Stratigraphic Nomenclature of Cambrian and Lower Ordovician Rocks of Easternmost Southern Arizona and Adjacent Westernmost New Mexico

GEOLOGICAL SURVEY BULLETIN 1372–B

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By PHILIP T. HAYES

CONTRIBUTIONS TO STRATIGRAPHY

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The areal extent is expanded for four stratigraphic units and restricted for one unit, and one term is abandoned

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 72-600143

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 25 cents
Stock Number 2401-2183

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STRATIGRAPHIC NOMENCLATURE OF CAMBRIAN AND LOWER ORDOVICIAN ROCKS OF EASTERNMOST SOUTHERN ARIZONA AND ADJACENT WESTERNMOST NEW MEXICO

By PHILIP T. HAYES

ABSTRACT

The Bolsa Quartzite and overlying Abrigo Formation, both of Cambrian age, have become firmly established in all but easternmost southern Arizona as the basic stratigraphic units of the oldest depositional sequence of the Paleozoic. The Bliss Sandstone of Cambrian and Ordovician age and the overlying El Paso Limestone of Early Ordovician age have become similarly firmly established in southern New Mexico east of long 108°45′ W. as the basic units of the oldest depositional sequence of the Paleozoic there. Terminology in the intervening area, where the Arizona and New Mexico sequences merge, has not been uniform.

In the southwestern part of this intervening area, where Cambrian rocks typical of the Bolsa Quartzite and the Abrigo Formation are overlain by Ordovician rocks typical of the El Paso Limestone, all these terms are usable. Farther to the north and east the Bolsa has largely lapped out, and all of the Abrigo except the uppermost part has merged into a sandstone sequence. I recommend that the sandstone sequence be referred to the Coronado Sandstone, that the overlying carbonate sequence, here of uppermost Cambrian and Early Ordovician age, be referred to the El Paso Limestone, and that the term Longfellow Limestone be abandoned. I also recommend that the dolomitized equivalents of the top member of the type Abrigo, the Copper Queen Limestone Member, be referred to the Copper Queen Member of the Abrigo wherever preserved.

INTRODUCTION

In 1904, Ransome named the basal two formations of the Paleozoic sequence in the Mule Mountains of southeastern Arizona (loc. 65, fig. 1) the Bolsa Quartzite and the overlying Abrigo Limestone, both of Cambrian age. In the same year, Richardson (1904) named the basal two formations of the Paleozoic sequence in the Franklin Mountains of extreme western Texas (loc. 45, fig. 1)

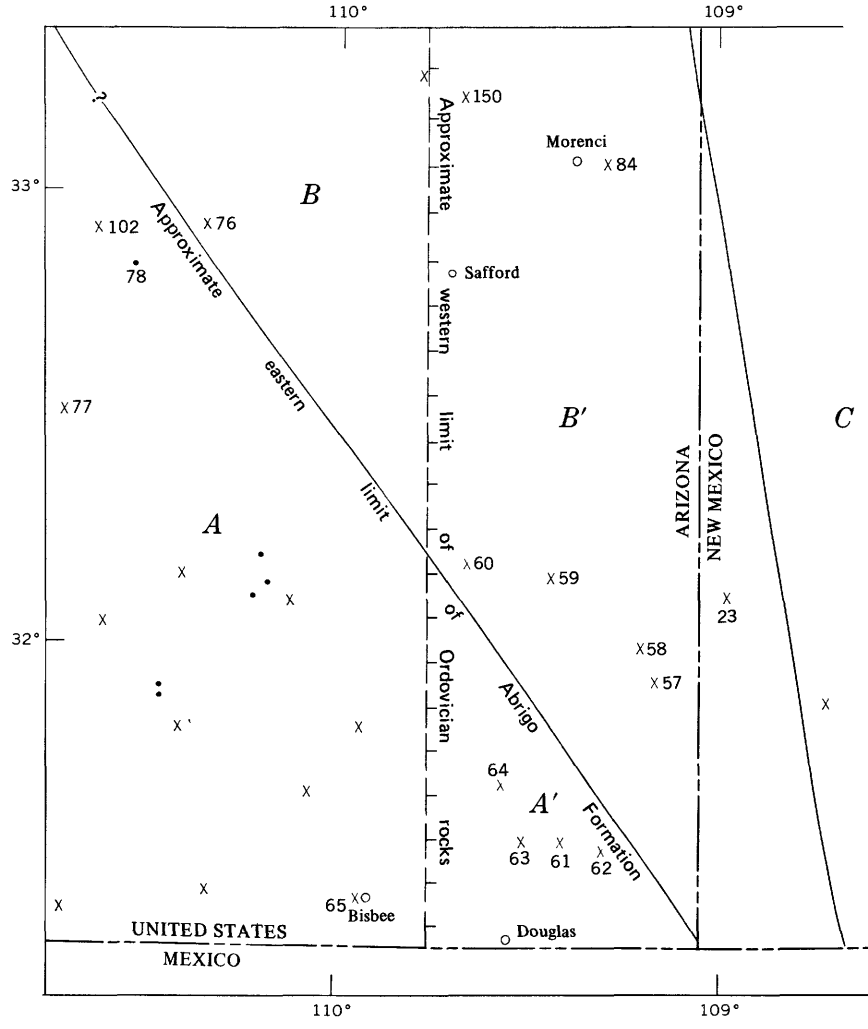
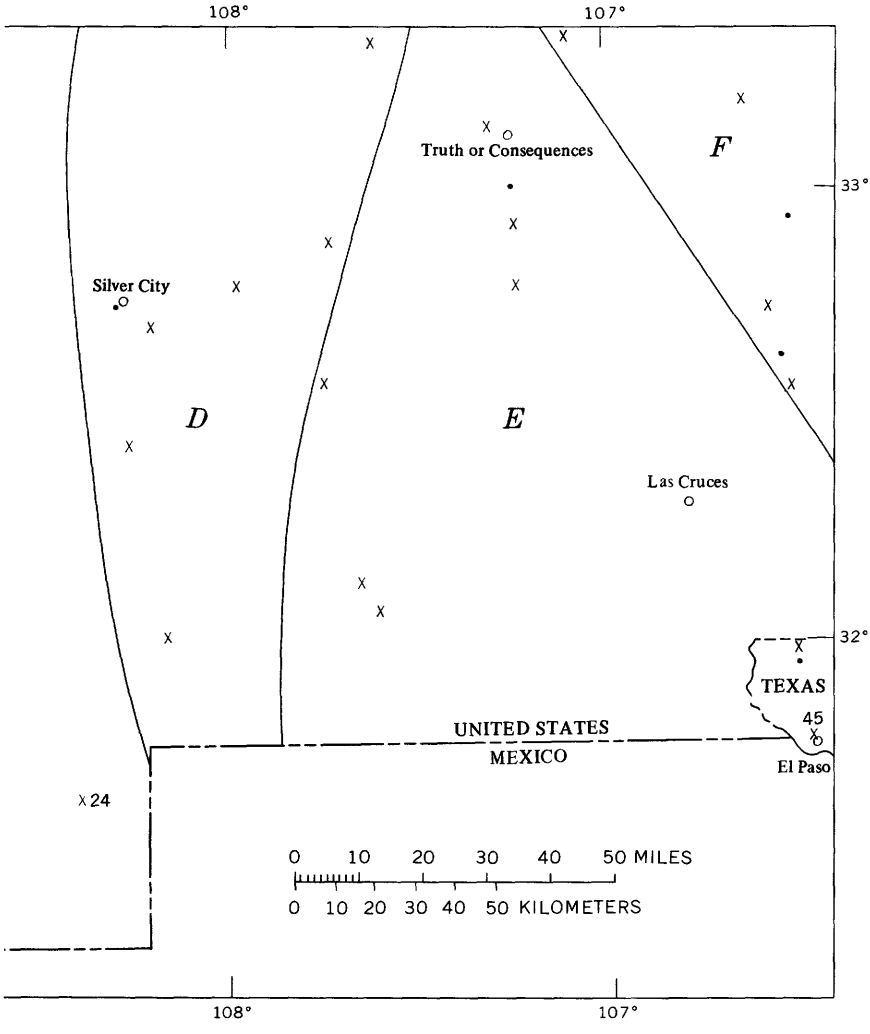


FIGURE 1. — Map of southeastern Arizona, southwestern New Mexico, and extreme western Texas, showing Cambrian and Lower Ordovician localities examined (×) or reported in literature (•) and approximate positions of some facies boundaries (solid lines). Large capital letters refer to areas discussed in text. Numbers refer to localities mentioned in text; see list on facing page.

the Bliss Sandstone and the overlying El Paso Limestone, which were respectively assigned Cambrian and Ordovician ages. A year later, Lindgren (1905) named the basal two formations of the Paleozoic in the Morenci area, near the east edge of Arizona (loc. 84, fig. 1), the Coronado Quartzite and the Longfellow Lime-



23. Peloncillo Mountains
24. Big Hatchet Mountains
45. Franklin Mountains
57, 58, 59. Chiricahua Mountains
60. Dos Cabezas Mountains
61, 62. Pedregosa Mountains
63, 64. Swisshelm Mountains
65. Mule Mountains
76. Aravaipa area
77. Santa Catalina Mountains
78. Galiuro Mountains
84. Morenci area
102. Galiuro Mountains
150. Nantac Rim

stone, which also were respectively assigned Cambrian and Ordovician ages. The names Bolsa and Abrigo have since been applied to Cambrian rocks in numerous isolated areas of southern Arizona and — with expectable minor revisions in boundaries, refinements

of age assignments, and subdivisions into local formally and informally named members — have become firmly established and almost universally accepted as the basic unit names for Cambrian rocks in all but easternmost southern Arizona. Similarly, the names Bliss and El Paso have been applied to Upper Cambrian and Lower Ordovician rocks in numerous isolated areas in southern New Mexico and far-western Texas and — with similar revising, refining, and subdividing — have become firmly established and almost universally accepted as the basic unit names for outcropping Upper Cambrian and Lower Ordovician rocks east of about long 108°45′ W. in southern New Mexico and far-western Texas.[1] There has been no such uniformity of nomenclature for the Cambrian and Ordovician rocks that crop out at various localities in the intervening area. In this intervening area the terms Coronado Quartzite and Longfellow Limestone have been applied only in their immediate type area in the Morenci vicinity. In the Dos Cabezas Mountains (loc. 60, fig. 1), Jones and Bacheller (1953) used the names Bolsa and Abrigo even though the Abrigo was recognized as being partly of Ordovician age. In the Chiricahua (locs. 57–59, fig. 1) and Peloncillo Mountains (loc. 23, fig. 1), Sabins (1957a, b) and Gillerman (1958), respectively, used the names Bolsa and El Paso even though the El Paso rocks were recognized as being partly of Cambrian age. In the Swisshelm and Pedregosa Mountains (locs. 61–64, fig. 1), Epis and Gilbert (1957) and Epis (1958) divided the sequence, in ascending order, into the Bolsa, the Abrigo, and two unnamed units of Cambrian age and the El Paso Limestone of Ordovician age. Although Epis and Gilbert contributed greatly to an understanding of stratigraphic relations across the region, the nomenclature problem has remained unresolved.

The purpose of this paper is to propose a standard nomenclature for the problem area (areas *A′*, *B*, and *B′* in fig. 1) of southeasternmost Arizona and southwesternmost New Mexico. The rocks and some of their lateral facies changes in the areas to the east and west are described first; then the lithologic and stratigraphic relations of the rocks of the problem area are briefly reviewed; and, finally, the probable relations of the rocks of the problem area to the rocks to the east and west are discussed. I draw heavily on the large body of data that has previously been published on the region, as well as on the data I accumulated in

[1]As originally defined by Richardson (1904), the El Paso included all Ordovician rocks at the type locality. Later he revised the El Paso to include only the Lower Ordovician rocks and included all later Ordovician rocks in his Montoya Limestone (Richardson, 1908). It is in its revised sense that the El Paso has been used so extensively.

having examined these rocks at nearly 50 localities in the region, including 13 localities in the problem area. A diagrammatic section (fig. 2) shows the interpreted stratigraphic relations and recommended nomenclature in the parts of Arizona and New Mexico under discussion.

STRATIGRAPHY

BOLSA QUARTZITE AND ABRIGO FORMATION IN ALL BUT EASTERNMOST SOUTHERN ARIZONA

The lithology, age, subdivisions, and correlations of the Bolsa Quartzite and Abrigo Formation in much of southeastern Arizona have been recently reviewed by Krieger (1968c) and briefly summarized by Lochman-Balk (1971), and the following descriptions are adapted in part from their excellent papers.

BOLSA QUARTZITE

The Bolsa Quartzite, 344 feet thick at its type section (Hayes and Landis, 1965) in the Mule Mountains (loc. 65, fig. 1), ranges in thickness from a little more than 30 m (100 ft) to about 150 m (500 ft) in areas *A* and *A'* shown in figure 1. Though the thickness varies locally owing to some relief on the underlying Precambrian surface, regionally it tends to be greater in the southern part of the region. In the southern part of the region the Bolsa lies on older Precambrian schists and granitic rocks; in the northern part of the region it lies on younger Precambrian sedimentary rocks, some of which formerly were occasionally confused with the Bolsa (Krieger, 1961). The Bolsa consists almost entirely of quartzitic siliceous sandstone. From base to top the sandstone decreases in grain size and feldspar content from commonly conglomeratic and somewhat feldspathic in the lower part to fine grained and very sparsely feldspathic in the upper part; commonly a few thin interbeds of siltstone and mudstone occur near the top. The Bolsa grades, generally rather abruptly, upward into the Abrigo Formation. It contains virtually no diagnostic fossils, but its age is considered to be Middle Cambrian by virtue of its transitional relations with the overlying Abrigo whose basal part is known to be Middle Cambrian. Regional correlations suggest that the age of the top of the Bolsa may decrease slightly from west to east across areas *A* and *A'* shown in figure 1. (See also fig. 2.)

ABRIGO FORMATION

The Abrigo Limestone at its type locality,[2] as described by Hayes and Landis (1965), comprises four members: in ascending

[2]Called Abrigo Formation except near its type locality.

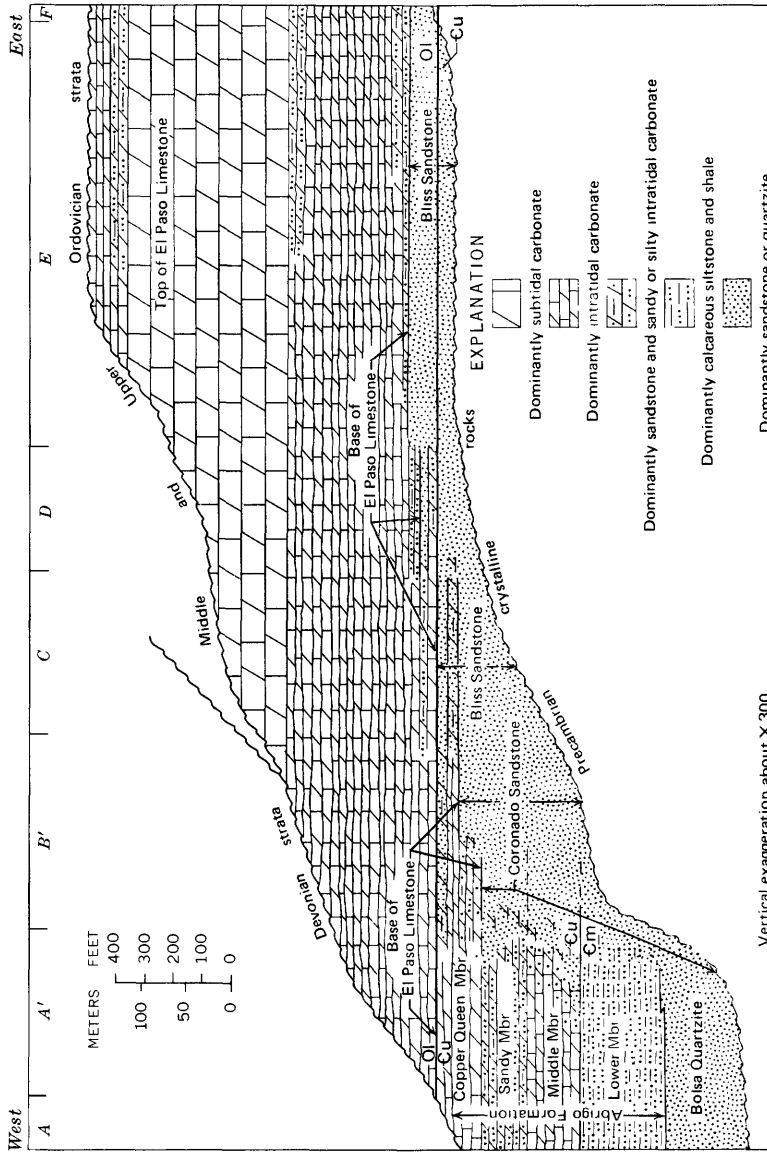


FIGURE 2.—Diagrammatic stratigraphic cross section of Middle (Cm) and Upper (Cu) Cambrian and Lower Ordovician (Ol) rocks between the area of the type Bolsa Quartzite and Abrigo Formation (left) and the area of the type Bliss Sandstone and El Paso Limestone (right). The letters at top indicate the positions of the lettered areas shown in figure 1. Thicknesses of individual units are only approximate between the ends of the section, and the positions of the lower and upper unconformities are depicted so as to show the near maximum Cambrian and Lower Ordovician section within each lettered zone.

order, the shaly member, the ribbed limestone member, the sandy member, and the Copper Queen Limestone Member. Each member can be widely correlated in southeastern Arizona, but because most members change lithologically across the region, Krieger (1968c) used the terms lower and middle members for the shaly and ribbed limestone members and combined the sandy and Copper Queen Limestone members into a single upper member, which she recognized is at least locally divisible into lower and upper parts. I agree that the terms lower and middle are more appropriate for regional use and are accordingly used here. Because I believe that her upper member is everywhere divisible into two parts where the upper part has not been removed by erosion and because I further believe that the upper part is of special stratigraphic significance, I will here continue to use the term sandy member for the lower part of Krieger's upper member and propose that the name Copper Queen Member be applied to the upper part on a regional basis. The lower, middle, sandy, and Copper Queen are described individually in the following paragraphs.

LOWER MEMBER

Within the region designated by *A* and *A'* in figure 1, the lower member of the Abrigo generally ranges in thickness from 75 to 135 m (250–450 ft), the thickest sections being toward the west. The member is characterized by predominant relatively fine grained clastic rocks, such as siltstone and mudstone or shale; but thin beds of sandstone are not uncommon, especially near the base; and thin beds of dolomite or limestone are generally common, especially in the upper part. Northward and eastward the amount and coarseness of sandstone seem to increase. The upper contact is fairly abrupt at most localities, but it appears to be conformable at all localities. Various parts of the member have yielded fossils, chiefly trilobites, at several localities, and all these fossils indicate a Middle Cambrian age. On the basis of regional correlations I believe that the top of the member is very nearly the same age throughout the region under discussion.

MIDDLE MEMBER

The middle member of the Abrigo, within the region designated by *A* and *A'* in figure 1, generally ranges in thickness from about 45 to 90 m (150–300 ft). In the southern part of the region the member is made up almost entirely of very thin-bedded carbonate, usually limestone, that is marked by abundant silty bands that characteristically stand out in relief on the outcrop. Farther north the lower part of the member contains one or more beds of resistant sandstone at the base, and in the Santa Catalina Mountains

(loc. 77, fig. 1) the sandstone at the base of the member is particularly conspicuous and has been separately designated as the Southern Belle Member (Creasey, 1967).[3] Still farther northward, such as in the northern Galiuro Mountains (loc. 102, fig. 1), the middle member is made up almost entirely of sandstone but can be recognized by its stratigraphic position between the more regionally uniform lower and sandy members. Fossils, chiefly trilobites, from the carbonate facies of the member indicate that it is almost entirely of early Late Cambrian (Dresbach) age; only the basal beds may, at least locally, be of Middle Cambrian age.

SANDY MEMBER

Where completely preserved within the region designated by *A* and *A'* in figure 1, the sandy member ranges in thickness from 13½ to 54 m (45–180 ft). At several localities in the western part of the region its top and the overlying Copper Queen Member were presumably removed by pre-Upper Devonian erosion, and in some of these localities only a few meters of the sandy member remains. The member is everywhere characterized by interbedded brown-weathering glauconitic crossbedded sandy dolomite and dolomitic sandstone that at many localities display remarkable chip conglomerate beds. Eastward the member seems to become more sandy and less dolomitic. Fossils in the member indicate an early Late Cambrian (Dresbach) age.

COPPER QUEEN MEMBER

In area *A* (fig. 1) the Copper Queen Member of the Abrigo is missing, probably owing to pre-Devonian erosion, in most western sections and is less than 30 m (100 ft) thick elsewhere; in area *A'* (fig. 1), however, it is completely preserved and apparently ranges in thickness from 36 to 54 m (120–180 ft). At the type section of the Abrigo, in the Mule Mountains (loc. 65, fig. 1), the only mountain range in which the Copper Queen has heretofore been recognized, the Copper Queen consists mostly of thin-bedded limestone interbedded with a few thin layers of sandy or argillaceous limestone. In most other mountain ranges in areas *A* and *A'* the member consists dominantly of thin-bedded dolomite interbedded with minor sandy layers. Fossils that have been found in the member indicate a late Late Cambrian (Franconia) age, but to my knowledge fossils have not been found in the upper part of the member, at localities where it seems to be most completely preserved. The upper part, thus, could be of latest

[3]Named the Southern Belle Quartzite and recognized as a distinct formation by Stoyanow (1936).

Late Cambrian (Trempealeau) age. In area *A* (fig. 1) the Copper Queen is disconformably overlain by Upper Devonian rocks. In area A′, discussed in more detail under "Cambrian and Ordovician Rocks of Arizona–New Mexico Border Area," it is conformably overlain by Ordovician strata.

BLISS SANDSTONE AND EL PASO SANDSTONE EAST OF LONG 108° 45′ W.

The regional stratigraphy of the Bliss Sandstone and El Paso Limestone in southwestern New Mexico has been described most recently by Kottlowski (1963), who concentrated mostly on lithologic characteristics, and by Flower (1969), who added considerably to knowledge of the regional distribution of faunal zones and of the lithologic character of subdivisions based on these zones. Flower (1959, 1969) suggested that because the age of the Bliss in its type section is uncertain and because the Bliss contains beds of both Cambrian and Ordovician ages in some areas, a "readjustment of formational names may be required when the age of the Bliss is definitely established." Certainly a much better knowledge of the age of various parts of the Bliss in various areas would be highly desirable; and if and when that knowledge becomes available, the formation should, if possible, be divided into lithologic members of distinct ages. For decades, however, the name Bliss has been usefully applied to the dominantly sandstone sequence that underlies the El Paso Limestone, regardless of age, and that usefulness will remain. Flower (1964) has also proposed elevation of the El Paso to group status and has proposed many formational divisions. These divisions are useful faunal zones, and some are lithologically distinctive; but herein the El Paso is more conveniently described as a single formational unit.

BLISS SANDSTONE

In the southern part of the region that comprises areas *C*, *D*, *E*, and *F* (fig. 1), the Bliss Sandstone ranges in thickness from about 30 to 90 m (100–300 ft) in most sections, and in the northern part of that region it ranges in thickness from a few meters to about 45 m (150 ft). Variations in thickness are due partly to irregularities on the underlying Precambrian surface and partly to a general northward thinning and eventual pinchout not far north of the area shown. In areas *E* and *F* the Bliss consists predominantly of sandstone; but toward the north, oolitic hematite is fairly common, and thin carbonate units are present. The sandstones of the Bliss are commonly glauconitic and hematitic and generally are less thoroughly cemented than those of the Bolsa Quartzite. In area *D* the upper part of the Bliss contains considerable thin-bedded, usually silty, carbonate that is very similar

to carbonate in the basal part of the overlying El Paso Limestone. In that area, the Bliss–El Paso contact is arbitrary but has generally been placed at the top of the highest conspicuous noncalcareous or nondolomitic sandstone (fig. 2). In area *C* the lower part of the Bliss contains much dolomite, and the upper part, as used by Zeller (1965) in the Big Hatchet Mountains (loc. 24, fig. 1), contains no nondolomitic sandstone. If Zeller had followed the practice generally employed to the east, he probably would have included the upper part of his Bliss in the basal El Paso. As noted by Flower (1969), details of the age of the Bliss at many localities are uncertain owing to the general sparsity of diagnostic fossils. However, the available faunal evidence and the lithologic correlations clearly indicate, despite the presence of depositional breaks within the formation at various localities (Flower, 1969; Lochman-Balk, 1971), that in general both the base and the top of the Bliss are progressively older from east to west. Throughout most, or all, of the areas *D* and *E* the lower part of the Bliss is of late Late Cambrian age and the upper part is of earliest Early Ordovician age. In area *F* the entire Bliss may be of Ordovician age. Conversely, in area *C*, rocks of Bliss lithology may be entirely of Cambrian age, although unfossiliferous sandy dolomites and dolomitic sandstones included in the upper part of the Bliss by Zeller (1965) are likely Ordovician.

EL PASO LIMESTONE

The El Paso Limestone, nearly 500 m (1,600 ft) thick at its type locality in the Franklin Mountains (loc. 45, fig. 1), thins both northward and westward, primarily owing to Middle Ordovician erosion on top. Although the El Paso is made up largely of limestone, all sections contain some dolomite, and some sections are almost completely dolomitized. The basal beds of the formation, which are of variable thickness, are sandy and (or) silty, and they grade upward into beds which almost everywhere consist of nearly pure carbonate but which in some places contain chert. In the thicker sections toward the south there are higher sandy horizons and many variations in the texture and bedding of the carbonates, but these higher sandy horizons are not of importance to the present discussion. Throughout areas *C, D, E,* and *F* (fig. 1) the El Paso is of Early Ordovician (Canadian) age, and in area *C* its base may very nearly coincide with the base of the Ordovician. Wherever exposed in areas *C, D, E,* and *F,* the El Paso is disconformably overlain by the Montoya Group of Middle and Late Ordovician age.

CAMBRIAN AND ORDOVICIAN ROCKS OF ARIZONA – NEW MEXICO BORDER AREA

SWISSHELM AND PEDREGOSA MOUNTAINS

Epis and Gilbert (1957) and Epis (1958) described the Cambrian and Ordovician rocks at several localities in the structurally complex Pedregosa and Swisshelm Mountains, which are in area *A'* (fig. 1), and they correlated their sections with sections in areas *A* and *B'* (fig. 1). I have examined all their localities, and although most localities are difficult to study because of structural complications, steep dip slopes, or poor exposures, I believe that these investigators correctly interpreted the sequence and described it well. A section in the northern Swisshelm Mountains (loc. 64, fig. 1) is best exposed and least disturbed and therefore is most reliably measured and described. This section as largely remeasured by me is briefly described in the following paragraphs.

At the base of the Paleozoic in the northern Swisshelm Mountains is about 90 m (300 ft) of quartzite that Epis and Gilbert (1957) assigned to the Bolsa Quartzite and correlated with the Bolsa of the Mule Mountains (loc. 65, fig. 1). I fully concur with them.

Above the Bolsa is 132 m (434 ft) (390 ft as measured by Epis and Gilbert, 1957) of rock that Epis and Gilbert (1957) assigned to the Abrigo Formation. Rock in the lower 90 m (295 ft) of this sequence is dominantly siltstone and mudstone interbedded with minor sandstone and carbonate, and it unquestionably is assignable to the lower member of the Abrigo as it is known to the west. The upper 42 m (139 ft) of rock assigned to the Abrigo by Epis and Gilbert (1957) is thin-bedded limestone which yields fossils of Dresbach age and which is undoubtedly assignable to the middle member of the Abrigo as it is used to the west.

Next above is 54.5 m (180 ft) (measured as 195 ft by Epis and Gilbert, 1957) of brown-weathering dolomitic sandstone which in the upper part is interbedded with much sandy dolomite. This unit was informally referred to as "Upper Cambrian sandstone" by Epis and Gilbert (1957), who compared it to the Bliss Sandstone and correlated it with the sandstone high in the Abrigo of the Mule Mountains (loc. 65, fig. 1). Krieger (1968c) referred the unit to the lower part of her upper member of the Abrigo. These correlations are undoubtedly correct, and the Upper Cambrian sandstone unit of Epis and Gilbert (1957) unquestionably represents the sandy member of the Abrigo as used in areas to the west.

Above the sandy member in the northern Swisshelm Mountains is 68 m (223 ft) (measured as 235 ft by Epis and Gilbert, 1957)

of thin- to thick-bedded dolomite containing sandy layers in the basal 45 m (148 ft) and containing lenses of white chert in the upper part of an upper, 23-m-thick (75-ft) nonsandy unit. Beds near the base of the lower, 45-m-thick interval yielded species of *Billingsella* of late Late Cambrian (Franconia) age. The upper, 23-m-thick nonsandy unit is apparently barren of fossils. The entire 68-m-thick interval was left unnamed by Epis and Gilbert (1957) but was assigned to the Cambrian by them. Both the lithology of the rock and the presence of *Billingsella* clearly indicate that at least the lower 45 m of the interval represents the Copper Queen Member of the Abrigo in areas to the west and can properly be given that designation here. The barren 23-m-thick chert-bearing dolomite at the top is conformably overlain by limestones that have yielded Ordovician fossils, and I tentatively conclude that this 23-m-thick interval, though dolomitized, is more similar to the overlying Ordovician beds than to the underlying Cambrian beds.

Epis and Gilbert (1957) measured 225 feet of limestone that contains Ordovician gastropods and cephalopods, and they reasonably assigned the beds to the El Paso Limestone. If the underlying 23-m-thick (75-ft) unit of barren dolomite is also assigned to the El Paso — as I think proper — then the El Paso at this locality is about 90 m (300 ft) thick. The El Paso is disconformably overlain by Upper Devonian beds.

MORENCI AREA

The Cambrian and Ordovician strata of the Morenci area (loc. 84, fig. 1) were divided by Lindgren (1905) into the Coronado Quartzite of Cambrian age and the Longfellow Limestone of assigned Ordovician age. With the permission of the Phelps Dodge Co., I examined the Coronado Quartzite in the Morenci pit area and, with the assistance of George C. Cone, remeasured the Longfellow Limestone 6 km (3¾ miles) east of Morenci along the San Francisco River.

The Coronado, 74 m (243 ft) thick as measured by Lindgren (1905) where we viewed it southwest of Morenci, is made up dominantly of rather resistant siliceous sandstone. Some conglomerate is interbedded near its unconformable basal contact with Precambrian diorite, and some shale is interbedded in the upper part. To my knowledge, no closely diagnostic fossils have yet been found in the Coronado, though it has yielded linguloid brachiopods.

The Longfellow Limestone as measured by us consists from base to top of:

(1) 12.8 m (42 ft) of sandy grayish-red dolomite;
(2) 9.1 m (30 ft) of fine-grained brownish-gray dolomite;
(3) 4.2 m (14 ft) of interbedded sandy and nonsandy dolomite;
(4) 8.2 m (27 ft) of cliff-forming dolomitic quartz sandstone;
(5) 36.5 m (120 ft) of laminated to cross-laminated dolomite which has minor slightly sandy layers and which has yielded Early Ordovician fossils from its upper half;
(6) 24.7 m (81 ft) of relatively thick bedded dolomite;
(7) 18 m (59 ft) of indistinctly bedded saccharoidal dolomite; and
(8) 4.5 m (15 ft) of medium-dark-gray dolomitic crinoidal limestone that appears to be disconformable at the base and top.

On the basis of the lithologic correlations with distant sections to the southeast and south and a fossil-bearing section I recently measured about 40 km (25 miles) to the northwest (loc. 150, fig. 1), the lower four units, or 34.3 m (113 ft), of the Longfellow here — that is, to the top of the resistant sandstone ledge — are probably of Cambrian age. The remaining part except unit 8, or the top 4.5 m (15 ft), is probably of Early Ordovician age. The top 4.5 m is undoubtedly the unit from which Hill (1959) identified corals of approximate Trenton age, and it almost certainly represents the basal beds of the Second Value Dolomite of the Montoya Group as it is known in southwestern New Mexico.

For the following reasons, I propose that the term Longfellow Limestone be abandoned: The term has never been used outside the Morenci vicinity; the formation as originally defined includes beds of Trenton age at the top that almost certainly are separated by a major disconformity from the beds below; and the lower 113.5 m (373 ft) of beds are similar in age and lithology to the lower 100 m or so of the El Paso Limestone as it is used in the nearest sections to the south and southeast. The medium-dark-gray limestone at the top should be referred to the Second Value Dolomite, and the remainder of the formation, to the El Paso Limestone. The lower four units, or 34.3 m (113 ft), of rocks of probable Cambrian age could properly be distinguished as a separate member. Although the term Coronado Quartzite has not previously been used outside the Morenci area, its original definition still appears to be valid. The term can usefully be applied to similar rocks to the south and west that lie between Precambrian rocks and the El Paso Limestone. Such rocks apparently

are a sandstone facies of the Abrigo Formation. Because in most areas the rocks included in the Coronado are dominantly sandstone rather than true quartzite, the formation is here designated the Coronado Sandstone.

DOS CABEZAS MOUNTAINS

A section of Cambrian and Ordovician strata about 3 miles west of Dos Cabezas, Ariz., was discussed by Darton (1925) and Stoyanow (1936), measured by Jones and Bacheller (1953), and further discussed by Sabins (1957b) and Epis and Gilbert (1957); more recently the rocks there and in the nearby Chiricahua Mountains were discussed by Krieger (1968c). With the assistance of George C. Cone, I remeasured the section near Dos Cabezas, and I generally concur with the correlations by Epis and Gilbert (1957) and Krieger (1968c).

As described by Jones and Bacheller (1953) and Sabins (1957b), the Cambrian and Ordovician rocks near Dos Cabezas (loc. 60, fig. 1) are divisible into two principal conformable lithologic units of approximately the same thickness: a lower, sandstone unit of Cambrian age and an upper, carbonate unit of Cambrian and Ordovician age. Regardless of how various parts of these units may correlate with rocks of other areas, the two units as recognized by those workers are obvious ones that any field geologist would normally select for mapping.

The lower unit, which unconformably overlies Precambrian schist, was called the Bolsa Quartzite both by Jones and Bacheller (1953) and by Sabins (1957b); and the upper unit, which is disconformably overlain by Upper Devonian shale, was called the Abrigo Limestone by Jones and Bacheller and the El Paso Limestone by Sabins.

The upper, carbonate unit as remeasured by us is 89.9 m (295 ft) thick and consists from base to top of:

(1) 24.4 m (80 ft) of cross-laminated sandy dolomite and dolomitic sandstone;
(2) 13.7 m (45 ft) of medium-gray dolomite with scattered sandy stringers;
(3) 6.4 m (21 ft) of very sandy dolomite and dolomitic sandstone like that at the base;
(4) 26.8 m (88 ft) of medium-gray dolomite that contains scattered sandy layers and silt-filled burrows; and
(5) 18.6 m (61 ft) of medium-gray dolomite which contains chert stringers and lenses and which has yielded fossils of Early Ordovician age from the upper part.

On the basis of the fossils found in this section and lithologic correlation with sections in other areas, the top two units, or

45.4 m (149 ft), of the carbonate unit are at least partly, and probably entirely, of Ordovician age and are correlative with the El Paso Limestone; the lower three units, or 44.5 m (146 ft), of the carbonate unit are almost certainly correlative with the Copper Queen Member of the Abrigo Formation.

The lower, sandstone unit near Dos Cabezas as remeasured by us is 97.5 m (320 ft) thick and consists from base to top of:

(1) 1.8 m (6 ft) of arkosic conglomerate;
(2) 5.2 m (17 ft) of resistant siliceous feldspathic sandstone;
(3) 51 m (168 ft) of partially poorly exposed sandstone that is dolomitic in part, glauconitic in part, and siliceous in part; and
(4) 39.5 m (129 ft) of somewhat dolomitic largely cross-laminated sandstone.

The upper 39.5 m of rock is lithologically similar to the sandy member of the Abrigo Formation and, although much sandier and less dolomitic than is typical of the sandy member, is probably equivalent to it. It is also lithologically similar to and probably coeval with the Cambrian part of the Bliss Sandstone as the Bliss occurs in western New Mexico. The lower 58 m of the sandstone unit is probably equivalent to the middle member of the Abrigo and possibly in part to the lower member of the Abrigo, although it is much sandier than typical Abrigo of areas to the west. Only a few beds in the unit bear much lithologic resemblance to the Bolsa Quartzite of areas to the west, and probably no part of the unit is so old as the Bolsa as it is used to the west.

For these reasons, I believe that the 97.5-m-thick sandstone unit here is most properly assignable to the Coronado Sandstone and that the 89.9-m-thick carbonate unit can properly be assigned to the El Paso Limestone. The 44.5 m (146 ft) of partly sandy dolomite at the base of the carbonate unit could be recognized as a distinct member of the El Paso, equivalent to the Copper Queen Member of the Abrigo.

CHIRICAHUA MOUNTAINS

The Cambrian and Ordovician sequence in the northern Chiricahua Mountains (locs. 57–59, fig. 1) is similar to that of Dos Cabezas. A basal sandstone unit, mapped by Sabins (1957a) as the Bolsa Quartzite, is similar to the sandstone near Dos Cabezas that I assign to the Coronado Sandstone, but the basal sandstone of the Chiricahua Mountains is even more difficult to relate to the Abrigo lithologically than is the Coronado Sandstone near Dos Cabezas. The sandstone of the Chiricahua Mountains con-

tains glauconitic beds and, in the eastern part of the mountains, hematitic units. The glauconitic and hematitic beds give the unit a Bliss-like aspect. An upper carbonate unit in the Chiricahua Mountains, mapped by Sabins (1957a) as the El Paso Limestone, is generally thicker than the El Paso Limestone near Dos Cabezas, but is otherwise similar. The carbonate unit includes a basal sandy dolomite which has yielded *Billingsella* from one locality; this occurrence strengthens the correlation of this part of the carbonate unit with the Copper Queen Member of the Abrigo Formation.

As with the Dos Cabezas section, I believe that the basal sandstone unit should be referred to the Coronado Sandstone rather than to the Bolsa Quartzite and that the upper carbonate was properly assigned to the El Paso Limestone. Also, as near Dos Cabezas, the sandy dolomite beds of Cambrian age at the base of the El Paso could be distinguished as a member of the El Paso equivalent to the Copper Queen Member of the Abrigo.

PELONCILLO MOUNTAINS

In the central Peloncillo Mountains (loc. 23, fig. 1), Gillerman (1958) mapped and described the Cambrian and Ordovician sequence, and with the assistance of George C. Cone, I remeasured it. A 120-m-thick (396 ft) basal unit of partly glauconitic and partly hematitic sandstone that rests unconformably on Precambrian granite was assigned to the Bolsa Quartzite by Gillerman (1958). Conformably overlying that is a 168-m-thick (553 ft) carbonate unit which he referred to the El Paso Limestone and which he assigned a Cambrian and Ordovician age. Cherty limestone near the middle of the unit yielded Early Ordovician cephalopods to Gillerman (1958). Rocks in the basal 26 m (86 ft) of the carbonate formation are sandy, especially toward the top, and as noted by Gillerman (1958), they strongly resemble beds at the base of the El Paso in the Chiricahua Mountains which have yielded *Billingsella* of Late Cambrian age. Gillerman (1958, p. 24) noted about 30 m (100 ft) of very cherty dolomite at the top of the Ordovician sequence at one locality which he "referred doubtfully to the Montoya" Limestone of Middle and Late Ordovician age. I have examined this locality and am confident that it is a local cherty part of the El Paso and that the El Paso is overlain directly by Devonian shale in the central Peloncillo Mountains.

I believe that Gillerman (1958) correctly correlated the lower part of his El Paso of the Peloncillo Mountains with Cambrian beds at the base of the El Paso in the Chiricahua Mountains, and also that he properly assigned the entire carbonate unit to the

El Paso Limestone. As in the Chiricahua and Dos Cabezas area, the partly sandy dolomite beds of the basal 26 m (86 ft) could properly be distinguished as a distinctive member of the El Paso equivalent to the Copper Queen Member of the Abrigo Formation.

On the other hand, I do not believe that the Cambrian sandstone unit at the base of the sequence in the Peloncillo Mountains should be referred to the Bolsa Quartzite. Rather, it should be assigned either to the Bliss Sandstone or to the Coronado Sandstone because (1) it is lithologically more like the Bliss or Coronado than the Bolsa and (2), less significantly, the sandstone unit of the Peloncillo Mountains is at least largely an age equivalent of the Coronado or the lower part of the Bliss of areas to the east, whereas it is probably entirely younger than any of the Bolsa in most of southern Arizona. Because the Cambrian and Ordovician sequence of the Peloncillo Mountains is closer spatially and lithologically to Arizona surface sections of equivalent rocks than to other New Mexico sections, the term Coronado seems preferable to Bliss.

ARAVAIPA AREA

Several small outcrop areas of sandstone and quartzite that occur near Aravaipa (loc. 76, fig. 1) were described by Simons (1964) and included in the Bolsa Quartzite. Simons noted that the Bolsa as he used it there might include beds of Precambrian age (assignable to the Troy Quartzite). That seems to be true of the section I examined at Imperial Mountain (loc. 76). Above the probable Precambrian at Imperial Mountain, George C. Cone and I measured 59 m (194 ft) of sandstone and quartzite that is of probable Cambrian age. From lithologic comparisons with the Bolsa Quartzite and Abrigo Formation in the northern Galiuro Mountains (loc. 102, fig. 1), I believe that the Cambrian sandstone and quartzite of Imperial Mountain probably includes equivalents of both the Bolsa and the lower member of the Abrigo. This correlation, along with the impracticability of trying to separate the two units on Imperial Mountain, leads me to conclude that the Cambrian sandstones and quartzites of the Aravaipa area (and in other localities in area *B* in fig. 1) preferably should be assigned to the Coronado Sandstone (whose type locality is about 90 km (55 miles) distant) rather than to the Bolsa Quartzite (whose type locality is about 170 km (105 miles) distant).

SUMMARY OF PROPOSED NOMENCLATURAL CHANGES

ARIZONA WEST OF PROBLEM AREA

The only nomenclatural proposal for the Cambrian and Lower Ordovician rocks in Arizona in area *A* (fig. 1) is the extension

of the term Copper Queen Member of the Abrigo Formation to all places where the member is still preserved above the sandy member (fig. 2). The Copper Queen Member is absent in most western sections, but in several eastern sections, equivalent rocks of the requisite lithology have been recognized by Krieger (1968c) as the upper unit of her upper member of the Abrigo. Besides separating lithologically distinct units, the contact between the Copper Queen and underlying rocks has regional stratigraphic significance in that it very nearly coincides with the boundary between the Dresbachian and Franconian Stages of Bell, Berg, and Nelson (1956) of the Upper Cambrian. Wherever the Copper Queen Member occurs in area *A*, it is disconformably overlain by Devonian strata.

NEW MEXICO EAST OF LONG 108°45′ W.

No nomenclatural changes are recommended for the Cambrian and Ordovician rocks in New Mexico east of long 108°45′ W., but I do urge a consistent definition of the Bliss–El Paso contact in western New Mexico. There, fairly thick carbonate units occur beneath fairly thick sandstone units. Choosing as the top of the Bliss the top of the highest conspicuous nearly carbonate-free sandstone — as most geologists have done — seems reasonable and is preferable to choosing the top of a very dolomitic sandstone or a sandy dolomite, as has been done in certain areas.

THE PROBLEM AREA

SWISSHELM AND PEDREGOSA MOUNTAINS

Krieger (1968c) has correlated units informally designated by Epis and Gilbert (1957) and Epis (1958) as "Upper Cambrian sandstone" and "dolomite" with the lower and upper units, respectively, of her upper member of the Abrigo and has referred all the strata between the Bolsa Quartzite and the El Paso Limestone to the Abrigo Formation. I basically concur with her but suggest that most of the dolomite, or upper unit, can properly be referred to the Copper Queen Member of the Abrigo and that the uppermost part is assignable to the El Paso Limestone.

MORENCI AREA

The term Coronado Quartzite should be changed to Coronado Sandstone.

The term Longfellow Limestone should be abandoned. The distinctive beds of approximate Trenton age at the top of the Longfellow as originally defined by Lindgren (1905) should be assigned to the Second Value Dolomite; the remainder of the original Longfellow should now be recognized as El Paso Lime-

stone; and the sandy beds of probable Cambrian age at the base may be separated as a member equivalent in age to the Copper Queen Member of the Abrigo Formation.

PELONCILLO, CHIRICAHUA, AND DOS CABEZAS MOUNTAINS

In the Peloncillo, Chiricahua, and Dos Cabezas Mountains (locs. 23 and 57–60, fig. 1), I suggest that rocks of Cambrian age formerly assigned by Gillerman (1958) and Sabins (1957a, b) to the Bolsa Quartzite be referred instead to the Coronado Sandstone. Krieger (1968c) has suggested that in the Chiricahua Mountains, and presumably in the Dos Cabezas, these rocks be called the Abrigo Formation. Admittedly, much of the rock in the unit is a facies equivalent of much of the Abrigo, and in the Dos Cabezas Mountains at least, equivalents of specific parts of the Abrigo can be tentatively identified. Nevertheless, the rocks in this unit are so different from the Abrigo as it is generally known and so similar to the Coronado that the term Coronado seems more reasonable. The rocks near Dos Cabezas are not much sandier than the very sandy facies of the Abrigo as used by Krieger (1968a, b) in the northern Galiuro Mountains at localities 78 and 102 (fig. 1); but the latter locality is not far from other, less sandy sections of the Abrigo, and in the Galiuro Mountains, distinguishing the several members is reasonably easy. The rocks in the Dos Cabezas and Chiricahua Mountains, on the other hand, are more conveniently related to the Coronado or to the Bliss sections of New Mexico. In figure 2, the section of the Galiuro Mountains may roughly be pictured as occurring near the east edge of area *A'*, and the section at Dos Cabezas may be roughly pictured as occurring near the west edge of area *B'*.

I propose no change in the use of the term El Paso Limestone in the Peloncillo, Chiricahua, and Dos Cabezas Mountains as used by Sabins (1957a, b) and Gillerman (1958), but I do suggest that the lower, partly sandy dolomites of Cambrian age in the lower part of the formation could be recognized as a distinctive member of the El Paso which is equivalent to the Copper Queen Member of the Abrigo Formation.

ARAVAIPA AREA

Rocks assigned by Simons (1964) to the Bolsa Quartzite probably include equivalents of the Troy Quartzite of Precambrian age as well as equivalents of the Bolsa Quartzite and the lower member of the Abrigo Formation. I believe that the Cambrian rocks there preferably should be referred to the Coronado Sandstone.

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U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 471-714