EARLY PALEOZOIC OF NEW MEXICO AND THE EL PASO REGION

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NOTE

The present article is largely that of the El Paso Geological Society guidebook, with one serious correction; in that work, one page (96) was misplaced; it belongs properly between pages 92 and 93. There are other minor emendations, mainly correction of typographic errors. The Devonian discussion was essentially unaltered from that of Flower 1959.

Cognizance should be taken of an important contribution to the Devonian: Bowsher, A. L., 1968, The Devonian System in New Mexico in Toomey, D. F. 1968, "1967 Symposium: Silurian-Devonian rocks in Oklahoma and environs": Tulsa Geol. Soc. Digest, vol. 35, p. 259-276, figs. 1-7. Some matters quoted there require clarification. The Agoniatites reported from the Sly Gap cannot now be found; I am inclined to believe the identification to be erroneous. The discussion of the Devonian in Kottlowski, et al., suffered from editorial emendation; there is no true Percha in the San Andres; the term was substituted for descriptions of the Thoroughgood and Rhodes Canyon formations.

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Preface

This is a report of investigation still in progress. Guidebooks, in requesting such articles perform a useful function, thereby recording some information that otherwise might not be made available for years. The conclusions presented are often revised as the result of subsequent work. Further revision is required from mistakes introduced by typists and editors.

In Flower 1958 (Roswell Geological Society) the word "atypical" was consistently altered to "typical". In a later publication (Flower, 1959) the name Aleman was substituted for Arnheim, to the confusion of any readers. The last contribution (Flower, 1965) had over 130 unauthorized emendations, and it is requested that if it is quoted at all it be cited as "Flower, with unauthorized emendations." Republication of the original was not desirable; further work had contributed new information, particularly in relation to El Paso correlations.

INTRODUCTION

Not too long ago, 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 most of the Early Paleozoic into one formation, as the Mimbres limestone. For mapping on the scale then used, and indeed, on many scales in current use, the Early Paleozoic shows such a narrow belt of outcrop that finer division is impractical. Interestingly, 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 the 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 to arrive at a clearer concept of the geological history in terms of periods of deposition alternating with intervals of elevation and erosion. It became increasingly apparent that it was necessary to know what parts of systems were represented and how the New Mexico sections correlate with those of other regions. Finding the answer to this seemingly simple question is not always easy; indeed, even after much investigation, present findings permit more than one interpretation, and the present summary is, like prices in our more dubious restaurants, subject to change without notice. It must be remembered that there are two realities in geology, the actual geological history and the succession of rocks as we see them today; the first is not always obvious from the second. A startling case is shown by the Montoya group of New Mexico. In some exposures, the Second Value and the Aleman are startlingly distinct, and we have reason to believe that they were separated by a general period of uplift and erosion. Yet where, as in the Sacramento Mountains or in the Mud Springs Mountain, 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. In many instances, the writer has had reservations in this regard, for 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 odd anomalies. In some cases established zonations have held well; this is particularly true of our Cambrian. The Canadian, however, shows an odd faunal succession including an odd mixture of eastern and western elements, with some features peculiar to New Mexico and western Texas.

With closer scrutiny, one sees that almost none of the older formations has retained their apparent simplicity. The early Paleozoic was a long time, extending roughly from 600 to 370 million years, 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. It is some comfort to reflect that even these regions still have unsolved problems.

Figure 1 is an attempt to show something of a chronological development of refinements of the geological column of the Early Paleozoic of New Mexico. The first column shows the old broad formations, roughly one to a system, which developed roughly from 1906 onward, and are found in Darton (1917) which has long, perhaps too long, been accepted as a standard. The second column shows divisions proposed within these broad formational units proposed through 1952. The main advances involve Entwistle (1944) for the Montoya, Stevenson (1945) for the Devonian, Kelley and Silver (1952) for El Paso and Montoya.

Since that time, a more refined succession has been achieved, which is shown in the third column. Here are combined formation names and faunal zones. The last column shows the correlation of these divisions in terms of a more general column for North America; notice that this column is incomplete; major intervals not represented in New Mexico are omitted.

Figure 2 is an attempt to evaluate the Early Paleozoic of New Mexico with a generalized column for North America. Here are included major divisions of systems from Upper Cambrian through the Devonian; indicated thicknesses of these intervals have no time significance; those unrepresented in New Mexico 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

In previous guidebooks, the writer has attempted to summarize the section in terms of periods of deposition, elevation, and erosion. The task is not as simple as it seems, and though some further refinements are now possible, some uncertainties still remain.

1. Deposition of Dresbachian sediments (earliest Upper Cambrian) in the region athwart the southern New Mexico-Arizona line. 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 next zone, 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 here been found only in one locality, at White Signal, but may possibly be represented 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. In New Mexico, the erosion at this time may have restricted the Eoorthis beds geographically.

5. Late Franconian deposits of the Ptychaspis-Prosaukia zone, divisible into three subzones. These are well developed in the Caballo and Mud Springs Mountains and on the east side of the Black Range and 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 Chiricahua Mountains.

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

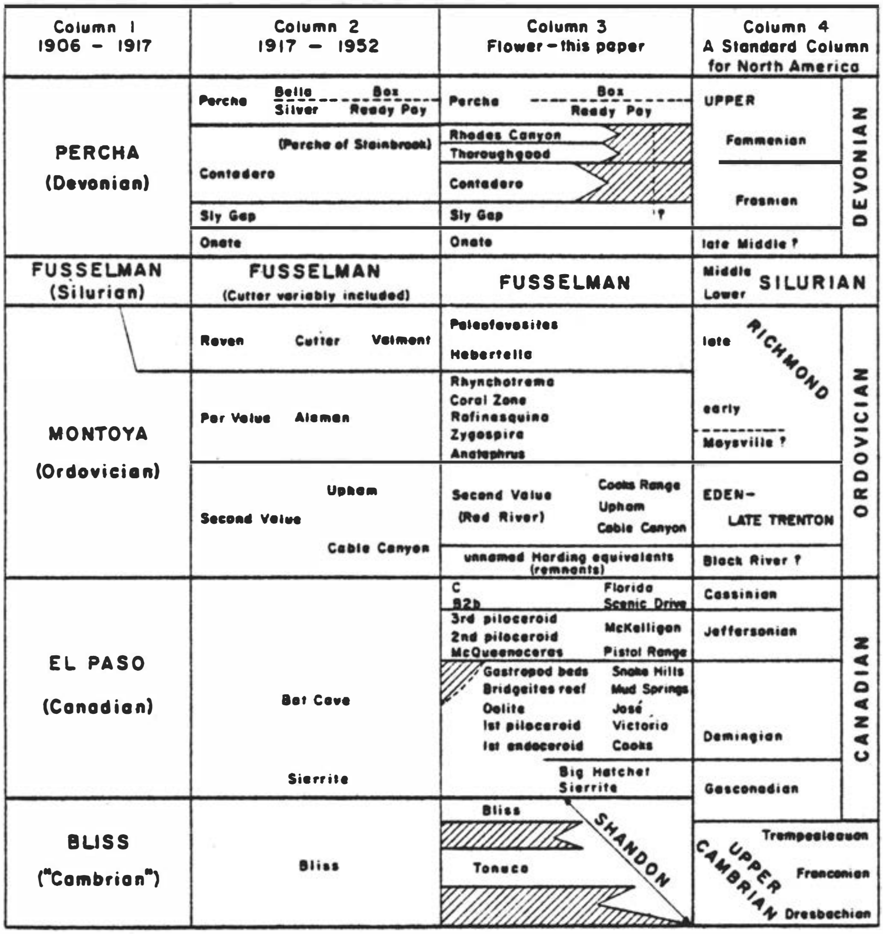

FIGURE 1

Development of Formational Units in New Mexico

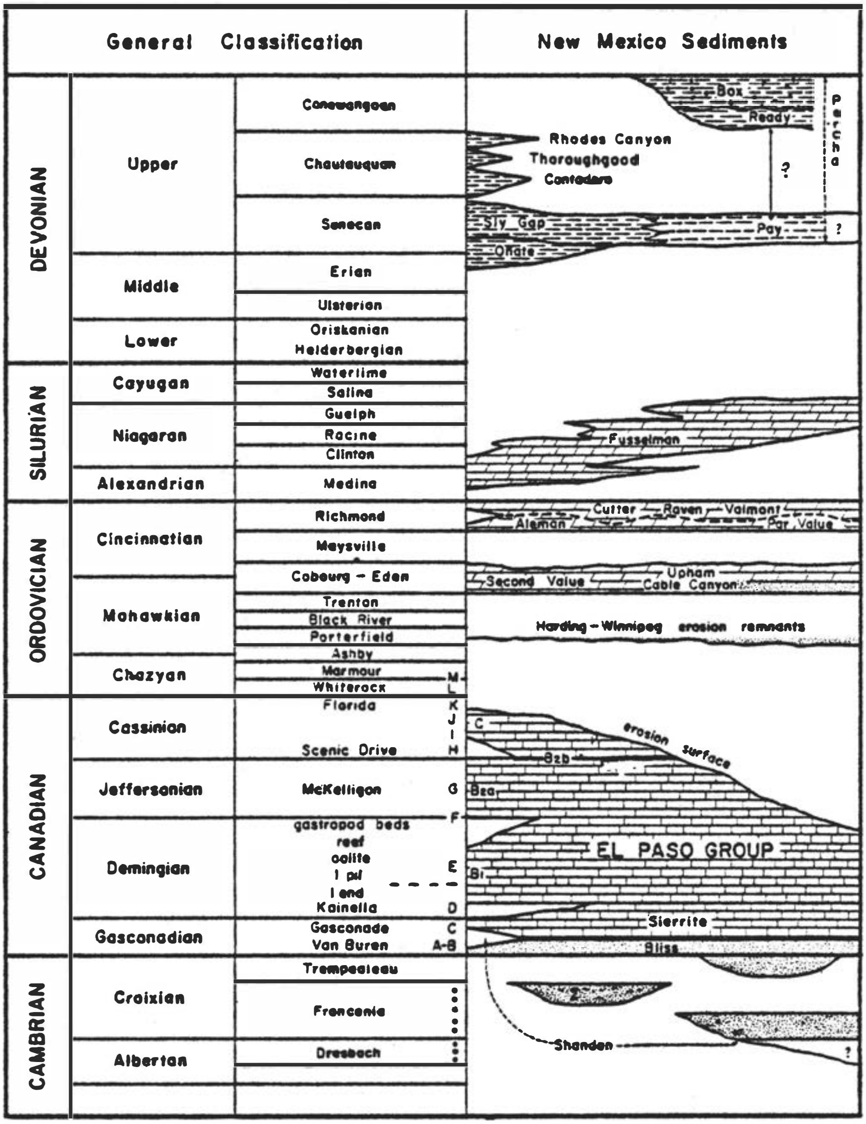

FIGURE 2

Correlation of the Early Paleozoic of New Mexico

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 widespread general biological change of continent- or world-wide significance without a demonstrable cause? This question 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. This question, when asked of most stratigraphers and paleontologists results in a discussion of the weather, federal overspending, Viet Nam, the race problem and current developments in art and music.

7. Early Gasconade deposits (Van Buren equivalents?) dominantly sandy beds of early Gasconade age, dominantly clastic in the east, with thin limestone lenses in the central part, and with dominantly dolomite between lower and upper sandstones in the western part of the state. The existence of correlates 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 in a six foot interval by a decrease first of sand and then of glauconite. Oddly, the Sierrite limestone shows odd variations in thickness; it is possibly wanting in the southeastern sections, and the greatest thickness found is in the Mimbres Valley.

9. In eastern North America, there is a general hiatus between Lower and Middle Canadian beds. In southwestern New Mexico, one finds in this interval a considerable thickness of beds with Kainella and Leiostegium, which are reasonably deposits laid down in this time interval in a sea which continued into Utah and Nevada but did not extend much farther east. Some problems now attend the decision as to whether these deposits are better placed in the Lower or Middle Canadian, as discussed more fully below; certainly they thin to the east. In the San Andres and Franklin mountains, dolomites with Apheoorthis finkelnburgiae may represent deposition in part of this interval or may represent slightly younger deposits. The discovery of the fauna of the first endoceroid zone high in zone D in Utah, indicates that this zone is better considered as earliest Middle Canadian rather than latest Lower Canadian. This continues uninterrupted as the sequence of first endoceroid, first piloceroid zones, oolite, Bridgeites reef and gastropod beds above is general in New Mexico; at El Paso, beds above the oolite are wanting.

10. Minor emergence in late Demingian time confined to the El Paso region, involving nondeposition or removal of beds above the oolite.

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

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

13. Cassinian deposition continuing locally to the close of the Canadian.

14. 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; its end is probably no younger than Black River.

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

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

17. Red River deposition, originally continuous north to Winnipeg and Greenland. Dated as Late Trenton and Eden.

18. Elevation, erosion of the Red River surface, which probably occupied much and possibly all of Maysville time.

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

20. Minor elevation, producing at least local extensive erosion of the Aleman surface. A section at the north end of Nakaye Mountain reveals only the Zygospira-Dalmanella fauna in the Aleman, with only 6' of barren dolomite above followed by the Cutter.

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

22. Elevation and erosion, beveling the Montoya surface.

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

24. 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.

25. Elevation and erosion, extending through Lower 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.

26. Submergence and Onate deposition.

27. Elevation and minor erosion of the Onate surface prior to --

28. Sly Gap deposition (Ithaca and Naples equivalents), Frasnian.

29. Contadero deposition, late Frasnian, Chemung equivalents.

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

31. Planation of the Thoroughgood surface

32. Deposition of the Rhodes Canyon shales.

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

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

34. Deposition of the Percha, late Fammenian.

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

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

37. Lake Valley deposition, continued north as the Kelley of the Magdalena area.

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

39. Chester deposition, now known only in the extreme south.

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

It must be realized that 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. It is evident that 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 dominantly sandy beds, dark weathering, 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. Within the limits of sandy beds, 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 in other localities. Toward the west, a considerable interval of only moderately sandy dolomite is found. There are sedimentary quartzites which may, at the base of the Paleozoic, contain Precambrian pebbles.

This interval was not unnaturally 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*

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*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.

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 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 more recent significant finds in New Mexico include (1) the discovery by Northrop and students (see Kelley and Silver 1952) of the brachiopod Apheoorthis and a dendroid graptolite which finally proved to be Dictyonema flabelliforme var. 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 line.

The writer has suggested that the prevalence of glauconite and other features suggests very slow deposition, so slow as to destroy much of the original faunal evidence. In such a situation, it is necessarily difficult to establish the geological history, for absence of faunas may not mean absence of deposits in the time interval involved. However, from these various finds, a general picture, shown in Figure 3, has emerged. Knowledge is still incomplete, and the most vexing problem remaining is that supplied by the "Bliss" of the Sacramento, San Andres, and Franklin Mountains. There the main constituents of the faunas are linguloid brachiopods, which seem allied to Lingulella deltoidea (Flower, ms) of the Gasconadian part of the Bliss. However, these forms are confined to the upper part of the Bliss; the lower beds

Stage	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 South
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	
Trempealeauan	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 — L-linguloid fauna
H-horizon recognizable without faunas — W-*Westonia*
P-probable development of fauna — B-*Billingsella*
S-reported by Sabins 1957 — 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.

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 for both units. This matter is, however, not settled, and several possibilities exist. Subsequent finds may prove the lower beds of the type Bliss to be Cambrian. Oddly, 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 containing marble-sized pellets of darker sand, the whole weathering with hues of pink and mauve, occupying the lower three fourths of the sandstone interval, and above, with an abrupt contact, fine-grained black weathering sandstones with abundant linguloid fragments. Without a similar sharp sedimentary break, it is apparent that traces of this lower facies can be found in the lower part of the type Bliss of the southern Franklin Mountains.

Another interpretation is possible, that the whole of the eastern Bliss is Cambrian. Recent collecting has brought to light true *Lingulepis* from the southern Franklin Mountains, and though the linguloids remain suspect as indicators of age, this find would tend to support such a view. Vexingly, 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) proposed restricting the 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 are present. This usage is employed in our diagrams, Figures 1 and 2. Thicknesses are not reliable guides, but it may be noted that the thickness of 71 feet between the top of the Bliss and the zone of *Apheoorthis* (with a *Bellefontia* indicating Lower Canadian age shortly below) is not widely different from a similar thickness in Mud Springs Mountain, where the upper Bliss is demonstrably Gasconadian.

As can be readily seen, readjustment of formational names may be required when the age of the type Bliss is definitely established; a good temporary measure would be to restrict the Bliss to the eastern sections of still uncertain age and to propose another term for the demonstrable Canadian portion. If ignorance is not bliss, the Bliss is still a center of our ignorance of the geological history of New Mexico. However, bypassing the problem of names, some considerable progress has been made.

CAMBRIAN HISTORY OF NEW MEXICO

Happily, much progress has been made in recent years in critical investigation of faunal zonation in the Cambrian. The zones developed have been found reliable over North America. Those expressed in the Cambrian Correlation Chart (Howell et al. 1944) have undergone some modification, and from one region to another there are some minor differences in names applied to the zones and in relative placement of some horizons as "zones" and others as "subzones." The general succession has shown a surprising validity in the light of much critical study. A good summary is found in

Lochman-Balk and Wilson (1958), showing the general faunal successions and the different faunas developed contemporaneously in disparate environments.

Figure 3 is a graphic representation of the faunas found and the portions of the Cambrian in which deposits can be established. It must be emphasized that future finds may well alter the present concept. In many places, 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 only after extensive work was a piece 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 cited as post-Aphelaspis zone). Oddly, the Crepicephalus zone is unrecognized there, and 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 at 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 amazingly confined to one narrow horizon; it is currently grouped as a subzone of a broadly defined Conaspis zone; the grouping depends on the affinities of associated trilobites in other regions; here only the Eoorthis is found. Interestingly, one piece of sandstone was found with a Camaraspis on the bottom, an Eoorthis on the top, with no apparent bedding plane. At White Signal Eoorthis occupies 9 feet of gray, tan-weathering sandstone of medium texture; at Lone Mountain it occupies hematitic sandstones with some hematite 20 to 28 feet above the base of the Paleozoic. Zeller 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 identical with that of the Ptychaspis-Prosaukia zone of the Black Range.

5. The Ptychaspis-Prosaukia zone is divisible into a number of subzones, as here indicated. The nomenclature stems from the fact that in these several subzones there is overlapping of the genera. The former correlation chart indicated Briscoia and Prosaukia as separate zones, a view now generally abandoned, and the first Dikellocephalus zone is now generally treated as Trempealeauan. Present finds are far from perfect owing to scarcity of good specimens, and precise zonation is possibly obscured by poor exposures; unfortunately the varied faunas from the east side of the Black Range come from a poorly exposed section, and most specimens are from loose pieces. Thus far, 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 in 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 horizon has been found in the Black Range. Both these upper subzones have yielded a broad Billingsella in abundance, which has also been found in dominantly barren glauconitic beds at Lone Mountain. The same genus was found by Sabins in the Blue Mountain section at the Arizona line, but came not from sandstone, but from limestone, which he called El Paso. The same Billingsella has been found with Prosaukia at Cable Canyon.

6. Westonea Horizon. -Above the Prosaukia-Briscoia beds are a few feet of purple-weathering micaceous silty sandstone with Westonea, prominent because the specimens weather out white. This horizon is a conspicuous one from Tonuco Mountain north to Mud Springs Mountain, but it has not been recognized in the several outcrops on the east side of the Black Range. Cable Canyon yielded two fragmentary genal spines of trilobites from this horizon, insufficient for identification, save that they are not obviously identifiable with either Prosaukia or Briscoia. Though the Westonea is a useful local zone marker, the position of this bed in the general scheme of Cambrian correlations is not yet evident. It could be a facies of the beds below, latest Franconian, but a Trempealeauan assignment could not be disproved.

7. Trempealeauan. -Light-gray, dominantly 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 here, but it is now recognized that varied facies in a section with sandstones, siltstones, and some

dolomite controls the faunal succession, in the Minnesota-Wisconsin region where these zones were established. No good continent-wide zonation within the Trempealeauan has yet been established. At Lone Mountain this occurs in 12 feet of sandstone, the uppermost unit in 89 feet of Cambrian overlain by 72 feet of Gasconadian sandstone.

Figure 3 suggests an interesting picture of depositional history, consisting of several possibly discrete periods of deposition, the first, in Dresbach time, confined to the southern Arizona line. 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 with dominantly barren glauconitic sands in the Silver City region. Relationships with Arizona are not clear, but it is of interest that this fauna occurs there (Stoyanow, 1949) in a limestone, and Sabins reported Billingsella, diagnostic of this horizon in New Mexico, in a limestone in the Chiricahua Mountains. As yet, there is not enough information on the Arizona Cambrian to permit postulation of relationships with the New Mexico sections in any detail.

Trempealeauan deposition is, as far as is known, confined to the Silver City region in general and consists there completely 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 cross-bedded, coarse sand at the base grade up into a succession of thin, sandy beds alternating with silty glauconitic layers, some dolomitic sandstones, some of which contain pebbles of sandier, darker material. There are thin beds and lenses of limestone, 4 inches thick at the maximum. In Cable Canyon they are commonly fossiliferous, and some are composed completely of scraps of Symphysurina or Apheoorthis or Girvanella. In Cable Canyon these lenses are good limestone; elsewhere they show recrystallization or dolomitization. Near the top, 6 to 18 inches of yellow-green silt and shale occur, yielding Dictyonema flabelliforme var. anglicum. This shale and the graptolite persist on the east side of the Black Range. On its 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, Lone Mountain, and White Signal, sands mark the base and top of the Bliss, but the middle portion is a nearly sand-free dolomite.

Some thicknesses for the Shandon, subject to error from minor faulting concealed by poor exposures, are as follows:

Location	Tonuco	Bliss
Tonuco Mt.	60	69
Cable Canyon	67	83
Mud Springs Mt.	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 limestones, and dominantly calcilutites, varyingly altered to dolomite. The beds commonly form a gray to tan weathering slope between the massive dark-weathering Bliss below, and the cliff-forming Montoya above. Thickness decreases in general from El Paso to the west and north, mainly the result of erosion which cuts into the El Paso to increasing depths in both directions, until none is left. Lithology shows wide variation in short vertical intervals, and also considerable small scale lateral variation. The subdivisions do, however, show characteristic lithic features. Chert is varyingly developed; some horizons are characterized particularly by stromatolitic biostromes; chert is variable, pebble conglomerates are present, but nowhere are either dominant lithic features.

Together with the Gasconadian upper Bliss, the El Paso deposition ranges through Canadian time, an interval better treated as a system than as a subdivision of the Ordovician. Elsewhere, this interval is found to involve an intricate series of periods of alternating deposition and erosion, and it is not surprising that the history here is not completely one of continuous deposition.

We have in treating the El Paso, two standards with which to compare it. The "standard" eastern section is taken from the Ozark uplift where the following succession has been recognized:

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

Unfortunately for purposes of correlation, faunas in this sequence are even yet imperfectly and incompletely described. A nearer and much better understood section is that described by Cloud and Barnes (1948) from the Llano uplift of central Texas, but unfortunately for our purposes, this section is eroded, and does not extend much above the middle of the Jefferson City group. Its fossils are still only incompletely described.

To the northwest in Utah, a zonation was established on the basis of trilobites. Ross (1951) recognized zones A through L in the Garden City limestone, with zone M in the overlying Swan Peak quartzite; subsequent finds have indicated the presence of part of zone N there also. Hintze (1953) found equivalent zones in the Pogonip of western Utah. Zone A occurs in the upper Notch Peak (Hintze, oral communication) zones B and C constitute the House Limestone, zones D through I the Fillmore limestone, zones J and K the Wahwah limestone, zone L the Juab limestone. Zone M occupies the lower part of the Kanosh shale, while zone N occupies the upper Kanosh and continues through the Fillmore limestone. Zone O is recognized as constituting the Crystal Peak dolomite. As zonation rested mainly on the trilobites, poorly known from most eastern sections, precise correlation was for some time doubtful, but recent investigations by Hintze and others, have alleviated the problems appreciably.

Flower (1957) proposed major divisions of the Canadian, Gasconadian, Demingian, Jeffersonian and Cassinian, which appear to be natural divisions in terms of periods of deposition in much of North America, but there still remain problems of correlation, stemming in part from our still incomplete faunal information, and in part from interpreting sedimentary histories, particularly great where dolomitization has altered original lithologies. The Gasconadian is a period of Lower Canadian deposition. In eastern North America elevation and erosion separated it from the succeeding Middle Canadian.

Such elevation may be reasonably dated as lying within zones C and lower D of the Utah succession. Further work has indicated the necessity of considering zone D as early Middle rather than late Lower Canadian. The Middle Canadian, the Demingian, is represented largely by the Lecanospira faunas of eastern North America. The sections in New Mexico are of exceptional thickness, and contain a variety of faunas and lithologies, corresponding to zones D and E and possibly F of the Utah sections. The early Middle Canadian, the Jeffersonian, is a period of rather variable deposition in the east; oddly, in New York the Theodosia member is present, though locally only as remnants, but none of the underlying Rich Fountain has been found.

The Cassinian marks a definite renewal of the marine invasion, shown most strikingly in the Fort Cassin beds of the Champlain Valley and the Scenic Drive formation of the El Paso group. One emendation has been required: new finds have shown that the Cotter and Powell should be grouped in the Cassinian rather than with the Jeffersonian.

Units of the El Paso were first defined as faunal zones, but later given geographic names (Flower, 1964). The succession is summarized below, with some comments on recent finds and current problems.

SIERRITE LIMESTONE

The Sierrite limestone succeeds the early Gasconadian without any serious break in sedimentation; rather the change is marked in the Caballo Mountains by a decrease in first sand and then glauconite in a 6 foot interval; in the Silver City region, the upper Bliss may be dolomitic, but is marked by a final conspicuous glauconitic sandstone. The Sierrite consists of dominantly thin beds of calcilutite, with some pebble beds, and a few thin arenite beds. Wavy bedding is probably the result of solution along bedding planes. The known fauna is small, with Apheoorthis cf. melita, Symphysurina cf. brevispina, Bellefontia, Lytospira gyrocera, Ophileta, and rare cephalopods of the genera Ectenolites and Clarkeoceras. There are rare polyplacophora and Finkelnburgia. Thickness ranges up to 80 feet, rarely more. Thin beds are generally evident in eastern and central New Mexico sections, but the interval is strongly dolomitized in the Hatchet Mountains. Some sections show a seeming gradation upward through beds showing more calcarenites, into the Middle Canadian, but some such sections have yielded insufficient faunal evidence in the seemingly transitional beds.

BIG HATCHET FORMATION

In the Big Hatchet Mountains the Sierrite is succeeded by (1) massive dolomites with shaly beds between and (2) limestones or dolomites with large white-weathering sphaeroidal chert masses.

The total thickness there is 345 feet. In south central New Mexico beds at this horizon are generally barren, and lithically seem to grade up from the Sierrite, showing an increase in calcarenites. In eastern sections the position of this horizon is marked by largely barren beds, mainly dolomitic, but containing one silicified brachiopod, Apheoorthis finkelnburgiae. In the Hueco Mountains this brachiopod is found abundantly in limestone over about 40 feet of the section. Equivalence with the Big Hatchet formation is suggested, but far from proved. As yet, no other fossils have been retrieved from the A. finkelnburgiae-bearing beds.

COOKS FORMATION - First endoceroid zone

Here are up to 80 feet of dominantly light-colored limestone, with some stromatolite layers, pebble breccias, and some chert nodules. In the El Paso section this interval is a dolomite. The fauna brings into the section many elements not known below. Slender endoceroids are common, including Proendoceras, Clitendoceras and some undescribed genera. There is a large gastropod assemblage with many forms of the aspect of Ophileta, Ozarkina, Lytospira and possible Gasconadia, giving the association a false Lower Canadian aspect, but with some more advanced types including Proliospira (Flower, in press). There is a cup-shaped sponge, an undescribed genus, brachiopods include Nanorthis and Diaphelasma. Trilobites are present, but do not chop out. There are hystricurids and Leiostegium. There are rare Protocycloceratidae and Baltoceratidae, Bassleroceras is present, Tarphyceratidae are represented by Aphetoceras and an undescribed genus.

Correlation is indicated with the upper part of zone D in Utah, from 95 to 200 feet above the base of the Fillmore limestone, and with the early Roubidoux, Gorman and Fort Ann of the east.

VICTORIO HILLS FORMATION - first piloceroid zone

Here are limestones, generally darker and dirtier looking, with calcilutites alternating with significant stromatolitic biostromes in beds up to 4 feet thick, with much detrital material in the interspaces. Such detritus may contain pebbles or fossils or both, but there are no persistent pebble beds. The conspicuous element in this fauna is the Endoceratida; here are slender endoceroids, attaining a size unknown in the underlying beds, and piloceroids are abundant, including true Piloceras, Bisonoceras and a number of unnamed genera. Sponge fragments are abundant in the reefs for the first time in the section, Gastropods include an Ophileta and a Proliospira. The only common brachiopod is Diaphelasma cf. complanatum. There are few identifiable trilobites so far, but there is certainly an Evansaspis here. Coiled cephalopods include several species of Campbelloceras.

This fauna, in similar reefy horizons, has been found in zone E in Utah. To the east, it is believed to be represented by the upper (Campbelloceras bed) of the Roubidoux in Missouri and the upper Fort Ann of the Champlain Valley.

JOSE FORMATION - THE OOLITE

In New Mexico these are strikingly black beds, up to forty feet in most sections, containing much oolite, some layers with pinkish pebbles, believed to be algal in origin, and layers choked with small fossils, of which the asaphid Aulacoparia is the commonest form. There are small low-spired gastropods (Bridgeina, Flower, in press) a small Hormotoma, and small orthoconic cephalopods, dominantly Baltoceratidae and Protocycloceratidae. At El Paso the unit is of exceptional thickness, occurring largely in black dolomites there, and contains several stromatolitic horizons. The faunal evidence thus far available is ambiguous. Oculomagnus and Leiostegium would suggest zone E, but Aulacoparia would suggest zone G. High E or F seem a reasonable guess.

MUD SPRINGS FORMATION

Here are 20 to 30 feet, rarely more, of massive cliff-forming light weathering cherty limestone, with considerable stromatolitic material throughout and a moderate amount of chert. The only abundant fossil is a characteristic discoidal gastropod, Bridgeites discoideus Flower (in press). The lithology is distinctive; the fauna is sparse and fails to indicate precise correlation to either the east or to the west. The interval is wanting in the section at El Paso.

SNAKE HILLS FORMATION

Succeeding the cliff-forming Mud Springs formation, are less resistant slope-forming thin beds, dominantly of calcilutite up to 60 feet in thickness. Some beds are filled with small gastropods which defy extraction. Leiostegium persists, but with it are several other forms including a Presbynileus. Precise correlation is uncertain.

McKELLIGON FORMATION

At its type locality, the McKelligon formation begins with 34 feet of sandstone, followed by stromatolitic reefs in dolomite yielding abundant small endoceroids, among which McQueenoceras is conspicuous. There follow limestones which contain a frequent alteration of (1) stromatolitic reefs with abundant sponges and piloceroids (2) massive beds with some sponges and piloceroids, (3) thin beds with little more than fossil scraps. The thickness at El Paso is about 680 feet. The lower half contains the typical fauna of the first piloceroid zone, and is dominated by piloceroids of the aspect of Allopiloceras. Sponges are common, and include Calathium and Archeoscyphia. Systematic collecting remains to be completed, but it is evident that within this interval there is some faunal variation. Lower beds have yielded Ceratopea torta and cf. capuliformis. The lower half shows affinities with the faunas of the Jefferson City group, but no precise division corresponding to the Rich Fountain and Theodosia faunas is yet apparent. From thickness and some faunal indications, I had at first thought that the middle and upper beds might be of Cotter or even Powell equivalence, but later a Cotter fauna was found in the lower Scenic Drive formation. The upper reefs have yielded some odd forms unknown in the lower beds, and may represent deposition occupying what is in the east a period of uplift and erosion.

SCENIC DRIVE FORMATION

Upper beds of the McKelligon canyon formation become dolomitic, to a depth and to an extent which vary locally. The beginning of the Cassinian deposition is marked by the sudden appearance of sand, coarse and prominent.

The Scenic drive formation is capable of further subdivision. A lower unit of 100 feet of dolomite is divisible further into a lower dominantly sandy part, 57 feet thick along the Scenic drive. A lens of sandy dolomite, 3 feet thick and 45 feet above the base of this unit has yielded a large fauna with abundant Ceratopea ankylosa, a species widespread in eastern North America and indicative of Cotter equivalence. Gastropods dominate the fauna with Ceratopea, Rhombella, Hormotoma. Pelecypods are represented by Euchasma, marking the earliest appearance of that group in the El Paso succession. Cephalopods include Arkoceras (3 species) Clelandoceras (2 species) Baltoceratidae, Protocycloceratidae, poorly preserved small endoceroids, and the earliest Michelinoceratida so far known. Arthropods include the chelicerate Lemoneites, the oldest ostrocodes so far found in the El Paso group, and trilobites. Both the ostracodes and the trilobites are imperfectly silicified.

The upper 42 feet are dominantly free from sand, though fine sand and silt can be recovered from etching. The top 13 feet are marked by a 2-foot bed of very black dolomite at its base, and a 1-1.5-foot bed of black dolomite-locally a limestone- at its top. Between, there are lighter dolomites in general, but lithology varies, there may be some black bands locally, and in McKelligon Canyon this interval contains a 10-inch bed of stromatolite, and surrounding limestones have yielded a rather odd silicified fauna. The entire interval contains Ceratopea hami and C. buttsi, not in succession, but in association. These species are elsewhere known only in the Arbuckle limestone of Oklahoma, where the associated fauna has not been recorded; the fauna here contains gastropods, a Euchasma, and cephalopods including Rioceras, Cyptendoceras and a Tarphyceras. The top bed contains large poorly preserved bivalved crustacea. The fauna is unique, and unfortunately as yet we cannot correlate it precisely with faunas either to the east or to the west.

The overlying 228 feet of limestone consist mainly of thin beds of calcilutite, commonly of "birdseye" lithology, some beds quite pure, some with siliceous seams, and occasional cherty intervals. 58 feet above the base is a 21-foot interval with a 2-foot massive bed of medium to dark gray limestone filled with orange weathering siliceous worm borings; another similar bed 3-5 feet below the top, while the top is a 2-foot orange-gray weathering lime mud filled with sponge cores, commonly silicified which comprises a useful horizon marker. The next 42 feet are particularly characterized by lenses of gastropods, cephalopods, and have yielded some graptolites. Fibrous macluritid opercula occur above, and 100 feet below the top is a thin bedded interval of 7 feet with abundant trilobite fragments, including Pseudocybele. The top 35 feet are massive, cliff-forming, with abundant red weathering chert.

Faunal evidence is yet insufficient for the precise correlations one might wish. The Ceratopea ankylosa fauna can be recognized as Cotter to the east, but we cannot place it precisely in relation to more western sections. The C. buttsi-hami fauna is of limited correlative value as yet, for we know these forms elsewhere only in Oklahoma, and the associated fauna there is not recorded. In the overlying limestones the fauna yielded has been one of Cassinian aspect, similar to that of the Fort Cassin, and the Smithville. There can be no question but that this is the equivalent of zone I of Utah, but zone H may also be represented either in the lower limestones or in the underlying dolomite faunas.

FLORIDA MOUNTAINS FORMATION

This consists of the top 36 feet of the El Paso at the Scenic drive. It is chert-free, but is lithically variable, containing some conspicuous orange-weathering silty layers, calcarenites, and two intervals of thin pure calcilutites in shale.

The fauna is a large one, with trilobites of the genera (but distinct species) of zone J, Buttsoceras Michelinoceras, Baltoceratidae and Protocycloceratidae, brachiopods include Diparalasma and Hesperonomia, which also occur earlier, but in addition, Tritoechia and Syntrophopsis appear. Sponges are rare. The horizon has yielded crinoids and cystids, and (Cooper, personal communication) a starfish, possibly the oldest so far known.

There can be no question but that this fauna has its equivalent in zone J of the Utah sections, and is latest Cassinian. To the east, we can correlate it with the Odenville which has many similar things, and less certainly with the Black Rock, the Providence Island, and in eastern Quebec, the Correy and Basswood Creek limestones.

In the El Paso group the Florida interval is known from three regions. In the Florida Mountains the calcarenited have calcilutites between them instead of orange-weathering silty dolomitic beds. The lithology at El Paso has been outlined above. At Beach Mountain the beds are mainly yellow-weathering lime muds.

POST-EL PASO EROSION

Uplift, accompanied by warping and gentle folding followed El Paso deposition, and subsequent peneplanation beveled the El Paso surface to varying depths. At El Paso the Florida formation is present at the Scenic Drive and at the mouth of McKelligon Canyon. At the head of McKelligon Canyon the top of the El Paso lies 150 feet lower, in the upper fourth of the Scenic Drive formation. On Ranger Peak the top of the El Paso lies about a hundred feet below the top of the McKelligon formation, but due west, in Nameless Canyon, the top is high in the Scenic Drive formation.

We know the Florida beds only at El Paso, the Florida Mountains, and at Beach Mountain. To the west only the lower fourth of the McKelligon formation is retained in the Hatchet Mountains and at Round Valley; at Dos Cabezas in Arizona the Victorio formation constitutes the highest beds, and at Clifton and Morenci the highest beds preserved are in the Cooks formation. Farther west, no El Paso has been found in Arizona.

Northward thinning is as significant. At Cable Canyon the highest beds are high in the McKelligon formation; at Mud Springs Mountain only the base of that unit is preserved, and in the San Mateo Mountains only 75 feet of the Gasconadian Sierrite limestone are preserved, between the Bliss and the basal Montoya.

There is similar northward thinning in the San Andres Mountains; at Rhodes Canyon the top of the El Paso lies in the higher Demingian; at Sly Gap only the Lower Canadian Sierrite limestone is retained.

There is a lithic, faunal and zonal accord between the El Paso of New Mexico and the Manitou of Colorado, suggesting that the now-discrete deposits were laid down in a sea continuous over these regions. The Manitou shows, shortly above the Apheoorthis melita zone, the fauna of the first endoceroid zone, and 80 feet higher the fauna of the first piloceroid zone is found. There are indications (most sections are eroded deeply) of the second piloceroid zone in the Mosquito Range. Further, the Manitou, though locally dolomitized, is very like the El Paso, particularly as developed in the eastern sections, as the Sacramento Mountains of New Mexico and the Hueco Mountains of Texas. No similar accord is evident between the El Paso and the Arbuckle of Oklahoma. An imperfect accord is found between the El Paso and the succession of the Ibex area. Lower zone D there equates with the Big Hatchet formation; in upper D are found two reefs with the fauna of the first endoceroid zone, which can be traced even into central Nevada. The first piloceroid fauna is found in zone E, but does not extend into Nevada. Higher beds for some distance show no close accord, but unquestionably zone I is represented in the upper Scenic Drive formation, and zone J, of the Wahwah limestone equates with the Florida Mountains formation.

The beveling at the top of the El Paso, when projected north, and west, not only removed the El Paso, but in northern New Mexico, must have eaten deeply into the Precambrian surface. The absence of early Paleozoic in northern New Mexico is the result of repeated periods of uplift and erosion, of which this is the first clearly demonstrable, though it is suspected that an earlier one occurred in Trempealeauan time.

Dating the erosion interval is yet not very precise. It is unquestionably materially older than Second Value deposition, which equates with the Red River, and less precisely with the Cobourg and Eden. On the El Paso surface are earlier erosion remnants of sandy beds which the writer would tentatively equate with the Harding of Colorado and the lower Winnipeg of Manitoba. Such beds, difficult to date precisely, probably belong in the early Mohawkian. It must be considered that the El Paso surface may well 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, though that is not too close; it is Juaboceras of the Juab limestone of western Utah. So many surprises have come to light in cephalopod ranges that Whiterock equivalence is suggested, but is far from proved.

MONTOYA GROUP

The Montoya is dominantly a dolomite, massive and cliff-forming. Only recently (Kelley and Silver, 1952) it was raised to group status and its divisions, which are quite distinctive, were treated as formations. Unfortunately, we have a superfluity of names. A generalized section of the Montoya is shown in Figure 4.

The divisions in New Mexico may be briefly summarized as follows: (1) unnamed remnants, probable Harding equivalents; (2) Second Value, generally massive beds, cliff-forming; 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 in some places), which may have some chert, most conspicuously in 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 consists of dark dolomites with conspicuous bands of chert; and (4) the Cutter–Raven consists of dominantly light gray, noncherty dolomite.

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

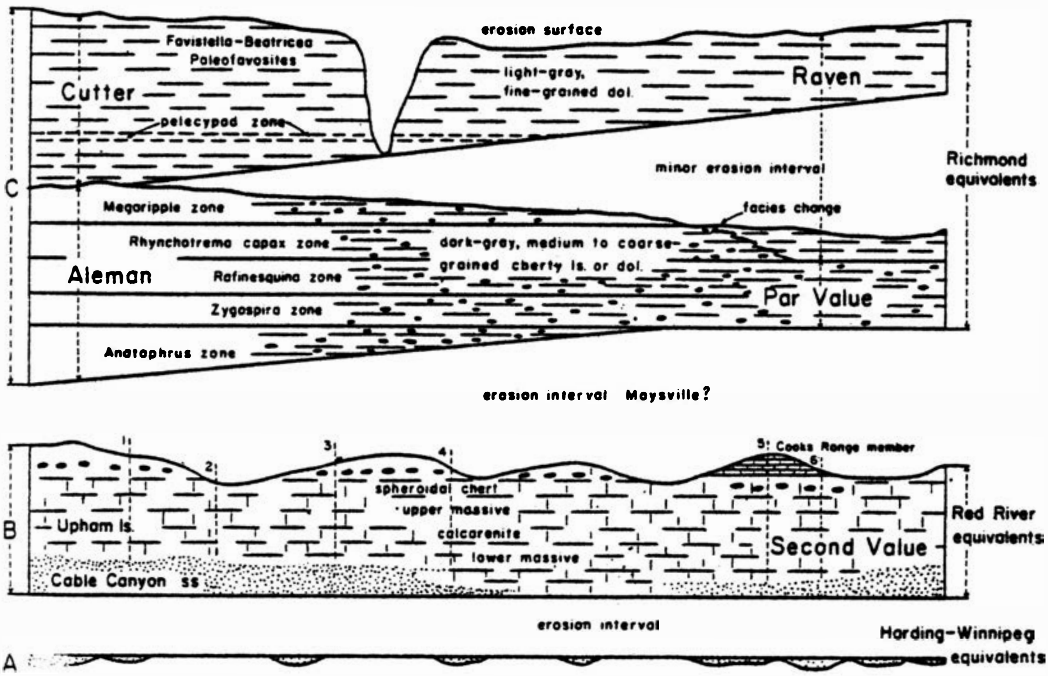

FIGURE 4

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

fossils and also, though less reliably, by lithology. There was minor elevation and erosion following Aleman deposition, and the succeeding Cutter–Raven shows evidence of onlap deposition from southeast to north and west.

This brief history is a part of a pattern of physical events which prevail over a surprisingly wide area, as shown in Figure 5. The Harding deposition, dated as approximately Black River in age, was widespread; it includes 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

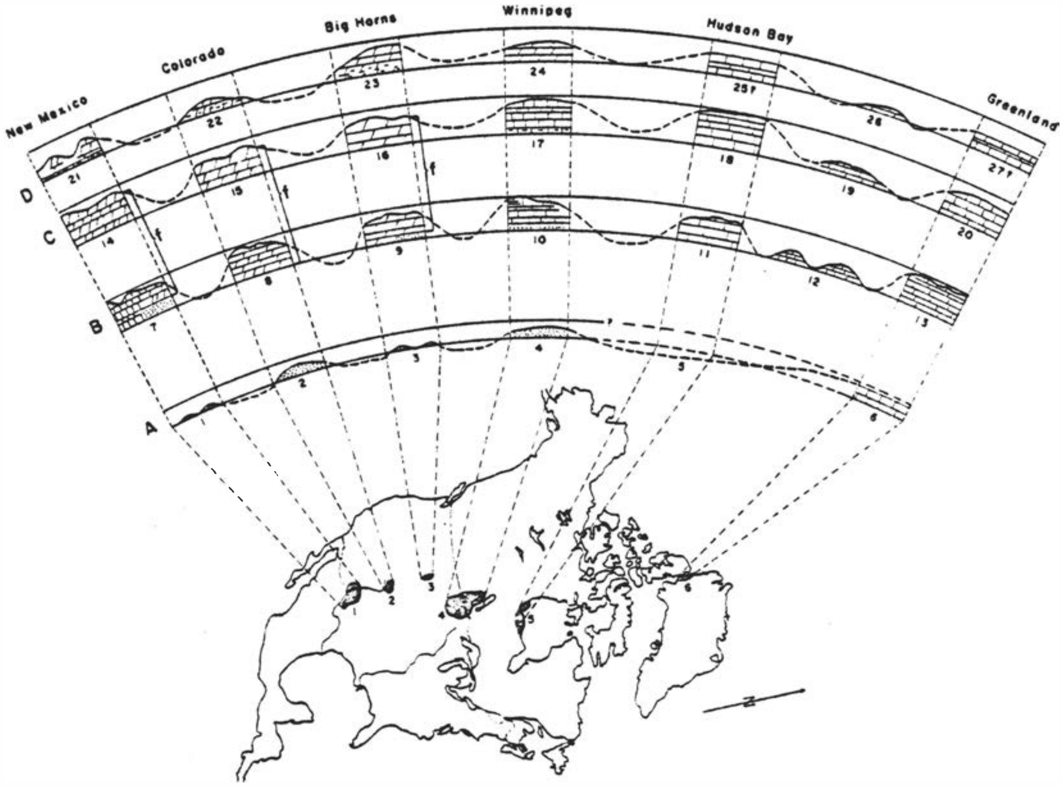

FIGURE 5

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

pattern suggesting beveling of a depressed basin prior to later (Red River) deposition. 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. On the west side of Hudson Bay, no corresponding deposits are known, and the suggestion of our diagram, that the Gonioceras Bay limestone and the Troedsson Cliff limestone are equivalents in northern Greenland, is necessarily inferrential. What is clear is that subsequent uplift and erosion reduced this deposit to remnants preserved in discrete basins.

A second period of deposition brought in marine deposits in Red River time. Where these are not too altered to dolomite they show a general massive structure, poorly bedded, with vermicular markings, though there is of course wide variation. The Upham dolomite in New Mexico is massive and vermicular, particularly in its lower part, and duplicates, except in its darker color, the type of deposition found in the Selkirk facies of the Red River formation. The fauna is general, with large _Receptaculites_, large gastropods and cephalopods, large corals, and though species are different, it is much the same fauna from New Mexico to Greenland. Evidence of a break in deposition at the close of this interval is supplied by the Second Value of New Mexico in uneven thickness and removal of upper units in the thinner sections. Where dolomitization is advanced, the lithic and faunal boundaries between this and the overlying unit may be obscured; this is true of some New Mexico sections of the Montoya and is the general condition in the Fremont and Bighorn groups. The Winnipeg area largely escaped dolomitization and here again the contact is clear. Here also, subsurface work has shown the presence of evaporites, presumably restricted seas developed at the close of deposition, and again suggest possible emergence for a significant interval of time. On the west side of Hudson Bay is the Nelson limestone, for which Nelson (1963) recently proposed a new nomenclature, calling it the _Bad Cache_ group.

In the arctic archipelago, similar beds and similar faunas are known from quite a number of localities, the most important of which, because they have been most closely studied, are on Baffin Island. The Cape Calhoun formation of Greenland contains a Red River fauna, but it contains beds both older and younger, not differentiated by the necessarily hurried collecting from which its fauna is known. Inclusion of older beds is suggested by _Vaginoceras_ and _Gonioceras_ and Black River species groups of _Actinoceras_. Koch proposed separating lower beds as the Troedsson Cliff formation, but not enough is known about ranges of some of the fossils to permit one to say whether this interval was the sole source of some of these seemingly older faunal elements. Certainly higher beds of the Cape Calhoun are materially younger than the Red River.

Early Richmond deposition was again general over the region, with the reservation that it may have begun in late Maysville time. Here the Aleman is distinct from beds below in some sections, but, as mentioned above, fused with them by dolomitization in others. The same fusion is general in the Fremont of Colorado and the Bighorn of Wyoming. Reasonable equivalents in Manitoba are found in the Stony Mountain formation. A logical extension is into the Shamattawa limestone (Churchill group) of the west side of Hudson Bay, and while possible equivalents in the arctic are less clear, there are reasonable equivalents in at least the Akpatok Island section and in the upper part of the Cape Calhoun of Greenland.

For some time it seemed likely that deposition was generally continuous from early to late Richmond, but the New Mexico sections show clear evidence of a minor depositional break, with some erosion. This break must have occurred in Liberty or early Whitewater time. The final phase of Ordovician deposition is here the Raven-Cutter; these are light beds with at least one shaly interval. Quite similar is the upper part of the Fremont limestone of Colorado, the Priest Canyon member. In the Bighorns, the Leigh member contains shaly units, but locally above it, at least, is an upper massive unit (fide Teichert). In Manitoba we find the Stonewall formation, not shaly, but a light dolomitic unit formerly placed with the Silurian. Possibly the Red Head Rapids formation of Manitoba is an equivalent. The section on Akpatok Island is thick and reasonably extends into the very late Richmond, but one cannot identify upper beds that are certainly equivalent to the units noted above. Whether there are equivalent beds at Cape Calhoun is not clear.

Oddly, the later Ordovician of all the regions shows some points in common. Many of these beds were confused with the Silurian. They are generally light-colored dolomites and tend to contain shaly zones to varying extents. There can be little question but that the Cutter-Raven is equivalent to the Priest Canyon member of the Fremont, the Leigh member of the Bighorn group (this is a shaly interval with, locally, higher massive dolomites preserved above). The Stonewall formation of Manitoba is not shaly, but is a dolomite formerly grouped with the Silurian. Farther north, divisions between early and late Richmond are less clear, but the Shamattawa limestone is replaced by the Churchill group, with, above, the Red Head Rapids formation, a fine-grained dolomite more like Silurian than Ordovician beds in lithology. A certain equivalent of these beds in the Cape Calhoun series of Greenland is not evident.

Subsequent erosion has again limited these beds; 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 wanting.

It is essential to realize that the general uniformity of pattern from New Mexico to Greenland indicates a uniformity of history, also the covering of the whole region by seas which probably left continuous deposits. Various parts of this concept can be questioned; for example, one can argue the equivalence of the units here dated with the Harding sandstone of Colorado, but evidence of erosion, indeed, 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 distinct embayments. There is good evidence for post-Red River general emergence and erosion, but it is not evident whether, as assumed in this diagram, the Red River beds were at this time completely confined to the basins in which they are now preserved.

MOHAWKIAN REMNANTS

Between the El Paso limestone and the base of the Second Value, erosion remnants of an intervening period of deposition are regarded as a probable equivalent of the Harding sandstone of Colorado. Dominantly clastic, they show some variation in aspect. In the Mimbres Valley there may be 2 to 3 feet of a white, sacharoidal 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, 14 feet of a massive dolomitic sand, full of large, sandier worm borings, are found. The same type of bed is found locally in Lone Mountain. In the Hatchet Mountains, the bed is less sandy, 12 feet thick, and shows variation in thickness being deposited on an uneven El Paso surface. Dating of these beds is not yet certain. Harding equivalence is admittedly an assumption, but a logical one. Exact equivalence of the Harding sandstone is still a problem on which there are conflicting opinions. It is not impossible that there are here remnants of more than one period of deposition, comparable to those found on the Llano uplift of Texas, but we have no evidence from the faunas to support this interpretation, and 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 limestones, generally poorly bedded, of Red River age. Basal beds are commonly but not universally a sandstone, which may vary from zero to 35 feet in thickness. The name Upham has been applied to the massive limestones, which, in many New Mexico sections, are altered to dolomite. There is here a general lithic succession of (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 chert, some scoriaceous and irregular, some forming conspicuous round nodules. Where the thickness of the Second Value is considered, it is found that the upper beds with chert nodules, with an associated horizon with silicified brachiopods commonly developed, is not universal; it is present in the thicker sections but wanting in thinner sections. Clearly, post-Second Value erosion is responsible for the removal of these upper beds by erosion in some places. The round chert nodules occur 87 to 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 wanting; in Ash Canyon where the section is 125 feet, the cherts develop at 80 to 90 feet; in the southern Franklins, the surface is uneven enough so that some sections just reach the cherty layers at 85 feet while others do not. In the Cooks Range, a 12-foot layer of white granular limestone, the Cooks Range member lies above typical Upham limestone; only a remnant of 3 inches to 2 feet of the Cooks Range member remains in the section at Lone Mountain.

The Second Value, where it is a limestone, contrasts strongly with the Aleman above, but where both show advanced dolomitization, the contact may be difficult and is sometimes impossible to place with certainty. Thus 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 Receptaculites, the large Maclurites, and a variety of large cephalopods. Such a fauna is general from New Mexico and western Texas north to Greenland, though it is preserved today as a series of isolated remnants. It is found again 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. The New Mexico exposures show how dolomitization may obscure the difference between this and overlying beds, a condition that is universal in the known outcrops of the Fremont of Colorado and the Bighorn of Wyoming. Likewise, necessarily hasty collecting, largely of materials loose at the foot of the cliff, obscured the zonation in the Cape Calhoun formation of Greenland, where certainly the Cape Calhoun contains an upper fauna with "Leptaena" unicostata of apparent Richmond age.

The age of the Red River faunas was long a problem, because many of the characteristic genera failed to penetrate eastern beds. For a long time it was argued that since relatives of these forms did penetrate the east in Richmond time, all faunas should be Richmond. However, it was also held that, since the introduction of these types was a clear case of migration, in or close to their source they might be much older than in the east. Later work brought to light Red River types in the late Trenton, particularly in Quebec, Ontario, and in the Tennessee basin, and, though less abundantly developed, in the Eden of Cincinnati. It had been known for some time that Red River types penetrated the Mississippi Valley in the Stewartville of Minnesota, even extending into the McCune of Missouri and the late Viola of Oklahoma. Furthermore, the type Red River beds are succeeded by others containing faunas of Richmond aspect. In some instances dolomitization fused Red River and overlying Richmond beds. Elevation and emergence between Red River and Richmond beds is well shown by comparison of several New Mexico sections, and subsurface work in the Williston Basin has demonstrated evaporites in the upper Red River which suggest emergence there also.

PAR VALUE-ALEMAN

This formation consists of originally rather thin-bedded limestones, dark, medium- to coarse-grained, dark gray to black, but altered in most sections to dolomite, the extent of alteration being variable. Dolomitization has obscured the bedding in some places but, particularly in the lower beds, bedding is shown by horizontal chert bands or bands of isolated chert nodules. Where dolomitization is advanced, only silicified fossils are retained; the commonest forms are the brachiopods. A definite zonation of fossils has been found in New Mexico, indicated in Figure 4, but while this is general, it is subject to some local variation.

The basal beds of the southern sections which are commonly barren, show conspicuous bands of chert; they thin northward and are wanting at Rhodes Canyon and at Mud Springs Mountain. Fossils are not silicified. The horizon has yielded an asaphid trilobite, determined by Whittington as Antaphrus, and allied forms occur in the lower Maquoketa shale of Iowa. Overlying beds, still commonly with discrete horizontal seams of chert nodules, are filled in most sections with silicified Zygospira, Dalmanella and Cornulites; less prevalent but conspicuous is a very slender ramose bryozoan, probably Bythopora. Overlying beds show cherts more massive, with those of successive layers joined and fused into irregular masses; this horizon is dominated by large Rafinesquina. An overlying bed, barren in some sections, has yielded, mainly in the Franklin Mountains, a significant coral assemblage; it is developed again at Lone Mountain but is not known in the areas between. Here the commonest form is Paleophyllum thomi. Overlying beds show a larger fauna, with Rhynchotrema capax common, but with a host of genera, including Platystrophia, Strophomena, and a host of orthoids. To the south, this zone thickens and is probably capable of further subdivision; there, the lower beds commonly yield a host of bryozoa. The highest bed to the north and east shows conspicuous megaripples and has yielded only a very sparse fauna; possibly it is wanting in some sections to the south, but in others it is apparently represented by an extension with some variation of the Rhynchotrema capax zone. For some time it was doubtful whether the Aleman was eroded prior to the deposition of the next unit, but recently some anomalously thin sections, with upper faunas wanting, suggest that such erosion was real.

The R. capax zone of the Aleman suggests the Vaureal of Anticosti and the Waynesville of the Cincinnati section. The lower beds below it contain faunas with long-ranging types; 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 demonstrably early Richmond; the deposition may have begun in late Maysville time.

RAVEN-CUTTER-VALMONT

Succeeding the Aleman are dolomites differing in finer graining, light gray color, and generally light weathering and showing a decline of chert. The lower beds may contain chert but in the form of small (1 inch to 2 inches) smoothly rounded nodules, contrasting with the sharply irregular masses found in the Aleman below. In higher beds chert is sparse or wanting; commonly, upper beds contain vugs lined with quartz crystal. We have three names for this general lithic unit; the Raven of Entwistle, the Cutter of Kelley and Silver, and the Valmont of Pray. The Cutter is largely barren of fossils, but they occur. Most conspicuous are one to three zones in the middle or upper part characterized by silicified corals, mainly Paleofavosites. A soft, nonresistant siltstone persists in eastern sections. It occurs 32 to 40 feet above the base in Hembrillo Canyon, at 23 feet in Rhodes Canyon, and at 9 feet at Nakaye Mountain. It is the basal unit of the Cutter at Mud Springs Mountain. It has yielded pelecypods and brachiopods, appears to be a single horizon, and suggests onlap of the Cutter from southeast to northwest. It is largely in beds below this interval, where they exist, that the spheroidal cherts are found. In the Rio Grande Valley from Mud Springs Mountain to Nakaye Mountain, there are two persistent, thin but conspicuous, ledge-forming, blue-weathering limestones a little above the silty pelecypod zone.

The Cutter fauna suggests a late Richmond age, in general, within the limits of the Whitewater, Saluda, and Elkhorn of the Cincinnati arch. It is the apparent equivalent of the upper Priest Canyon member of the Fremont, the Leigh member of the Bighorn group, the Stonewall of Manitoba, and the upper beds included in the Shamattawa limestone of Hudson Bay, extending northeast to Akpatok Island. Certain equivalents elsewhere in the arctic have not been demonstrated but may well exist. Oddly, these beds, when taken together, show several similar features. They are dolomites, generally light-colored and fine-grained; they have shaly zones from which the fossils weather; in this they contrast strongly with the dolomites with which they are generally associated. Oddly, also, they have been mistaken for Silurian strata to varying extents. 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, it appears that upper beds of the Aleman may become lighter in color and have been identified with the Cutter.

SILURIAN

FUSSELMAN DOLOMITE

For the Silurian rocks of New Mexico, we have as yet only one formation name, the Fusselman dolomite. The dolomites are massive, generally dark and dark weathering, with silicified fossils, and with conspicuous chert in places. Reports of thickness show wide variation; almost certainly the extreme thickness reported in the Florida Mountains is the result of thrusting of the formation upon itself.

Dolomitization is general and has altered original lithologies and destroyed most fossils that are not silicified; these facts have undoubtedly been largely responsible for failure thus far to recognize significant divisions or to permit 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 seemingly simple of our long-recognized formations that has not yielded such results.

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 is known to be eroded to varying depths, the youngest of these deposits, originally containing these corals, has been destroyed completely.

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 also range up into the Clinton if not into the Lockport. However, these fossils may be Alexandrian; they are certainly from lower beds, and largely from beds somewhat lighter than the regular Fusselman, and coarser-textured.

Reports of large pentameroid brachiopods range from listing of Pentamerus and Conchidium. Rather oddly, the most prevalent forms seem to belong to neither of these genera but to Virgiana and are close to the northern Virginiana decussata. This form is a zone marker throughout the north-central Silurian and is succeeded by beds with Leperditia hisingeri fabulina and Pterinea occidentalis, which in turn are succeeded by the Discosorus-Huronia faunas. These faunas are certainly Clinton in age, and early rather than late Clinton. The Virgiana beds have been variously considered as the base of the Clinton or the top of the Alexandrian. As yet, difficulties in removing specimens result in very incomplete collections for the Fusselman, and beyond what has been noted here, no faunal zonation is yet established. A subsurface core from eastern New Mexico yielded true Pentamerus. The Fusselman may be regarded as probably containing 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, however, of Salina or Cayuga beds, Upper Silurian*

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* Upper Silurian is a term at present ambiguous. It now appears that the beds we have been calling late Middle Silurian, notably the Guelph and Port Byron, have their British equivalents, in part at least, of the Upper Silurian of the type section. What adjustments will be made are anybody's guess.

DEVONIAN

The Devonian of New Mexico is dominantly a shale, forming slopes on which 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 commonly thinner; at Whiskey Canyon in the Mud Springs Mountains, there is a 5-foot covered interval between Ordovician and Pennsylvanian; Devonian may even be wanting 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, deposition was believed to be simple, and only one formation, the Percha shale, was recognized. Vexingly, closer study has shown that the depositional history was far from simple, and six formations have been currently recognized, to which might be added two more, the Canutillo of the Franklin 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 again in the Canutillo formation. Unfortunately, the faunas are dominated by brachiopods and other nondescript types, the use of which in correlation is complicated by the fact that records, descriptions, and illustrations of western Devonian faunas in general have lagged far behind discoveries. Happily, 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 Sly Gap formation above by the predominance of silty rather than shaly beds, a generally more resistant aspect, and an odd and very different fauna. Stevenson cited a Leiorhynchus and Sulcoretopora anomalotruncata, one of the few readily recognized bryozoa consisting of flat strands which bifurcate regularly. Stevenson also mentioned Spirifer cf. acuminatus from Hayes Gap; this is (fide Cooper) instead related to the Ithaca species Spirifer mesastrialis.

The Onate of the San Andres and Sacramento mountains was considered as terminating at the top of a resistant, orange-weathering siltstone, but the writer has found silty and clay shales above for as much as 18 feet, though the thickness of this interval varies rapidly locally, suggesting erosion of the Onate surface prior to Sly Gap deposition.

It is to the Onate rather than the Sly Gap that the shaly beds of the Caballo Mountains are to be attributed; here at the base are a few feet of argillaceous limestone with Ambocoelia and Chonetes, shales above, commonly weathering to clay, with some gypsum locally, with a characteristic large Atrypa, Schizophoria, Warenella, and a few other brachiopods. It is these beds at Mud Springs Mountain that have yielded the receptaculitid, properly Sphaerospongia with Sulcoretopora. At Hermosa, lower limestones are well developed, with Chonotes cf. aurora and a varied brachiopod fauna, including Hypothyridina; above are clay shales with the Warenella fauna, and still higher Sulcoretopora is found. Here the contact with the overlying Sly Gap is marked by a 4 inch limonitic band.

The age relationships of the Onate involve also questions of conflicting interpretations elsewhere, as whether the Tully limestone and its equivalents are properly Middle or Upper Devonian. Chonetes aurora is a species of the lower (Tinkers Falls) member of the Tully limestone; Hypothyridina makes its first and only appearance in New York in the overlying Apulia member. One is tempted to suggest that the Warenella is allied to "Spirifer laevis" of the Sherburne of New York, but this may be based on superficial resemblances. The S. mesastrialis appears in New York in the middle (West Brook member), of the Ithaca shale. On the other hand, the upper Onate of the Sly Gap section has yielded Rhipidomella cf. vanuxemia, a Hamilton species, but one found again in the recurrent Hamilton fauna of the West Brook member of the Tully limestone. The Onate can be placed within the limits of either very late Devonian or earliest Upper Devonian.

The thickness of the Onate varies widely in the type section, it is approximately 65 feet thick; about 10 feet of shale at the top belongs to the Sly Gap. At Sly Gap, the lower 9 feet attributed to the Sly Gap below the Mocgea beds belong with the Onate, and at Rhodes Canyon, lower dominantly silty beds of 32 feet and a variable amount of shale above, but up to 17 feet belong in the Onate.

SLY GAP FORMATION

This interval consists of shales with limy bands and nodules. At the type section, it consists of 40 feet; there are 37 feet at Rhodes Canyon; other sections are thinner. Together with the Onate below, 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) and is allied to the Independence shale of Iowa. It is early but not earliest Upper Devonian. It has yielded Manticoceras. It is generally wanting in the Caballos, is present in only one small part of Mud Springs Mountain, is wanting at Chise, and appears again at Hermosa. Present distribution is influenced by 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 Mountain to Hermosa.

There is some facies and faunal change in the Sly Gap formation. Exposures near Indian Wells, near Alamogordo show mainly tan-weathering silty beds with a sparse but varied brachiopod fauna. A few miles south, beds are shalier and blacker, yielding a smaller fauna. At Sly Gap and at Rhodes Canyon, the shales are gray and contain many limestone nodules; here one finds Atrypa abundant, a genus uncommon at Indian Wells, with a large and varied brachiopod fauna, some corals, and Mollusca, which are best developed in the upper limy beds. At Mud Springs Mountain and at Hermosa, the fauna is smaller and less varied, with Atrypa and Thomasaria the commonest forms.

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 Contadero at Rhodes Canyon consists of 45 feet of shaly beds, 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 which contain an abundant and distinctive brachiopod fauna; at the very top is a 3-foot hard limestone, nodular, weathering bluish, which at this locality is largely barren.

At Sly Gap the basal beds of the Contadero are similar, showing 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 yields mostly large solitary corals (Stevenson seems to have mistakenly attributed to this the abundant colonial forms that occur in numbers at the top of the Sly Gap), but one colonial form was found. Another foot of calcareous siltstone with the Contadero fauna may occur above, but in places this bed is wanting.

The Contadero fauna is in the process of study by Cooper and Dutro. It is probably Chemung in age.

The fauna of the Contadero includes abundant Hystricina, a small fimbriate Spirifer, several stropheodontids, a large Camarotoechia, and abundant small Ambocoelia and has yielded several genera of pelecypods, a gastropod fragment, and unidentifiable small, smooth, orthoconic cephalopods. Some difficulty has possibly arisen from collecting of specimens weathered from the Contadero on the Sly Gap surface, leading to the idea that the Contadero and Sly Gap faunas had much in common.

THOROUGHGOOD FORMATION

This consists of the top 10 to 12 feet of the Devonian section at Sly Gap; thickness varies slightly within the outcrop. It consists dominantly of tan-weathering, light-gray sandstones and siltstones, varying in hardness and calcareous content. The basal layers (the fish bed of Stevenson—our material contains no fish remains) have phosphatic black nodules that 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 Leiorrhynchus cf. mesacostalis of the Three Forks (the species is from the "Ithaca and Chemung" of New York), as figured by Raymond, and a Spirifer, 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 to 11 inch remnant of this formation is present in Rhodes Canyon and has yielded the same Cyrtospirifer.

RHODES CANYON FORMATION

This name was proposed for 73.5 feet of shale in the Rhodes Canyon section lying on a remnant of the Thoroughgood formation, 2 to 11 inches thick, which in turn lies on the Contadero. The shales are largely fissile with some siltstones, dominantly gray, and finely micaceous. The section is as follows:

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

E. 10 feet— dominantly silty shales with several beds of soft calcareous siltstone; it yields a brachiopod fauna with conspicuous productids, Athyris, and a Leiorhynchus.

D. 20 feet- dominantly fissile noncalcareous shales with ½ inch to ¼ inch widely spaced siltstones. Very sparse fauna.

C. 8 inches- fissile shales, paper thin, light gray to white, finely micaceous, slightly calcareous, with a considerable brachiopod fauna, including a Camarotoechia resembling C. sobrina.

B. 6 feet- shales, darker gray, moderately silty.

A. 3 feet- 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 that Stainbrook ascribed to the Percha. My collections have been on loan to Washington for some years and are not immediately available for review. Cooper (fide litt.) considered this a fauna of possible Three Forks age.

PERCHA SHALE

The Percha shale consists of 184 feet at the type locality (Stevenson, 1945) with 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 in some places are so close as to constitute layers of nodular limestone with shaly partings. The general lithic succession is widespread, though with some variation in the extent of lime in the upper part.

Names have been applied. Keyes proposed the Silver shale for the lower fissile shales and the Bella member for the upper calcareous part. Stevenson proposed the Ready Pay member for the lower fissile shales and the Box member for the upper part. It is misleading to speak of a Percha fauna; rather 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. Equivalent beds with 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) placed it only a little higher than the Three Forks shale, but Cooper placed it considerably above that interval and would now regard it as possibly latest 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 occupied 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.

Again, the Sly Gap, and to a lesser extent the Onate, shows a facies change to darker and more fissile shale from Mud Springs Mountain to Hermosa. A further change to a perfectly black fissile shale at Hillsboro, 22 miles to the south, the type section of the Percha, is not unreasonable. A reported Manticoceras (specimen lost) from the Percha at Silver City would also support this interpretation.

On the other hand, fissile dark shales lie unconformably on the Onate-Sly Gap, with an erosion surface between; at Mud Springs 15 feet of such shale lie above the Sly Gap; at Chise, about 100 feet lie on the Onate, with the Sly Gap wanting; at Hermosa, 137 feet lie above the Sly Gap. These 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 at least the Bella-Box member.

In the extreme southwestern part of the state, near Portal, Arizona, the Devonian consists of black shales below like those of the Silver-Ready Pay member but above are calcarenites with a long-winged Spirifer. This Cooper (in Sabins, 1957) considered of probable Chemung age. The writer has found similar long-winged 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, black shales of the Devonian grade up into limy beds with a different fauna, as yet undescribed and not precisely dated.

It should be noted that 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), and in the east Pharciceras in the Tully limestone and Ponticeras 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) 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 place it slightly higher in the same zone, and House recognized in the Chonopectus sandstone of Missouri forms assignable either to the Clymenia or the Wocklumeria zone.

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

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