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INTRODUCTION

It was not too long ago that the Early Paleozoic of New Mexico was regarded as simple, with almost one formation for each geological system. Even this was an advance, for earlier work lumped the whole of the Early Paleozoic into one formation, the Mimbres limestone. For mapping on the scale then used, and indeed, in many cases on scales in current use, the Early Paleozoic shows such a narrow belt of outcrop that finer division is impractical. While Kelley and Silver (1952) made an important step in the recognition of finer units, their units, new formations, had to be grouped together in mapping because of scale of the map and the limited areas of outcrop.

It has, however, been necessary to inquire more closely into the parts of systems represented by the deposits in the Early Paleozoic of New Mexico, in order to arrive at a clearer concept of the geological history in terms of periods of deposition alternating with intervals of elevation and erosion. It was necessary to know what parts of systems were represented and how the New Mexico sections correlate with those of other regions. There are two realities in geology, the actual geological history, and the succession of rocks as we see them today, and the first is not always obvious from the second. A case is shown by the Montoya Group of New Mexico. In some exposures, the Second Value and the Aleman are distinct, and we have reason to believe that they are separated by a general period of uplift and erosion. Yet where, as in the Sacramento Mountains or in the Mud Springs Mountains, both show advanced dolomitization, lithic differences are obscured, only previously silicified fossils are retained, and the two units may be so fused that it is difficult and in some sections impossible to point out the contact.

Interpretation has depended to a large extent upon the faunas, which have made possible correlations with other regions. Yet there may be regional peculiarities in zonation, and regions such as New Mexico, which may be invaded by faunas from both eastern and western geosynclinal belts, are particularly apt to show some zonal anomalies. In some cases established zonations have held well. This is particularly true of our Cambrian. The Canadian, however, shows a faunal succession including mixtures of eastern and western elements, with some endemic features.

With closer scrutiny, almost none of the older formations have retained their apparent simplicity. The Early Paleozoic was a long time, extending roughly from 600 to 370 million years ago, and it is perhaps too much to hope that the physical history in terms of periods of deposition and erosion, was any simpler here than it has been found to be in other regions in North America. Eastern sections, which have been longer under investigation, show quite complex histories in each of the systems.

Figure 1 shows the development of the geologic column of the Early Paleozoic of New Mexico. Column 1 shows the old broad formations, roughly one to a system, which developed from 1906, and are found in Darton (1917). Column 2 shows divisions proposed within these broad units up through 1952—Entwistle (1944) for the Montoya, Stevenson (1945) for the Devonian, Kelley and Silver (1952) for El Paso and Montoya. Column 3 shows the divisions used in this paper—both formation names and faunal zones are given. Column 4 shows the correlation of these divisions in terms of a general column for North America. This column is incomplete; major intervals not represented in New Mexico are omitted.

Figure 2 relates the Early Paleozoic sediments of New Mexico to a generalized column for North America which includes the major divisions of systems from Upper Cambrian through the Devonian. The thicknesses of these intervals have no time significance and intervals unrepresented in New Mexico sediments have been reduced in thickness to permit fuller representation of the New Mexico section.

SEQUENCE OF EVENTS

"These things," the Golux said, "I hope are true."
Thurber—the 13 clocks

1. Deposition of Dresbachian sediments (earliest late Cambrian) in the region athwart the southern New Mexico-Arizona border. It is not yet clear whether this is a continuation of deposition which began earlier in Middle Cambrian time in southern Arizona, or whether it marks a separate invasion of the sea. Some complexity of events is suggested by the presence of the *Cedaria* zone, absence of the *Crepicephalus* zone, and indications of the next two, the *Aphelaspis* and *Dunderbergia* zones.

2. Early Franconian beds of the *Elvinia* zone, generally widespread in North America, have been found only in one locality, at White Signal, but may be rep-

resented by barren beds at Lone Mountain. This period of deposition is greatly restricted.

3. *Eoorthis* zone. Deposition was possibly continuous from the preceding interval into this one, but deposits cover a wider area ranging from the Silver City region to the Hatchet Mountains.

4. Apparent elevation in the succeeding interval, marked by the *Conaspis* zone (restricted) and the *Taenicephalus* zone.

5. Late Franconian deposits of the *Ptychaspis-Prosaukia* zone, divisible into three subzones. These are well developed in the Caballo, Mud Springs Mountains and on the east side of the Black Range, are represented by nearly barren, dominantly glauconitic beds in the Silver City region, and continue west into Arizona. There is some indication that these beds may be limy in the extreme southwest, in the Chiracahua Mountains.

6. Trempealeauan deposition is known only in the Silver City region. Seas were more restricted, and deposits are conspicuously cross-bedded, coarse sandstones. Presumably New Mexico was emergent east of the Black Range.

Question: Is the marked faunal change at the top of the Cambrian the result of uplift and withdrawal of the seas, which then return, bringing in a new association of organisms, or is this a general biological change of continental or world-wide significance without a demonstrable cause? This is a question which may well be repeated at several other faunal breaks in the section; as yet we have no sure answer except that we are certainly dealing with widespread rather than local phenomena, and such changes can occur in regions in which there is no demonstrable serious gap in deposition.

7. Early Gasconade deposits (Van Buren equivalents?) are dominantly sandy beds in the east, with interbedded thin limestone lenses in the central part, and with dolomites between lower and upper sandstones in the western part of the state. The existence of correlatives of this interval in Arizona is yet dubious.

8. Later Gasconade deposition of limestones, largely the Sierrite Limestone, which, locally, grades up from the Bliss by a decrease first of sand and then of glauconite. The Sierrite Limestone shows odd variations in thickness. It is possibly wanting in the southeastern sections, and the greatest thickness is in the Mimbres Valley.

9. Later Gasconade deposition, absent in most of eastern North America and represented there by an erosional break at the top of the Gasconade and its equivalents, is marked in the Utah-Nevada sections by deposition of zone D, with *Kainella* and *Leiostegium*. Such beds are well developed in New Mexico in the Hatchet Mountains, and continue eastward, being represented largely by calcarenites. In the extreme east at this position are dolomites with *Apheoorthis* cf. *emmonsi*. It is not yet certain whether these beds are equivalents of the *Kainella* zone or whether they are an initial phase of Middle Canadian deposition.

10. Demingian deposition, comprising the sequence of first endoceroid, first piloceroid zones, oolite, *Bridgeites* reef and gastropod beds above, is general in New Mexico. At El Paso the beds above the oolite are wanting.

11. Minor emergence in late Demingian time was confined to the El Paso region and involved nondeposition or removal of beds above the oolite.

12. Widespread deposition of Jeffersonian limestones. Deposits are thick and contain many stromatolitic beds, particularly well developed in eastern sections.

13. A minor break, known only in the east, followed by Cassinian deposition.

14. Cassinian deposition continued locally to the close of the Canadian.

15. General emergence with warping, and erosion of the El Paso. Warping makes depth of erosion somewhat irregular, but it penetrates increasingly lower levels to the west and to the north. Precise dating is not yet possible. Erosion may have begun as early as Whiterock and its end is probably no older than Black River.

16. Deposition of dominantly sandy beds, the apparent Harding-Winnipeg equivalents.

17. Elevation, erosion, and reduction of these beds to mere scattered remnants.

18. Red River deposition, originally continuous north to Winnipeg and Greenland is dated as Late Trenton and Eden.

19. Elevation, and erosion of the Red River surface, probably occupying much and possibly all of Maysville time.

20. Par Value-Aleman deposition, dominantly dark cherty beds, occupying early Richmond time and possibly beginning in the late Maysville.

21. Minor elevation, producing at least local erosion of the Aleman surface.

22. Raven-Cutter deposition, which shows evidence of onlap from southeast to north and west on the Aleman surface.

23. Elevation and erosion, beveling the Montoya surface.

24. Restricted sediments of probable Early Silurian age. A break at the top is not clearly evident.

25. Middle Silurian deposition, Clinton, possibly continuing through the Lockport. Exact age-range of

the Fusselman is not yet precisely known, but there is no indication of Upper Silurian in this region.

26. Elevation and erosion, extending through Early and most, if not all, of Middle Devonian time. The Fusselman was, by this erosion, restricted to southern regions, so that in the northern extent of the early Paleozoic the Devonian lies on the Ordovician. Warping of the erosion surface of the Ordovician cannot be dated precisely, as it has been found only where no Fusselman is present. Both warping and erosion may have been pre-Fusselman, but both or either could also be post-Fusselman. The region was again faulted slightly later, producing some unplaned faults, which are possibly connected with sinking and return of the seas in Onate time.

27. Submergence and Onate deposition.

28. Elevation and erosion of the Onate surface prior to

29. Sly Gap deposition. (Ithaca and Naples equivalents) Frasnian.

30. Contadero deposition, late Frasnian, Chemung equivalents.

31. Thoroughgood deposition, known only in the north San Andres with a remnant in the Sacramentos, Early Fammenian.

32. Planation of the Thoroughgood surface.

33. Deposition of the Rhodes Canyon shales.

34. Elevation and erosion of the above, with planation extending in some places down into the Onate, and removing it locally.

It is still problematical whether the Bella-Box member of the Percha contains some black shale equivalents of the older Onate and Sly Gap.

35. Deposition of the Percha, late Fammenian.

36. Early Mississippian deposition, Caballero Formation, widespread, and with remnants continuing north of the earlier Paleozoic as the Caloso Formation.

37. Possibly uplift and minor erosion prior to Lake Valley deposition.

38. Lake Valley deposition, continued north as the Kelly of the Magdalena area.

39. Meramec deposits confined now to extreme southern New Mexico, but with remnants of the Arroyo Penasco in northern New Mexico.

40. Chester deposition now known only in the extreme south.

41. General elevation and erosion, truncating pre-Pennsylvanian beds to their northern limits with removal of Mississippian over much of the Rio Grande valley.

Much of the geological history of New Mexico is involved in periods of uplift and erosion which have altered the original picture of deposition materially and are responsible for the present restriction of the sediments. The supposed land mass separating the Early Paleozoic of New Mexico from that of Colorado was traversed by seas and sediments several times, possibly in the Franconian, certainly in the Canadian, Red River, and Richmond with intervening periods of elevation and erosion. Possibly this occurred again in the Silurian, and it certainly did in the western Devonian in the Ouray and Percha.

SHANDON-BLISS FORMATIONS

The basal Paleozoic of southern New Mexico consists of dark-weathering, sandy beds which, when seen at a distance, form a prominent black band between the pink-weathering granites of the Precambrian and the light-tan to gray-weathering El Paso slope above. The unit shows wide variation. Conspicuous are sandy ledges which weather black, with stains of green, red, purple and yellow from iron and other minerals. Glauconite is common. There are beds of red-weathering, ferruginous sandstone and beds of quite pure hematite. There are shaly layers, dolomitic sands, in some of which a light brown-weathering, dolomitic sand contains pebbles of darker-weathering, dolomitic sandstone. There are, particularly in the Caballo Mountains, thin layers of pure limestone which may be dolomitized locally. Toward the west, a considerable interval of moderately sandy dolomite is found. There are sedimentary quartzites which may, at the base of the Paleozoic, contain Precambrian pebbles.

This interval was assumed to be all one depositional unit in New Mexico, a view which recent findings have opposed. It was first named, in New Mexico, the "Shandon quartzite," from exposures in the southern Caballo Mountains, but this name was generally suppressed in favor of "Bliss sandstone" which was proposed a few years earlier from exposures in the southern Franklin Mountains.

The Bliss was assigned to the Cambrian on the basis of early reports of *Lingulepis acuminata*, a species first described from the Potsdam Sandstone of New York where it is Dresbachian in age. Some reservations exist, however, because linguloid brachiopods are wide-ranging types, and not necessarily reliable guides as to age. Paige (1916) cites *Ptychoparia* and *Billingsella* from the Silver City region which would support Cambrian age, but the specimens cannot be found, and both determinations are now suspect.*

The Van Horn region of Texas yielded from the "Bliss" gastropods and cephalopods of unquestionable Gasconade age, a find which required review of the age

**Ptychoparia* was then used very broadly. Today it is restricted to Middle Cambrian trilobites. *Billingsella* has been found, though it is rare in the Silver City region, and the form was more probably the commoner *Eoorthis*.

of the Bliss in New Mexico and elsewhere. A further collection from the same locality yielded impressions of endoceroid siphuncles, showing that the first endoceroid zone of the El Paso, ordinarily at least 100 feet above the Bliss, is included in it. The lowest El Paso there contains the fauna of the first piloceroid zone.

The recent significant finds in New Mexico include (1) discovery by Northrop and students (see Kelley and Silver (1952) of the brachiopod *Apheoorthis* and a dendroid graptolite which proved to be *Dictyonema flabelliforme anglicum:* (2) discovery of late Franconian faunas in Tonuco Mountain, Cable Canyon, and exposures on the east side of the Black Range: (3) discovery of Gasconadian, Lower Canadian, faunas above, including the *Apheoorthis, Symphysurina,* and the *Dictyonema:* (4) discovery of early Franconian beds in the Silver City region, with Trempealeauan beds in the same general area: (5) finds indicating earlier beds, Dresbachian, essentially athwart the southern New Mexico-Arizona border.

The prevalence of glauconite and other features suggest very slow deposition, so slow as to destroy much of the original faunal evidence. It is difficult to establish the geological history, for absence of faunas may not mean absence of deposits in the time interval involved. From these finds there has emerged the general picture shown in figure 3. Knowledge is still incomplete, and the most vexing problem remaining is that of the "Bliss" of the Sacramento, San Andres and Franklin Mountains. There the main constituents of the faunas are linguloid brachiopods, which seem allied to *Linguella deltoidea* (Flower, ms) of the Gasconadian part of the Bliss. These forms are confined to the upper part of the Bliss. The lower beds are barren, and further, fail to show such lithic contrast as is found in the Caballo Mountains separating Cambrian from Canadian beds. The evidence suggests that the whole of the type Bliss is Canadian. This usage is employed in our present diagrams. Bliss is used for Canadian beds, Tonuco (Flower 1959) for the Cambrian, and Shandon to include both units. Subsequent finds may prove the lower beds to be Cambrian. While no clear sedimentary break exists in the southern Franklin Mountains, the "Bliss" of the Hueco Mountains consists of two contrasting elements. A lower light gray, medium to coarse-grained sandstone contains marble-sized pebbles of darker sand, weathers with hues of pink and mauve, and occupies the lower three-fourths of the sandstone interval. Above, with an abrupt contact, are fine-grained black-weathering sandstones with abundant linguloid fragments. Traces of this facies can be found in the lower part of the type Bliss of the southern Franklin Mountains, but without a similar sharp sedimentary break below it.

The whole of the eastern Bliss may be Cambrian. Recent collecting has yielded true *Lingulepis* from the southern Franklin Mountains, and though the linguloids remain suspect, this find would tend to support such a view. While we know age relationships of much of the western "Bliss" the evidence is ambiguous for the eastern Bliss, which contains the type section. Flower (1959) restricted Bliss to the Canadian beds, proposed the name Tonuco for the Cambrian beds, and revived the name Shandon for sections where both Canadian and Cambrian may be present (figs. 1 and 2). Readjustment of formational names may be required when the age of the type Bliss is definitely established. A temporary measure might be to restrict Bliss to the eastern sections of still uncertain age, and to propose another term for the demonstrable Canadian portion.

The faunal zones expressed in the Cambrian Correlation Chart (Howell and others, 1944) have undergone some modification, and from one region to another there are some minor differences in names applied to the zones, and to relative placement of some horizons as "zones" and others as "subzones", but the general succession is one which has shown a surprising validity in the light of critical study. A good summary in Lochman-Balk and Wilson (1958) shows the general faunal successions and the different faunas developed contemporaneously in disparate environments.

Figure 3 shows the faunas found and the portions of the Cambrian in which deposits can be established in New Mexico. Future finds may alter the picture. Faunas are extremely sparse, and only a combination of work and luck has yielded the present results. The section at Carbonate Hill yielded numbers of unidentifiable free cheeks, but after extensive work a piece was found which bore not one, but two identifiable heads of an *Eoptychaspis*.

1. Dresbachian faunas have been found only in the extreme southwest. Flower found material at Dos Cabezas determined by Balk as representing the *Cedaria* zone. Sabins (1957) found trilobites indicating the *Aphelaspis* zone and the *Dunderbergia* zone (formerly cite as post-*Aphelaspis* zone).

The *Crepicephalus* zone is unrecognized there, but it is generally far more widespread over North America than the zones immediately below or above.

2. The *Elvinia* zone at the base of the Franconian is found in 24 feet of ferruginous sandstone at the base of the section in an outlier southwest of White Signal. It yields abundant *Camaraspis*. It is possible that the basal beds, so far barren, at Lone Mountain are equivalent.

3. *Eoorthis* is a genus which is amazingly widespread and confined to one narrow horizon. It is cur-

rently grouped as a subzone of a broadly defined *Conaspis* zone. The grouping depends on the affinities of associated trilobites in other regions, but only the *Eoorthis* is found. One piece of sandstone was found with a *Camaraspis* on the bottom, and an *Eoorthis* on the top, with no apparent bedding plane between

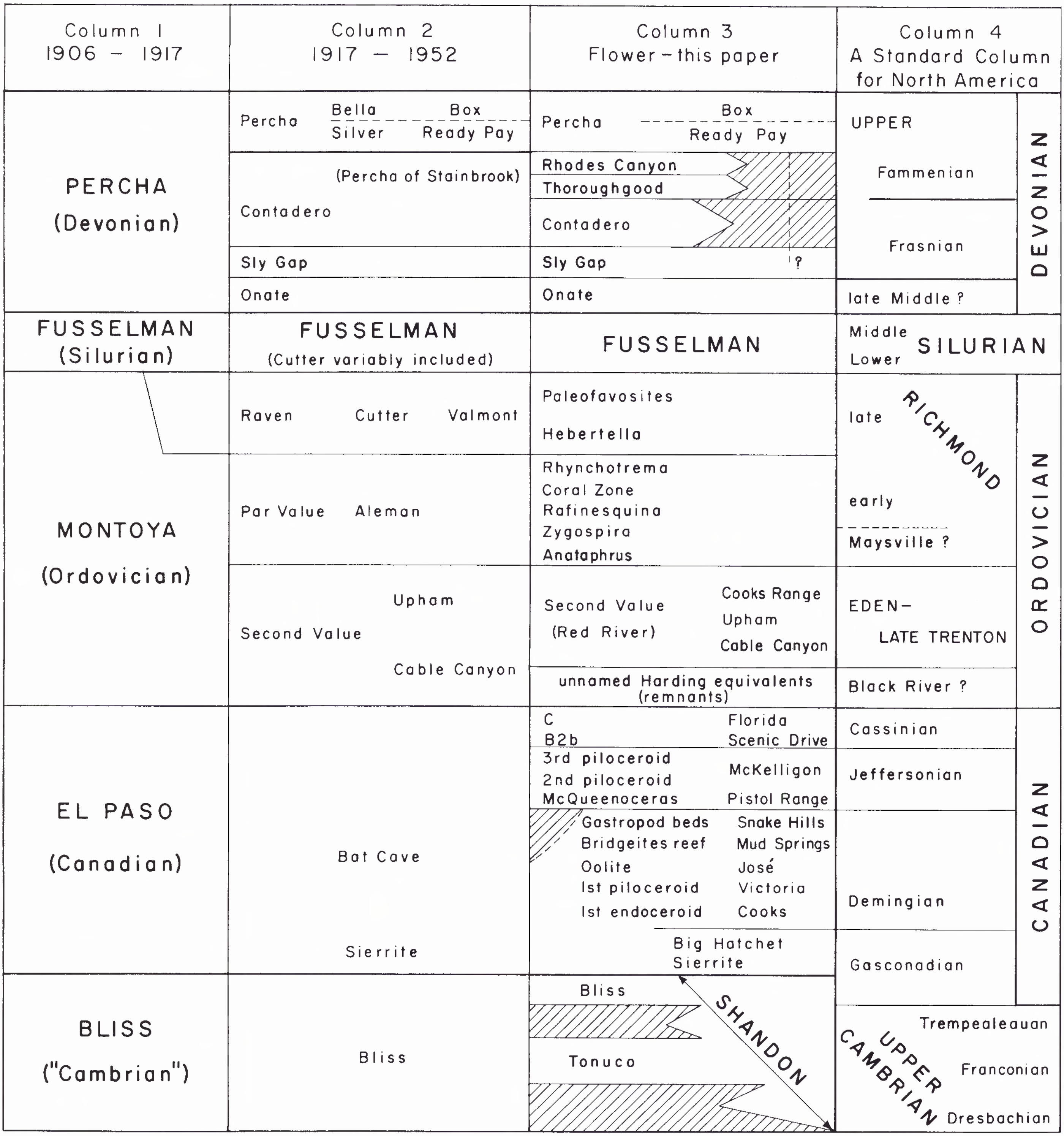

FIGURE 1

Development of Formational Units in New Mexico

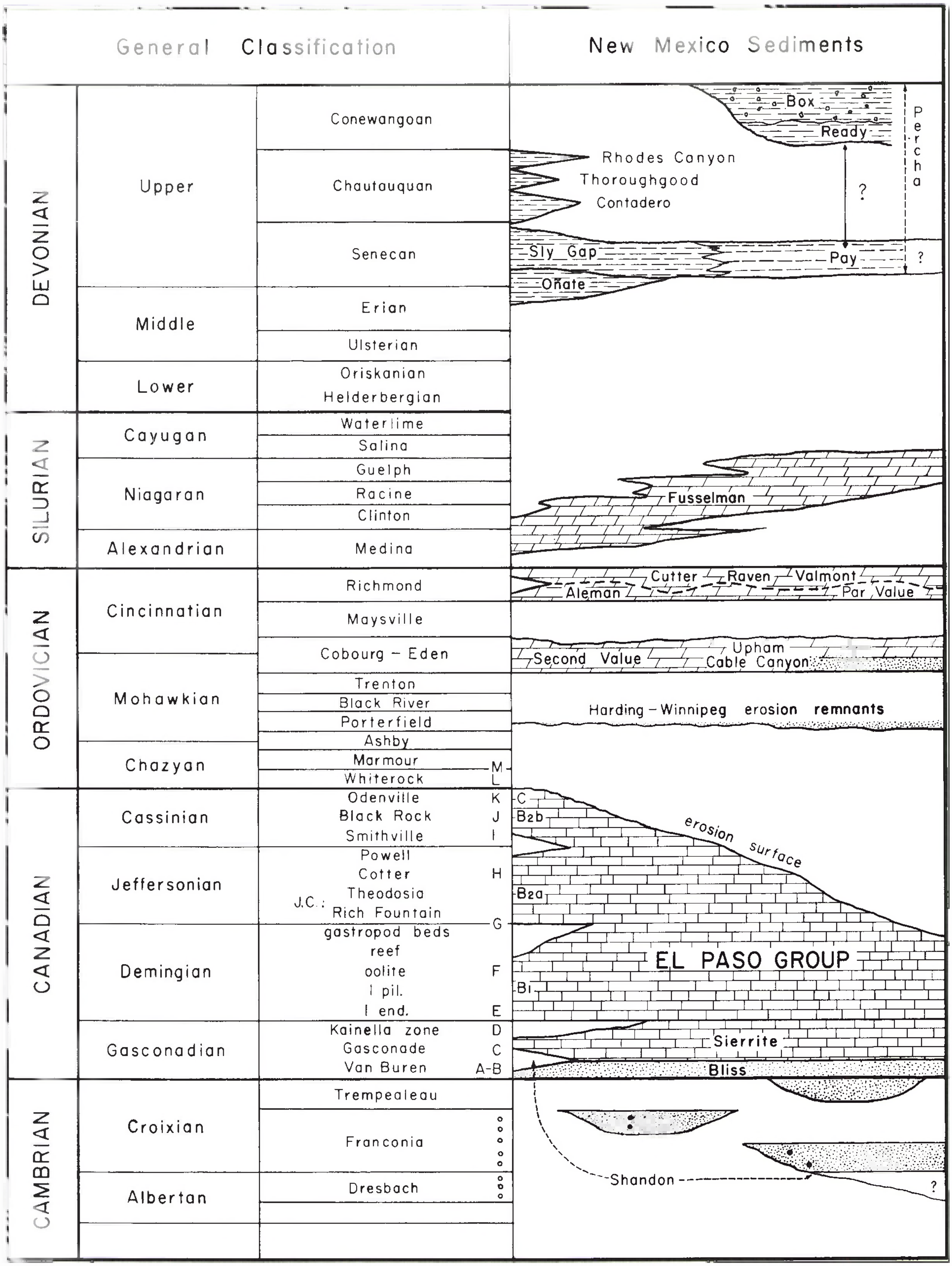

FIGURE 2

Correlation of the Early Paleozoic of New Mexico

	Zones and Subzones		San Andres	Tonuco Mt.	Cable Canyon	Mud Springs Mts.	east side Black Range	Cooks Range	Mimbres Valley	Lone Mt.	White Signal	extreme Southwest
Gasconadian	Symphysurina	Dictyonema flabelliforme anglicum		X	X	X	X			h		
					X	X	X	X	X	X	X	
		Apheoorthis melita	L	L	L X	L X	X	X	X	X	X	
Trempea-leauan	Saukia							h	h	X	X	
Franconian	Prosaukia	Prosaukia-Briscoia		h W	X W	h W	X					
		Ptychaspis striata		X	h	h	X B			B		B
	Ptychaspis	Ptychaspis granulosa					P					
		Stigmacephalus oweni					X					
	Conaspis	Taenicephalus										
		Conaspis										
		Eoorthis								X	X	X
	Elvinia										X	
Dresbachian	Dunderbergia											S
	Aphelaspis											S
	Crepicephalus											
	Cedaria											F

FIGURE 3

Faunal zones of Cambrian and Early Canadian found in New Mexico

X-diagnostic fauna found
H-horizon recognizable without faunas
P-probable development of fauna
S-reported by Sabins 1957
L-linguloid fauna
W-*Westonia*
B-*Billingsella*
F-reported by Flower

Dotted lines suggest regional extent of depositional units.

In the Gasconadian no faunal succession is implied by the vertical distribution of the faunal elements, except that the *Dictyonema* is always found just below the top.

them. At White Signal *Eoorthis* occupies 9 feet of gray, tan-weathering sandstone of medium texture. At Lone Mountain it occupies hematitic sandstones 20-28 feet above the base of the Paleozoic. Zeller has reported the genus from the Hatchet Mountains.

4. There is no general agreement as to nomenclature of the next two subzones. I have regarded the lower one as characterized by true *Conaspis* (the broader *Conaspis* zone was based on an older and somewhat wider usage of that generic name), with *Taenicephalus* above. No evidence of these two subzones has been found anywhere in New Mexico. For a time I thought they might be present in glauconitic sands above the *Eoorthis* zone, but the whole of this interval is reasonably assigned to the succeeding horizons, as indicated by the find of a *Billingsella* in the Lone Mountain section.

5. The *Ptychaspis-Prosaukia* zone is divisible into a number of subzones. The nomenclature arises from the overlapping of the genera in these several sub-

zones. The former correlation chart indicated *Briscoia* and *Prosaukia* as separate zones, a view now abandoned, and the first *Dikellocephalus zone is now* treated as Trempealeauan. Present collections are far from satisfactory owing to scarcity of good specimens, and precise zonation is obscured by poor exposures. The faunas from the east side of the Black Range come from a poorly exposed section, and most specimens are in loose pieces. *Eoptychaspis*, a genus of the *Stigmacephalus* zone, has been found only in the Carbonate Hill section. The *P. granulosa* horizon is suggested by forms obtained from Pierce Canyon in the Black Range, where overlying zones are better developed. *Ptychaspis striata* and a *Chariocephalus* are abundant in a 2-foot bed on Tonuco Mountain, and both genera have been found in the Black Range. A 1.5-foot bed in Cable Canyon of the Caballo Mountains yielded large *Prosaukia* and *Briscoia*, and the same horizon has been found in the Black Range. Both of these upper subzones yielded a broad *Billingsella* in abundance. The same brachiopod was also found in dominantly barren glauconitic beds at Lone Mountain. *Billingsella* was found by Sabins in the Blue Mountain section at the Arizona border, where it occurred not in sandstone, but limestone which he called El Paso. This is the same species which occurs with *Prosaukia* at Cable Canyon.

Light gray, light-tan-weathering, coarse cross-bedded sandstones at Lone Mountain and White Signal have yielded a Trempealeauan fauna. The Cambrian Correlation Chart indicated a number of zones in the Trempealeauan. It is now recognized that varied facies in a section with sandstones, siltstones and some dolomite control the faunal succession in the Minnesota-Wisconsin region where these zones were established. No continent-wide zonation within the Trempealeauan has been established. At Lone Mountain this zone occurs in 12 feet of sandstone, the uppermost unit in 89 feet of Cambrian, overlain by 72 feet of Gasconadian, sandstone.

Figure 3 suggests a picture of the depositional history consisting of several discrete periods of deposition. The first, in Dresbach time, is confined to the southern Arizona border. The second in early Franconian time, is at first restricted to White Signal, but later spreads throughout the Silver City region south to the Hatchets. Presumably, the *Conaspis* and *Taenicephalus* subzones represent a short period of emergence. The *Ptychaspis-Prosaukia* interval thus appears as a distinct period of invasion of the sea, depositing dominantly sandy beds in the region of the Caballos west to the east side of the Black Range, but dominantly barren glauconitic sands in the Silver City region. Relationships with Arizona are not clear, but the fauna occurs there (Stoyanow, 1949) in a limestone, and Sabins reported *Billingsella*, diagnostic of this horizon, in a limestone also.

Known Trempealeauan deposition is confined to the Silver City region and consists of rather coarse, cross-bedded sandstones.

GASCONADIAN SANDSTONES

These sandstones, to which the name Bliss is tentatively applied, show considerable regional variation. In the Caballo and Mud Springs Mountains 2 feet of crossbedded coarse sand at the base grade up into a succession of thin sandy beds alternating with silty glauconitic layers, and some dolomitic sandstones which may contain pebbles of sandier, darker material. There are thin beds and lenses of limestone, 4 inches thick at the maximum. In Cable Canyon these are commonly fossiliferous, and some are composed of fragments of *Symphysurina*, *Apheoorthis* or *Girvanella*. In Cable Canyon these lenses are good limestone; elsewhere they show recrystallization or dolomitization. Near the top, a few feet of yellow-green silt and shale occur, yielding *Dictyonema flabelliforme anglicum*. This shale, and the graptolite, persist on the east side of the Black Range. On the west side, the shale horizon is recognizable as far as Lone Mountain, but the graptolite has not been found.

In the Caballo and Mud Springs Mountains the Bliss-El Paso contact is gradational, marked by a decrease in sand and glauconite. On the east side of the Black Range the top of the Bliss is a slightly calcareous sandstone, weathering to ledges with rounded surfaces, and yielding *Symphysurina*. The same sandstone is traceable through the Cooks Range into Lone Mountain.

In the Mimbres Valley and at Lone Mountain and White Signal, sands mark the base and top of the Bliss, but the middle portion is a nearly sand-free dolomite.

Thicknesses (in feet) for the basal sands, Shandon, in these regions are:

	Tonuco	Bliss
Tonuco Mt.	60	69
Cable Canyon	67	83
Mud Springs Mtns.	72	91
Carbonate Hill	68	95
Lone Mt.	89	72
White Signal	123	116
Cooks Range	67	99

EL PASO GROUP

The El Paso Group consists dominantly of calcilutites, and weathers light gray to tan, commonly forming a slope between the dark sandy Bliss below and the more massive cliff-forming Montoya above. Its thickness ranges from 1200 to 75 feet largely as the result of later erosion. Wide lithic variations can be observed in short intervals. The calcilutites may be massive or thin bedded. Frequently calcareous shales separate the more massive beds, but these layers are usually covered. Stromatolites are common from the base of the Middle Canadian upward, and occur as biostromes, and some bioherms. Interstices in the algal reefs contain poorly sorted material, fossil hash, calcarenites, or pebble beds. Horizons with limestone pebbles and some sandy layers may occur throughout. Dolomitization is local, but in eastern sections, several horizons are persistently dolomitic.

With the underlying Canadian beds included in the Bliss, the El Paso represents nearly continuous deposition throughout Canadian time. This interval is here regarded as a system apart from the Ordovician. This interval of time involves complex events of varied types of deposits, and an intricate history of deposition and erosion, with changing patterns of the seas. For eastern sections a standard section is accepted in the Ozark uplift. There the following formations are recognized:

Black Rock
Smithville
Powell
Cotter
Theodosia } Jefferson City Group
Rich Fountain } Jefferson City Group
Roubidoux
Gasconade
Van Buren

The faunas which characterize these formations have been only partly described. A nearer and much better understood section (Cloud and Barnes, 1948) is that of the Llano uplift of Texas. Unfortunately, this section has been eroded to a level in the later part of the Jefferson City Group, but enough is known to supply some basis for correlation.

In northern Utah are the Garden City and Swan Peak Formations, and in western Utah and Nevada the Pogonip Group. These formations have been zoned by Ross (1951) and Hintze (1953), with the zones indicated by letters. Their zonation is based primarily on trilobites. Correlation of the El Paso with these western sections is still incomplete, because the El Paso does not yield many trilobites. There is some indication that the trilobites obtained belong to another realm and some genera, as *Leiostegium*, show somewhat different ranges.

Flower (1958, 1959) zoned the El Paso, and the faunas are in the process of description. Kelley and Silver (1952) raised the El Paso to a group, and recognized two formations in it: Sierrite Limestone, the lower thin-bedded calcilutites with stylolitic beds and siliceous seams, but generally free from chert, and the Bat Cave Formation, the upper more massive beds of varied lithologies, with cherts and stromatolites. The boundaries proved gradational on lithology, and the two units are unsatisfactory. The zones of Flower have been given geographic names (Flower, 1964) and treated as formations, but difficulties in placing boundaries precisely are such that member status would be equally acceptable. Study of these intervals has indicated some variations in the history of deposition, with breaks in the section particularly evident in the more easterly exposures.

LOWER CANADIAN-GASCONADIAN

The Lower Canadian begins with sandy beds, included in the Bliss Sandstone. The transition into the El Paso is gradational, and is marked by a decrease in first sand and then glauconite. The Gasconadian part of the El Paso is composed of thin beds of calcilutite, often dolomitized. Faunas are poorly preserved, but include *Symphysurina*, *Apheoorthis melita*, *Lytospira gyrocera*, a few Ellesmeroceratidae, *Girvanella* and some undescribed tubular algae. These beds are thicker in the northern than in the southern exposures, and it may be that none of these beds are present in the El Paso section. Previously assigned beds may belong to an overlying interval.

In the Hatchet Mountains the Sierrite lithology is not typically developed. Its equivalent may be represented by some beds altered to massive dolomites. Above them are massive dolomites interbedded with dolomitic shales which have yielded *Leiostegium* and *Kainella*, indicating the position of zone D of the Utah-Nevada sections, and still higher beds with spheroidal cherts. These beds, thinning, can be traced into the more eastern sections, and seemingly grade into the Sierrite unit below, but differ from it by the occurrence of minor chert, and the dominance of calcarenites. This interval is not recognized in the eastern sections.

MIDDLE CANADIAN-DEMINGIAN

The Middle Canadian part of the El Paso shows a varied lithic section and a signficant succession of faunas. The units hold well over the state and are in ascending order:—

First endoceroid zone (Cooks Formation). Calcilutites in which there appear stromatolitic biostromes, with calcarenite and fossil hash in the interstices, and some calcarenites generally light in color. The horizon bears the first endoceroids known in the section associated with the brachiopod *Diaphelasma*, and assemblage of gastropods including such forms of Lower Canadian aspects as *Ophileta* and *Ozarkina*, and a new form allied to *Liospira* (identified erroneously as *Raphistoma trochiscus* in some early reports). The beds contain minor chert.

First piloceroid zone (Victorio formation): This is an interval characterized by dark-weathering massive beds with abundant stromatolites, containing piloceroid siphuncles distinguishable from the siphuncles of the first endoceroid zone by their larger size, and forms showing curvature or rapid expansion or both. Sponges are conspiciuous for the first time and silicified fragments showing a fenestrate pattern suggest fenestellid bryozoa. No bryozoa are known in the Canadian. Some beds in interstices in the biostromes are limestone conglomerates. Ordinarily, these conglomerates are readily recognizable from the darker, dirty, poorly sorted sediments which make up much of the material between the stromatolites.

Oolite (Jose Formation). Here are as much as 40 feet of a most distinctive, dark gray to black weathering limestone unit. The limestone is oolitic, and some beds are crowded with fragments of an asaphid trilobite. Other beds include pinkish weathering nodules, probably algal in origin. Small gastropods are conspicuous.

Bridgeites reef, (Mud Springs Mountain Formation): Succeeding the oolite with a few feet of transition of light thin-bedded calcilutites, is a massive stromatolitic reef, usually 25-35 feet, generally cliff forming, and with a sparse fauna, the most characteristic form of which is a large flat gastropod *Bridgeites* (ms.).

The uppermost unit is thin-bedded nondescript calcilutites in places filled with small gastropods, but also containing the trilobite *Leiostegium*. These calcilutites, which may be 45 feet thick in the Cooks Range, are the Snake Hills Formation.

These units prevail throughout the New Mexico sections, but to the southeast the upper beds are wanting, and at El Paso sand separates a thin remnant of the oolite from beds below, and there is another sand above which is the base of the Jeffersonian.

JEFFERSONIAN

McKELLIGON FORMATION

At El Paso this unit begins with a sandstone overlain by a massive stromatolitic biostrome, dolomitized and characterized by abundant tiny endoceroid siphuncles, none much over ¼ inch across. These beds have been named the Pistol Range member,* and can be traced widely. The succeeding beds show a wide variation in lithology but include at El Paso massive stromatolites, some true bioherms replete with sponges and piloceroids—the second piloceroid zone. The unit is widely developed, but in some places is not obviously stromatolitic. At El Paso there is an alternation of stromatolitic beds, and massive and thin-bedded limestones for over 400 feet. In the Florida Mountains and Cooks Range, where these beds are well developed and of comparable thickness, stromatolites are less conspicuous. Often this horizon may yield no obvious fossils other than sponges and stromatolites. The fauna shows relationships with the Jefferson City and Cotter.

CASSINIAN

The Cassinian portion of the El Paso Group is found in units B2b and C of Cloud and Barnes. In the southern Franklins it is marked by conspicuous cross-bedded dolomitic sandstone at the base, passes upward into arenaceous dolomites, overlain by 200 feet of thin-bedded limestone, the Scenic Drive Formation. The uppermost beds are dominantly ledge-forming calcarenites with some calcilutites and orange-weathering calcareous siltstones, the Florida Formation.

The Scenic Drive Formation is unquestionably the equivalent of the Smithville and Fort Cassin Formations. Correlation to the west is less precise. It certainly includes the general fauna of Zone J of the Wahwah limestone, though the *Pseudocybele* fauna appears to be confined only to its upper half.

The Florida Formation is unit C of Cloud and Barnes. In the Franklin Mountains it contains conspicuous orange weathering silts in addition to calcarenites and some calcilutites. The silts are absent in the Florida Mountains. This bed contains a distinctive fauna which Cloud and Barnes (1948) regarded as equivalent to the latest Canadian, the Odenville of Alabama and the Black Rock of the Ozarks. The brachiopods, larger than those below, and quite distinctive, include *Syntrophopsis*, and *Tritoechia*. There are some gastropods, including *Maclurites* cf. *M. sordida*, and the cephalopod *Buttsoceras*. This general fauna is found in the Wahwah Limestone of western Utah in a few feet of calcarenite just below the *Hesperonomiella minor* bed. The *Buttsoceras* has been found in the Garden City Limestone, in upper cherty beds below the upper 20 feet with the early Whiterock *Rossoceras-Williamsoceras* fauna. This is the youngest Canadian known, and is not, as has been suggested, post-Canadian.

*This was named from the pistol range on the Scenic Drive at El Paso. The name was no sooner published than the "Pistol Range" was changed to the "Police Academy."

POST-EL PASO PRE-MONTOYA EROSION

Sections of the El Paso in New Mexico show in general a beveling of the El Paso surface beneath the Montoya to depths which increase in general north and west from the Florida and the southern Franklin Mountains. The Cassinian portion of the El Paso is present in the southern Franklins (though it is gone at Ranger Peak), in Beach Mountain in Texas, and in the Florida Mountains in New Mexico. The Hatchet Mountains show only part of the McKelligon Formation, enough to establish the development of the second piloceroid zone. The same is true of Round Valley in the Chiracahua Mountains, north of Portal, Arizona. At Dos Cabezas we find the first piloceroid zone at the top, and at Clifton and Morenci nothing above the first endoceroid zone is preserved. The Montoya is unknown at Dos Cabezas, so later erosion may also be involved. However, a remnant of Montoya found at Clifton, Arizona, suggests that pre-Montoya erosion is responsible for the El Paso erosion surface there. To the north, the Cassinian is absent in the Cooks Range. The sections around Silver City and the Mimbres valley show a good development of the second piloceroid zone, but not the top of the McKelligon formation. At Cable Canyon in the Caballo Mountains the El Paso top beds are in the McKelligon formation. At Mud Springs Mountains only the base of this formation is present, and on the northeast side of the San Mateo Mountains there are 75 feet of El Paso below the Cable Canyon, representing part of the Lower Canadian. Similarly in the San Andres Mountains there is a rapid northward thinning. At Rhodes Canyon the top lies in the higher beds of the Demingian, at Sly Gap only the Lower Canadian is present.

There is a lithic, faunal and zonal accord between the El Paso of New Mexico and the Manitou of Colorado which is not shared by the known Ordovician to the east (Arbuckle) or west (Garden City and Pogonip) and which suggests that the beds were laid down in a sea continuous over northern New Mexico and southern Colorado where today no early Paleozoic exists. The Manitou shows, just above the red beds with *Apheoorthis* cf. *melita*, a good development of the first endoceroid zone, and 80 feet higher, of the first piloceroid zone. The Manitou, though usually dolomitized, is lithically much like the El Paso, a light yellow to gray limestone as developed in the exposures of the Sacramento Mountains. The El Paso tends to a darker hue, of medium to blue grays, in more westerly sections.

Much of the northward and westward thinning of the El Paso results from erosion beneath the Montoya Group. The beveling evident in the northern exposures, projected farther north, not only would have removed all of the earlier Paleozoic, but must have cut deeply into the then-existing pre-Cambrian surface. The absence of Early Paleozoic in northern New Mexico and southern Colorado is the result of several major periods of erosion of which this is the earliest clearly demonstrable, though an earlier one in Trempealeauan time is suspected.

Dating of the erosion interval on the El Paso surface is uncertain. It is older than the Second Value which equates with the Red River. On it are remnants of sandy beds which the writer has tentatively correlated with the Harding Sandstone of Colorado, rather, than, as previously proposed, with the Simpson of Oklahoma.*

The El Paso surface may bear remnants of more than one period of deposition. An odd endoceroid siphuncle found in the pre-Second Value remnants proves to have only one known American relative, a new genus known from one species in the Juab Limestone (lowermost Whiterock) of western Utah.

MONTOYA GROUP

The Montoya is dominantly a massive, cliff-forming dolomite. Recently Kelley and Silver (1952) raised it to group status and treated its divisions, which are quite distinctive, as formations. Generalized sections of the Montoya are shown in Figure 4.

The divisions in New Mexico may be summarized. (1) Unnamed remnants, probable Harding equivalents. (2) Second Value massive cliff-forming beds, with chert minor. A basal unit, the Cable Canyon Sandstone, is a conspicuous dark-weathering coarse sandstone in dolomite. Above, massive dark beds comprise the Upham Dolomite (a limestone locally), which may have some chert, as large spheroidal masses, near the top. Restricted to the Cooks Range and Lone Mountain is a white granular calcarenite, the Cooks Range member. (3) The Aleman-Par Value, dark dolomites with conspicuous bands of chert. (4) The Cutter-Raven, dominantly light gray, noncherty dolomite.

The Montoya represents three, probably four periods of deposition separated by intervals of erosion. Earliest are sandy beds of approximate Black River age, probably southern equivalents of the Harding Sandstone of Colorado. Elevation and erosion has restricted them to their present small limits. The second period of deposition occurred in Red River time, which can now be dated within the limits of late Trenton and Eden, probably in part equivalents.

*Simpson is not at all precise. It ranges from Whiterock probably to Black River, or at least into the Ashby-Porterfield. In the Simpson, sand increases to the east, not to the west. Dating of the Harding is uncertain. It possibly lies in the Ashby-Porterfield, or may be as young as the Black River.

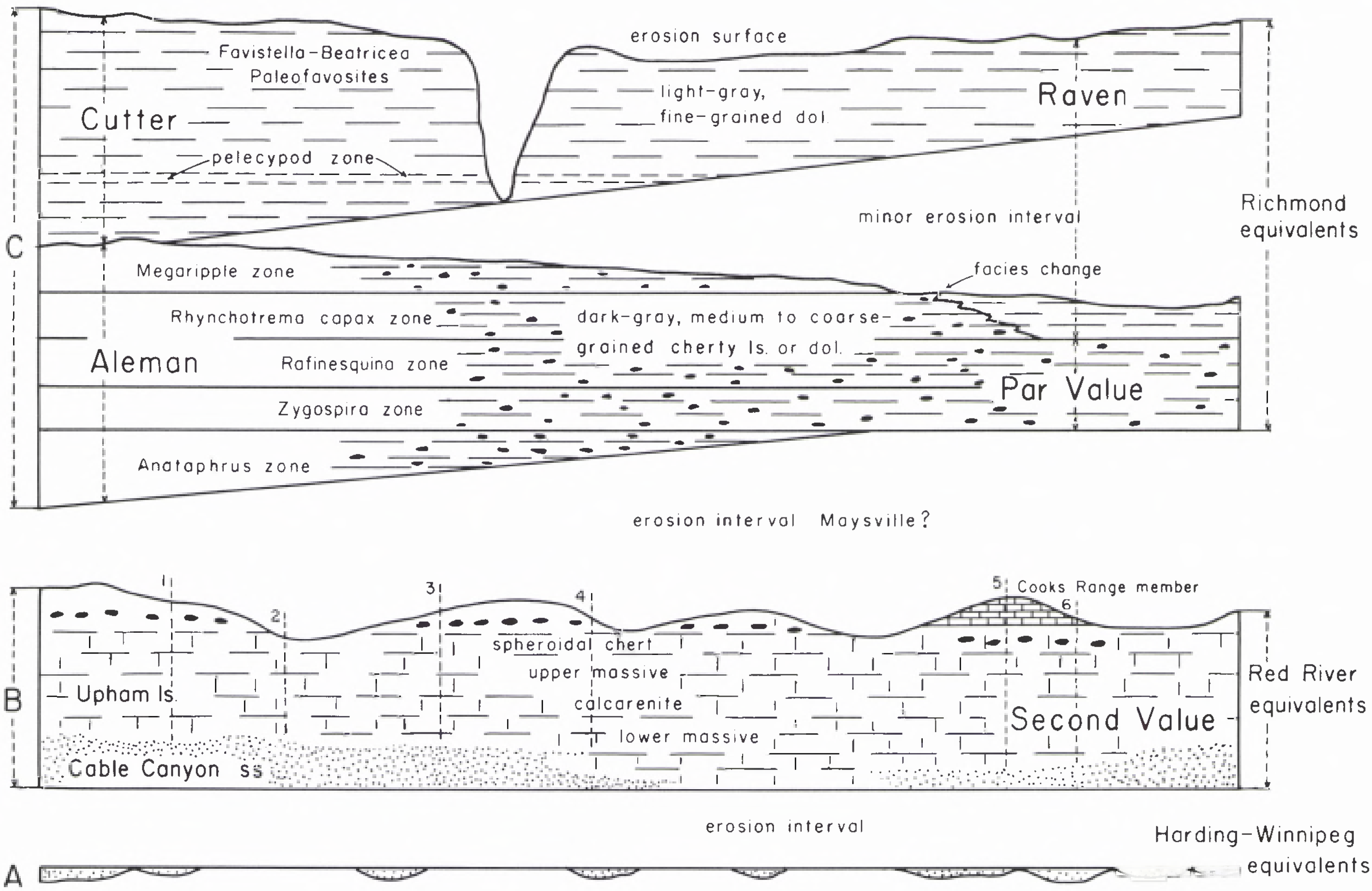

FIGURE 4

Generalized sections of the Montoya Group in New Mexico, showing periods of deposition and erosion, names, lithic variation, and zonation of the units.

1. Rhodes Canyon section
2. Hembrillo Canyon section
3. Ash Canyon section
4. Southern Franklin Mountains
5. Cooks Range
6. Lone Mountain

This deposition was followed by elevation and beveling of the warped surface to varying depths. Par Value-Aleman deposition followed, leaving a series of cherty beds, dominantly dolomitic, within which a good zonation is shown both by fossils and lithology. There was minor elevation and erosion following Aleman deposition. The succeeding Cutter-Raven shows evidence of onlap deposition from southeast to north and west.

This brief history is part of a pattern of physical events which prevailed over a surprisingly wide area, figure 5. The similarity of pattern from New Mexico to Greenland indicates a uniformity of history, and the covering of the whole region by seas which left continuous deposits. Harding deposition, dated as approximately Black River in age, was widespread. It includes the unnamed sandy remnants in New Mexico, usually only a few feet thick, but 10 feet in the Cooks Range and 12 feet in the Hatchets. The Harding itself shows (Sweet, 1954) an isopach pattern suggesting beveling of a depressed basin prior to later (Red River) depositon. Remnants of a fish-bearing sandstone beneath the Bighorn Group are logical equivalents. In Manitoba, some faunal elements indicate that part of the Winnipeg Sandstone is a probable equivalent, though it is in large part a basal sand of the Red River deposition. On the west side of Hudson Bay no corresponding deposits are known. The suggestion in figure 5, that the Gonioceras Bay Limestone and the Troedsson Cliff Limestone are equivalents in northern Greenland, is inferential. Subsequent uplift and erosion reduced this deposit to remnants preserved in discrete basins.

A second period of deposition resulted in marine deposits of Red River age. Where these are not altered

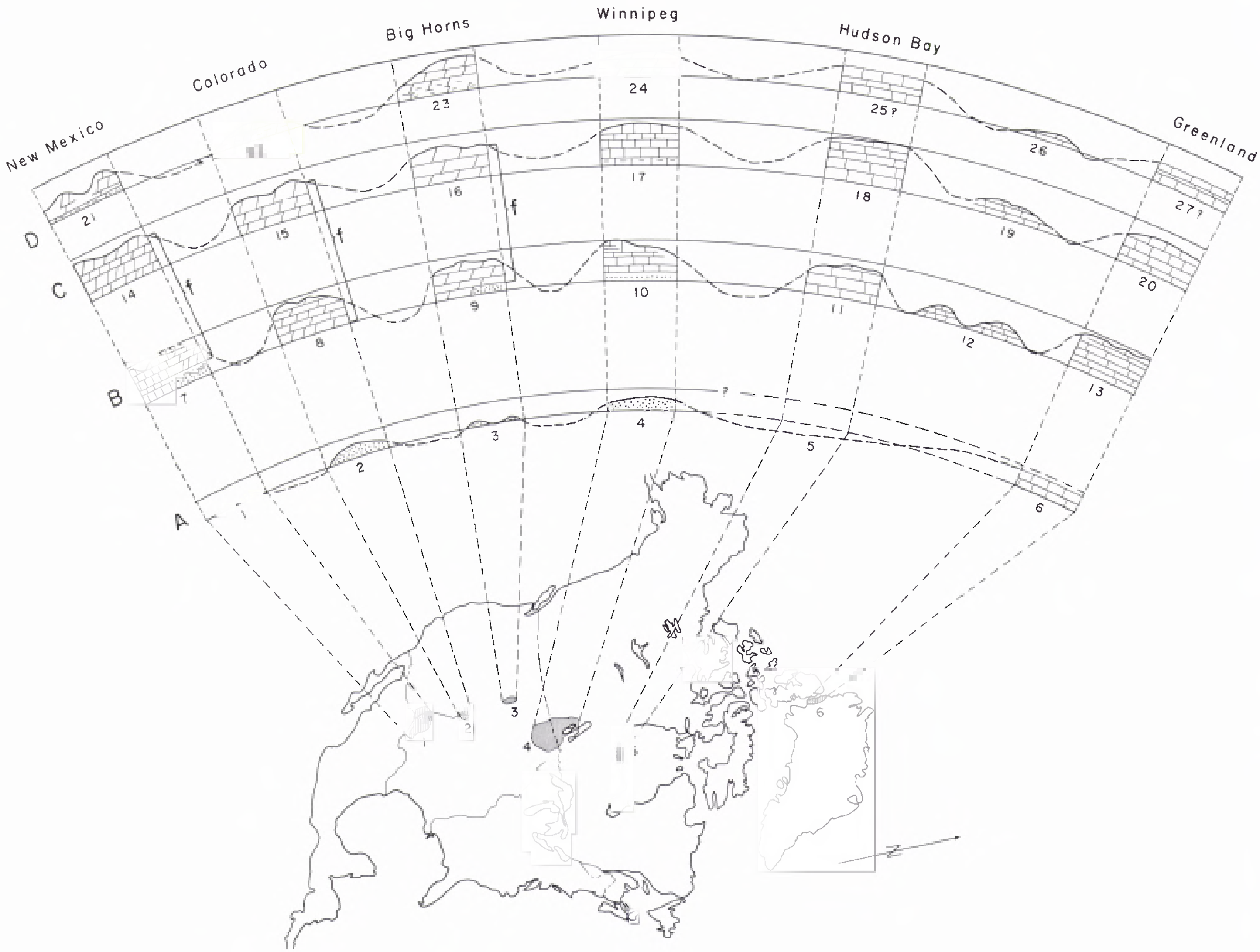

FIGURE 5

Geologic history of the later Ordovician of west-central North America. The Montoya is shown as a local expression of a general pattern extending from New Mexico and Texas to Greenland.

A. Deposits of essentially Black River age.
B. Red River deposits.
C. Early Richmond deposits, may include late Maysville.
D. Late Richmond deposits.
f- apparent fusion of discrete beds by dolomitization

1. Sandy remnants, unnamed
2. Harding Sandstone
3. Remnants of fish-bearing sandstones of the Bighorns
4. Lower sands in the Winnipeg Sandstone
5. Deposits unknown
6. Gonioceras Bay Limestone and Troedsson Cliff Limestone
7. Second Value formation, with Cable Canyon a local, prevalent basal sandy facies
8. Lower Fremont Limestone.
9. Lower Bighorn Dolomite, with basal Lander Sandstone
10. Red River limestone, and local shaly evaporites, most of Winnipeg Sandstone a basal sandy facies
11. Nelson Limestone and Bad Cache Formation
12. Beds with Red River faunas in the Arctic Archipelago
13. Cape Calhoun Formation (pars)
14. Par Value-Aleman
15. Upper massive Fremont Dolomite
16. Upper beds of massive Bighorn Dolomite
17. Stony Mountain Formation
18. Churchill River Group (Shamattawa limestone)
19. Richmond beds of Arctic Archipelago
20. Upper part of Cape Calhoun Formation
21. Raven-Cutter Formations
22. Priest Canyon member of the Fremont
23. Leigh member of the Bighorn, with a local massive dolomite at top
24. Stonewall Formation
25. Red Head Rapids Formation
26-27. Equivalents not known

to dolomite, they show massive poorly-bedded structure, with vermicular markings, though there is wide variation in details. The Upham Dolomite is massive and vermicular, particularly in its lower part, and duplicates, except in the darker color, the Selkirk facies of the Red River Formation. The fauna of large *Receptaculites*, large gastropods and cephalopods, and large corals is much the same from New Mexico to Greenland though species are different. The uneven thickness, and removal of the upper units of the Second Value in New Mexico is evidence of a break in deposition at the close of this interval. Where dolomitization is advanced, lithic and faunal boundaries between this and the overlying unit may be obscured. This is true of the Montoya in some New Mexico sections, and is common in the Fremont and Bighorn Groups. The Winnipeg area escaped dolomitization, and here the contact is clear. Subsurface work has shown the presence of evaporites developed in restricted seas at the close of deposition. Emergence for a significant interval of time is suggested. On the west side of Hudson Bay is the Nelson Limestone which Nelson (1963) proposes to name the Bad Cache Group.

In the Arctic Archipelago similar beds and similar faunas are known from a number of localities. The most important and most closely studied, are on Baffin Island. The Cape Calhoun Formation of Greenland contains a Red River fauna, and beds both older and younger are present but not yet differentiated. Older beds are suggested by *Vaginoceras*, *Gonioceras* and *Actinoceras* of Black River species groups. Koch proposed separating the lower beds as the Troedsson Cliff Formation, but it is not yet possible to say whether this interval was the sole source of some of the seemingly older faunal elements. Certainly the higher beds of the Cape Calhoun are younger than the Red River.

One can argue the equivalence of the units dated with the Harding Sandstone of Colorado, but evidence of erosion almost to the point of obliteration is clear prior to Red River deposition. The remarkable uniformity of Red River beds and faunas over the region is incompatible with the concept of deposition in discrete embayments. There is good evidence for post-Red River general emergence and erosion, but it is not clear whether the Red River beds were at this time completely confined to the basins in which they are now preserved.

Early Richmond deposition was general over the region, and may have begun in late Maysville time. The Aleman is distinct from the beds below in some sections, but where it is a massive dolomite it is difficult to distinguish from the Second Value and appears fused to the lower beds. The same dolomitic fusion is general in the Fremont of Colorado and the Bighorn of Wyoming. In the Winnipeg region, the equivalent is found in the Stony Mountain Formation, which, with its several members, is distinct. This condition continues to the north where it passes into a mottled limestone facies formerly confused with the Selkirk facies of the Red River. On the west side of Hudson Bay the equivalent is in the Churchill River Group (the former Shamattawa limestone). Farther north, beds overlying the Red River may equate with this interval at several localities, as the Akpatok Island section; and the upper part of the Cape Calhoun of Greenland is a possible equivalent.

Previously it was thought that deposition was generally continuous from early to late Richmond, but the New Mexico sections show clear evidence of a break. There is evidence both of erosion of the Aleman surface, and of progressive onlap of the Cutter-Raven beds. The break was of short duration, in terms of the Ordovician column of other regions, and is placed in Liberty or Early Whitewater time.

The later Ordovician of all the regions show similarities. The beds are generally light-colored dolomites containing some shaly zones, and have often been confused with the Silurian beds. Darton included part or all of the Cutter with the Silurian in New Mexico, and it is only recently that the Stonewall of Manitoba was demonstrated to be Ordovician rather than Silurian. Some confusion surrounds separation of Cutter and Aleman on lithic grounds. In part this is due to differences in interpretation, but in some southern exposures, the upper beds of the Aleman become lighter in color, and have been identified with the Cutter. The final phase of Ordovician deposition in New Mexico is the Raven-Cutter light-colored dolomites with at least one shaly interval. The upper part of the Fremont Limestone of Colorado, the Priest Canyon member, is similar in lithology and equivalent in age. In the Bighorns the equivalent Leigh member of the Bighorn Group contains shaly units, but locally, higher massive dolomites are preserved at the top (fide Teichert). In Manitoba the Stonewall Formation is a light dolomite, not shaly, and was fomerly grouped with the Silurian. The Red Head Rapids Formation, possibly an equivalent, is a fine-grained dolomite more like Silurian than Ordovician beds in lithology. The section on Akpatok Island is thick, and should extend into the very late Richmond, but upper beds which may be equivalent to the above units cannot be identified. Whether there are equivalent beds in the Cape Calhoun of Greenland is not clear.

Subsequent erosion has limited these beds and in New Mexico folding preceded peneplanation. There is evidence that some peneplanation preceded Silurian deposition, but the most striking cases of erosion on a folded and faulted Ordovician surface are not demonstrably pre-Silurian for they occur in sections where the Silurian is absent.

MOHAWKIAN REMNANTS

Between the El Paso Limestone and the base of the Second Value there are erosion remnants of an intervening period of deposition, probable equivalents of the Harding Sandstone of Colorado. They are dominantly clastic, but show some variation. In the Mimbres Valley there may be 2-3 feet of a white saccharoidal sandstone which contrasts sharply with the darker, coarser Cable Canyon Sandstone above. In Hembrillo Canyon 4 feet of gray silt appear on one side of the canyon, but not on the other. In the Cooks Range there is 14 feet of a massive dolomitic sand, full of large sand-filled worm borings. A similar sand occurs locally in Lone Mountain. In the Hatchet Mountains the unit is more dolomitic, 12 feet thick, but shows variation in thickness due to deposition on the uneven El Paso surface.

The dating of these beds is uncertain in the absence of fossils. Harding equivalence is an assumption, but a logical one. It is possible that there are remnants of more than one period of deposition. Lithic variation is such as might reasonably be expected in one formation over the area involved.

SECOND VALUE FORMATION

The Second Value Formation consists of massive poorly bedded limestones, of Red River age. The basal beds are commonly a sandstone which ranges from 0 to 35 feet in thickness. The name Upham has been used for the massive limestones, which are often altered to dolomite. The lithic succession is (1) lower dark massive beds (2) a middle calcarenite, thin, light-colored and crinoidal to the east, somewhat thicker, darker, and populated mainly by brachiopods in the west, and (3) an upper massive layer which may contain cherts, some scoriaceous and irregular, others conspicuous round nodules. The upper beds with chert nodules, and a frequently associated horizon with silicified brachiopods, are not found everywhere. They are present in the thicker sections, but absent in the thinner sections. Local post-Second Value erosion is responsible for the removal of these upper beds. The round chert nodules occur 87-92 feet above the base in the 117 feet of the Second Value at Rhodes Canyon; in the 80 feet present in Hembrillo Canyon, the cherts are absent; in Ash Canyon where the section is 125 feet thick, the cherts are developed at 80-90 feet above the base; in the southern Franklins the upper surface is uneven enough so that some sections just reach the cherty layers at 85 feet, but other sections are too thin. In the Cooks Range a 12-foot layer of white granular limestone is the Cooks Range member and only a remnant of the member, 3 inches to 2 feet thick, remains at Lone Mountain.

The Second Value, where it is a limestone, contrasts strongly with the Aleman but where both show advanced dolomitization the contact may be difficult or impossible to place. The erosion interval between the two may be completely obscured.

The Second Value Formation is of Red River age, and has yielded typical Red River forms including the familiar *Receptaculties*, the large *Maclurites*, and a variety of large cephalopods. The fauna is known from New Mexico and Western Texas north to Greenland, but the deposits occur now as isolated remnants. The fauna is found in the lower Fremont of Colorado, the lower Bighorn Dolomite, the Red River Formation of Manitoba, the Nelson Limestone on the west side of Hudson Bay, in various localities in the Arctic Archipelago, and in the Cape Calhoun Formation of Greenland. Necessarily hasty collecting, largely of materials loose at the foot of the cliffs, obscured the zonation in the Cape Calhoun Formation of Greenland, where certainly an upper fauna with "*Leptaena*" *unicostata* of apparent Richmond age is also present.

The age of the Red River faunas was long a problem, because they do not appear in eastern beds. It was argued that since relatives of these forms appear in the east in Richmond time, all the faunas should be Richmond. It was also thought that since the eastern appearance of these forms was a clear case of migration they might be older in their source region. Later work discovered Red River species in the late Trenton, particularly in Quebec, Ontario, the Tennessee basin, and less abundantly in the Eden of Cincinnati. Red River species occur in the Stewartville of Minnesota, the McCune of Missouri and the late Viola of Oklahoma. Furthermore, these Red River equivalents are succeeded by others containing faunas of Richmond aspect.

PAR VALUE-ALEMAN

This formation consisted originally of rather thin-bedded limestones, medium to coarse grained, dark gray to black. In most sections it is altered to dolomite, but the extent of alteration is variable. Dolomitization has obscured the bedding locally but, in the lower beds, horizontal chert bands or bands of isolated chert nodules reveal the bedding. Where dolomitization is advanced, only silicified fossils, commonly brachiopods are found. Four definite fossil zones (fig. 4) are usually found in New Mexico.

In the southern sections the basal beds are commonly barren, but carry conspicuous bands of chert. Northward they thin and are absent at Rhodes Canyon and in Mud Springs Mountains. Fossils are not silicified. The horizon has yielded an asaphid trilobite, determined by Whittington as *Anataphrus*. Allied forms occur in the lower Maquoketa shale of Iowa. Higher beds, also with horizontal seams of chert nodules, are commonly filled with *Zygospira*, *Dalmanella* and *Cornulites*. A very slender ramose bryozoan, probably *Bythopora*, is conspicuous but less common. The overlying beds contain more massive cherts often joined and fused into irregular masses across successive layers. This horizon is dominated by large *Rafinesquina*. A succeeding bed, commonly barren, has yielded a significant coral assemblage in the Franklin Mountains. It is developed also at Lone Mountain, but is not found in the intervening areas. The commonest species is *Paleophyllum thomi*. The upper beds of the Aleman yield a large fauna, with many brachiopod genera, *Rhynchotrema capax* most common, *Platystrophia*, *Strophomena*, and many orthoids. Southward, this zone thickens, and may be further subdivided. The lower beds are commonly filled with bryozoa. To the north and east, the highest bed shows conspicuous megaripples, and has yielded only a sparse fauna. This bed may be absent in some sections to the south, but elsewhere in the south it is apparently represented by a continuation upward, with some variation, of the *Rhynchotrema capax* zone. Some recently discovered, anomalously thin sections, with the upper faunas missing, suggest that the Aleman was eroded priod to the deposition of the Raven-Cutter.

The *R. capax* zone of the Aleman suggests the Vauréal of Anticosti and the Waynesville of the Cincinnati section. The lower beds contain faunas with long-ranging forms. They may be Arnheim, (which itself shows faunal anomalies as it is traced around the Cincinnati arch), but there is nothing in the lower beds that is demonstrably early Richmond. Thus, deposition may have begun in late Maysville time.

RAVEN-CUTTER-VALMONT

Succeeding the Aleman are finer grained dolomites light gray in color, generally light weathering, and with minor chert. The lower beds may contain small smoothly rounded chert nodules, contrasting with the irregular masses found in the Aleman. In higher beds chert is sparse or absent. The upper beds may contain vugs lined with quartz crystal. We have three names for this lithic unit, the Raven of Entwhistle, the Cutter of Kelley and Silver, the Valmont of Pray. The Cutter is largely barren, but a few fossils have been found. Most conspicuous are one to three zones in the middle or upper part characterized by silicified corals, mainly *Paleofavosites*. A soft nonresistant siltstone is persistent in eastern sections. It occurs 32-40 feet above the base in Hembrillo Canyon, at 23 feet in Rhodes Canyon, at 9 feet on Nakaye Mountain, and is the basal unit of the Cutter in Mud Springs Mountains. It has yielded pelecypods and brachiopods, appears to be a single horizon, and suggests onlap of the Cutter from southeast to northwest. The spheroidal cherts occur mainly in beds below this interval, where they exist. In the Rio Grande valley from Mud Springs Mountains to Nakaye Mountain, there are two persistent thin, conspicuous, ledge-forming, blue-weathering limestones a little above the silty pelecypod zone.

The Cutter fauna suggests a late Richmond age, within the limits of the Whitewater, Saluda and Elkhorn of the Cincinnati arch. Equivalent units throughout western and northern North America are discussed on pages 123-125.

SILURIAN
FUSSELMAN DOLOMITE

For the Silurian rocks of New Mexico there is only one formation name, the Fusselman Dolomite. The dolomites are massive, generally dark and dark weathering, with silicified fossils, and conspicuous chert locally. Reports of thickness give wide variations. Certainly the extreme thickness reported in the Florida Mountains is the result of thrusting of the formation upon itself.

Dolomitization is general, has altered original lithologies and destroyed most fossils which are not silicified. These features are largely responsible for failure thus far to recognize significant divisions or to give precise dating of the interval. If it is not composed of several units representing different parts of the Silurian, it will be the only one of the old seemingly simple formations which is not so composed.

The basal Fusselman in Lone Mountain has yielded small silicified cup corals identified as *Streptelasma* by Miss Helen Duncan. This is a genus unknown in the Silurian, and Miss Duncan has suggested that possibly these fossils were silicified, weathered from the Cutter, and redeposited. If this is true, and it is the only reasonable suggestion, we have not yet found a bed in the Cutter yielding such forms. It may well be that, since the Raven-Cutter-Valmont unit is known to be eroded to varying depths, the youngest beds of these deposits have been completely destroyed.

Pray (1953) reported a fauna in the lower Fusselman regarded as of Early Silurian age. The writer has questioned the age assignment because the fossils were stated to be poorly preserved, leaving some question as to species, and are members of genera which range up into the Clinton, if not into the Lockport. These fossils may be Alexandrian. They are certainly from lower beds, which are somewhat lighter in color and coarser-textured than the regular Fusselman.

Reports of large pentameroid brachiopods have listed *Pentamerus* and *Conchidium*. The most common forms seem to belong to neither of these genera, but to a *Virgiana* close to the northern *Virgiana decussata*. This species is a zone marker throughout the north-central Silurian, and is succeeded by beds with *Leperditia hisingeri fabulina* and *Pterinea occidentalis*. The latter beds are succeeded by the *Discosorus-Huronia* faunas. These faunas are certainly Clinton in age, early rather than late Clinton. The *Virgiana* beds have been variously considered as the base of the Clinton or the top of the Alexandrian. Difficulties in removing good specimens have resulted in incomplete collections for the Fusselman; there is no faunal zonation yet established. A core from eastern New Mexico yielded true *Pentamerus*. The Fusselman probably contains Alexandrian, certainly the *Virgiana* horizon, and may extend into late Clinton or Lockport. (Lockport is used here in the sense of containing the two intervals, Racine and Guelph. Both are present in the type Lockport.) There is no indication of Salina or Cayuga beds of Upper Silurian.*

DEVONIAN

The Devonian of New Mexico is dominantly a slope-forming shale, and good outcrops are scarce. East of the Rio Grande thicknesses are less than 100 feet. In the Caballo and Mud Springs Mountains the Devonian was eroded and is thin; at Whiskey Canyon in the Mud Springs Mountains there is a 5-foot covered interval between Ordovician and Pennsylvanian. The Devonian may even be absent there. In the typical development of the Percha, from Hillsboro to the Silver City region, thicknesses range up to 250 feet, and exceed 300 feet in the extreme southwestern part of the state.

Formerly only one formation, the Percha Shale, was recognized. Closer study has shown that the depositional history was complex, and six formations are currently recognized, to which might be added two more, the Canutillo of the Frankin Mountains, and the "Swisshelm" of the extreme southwest. Lithologies include shales, siltstones, some sandstone, argillaceous shales and limestones, with chert in the northern extent of the Onate and also in the Canutillo Formation.

The faunas are dominated by brachiopods and some nondescript forms, the use of which in correlation is complicated by the fact that records, descriptions, and illustrations of western Devonian faunas have lagged far behind discoveries. The Devonian brachiopods of New Mexico are in the process of study by Dr. G. A. Cooper and Dr. T. E. Dutro, and their results, which may be expected in a few years, should contribute materially to current problems. I am indebted to both for much information included in the following pages.

ONATE FORMATION

As originally defined, the Onate was distinguished from the overlying Sly Gap shales by the predominance of silty rather than shaly beds, and the presence in it of a different fauna. Stevenson cited a large *Leiorhynchus* and the bryozoan *Sulcoretopora* (readily recognized as it consists of flat fronds which bifurcate regularly). Stevenson also mentioned *Spirifer* cf. *acuminatus* from Hayes Gap. This form (fide Cooper) is actually related to the Ithaca species *Spirifer mesastrialis*.

The top of the Onate of the San Andres Mountains was considered to be an orange-weathering siltstone or fine sandstone, usually 1.5-2.5 feet thick, which forms a prominent ledge. However, the soft shales above the ledge differ lithically and faunally from the typical Sly Gap. These are clay shales, some beds with limy nodules, that weather to a resistant clay. They have yielded *Warrenella*, *Rhipidomella* cf. *vanuxemi* and other forms, alien to the Sly Gap faunas. Such shales vary from 2 to 18 feet thick in the San Andres and are directly overlain by shales carrying the *Mcgeea* zone. the lowest of the Sly Gap faunules. Variation in thickness of these upper shales of the Onate may be caused by differential warping and uneven deposition, or may be the result of post-Onate erosion. If the Onate is Middle Devonian, there is a potential time interval for such erosion in the early Late Devonian.

Most of the Devonian shales of the Rio Grande valley from Palmer Park, Derry and north through the Caballo Mountains should be assigned to the Onate rather than the Sly Gap. Where the base is seen, there is a lower limy layer of thin, moderately resistant beds with *Ambocoelia* and *Chonetes* cf. *aurora*. Higher the shales are of somewhat variable aspect, with silts and sands to the south, some good sandstones at Derry, and dominantly clay shales to the north. These beds have a distinctive fauna with a large *Atrypa*, *Schizophoria*, *Eatonia* and *Warrenella*. In Mud Springs Mountains these beds have yielded the "*Receptaculites*", more properly named *Sphaerospongia*, and the

*Upper Silurian is a term which at present is ambiguous. It appears that the beds we have been calling upper Middle Silurian, notably the Guelph and Port Byron, have their British equivalents in part at least of the Upper Silurian of the type section.

characteristic *Sulcoretopora.* At Chise the beds are a dark gray siltstone with *Atrypa* and a stropheodontid. At Hermosa the lower *Chonetes* beds are a sequence of quite pure limestones with a varied fauna, including *Hypothyridina;* above are the clay shales with *Warrenella* and other forms, and at the top are gray shales and limestones with *Sulcoretopora.* Here the contact with the overlying Sly Gap is marked by a 4-inch limonitic band.

The age relationship of the Onate involves the question of conflicting interpretations in other regions, as to whether the Tully limestone is to be considered late Middle or early Upper Devonian. *Chonetes aurora* is a species characterizing the Tinkers Falls, the basal member of the Tully in New York. *Hypothyridina* makes its first appearance there in the overlying Apulia member. One may suggest that the *Warrenella* is allied to "*Spirifer*" *laevis* of the Sherburne Sandstone, but the resemblances may be superficial. *Spirifer mesastrialis* is an Ithaca species, appearing not at the base, but in the Williams Brook member. The *Rhipidomella* cf. *vanuxemi* from Sly Gap is a species common in the upper Hamilton of New York. The Onate can certainly be placed within the limits of late Middle Devonian or lowermost Upper Devonian.

SLY GAP FORMATION

This interval consists of shales with limy bands and nodules. At the type section it is 40 feet thick; at Rhodes Canyon the thickness is 37 feet, and other sections are thinner. With the underlying Onate, the Sly Gap grades southward in the Sacramento and San Andres Mountains into a black fissile shale which has been called the Percha, but this may be too broad an identification.

The Sly Gap has yielded a large fauna dominated by brachiopods (Stainbrook, 1948), is allied to the Independence Shale of Iowa, and is lower but not lowermost Upper Devonian. It has yielded *Manticoceras.* It is generally absent in the Caballos Mountains, is present in only one small area of the Mud Springs Mountains, is absent at Chise, and is found again at Hermosa. The present distribution results from post-Sly Gap erosion, difficult to date, but clearly prior to the deposition of the Percha which lies on an eroded Sly Gap-Onate surface from Mud Springs Mountains to Hermosa.

CONTADERO FORMATION

The type Contadero is in Rhodes Canyon, where it was originally defined as the whole of the Devonian exposed above the Sly Gap. The upper part is removed as the Thoroughgood Formation, with the Rhodes Canyon Formation above. As restricted, the Contadera at Rhodes Canyon consists of 45 feet of shaly beds, becoming limy at the top. The lower 14 feet consist of thin fissile shales with widely-spaced, thin layers of siltstone, the under surfaces of which show abundant strand markings. Near the top some silty limestones alternate with shale containing an abundant and distinctive brachiopod fauna. The top is a 3-foot bed of hard limestone, nodular, weathering bluish, largely barren at this locality.

At Sly Gap the basal beds of the Contadero show 20 feet of similar fissile shale and siltstone, barren except for the top foot which yields the same fauna as that found at Rhodes Canyon. Above this is a 1-foot bed of limy siltstone, the coral bed of Stevenson, which yielded many large solitary corals; but only one colonial form was found. Stevenson seems to have mistakenly attributed to this horizon the abundant colonial forms which occur at the top of the Sly Gap. Another foot of calcareous siltstone with the Contadero fauna may occur above, but in places this bed is absent.

The Contadero fauna is being studied by Cooper and Dutro The fauna includes abundant *Hystricina,* a small fimbriate *Spirifer,* several stropheodontids, a large *Camarotoechia,* abundant small *Ambocoelia,* several genera of pelecypods, a gastropod fragment and unidentifiable small smooth orthoconic cephalopods. It is probably Chemung in age. Some difficulty has possibly arisen from collecting specimens, weathered from the Contadero, on the Sly Gap slope, leading to the idea that the Contadero and Sly Gap faunas had much in common.

THOROUGHGOOD FORMATION

The Thoroughgood Formation consists of the top 10-12 feet of the Devonian section at Sly Gap. It is dominantly tan-weathering, light gray sandstones and siltstones, varying in hardness and calcareous content. The basal layers, called the fish bed by Stevenson (but our collections contain no fish remains) have phosphatic black nodules which include fragments of a slender orthoconic nautiloid, unidentifiable, as no specimens have been found preserving the interior, and a high spired gastropod of the aspect of *Loxonema,* in addition to brachiopods. Throughout the formation brachiopods are common. The dominant types are a *Leiorhynchus* cf. *mesacostalis* of the Three Forks (the species is from the "Ithaca and Chemung" of New York) as figured by Raymond, and a "*Spirifer,*" closely allied to *Cyrtospirifer portae* of the Devils Gate limestone of Nevada. Less closely allied are *C. monticola* of the Three Forks, *C. whitneyi* of the Ouray and C.

kindlei of the Percha. A 2-11-inch remnant of this formation is present in Rhodes Canyon, and has yielded the same *Cyrtospirifer*.

RHODES CANYON FORMATION

The Rhodes Canyon Formation was proposed for the 73.5 feet of shale which overlies the remnant of the Thoroughgood Formation in the Rhodes Canyon section. The shales are largely fissile, with some siltstones, dominantly gray and finely micaceous. The section is:—

F. 20 ft. dominantly soft fissile clay shale with a few beds of resistant siltstone; siltstone gray, weathering tan; shales weather in pale green and pale rose layers; a few calcareous lenses; contains sparse fossils of C and E.

E. 10 ft. dominantly of silty shales with several beds of soft calcareous siltstones; yields a brachiopod fauna with conspicuous productids, *Athyris*, and a *Leiorhynchus*.

D. 20 ft. dominantly fissile noncalcareous shales with ¼- to ½-inch thick widely-spaced siltstones; very sparse fauna.

C. 8 ft. fissile shales, light gray to white, finely micaceous, slightly calcareous, with large brachiopod fauna including a *Camarotoechia* resembling *C. sobrina*.

B. 6 ft. shales darker gray, moderately silty.

A. 3 ft. gray silty shales.

The fauna is largely of brachiopods, and has not yet been adequately studied. It is this interval which, near Rhodes Canyon, yielded the species which Stainbrook ascribed to the Percha. My collections have been on loan to Washington for some years, and are not immediately available for review. Cooper has considered this a fauna of possible Three Forks age.

PERCHA SHALE

The Percha Shale, 184 feet thick at the type locality (Stevenson, 1945), consists of 120 feet of black barren fissile shale, 12 feet of gray argillaceous shale grading up into 46 feet of calcareous shale with limy nodules, which locally may be so numerous as to constitute layers of nodular limestone with shaly partings.

Keyes proposed the name Silver shale for the lower fissile shales, the Bella member for the upper calcareous part. Stevenson proposed the Ready Pay member for the lower fissile shales, the Box member for the upper part. It is misleading to speak of a Percha fauna, because the known fauna is confined to the upper Bella-Box member.

The Bella-Box fauna consists dominantly of brachiopods which weather readily from the shales and limy nodules. The commonest form is a small *Cleiothyridina*, but more conspicuous are *Cyrtospirifer kindlei*, *Schizophoria australis*, and *Paurorhyncha cooperi*. Closely allied faunas are found in the lower Ouray beds of southwestern Colorado and the Dyer Dolomite of northwestern Colorado. Precise dating in the Devonian involves some differences of interpretation. House (1962) would place the horizon only a little higher than the Three Forks Shale, but Cooper placed it considerably above that interval, and would now regard it as possibly very late Upper Devonian.

The dating of the Silver-Ready Pay member of the Percha still is uncertain. It may not be materially older than the Box member, or it may contain equivalents of the Onate and Sly Gap. If it does, there is an erosional break within it, a hiatus represented farther east by the Contadero, Thoroughgood and Rhodes Canyon beds.

In the Sacramento and San Andres Mountains the Onate and Sly Gap show a southward change into a black shale facies, but this is not necessarily identical with the Silver shale. The Sly Gap and to a lesser extent the Onate show a facies change to darker and more fissile shale from Mud Springs Mountains to Hermosa. A change to a perfectly black fissile shale at Hillsboro, 22 miles to the south, the type section of the Percha, would not be unreasonable. A reported *Manticoceras* (specimen lost) from the Percha at Silver City would also support this interpretation. However, dark fissile shales do lie disconformably on the Onate-Sly Gap. At Mud Springs Mountains there are 15 feet of such shale above the Sly Gap; at Chise, there are about 100 feet, which lie on Onate, with the Sly Gap missing; at Hermosa there are 137 feet above the Sly Gap. These shales could represent the Silver, the Bella, or the whole Percha. An impression of *Cyrtospirifer kindlei*, too fragile to be preserved, found in the upper part would suggest an equivalence with the Bella-Box member.

In the extreme southwestern part of the state, near Portal, Arizona, the Devonian consists of black shales like those of the Silver-Ready Pay member, overlain by calcarenites with a mucronate "*Spirifer*." This specimen Cooper (in Sabins 1957) considered of probable Chemung age. The writer has found similar mucronate spirifers in the top of the Dyer Formation of northwestern Colorado, lying above beds with a fauna of Bella-Box aspect. In the Hatchet Mountains, the black shales of the Devonian grade up into limy beds with a different fauna, as yet undescribed and not precisely dated.

The ammonoids contribute to the problem of dating the New Mexico Devonian. The Sly Gap has yielded *Manticoceras*. This genus is confined to the upper part of the lower half of the Upper Devonian (the Frasnian of Europe). In the east, *Pharciceras*, in the Tully Limestone, *Pontoceras* and *Koenites* in the Geneseo-Sherburne, precede *Manticoceras* which ranges through the Ithaca and Chemung. The upper part of the European Devonian, the Fammenian, is divided in Europe into the zones of *Cheiloceras*, *Platyclymenia*, *Clymenia*, and *Wocklumeria*. House (1962) has recognized *Cheiloceras* in the Gowanda Shale of New York. The Three Forks Shale contains *Platyclymenia*. *Cyrtoclymenia* and *Falciclymenia* in the Bella-Box member of the Percha he placed slightly higher in the same zone, and recognized in the *Chonopectus* sandstone of Missouri forms assignable either to the *Clymenia* or the *Wocklumeria* zone.

The reported *Manticoceras* (determined by Miller, the specimen unfortunately lost), from the lower Percha near Silver City, has not yet been duplicated. If correct, it would indicate an equivalent of the Sly Gap in the lower Percha at that locality. The only ammonoid from the Onate so far is a crushed *Tornoceras*, too poorly preserved to be diagnostic.

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