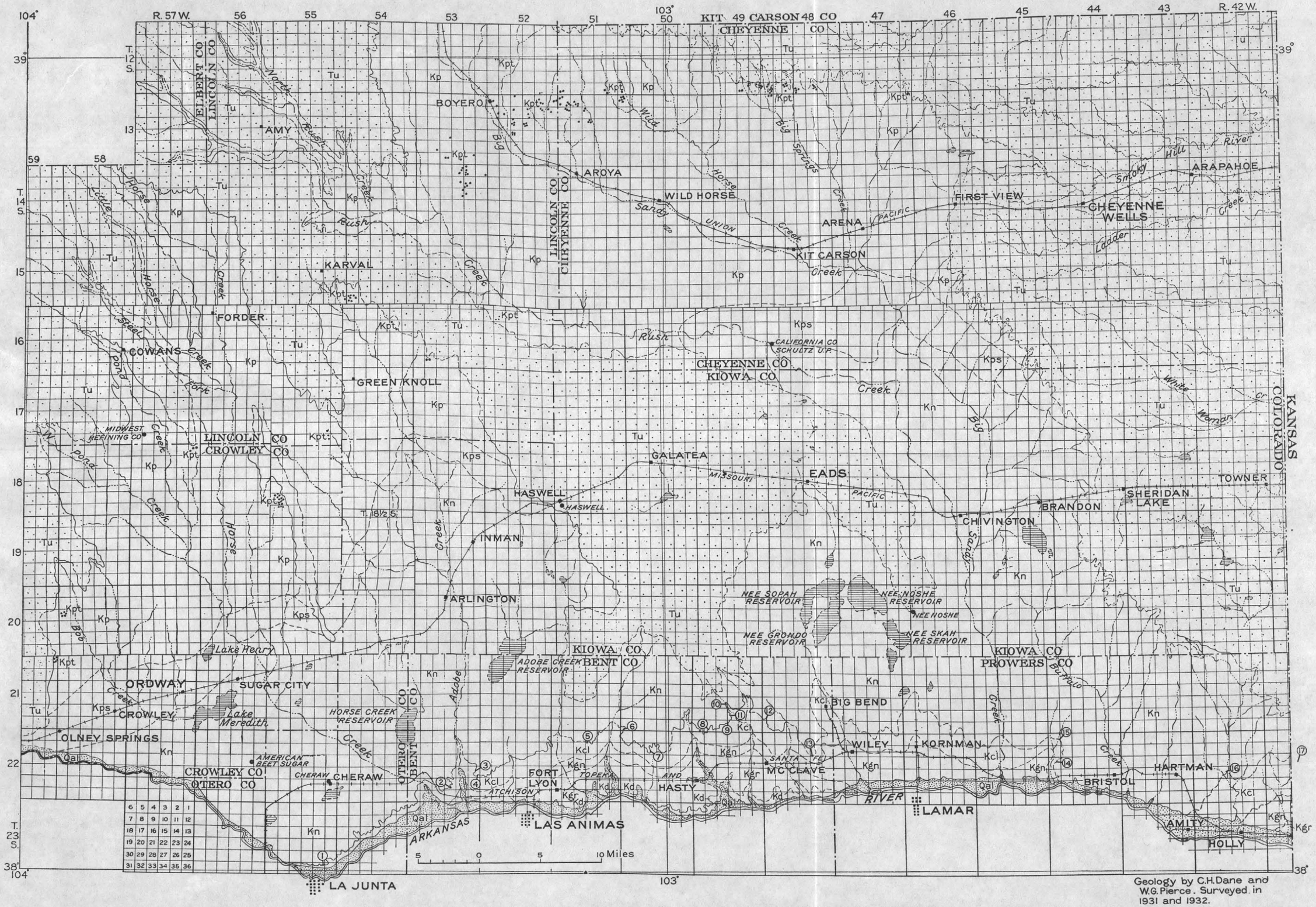
As an interesting speculation, the writers advance the hypothesis that the predicated submarine springs arose from the pressing out of connate water during the compaction of the sediments deposited to the north in the more rapidly subsiding portion of the Denver Basin. The "tepee zone" contains the same fauna in general as the Hygiene sandstone member and overlying sandstone members in the Pierre shale of the northern foothills, where the total thickness of the Pierre shale is much greater. These sandstones alternate with intervening shalier zones and diminish in thickness southward and southeastward. As they were deposited in the more rapidly subsiding portion of the basin, the tapering margins of the sandy wedges would gradually acquire a gentle upward slope to the southeast, outward and upward from the basin. It seems possible that with the compaction of the sediments connate water of high mineral content would be squeezed out of muds and sandy silts into overlying tongues of sand that might then serve as channel courses for the movement of water upward and southward, there to escape upward through the soft sediments of the sea floor along local lines of weakness. H. F. Davies[86] has suggested a more direct relationship of the tepee buttes to the Hygiene and other sandstones, supposing that they may represent offshore deposition of the colloidal silica and calcium carbonate left in solution at the outer margins of deposition of the sandy materials.

Whatever the actual mode of origin of the tepee cores, if their vertical dimension is materially greater than their horizontal dimension, it seems that there must have been a balance of some sort between the rate of deposition of the surrounding sediments and the rate of accumulation of the tepee core rock, in order that the required conditions for forming that rock might persist in one locality through the long period of time that must have been required to build up the tepee core and deposit the surrounding shale. That there were some variations in conditions from time to time is seen by the irregular nature of some exposed side walls of cores. In Gilbert's words, they "exhibit shoulders, shelves, and overhangs, besides being rugose in detail." In general, it may be concluded that such conditions could be maintained only in places where the rate of shell and calcium carbonate accumulation could keep pace with the rate of sedimentation. Where sediments accumulated more rapidly nearer the source of supply, such conditions could not long be maintained. On the other hand, the rate of accumulation of the shells would also seem to be a variable one, depending on available supplies of necessary materials for shell construction.

The foregoing discussion of the origin of the tepee cores is intended primarily to emphasize the point that the nature of the masses themselves indicates that they represent a type of deposition which would occur at a certain time within a geographically limited belt, and that this belt of tolerance would be very likely to migrate to and fro, owing to variations in the rate of supply of the sandy sediment that was being deposited farther north and to variations in the rate of subsidence of the basin. If so, the shale that contains the tepee cores probably has an intertonguing relation with the enclosing shales that are barren of the tepee masses.

The part of the Pierre shale above the "tepee zone" is composed of sandy shale and soft sandstone, particularly in the upper part. It is lithologically a transition unit from the dominantly fine sedimentary beds of the Pierre shale to the sandstone of the Fox Hills. As will be seen from the faunal lists below, it is likewise in its upper part a transition zone from the faunal assemblage characteristic of the Pierre shale to that characteristic of the Fox Hills sandstone. Neither top nor base of this transition zone is sharply defined, but it is certainly some hundreds of feet thick and appears to be characterized faunally by *Inoceramus fibrosus* (Meek and Hayden), *Baculites grandis* Hall and Meek, and several species of *Discoscaphites*. It is notable that in this region in the upper part of the transition zone and in the base of the overlying Fox Hills sandstone an association of such forms as *Inoceramus sagensis* Owen and *Baculites grandis* Hall and Meek with the *Discoscaphites* and species of *Sphenodiscus* is not uncommon. In other regions where Pierre and Fox Hills are recognized this association is so rare as to be virtually nonexistent.

[85] Gilbert, G. K., and Gulliver, F. P., op. cit., p. 339.
[86] Lavington, C. S., op. cit., p. 402.



GEOLOGIC MAP OF PART OF EASTERN COLORADO NORTH OF THE ARKANSAS RIVER.

Numbers in circles indicate location of graphic sections in figure 11.

77388—37 (Face p. 212).

the argillaceous material as included shale, and therefore an impurity rather than an essential constituent of the tepee rock.

The rock has a coarse texture, breaks with rough fracture, and its general color is a light, warm gray. It is full of fossil shells, and the microscope shows that they are embedded in a matrix which is composed of fragments of shell, water-worn grains of calcite, Foraminifera, and clay. Cross sections of *Lucina* shells show that the original shell structure remains, although the lime of the shell has been recrystallized into calcite. Inside of the shell wall there is a band of radiating crystals of calcite, showing well-marked spherulitic structure. The calcareous ooze which must have at first occupied the central cavity of the shell has recrystallized into very pure calcite, leaving the clay impurities at one side of the shell. This central calcite crystal is the same individual which has replaced the lime of the shell, for the two parts extinguish together, the cleavage cracks extend from the center through the outside, and when the spherulitic band is faulted the clear calcite is continuous through the cracks. Experiments showed the spherulitic layer to be slightly less soluble in dilute hydrochloric acid than the clearer calcite.

In a few thin sections examined by the writers there is considerable variation in the nature of the rock. On the whole, the proportion of shell material is much less than half of the total bulk. In some of the *Lucina* shells there is a division of the shell into three zones—an outer band that is composed of relatively few calcite crystals, a wider central layer of fibrous calcite with flamboyant extinction, and an inner layer of variable thickness which consists of small calcite crystals interlocking in a granular mass that grades into the matrix filling the shell. This granular layer is not common, and where it is absent the fibrous layer grades into the matrix. The fibrous layer may also be absent from either one or both valves of the shell, but the outer layer of large calcite crystals retains a sharp boundary with the shell filling, although it may be partly or wholly replaced by chlorite. No central calcite crystals were observed within the matrix that fills the shells.

The bulk of the rock is fine-grained, consisting of intimately intermixed clay and calcite. Although the distribution of these materials varies greatly, there is a marked tendency for the clay to occur in somewhat darker, cloudier patches, in cross section having a circular, elliptical, or irregular shape. These clay patches range from 0.1 to 1 millimeter in diameter in different slides examined but exhibit less size variation in individual slides. Although the appearance of some of them suggests a coprolitic origin, it seems probable that most of them may represent flocculated clay pellets. In some slides granular interlocking areas of calcite occur in a fine-grained clay-calcite matrix; darker patches, chiefly of clay, occur in the same type of matrix; and patches of clay occur in areas of more coarsely crystalline calcite. Some of the clay patches are irregular and bounded by areas of calcite grains with crystal outlines. These irregular clay masses seem to be segregations produced during recrystallization of the rock. Brown, darkly translucent or black opaque organic matter of various types occurs in small and broken fragments throughout much of the rock. In some areas, notably in the matrix within one *Lucina* shell near the hinge and within the outer calcite layer of another *Lucina* shell, in lines paralleling the shell banding, are minute nearly black grains, 15 to 50 microns across, which from their crystal form were pyrite, but which because of their slight translucency and reddish-brown color in reflected light now appear to be of limonitic composition. The writers' thanks are due to C. S. Ross, of the Geological Survey, for confirmatory examination of these grains and some advisory comments on the nature of the rock in general.

The clastic content of the rock is small and variable, some slides showing virtually none and others having an appreciable amount of very angular grains of quartz, feldspar, and accessory ferromagnesian minerals. The grains observed were as much as 0.2 millimeter in diameter.

Foraminifera were observed in most of the slides but are not numerous.

Gilbert [84] concluded that the most satisfactory explanation of the tepee cores was that each "was the site of a colony of *Lucina* and that the remains of each perishing generation furnished in some way conditions favorable to the life of the next", although he considered that knowledge of the tepees at that time was not sufficient to definitely establish this as the correct explanation. Some of the difficulties in accepting the theory of colonial origin, as above outlined, were pointed out by Gilbert. In the first place the predominant shell of the tepee cores, *Lucina*, is neither known to be a colonial species nor to be a species that would especially flourish on the presumably more stable foundation afforded by the shells and broken shell fragments of preceding generations. *Lucina* occurs in some abundance in the adjoining shales and is found elsewhere in sandy shales and sandstones. Some of the shells in the tepee cores are wholly embedded in the matrix and in general are no more commonly adjacent to or resting on other shells than would be expected from their relative abundance in the rock. Nor is it known that individuals of *Lucina* at any stage utilized or required an attachment. In the second place, the bulk of the material of the tepee cores is fine-grained calcite and clay, which gives no indication of being of organic origin, except for the possible coprolitic structures mentioned above.

On the other hand, the slight differences observed between the matrix within and outside the shells and other features of the rock suggest that it is an original sedimentary deposit rather than a concretionary aggregate, and the particular abundance of *Lucina* shells

[84] Gilbert, G. K., and Gulliver, F. P., op. cit., p. 339.

Section of upper part of Greenhorn limestone 1½ miles north of McClave—Continued

	Ft.	in.
Chalky marl, tan, with shell fragments	3	
Limestone, gray		3
Marl, tan	1	3
Limestone, light blue gray, with *Inoceramus labiatus*		5
Marl and shale	2	
Limestone, marly		6
Shale and marl	1	5
Limestone, light gray		6
Shale, calcareous	3	6
Limestone, light gray		4
Marl	2	6
Limestone, blue gray, with *Inoceramus labiatus*		10
Marl, tan		10
Limestone		3
Marl, tan		8
Limestone, blue gray, hard		3
Marl, with a small amount of limestone	2	
Marl and shale, buff		8
Limestone, gray		5
Marl	1	5
Limestone, granular, soft		3
Marl, shaly, tan, with *Inoceramus labiatus*		7
Limestone, white to light gray		9
Marl, with a small amount of limestone	2	10
Limestone, gray, with *Inoceramus labiatus*		5
Marl, tan	1	
Limestone, white		6
Marl, tan	1	3
Limestone, blue gray		1½
Marl		10
Limestone		1½
Marl, tan	1	
Limestone, light gray		6
Marl		2
Limestone, blue gray, hard		1½
Marl, tan and light gray	1	8
Limestone, blue gray		4
Marl, tan and dirty brown	1±	
Limestone, light gray, vertically jointed		4
Marl, tan		10
Limestone, white		3
Marl, tan		11
Bentonite		7
Shale, chalky		7
Limestone, white		3
Shale, chalky tan		6
Limestone, white		10
Shale, chalky tan		6
Limestone, white		10
Marly chalk	2	
Total measured	56	8½

Small exposures of the upper part of the Greenhorn limestone in the SW¼ sec. 16, T. 22 S., R. 50 W., along the western part of the south line of sec. 8, T. 22 S., R. 50 W., in the SE¼ sec. 11, T. 22 S., R. 51 W., and in the northern part of sec. 35, T. 22 S., R. 53 W., show that it persists westward as a lithologic unit of alternating limestone and chalky shale beds, but its thickness is not known, and exposures of the lower part were not observed.

In the NW¼NW¼ sec. 5, T. 24 S., R. 54 W., south of the Arkansas River, exposures of Greenhorn limestone about 30 feet thick show that it consists of beds of white limestone from 4 to 8 inches thick interbedded with gray calcareous shale in beds 6 to 12 inches thick. *Inoceramus labiatus* is present in abundance at these exposures.

In the Pueblo quadrangle [30] the Greenhorn has a thickness of 35 to 50 feet. East of that area, in the Nepesta quadrangle,[31] it has an aggregate thickness of 50 feet, and to the south, in the Apishapa quadrangle,[32] it is reported to be about 30 feet thick. In the Walsenburg quadrangle it is described as consisting of layers, from 3 to 4 inches thick, of dove-colored limestone, separated by partings of gray shale. The aggregate thickness is about 30 feet. At a locality 10 miles northwest of Vermejo Park, on the east flank of the Sangre de Cristo Range, in New Mexico near its northern boundary, the Greenhorn, as separated by the writers, includes 25 feet of such alternating limestones and shales and also 25 feet of hard gray limy shale overlying them. The Greenhorn may also be recognized farther west in southwestern Colorado and on the east side of the San Juan Basin in northwestern New Mexico as a similar thin unit of alternating beds of limestone and shale. In the La Junta region [33] the total thickness is about 50 or 60 feet. In view of the fact that the thickness of the Greenhorn in western Kansas is from 100 to 130 feet, it seems likely that the lower members of the Greenhorn in Kansas merge westward into the upper part of the Graneros shale. This inference is supported by the westward thickening of the Graneros shale.

The thickness of the rocks of Benton age in the aggregate remains nearly the same from west to east, as shown by the plotted logs of several wells (fig. 10) and also by the thicknesses given for the several formations by writers on various areas (to defer, for the present, consideration of an anomalously thin Carlile shale section in the La Junta region). The published descriptions of the upper portion of the Graneros where it has a thickness of 200 feet also suggest that its content of calcareous shale and limestone is greater than that of the Graneros of western Kansas and that it may represent an equivalent of the lower portion of the Greenhorn of Kansas. For example, in the La Junta region [34] the Graneros contains thin limy beds 40 to 50 feet below the top of the formation, and in the Apishapa quadrangle [35] a thin fossiliferous platy sand-

[30] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.
[31] Fisher, C. A., op. cit., p. 2.
[32] Stose, G. W., op. cit., p. 6.
[33] Patton, H. B., op. cit., p. 15.
[34] Idem, pp. 14–15.
[35] Stose, G. W., op. cit., p. 5.

stone is found about 45 feet below the top of the Graneros. Farther west, however, in a section measured by the writers at Colorado City, west of Colorado Springs, the upper portion of the Graneros contains no limy beds. In this section the Graneros is 210 feet thick and the Greenhorn somewhat more than 20 feet. The width of outcrop of the Greenhorn as shown on the geologic map diminishes rather abruptly westward from the vicinity of Wiley.

So far as known the Greenhorn in Colorado is transitional into the overlying Carlile shale as well as into the underlying Graneros shale. A paleontologic distinction between Carlile and Greenhorn is reported in western Kansas and may exist also in eastern Colorado.

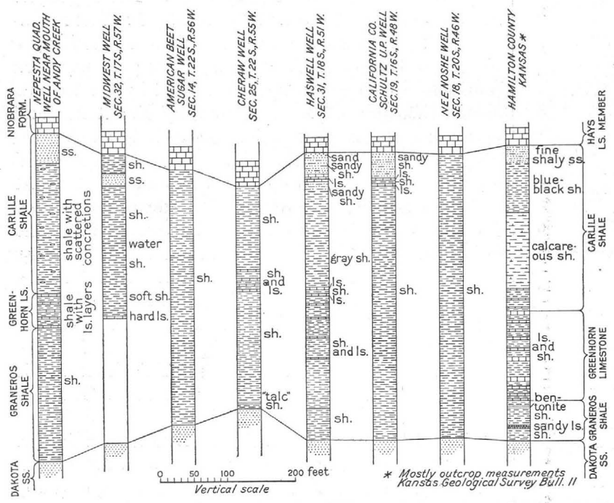


FIGURE 10.—Graphic sections showing the thickness of the rocks of Benton age at various places in the Arkansas Valley as given by drillers' logs of several wells, with a comparison of the stratigraphic section of these rocks as divided in Hamilton County, Kans., and in the Nepesta quadrangle, Colo.

The fossils recorded from the Graneros of eastern Colorado are of types also found in the Greenhorn and may therefore have come from shaly beds equivalent to the lower part of the Greenhorn.

Fossils other than a few species of Foraminifera and *Inoceramus labiatus* are not common in the Greenhorn limestone. Seven collections made by the writers contain the following species. The large numbers (15743, etc.) in this and other lists of localities are the numbers in the United States Geological Survey Mesozoic invertebrate collection.

	Locality
Globigerina sp.	1, 2, 3, 6
Globotruncana sp.	2
Inoceramus labiatus Schlotheim	1, 2, 3, 4, 5, 6, 7
Inoceramus sp.	1
Lunatia? sp.	2
Exiteloceras pariense (White)	7

1. 15743, Mount Morrison-Bear Creek locality. (See p. 210.)
2. 15818, secs. 16 and 17, T. 22 S., R. 50 W.
3. 16068, NW¼ sec. 18, T. 22 S., R. 44 W., along Cottonwood Creek.
4. 16069, SW¼ sec. 7, T. 22 S., R. 44 W.
5. 16076, NE¼ sec. 11, T. 22 S., R. 48 W.
6. 16077, NW¼ sec. 30, T. 22 S., R. 46 W.
7. 16078, NE¼ sec. 12, T. 22 S., R. 49 W.

The rarer species, however, include a considerable variety of forms. Reeside has under study collections from the Greenhorn limestone of the Arkansas Valley and the foothill region of Colorado that contain the following forms in addition to those listed above: Echinoid, *Sternotaxis?* n. sp.; brachiopod, *Crania* n. sp.; pelecypods, *Inoceramus* cf. *I. lamarcki* Parkinson, *Ostrea* sp., *Sauvagesia?* sp.; gastropods, *Cerithium?* sp., *Anchura?* sp., *Aporrhais* (*Perissoptera*) *prolabiata* White; *Anisomyon?* sp.; cephalopods, *Neoptychoceras* sp., *Baculites gracilis* Shumard, *Tragodesmoceras* n. sp., *Watinoceras? coloradoense* (Henderson), *Watinoceras?* n. sp., *Romaniceras* n. sp., *Neocardioceras septemseriatus* (Cragin), *Thomasites* n. sp., *Mammites* n. sp., *Neoptychites* n. sp., *Scaphites* n. sp., *Pseudotissotia* (*Choffaticeras*) n. sp., *Metoicoceras whitei* Hyatt, *Metoicoceras* cf. *M. irwini* Moreman. Morrow[36] records *Tragodesmoceras bassi* Morrow from Colorado.

CARLILE SHALE

The Carlile shale was named by Gilbert[37] from Carlile Spring and Carlile station, 21 miles west of Pueblo. It was described as a gray argillaceous shale 175 to 200 feet thick. In the Pueblo quadrangle the upper fourth contains some sand, and the topmost portion is described as a yellow friable sandstone. Farther east "the sandstone is often replaced by a purplish limestone." Large septarian calcareous concretions occurring 20 to 50 feet below the top of the formation are also noted.

In Russell County, Kans., the Carlile shale was divided into two members, the Blue Hill shale member above and the Fairport chalky shale member[38] below. These subdivisions were later recognized in Ellis and

[36] Morrow, A. L., Cephalopods from the Upper Cretaceous of Kansas: Jour. Paleontology, vol. 9, no. 6, p. 468, pl. 53, fig. 4; text fig. 1, 1935.

[37] Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 565–566, 570, 1896.

[38] Rubey, W. W., and Bass, N. W., The geology of Russell County, Kans.: Kansas Geol. Survey Bull. 10, p. 33, 1925.

several hundred feet above the main series of tepee buttes.

In the vicinity of Fountain, in the Colorado Springs quadrangle, the writers estimated that the "tepee zone" was roughly 1,500 feet thick and the overlying portion of the Pierre shale was also 1,500 feet thick. As these estimates agree moderately well with the thicknesses of 1,275 feet for the "tepee zone" and 1,885 feet for the overlying Pierre shale measured by Lavington,[78] the writers believe that their estimate of 2,000 feet of the Pierre shale below the "tepee zone" west of Fountain and south of Little Fountain Creek may be correspondingly reliable. The total thickness of the Pierre in the Colorado Springs region is therefore about 5,000 feet. If these estimates are correct, the "tepee buttes" occur considerably lower in the section in the Pueblo region, where they are found at horizons beginning 1,200 feet above the base of the Pierre and only 200 feet above the top of the "rusty zone."

As the total thickness of the Pierre is known to diminish greatly southward from Colorado Springs,[79] the lower occurrence of "tepee buttes" in the Pueblo region may be due to thinning of the 1,000 feet of shaly beds below the "tepee zone" in the vicinity of Fountain to about 200 feet near Pueblo. In fact, Lavington[80] believes that on the west side of Baculite Mesa, northeast of Pueblo, small conical buttes from the overlying "tepee zone" actually range down into the "rusty zone." The "tepee zone" also apparently thins southward from Colorado Springs to Pueblo and eastward from Pueblo to about 500 feet in the Nepesta region and in the region north of Olney Springs, Ordway, and Arlington. In this region also the interval between the base of the "tepee zone" and the top of the "rusty zone" is apparently less than 100 feet. The base of the zone in which "tepee buttes" occur is about 1,350 feet above the base of the Pierre southwest of Boyero and about 1,100 feet above the base north of Kit Carson. Exclusive of the Sharon Springs member and the overlying "rusty zone" at these places the intervening part of the Pierre shales below the "tepee zone" thins eastward from perhaps 650 feet southwest of Boyero to 400 feet north of Kit Carson. It should be understood that the thicknesses given above are estimates only.

Because the "tepee buttes" occur in widely separated groups and because the concretions that form them are embedded in shale in which no distinguishable lithologic or faunal zones have yet been discovered, there is no real assurance that these concretions are actually confined to a stratigraphically definable zone in the Pierre shale. Nevertheless, from their distribution it seems probable to the writers that they are restricted to a certain zone whose limits differ somewhat from place to place, that this zone diminishes southeastward in thickness, and that the shales below it but above the "rusty zone" also diminish southeastward in thickness.

In form, the tepee buttes, as their name implies, are low conical hills rising above the general level of the surrounding country. At the top of each is an irregular cap of light-gray or brown limestone, much fractured and containing great numbers of fossil shells, among which *Lucina occidentalis* is everywhere predominant. The shells are more or less completely recrystallized to translucent or transparent calcite, normally with a yellowish cast, and the containing rock is in places seamed with intersecting veinlets of similar calcite. On some of the buttes the limestone rock reveals a poorly defined, irregular horizontal stratification. The slopes of most of the buttes expose the shale in which the limestone masses are embedded, but almost all of them are thickly strewn with disintegrated fragments of the hard rock exposed at the top. It is obvious that the topographic form of the buttes is due to the greater resistance to erosion of the central capping mass of limestone. As the result of the most critical study of the origin of the tepee buttes which has been made, Gilbert and Gulliver[81] concluded that the limestone masses had the general form of vertical cylindrical cores, and this conclusion has been followed by all subsequent observers. Inasmuch as it seems to the writers that the same topographic form might well be produced by an essentially equidimensional concretionary mass, it is unfortunate that exposures of the vertical dimension of the tepee cores are rare. The greatest height of a core actually observed by Gilbert was 18 feet, and the horizontal dimensions of this core were not stated. In only one tepee butte examined by the writers could it be definitely ascertained that the vertical dimension was greater than the horizontal.

Tepee cores have, however, been reported to have vertical dimensions of as much as 50 feet,[82] and the shape of one core has been described as tapering downward like an inverted cone.

The tepee-core rock has been described as follows:[83]

> The tepee rock is essentially a calcium carbonate, the ratio of calcium carbonate to magnesium carbonate being 18 to 1 in the single sample analyzed. That sample contained also 12 percent of argillaceous material. For comparative purposes, analyses were also made of the enclosing shale and of one of the ordinary concretions of the shale, the determinations showing that the tepee rock does not differ materially in composition from the concretions, and that the argillaceous material is practically identical with the shale. This permits us to regard

[78] Lavington, C. S., op. cit., fig. 1.

[79] Hills, R. C., U. S. Geol. Survey Geol. Atlas, Walsenburg folio (no. 68), p. 2, 1900.

[80] Lavington, C. S., op. cit., pp. 399–400.

[81] Gilbert, G. K., and Gulliver, F. P., Tepee buttes: Geol. Soc. America Bull., vol. 6, pp. 333–342, 1895.

[82] Fisher, C. A., U. S. Geol. Survey Geol. Atlas, Nepesta folio (no. 68), p. 2, 1906.

[83] Gilbert, G. K., and Gulliver, F. P., op. cit., pp. 336–337.

On the north side of Apache Creek, 1½ miles southwest of Hayden Butte, in the Walsenburg quadrangle, there are extensive exposures of an earthy sandstone about 60 feet thick. Near the middle is a zone of large limestone concretions. Below the sandstone dark shale with rusty concretionary beds a few inches thick is exposed for 50 feet, more or less, and above it lie black thin-bedded shales with some rusty streaks. The exact stratigraphic position of the exposures was not ascertained, but they are clearly in the lower part of the Pierre, possibly about 500 feet above the base. *Inoceramus sagensis* Owen and *Baculites asper* Morton were collected from concretions about 5 feet above the top of the sandstone.

On the north side of the Huerfano River 3 miles northeast of Badito there are exposures of an earthy gray and buff well-bedded sandstone, for the most part well indurated, with some brown concretionary beds. Overlying the sandstone is 5 feet of sandy shale with a concretionary zone at the top from which *Inoceramus sagensis* Owen, *Baculites asper* Morton, and *Scaphites nodosus* Owen var. were collected. This concretionary zone is overlain by black paper-bedded shales that contain a few rusty concretionary beds. Below the sandstone there is sandy shale with some rusty concretionary beds and a few yellow flattish concretions 1 foot thick and as much as 20 feet in length. The interval from the sandstone described to the top of the Niobrara was not determined but is probably more than 300 feet. The two exposures of sandstone described may be the Apache sandstone of Prommel.[75]

Still farther south, at a locality 6 miles north of Stonewall, road cuts expose the lower part of the Pierre shale, which at this place dips vertically. Although penetrated by sills of dark igneous rock and possibly somewhat squeezed and faulted, these exposures give a good idea of the lithology of the lower part of the Pierre. A carefully estimated section is as follows:

Section of Pierre shale 6 miles north of Stonewall

	Feet
Pierre shale:	
Shale, black	200
Sandstone, fine-grained, earthy, lumpy-bedded, and sandy shale	20
Shale, slightly sandy. In the upper part are two beds of yellow-weathering concretionary limestone and a few thin streaks of shaly limestone	260
Shale, light gray, lumpy-bedded, with some small rusty concretions	120
Concealed	40
Shale, like that exposed next above	150
Shale, black, thin-bedded. In the basal part are a very few thin sand streaks	100
Thickness exposed	890
Niobrara formation: Shale, calcareous, with a thin dense impure limestone bed in the upper part.	

[75] Lavington, C. S., op. cit., p. 399.

In the western part of the town of Pueblo, 0.6 mile north of the Arkansas River and 0.6 mile east of Dry Creek, outcrops of the basal part of the Pierre reveal a sandy lithology not observed in areas to the north or east. At this place the exposures display alternating beds of dark-gray shale and yellowish-weathering sandy shale, overlain by at least 10 feet of very fine grained yellow earthy sand, some beds of which are soft, though others are cemented by lime to a hard coherent rock. This sandy zone may be as much as 300 feet stratigraphically above the highest exposures of Niobrara observed by the writers, but as it appears to lie near to or even below the Niobrara-Pierre contact as mapped by Gilbert, the sand presumably lies in the basal part of the Pierre. These beds contain fish scales and numerous macerated plant remains, together with a few invertebrate fossils. (See collection 15753, p. 230.)

UPPER PART

In the area north of the Arkansas River a wholly satisfactory lithologic or faunal subdivision of the Pierre above the "rusty zone" is difficult to make. In part this is due to the absence of readily distinguishable differences or reliable key beds in the thick mass of shaly rocks. In part also it is due to the wide expanse of exposure with low dip and broadly level topography, with a resulting lack of extensive vertical exposures. There is also much concealment by younger unconformable Tertiary and later deposits. The differentiation of the Pierre is further complicated by the fact that the original thickness of the formation diminished by several thousand feet across the area which is now eastern Colorado.

Several previous writers have differentiated the "tepee zone" of the Pierre, distinguished by the presence of "tepee buttes"—small, sharply conical hills, formed by the superior resistance to weathering of large concretionary masses of limestone. (See pl. 65, *A*, *B*.) As defined by Gilbert,[76] the zone is 1,000 feet thick, overlying the "Baculite zone" and including the upper part of the Pierre as exposed in the Pueblo quadrangle. According to Fisher's description of the Pierre of the Nepesta quadrangle, the zone is 500 feet thick, underlain as in the Pueblo area by about 1,200 feet of shales but overlain by about 600 feet of light-gray sandy shales.

Two zones of tepee buttes were recognized near Fountain by Lavington.[77] East of Hugo, in the southwestern part of T. 11 S., R. 52 W., there are large concretionary masses much like tepee cores, but probably having less vertical than horizontal extent. These occur

[76] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

[77] Lavington, C. S., op. cit., p. 402.

Hamilton Counties.[39] In Ellis County a fine-grained sandstone about 20 feet thick at the top of the Carlile shale was named the Codell sandstone bed of the Blue Hill member by Bass. The Codell sandstone bed was also found in Hamilton County, Kans., near the Colorado State line, where it consists of sandstone about 2 feet thick in the upper part, underlain by 20 feet of sandy shale. The subdivisions of the Carlile shale made in Kansas are distinguishable also in the Arkansas Valley in eastern Colorado. As it is now generally regarded as desirable to eliminate the application of names to units of less than member rank, the Codell sandstone as herein described is considered to be a member of the Carlile shale, equivalent in rank to the Blue Hill shale member, which underlies it, and to the Fairport chalky shale, which is the basal member of the Carlile shale in the area of this report. The Codell sandstone has previously been recognized as a member of the Benton shale in northeastern Colorado.[40]

FAIRPORT CHALKY SHALE MEMBER

In Hamilton County, Kans., the Fairport chalky-shale member consists of calcareous blue-black shale in the upper part, which becomes more limy and somewhat lighter in color downward. Thin beds of chalky limestone alternate with limy shales in the basal 35 feet. The member as a whole has a thickness of nearly 150 feet. The contact with the overlying Blue Hill was not sharply distinguished. At the base the Fairport lithologically resembles the upper part of the Greenhorn limestone, but is paleontologically distinguishable from it.

At most places in the area shown on the map this lowest member of the Carlile is poorly exposed in comparison with the two overlying members. There are some typical exposures of the upper part of the Fairport in the NW¼ sec. 28, T. 22 S., R. 41 W. The exposures consist of yellowish well-bedded chalky shale with rather numerous specimens of *Ostrea* sp., *Inoceramus* sp., fragmentary remains of fish, and rarer ammonites.

The best exposures of the Fairport member are in the SE¼ sec. 6 and the NE¼ sec. 7, T. 22 S., R. 44 W. At the base it is much like the upper part of the underlying Greenhorn, as shown in the measured section on page 212, but has possibly a somewhat more chalky aspect. The proportion of limestone diminishes rapidly upward, and the bulk of the exposures consists of chalky shale. In the SW¼SE¼ sec. 6 a hard thin-bedded oyster-shell limestone near the top of the Fairport makes a small ledge. There are, however, some chalky marls above it, and the contact with the overlying Blue Hill shale member is not sharply distinguishable.

Small exposures in the northeastern part of T. 22 S., R. 48 W., show that much of the Fairport there consists of chalky marl with lenses of hard gray crystalline limestone a fraction of an inch thick. Oyster shells are abundant, as are also impressions of *Inoceramus* shells. Beds of limestone as much as 1 foot thick are locally present.

The contact between the Fairport and the overlying Blue Hill in sec. 27 and the NE¼ sec. 34, T. 21 S., R. 49 W., cannot be precisely set, but near the top of the Fairport is a bed 1 to 6 inches thick of very fine grained sandy crystalline limestone or calcareous sandstone. This bed is really an aggregate of lenticular beds 1 inch or less thick. Some of the lenses consist of closely packed oyster shells, and many of them carry broken *Inoceramus* fragments, worn shark teeth, and oyster shells. Below the bed lie slightly calcareous well-bedded shales and marly shales. There is apparently considerable variation in the lime content of individual beds, which range from one-sixteenth to one-half inch thick. The proportion of calcareous or marly shales increases downward, and the lamination of the rock becomes less regular and less distinct. The lowest exposures consist of light-gray chalky marl, with numerous fish scales, oysters, and *Inoceramus* impressions. At least 25 feet of the upper part of the Fairport is exposed.

Somewhat more than 20 feet of chalky marl of the Fairport is also exposed in the SW¼ sec. 9 and the NE¼ sec. 16, T. 22 S., R. 50 W. The basal part of the overlying Blue Hill member is concealed.

The Fairport chalky shale member is 147 feet thick in Hamilton County, Kans.,[41] as determined from the log of a water well. No complete measurements of the member were made in eastern Colorado, but the member is estimated to be from 75 to 125 feet thick.

In the La Junta region and farther west in the Nepesta and Pueblo quadrangles [42] the Fairport chalky shale member cannot be recognized from the descriptions of the Carlile shale given in the literature. In a section of the Carlile measured by the writers at Colorado City, west of Colorado Springs, 55 feet of gray limy shale underlies black noncalcareous shale and overlies gray limestone assigned to the Greenhorn limestone.

BLUE HILL SHALE MEMBER

The Blue Hill shale member consists predominantly of black fissile noncalcareous shale. In the lower part

[39] Bass, N. W., Geologic investigations in western Kansas, pt. 1, Geology of Ellis County: Kansas Geol. Survey Bull. 11, p. 26, 1926; pt. 2, Geology of Hamilton County: Idem, p. 63.

[40] Mather, K. F., Gilluly, James, and Lusk, R. G., op. cit. (Bull. 796), p. 81.

[41] Bass, N. W., op. cit., p. 65.

[42] Patton, H. B., op. cit., pp. 42–43. Fisher, C. A., op. cit., p. 2. Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

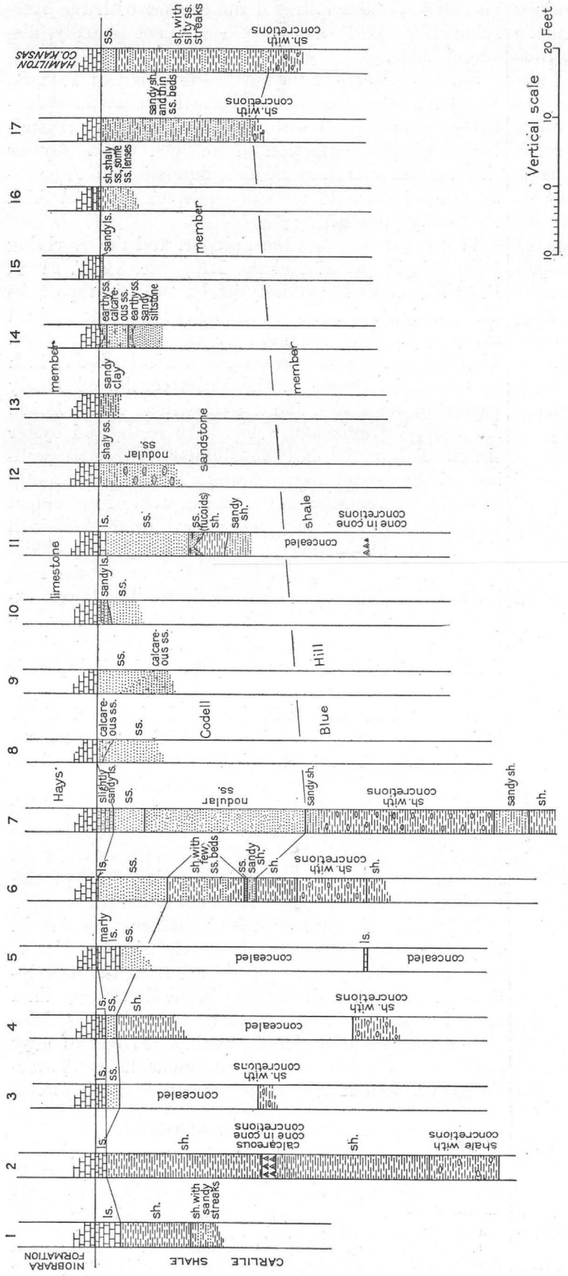


FIGURE 11.—Graphic sections of the Codell sandstone member and part of the underlying Blue Hill shale member of the Carlile shale. Numbers correspond with those shown on plate 64.

there is some calcareous shale, and the unit is not sharply separable from the underlying Fairport. The uppermost part consists of slightly sandy shale, locally as much as 30 feet thick. In the upper part of the member there are almost everywhere large calcareous septarian concretions. These are commonly several feet in diameter and may be as much as 10 feet. The material of which they are composed is a dull bluish-gray dense argillaceous limestone, but they weather yellowish tan. They are abundantly seamed with septaria of calcite in coarse translucent tan crystals. Cone-in-cone structure is developed on many of the upper surfaces. These large septarian concretions may occur through a zone from 5 to 30 feet in thickness, in most places about 10 feet. The stratigraphic position of the zone, however, seems to vary somewhat, for they may occur from 20 to 55 feet below the top of the Carlile shale. (See fig. 11.) Concretions of the same nature and at the same stratigraphic position in the Carlile shale have been described as far west as the Pueblo quadrangle [43] and also to the east in Kansas.[44]

CODELL SANDSTONE MEMBER

At the top of the Carlile shale is a persistent but rather variable unit consisting of sandstone and sandy shale. This is the Codell sandstone member. Where originally described in Ellis County, Kans.,[45] it consists chiefly of sandstone with some shaly sandstones interbedded. At the base it grades into the shale beds of the Blue Hill member. The Codell becomes less sandy southward, and in Hamilton County, Kans., it is made up of about 20 feet of gritty shale containing thin streaks of shaly sandstone, overlain by 2 feet of sand at the top.

At the easternmost locality observed by the writers (locality 17, pl. 64), along Cheyenne Creek in Kansas, a third of a mile southeast of the northeast corner of sec. 17, T. 22 S., R. 41 W. (Colorado), the Codell consists of 22 feet of soft, nodular-weathering sandy shale. Near the

[43] Gilbert, G. K., op. cit., p. 3.
[44] Bass, N. W., op. cit., p. 63.
[45] Idem, p. 28.

states that they are present in the Canon City-Florence district. Lavington [71] believes that in northeastern Colorado the Baculite zone recognized by Gilbert is not persistent over widespread areas.

In the Nepesta quadrangle, which lies to the east of the Pueblo quadrangle, Fisher [72] recognized in the Pierre a basal black shaly "barren zone", 400 to 500 feet thick, succeeded by 500 feet of dark-gray shale with numerous rusty concretions of iron and lime carbonate, and this in turn by 100 to 200 feet of somewhat lighter gray shale with numerous baculites.

Eastward to the Kansas line in the area shown on the map (pl. 64) small isolated outcrops show that the divisions recognized above carry through eastward. Some 2.4 miles north of Olney Springs are outcrops of shale with rusty concretionary beds and gray septarian concretions, representing a zone 300 to 350 feet above the base of the Pierre shale. These outcrops are probably near the base of the "rusty zone" and indicate a somewhat diminished thickness of the basal "barren zone", which is not exposed in this locality. Outcrops near the base of the Pierre in a large ditch in the southwest corner of sec. 29, T. 20 S., R. 56 W., northeast of Lake Henry, consist chiefly of thin-bedded gray and dark-gray shale that is neither sandy nor calcareous. One thin bed of white bentonitic clay and two beds of red clay less than 1 inch thick were observed, and also a few yellowish and slightly sandy beds. About 3 miles northeast of Lake Henry, in the bank of Pond Creek where it crosses the line between secs. 16 and 17, T. 20 S., R. 56 W., are outcrops of shale which are estimated to be not more than 300 feet above the base of the Pierre. The lower part of the exposure consists of gray and dark-gray bedded shale, slightly sandy toward the top. The upper part consists of gray somewhat sandy shale and gray shale with abundant yellow and brown resinous fragmentary remains of fishes. One reptilian rib, possibly that of a mosasaur, was observed. There are some sandy layers. At the base of the upper part is a layer of soft white bentonitic clay. In the upper part of the exposure are large dark-gray dense limestone concretions. This exposure apparently represents the top of the basal "barren zone" of the Pierre. Although it is not definitely known to be immediately overlain by beds in which the rusty-weathering carbonate concretions are abundant, the next overlying exposures exhibit the "rusty zone" lithology.

The basal portion of the Pierre is exposed also west and northwest of Haswell. The beds are mostly dark nonsandy shales with numereous gypsum crystals, though there are a few thin purplish-brown concretionary beds and some bentonite beds, of which one has a thickness of 3½ inches. In the NW¼ sec. 16, T. 18 S., R. 52 W., a zone of large gray dense septarian limestone concretions in gray shale is succeeded upward by shale in which the dark reddish-brown "rusty zone" concretions are abundant. These exposures may represent the top of the basal "barren zone" of the Pierre, which cannot much exceed 200 feet in thickness in this vicinity.

In the area intervening between the exposures northeast of Lake Henry and the exposures west of Haswell no outcrops having the lithology of the basal Pierre were observed. In the NW¼ sec. 14, T. 18 S., R. 54 W., there are exposures of shale with abundant rusty-brown concretions less than 2 miles west of topographically higher exposures of calcareous shale that apparently belongs to the Niobrara formation. It seems more likely that this occurrence is due to a somewhat steeper northwestward dip at this place than to absence of the "barren zone."

In the western part of sec. 29, T. 15 S., R. 46 W., an exposure shows calcareous concretions with septaria of crystalline calcite embedded in gray to black nonsandy shale with much soft powdery gypsum. This exposure may also represent the top of the "barren zone" of the basal Pierre.

Detailed studies in Wallace County, Kans., enabled Elias [73] to subdivide the lower part of the Pierre into several members, the lowest of which, the Sharon Springs member, conforms in lithology with the "barren zone" of the Pierre of eastern Colorado. The Sharon Springs member is 155 feet thick. It is overlain by the beds called "Weskan member" by Elias, which are succeeded by his Lake Creek member and that in turn by his Salt Grass member. These three members are characterized by abundant limonitic concretions, which have a rusty appearance. They have a combined thickness of 430 feet and appear to be equivalent to the "rusty zone" of the Pierre of eastern Colorado.

The writers propose to extend the name "Sharon Springs member" into eastern Colorado to include the basal black-shale member above described, which is equivalent to the "barren zone" previously recognized. They feel that the overlying "rusty zone" has not yet been sufficiently studied or its upper limit in Colorado determined with sufficient accuracy to warrant designation by a specific name.

Although the Sharon Springs member as above defined appears to be a widespread and homogeneous unit of black clay shale which is present also in the northern foothill region and is recognized by drillers in northeastern Colorado,[74] scattered observations indicate that the lowest part of the Pierre may be more variable in its lithologic features in the southern foothill region.

[71] Lavington, C. S., op. cit., p. 403.
[72] Fisher, C. A., op. cit., p. 2.
[73] Elias, M. K., The geology of Wallace County, Kans.: Kansas Geol. Survey Bull. 18, pp. 58–116, 1931.
[74] Lavington, C. S., op. cit., p. 399.

FAUNA

The following fossils were collected by the writers from the Niobrara formation:

	Locality
Smoky Hill marl member:	
Inoceramus sp.	2, 9, 10
Inoceramus deformis Meek?	8
Inoceramus aff. *I. stantoni* Sokolow?	8
Ostrea congesta Conrad	1, 2, 9, 10
Baculites codyensis Reeside	2
Fish remains, undetermined	10, 11
Hays limestone member:	
Globigerina sp.	5
Inoceramus deformis Meek	3, 4, 7
Inoceramus aff. *I. stantoni* Sokolow	7
Ostrea congesta Conrad	5
Ostrea sp.	6, 7, 8
Scaphites ventricosus Meek and Hayden	3

1. 16071, NE¼ sec. 6, T. 22 S., R. 44 W.
2. 16080, NW¼ sec. 19, T. 20 S., R. 43 W.
3. 15745, Mount Morrison-Bear Creek locality. (See p. 210.)
4. 15747, Colorado City, west of Colorado Springs.
5. 15751, Cuesta ridge on east flank of small anticline on Arkansas River about 7 miles west of Pueblo.
6. 15811, SE¼ sec. 24, T. 22 S., R. 53 W.
7. 16073, NW¼ sec. 32, T. 21 S., R. 44 W.
8. 16075, SW¼ sec. 27, T. 20 S., R. 49 W.
9. 16079, NW¼ sec. 17, T. 19 S., R. 44 W.
10. 16081, SE¼ SE¼ sec. 26, T. 20 S., R. 43 W.
11. 16082, NW¼ SW¼ sec. 34, T. 17 S., R. 44 W.

The late Prof. I. A. Keyte collected from beds at a horizon near the top of the Apishapa shale (top of Smoky Hill member of this paper), southwest of the area treated here, the following forms: Pelecypods, *Inoceramus* sp., *Turnus* n. sp.; gastropod, *Anchura?* sp.; cephalopods, *Eutrephoceras* sp., *Baculites asper* Morton, *Baculites codyensis* Reeside, *Scaphites vermiformis* Meek and Hayden, *Scaphites ventricosus* Meek and Hayden with several varieties, *Placenticeras* sp., *Texanites* cf. *T. pseudotexanus* (Grossouvre). G. K. Gilbert collected from the upper part of the Niobrara northwest of Pueblo a very large specimen of *Inoceramus undulatoplicatus* Roemer.

PIERRE SHALE

The lower part of the Pierre shale is present in the area shown on the map (pl. 64). It is poorly exposed, but lithologic subdivisions can be recognized and can be traced through the scattered outcrops available for examination. Much of the upper part of the formation lies outside of the area shown on plate 64, and the uppermost beds are not treated in detail in this paper, though certain data on these beds that have been collected are given on pages 230–231.

LOWER PART

Several divisions have been recognized in the lower part of the Pierre shale of eastern Colorado and in that of western Kansas by previous students of these areas. It does not yet appear possible, however, to establish definite correlations between the series of units set up in the several areas. As set forth below, the writers propose to apply in the Arkansas Valley only one formal member name, the "Sharon Springs shale member", using for the present only informal names for other divisions.

Before describing the exposures of the lower part of the Pierre in the mapped area, however, it seems best to describe the nature of this part of the Pierre shale farther west, where exposures are more complete.

The lower part of the Pierre shale is well exposed along the south side of Little Fountain Creek in the northern part of sec. 18, T. 16 S., R. 66 W., about 6 miles somewhat south of west from the town of Fountain, in the Colorado Springs quadrangle. The Pierre and underlying Niobrara dip generally eastward and northeastward at angles of 10° to 15°, the dip diminishing toward the east. The basal portion of the Pierre includes an estimated thickness of 550 feet of thin-bedded dark-gray shale. There are a few thin beds of hard yellowish-gray sandy limestone and a few beds a small fraction of an inch thick of yellowish earthy sand, also a few beds of bentonite. The only fossil remains observed were fish scales. At the top of this lithologic unit, near the center of the north line of sec. 18, there is a zone of large gray septarian concretions, seamed with brownish crystalline calcite. Immediately above this zone lie brownish-gray and dark-gray shales, with numerous reddish-brown calcareous beds and small flattish red-brown concretions. This lithology continues upward for an estimated thickness of 450 feet, and at the top the shales contain numerous fossils, chiefly *Inoceramus sagensis* Owen and *Baculites ovatus* Say.

The general subdivision of the lower part of the Pierre described above was also recognized by Gilbert[69] in the vicinity of Pueblo. He says:

> The Barren zone, so called on account of the rarity of its fossil remains, lies at the bottom of the series and is 400 to 500 feet thick. It is of bluish-gray color and in its lower part resembles the Niobrara shale in the tendency to divide into papery layers, rough from the crystallization of selenite. The Rusty zone, 600 feet thick, is also bluish gray in color but is comparatively free from gypsum. It contains many concretions composed of lime carbonate and iron carbonate, and these are of oval form, measuring, usually, from 1 foot to 2 feet across. Their material is originally dark gray but under the action of the weather turns a rusty brown, and the soil derived from the formation is usually so strewn with their angular fragments as to appear reddish brown. The Baculite zone, 100 to 200 feet thick, is pale gray and is so called from the abundance of a fossil shell of that name.

The "Barren zone" and "Rusty zone" of the Pierre are also recognized and described by Lavington,[70] who

[69] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (no. 36), p. 3, 1897.

[70] Lavington, C. S., Montana group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, no. 4, pp. 398–400, 1933.

center of sec. 21, T. 22 S., R. 42 W. (locality 16, pl. 64), good exposures of the upper part of the Codell in a creek bank show that it consists of regularly bedded gray shale and lighter-colored, fine-grained shaly sand, with a few lenses of yellowish-gray hard sandstone.

Near the center of sec. 18, T. 22 S., R. 44 W. (locality 14, pl. 64), the upper part of the Codell is exposed in the wall of the Amity Canal ditch. At this place it has a somewhat different aspect. (See fig. 11.) At the top is a bed of soft earthy sand from 6 to 12 inches thick. Below this is a hard calcareous sandstone or sandy limestone 3 feet thick, of a rusty-brown color. Irregular bedding is outlined by sheets and lenses of softer earthy sandstone, which is cross-bedded within lenses. Fucoids interlace through the rock in great numbers. It also contains the typically prismatic fragments of *Inoceramus* shells. Below this hard bed is 6 to 12 inches of soft earthy sand, which is underlain by soft gray sandy siltstone. In sec. 6, T. 22 S., R. 44 W., the top bed of the Codell is a hard brown, slightly sandy limestone. It is underlain by soft sandy siltstone. Good exposures of the Codell were not observed for about 20 miles west of this locality.

In a deep gully along the east side of the section-line road between secs. 10 and 11, T. 22 S., R. 48 W. (locality 13, pl. 64), however, the Codell consists of gray sandy clay mottled irregularly with white and light-gray sand, and no hard beds were observed in it. At several localities in the southwestern part of T. 21 S., R. 49 W., one or more beds of hard dark brownish-gray calcareous sandstone are present in the Codell. Such beds were observed as much as 12 feet below the top and also near or at the top. Characteristically they contain fish scales, fucoids, *Halymenites major*, and other fossil impressions. The mass of the Codell is soft crumbly silty sandstone, poorly bedded, and for the most part having a nodular or lumpy surface in vertical though somewhat weathered exposures.

West of locality 8 (pl. 64 and fig. 11) there is a hard gray bituminous limestone at all exposures observed. This limestone ranges from a few inches to several feet in thickness and is believed to be the bed which has been widely termed "Niobenton." Weathering to a rusty-brown color and having a rough granular fracture, it has the appearance of a calcareous sandstone, but in reality it contains only a small percentage of sand. It is characteristically interlaced with fucoids and carries numerous other fossils, including shark teeth. Even where thin it is notably persistent. It is much more resistant to erosion than the underlying beds and forms a definite escarpment. The thickness of the soft sandy shale and earthy sand of the Codell diminishes rapidly westward from about 30 feet in T. 22 S., R. 50 W., to less than 5 feet in the western part of T. 22 S., R. 51 W. (See fig. 11.) In the south-central part of T. 22 S., R. 53 W., and thence southwestward there is no appreciable sand or sandy shale below the hard gray limestone. The limestone is, however, recognized to the west, in the La Junta region.[46]

A petrographic examination of several specimens of the hard bed at the top of the Carlile shows that in most places it is a limestone that contains 3 percent or less of sand, but in some places it contains about 60 percent of sand. In the SE¼ sec. 21, T. 21 S., R. 49 W., there are lenses of bituminous limestone in a bed as much as 6 inches thick of shale and sandstone cemented with lime, which overlies a hard sandstone bed that is as much as 18 inches thick. (See pl. 65, *D*.) The upper bed contains less than 2 percent of sand and the lower bed about 60 percent. The minerals in either the predominantly limestone or predominantly sandstone beds, after the $CaCO_3$ has been removed, are found to be practically the same and in roughly the same proportions. This is also true of the Codell sand. These minerals and their approximate proportions, as determined by M. N. Bramlette, of the United States Geological Survey, are as follows:

> Quartz, 50 percent or more.
> Orthoclase, 20 percent, more or less.
> Chert grains, 10 to 15 percent.
> Indeterminate aggregates, 10 to 15 percent.
> A little sodic plagioclase.
> Zircon, green and brown tourmaline, rare.

The writers regard the hard limestone (so-called "Niobenton") at the top of the Carlile in the westernmost part of the area as forming part of the Codell sandstone—in fact, as being the sole representative of the Codell in that area. Similar limestones occur within or at the top of the more typical Codell farther east, having the same abundance of fucoids, shark teeth, fish fragments, and imprints and casts of the same types of invertebrate fossils. As has been shown, these limestones contain a small percentage of sand, which in its more general aspects of composition and grain size at least is like that of the more sandy phases of the Codell. Moreover, limestone of this type is not present in either the underlying Blue Hill or the overlying Niobrara formation. As there is good reason to believe that the nondeposition of sand at this horizon in the La Junta region and perhaps somewhat farther west is a local phenomenon, it seems better to regard the contemporaneous limestone at the same horizon as a phase of the Codell.

[46] Patton, H. B., op. cit., pp. 17–18.

About 5 miles west of Pueblo, on the north side of the Arkansas River, the following section of the top of the Carlile was measured by the writers:

Section of Carlile shale 5 miles west of Pueblo

	Feet
Niobrara formation.	
Carlile shale:	
Shale, gray	1
Sandstone, light gray, hard, massive; weathers brown; *Halymenites major* and many fucoids, particularly near the base. Makes a vertical ledge, but the top few feet weathers back to a slope	15
Shale, gray, and sandstone, thin-bedded, cross-bedded, with large ripple marks. This unit is separated by prominent shale partings above and below but is highly variable in lithology from place to place	4
Sandstone, earthy; weathers dark gray to almost white, with the most part a yellowish tinge; weathers into irregular small nodular masses and has a "knotted" appearance on vertical or steep exposures; merges downward into sandy shale	20
Shale, sandy	30±
Shale, gray.	
Total measured	70±

At Colorado City, west of Colorado Springs, the top bed of the Carlile is a light-gray, thin-bedded, shaly sandstone from a fraction of an inch to 10 inches thick, containing vast numbers of *Inoceramus*. Below it is 9 feet 4 inches of hard brown calcareous sandstone with many fish teeth and scales, *Ostrea* sp., *Inoceramus*, probably *I. fragilis*, *Scaphites warreni* Meek and Hayden, and *Prionocyclus wyomingensis* Meek. This sandstone is ripple-marked, and the ripples have a wave length of 2 to 5 inches. Farther north, at Perry Park, in the NW¼ sec. 24, T. 9 S., R. 68 W., a similar hard limy sandstone about 4 feet thick was observed.

Sandstone has been found at the top of the Carlile in many wells in northeastern Colorado;[47] and the Codell sandstone, 3 to 20 feet or more thick, has also been recognized on the outcrop in the northern foothill region.[48] It has been recorded also in most of the wells drilled within the area of the map. Its absence in a driller's log (see fig. 10) does not necessarily mean that the member is not present, as it may not have been noticed or recorded.

The top of the Carlile shale at the type locality[49] is a yellow friable sandstone, which corresponds in stratigraphic position and general lithologic features with the Codell sandstone. Similar sandstone at the top of the Carlile has also been found farther south in the Walsenburg quadrangle. The Carlile is there dark-gray shale, 170 to 180 feet thick, with 10 to 15 feet of yellow sandstone at the top, capped by bituminous limestone 2 to 4 feet thick. Still farther south, in the Spanish Peaks quadrangle, the Carlile includes 200 feet of dark-gray shale which grades near the top into 10 feet of sandy shale and friable yellowish sandstone, with an overlying layer of purplish bituminous limestone 1 to 2 feet thick.

The top of the Carlile, as observed by the writers on the north side of the Huerfano River in the extreme western part of the Walsenburg quadrangle, includes a considerably greater thickness of sand than is given in published descriptions. There is at least 25 feet of medium-hard light-gray fine-grained sandstone, buff colored and nodular-weathering in the lower part. Above this is 9 feet of soft sand and sandy shale, and at the top a bed 2 feet thick of hard brown-weathering gray limestone, which has an irregular under surface, contains abundant broken fossils and shark teeth, and at the top appears to be interbedded with thin streaks of soft sandy shale.

Sandstone at the top of the Carlile as a persistent lithologic unit apparently does not extend southward into New Mexico, however, for at a locality northwest of Vermejo Park (on Gold Creek west of old Pinafore post office) the upper part of the Carlile consists of yellowish-gray shale with septarian concretions and a few thin beds of hard, somewhat sandy, highly fossiliferous limestone.

The Codell sand is a source of nonflowing artesian water in a large area north of the Arkansas River, especially in the vicinity of Eads and Chivington, but the water is not potable and in some wells is unfit for stock use.

Nine samples of water were collected in the vicinity of Eads and Chivington from wells that obtain water from the horizon of the Codell sand. Partial analyses by the water-resources branch of the United States Geological Survey show that all the samples have a large amount of dissolved mineral matter. The smallest amount of total dissolved solids in any sample was 1,700 parts per million and the greatest was over 10,000 parts per million; most of them were between 2,500 and 6,500 parts. In all the samples the calcium carbonate content was small, which is surprising in view of the fact that the Codell is overlain by 50 feet or more of limestone and locally itself contains calcareous beds. The principal mineral constituents are sodium salts, bicarbonate, chloride, and sulphate. There is, however, a large difference in the relative amounts of these constituents, even in wells that are a mile or less apart, a difference difficult to explain unless it is assumed that there is little or no lateral movement in the aquifer. A greater number of samples and a more complete analysis of each will be necessary before any tentative conclusions can be drawn as to the nature of the water movement.

[47] Waldschmidt, W. A., Characteristics of older Cretaceous formations of northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, no. 4, pp. 415–416, 1933.

[48] Mather, K. F., Gilluly, James, and Lusk, R. G., op. cit. (Bull. 796), p. 81.

[49] Gilbert, G. K., op cit. (17th Ann. Rept., pt. 2), pp. 565–566, 570.

stone swings southward across the Arkansas River but swings back before the Kansas line is reached.

SMOKY HILL MARL MEMBER

Although the entire thickness of the Smoky Hill marl member is present, little is known of it in detail because of poor exposures (pl. 65, *C*). It lies upon the white chalky limestone beds of the Hays member, from which it is easily distinguishable because it is softer and has a characteristic yellowish-orange color. The Smoky Hill contains beds of white limestone, but they are in most places only a few inches thick and are separated by much greater thicknesses of yellowish chalk. Several thin bentonite beds have been noted within the Smoky Hill, as well as beds of dark-tan and bluish shale. Much of the Smoky Hill has a tan to yellow color when fresh, and practically all of it has some shade of yellowish orange on weathered exposures. Another distinguishing feature is the occurrence of small white calcareous flecks throughout the chalk, which give it a mottled "salty" appearance. The total thickness of the Smoky Hill is not known precisely, but from well logs it is believed to be between 600 and 700 feet. Within probably the upper 100 feet of this member are chalk beds that are somewhat harder and purer than the beds below. On weathered outcrops the bedding planes have opened, and these horizontal or tabular spaces are loosely filled with needlelike interstitial calcite in which the larger dimension of the crystals is perpendicular to the bedding. As a whole, the Smoky Hill is well stratified and thin-bedded. It is practically all calcareous, but the larger part of it may be properly termed marl rather than chalk.

Inoceramus (*Haploscapha*) *grandis* is the most diagnostic fossil of the Smoky Hill member. Complete well-preserved specimens are seldom found, but in places large fragments covered with oyster shells are numerous. Fish scales are abundant in some exposures of the upper part of the member.

NIOBRARA FORMATION IN SOUTHERN FOOTHILL REGION

The Timpas limestone has been differentiated as far south as the area of the Spanish Peaks folio,[68] in which it is described as 200 feet thick, including a lower portion, 45 to 50 feet thick, consisting chiefly of limestone. Just a short distance to the south, along the east flank of the Sangre de Cristo Range in extreme northern New Mexico, however, limestone forms a much smaller proportion of the Niobrara formation, as shown in the following section:

[68] Hills, R. C., U. S. Geol. Survey Geol. Atlas, Spanish Peaks folio (no. 71), p. 1, 1901.

Section of Niobrara formation on Gold Creek, west of old Pinafore post office, northwest of Vermejo Park on the road to Costilla, Colfax County, N. Mex.

	Ft.	in.
Pierre shale.		
Niobrara formation:		
Shale, hard, gray, calcareous; thickness (estimated)	250	
Shale, hard, gray, calcareous, with a zone of thin lenticular beds of hard gray calcareous sandstone near the top; thickness (estimated)	500	
Limestone, gray, in beds 4 inches to 1 foot 4 inches thick, with intervening beds of gray calcareous shale	8	
Shale, gray, calcareous	4	
Bentonite		1
Shale, gray, calcareous		10
Bentonite		5
Shale, gray		7
Bentonite		4
Shale, gray, calcareous, with thin lenses and beds of hard gray marl	2	6
Rusty streak.		
Shale, gray, calcareous	1	3
Bentonite		2
Shale, gray, calcareous, some thin shaly limestone beds	2	
Bentonite?		¼
Shale, gray, calcareous	1	2
Bentonite		4
Thickness of Niobrara formation, about	770	
Carlile shale: Gray shale with septarian concretions and thin beds of hard sandy limestone.		

This section is of interest in representing the character of the Niobrara formation at a place probably near the southwesterly limit at which a limestone unit equivalent to the Hays limestone of the Arkansas Valley is present in the Cretaceous section.

The rather conspicuous bentonite zone in the basal part of the Niobrara in the preceding section has not been described in previously published reports and was not observed by the writers along the Arkansas River. There is a suggestion, however, that it extends some distance northward along the east flank of the Sangre de Cristo Range into Colorado. Bentonite beds, probably in the basal part of the Niobrara, were observed at a locality about 6 miles south of Stonewall, in western Las Animas County, Colo. (west of Trinidad). Still farther north, on the north side of the Huerfano River just northeast of the bridge at Badito, there is a soft concealed interval of 10 feet above the sand at the top of the Carlile shale. At the top of the concealed interval are soft bedded marls, and at the base of it there may be some bentonite. The softer beds making the interval of concealment were included by the writers in the Niobrara formation.

from the top of the Dakota to the base of the present Smoky Hill member. Williston[65] later restricted the name to include only the present Hays limestone member.

The Hays limestone member includes beds of white to cream-colored, chalky limestone 6 inches to 3 feet thick separated by beds of gray calcareous shale 1 to 6 inches thick. The limestone makes up nearly three-fourths of the member. Near the base there are numerous small irregular or capsule-shaped nodules of pyrite (or marcasite?) from one-fourth to three-fourths of an inch in longest dimension. The surface of these nodules is made up of an aggregate of interlocking cubical crystals. In the lower foot or two of the member there are small lenses of hard gray limestone which have a petroliferous odor on fresh fracture and resemble the limestone bed that in places forms the top of the Codell sandstone member of the Carlile.

The following section of the Hays limestone member was measured approximately midway east and west within the area covered by the map:

Section of Hays limestone member of the Niobrara formation in secs. 16 and 21, T. 21 S., R. 49 W.

	Ft.	in.
Niobrara formation.		
Smoky Hill marl member:		
Shale, tan; weathers yellow.		
Limestone, white		4
Shale, chalky, gray to tan; weathers tan-yellow	5	
Hays limestone member:		
Concealed, limestone and shale	17	½
Shale, chalky, light tan		7
Limestone, white	3	2
Limestone and shale, interbedded, partly concealed	4	6
Limestone, white; contains *Inoceramus deformis* and fucoids	2	3
Limestone, white, chalky, and gray shale		4
Limestone, white, chalky, irregular bedding	1	8
Chalk, shaly, white to gray		5
Limestone, white		10
Shale, gray to tan; contains many *Inoceramus deformis?*		5
Limestone, white, chalky	1	4
Chalk, white		2
Limestone, white; weathers into small tabular pieces	2	6
Chalk, shaly		1
Limestone, white		10
Shale, tan to gray; contains *Inoceramus* sp.		6
Limestone, white; lower 2 feet massive	3	6
Chalk, shaly, tan to gray		1½
Limestone, white	1	2
Chalk, tan		1
Limestone, white		8
Shale, chalky, tan		5
Shale, blue		3
Limestone, white	1	10

[65] Williston, S. W., The Niobrara Cretaceous of western Kansas: Kansas Acad. Sci. Trans., vol. 13, pp. 108–109, 1893.

Section of Hays limestone member of the Niobrara formation in secs. 16 and 21, T. 21 S., R. 49 W.—Continued

	Ft.	in.
Niobrara formation—Continued.		
Smoky Hill marl member—Continued.		
Chalk, tan, and limestone		1½
Limestone, white	1	5
Shale, greenish gray		6
Limestone, white		8
Chalk, tan		1
Limestone, white		2
Shale, blue gray, calcareous		6
Limestone, white; weathers into tabular pieces	1	1
Shale, gray, chalky		2
Limestone, white; contains abundant *Inoceramus deformis*	1	3
Chalk, tan, and gray calcareous shale		7
Limestone, white		7
Chalk, tan		1
Limestone, white		3
Shale, gray, calcareous		6
Limestone, white		10
Chalk, tan to gray		2
Limestone, white; irregular bedding; weathers into tabular pieces	1	
Shale, tan, chalky		6
Limestone, white		9
Chalk, light gray, shaly		2
Limestone, white, irregular		2
Chalk, light gray, shaly		3½
Limestone, white	1	
Limestone, white, and tan chalk		8
Limestone, white	1	6
Chalk, tan, shaly		2
Limestone, white	1	3
Shale, tan, chalky		3
Limestone, white, containing capsule-shaped pyrite nodules	3	
Carlile shale:		
Codell sandstone member:		
Sandstone and shale, gray, cemented with lime; contains lenses of hard limestone	0–6	
Sandstone, gray to brown, hard; contains fish scales, fragments of fossils, and fucoids. From 0 to	1	6
Sandstone, gray, fine-grained.		
Total measured	71	8
Thickness of Hays limestone	64	4

The thickness of the Hays in the above section is about 65 feet. In Hamilton County, Kans.,[66] the thickness of the member is 61 feet. In the Nepesta quadrangle[67] and adjoining areas the thickness of the limestone unit at the base of the Timpas is about 50 feet.

The Hays limestone is much more resistant to weathering than the beds above or below and consequently generally forms an escarpment or cliff. It is exposed almost continuously from La Junta to a point north of McClave. Thence eastward, however, it is poorly exposed. East of Lamar the base of the lime-

[66] Bass, N. W., op. cit., p. 62.
[67] Fisher, C. A., op. cit., p. 2.

POSSIBILITY OF UNCONFORMITY AT TOP OF CODELL

The Codell sandstone clearly represents the widespread occurrence of a set of environmental conditions different from those under which the deposition of the underlying rocks of Benton age occurred, or from those under which the overlying Niobrara formation was laid down. The Graneros and Greenhorn formations particularly give evidence that the sediments which compose them were deposited in moderately deep water, almost certainly below the depth of wave agitation—for individual beds even of small thickness persist for considerable distances. The lower part of the Carlile is also evenly bedded, but much of the Codell was clearly deposited within the reach of wave and current agitation. This is shown not only by its sandy composition but also by the irregularity and cross-bedding which in places appear within it. Ripple marks have been observed at some places, and the shark teeth locally present are worn by abrasion. In a larger way the differences in lithology of the member from place to place indicate that it was deposited under the variable conditions to be expected in a shallow-water environment.

Although in many places thin and possibly locally absent, the Codell is surprisingly widespread, extending over most of eastern Colorado and western Kansas, with little significant variation in content or bedding. The Codell therefore seems to represent a time when deposition had filled a large area of the Cretaceous sea to a level at which the deposited material was within the reach of wave agitation. There is reason to believe that this condition was maintained for a considerable period.

Johnson[50] has already summarized the evidence for an unconformity at the base of the overlying Niobrara formation, concluding that "Sufficient time, at least * * * elapsed to account for a complete cessation of deposition of one type, its alteration, and, in places, partial erosion and the development of conditions under which sediment of a completely new type was deposited." Certainly the abrupt change in fauna from the Carlile to the Niobrara suggests, even if the difference in lithologic character of the formations is discounted, that there was a lapse of time that permitted the development of new faunas.

Johnson also cites as evidence of unconformity a "thin conglomerate containing plentiful fish teeth, well-rounded pebbles, and phosphate nodules" which "occurs at the base of the Niobrara in all the areas studied." The pebbles are described as small, smooth, and well rounded, some as much as 3 inches in diameter. They consist chiefly of black chert but also of quartzite and white quartz, and they occur together with phosphate nodules and shark teeth in a matrix of gray to brown crystalline sandy limestone. Although pebbles are also reported at this horizon in southeastern Colorado, none were observed by the writers in the outcrops extending from La Junta eastward to the Kansas State line. The possibly similar bituminous limestone with some shark teeth (and phosphatic nodules?) occurring there at the top of the Carlile has already been described (p. 217). This rock is, however, faunally and lithologically allied with the Codell, to which it is assigned by the writers. The base of the overlying Niobrara formation is for the most part sharp and locally slightly irregular. Angular discordance was nowhere observed. Particularly from T. 22 S., R. 53 W., to T. 22 S., R. 51 W., however, the basal contact of the Niobrara is somewhat obscure. The hard brown limestone assigned to the Codell by the writers appears to grade upward into the overlying gray or white limestone, and locally lenses of hard brown limestone like the underlying rock also appear in the basal Niobrara. Also the brown limestone itself becomes somewhat lighter colored eastward. The gradation, in fact, is so pronounced that the hard brown limestone has been interpreted by Patton[51] as merging into the basal limestone bed of the Niobrara. Patton supposed that the occurrence near the bottom of the Niobrara of a fossil identified as *Inoceramus labiatus*, a characteristic Benton form, reinforced this interpretation. It is now known, however, that an *Inoceramus* much like *Inoceramus labiatus* but distinct from it is present in many places in the lowest beds of the Niobrara. On the whole the appearance of the contact itself as seen by the writers neither suggests nor disproves unconformable relations.

In some areas local thinning of the Carlile suggests the possibility that the thinning may be due to erosion in those areas before the deposition of the Niobrara. Notably in the vicinity of La Junta the Carlile is abnormally thin. A section measured by Patton[52] shows a thickness of 130 feet. The logs of wells at Cheraw and Swink indicate that the Carlile is about 125 feet thick. (See fig. 10.) The logs of other wells in the vicinity of La Junta show that the beds of Benton age are from 50 to 75 feet thinner than to the east or west, and this thinning presumably also is due entirely to thinning of the Carlile. To the west, the Carlile is from 210 to 225 feet thick in the Nepesta quadrangle[53] and 200 to 232 feet thick in the Apishapa quadrangle;[54] east of Las Animas it is probably over 200 feet thick, and in Hamilton County, in western Kansas,

[50] Johnson, J. H., Unconformity in Colorado group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 14, no. 6, pp. 789–794, 1930.

[51] Patton, H. B., op. cit., pp. 18, 21.
[52] Idem, p. 17.
[53] Fisher, C. A., U. S. Geol. Survey Geol. Atlas, Nepesta folio (no. 135), p. 2, 1906.
[54] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), p. 6, 1912.

about 250 feet thick. If the writers' view is accepted, that the hard brown limestone above described is to be assigned to the Codell, the thinning of the Carlile in the vicinity of La Junta takes place within the Carlile and not as a result of erosion at the base of the overlying Niobrara. The thinning is thus presumably to be ascribed to lesser deposition in that area. The sandy phase of the Codell thins out over the same area, but its diminution from 30 feet to the vanishing point is not adequate to explain the total thinning of 50 to 75 feet, part of which must therefore be due to thinning of lower beds in the Carlile. Lest the thinning of the sandy Codell westward be interpreted as due to erosional unconformity at the base of the hard brown limestone, it should be pointed out that the sandy phase appears to merge westward into nonsandy beds by intertonguing and also that the distinctive zone of septarian concretions at the top of the Blue Hill shale member appears to maintain approximately its vertical distance from the base of the Niobrara across the area in which there is no Codell sand. (See fig. 11.) For some reason, therefore, the area about La Junta appears to have received less sediment than the surrounding regions. A plausible explanation for similar features in the Benton stratigraphy in other areas in eastern Colorado has already been offered by Johnson and Aurand.[55] They suggest that structural features in existence during early Cretaceous time were rising slowly throughout Benton time, sufficiently high to divert or check the velocity of the submarine currents. "Part of the time their tops seem to have been approximately at the plane of equilibrium, where, though the waters were free to pass over them, there was almost no erosion or deposition, though deposition was taking place around the sides."

As neither the local thinning of the Carlile and absence of the Codell member nor the details of the contact between the Niobrara and Carlile offer incontrovertible evidence of unconformity at the base of the Niobrara, the writers believe that the most valid evidence of such unconformity is the faunal discontinuity between the two formations. There seems no reason to suppose that the top of the Carlile emerged above sea level and was eroded. The faunal discontinuity seems rather to indicate a period at which the top of the Carlile sediments stood at wave base, with submarine erosion counterbalancing deposition. This was followed by subsidence or the deepening of the sea waters from some more remote cause, and in these less agitated waters the calcareous sediments of the Niobrara were deposited.

[55] Johnson, J. H., and Aurand, H. A., A preliminary contribution to the Benton paleogeography of eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, no. 7, pp. 850–853, 1929.

FAUNA

Fossils collected from the Fairport and Codell members include the following forms:

	Locality
Codell sandstone member:	
Inoceramus fragilis Hall and Meek	1, 2, 3, 7
Inoceramus dimidius White	7
Inoceramus sp	6
Ostrea lugubris Conrad	2, 3, 4
Ostrea sp	1
Gryphaea sp	3
Scaphites warreni Meek and Hayden	1, 2, 3
Prionocyclus wyomingensis Meek	1, 2, 3, 5, 6, 7
Lamna? sp	1, 3
Ptychodus sp	3
Fairport chalky shale member:	
Inoceramus sp	8, 9, 10
Ostrea sp	8, 10
Baculites sp	8
Exiteloceras cf. *E. pariense* (White)	8
Prionotropis woolgari (Mantell)	8, 9, 10

1. 15746, Colorado City, west of Colorado Springs.
2. 15758, NW¼ sec. 24, T. 9 S., R. 68 W., Perry Park.
3. 15820, SW¼ sec. 9, T. 22 S., R. 50 W.
4. 15823, SE¼ sec. 35, T. 21 S., R. 50 W.
5. 16066, SW¼ sec. 32, T. 21 S., R. 48 W.
6. 16070, NE¼ sec. 6, T. 22 S., R. 44 W.
7. 16084, NE¼ sec. 26, T. 21 S., R. 49 W.
8. 15822, NE¼ sec. 16, T. 22 S., R. 50 W.
9. 16067, SE¼ sec. 27, T. 21 S., R. 49 W.
10. 16074, northeast corner sec. 34, T. 21 S., R. 49 W.

Bass[56] reports from the lower 18 feet of the Fairport shale member of Hamilton County, Kans., the following species: *Globigerina bulloides* D'Orbigny, *Inoceramus fragilis* Hall and Meek, *Inoceramus labiatus* Schlotheim (broad variety), *Ostrea* cf. *O. congesta* Conrad, *Baculites gracilis* Shumard, *Prionotropis woolgari* (Mantell), *Ichthyodectes?* sp. From the Blue Hill shale member Bass[57] reports *Inoceramus* sp. (fragments) and *Prionocyclus wyomingensis* Meek. From the top of the Codell Bass[58] reports *Inoceramus fragilis* Hall and Meek, *Ostrea congesta* Conrad (float?), *Prionocyclus wyomingensis* Meek, *Ptychodus* sp., *Lamna?* sp., *Corax?* sp., coprolites, and phosphate nodules.

NIOBRARA FORMATION

The Niobrara formation is the uppermost formation of the Colorado group. It is distinctly separated from the underlying Carlile shale but less readily separable from the overlying Pierre shale, the lowest formation of the Montana group. It includes about 700 feet of beds, chiefly chalk and chalky shale but with a well-marked, persistent limestone member, from 50 to 65 feet thick, at the base. This limestone is continuous in outcrop with the limestone member of the Niobrara

[56] Bass, N. W., op. cit., p. 66.
[57] Idem, pp. 64–65.
[58] Idem, p. 65.

formation in western Kansas that has long been called "Fort Hays limestone" and is equivalent to it in lithology, thickness, and age, so far as known. The writers propose that the limestone at the base of the Niobrara within the area which they have mapped be called the "Hays[59] limestone member" and that the overlying portion of the Niobrara be called the "Smoky Hill marl member", to correspond with the usage of "Smoky Hill" for the upper chalk member of the Niobrara formation in the adjoining area of western Kansas.

The Niobrara formation of southeastern Colorado has heretofore been divided into a lower member, the Timpas limestone, and an upper member, the Apishapa shale. These previously defined units differ somewhat from those recognized in western Kansas and from those recognized by the writers north of the Arkansas River in eastern Colorado.

According to Stose,[60] the Timpas limestone was named by Gilbert from Timpas Creek, which flows through the southeast corner of the Apishapa quadrangle and thence into the Arkansas River. The description of the Timpas limestone by Gilbert[61] is quoted below, in part:

> The general thickness of the Timpas is 175 feet, and it may be characterized as a series of limestones and calcareous shales with prevailing pale colors.
>
> At the base is a limestone series about 50 feet thick. The individual beds range in thickness from a few inches to 3 feet, the average being about 1 foot. They are separated by layers of gray shale, usually 1 or 2 inches thick. The limestone has a light-gray color, which becomes creamy white on weathered surfaces. It is compact and rather fine grained and where exposed to the weather breaks up into rough flakes, of which the longer dimensions are parallel to the bedding. This peculiarity ordinarily serves to distinguish it from the Greenhorn limestone, which cleaves into vertical plates. * * * In its lower layers are small nodules of iron sulphide, which are converted by the chemical reaction of the air to limonite. As the limestone is broken up and removed by the action of weather, the more resistant nodules are freed from their matrix so as to lie loose on the surface. They are of a dark-brown color and of oval or cylindrical form, with a diameter of about half an inch. Their surfaces are not even but are set with angular projections, the end of crystals. * * *
>
> The upper limit of the limestone is indefinite. It passes gradually into a light-gray limy shale, which contains occasional thin beds of limestone and has a total thickness of 100 or 125 feet, terminating at top in one or two layers of chalky limestone containing several species of fossil shells and also the remains of fishes.

The Hays limestone member as recognized by the writers is probably closely equivalent to the "limestone series about 50 feet thick" at the base of the Timpas as defined in earlier reports. In the region mapped, and in some sections examined in adjoining areas, the limestone unit about 50 feet thick forms a natural, convenient, and practicable unit. It is, moreover, the unit readily recognizable in records of deep wells, both in this area and in northeastern Colorado.[62]

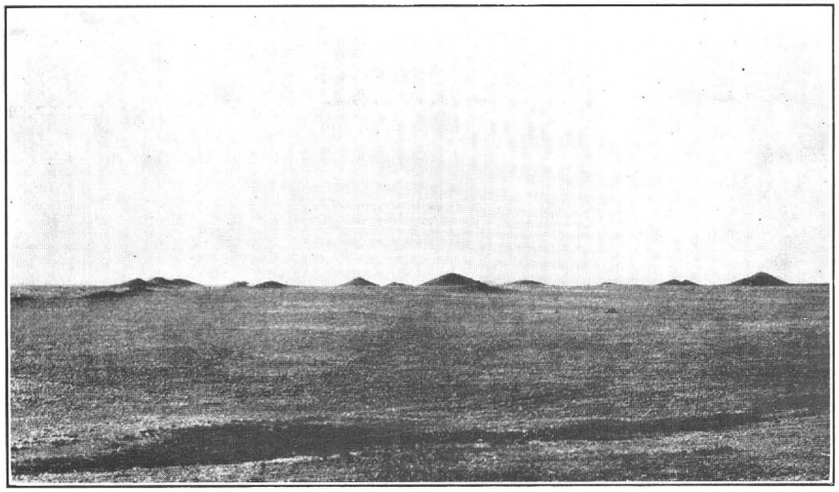
The Timpas was differentiated in the La Junta region,[63] but farther east the limestone bed at the top of the Timpas was not recognized with assurance nor mapped by the writers. This may be in part attributable to scarcity and discontinuity of exposures. Two limestone beds, each 1 foot or less in thickness and separated by 12 feet of cream-colored or tan chalk, are exposed in the eastern part of sec. 23, T. 23 S., R. 55 W., and may lie near the top of the Timpas formation as previously defined. In the eastern part of sec. 27, T. 21 S., R. 53 W., along Adobe Creek, there is a bed of white limestone about 4 feet thick underlain by chalk which may also be near the same horizon. These limestone beds are included by the writers in the Smoky Hill marl. Even were exposures adequate, there is some doubt that the Timpas limestone as previously defined is a stratigraphic unit of widespread usefulness within the area described by the writers.

Inoceramus deformis, which is abundant in the Hays limestone member, does not occur above it, and immediately overlying beds contain large flat *Inoceramus* (*Haploscapha*) *grandis*. These fossils appear to have distinct ranges over most of the region of western Upper Cretaceous sedimentation, regardless of lithologic environment. There is thus some suggestion that the lithologic unit of the Hays limestone is also a faunal unit. The unit named "Timpas limestone" by Gilbert therefore includes in its upper part beds that are both lithologically and faunally more closely allied to the upper part of the Niobrara. The names "Timpas" and "Apishapa" have, however, been applied to mappable units over a large area west and southwest of the area in which the writers have had opportunity to make detailed observations and should therefore be retained for areas in which the propriety of distinguishing the Hays limestone member has not yet been made evident.

HAYS LIMESTONE MEMBER

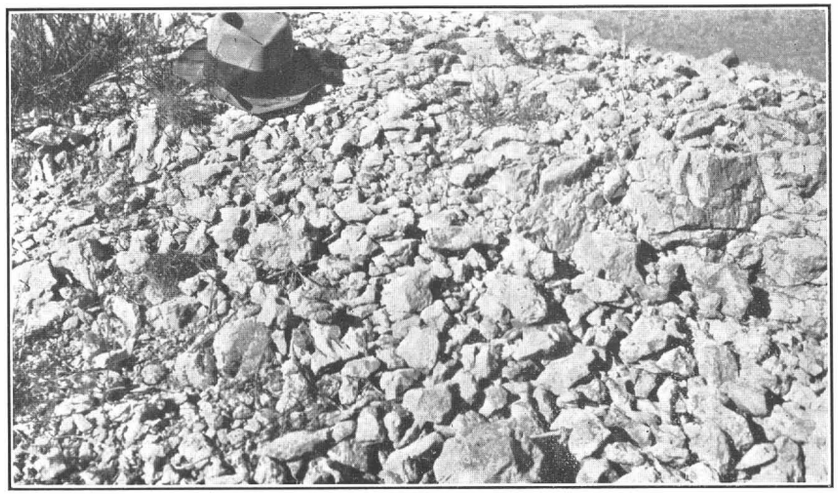
The term "Fort Hays" (from the former fort of that name in Ellis County, Kans.) was first used by Mudge[64] as a division name, defined thus: "The massive stratum of limestone above described, together with all the deposits above the sandstone of the Dakota, I shall call the Fort Hays division." This included all the strata

[59] The shorter name "Hays" has been adopted for this member with the approval of R. C. Moore, State geologist of Kansas. The name of the type locality has for some time been "Hays."
[60] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (no. 186), p. 6, 1912.
[61] Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 566–567, 1896.
[62] Waldschmidt, W. A., op. cit., pp. 412–415.
[63] Patton, H. B., op. cit., pp. 43–44.
[64] Mudge, B. F., Notes on the Tertiary and Cretaceous periods of Kansas: U. S. Geol. and Geog. Survey Terr. 9th Ann. Rept., p. 289, 1877.



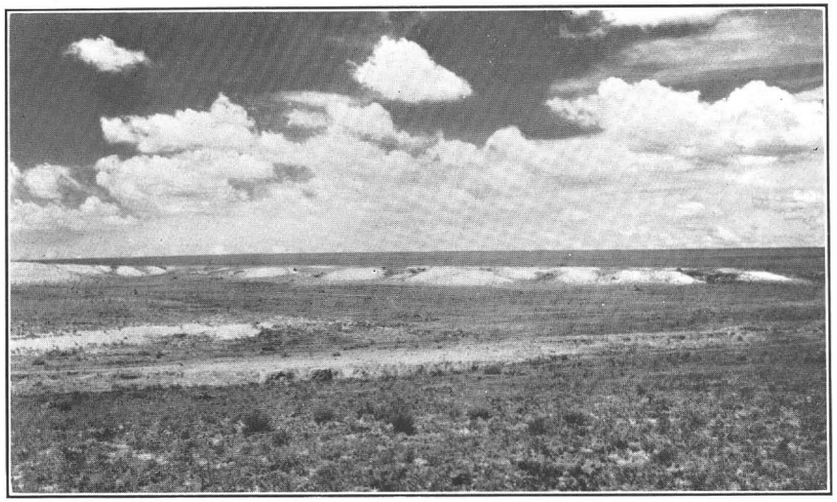
A. A GROUP OF "TEPEE BUTTES."

Small conical hills in the Pierre shale formed by the greater resistance to weathering of large masses of limestone. Looking north from the center of sec. 3, T. 17 S., R. 65 W.



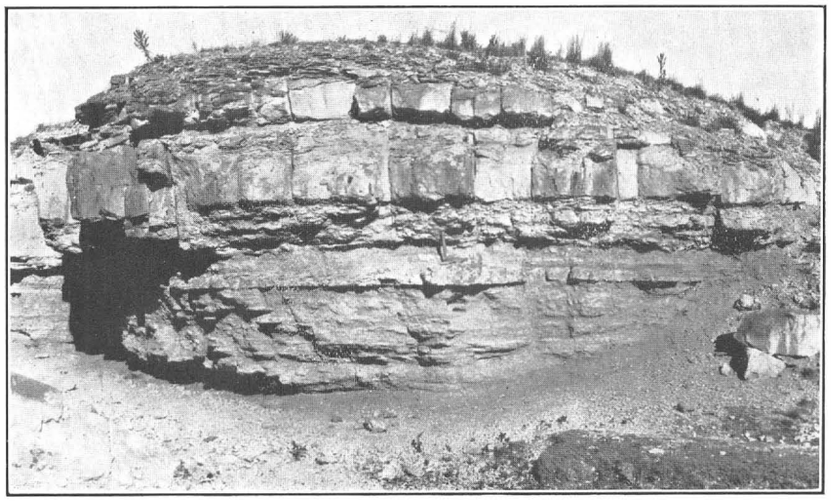
B. DETAILED VIEW OF WEATHERED TOP OR CORE OF A "TEPEE BUTTE" IN THE NE¼ SEC. 35, T. 12 S., R. 49 W.

The rock is an impure limestone in which *Lucina occidentalis* is exceedingly abundant.



C. TYPICAL OUTCROP OF THE LOWER PART OF THE SMOKY HILL MARL MEMBER OF THE NIOBRARA FORMATION.

Looking northwest from the SW¼ sec. 16, T. 21 S., R. 49 W.



D. CONTACT BETWEEN THE HAYS LIMESTONE MEMBER OF THE NIOBRARA FORMATION AND THE CODELL SANDSTONE MEMBER OF THE CARLILE SHALE IN THE SE¼ SEC. 21, T. 21 S., R. 49 W.

The hammer rests on a hard bed of calcareous sandstone within the Codell, about 2 feet below the base of the Hays limestone.

San Juan Basin
USGS Bull
860 B

SOME URANIUM OCCURRENCES IN THE CENTRAL AND SOUTHWESTERN PARTS OF THE COLORADO MINERAL BELT*

BGSA 63(52)
P. 1368

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Recent discoveries of uranium in the Alma, St. Kevin, and Leadville mining districts of the central part, and in the Upper and Lower Uncompahgre, and Red Mountain mining districts of the southwestern part of the Colorado Mineral Belt have considerably increased the area within the Mineral Belt that warrants extensive prospecting for uranium deposits. The discoveries resulted from work undertaken by the U. S. Geological Survey for the Atomic Energy Commission.

Uranium minerals are associated with base- and precious-metal veins in the Alma, St. Kevin, and Lower Uncompahgre districts; and with pyritic veins and copper-lead-silver volcanic breccia pipe deposits in the Red Mountain district. They occur as coatings on fracture surfaces and as disseminations in country rocks in the Leadville, St. Kevin, and Upper Uncompahgre districts.

Pitchblende has been found in the Alma, Leadville, Upper and Lower Uncompahgre, and Red Mountain districts. Torbernite and pitchblende (?) occur in the St. Kevin district.

In the Lower Uncompahgre district, a genetic relationship between the uranium deposits and the zoning of metalliferous deposits related to the eruptive center of the Lower Uncompahgre district is suggested by the occurrence of uranium close to the boundary between a pyrite-gold-base-metal core and an outer silver-lead-zinc zone. No clearly defined zonal relationships were noted in the other districts.

The pitchblende(?) in the veins of the Red Mountain district, and in the Alma, St. Kevin, Leadville, and Upper and Lower Uncompahgre districts was probably deposited by hypogene processes. In the St. Kevin district, torbernite and sooty pitchblende(?) are alteration products of primary pitchblende(?). The origin of the high-grade copper-lead-silver breccia pipe deposits has previously been explained as caused by vaporization of ore solutions at high temperatures in a semisealed environment. Such an environment would be favorable for the retention of relatively soluble uranium compounds and may explain the association of the pitchblende(?) with the ore.

XLI C-4

GSA Bull. vol. 71, 1960, p. 1951

THICKNESS OF THE EARTH'S CRUST AS RELATED TO TECTONISM, VULCANISM, AND MINERALIZATION IN COLORADO

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An Airy-Heiskanen anomaly map of Colorado, prepared by applying isostatic reductions to gravity data supplied by Ralph C. Holmer, is interpreted in terms of crustal thicknesses. The crustal model selected for computations was one having material of density 2.67 gm/cm^3, underlain by material of density 3.27 gm/cm^3.

Minimal thickness values result over most mountain ranges and plateau areas in Colorado. For example, thicknesses as low as 35 km are found over the Front Range and the Uncompahgre uplift. This figure agrees with that obtained by Tatel and Tuve by seismic methods in the Colorado Plateau (Arizona, New Mexico, Utah).

Maximum inferred thicknesses, however, are found in areas where intrusive or extrusive igneous rocks are present. Examples are the Colorado Mineral Belt and the San Juan volcanic rocks. In both these areas, thicknesses of about 50 km are found.

The conclusions drawn are: (1) the crust in Colorado is warped and perhaps split in distinct blocks; (2) warping probably occurred during Precambrian; (3) mountain ranges are perhaps genetically related to the upwarps; and (4) igneous activity and mineralization may have been a response to melting of the sialic rocks which were pushed deep into the mantle during warping.

XLI C-4

GSA Bull. vol. 71, 1960. p. 2065

PORPHYRY INTRUSIVE ROCKS OF THE MANHATTAN DISTRICT, NORTHERN FRONT RANGE, COLORADO

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A belt of intrusive rocks regarded as of probable Laramide age by Lovering and Goddard (1950) trends northeast in the Front Range west of Fort Collins, Colorado. It parallels the central Colorado intrusive belt to the south and contains granodioritic and monzonitic porphyries similar to those in the larger and better-known belt.

In the Manhattan mining district the country rocks are Precambrian quartz-biotite schist, hornblende schist, and granitic rocks. Detailed mapping shows the porphyry to be dikes, sills, and small stocks. Tabular bodies are most abundant and are from a few feet to 200 feet wide and up to 1½ miles long. Most of them are discordant to the country rock foliation but locally parallel it. The stocks are irregularly shaped and formed at the intersections of dikes. Most of the dikes follow east-west and northwest-southeast joints and shear zones that parallel major Laramide structural trends. Arcuate outcrop patterns suggestive of ring dikes result where dikes followed gently curving schist–granite contacts.

Although mineralized shear zones are common near the intrusive rocks, there is little evidence of wall-rock alteration indicative of potentially commercial deposits.

ROCKY MOUNTAINS

Notes from: Geologic History of Rocky Mt. Region, J.D.Haun & H.C.Kent, 1965, AAPG Bull. v.49,1781-1800.

1789 In Jurassicnthickest marine depositionwas centered in the Twin Creek trough along W boundary of the region (longitude of W Wyoming border). Twin Creek sedimentation (lower Bajocian-Middle Callovian, 168-160) is the last significant carbonate deposition inn the Rocky
1790 Mountain region. Middle Jurassic paleogeographic map (170-160) shows NE trend of depositional environments. Normal marine on NW; NE Belt island separates this from restricted environment on SE. (Island on my map I) This depositional strike continued into Late Ju and was controlled by the transcontinental arch.

Several Middle and Late Jurassic invasions by the Arctic sea; most extensive representaed by shallow marine and transitional sediments of Sundance and Todilto ls. (~~xxxxxxxxxxxx~~ Todilto Oxfordian, 155-153; Sundanca, upper, 155-151). Entire Oxfordian. Maximum limit of this sea shown o my Map II. Source area fir most Jurassic clastics on W along a N-S uplift which formed in the Cordilleran trough during Nevadan orogeny. After northward withdrawl of Sundance sea non-marine shales and coarser clastics of the Morrison formation were deposited.

1791 Cretaceous.- In early K Arctic sea again invaded Rocky Mt. region. Dakota group became younger southward; deposited in transitional environments near margins of this sea. Arctic sea joined, over the transcontinental arch, a seaway extebding N from Gulf of Mexico. Seas separated for a short time by joining of deltaic deposits from E and W; reunited in Late K. Sea did not reach NW New Mexico until late K. Major sources of clastics were E and W of seaway in Early K, but in Late K dominent source was on W. Thick deposits on W reflect nearness of clastic source as well as major downwarping; slightly E of thickest deposits of earlier periods.

1794 West-to-east progression of Late K sea periodically interrupted by transgression s giving intertonguing of marins and non-marine sediments Thick non-marine and transitional Mesaverde accumulated in coastal plain and deltaic environments along the W shore (Mesaverde-Coniacian to mid-Santonian, 87-79

Cenozoic.- Laramide orogeny began in mid-Maetrichtian (67 m.y.) lasted until end of Eocene. Arbitrary definition, but applies to area described In Laramide came vertical uplifts and basins, folds, reverse and normal faults; tremendous thickness of non-marine sed 15,000 to 45,000 ft. of structural relief developed. Post-Laramide tectonic activity was different, involving regional uplift and normal faulting.

Notes from TECTONIC CONTROL OF MINERAL BELTS IN THE SOUTHWESTERN COLORADO METALLOGENIC PROVINCE.

J.W.Gabelman,W.H.Boyer, 1960, AIME Trans. v.217,296-310.

Notes from

DEFINITION OF A MINERAL BELT

J.W. Tabelman, Econ.Geol. v.48, 1953, 177-210

Belt extends SE from Bona za to La Veta, Colo.

Refer to maps.

182. Stratigraphy.- Lower Paleo, unconformable on Prec basement, 600 -1000'. Cambrian-Miss. basal qtzite, then dolomite, qtzite, dolomite, ss sh., ls. Only in N part. Penn-Permian, mostly red beds, covered most of region. Most of present surface excdpt where cryst. rocks exposed by uplift.

Meso seds covrered most of region unconformably; removed except in Huerfano basin.

Tertiary formations only in the latter; his was depressed as Sangre de Cristo and Wet Mountains rose; received from these sandy and shaly seds.

Geologic History.- Ear y Paleozinc, belt part of shallow cdntral Colo. basin embayment. During la e Paleo uplift of ancestral Rockies, region near center of the deepening basin (Colorado geosyncline). This received great thi knesses of clasric from destruction from destruction of San Luis and ancestral Front Ranges.

Region bevelled; Meso seds, statewide. Laramide Rockies development gave rise to structures that eventually controlled Tertiary volcanism and ore deposition.

183 Uplift of Front Range-Wet Mts. s arted late K, culminzted early Eocene. Folding, underthrusting (N.B.), and overthrusting toward the west.

Note: Fig, 2 shows Wet Mts. uplift bounded on E and W by thrusts which on the W border at least ar steep-dipping. In order to have regional compression from the E in early Eocene timr, he thrust on the E boundary is called an underthrust. Both are marginal thrusts due to uplift.

Middle Eocene, Siarra Blanca massif in San Luis Valley rose and expanded; caused strong overthrusting toward N in upper San Luis Valley, towrd NE in Sangre de Cristo Range and toward E in Huerfano Park.

Huerfano basin sinking throughout the Eocene; received sediments from Wet and Sangre de Cristo Mts.

Late Eocene to early Oligocene Sierra Blanca and Culebra massifs, and the Wet Mts. were differentially uplifted, vertically breaking thru the thrust faults.

Oligocene -Recent downfaulting of San Luis Valley, Basin-range deformation, ou lined present W slope of San gre de Cristo. This foundering accompanied by extrusion of San Juan volcanics to W. Valley flows filled much of the valley. During same period, entire region NE of San Luis Valley was broadly uplifed several times.

Colorado geosyncline replaced in Laramide by Sangre de Cristo, replaced by Huerfano-Trinidad bason on E.

Zone of Structural Intersections.- Author's thesis, starting here, is unconvincing. Here is mine.

During late Paleo uplift of Ancestral Rockies, belt was near center of the deepening basin. Both Front Range and San Luis upland were rising as basin sank (check San Luis). Perfect hinge zone, on flanks of basin. Note in Fig.4 that all his ore districts South Bonanza, Orient and Blakr are outside his zone of structural intersections; latter 2 on margins. Uplift of Front Range-Wet Mt. region started in late K, culminated in Early Eocene, with folding and thrusting (maginal thrusts dipping into core of uplift. Close tiein of folding, thrusting, uplift. (Check overturning of folds).

Middle Eocene: Uplift of Sierra Blanca massif; marginal thrusting on E flank.

Uplift continued, late Eocene to early Oligocene, Wet Mts., NE hinge zone, Siarra Blanca-Culebra massif, SW hinge zone. High-angle normal faults breaking thru thrusts.

Oligocene to recent, San Luis Valley downfaulted; volcanism filled much of valley. At same time region NE of S.L valley broadly uplifted several times. If age of epithermal deposits is Miocene, as seems probably, one of these periods of uplift accompanied the mineralization.

Th s the NE region was uplifted:

1. Late Paleo
2. Early Eocene Thrusts marginal to Wet Mts. formed.
3. Late Eocene
4. " " to early Oligocene
5. Oliggeene to recent. (Several uplifts).

Sier a Blancs uplif ed:

1. Middle Eocene
2. Late Eocene to early Oligocene

The two uplifts carry nearly all the ore districts

Note: Proof that the Pleasant Valley fault on W margin of Wet Mts. is a marginal thrust is furnishedby the probable fact that it continues SE bounding Huerfano Valley on E, as a verticl fault, up on E. (P.185).

Ore belt splits at Orient; one split ENE thru Silver Cliff and Rosita. On SW flank of Wet Mts. uplift. Other split, to SW, coincides with late Eocene high-angle fault zones along which Sierra Blanca-Culebra massifs rose (on E). At W scarp of Sangre de Cristo and Culebra ranges. Almost coextensive with Oligocene or later h gh-angle fault zones along which he massifs and San Luis Valley subsequently sank, to crea e present scarp.

Author explians stronger mineralization in NE split (Bonanza-Rosita) by fact hat Wet Mts, marginal thrusts, dipping E, are steeper than he thrusts marginal to Sierra Blanca-Culebra massifs, which are flat, shallow.

P.189. Objections to mineral belt. Wide gaps between districts and deposits within the belt. Belt much wider than zone of intersection. Many distric s N of belt (Cripple Creek). Central part of zone of intersections S of Blake has no ore deposits.

He ascribes deposits north of belt to later vertical uplift faults intersecting thrusts, W or E-directed.

P.190. Epithermal character: shattering of wll rocks near larg faults. Predominance oc local faulting and shatering over local folding. Abundunt cavities; open-fussure filling. Lack of strong alteration except locally. Shallow depth below old erosion surface. LowT minerals: Au, Ag. tellurides, argentite, sphalerite, galena, ccpy; gangue chalcedony, low-T fluorite, pyrite, adularia, alunite, calcite, barite. Base metals subordinate to gold and silver. A mineralogic province.

P.195 Bonanza. Volcanic center, 4000'. Arched and differentially tilted by shallow large bulging intrusuves. Upwarping of vol canics caused by rising magma. Dome collapsed etc. Gravity faults caused by tension.

Bonanza has nothing to do with his zone of structural intersections.

P.205. In Rito Peco district, volcanics marked Pliocene? on g ologic map of Colorado. Mineralization may be middle or late Pliocene. However at Bonanza the volcanics are all, or at least, pre-Miocene Potosi (Burbank PP169, p.15). Eruptive period may have been in Ologocene. However, youngest premineral rock near top of 4000' section-may well be lower Miocene.

D.E. Karig, 1963, Tertiary tectonic history of the northern Sangre de Cristo Rge., Colo. GSA Spec. Pap. 76, 278.

3 phases of deformation. Present range is E flank of 2 earlier, larger uplifts.

First: commenced in late K as broad domal uplift; elevated eno gh by Paleocene to cause gravity sliding of thick Permian-Penna seds. along bedplane thrusts. Prec basement rocks involved in some cases. Total displacement 10-15 miles on NE and E flanks of uplift.

Second: Block uplift of San Luis Val ey area caused second dtage of thrusting along flattened upper segments of boundary faults whihh extended E into site of present range. Lesser magnitude but folded earlier bedding thrusts and deformed Olgocene? welded tuffs in E foothills. Nother block rose to the NE interfe ed with this thrusting at N end of range and was probably responsible for high-angle faults there,

Third: Collapse of San Luis Valley uplift along steep portions of the second-stage thrusts began in Miocene ? ; still continues, shown by fault scarps along W margin of range. Caused by volcanic-tectonic depression related to volcanism in San Juan Mts.? Basin-Range faulting? Tensional faulting following wedge uplift?

All features of region due to vertical tectonics-mainly uplift.

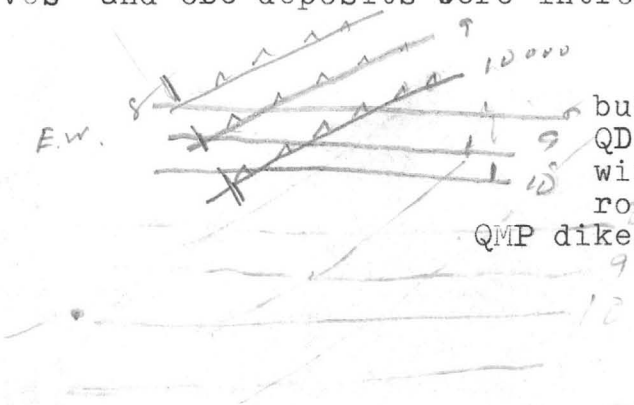
COLORADO

Monarch
Monerach mining district-Princeton stock: J.W. abelman,1950, Structural control of limestone alteration in the Monrach mining district,Colo. GSA Bull.v.61,1552-3.

Williams thrust, horiz.to E dip: .Precambrian thrust over Mesozoic. M Main movement post Middle Park (late K-Paleocene) ,before extrusion of Eocene volcanicsRenewed movement in Late Eocene. Arthur Richards, 1950, Geology along the Williams thrust near Kremmling,Colo. GSA Bull. v. 61,1496-7.

Note: This and the Gore thrust to the W are marginal thrusts accompny-uplift. Main movement on Williams thrust corresponds very closely to age of metallization on porphyry belt. Leadvillde ore is post-Lincoln porphry,64 m.y. ~~Ptchblene in belt is~~ Uplift starts first,then marginal thrusts develop.It is almost eertain that uplift accompanied the Leadville mineralization,and that of the entire porphyry belt.

Fulford, Brush Creek Mining DistrictsJ.W. abelman,1949, Laramide structure & igneous activity of Fulford & Brush Creek mining districts,Colo. GSA Bull.v.60,1960-61. NW Sawatch Rge.Laramide structure: NE syetm,E-W system,and combination of the two. NE: 4 thrusts,a large nasin,related smaller folds. Result o southeastwardly directed pressure at andant to ma n uplift of Swatch massif. E-W: monclinal northefly dips and high-angle faults of large displacement caused by uplift of a large anticline in Frying Pan Creek. In area of intersectio resultamt forces produced combined structures and a NW narrow zone of weakness,alojg which intrusives and ore deposits were introduced:



Small stock near Fulford in seds has minimum of contact phenomena, but shows intermal differentiation from QD thru GD to QMP. HT alteration intense with n the stock but near O in confining rocks. Many sills of QMP near stockechelon QMP dikes SE along zone of weakness.

Notes from PETROLOGY ANF STRUCTURE OF THE SOUTHERN WET MTS.,COLO.
R.E.Boyer,1962, GSA Bull. v.73,1047-170.

1047. Precambrian core :metasedimentary gneiss and schist concordantly foliated with granite gneiss.1050. The precambrian complex is bounded by Upper Paleo or younger seds.which wrap around its S end.Sangre de Cristo formation-late Penn or early Permian. upper Jurassic Netrada ss rests unconformably on this. Flanks S end of Wet Mts. Cretaceous rocks.

Felsic and mafic dikes:dominant trend N55W parallel to most of faults. Subordinate trend,extrme W part, N10-30E. 1052. Age unce tain; probably Tertiary. Several hypabyssal rhyo stocks. Rhyolite tuff deposited on erosional Precambrian surface.Probably Miocene. Scattered andesite remnants on Precanbrian surface;in places underlain by the rhyo tuff.

1056. Granitic rocks,youngest Precambrian, cover half the map area.
1061. Regional Structure: Wet Mts,form central unit of en echelon patttern with Sangre de Cristo Range on W and Front Rge.to the N. Wet Mts. have close genetic co nection with Fron Rge.

S W et Mts,form SE*plunging anticline outlined by the upturned sed. beds which bound the range. Along SW edge range bounded by highaangle nrmal and reverse faults which separate it from Huerfano Park.(On my Larami e ectonic ap,this is shown as a single fault turning to a thrust on the NW). W-dipping thrust on NE border.

Structural elements trend dominantly NW,parallel to elongationoff the range. Fau ts,dikes,joints.

1062. Several periods of faulting,but most faults have had Laramide or yunger movements.

Dominant fault set N60W parallels elongation of range. Inclides faults on NE and SW flanks of rge. Many dikes parallel. Second group,mainly branches off the first,strike N30 W. Foliation is a prominent control for the NW trend.

1063. Most faults dip 75 or steeper. On NE flank the N60W faults dip NE,on the SW slope SW. Movement dip-slip normal. As dips are steep, slight variations may change a normal to a reverse fault in a few miles on strike. At dpth these faults are thrught to remain high-angle,as would be consistent with upward movement of the crystalline core by vertical uplift.

Faulting in Precambrian,late Paleo,Laramide through Tertiary. Most Precambrian faults of N60 W set,developed late in the emplacement of the major San Isabel batholith. Many Precambrian faults were rejuvenated during later distrurbances. Other faults developed fpm new stress orientations. Late Paleo deformation(Ancestral Rockies) confined to reggional upwarps and mov ments al ng older faults.

Laramide-Tertiary movements,much along preexisting fauot zones and their extensions;but new fractures also formed. Movement of the Wet Mt. massif was primarily vertical; it moved upward en bloc between the NW faults. Regional compression is indicated by the inetense fauding and thrusting of the Tertiary units of Huerfano Park.However, uplift of the Wet Mt,block may have been the result of solely vertical stresses as suggested by J.C.Harms.1961,for the Front Range. (Paper presented at AAPG Annual Meeting,Denver).

Paleo-Meso History. In earlier Paleo Wet Mts. were a positive element on the Colorado sag of the Transcontinental arch.

1067. Miss or early Penn. Wet Mts.uplifted as part of Ancestral Rockies. Downdrop of adjacent basin,rapid deposition. Accumulation of seds. greatest in Penn.Permian.,although erosion of the range continued during most of Meso. Cse cgl of Penn-Permian Sangre de Cristo formati n ttrstifies to rapid xeposition.

Just before late K,seas advanced slowly ;marine deposition continued until near the end of K and beginning of Laramide orogeny.

Laramide History: Erosional unconformity between Ku Pierra shale and the Paleocene Poison Canyon formation gives evidence of the unrest that began as thrusting in nearby basins and culminated in uplift of the range. Laramide probably attained its peak in late of post-Bridger time;as f rmations as young as Eocene Farasita have been dsiplaced by faults bordering the Wet Mts.(Bridger is just above mid-Eocene). Main uplift was probably late early Eocene;sed.cover stripped.

Post-Laramide History: Erosion preceded extrusion of the Miocene volcanics;development of this erosion surface c uld have s arted in Eocene.

Most probably major uplift took place after the volcanism.Major NW fault on SW flank cuts the volcanics.

COLORADO

J.H.Howard, 1966: STRUCTURAL DEVELOPMENT OF THE WILLIAMS RANGE THRUST, COLO. GSA Bull. v.77,1247-1264

m Typical marginal thrust to Front Range-vertical at depth,flattens to horizontal on W. Mathematical analysis. Age post Pierre (end of Pierre, about 71 m.y.);this is initial movement. Pre-Middle Park (highest K). But resumption of movement into Paleocene. Block to E rising; Checks well for Leadvulle,on the S, being on the hinge zone. (Latest Pbville porphyry 64 m.y.).

COLORADO-WYOMING

Gary W.Crosby, 1967: Isostasy and Overthrusting in western Wyoming. AAPG Bull. v. 51,1900.Abstr.

Coinciding with frontal belt of the overthrust belt in W.Wyo is the axis of a former narrow trough along which max.of 25,000 ft.of K seds. accumulated. Intermittent marine deposition persisted to near top. During this subsidence,former miogeosyncline in SE Idaho was rising. Overthrus ing progressed eastward in time;Adaville and Evanston formations were overriden by easternmost Hogback thrust soon after deposition,while top of system was near sea level.

Cret.Hilliard shale,3000' below top of Adaville,crps out at 7500', cratonward from easternmost thrust;hence restored elevation of 2 mi. for top of Cret. is not due to thrusting,but to post-thrusting vertical uplift.

Pre-Cret,surface in the miogeosyncline-shelf boundary zone subsided 25,000' during Cret. sedimentation while former miogeosyncline was uplifted and unknown amount. Since overthrusting,Cret.frontal trough has risen 10,000+ ft.;possible subsidence in SE Idaho. This oscillatory mo- seems of sufucient magnitude to reverse dips on major thrust surfaces, from down-to-east at end of Cret. to down-to-west at present. Thus present attitudes do not preclude gravitational gliding as the mechamism of overthrusting.

Ave. of 100 Bouger gravity measurements in SE Idaho plots 20 mgal on positive side f Woolard s mean world curve,while ave.of 30 Bouuer measurements over frmer Cret.trough in W Wyo plots 32 mgal on negative side.In terms of isostasy,the vertical movements tending to reverse the movements on overthrust faults appear to be active at present.

AAPG Mid-Continent Section Biennial Meeting
Wichita Kan.

LONDON FAULT, COLORADO

Compiled from:

(1)Singewald, Q.D.,Butler, B.S.,1933: Suggestions for pr specting in the Alma district, Colo. Colo.Sci.Soc.Proc. v.13,No.4,89-131.
(2)******,******(1936: Structure and mineralization along the London fault, Colo. AIME Trans.vol. 126(1937) 426-441.
(3) Butler and Singewald,1940: Zonal mineralization and silicification in the Horseshoe and Sacramento districts,Colo. Econ.Geol.v.35,793-838

(4) Singewald and Butler,1941: Ore deposits in the vicinity of the London fault of Colorado. USGS Bull.911/ Alma and Horseshoe districts

Data from last reference except where otherwise noted.

1 Penn. Weber (?) qtzzite cgl.kq zitearkose,shale,ls.
Miss. Leadville ls.
Dev. Chaffee formation:qtzite below Dyer dolomite
Ordov. Manitou ls.
Camb. Sawatch qtzite
x x x x x x
Prec. Gneiss,schist,granite etc.

Tertiary(?) sills in seds.dikes in Prec. QMP. Oldest White porphyry (70 m.y.);Gray porphyry 64 m.y.).

22 Structure:Regional dip in Mosquito Rge E, away from Sawatch uplift. Long narrow folds associated with reverse faults.

Attached cr oss-sections show London and other ~~marg~~ inreverse faults to be typical marginal thrusts such as Elk Mts.and Castle Creek faults to the west.

Most of the production along the London fault came rom gold veins in he sharply ¾upturned sedimens and sil.s in he immediate FW of the London fault. See sections, the veins are along mino faults which dip slightly more flatly than the beds and sills. Qtz,subordinate py, ZnS, PbS ccpy.

Compliments of P. Edward Byerly

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XLI C-4

AEROMAGNETIC AND GRAVITY PROFILES ACROSS THE URAVAN AREA, COLORADO

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and
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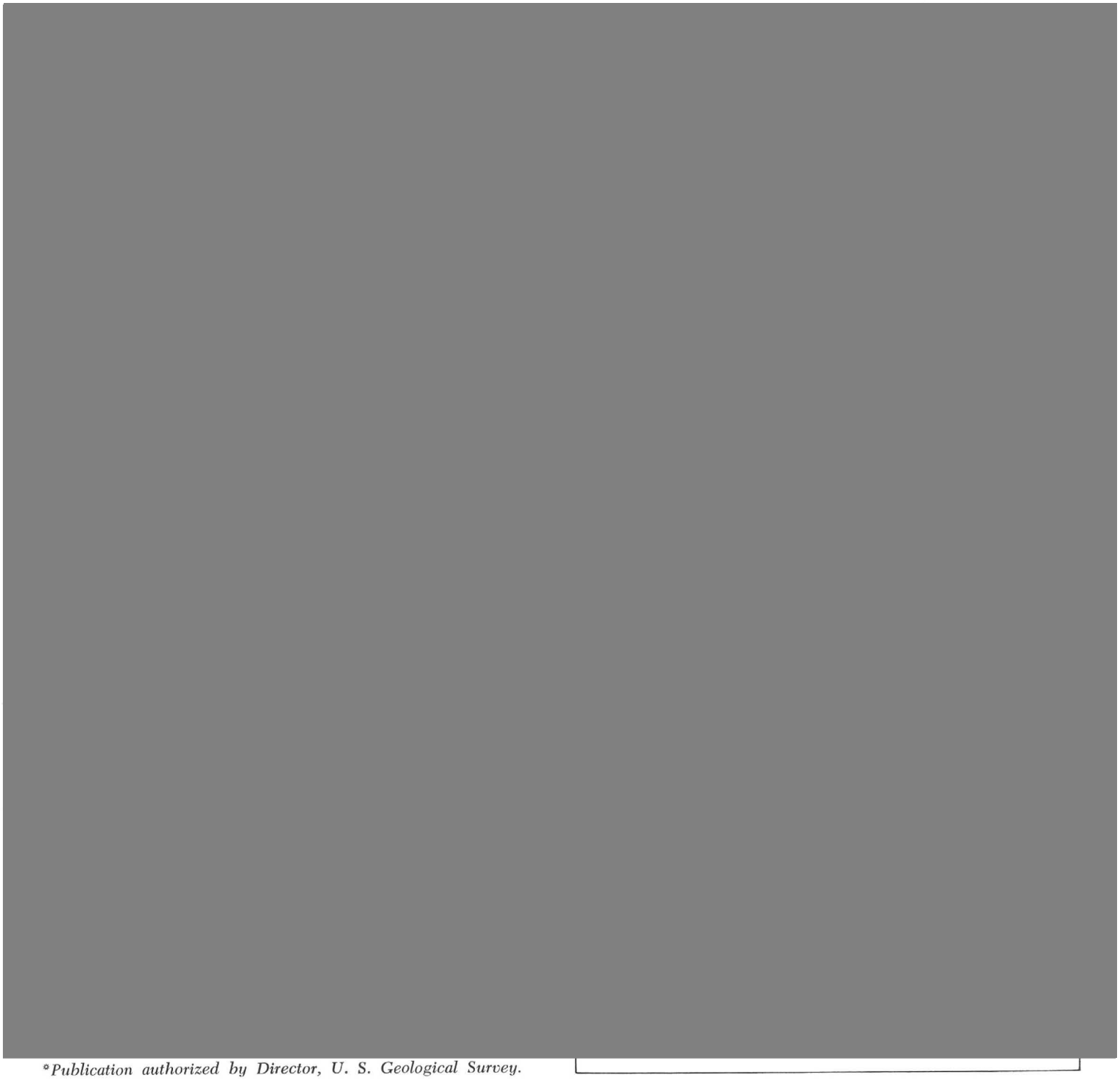

*Publication authorized by Director, U. S. Geological Survey.