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GEOLOGICAL SURVEY BULLETIN 1537–B

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By ELMER H. BALTZ *and* DONALD A. MYERS

CONTRIBUTIONS TO STRATIGRAPHY

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CONTENTS

ILLUSTRATIONS

CONTRIBUTIONS TO STRATIGRAPHY

PORVENIR FORMATION (NEW NAME)— AND OTHER REVISIONS OF NOMENCLATURE OF MISSISSIPPIAN, PENNSYLVANIAN, AND LOWER PERMIAN ROCKS, SOUTHEASTERN SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

By ELMER H. BALTZ and DONALD A. MYERS

ABSTRACT

In the Sangre de Cristo Mountains in New Mexico, Precambrian rocks are overlain at most places by thin sandstone and carbonate rocks of Mississippian age that were deposited in shallow seas on a widespread erosional surface of low relief.

The Pennsylvanian and Lower Permian rocks of this region are syntectonic deposits of the structurally deep Paleozoic Rowe-Mora basin which is now mainly the site of the Sangre de Cristo Mountains; the eastern part of the basin is in the subsurface of the Cenozoic Las Vegas basin. The mainly marine rocks of the Rowe-Mora basin thicken northward from about 2,200 ft (670 m) near Pecos to more than 6,730 ft (2,050 m) near Mora. Nonmarine arkoses and red beds of Late Pennsylvanian and Early Permian ages are locally only 300 ft (90 m) thick, but are as much as 3,000 ft (915 m) thick in the deep parts of the Rowe-Mora basin. In the southern part of the present mountains, unconformities within the section indicate that intrabasinal uplifts were recurrently active in Pennsylvanian and Early Permian time; locally, Lower Permian nonmarine rocks truncate all older sedimentary rocks and lie on the Precambrian basement.

A varied stratigraphic nomenclature has arisen for the mainly marine rocks, which were originally assigned to the Magdalena Group and were considered to be entirely Pennsylvanian. Recently completed detailed mapping and biostratigraphic studies in the Las Vegas-Mora area of the southeastern Sangre de Cristo Mountains provide a basis for recommending some adjustments and revisions of the nomenclature of the southeastern part of the mountains. This revised nomenclature retains, where possible and useful, the previous terminology, and also reflects regional classifications based on both lithologic and biostratigraphic data acquired in the last 25 years.

Pre-Pennsylvanian rocks are referred to the Espiritu Santo Formation and the overlying Tererro Formation that, together, constitute the Arroyo Peñasco Group. This group is tentatively assigned entirely to the Mississippian.

The use of the term Magdalena Group is discontinued in the southeastern part of the mountains. To the north, where mainly marine rocks of Pennsylvanian age have not been subdivided, the Magdalena Group is still in use.

The name Sandia Formation is retained for Lower and Middle Pennsylvanian rocks that consist of marine and nonmarine shale, conglomeratic sandstone, sandstone, carbonaceous to coaly shale, and thin beds of limestone. The thickness of the Sandia ranges from about 10 ft (3 m) at the south to more than 5,000 ft (1,525 m) at the north. Brachiopods from the lower part of the formation are Morrowan age; fusulinids from near the top are late Atokan age.

The Madera Limestone, or Formation, of earlier reports on this area is raised to group status. The Madera Group includes the Porvenir Formation (named here) and the overlying Alamitos Formation (name here adopted). The Porvenir Formation is the lower, gray limestone member, and the Alamitos is the upper, arkosic limestone member of the Madera Formation of former usage. The Porvenir Formation lies conformably on the Sandia Formation and is overlain disconformably, and, locally, unconformably by the Alamitos Formation.

The Porvenir Formation is mainly marine and consists of three laterally intergrading facies. At the type locality, and generally south of Sapello River, the Porvenir is mostly limestone with interbedded thin to thick gray shale and minor amounts of sandstone. North and northwest of the type section, the Porvenir is mostly gray shale that contains thick units of limestone and some thin sandstones. Northeast of the type section, near the eastern front of the mountains, the Porvenir consists of shale, limestones, sandy and oolitic limestones, and thin to thick arkosic sandstones. At the type section, the Porvenir is 1,065 ft (325 m) thick; north of the type section, the formation is about 1,615 ft (491 m) thick east of Rociada, about 1,170 ft (357 m) thick at the principal reference section northwest of Manuelitas, and about 700 ft (213 m) thick at Mora River. Fusulinids from the Porvenir are of early to late Des Moinesian age.

The Alamitos Formation is gray to greenish-gray and red-weathering silty to marly shale interbedded with arkose, conglomerate, nodular limestone, and sandy and arkosic limestone. Most of the limestone and shale and some of the sandstone is marine; some sandstones, however, probably are nonmarine fluviatile deposits. The basal part of the Alamitos is arkose and conglomerate or arkosic limestone that grades laterally into sandstone. At most places, the basal arkoses contain interbedded maroon-weathering shale. The top of the formation is mapped as the top of the highest marine beds. Thickness ranges from a feather edge at the south to more than 1,285 ft (390 m) at the north. The formation contains fusulinids of late Des Moinesian, Missourian, Virgilian, and, locally, early Wolfcampian ages.

The Alamitos is overlain with local angular unconformity by nonmarine rocks of the Sangre de Cristo Formation. The Sangre de Cristo Formation is mainly Early Permian age at the south, but, at Mora River, it also may contain beds of Late Pennsylvanian (Virgilian?) age.

INTRODUCTION

In the Sangre de Cristo Mountains of north-central New Mexico (fig. 1) rocks of Mississippian, Pennsylvanian, and Early Permian ages are exposed widely. The lithologies, ages, thickness variations, and facies of these rocks in the southern part of the mountains have been known generally since U.S. Geological Survey studies by Read and others (1944), Northrop and others (1946), and Read and Wood (1947). However, the details of stratigraphy still are not known well because

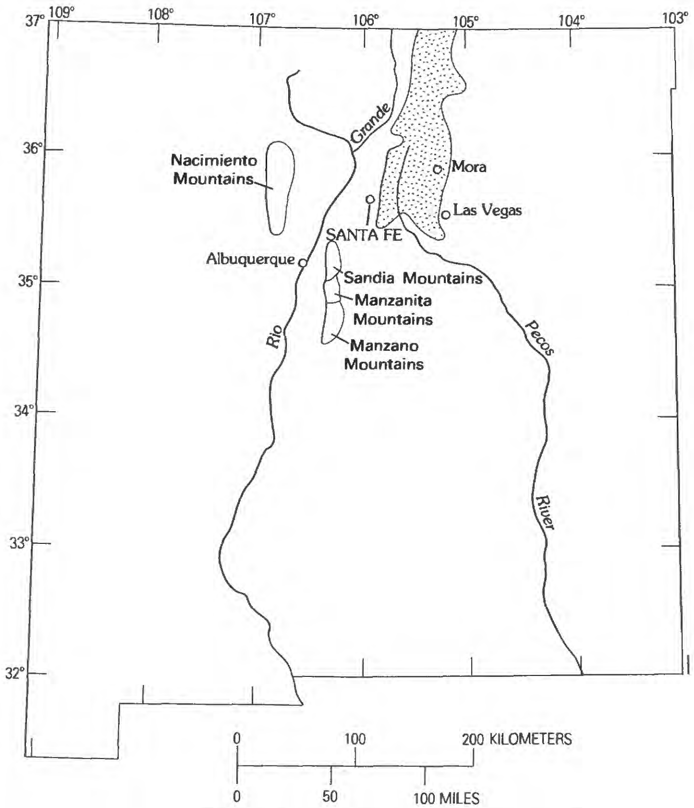


FIGURE 1.—Map of New Mexico showing location of Sangre de Cristo Mountains (stippled).

of the stratigraphic and structural complexity of the rocks and the rugged terrain that is poorly accessible.

A varied stratigraphic nomenclature has evolved, partly for the reasons just cited, and partly because of differences of approach of different investigators. Therefore, the purposes of this report are to review the history of nomenclature and to specify some adjustments and revisions of stratigraphic terminology that are consistent with recent regional geologic and paleontologic findings as well as with older work. The revised terminology of the Paleozoic rocks will be applicable to recently completed mapping by the U.S. Geological Survey in the southeastern part of the mountains.

LATE PALEOZOIC REGIONAL SETTING

Precambrian metamorphic and igneous rocks of the Sangre de Cristo Mountains are overlain at most places by generally less than 150 ft (46 m) of sandstone and carbonate rocks that are thought to be entirely of Mississippian age. These rocks were deposited in shallow seas upon a widespread erosion surface of low relief (Baltz and Read, 1960; Armstrong and Mamet, 1974).

In Early Pennsylvanian (Morrowan) time, tectonic events began to produce the basins and uplifts of the so-called Ancestral Rocky Mountains. The Pennsylvanian and Early Permian marine and nonmarine rocks of north-central New Mexico were deposited syntectonically in one of these deep structural basins—the Rowe-Mora basin (Read and Wood 1947; Brill, 1952; Baltz, 1965, 1978; Bachman, 1975; Armstrong and others, 1979). Paleozoic intrabasinal anticlinal uplifts occurred in the southern part of the Rowe-Mora basin and the adjacent Pecos shelf (Northrop and others, 1946; Read and Wood, 1947). Later, most of the Rowe-Mora basin (fig. 2) was uplifted to form the Cenozoic Sangre de Cristo Mountains; however, the eastern part of the basin is now in the subsurface of the Cenozoic Las Vegas basin east of the mountains.

The Rowe-Mora basin was bounded by major Paleozoic positive elements. At the west was an uplift, or series of uplifts, that may have been parts of the ancient Uncompahgre uplift (fig. 2). The Cañoncito uplift, which may have been part of the Uncompahgre uplift, is exposed east of Santa Fe where it has been modified by Cenozoic uplift, faulting, and erosion and incorporated with the Sangre de Cristo Mountains. At the east, in the subsurface of the Great Plains, is the ancestral Sierra Grande uplift or arch (Foster and others, 1972, p. 14–15), a major Paleozoic tectonic feature whose configurations and history are poorly understood because of the sparsity of deep drill holes in northeastern New Mexico.

The mainly marine Pennsylvanian rocks of the Rowe-Mora basin generally thicken northward. At the south, near Pecos, rocks of Morrowan through Virgilian age are about 2,200 ft (670 m) thick (Read and Wood, 1947, fig. 7). Southeast of Mora, rocks of Morrowan through Missourian age are more than 6,730 ft (2,050 m) thick (Baltz and O'Neill, 1980a). Isopachs of theoretically restored Pennsylvanian rocks indicate that the rocks might have been as much as 8,500 ft (2,590 m) thick originally in the axial part of the basin southeast of Taos prior to Cenozoic uplift and erosion of the upper part of the section (Baltz, 1965, fig. 5). This inferred thickness is consistent with known directions of thickening of various units (Baltz and Read, 1956, p. 50–51; Sutherland, 1963, fig. 10).

Pronounced east-west variations in thickness of Pennsylvanian rocks occur across the southern part of the Rowe-Mora basin and the Paleozoic Pecos shelf. Southeast of Santa Fe, Pennsylvanian rocks are locally about 300 ft (135 m) thick (Booth, 1976, 1977) on the southern part of the Paleozoic Cañoncito uplift. In the Rowe-Mora basin near

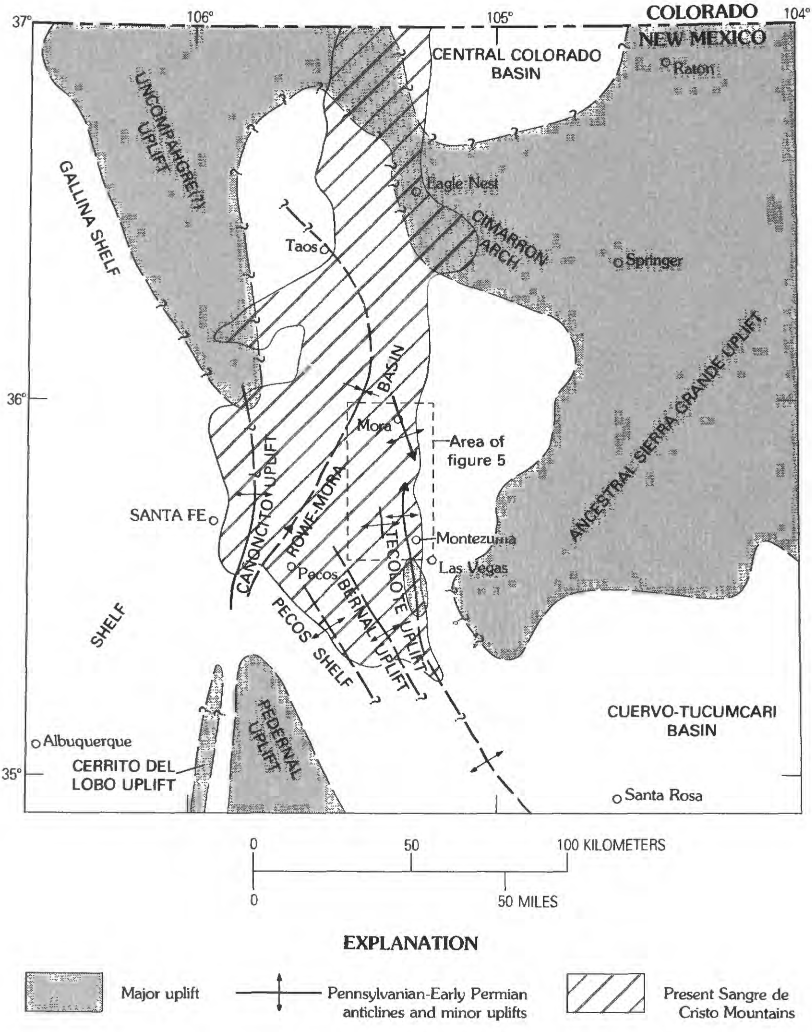


FIGURE 2.—Uplifts and sedimentary basins of Pennsylvanian and Early Permian time in part of northern New Mexico.

Pecos, the Pennsylvanian rocks are about 2,200 ft (670 m) thick, whereas on the Paleozoic Bernal uplift these rocks are locally only about 675 ft (205 m) thick. On the Paleozoic Tecolote uplift southwest of Las Vegas, the thickness ranges from locally absent at the south (Northrop and others, 1946), to about 1,000 ft (305 m) south of Montezuma. The variations in thickness and the lithologies of the Pennsylvanian rocks clearly represent recurrent episodes of Paleozoic tectonic activity in the region.

Read and others (1944) and Read and Wood (1947, p. 225) recognized that facies changes accompanied the general northward thickening of the Pennsylvanian rocks of the Sangre de Cristo Mountains. At the south, the deposits are mainly limestones, but also some shale and sandstone, that characterized the slowly subsiding, tectonically unstable Pecos shelf. To the north, in what was the deeper part of the Rowe-Mora basin, shaly rocks predominate, coarse sandstone and arkose are common, and limestone is subordinate.

Lower Permian terrestrial red beds and arkoses of the Sangre de Cristo Formation are preserved in a broad belt around the southern part of the mountains and in hogbacks along the eastern front. The Sangre de Cristo Formation generally is conformable with the underlying Pennsylvanian rocks in the central part of the Rowe-Mora basin southwest of Pecos, but locally is unconformable with the Pennsylvanian on the Cañoncito uplift, on the Bernal and Tecolote uplifts, and on the north flank of the subsurface Sierra Grande uplift. In the latter two areas, the Sangre de Cristo bevels Pennsylvanian rocks to rest on the Precambrian (Northrop and others, 1946; Read and Wood, 1947; Baltz, 1965; Foster and others, 1972). The Sangre de Cristo Formation is locally about 300 ft (90 m) thick on the southern part of the Cañoncito uplift; a short distance east, near the trough of the Rowe-Mora Basin, these rocks are more than 3,000 ft (915 m) thick (Booth, 1976, p. 37). The Sangre de Cristo Formation thins irregularly eastward across the Pecos shelf and is locally only 300–500 ft (90–150 m) thick on the Bernal and Tecolote uplifts. The formation thickens northward along the eastern front of the Sangre de Cristo Mountains and is as much as 2,700 ft (830 m) thick east of Mora. In the Mora River area, the lower part of the Sangre de Cristo contains nonmarine rocks of probable Late Pennsylvanian age, although most of the formation is Early Permian.

HISTORY OF NOMENCLATURE

PRE-PENNSYLVANIAN SEDIMENTARY ROCKS

Pre-Pennsylvanian sandstone, dolomitic limestone, limestone breccia and conglomerate, crystalline limestone, and sandy limestone lie on Precambrian basement rocks at most places in the Sangre de Cristo Mountains and at places in all the other ranges of north-central New Mexico. The pre-Pennsylvanian age of these rocks originally was not known and they were included in the basal part of the Magdalena Group of Pennsylvanian age by early investigators (Darton, 1922, 1928a) of the Sangre de Cristo Mountains. Thompson (1942, p. 19) first suggested that a thin limestone beneath Pennsylvanian rocks at

Gallinas Canyon in the eastern part of the mountains may be of middle or early Paleozoic age.

Later, these rocks continued to be classified in the Magdalena Group (fig. 3) in reports of the U.S. Geological Survey, as the lower limestone member of the Pennsylvanian Sandia Formation. Read and Wood (1947) and Northrop and others (1946) recognized that part or all of this member might be Mississippian or older, and Henbest (1946) reported the Mississippian foraminifer *Endothyra baileyi* in the lower limestone member of the Sandia at unspecified localities in the southern Sangre de Cristo Mountains.

Armstrong (1955) and Fitzsimmons, Armstrong, and Gordon (1956) described the pre-Pennsylvanian rocks in the Nacimento Mountains of northwestern New Mexico and named them the Arroyo Peñasco Formation. The upper part of the Arroyo Peñasco contains megafossils of probable Late Mississippian (Meramecian) age; identifiable megafossils were not found in the lower part (Fitzsimmons, and others, 1956, p. 1941). Armstrong (1955) extended the name Arroyo Peñasco Formation to rocks in similar stratigraphic position in the Sangre de Cristo Mountains and concluded that they were Late Mississippian, based on studies of microfossils.

Baltz and Read (1960) determined that the pre-Pennsylvanian sedimentary rocks in the Sangre de Cristo Mountains contain two distinctive lithologic units separated by an unconformity. The lower unit, consisting of a basal sandstone and overlying sandy limestone, dolomitic limestone, and chert-bearing limestone was named the Espiritu Santo Formation. The upper unit, consisting of limestone breccia, limestone conglomerate, crystalline limestone, and sandy clastic limestones was named the Tererro Formation and was subdivided into three members. No identifiable fossils were found in the Espiritu Santo Formation; it was classified as Upper Devonian(?) because of its stratigraphic position and lithologic similarity to Upper Devonian rocks of southern Colorado. The Tererro Formation was classified as Lower and Upper Mississippian mainly on the basis of a scanty brachiopod fauna.

Sutherland (1963) recognized the Espiritu Santo and Tererro Formations in the south-central part of the Sangre de Cristos, and also noted the unconformable relation of the two formations. He separated the basal sandstone from the Espiritu Santo and named it the Del Padre Sandstone. Sutherland noted that no identifiable fossils had been discovered in the Del Padre or in the overlying carbonate rocks of the Espiritu Santo, and he concluded (1963, p. 25–26) that the age of the Del Padre and Espiritu Santo is unknown, but presumably Paleozoic. He classified the Tererro as Late Mississippian, probably Meramecian, because of its microfossils.

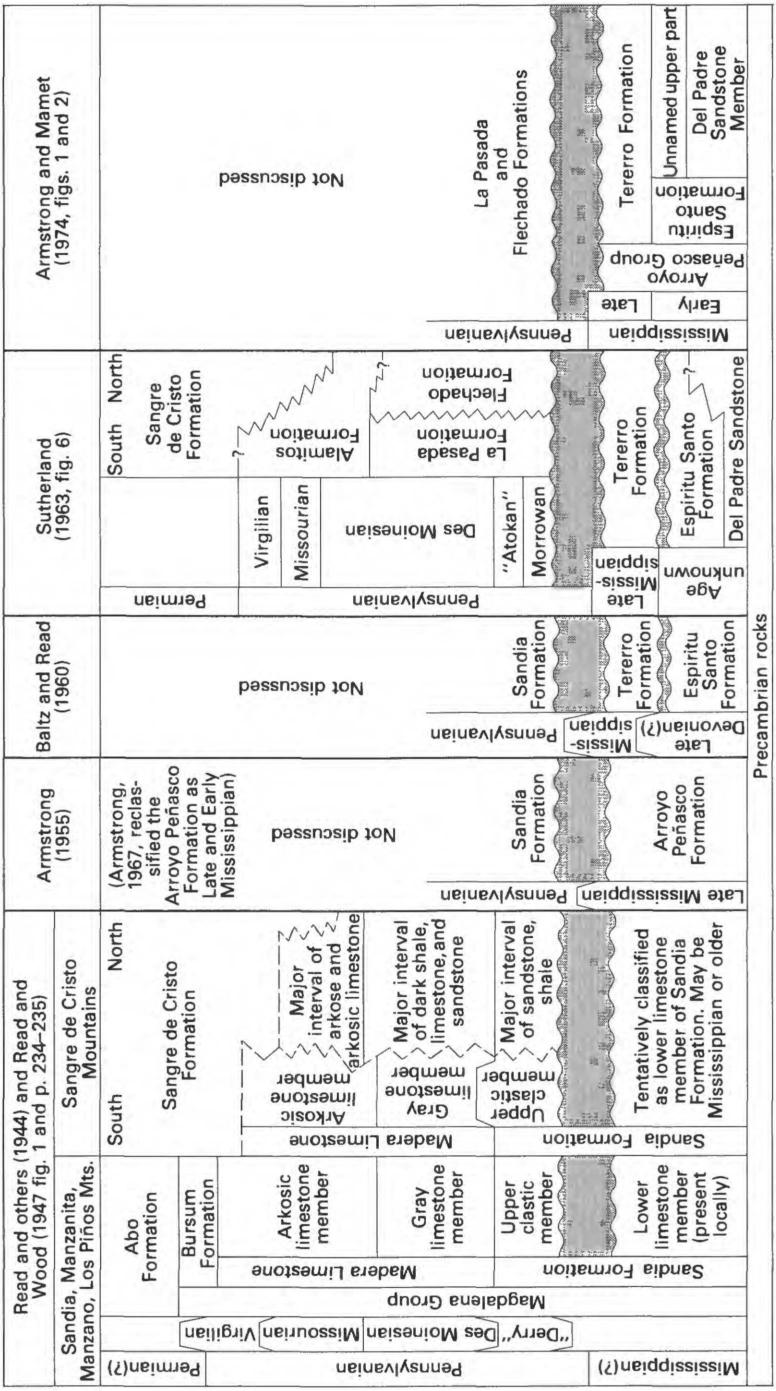


FIGURE 3.—Historical summary of age assignments and nomenclature of Mississippian, Pennsylvanian, and Lower Permian rocks of central New Mexico (left-hand column) and southern Sangre de Cristo Mountains, New Mexico (remainder of diagram).

Armstrong (1967) continued to include all the pre-Pennsylvanian sedimentary rocks in the Arroyo Peñasco Formation, but he reported Early Mississippian microfossils in the lower part of the formation in the Sangre de Cristo Mountains and classified the entire sequence as Mississippian. Later, Armstrong and Mamet (1974) accepted the Tererro and Espiritu Santo Formations and extended these terms through a wide region in northern New Mexico. They reclassified Sutherland's Del Padre Sandstone as the basal member of the Espiritu Santo Formation, and, on the basis of microfossils, classified the Espiritu Santo as Early Mississippian (Osagean) and the Tererro as Late Mississippian (Meramecian and Chesterian). They raised the term Arroyo Peñasco to group status to include both the Espiritu Santo and Tererro Formations.

PENNSYLVANIAN AND LOWER PERMIAN ROCKS

The first geologic map of the Sangre de Cristo Mountains in Colorado and New Mexico was published by Stevenson (1881) to accompany his classic summary report on the geology of this region. He summarized the previous scanty observations of the Pennsylvanian rocks, published a composite stratigraphic section of these rocks in the Mora-Sapello area of New Mexico, and gave lists of Pennsylvanian fossils. He referred to the rocks only as "the Carboniferous rocks."

The term "Sangre de Cristo conglomerate" was the first name applied to the Carboniferous rocks of the Sangre de Cristo Mountains west of Trinidad, Colo. by Hills (1899). Later, Melton (1925, p. 811–812) subdivided these rocks into the "Upper Sangre de Cristo conglomerate" and the "Lower Sangre de Cristo conglomerate,"specifying that these rocks are Permian and Pennsylvanian. Melton named the marine part of the lower unit the "Veta Pass limestone member." Melton (1925, fig. 1) correlated his "Lower Sangre de Cristo conglomerate" with the mainly marine Pennsylvanian rocks in the southern part of the Sangre de Cristo Mountains in New Mexico that had been referred to the Magdalena Group by Lee (1909, p. 33–38) and Darton (1922, p. 201). Melton (1925, fig. 1) correlated his "Upper Sangre de Cristo conglomerate" with the nonmarine arkoses and red beds above the Magdalena in New Mexico that had been assigned to the Abo Sandstone of Permian age by Lee (1909) and Darton (1922). Darton (1928a, p. 255–274; 1928b) continued to classify the mainly marine rocks as the Pennsylvanian Magdalena Group and the overlying nonmarine rocks as the Permian Abo Sandstone.

Read and others (1944) were the first to subdivide and to map various lithologic units of Mississippian, Pennsylvanian, and Early Permian ages in the southern part of the Sangre de Cristo Mountains. They applied parts of the then-existing terminology (fig. 3, left-hand columns) of central New Mexico in the Sangre de Cristos. Marine and mixed marine-nonmarine rocks of Pennsylvanian age, and the rocks now known to be Mississippian, were included in the Magdalena Group. Nonmarine arkoses and red beds above the Magdalena were classified as the Sangre de Cristo Formation of Pennsylvanian and Permian(?) age.

Read and others (1944) subdivided the Magdalena Group into the Sandia Formation and the overlying Madera Limestone, formation names that were derived from the Sandia and Manzanita Mountains east of Albuquerque (Read and Wood, 1947). The Sandia Formation, a mainly clastic unit of Early and Middle Pennsylvanian age, was subdivided into a lower limestone member and an upper clastic member. Later, Read and Wood (1947, fig. 1) excluded the (Mississippian) lower limestone member from the Sandia, and, thereby, from the Magdalena Group.

Read and others (1944) subdivided the Madera Limestone into a lower gray limestone member and an upper arkosic limestone member in the southern part of the Sangre de Cristo Mountains. Read and Wood (1947) indicated that, from south to north, the upper part of the arkosic limestone member of the Madera grades laterally into nonmarine beds of the overlying Sangre de Cristo Formation, so that, in their view, the lower part of the Sangre de Cristo Formation becomes progressively older to the north. They wrote (1947, p. 225): "Farther north, in the Sangre de Cristo Mountains, equivalents of the Sandia and Madera formations show major changes in lithology and marked thickening. Since this area is now being mapped, it is not advisable to recommend a final nomenclature."

The general rock-stratigraphic terminology of Read and Wood (1947) for Pennsylvanian and Lower Permian rocks—the Sandia Formation, the Madera Limestone and its two members, and the Sangre de Cristo Formation—have continued to be used in U.S. Geological Survey reports on the southern Sangre de Cristo Mountains, although the Madera is called the Madera Formation, and its two members are called, simply, the upper and lower members (for example, Baltz, 1972; Johnson, 1973).

Brill (1952), by a series of stratigraphic sections and paleontologic analyses, extended the terminology of the Sandia Formation and the Madera Limestone and its two members northward from the southern Sangre de Cristo Mountains into Colorado.

Sutherland (1963) and Sutherland and Harlow (1973) reported the results of extensive paleontologic and stratigraphic investigations of the south-central and southwestern parts of the Sangre de Cristo Mountains. Sutherland (1963, p. 30) reviewed the previous stratigraphic nomenclature and proposed changes. He did not use the term Magdalena Group for this region because he considered it to be nearly synonymous with Pennsylvanian. He reported (1963, p. 30) that there were no consistent criteria for delineating the Sandia Formation in this region and did not use the terms Sandia and Madera because he believed that the stratigraphic relations of the Pennsylvanian rocks to the Madera Limestone of the Sandia Mountains were unknown. The name Sangre de Cristo Formation was retained by Sutherland (1963, p. 38–39) for the arkoses and red beds above the mainly marine Pennsylvanian rocks.

Sutherland (1963) proposed new names for Pennsylvanian rocks of the south-central and southwestern parts of the mountains. Rocks previously assigned to the Sandia Formation and to the lower gray limestone member of the Madera were combined in stratigraphic sections and were named the La Pasada Formation (Sutherland, 1963, p. 30) for exposures near Dalton Picnic area along the Pecos River. Rocks above the La Pasada, that previously were assigned to the arkosic limestone member of the Madera, were named the Alamitos Formation (Sutherland, 1963, p. 36) for exposures north and southwest of Pecos.

Northward from the Pecos area, the mainly carbonate upper part of the La Pasada becomes more shaly, the lower part becomes more conglomeratic, and the entire unit thickens greatly. On Rio Pueblo southwest of Taos, rocks approximately equivalent to the La Pasada are mostly shale and sandstone with subordinate limestone. The rocks of this northern facies were named the Flechado Formation by Sutherland (1963, p. 33). In the Rio Pueblo area, the Flechado is overlain by rocks assigned to the Alamitos Formation by Sutherland. He (1963, p. 30, pl. 1) did not delineate any of these formations on the geologic map because of extensive covered areas in the high, heavily timbered country.

NOMENCLATURE OF SOUTHEASTERN SANGRE DE CRISTO MOUNTAINS

GENERAL DISCUSSION

Northrop and others (1946) published the first detailed geologic map of the southeastern foothills of the Sangre de Cristo Mountains. They established Paleozoic rock-stratigraphic units suitable for depicting complex stratigraphic relations along the then-unnamed Paleozoic Tecolote uplift (fig. 2) which is near the eastern structural front of the present mountains. The stratigraphy of the Pennnsylvanian and Permian rocks was illustrated by detailed stratigraphic sections. They used the stratigraphic nomenclature for Mississippian, Pennsylvanian, and Permian rocks that Read and others (1944) had used farther west (fig. 4).

Baltz (1972) remapped part of the foothills belt and also the Gallinas Creek area (fig. 5), recognizing and extending the Paleozoic rock-stratigraphic units of Northrop and others (1946). Recent mapping (Baltz and O'Neill, 1980a,b) determined that these units could be traced northward past Mora through part of the area of facies change and thickening of various units that was described briefly by Read and Wood (1947).

The present writers have continued biostratigraphic studies of the southeastern part of the mountains and have additional new fusulinid

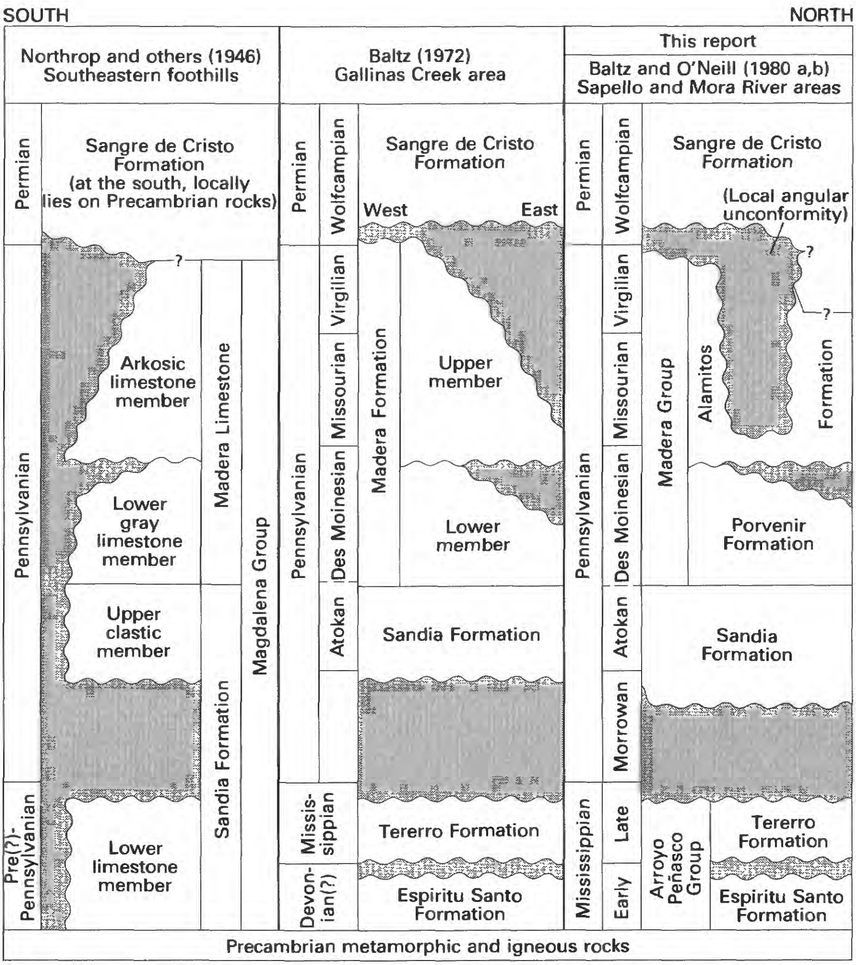


FIGURE 4.—Age assignments, nomenclature, and correlation of mapped rock-stratigraphic units of the southeastern Sangre de Cristo Mountains, N. Mex.

and megafossil data that provide corroborative evidence for extending the Pennsylvanian and Lower Permian rock-stratigraphic units and for correlating between areas where Cenozoic faults and erosion have removed parts of the section. The paleontologic data also provide a good basis for regional correlations and, therefore, for recommending some revisions of the stratigraphic terminology of the southeastern part of the mountains. In recommending these revisions, we believe it is desirable to retain, where possible and useful, the terminology of previous published literature that reflects the regional unity of extensive mapped bodies of rocks of generally similar lithology and age. Our revised nomenclature for the southeastern Sangre de Cristo Mountains is summarized in the right-hand column of figure 4.

PRE-PENNSYLVANIAN SEDIMENTARY ROCKS

The pre-Pennsylvanian sedimentary rocks of the southeastern Sangre de Cristo Mountains are included by the present writers in the Espiritu Santo and Tererro Formations of Baltz and Read (1960), and constitute the Arroyo Peñasco Group of Armstrong and Mamet (1974). A locally thin sandstone at the base of the section is considered to be the Del Padre Sandstone Member (as assigned by Armstrong and Mamet, 1974) of the Espiritu Santo Formation. The overlying carbonate part of the Espiritu Santo remains unnamed, as do the informal carbonate units within this part of the Espiritu Santo that were described by Baltz and Read (1960).

We tentatively accept the assignment of the Arroyo Peñasco Group entirely to the Mississippian by Armstrong and Mamet (1974). However, we continue to note the abundant evidence of unconformity between the Espiritu Santo and the Tererro in the Sangre de Cristo Mountains, as reported by Baltz and Read (1960), Sutherland (1963), and Clark and Read (1972). Identifiable megafossils still have not been reported in the Espiritu Santo, and its Mississippian age in the Sangre de Cristo Mountains is established by a meagre microfauna.

MAGDALENA GROUP

We recommend that the term Magdalena Group no longer be used in the southern part of the Sangre de Cristo Mountains. As described by Lee (1909) and Darton (1922, 1928a), the Magdalena Group of this region originally included the entire undivided section of mainly marine limestone, shale, and sandstone between the underlying Precambrian basement and the overlying arkoses and red beds that they assigned to the Abo Sandstone. The Magdalena was thought then to be entirely Pennsylvanian, and the Abo was thought to be entirely Permian. As is now known, the Magdalena of this region included rock units of considerable lithologic diversity and stratigraphic complexity that range in age from Mississippian through Early Permian, and the overlying arkoses and red beds (Sangre de Cristo Formation) are locally partly of Late Pennsylvanian as well as Permian age. Furthermore, the continued use of the term Magdalena Group in this region inhibits additional formal classification of its included units.

Rather than restrict the Magdalena Group locally, or raise its status to supergroup, the most reasonable procedure seems to be to discontinue its use in the southern part of the Sangre de Cristo Mountains, as was proposed by Sutherland (1963, p. 30). The usage of Magdalena Group already has been discontinued by the U.S. Geological Survey for the Manzano and Manzanita Mountains of central New Mexico (Myers, 1973). However, farther north in the Sangre de Cristo Mountains, where marine and mixed marine-nonmarine rocks of Pennsylvanian age have not been subdivided, the term "Magdalena Group" is still in use in a restricted sense for rocks between the Arroyo Peñasco Group and the Sangre de Cristo Formation (Bachman, 1953; Clark and Read, 1972, p. 31).

SANDIA FORMATION

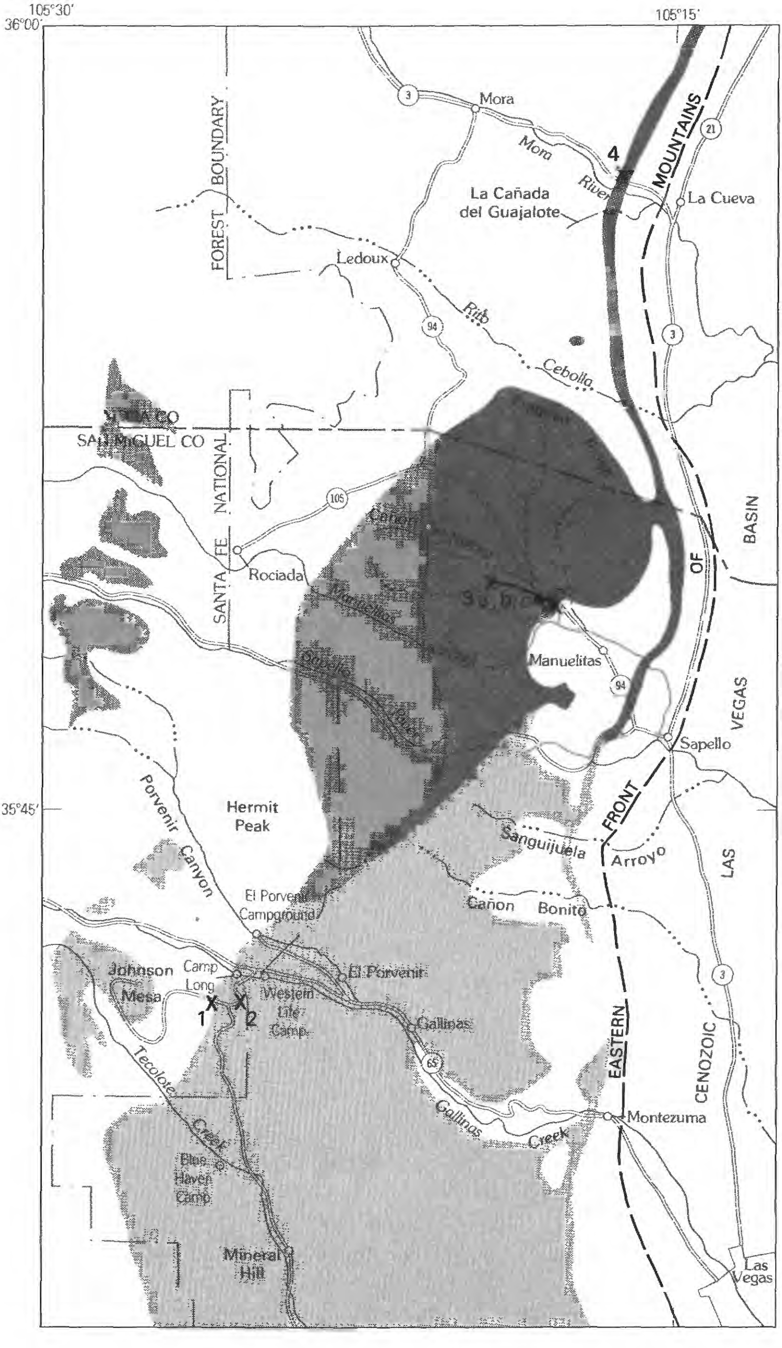
Throughout most of the Sangre de Cristo Mountains in New Mexico, the Arroyo Peñasco Group or, locally, Precambrian rocks are overlain by a complex sequence of Pennsylvanian shale, sandstone, conglomeratic sandstone, and subordinate amounts of thin limestone. The shales commonly are carbonaceous, and thin units of highly carbonaceous shale and coal are present at many places. In the southeastern part of the mountains these mixed marine-nonmarine rocks have been mapped as the Sandia Formation.

In the area of the Paleozoic Tecolote uplift (fig. 2), the thickness of the Sandia Formation ranges from about 10 ft (3 m) at the south (Northrop and others, 1946) to locally only 90 ft (27 m) near Montezuma (fig. 5). At the west, the Sandia is about 500 ft (152 m) thick at locality 1 (fig. 6). To the north, a little south of Rito Cebolla and about 1 mi (1.6 km) west of the structural front of the mountains, the Sandia is about 1,000 ft (305 m) thick. Farther north, 1 mi north of Mora River, the Sandia is at least 5,080 ft (1,548 m) thick, with an unknown but probably small (400–600 ft; 120–180 m) amount cut out by Cenozoic faults near the base (Baltz and O'Neill, 1980a). Throughout this region, despite the changes in thickness, the overall lithologies remain about the same as just described, with two notable exceptions: from Sapello River north, a major part of the formation is shale; and from Rito Cebolla north, the upper third contains several thick units of coarse to conglomeratic, highly arkosic sandstone. Feldspathic sandstones are present at the south, but there the feldspar grains tend to be small, highly weathered, and generally inconspicuous.

Our paleontologic data for the Sandia Formation in the southeastern part of the Sangre de Cristo Mountains are meagre but are definitive of its age. Brachiopods from the lower part of the formation in the western part of the Gallinas Creek area (loc. 1, fig. 6) are of Early Pennsylvanian (Morrowan) age (J. T. Dutro, Jr., written commun., 1979) and are similar to Morrowan brachiopod faunas reported from the lower part of the La Pasada Formation by Sutherland and Harlow (1973). Brachiopods from the lower part of the Sandia about 1 mi north of Mora River also are Morrowan (J. T. Dutro Jr., written commun., 1978). Fusulinids are rare in the Sandia. However, *Fusulinella* aff. *F. juncea* Thompson found near the top of the Sandia east of Gallinas and near the top of the Sandia just north of Rito Cebolla indicate late Atokan age. *Fusulinella* cf. *F. devexa* Thompson, found in the upper part of the Sandia at the north side of Sanguijuela Arroyo, also suggests late Atokan age. Abundant fusulinids at many places in the basal part of the overlying Madera Group are early Des Moinesian age.

Sutherland (1963, p. 29–30) reported that his studies in the western part of the Sangre de Cristo Mountains yielded no criteria for consistently delineating the Sandia Formation (of various authors) from the overlying Madera Limestone. Therefore, he did not use the terms Sandia and Madera Formations and he combined rocks equivalent to the Sandia and lower part of the Madera in his La Pasada and Flechado Formations. He reviewed the problems, as then reported in the literature, of lithologic and paleontologic regional correlations of Pennsylvanian rocks among various mountain ranges in New Mexico, and he concluded that the stratigraphic relations of the Pennsylvanian formations of the Sangre de Cristos to the Madera of the Sandia Mountains were unknown.

In the southeastern part of the Sangre de Cristo Mountains, lithologic and paleontologic bases exist for separating the Sandia Formation from the Madera. Generally south of Sapello River, the upper part of the Sandia consists of dark-gray shale that contains interbeds of thin to thick sandstone, sandy limestone, and thin micritic limestone. Nearly everywhere south of Sapello, the basal part of the overlying Madera is thick, ledge-forming, light-gray limestone. Northward from Sapello River past Mora River, the upper part of the Sandia is also mainly dark-gray shale that contains varied proportions of interbedded thin to thick sandstones and thin, micritic limestones. Here, the lower part of the Madera Group contains a heterogeneous assemblage of carbonate and clastic rocks that are lithologically distinct from the Sandia, as will be discussed. Although the lithology of the


105°30'
36°00'
105°15'
35°45'
FOREST BOUNDARY
SANTA FE NATIONAL
MORA CO
SAN MIGUEL CO
Mora
Mora River
La Cañada del Guajalote
La Cueva
Ledoux
Rito Cebolla
Rociada
Cañon
Manuelitas
Sapello River
Manuelitas
Sapello
Hermit Peak
Porvenir Canyon
El Porvenir Campground
Johnson Mesa
Camp Long
Western Life Camp
El Porvenir
Gallinas
Tecolote Creek
Blue Haven Camp
Mineral Hill
Sanguijuela Arroyo
Cañon Bonito
Gallinas Creek
Montezuma
Las Vegas
EASTERN FRONT OF MOUNTAINS
LAS VEGAS BASIN
CENOZOIC
1
2
4

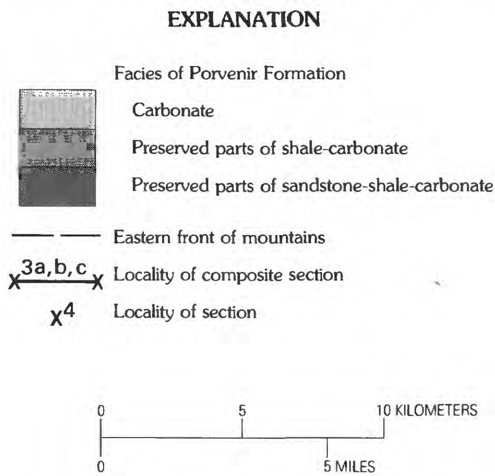


FIGURE 5.—Index map of part of southeastern Sangre de Cristo Mountains, N. Mex., showing localities of type section (loc. 1), principal reference section (locs. 3a–3c), Mora River section (loc. 4) of the Porvenir Formation of the Madera Group, and stratigraphic section (loc. 2) of the Alamitos Formation. Contacts of facies of the Porvenir are generalized because facies merge into each other through several miles. Unpatterned areas west of the front of the mountains indicate areas where Porvenir has been removed by Cenozoic erosion.

basal Madera varies laterally, a contact can be mapped by physical tracing. Inasmuch as the contact is mainly conformable and is locally transitional through a few feet, there is surely some minor local variation of its mapped stratigraphic position. Additionally, the potential exists for minor miscorrelations across covered areas and areas of Cenozoic faults. Nevertheless, our fusulinid data indicate that the contact is near the Atokan-Des Moinesian boundary throughout this region.

Since the time of Sutherland's (1963) report, a large amount of new data on the mountain ranges of central New Mexico has been published. These new data bear on the regional-correlation problems that he discussed. The Sandia Formation and the Madera Formation of the Sandia Mountains have been mapped, and their stratigraphy and paleontology discussed by Kelley and Northrop (1975). They (p. 31) described a transitional contact between the Sandia and Madera, and they indicated that its stratigraphic position varies somewhat from place to place. Kelley and Northrop (1975, p. 49) did not express a firm opinion on the age of the Sandia, but they reported megafossil evidence from localities scattered throughout the Sandia Mountains that suggests a possible age span of Morrowan through early Des Moinesian.

At good exposures in the northern part of the Sandia Mountains, the Sandia Formation lies on the Mississippian Arroyo Peñasco Group and is overlain by ledge-forming limestones of the Madera Formation of Read and others (1944) and Kelley and Northrop (1975, fig. 20). In this area, at the ridge called "Crest of Montezuma" about 1¼ mi (1.7 km) east of Placitas, the Sandia is composed of conglomerate, sandstone, gray shale, and a little thin, sandy limestone, all about 110 ft (33.5 m) thick where we have measured it. In this vicinity, the thickness ranges from locally absent to about 150 ft (45 m). We found *Beedeina arizonensis* and *Wedekindellina* sp. of early Des Moinesian age in the interval 56–117 ft (17–52 m) above the base of the ledge-forming limestones of the Madera at the Crest of Montezuma. These data indicate that the underlying upper part of the Sandia is no younger than earliest Des Moinesian, which is consistent with the data presented by Kelley and Northrop (1975).

The type locality of the Sandia Formation (Herrick, 1900) is near the northern end of the Manzanita Mountains, which are contiguous with and south of the Sandia Mountains. The Manzanita Mountains were mapped by Myers and McKay (1976), and the Manzano Mountains to the south also have been mapped. A summary of the stratigraphy and the fusulinid data of post-Atokan Pennsylvanian and Lower Permian rocks of these ranges was presented by Myers (1973). In the Manzanita and Manzano Mountains, the Sandia in most places rests on Precambrian rocks, but locally on Mississippian rocks referred to the Arroyo Peñasco Group; has heterogeneous clastic and carbonate lithology similar to that in the Sandia Mountains; and ranges in thickness from about 60 ft (18 m) (Myers, 1969), to a little more than 300 ft (90 m), depending on local relief on the top of the Precambrian. In this region, fusulinids indicate late Atokan age for the upper part of the Sandia and early Des Moinesian age for the overlying limestones of the Madera. Whether Morrowan- age rocks are present locally in the Sandia is not known.

In summary, the general lithologies, stratigraphic relations to bounding rocks, thickness variations, and (at least the minimum) age of the Sandia in its typical areas of central New Mexico are similar to those features of the Sandia Formation in the southeastern part of the Sangre de Cristo Mountains. The only striking difference between the two regions is the great northward thickening of the Sandia Formation north of the Paleozoic Pecos shelf in the Sangre de Cristo Mountains. Therefore, we retain the name Sandia Formation for these Lower and Middle Pennsylvanian rocks in the southeastern Sangre de Cristo Mountains.

Baltz and O'Neill (1980a) subdivided the Sandia Formation into five informal lithologic units north of Mora River where it is more than 5,000 ft (1,525 m) thick to determine and portray the Cenozoic structure and to determine places suitable for measuring the thickness of the formation. No attempt was made to extend the correlation of these informal units or to determine their stratigraphic usefulness outside the area where they were mapped. Nevertheless, with additional study, the Sandia probably could be subdivided in many places to understand its complex internal stratigraphy in the parts of the Sangre de Cristo Mountains where it is extremely thick.

MADERA GROUP

In the southeastern part of the Sangre de Cristo Mountains, the Sandia Formation is overlain by limestone, shale, and sandstone mapped by Northrop and others (1946) and Baltz (1972) as the Madera Formation. These rocks are lithologically generally similar to, and their overall age span is the same as, the Madera Formation in its typical region of the Sandia Mountains, and the Madera Group (Myers, 1973) in the Manzanita and Manzano Mountains. Therefore, the term Madera is retained and is hereby raised to group status for the southeastern Sangre de Cristo Mountains (fig. 4).

The lower part of the Madera Group in the southeastern Sangre de Cristo Mountains is here named the Porvenir Formation. The Porvenir Formation is mainly marine and consists of three laterally intergrading facies. (See fig. 5 for facies distribution.) At the south, the Porvenir consists of thin to massive limestones and interbedded gray shales and minor amounts of sandstone. At the north, near the eastern front of the mountains, the Porvenir consists of limestone, sandy and oolitic limestone, gray shale, and thin to thick quartzose and arkosic sandstones. Also at the north, but in the western interior part of the mountains, the Porvenir consists of gray shale, subordinate amounts of thin to thick limestone, and minor amounts of sandstone. Fusulinids indicate that the Porvenir is of early to late Des Moinesian age; it is the lower member of the Madera of Northrop and others (1946) and Baltz (1972), and it is the informally designated "formation of El Porvenir" of Baltz and O'Neill (1980a,b).

The name Alamitos Formation (of Sutherland, 1963) is hereby adopted for the unit of limestone, sandy limestone, nodular limestone, gray, greenish-gray, and red shales, and conglomeratic arkoses that rests on the Porvenir Formation and that forms the upper part of the Madera Group in the southeastern part of the mountains. The Alamitos in this area is mainly marine, but also contains probable nonmarine rocks. It contains rocks of late Des Moinesian, Missourian, and Virgilian ages, and, locally, of Early Permian (early Wolfcampian)

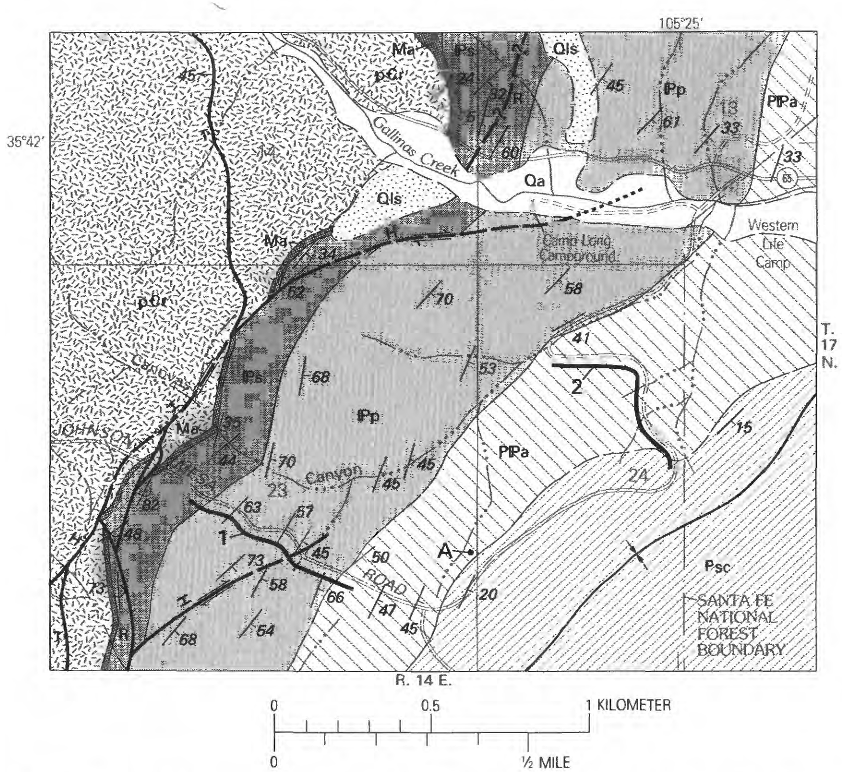


FIGURE 6.—Geologic map of type locality of Porvenir Formation (loc. 1) and locality of stratigraphic section of Alamitos Formation (loc. 2). For regional location see figure 5. Geology from Baltz (1972).

age. The Alamitos is the upper member of the Madera of Northrop and others (1946) and Baltz (1972), and the Alamitos Formation of Baltz and O'Neill (1980a,b).

The Alamitos is overlain by the nonmarine rocks of the Sangre de Cristo Formation which is mainly Early Permian in the southeastern part of the mountains, although, at the north near Mora River, the Sangre de Cristo includes at the base some nonmarine rocks of probable Late Pennsylvanian age.

PORVENIR FORMATION

TYPE LOCALITY AND TYPE SECTION

The type locality of the Porvenir Formation is along the U.S. Forest Service Johnson Mesa road on the ridge south of Canovas Canyon which is a south tributary of Gallinas Creek about 12.5 mi (20 km) northwest of Las Vegas. (See fig. 5.) This locality is in the Santa

EXPLANATION

Qa	Quaternary alluvium
Qls	Quaternary landslide deposits
Psc	Permian Sangre de Cristo Formation
PIPa	Permian and Pennsylvanian Alamitos Formation
IPp	Pennsylvanian Porvenir Formation
IPs	Pennsylvanian Sandia Formation
Ma	Mississippian Arroyo Peñasco Group
p€	Precambrian metamorphic and igneous rocks
	CONTACT—Dashed where approximately located
	SYNCLINE
H	HIGH-ANGLE FAULT—H, upthrown side; arrows indicate relative horizontal movement. Dashed where approximately located; dotted where concealed
R ?—	REVERSE FAULT—R, upthrown side. Dashed where approximately located; queried where probable
45 T	THRUST FAULT SHOWING DIP—T, upthrown side.
2	LINE OF STRATIGRAPHIC SECTION
	STRIKE AND DIP OF BEDS
15	Inclined
48	Overturned
A	FUSULINID COLLECTION FROM UPPER PART OF ALAMITOS FORMATION—Dot on leader shows locality. Stratigraphic position, as traced to section (loc. 2), is shown on fig. 10

FIGURE 6.—Continued.

Fe National Forest, near the center of sec. 23, T. 17 N., R. 14 E. A geologic map of the area is shown on figure 6, a graphic type section of the Porvenir at this locality is shown on figure 7, and an explanation of lithologic and other symbols for the section is shown on figure 8. In this area, and farther north and south, the steeply east-dipping rocks of the Porvenir Formation crop out in a series of topographically high hogback ridges.

The name of the formation is derived from exposures in the hogbacks near El Porvenir Campground (fig. 5). However, the type locality was chosen farther south because almost the entire formation is preserved and is well exposed in cuts on the Johnson Mesa road, as are the underlying Sandia Formation and parts of the overlying Alamitos Formation. The thickness of the Porvenir Formation is about 1,065 ft (325 m) at the type section. An unknown amount of the upper part of the formation may be missing because of a concealed strike-slip

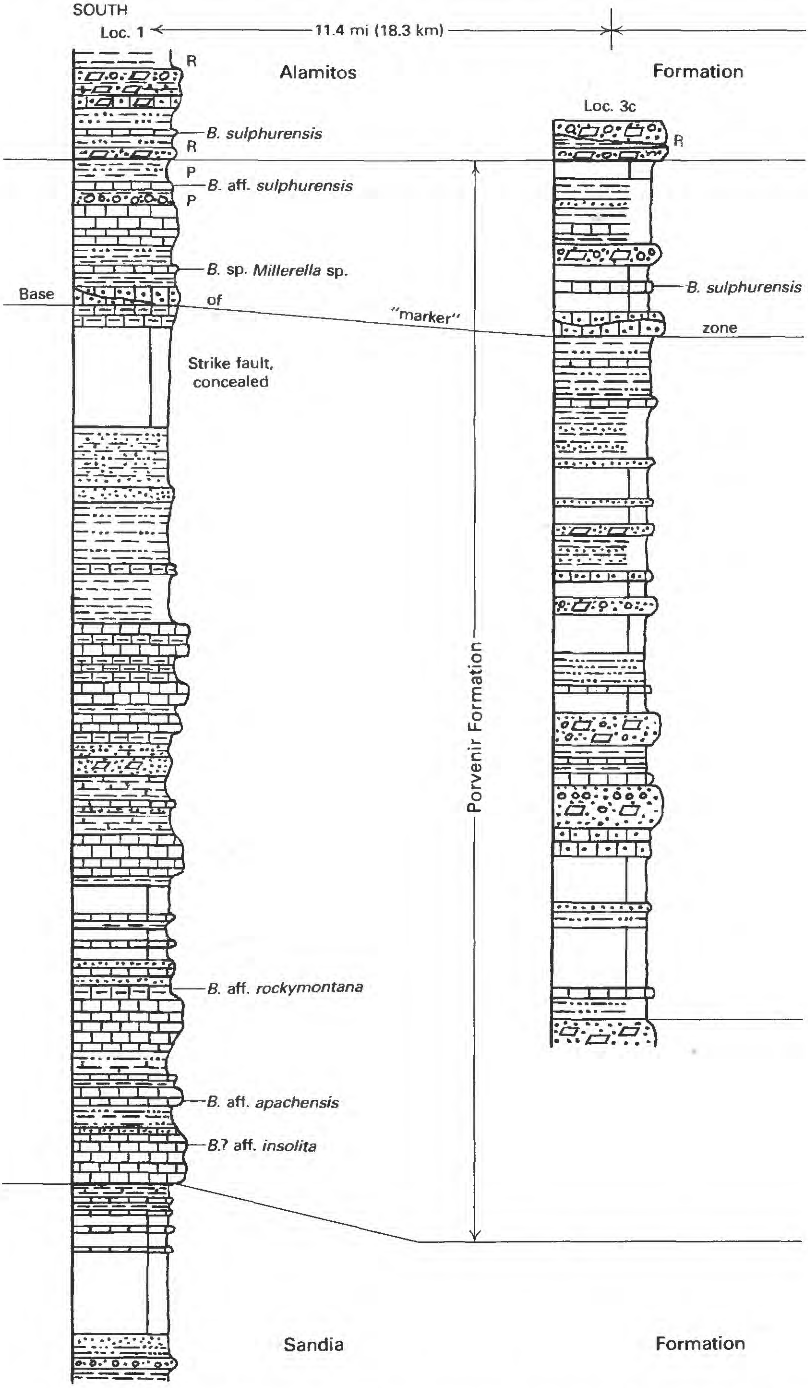
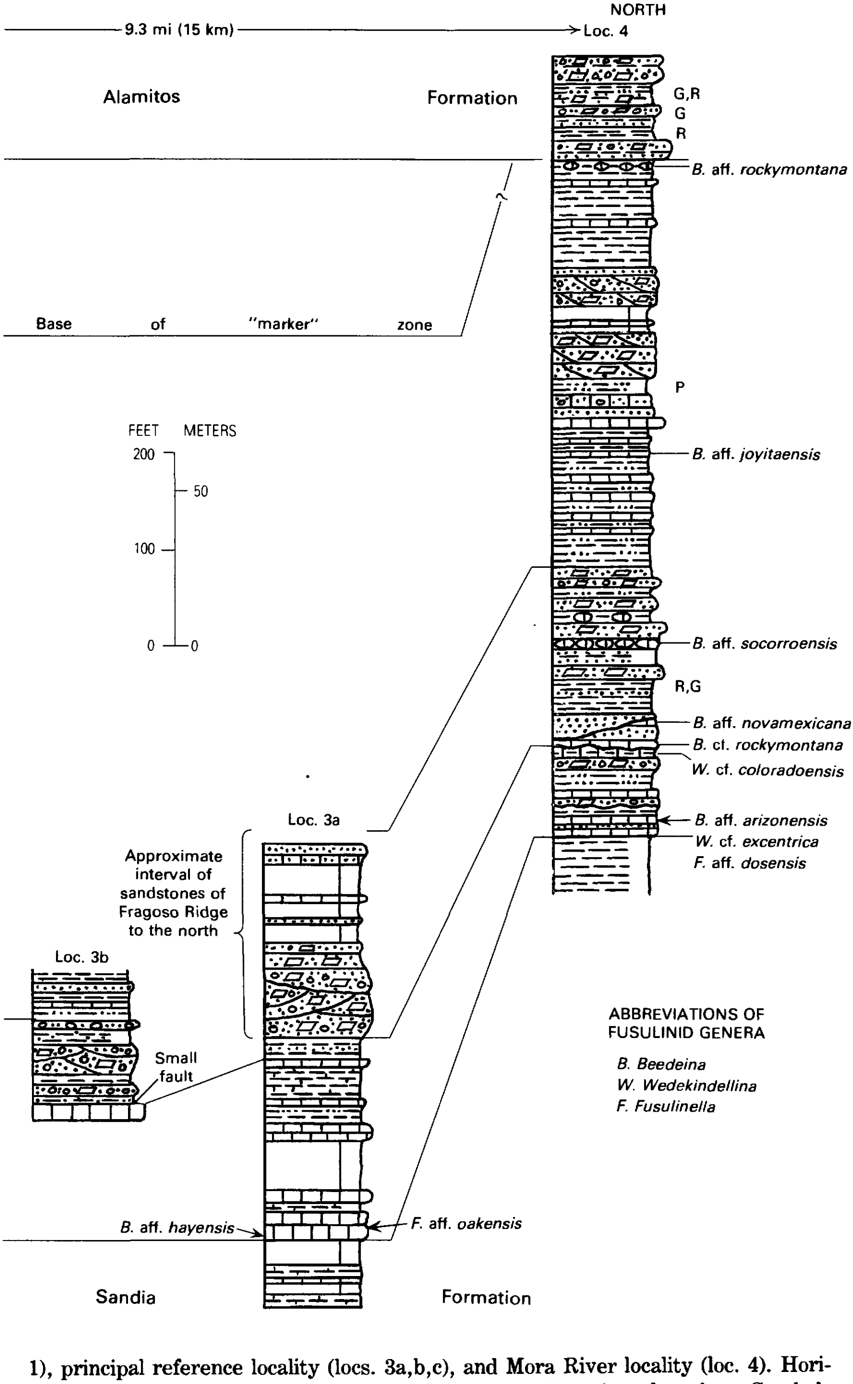


FIGURE 7.—Stratigraphic sections of the Porvenir Formation at the type locality (loc.



1), principal reference locality (locs. 3a,b,c), and Mora River locality (loc. 4). Horizontal distances not to scale. See figure 5 for regional location of sections. Symbols used are explained in figure 8.

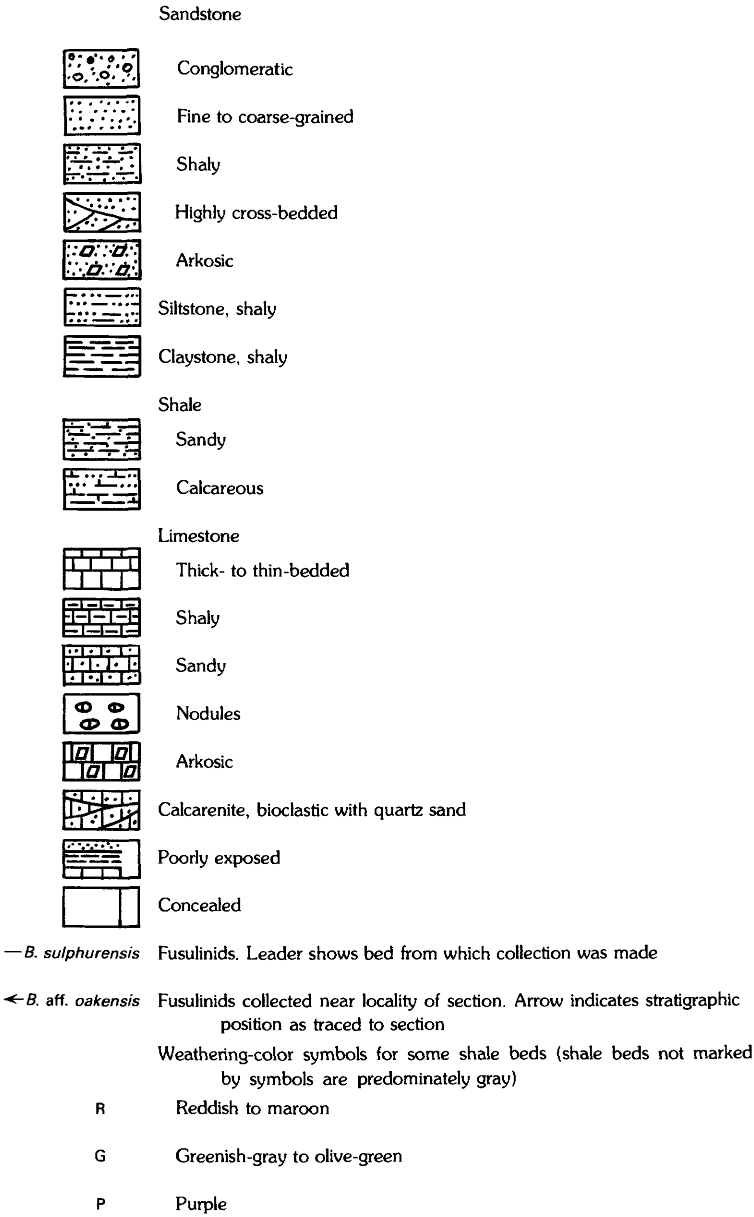


FIGURE 8.—Explanation of symbols used in stratigraphic sections (figs. 7 and 10).

fault (fig. 6) within the formation; however, based on observations of this part of the section elsewhere in the vicinity, the amount is believed to be small.

At the type section, the lower 580 ft (177 m) of the Porvenir consists mainly of ridge-forming, highly fossiliferous limestones with intervening nonresistant units of calcareous shale, siltstone, and a few thin beds of fine- to coarse-grained quartz sandstone that locally contains traces of weathered yellowish-pink potash feldspar. Several <1-in.- to 3-ft-thick beds of highly carbonaceous to coaly shale are present locally. Bedding of the limestones ranges from almost shaly to massive. Several thick limestone units are dense and nearly structureless internally, and, as shown by lateral tracing away from the roadcuts, thicken and thin, suggesting that they are bioherms or biostromal banks. Similar biohermal or biostromal-bank limestones are present in the lower part of the Porvenir at many places in the Gallinas Creek area, the foothills area, and also southward from the type locality to the southernmost exposures of the Porvenir near Bernal that were mapped as the gray limestone member of the Madera by Read and others (1944).

At the type section, the ridge-forming lower part of the Porvenir is overlain by gray shale, sandy and silty shale that contains fine-grained to silty sandstone, and a few beds of shaly limestone. This unit, including a concealed upper part, is about 310 ft (94 m) thick. It can be recognized north and south of the type locality, although, to the south it becomes more calcareous, and to the north more sandy. This unit and overlying beds generally are absent in the eastern foothills south of Sapello River because of unconformity with the Alamitos Formation on the Paleozoic Tecolote uplift. In the eastern foothills, the Porvenir is no more than 600 ft (180 m) thick.

The stratigraphically highest part of the Porvenir at the type section is a unit, about 175 ft (53 m) thick, of fossiliferous limestone, shaly limestone, calcareous shale, siltstone and thin beds of sandstone, and a thin bed of limestone-pebble conglomerate. These rocks form minor ridges. The rocks are predominantly gray, but contain two thin beds of greenish-gray shale that weather purple locally. Notably, not far above the base of this unit are several beds of cross-laminated to cross-bedded, bioclastic calcarenite that contains much silt, sand, and granules of angular quartz. We informally designate these beds as a "marker zone" in the upper part of the Porvenir. As determined elsewhere, the stratigraphically lowest occurrence of the fusulinid *Beedeina sulphurensis* at places is within the marker zone. Although the marker zone has not been mapped, it appears to be widespread in the southeastern Sangre de Cristos. Similar sandy, bioclastic rocks have been observed in similar stratigraphic position from north of the San Miguel-Mora County line (fig. 5) to at least as far south as east of San Geronimo southwest of Las Vegas. Locally, however, the zone is absent by nondeposition. On the Paleozoic Tecolote uplift, this part of the section probably is absent because of the unconformity between the Porvenir and the overlying Alamitos Formation.

CONTACTS WITH ADJACENT ROCKS

At the type section, the Porvenir Formation lies on shale containing interbedded thin micritic limestones assigned to the Sandia Formation. The basal contact of the Porvenir, previously chosen (Baltz, 1972) because of its mappability, is at the base of ridge-forming thick limestones and marks a relatively abrupt vertical transition from the predominantly shaly upper part of the Sandia that occurs throughout the region south of Sapello River (fig. 5). North of Sapello River, the contact is at the base of biohermal and stromatolitic-mound limestones, and a complexly varied zone of interbedded limestone, sandy limestone, sandy oolite, and conglomeratic sandstone, as will be discussed. Regionally, the contact is mainly conformable.

At the type section, the Porvenir Formation is overlain by a locally thin, arkosic sandstone that contains subangular to angular clasts of fine to coarse, reddish-pink, little-weathered potash feldspar. This sandstone, assigned to the Alamitos Formation, is overlain by a sequence of red-weathering silty, shaly sandstone, thin limestones, arkosic limestone, and arkosic conglomerate, all of which are fairly well exposed in the roadcuts and are assigned also to the Alamitos. The contact is disconformable locally because of slight channeling at the base of the Alamitos but is unconformable in much of the eastern part of the mountains where the upper part of the Porvenir is missing.

FACIES

Three facies of the Porvenir have been recognized (fig. 5): a southern, predominantly carbonate facies; a shale-carbonate facies; and a northern, sandstone-shale-carbonate facies. All the facies are laterally intergradational through several miles, and each facies locally contains lithologic units that are characteristic of the other facies. Because of the gradual lateral transitions of the facies, no contacts can be mapped between them and they are considered as regional lithologic variations within the Porvenir.

The Porvenir at the type locality is characteristic of the southern, predominantly carbonate facies that was deposited in shallow seas on the tectonically slightly unstable Pecos shelf in the southern part of the Rowe-Mora basin.

The Porvenir thickens northward from the type locality and the proportion of gray shale throughout the formation increases northward. This shale-carbonate facies is well exposed in the interior hogback belt at Sapello River north of Hermit Peak, and at Manuelitas Creek east of Rociada where the formation is 1,615 ft (491 m) thick.

Relatively thick units of limestone are interbedded in the shales, but the limestones are, generally, thin even-bedded rocks; biohermal and biostromal limestones are not common. Thick to thin sandstones are present, but they constitute a minor part of the formation. Only the lower 1,000 ft (300 m) of the shale-carbonate facies of the Porvenir is preserved from Cenozoic erosion in synclines in the topographically and structurally higher part of the mountains northwest of Hermit Peak and Rociada. These rocks are similar to the lower part of the Porvenir at Manuelitas Creek. They consist of units of even-bedded limestone and intervening thick units of calcareous shale containing a few beds of sandstone and thin beds of limestone. The sediments of the shale-carbonate facies were deposited on the eastern margin of the central deep part of the Rowe-Mora basin, as that configuration of the basin existed in Des Moinesian time.

Northeastward in the interior hogback belt east and northeast of Rociada (Baltz and O'Neill 1980b), the shale-carbonate facies of the Porvenir thins, and contains increasingly greater amounts of feldspathic to arkosic sandstone, until, near the San Miguel-Mora County line, it becomes indistinguishable from the sandstone-shale-carbonate facies described next.

Generally near and a little south of Sapello River, in the eastern part of the mountains, the lower part of the carbonate facies grades northward into a facies that contains thick, arkosic sandstones, gray shale, sandy shale, and sandy limestones. The basal part of this sandstone-shale-carbonate facies sporadically contains biohermal and stromatolitic limestones and interbedded lenticular conglomeratic sandstone as far north as Rito Cebolla. This facies of the Porvenir has been mapped to several miles north of Mora River (Baltz and O'Neill 1980a) and has been recognized by the authors north of the area of figure 5. The thickness of the sandstone-shale-carbonate facies of the Porvenir is about 1,170 ft (357 m) at localities 3a,b, and c (fig. 5) northwest of Manuelitas, about 1,140 ft (347 m) at the northwest margin of Fragoso Ridge, and about 700 ft (213 m) at Mora River (loc. 4, fig. 7). This northern facies appears to have occupied a north-trending area of Paleozoic intrabasinal uplift (or slow subsidence), that was structurally slightly lower than the Tecolote uplift south of Sapello (fig. 2), but that was structurally slightly higher than the part of the Rowe-Mora basin to the west in which the shale-carbonate facies was deposited.

PRINCIPAL REFERENCE LOCALITY

Because the Porvenir changes considerably northeastward from the carbonate facies at the type locality to the sandstone-shale-carbonate facies north of Sapello, a principal reference locality is specified for the northern facies (fig. 5). Parts of the northern facies are well exposed at many places along New Mexico Highway 94 from about 1.5 to about 4.8 mi (2.4–7.7 km) northwest of Manuelitas. However, the rocks mainly dip gently west and it is difficult to find a single locality where they can be measured conveniently and continuously. Therefore, a composite stratigraphic section (locs. 3a–3c, fig. 7) that was measured westward from near San Isidro Cemetery and church, across the lower valley of Cañon del Horno, and west along the ridge south of that canyon is designated as the principal reference locality. A geologic map of the principal reference locality is shown on figure 9.

The basal part of the Porvenir and the upper part of the Sandia Formation are fairly well exposed along the north edge of the valley north of the Bahai school (loc. 3a, fig. 9). Part of the Porvenir above the basal limestones is concealed here, but good exposures of this part of the section exist northeast of San Isidro Cemetery and along New Mexico Highway 94. A distinctive limestone exposed in the roadcuts near the middle of locality 3a was traced south and was correlated west across the valley of Cañon del Horno to a similar limestone in the valley at locality 3b. Beds near the top of section 3b were traced west across an anticline to locality 3c near the crest of the ridge south of Cañon del Horno. The total thickness of the northern facies at this reference locality is about 1,170 ft (357 m).

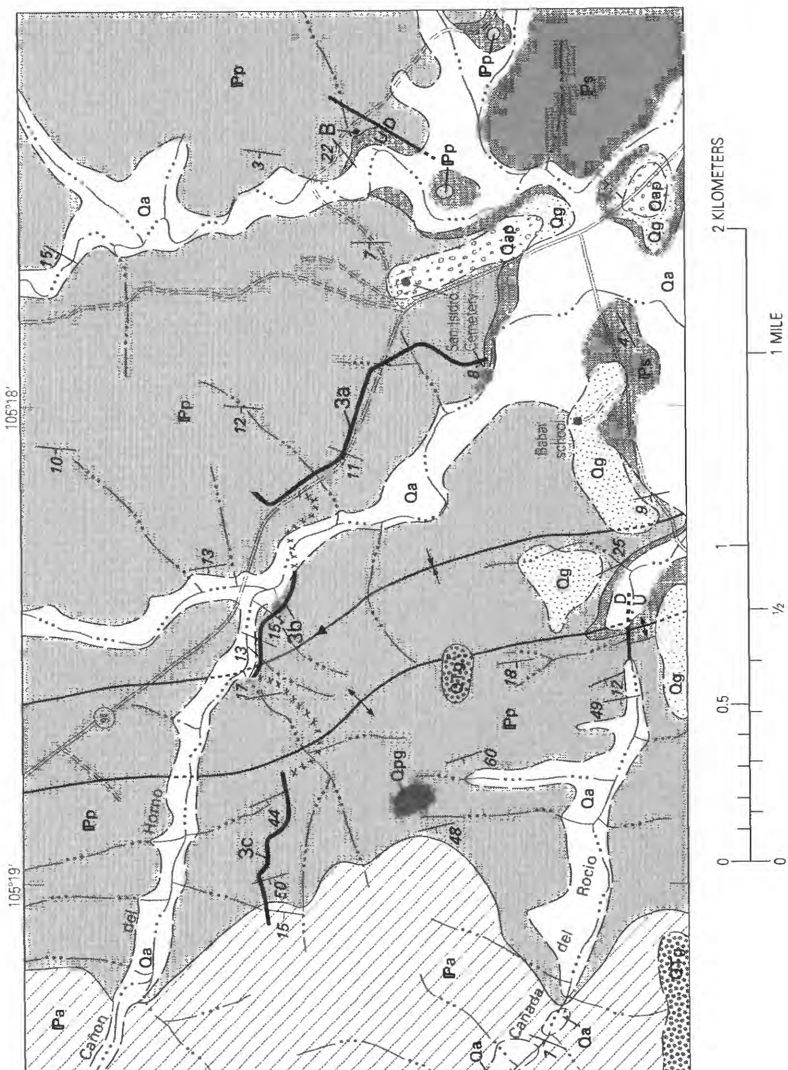
The basal part of the Porvenir at the principal reference locality is a persistent zone of thin limestones that characteristically contain small to large biohermal mounds. Isolated, small outcrops of the Porvenir southeast of San Isidro Cemetery (fig. 9) are circular biohermal-limestone mounds as much as 60 ft (18 m) in diameter; one of these was illustrated by Baltz and Read (1956, p. 70). Small biohermal mounds are well exposed near the mouth of Cañada del Rocio southwest of Bahai school. Similar small bioherms and small stromatolitic mounds are present in the lower part of the Porvenir about 3 mi (4.8 km) north of Sapello near the eastern edge of the mountains. The basal limestone zone has been mapped south continuously from the reference section to the Sapello River (Baltz and O'Neill, 1980b) where it merges into thick limestones characteristic of the basal part of the carbonate facies of the Porvenir.

Northeast of the reference section, the basal limestone zone contains thin, lenticular beds of arkosic sandstone that locally contains limestone pebbles. In places, as about 1.2 mi (2 km) north of Manuelitas, these sandstones thicken locally to form a massive ledge and they cut out underlying limestone, to rest disconformably on the Sandia Formation. Farther northeast, the sandstones become thin again and are underlain by limestone. The basal part of the Porvenir cannot be traced entirely between Rito Cebolla and Mora River because it is cut out locally by Cenozoic reverse faults. However, the upper part of the formation can be traced, and the basal limestone zone of the reference section appears to be equivalent to the complex zone of lenticular sandy oolite, sandy limestone, limestone, and conglomeratic sandstone mapped as the base of the Porvenir (Baltz and O'Neill, 1980a) from La Cañada del Guajalote northward past Mora River. The correlation of the basal zone is confirmed by the presence of abundant early Des Moinesian fusulinids near locality 4 (figs. 5, 7). Fusulinids are particularly abundant in the lenses of sandy oolite that occur at and just above the base of the Porvenir about 1,500 ft (455 m) north of Mora River and about 500 ft (150 m) south of the river.

Above the basal limestones at the reference section (loc. 3a), is a 150-ft- (45-m-) thick unit of gray shale and calcareous shale containing several parallel-bedded limestones. To the south, this unit grades into the lower part of the carbonate facies south of Sapello River. To the north, the unit persists north of Rito Cebolla. The unit is thin or is not present at locality 4 at Mora River where intraformational unconformities have caused stratigraphically higher arkosic sandstones to rest on the lower part of the Porvenir.

Above the shale and limestone unit, at roadcuts at locality 3a (fig. 7), is a sequence, almost 100 ft (30 m) thick, of coarse-grained to conglomeratic arkosic sandstones, some of which are almost a "gruss" of detritus derived from a granitic terrane. The sandstones exhibit large-scale trough crossbedding. Above these rocks are poorly exposed sandstone, shale, and limestone. All these rocks are informally designated as the sandstones of Fragoso Ridge (fig. 7). North of the reference section, the entire stratigraphic interval designated as the sandstones of Fragoso Ridge becomes a massive sequence of fine-grained to conglomeratic sandstones with only minor intervals of shale. At the northwest end of Fragoso Ridge (fig. 5) south of Rito Cebolla, the sandstone sequence is about 200 ft (60 m) thick and forms massive ridges above the poorly exposed shales and thin limestones of the lower part of the Porvenir. North of Rito Cebolla past Mora River, the sandstones of Fragoso Ridge persist and form hogbacks in the eastern part of the mountains where they are represented by arkosic conglomerates and sandstones with interbedded shale and thin limestone that form the lower half of the Porvenir. From La Cañada del Guajalote north to locality 4, reddish-weathering shales are present locally in this interval.

Southwest of locality 3a of the reference section, the sandstones of Fragoso Ridge thin and become interbedded with shale and limestone. Some of the lower sandstones persist southwestward into the carbonate facies a little past the upper part of Cañon Bonito (fig. 5). The sandstones of Fragoso Ridge mainly die out to the west but


105°19'
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Cañon
del
Homo
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San Isidro Cemetery
Bahai school
3a
3b
3C
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2 KILOMETERS
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½
1 MILE

EXPLANATION

Qa	Quaternary alluvium
Qap	Quaternary alluvium on low-pediment remnants
Qg	Quaternary gravel on low-terrace remnants
	Quaternary gravel on intermediate pediment
QTg	Quaternary or Tertiary gravel on high pediment
IPa	Pennsylvanian Alamitos Formation
IPp	Pennsylvanian Porvenir Formation
IPs	Pennsylvanian Sandia Formation

CONTACT—Dashed where approximately located

ANTICLINE—Dotted where concealed

SYNCLINE—Dotted where concealed

D U NORMAL FAULT—D, downthrown; U, upthrown side. Dotted where concealed.

3a LINE OF STRATIGRAPHIC SECTION

CORRELATIVE BEDS TRACED BETWEEN STRATIGRAPHIC SECTIONS

22 STRIKE AND DIP OF BEDS

B FUSULINID COLLECTION FROM LOWER PART OF PORVENIR FORMATION—Dot on leader shows locality. Stratigraphic position as traced to locality 3a, is shown on right side of section (fig. 7)

FIGURE 9.—Geologic map of principal reference locality of Porvenir Formation. Composite stratigraphic section (locs. 3a,b,c) is the principal reference section for the sandstone-shale-carbonate facies. For regional location see figure 5. Geology from Baltz and O'Neill (1980b).

are represented by several thin, slightly arkosic sandstones in the lower part of the shale-carbonate facies east and west of Rociada.

Above the interval of the sandstones of Fragoso Ridge at locality 3c of the reference section, the Porvenir is mainly silty to sandy gray shale that contains thin to thick beds of arkosic sandstone, limestone, and sandy limestone. The "marker zone" of sandy, bioclastic calcarenite, that is found in the upper part of the Porvenir at the type locality, forms a well-defined ledge at locality 3c. A thin limestone above the marker zone contains the fusulinid *Beedeina sulphurensis*. The marker zone was traced northward almost to the San Miguel-Mora County line in the interior hogback zone east of Rociada but was not recognized farther north.

At locality 4 at Mora River, the uppermost part of the Porvenir contains the fusulinid *Beedeina* aff. *B. rockymontana* (Roth and Skinner) that is found stratigraphically below the "marker zone" farther south. Therefore, the Porvenir at Mora River does not contain rocks as young as in the areas farther south, probably because of unconformity with the overlying Alamitos Formation.

AGE

The Porvenir Formation is within the fusulinid faunal zone of *Beedeina* (formerly, the genus *Fusulina*), and is entirely of Des Moinesian age. The basal beds of the formation contain *Beedeina* aff *B. arizonensis* (Ross and Sabins) associated with biologically advanced forms of *Fusulinella* that are similar to *F. famula* Thompson. The association of these forms indicates that the rocks are of early Des Moinesian age. The lower, but not basal, beds also contain *Wedekindellina*, which genus has been found throughout the lower two-thirds of the Porvenir Formation. *Plectofusulina* spp. also is found throughout the formation, but is more common in the upper part where it is associated with *Beedeina sulphurensis* (Ross and Sabins). *B. sulphurensis* is the youngest fusulinid that has been found by the writers in the formation and it indicates late Des Moinesian age.

ALAMITOS FORMATION

The Alamitos Formation in the southeastern Sangre de Cristo Mountains is generally similar to the formation at its type section near Pecos, about 25 miles west of Las Vegas, that was described by Sutherland (1963, p. 36–38), although there are variations in lithologic details and thickness between the two regions. At its type section northwest of Pecos, the Alamitos consists of arkosic sandstone and conglomerate; olive-gray, gray, and red shale; and nodular limestone, sandy limestone, and gray to olive-gray, thin- to thick-bedded limestone. All these rocks are complexly interbedded and are marine and nonmarine. In the type section the Alamitos is about 1,275 ft (390 m) thick. Its age in that area is late Des Moinesian, Missourian, and Virgilian. According to Sutherland (1963), the Alamitos Formation is approximately equivalent to the arkosic limestone member of the Madera Formation as assigned by Brill (1952) in the Pecos area.

LITHOLOGIC DESCRIPTION

A composite stratigraphic section of the Alamitos (fig. 10) at the type locality of the Porvenir Formation (fig. 6) is shown to illustrate the general lithology of the Alamitos in the southeastern part of the Sangre de Cristo Mountains. In the southeastern part of the mountains, the Alamitos consists of a heterogeneous assemblage of gray to greenish-gray silty shale and interbedded arkosic sandstones and conglomerates, nodular gray limestones, sandy and arkosic limestones, and some thick-bedded gray limestone. Nearly all the limestones and shales, and some sandstones, contain marine fossils; however, some of the sandstones have bedding characteristics that indicate they are probably nonmarine, fluviatile deposits. Characteristically, many of the shales are marly and commonly contain limestone nodules and interbedded nodular limestones. Many shales weather to a distinctive olive green; other shales weather distinctive maroon to purplish red.

Throughout most of the southeastern part of the mountains, the lowest beds of the Alamitos are arkosic, crossbedded sandstones and conglomerates that contain granule- to small-pebble-size angular to subangular clasts of little-weathered reddish-pink potash feldspar. At some places, the basal beds are arkosic limestones that grade laterally into arkosic sandstone. Locally, thin distinctively green arkosic sandstone is at or near the base.

At most places, red- to maroon-weathering shale is interbedded with the basal arkoses of the Alamitos or is not far above them and provides an excellent criterion for distinguishing the Alamitos from the Porvenir, especially at the north where parts of the Porvenir also contain arkose. At some outcrops of the basal arkoses of the Alamitos, red shale is not present, but lateral tracing for short distances usually discloses red-shale interbeds. At places, a few shale beds in the upper part of the Porvenir weather locally to a purplish hue, as at the type locality (loc. 1) and in roadcuts at Mora River (loc. 4). However, the purplish hue is distinctive and almost always is of limited (a few meters) extent.

Although arkosic sandstones and conglomerates are present throughout the Alamitos, the thickest arkoses generally are in the upper half or third of the formation. These rocks commonly contain irregularly shaped pebbles of quartzite, other metamorphic rocks, and granite. At many places in the upper part of the Alamitos, fluviatile

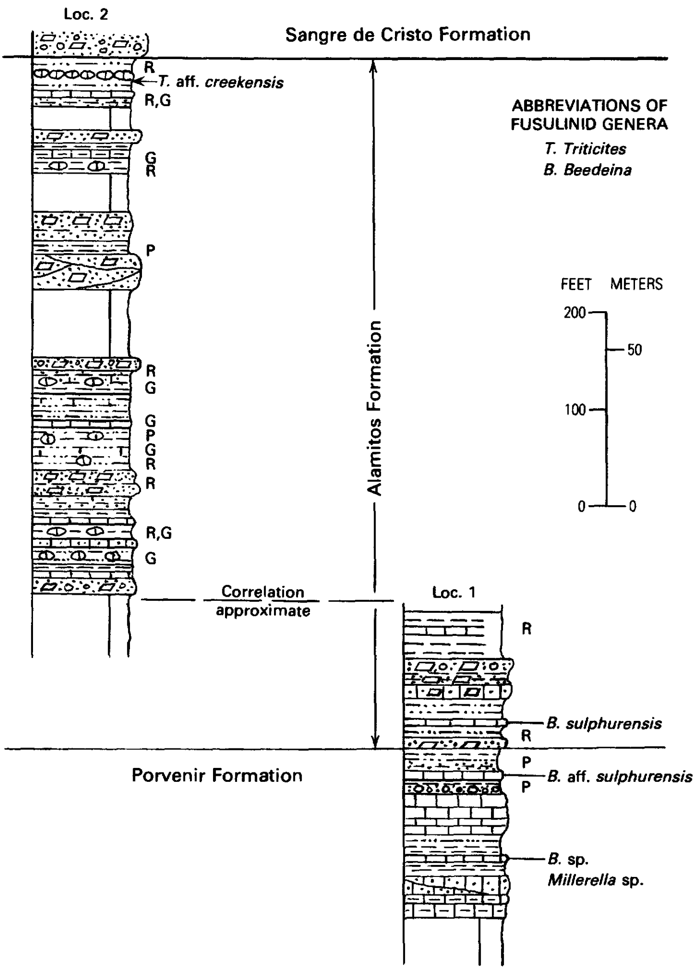

FIGURE 10.—Composite stratigraphic section of the Alamitos Formation along U.S. Forest Service road (loc. 2) and at the type locality of Porvenir Formation (loc. 1). Localities shown on figures 5 and 6. Symbols used are explained in figure 8. Base of section at locality 2 is about 3,000 ft (915 m) northwest of top of section at locality 1.

arkosic conglomerates form massive units that commonly are interbedded with unfossiliferous red shales. These rocks are similar to some parts of the overlying Sangre de Cristo Formation and locally cause confusion in determining the contact with that formation. However, the uppermost part of the Alamitos contains fossiliferous marine limestone, sandy limestone, and commonly olive-green shale. The top of the Alamitos (the equivalent upper member of the Madera of past usage) is mapped at the top of the highest marine beds by Northrop and others (1946), Baltz (1972), and Baltz and O'Neill (1980a,b).

THICKNESS

Near the eastern front of the mountains south of Montezuma, the Alamitos is absent locally, and it is only about 180 ft (55 m) thick about 1 mi (1.6 km) southwest of Montezuma. Farther west, the Alamitos is about 715 ft (218 m) thick at locality 2 (figs. 6 and 10) south of Gallinas Creek. The formation thickens northward and is at least 1,285 ft (390 m) thick about 1.5 mi (2.4 km) northwest of Sapello where part is cut out by a Cenozoic fault in the upper part of the formation. Between Rito Cebolla and Mora River, the formation is locally only about 100 ft (30 m) thick. At Mora River (east of loc. 4) the Alamitos is about 1,050 ft (320 m) thick.

CONTACTS WITH ADJACENT ROCKS

On the Paleozoic Tecolote uplift from Montezuma south, the Alamitos lies unconformably on the Porvenir Formation and locally overlaps it to the south. The Alamitos is overlain unconformably by the Sangre de Cristo Formation that laps southward onto Precambrian rocks (Northrop and others, 1946).

At the west, from the vicinity of locality 2 northward past Sapello River, the contact of the Alamitos and Porvenir is locally disconformable but the hiatus may be small, inasmuch as *Beedeina sulphurensis* is present in both formations. Not far east of locality 2, the Alamitos is folded sharply along the Cañon del Medio anticline and thins because of local angular unconformity with the overlying Sangre de Cristo Formation. (See Baltz, 1972, sheet 2, section *F–F'*.)

In the eastern part of the mountains between Rito Cebolla and Mora River, the contact of the Alamitos and Porvenir is locally unconformable. In this area, where the Alamitos is thin (100–250 ft; 30–75 m), the contact with the Sangre de Cristo Formation apparently is a local angular unconformity.

At Mora River (loc. 4) and farther north, the contact of the Alamitos and Porvenir is unconformable, as is shown by thinning of the Porvenir and because the fusulinid-bearing youngest rocks of the Porvenir, just below the contact, are older than the marker zone of the Porvenir farther south. The contact of the Alamitos and the Sangre de Cristo here seems to be transitional, and the oldest part of the Sangre de Cristo here could be Late Pennsylvanian (Virgilian?), although our paleontologic data from these rocks currently are too sketchy to be certain.

AGE

Fusulinids occur at many places in the lower part of the Alamitos. The stratigraphically lowest fusulinids are *Beedeina sulphurenesis* of late Des Moinesian age. Near locality 2 of this report (figs. 5, 6, and 10), *Triticites* aff. *T. creekensis* Thompson was found in nodular limestones about 40 ft (12 m) stratigraphically below the top of the Alamitos at locality A (fig. 6) along an abandoned road. This form indicates an Early Permian (early Wolfcampian) age.

North of New Mexico Highway 65, a few hundred yards northeast of Western Life Camp (fig. 6), a limestone near the middle of the Alamitos contains *Triticites nebrascensis* of early Missourian age. West of Tecolote Creek about 1.3 mi (2 km) southeast of Blue Haven Camp (fig. 5), fusulinids belonging to the group of *Triticites secalicus* were found in limestone about 150 ft (45 m) below the top of the Alamitos. These triticites suggest a mid-Virgilian age. Therefore, in the western part of the Gallinas Creek area, the Alamitos contains marine rocks representing Middle and all the Upper Pennsylvanian Series, as well as part of the Lower Permian.

We did not find fusulinids in the upper part of the Alamitos farther north. Most of the brachiopods, pelecypods, and gastropods we collected from the upper part from Sapello River northward are definitive only of Late Pennsylvanian age (J. T. Dutro, Jr., written commun., 1980). However, shale just below the top of the Alamitos in roadcuts a little less than 1 mi (1.6 km) west of Sapello contains *Isogramma* cf. *I. renfrarum* Cooper, *Stegocoelia* (*Taosia*) cf. *S.* (*T.*) *percostata* (Girty), and *Orthomyalina* sp. which are suggestive of Virgilian age (J. T. Dutro, Jr. and E. L. Yochelson, written commun., 1980). Therefore, rocks of probable Virgilian age are present in the Alamitos at least as far north as Sapello.

North of Rito Cebolla, where the Alamitos is locally thin, only the Des Moinesian part containing *Beedeina sulphurensis* is present. At Mora River (east of loc. 4) the Alamitos has thickened considerably. The lower-middle part contains *Beedeina sulphurensis*. Brachiopods and pelecypods from near the top of the Alamitos indicate a Late Pennsylvanian, probably Missourian age, according to J. T. Dutro, Jr.

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