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GEOLOGIC HISTORY OF THE SAN JUAN BASIN AREA, NEW MEXICO AND COLORADO

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Introduction

The San Juan Basin has a rich and varied geologic history. It has been the site of many epochs of marine and continental sedimentation and its margins reveal the results of several orogenic episodes. The records of these events are, of course, in the rocks of the area; but these can very easily be interpreted in diverse ways. As investigations progress, new records are brought to light. In consequence, any geologic history of the San Juan Basin must, at this time, be regarded as preliminary and provisional.

Pre-Cambrian Eras

Data on the paleogeography of the San Juan Basin area during pre-Cambrian time are inadequate for other than generalizations. It is clear, however, that much of the region was occupied by a geosyncline into which debris from adjacent rising masses was poured. The resulting rocks appear to be in excess of 10,000 feet in thickness and are referred to as the Needle Mountains group. They unconformably overlie older schist and gneiss, from which they may have been derived. The Needle Mountains group is locally intruded by younger pre-Cambrian granite and is regionally metamorphosed into quartzite, slate, schist, and phyllite as a result of widespread late pre-Cambrian orogeny.

Cambrian, Ordovician, and Silurian Periods

The Paleozoic seas do not appear to have transgressed into the San Juan Basin region until late Cambrian time. It is believed that this transgression was from a northerly direction and that the sea lapped against a low-lying land that occupied parts of the central and southern San Juan Basin as well as a portion of central New Mexico. The sediments that were deposited are quartzose sandstone and sandy shale and are called the Ignacio quartzite. At the outcrop the Ignacio quartzite is present in Colorado in the Needle Mountains and in the Piedra Uplift on the north margin of the San Juan Basin. It is unknown in the uplifts along the east, west, and south sides of the basin but appears to be locally present at depth in the northern part of the basin. The Ignacio quartzite rarely exceeds 200 feet in thickness and commonly consists of a few feet of ferruginous and conglomeratic sandstone that rest unconformably on the pre-Cambrian.

Neither Ordovician nor Silurian rocks are known in the San Juan Basin and the adjacent uplifts. It is possible that sequences of strata belonging to these systems may have been deposited; but if so, they were stripped prior to deposition of Upper Devonian strata.

Devonian and Mississippian Periods

The Elbert formation of late Devonian age disconformably overlies the Ignacio quartzite of Upper Cambrian age or locally rests directly on the pre-Cambrian rocks. The Elbert formation consists of a sequence of quartzose sandstone, red and yellow calcareous shale, and thin beds of dolomitic limestone that rarely exceeds 60 feet in thickness. The Elbert appears to be a deposit that resulted from transgression of the late Devonian seas. The distribution of the Elbert in the San Juan Basin area is somewhat similar to that of the Ignacio quartzite. It is present in the northern rim of the basin and is locally encountered at depth in San Juan County, New Mexico, but it has not been reported farther south. It is possible that its distribution may have been controlled by the central New Mexico positive area that restricted the late Cambrian seas.

Succeeding the Elbert formation is the Ouray limestone, of late Devonian age, which reaches a thickness of 75 feet. It appears to have had originally a wide distribution in the San Juan Basin area as well as in other parts of northern New Mexico. Although the sea probably transgressed the central New Mexico positive mass, the Ouray, as well as the succeeding Mississippian Leadville limestone, was stripped widely in central New Mexico and the southern part of the San Juan Basin as a result of pre-Pennsylvanian erosion. In consequence, the Ouray limestone is rather continuously present only along the northern rim of the basin in Colorado and in San Juan County, New Mexico. Erosional remnants are known in some of the uplifts along the Rio Grande Valley, but have not been reported at depth in the southern part of the San Juan Basin.

Disconformably overlying the Ouray limestone is the Leadville limestone of early Mississippian age. Although a hiatus between the two units is indicated by faunal data the formations are parallel and can be separated only with difficulty in the San Basin area. In this region the Leadville is rarely in excess of 280 feet in thickness and appears to be a remnant of the widespread early Mississippian marine transgression of the western United States. Its distribution appears to have been modified greatly by pre-Pennsylvanian erosion; and, like the Ouray limestone, it is generally present only in the northern part of the San Juan Basin.

Later Mississippian rocks are unknown in the San Juan Basin area, and it is doubtful if any were

deposited. If present, they may be presumed to have been quite thin and to have been completely removed prior to Pennsylvanian time.

Pennsylvanian Period

After deposition of the Lower Mississippian Leadville limestone there were epeirogenic movements that resulted in the emergence of the San Juan Basin area, as well as much of the adjacent region to the south. The Leadville limestone, the Ouray limestone, and older Paleozoic formations, if present, were subjected to long continued subaerial erosion. In the area that is now the southern part of the San Juan Basin the formations were generally removed. Farther north the limestones were subjected to extensive solution by shallow ground waters that resulted in a karst topography. Remnants of pre-Pennsylvanian Paleozoic strata in central New Mexico likewise show evidences of solution by these ground waters. It is suggested that a generally east-trending arch existed, the northern margin of which lay in the southern part of the present San Juan Basin. On the higher portions of this arch the strata were more deeply eroded, whereas in slightly depressed areas as in the northern part of the San Juan Basin they were affected by ground-water solution but less deeply eroded by surface agencies.

Pennsylvanian seas widely transgressed across this area and covered all except two exceedingly stable but only mildly active positive areas, the sites of the present Zuni and Defiance Uplifts. This marine transgression was marked by the deposition of brown clastic sediments and impure limestone. These basal strata are the Molas formation, which rarely exceeds 200 feet in thickness.

Immediately after this marine transgression a southeast-trending fold belt in southwestern Colorado came into existence. From this positive element, one of the ranges of the Paleozoic Ancestral Rocky Mountains, clastic sediments were shed into the adjacent northern part of the present San Juan Basin.

As this Uncompahgre fold-belt grew it expanded southward into New Mexico. Presently a chain of mountains separated by intermontane basins was defined. Thus in rather early Pennsylvanian time the setting of the present San Juan Basin was that of a shallow but broad trough between the actively rising Ancestral Rocky Mountain province on the northeast and the inactive but stable Zuni and Defiance arches on the southwest and west. This old basin was open to the southwest and northwest.

Clastic materials were derived from the rising Ancestral Rocky Mountains and transported into the basins, where they were deposited in association with marine limestone to constitute the Hermosa formation of southern Colorado and the lower part of the Madera formation of New Mexico. Farther to the northwest and largely beyond the limits of the present San Juan Basin a deep basin marginal to the Uncompahgre axis was apparently characterized by almost complete lack of aeriating currents and was the site of accumulation of fetid shale and chemical precipitates. Such strata constitute the Paradox member of the Hermosa formation of the northwestern San Juan Basin and adjacent parts of Colorado and Utah, which interfingers with the lower part of the normal facies of the Hermosa. The Hermosa attains a thickness of about 2,000 feet, but no reliable original thicknesses of the Paradox member have been established.

Thus Pennsylvanian sediments of various types, in general clastic to the northeast and more calcareous to the south and west, accumulated in the San Juan Basin area under virtually geosynclinal conditions. They lapped around the low flanks of the Zuni and Defiance axes and were deposited in deep subsiding linear troughs adjacent to and between the Ancestral Rocky Mountain axes.

Rather late in Pennsylvanian or early Permian time sedimentation of clastics in the Rocky Mountain province appears to have exceeded subsidence in the marine basins. In consequence, the strand lines gradually migrated away from the active tectonic areas. This migration is reflected first in the increasing quantities of clastic materials that contain the remains of land-living organisms and finally by continuous sequences of detritus that appear to have been deposited under dominantly fluviatile and piedmont conditions. The forerunners of this change of sedimentary environment are the upper member of the Pennsylvanian Madera limestone in New Mexico and the Permian (?) Rico formation of parts of Colorado. The clastic piedmont and fluviatile sequence is the Cutler formation in Colorado and the Abo formation in New Mexico.

Permian Period

Sedimentation of clastics, proceeding at a pace that exceeded the subsidence of the flanking and intermontane basins of the Ancestral Rocky Mountains region, continued in early Permian time. Locally more than 2,000 feet of coarse-grained red or brown arkose accumulated. By the end of early Permian time the seas had withdrawn a considerable distance to the west and south of the San Juan Basin area. Activity in the tectonic belt of the Ancestral Rocky Mountains had ceased and the fold belts were low lying.

Epeirogenic movements then gradually downwarped the San Juan Basin region and tilted it southward, thus permitting encroachment of the Permian sea from the south. The deposits that resulted were basal massive-bedded clastics succeeded by evaporites to the south and even bedded

siltstone and fine-grained sandstone to the north. These sediments constitute the Yeso formation, which is as much as 1,400 feet in thickness. The strand line of this sea does not appear to have reached farther than about 36° north latitude on the eastern margin of the San Juan Basin and 37° north latitude on the west margin.

Minor fluctuations of the strand occurred and the succeeding San Andres formation, more than 800 feet in maximum thickness, and consisting of the Glorieta sandstone member overlain by a limestone member, were then deposited.

The top of the San Andres formation, or, north of its sedimentary limit, the top of the Cutler formation, is a plane of disconformity. No younger Permian sediments are known, and in consequence late Permian history in the San Juan Basin area is conjectural.

Triassic Period

There are no well-established records of Lower Triassic sediments in the San Juan Basin area. However, the marine Moenkopi formation of early Triassic age is widely distributed to the west. Whether its absence to the east is due to nondeposition or to pre-late Triassic erosion is problematical. Farther north, in western Colorado, the Uncompahgre positive element is known to have been sufficiently emergent to have shed coarse clastics into the border area of the early Triassic Moenkopi sea. This fact suggests that a rather large eastern area may, during early Triassic time, have been a highland rather than a basin, and that the San Juan Basin was not a site of deposition at that time. The setting prior to deposition of the Upper Triassic Chinle formation was one of general emergence. To the south in the area of deposition of the San Andres formation a karst topography was developed. Farther north a rolling plain rose to the mature Ancestral Rocky Mountain area, which had been reduced to an upland of low relief.

Fluviatile deposits of late Triassic age were widely deposited on this plain. The basal coarse beds are the Shinarump conglomerate, the Agua Zarca sandstone member and Poleo sandstone lentil of the Chinle formation, and the Santa Rosa sandstone. The overlying beds are dominantly red and variegated clay shale of the Chinle formation, which locally attains a thickness of 1,500 feet. Sources of these materials were from upland areas, chiefly in the Ancestral Rocky Mountains.

Jurassic Period

After deposition of the Upper Triassic Chinle formation a broad east-trending arch was developed south of the present San Juan Basin. At the same time the Ancestral Rocky Mountains were locally rejuvenated. Red sand and silt derived from these source areas were deposited in the San Juan Basin during Jurassic (?) time under aqueous and floodplain conditions. These constitute the Glen Canyon group. Although thin over most of the area, the Glen Canyon is at least 700 feet thick in the vicinity of the Four Corners. Farther west this group comprises in ascending order the Wingate sandstone, Kayenta formation, and Navajo sandstone.

Immediately after deposition of the Glen Canyon group the southern arch and the Ancestral Rocky Mountains were slightly rejuvenated and the areas that had received Jurassic (?) sediments were locally folded and then planed by erosion. Sediments of the San Rafael group that attain a maximum thickness of more than 300 feet were deposited in the San Juan Basin area under alternating shallow marine and littoral conditions. A series of strand-line fluctuations resulted in the deposition of cross-bedded sandstone. This epoch was culminated by withdrawal of the seas and deposition of the Junction Creek and Bluff types of sandstone.

Onto the floodplain that resulted from this marine regression fluviatile sediments of the Morrison formation, which reach a maximum thickness of about 800 feet, were deposited. The southern arch as well as parts of the Ancestral Rocky Mountains continued to be sources of clastic materials.

Cretaceous Period

Lower Cretaceous strata, although of great thickness in northern Mexico, southern New Mexico, and adjacent Texas, are thin and in many places absent in the San Juan Basin area. This appears to be a result of accentuation of the east-trending arch in central New Mexico during parts of early Cretaceous time, for it is clear that this arch was a hinge line of subsidence, separating a deep basin with thick marine deposits to the south from a shelf area to the north on which pediment and fluviatile deposits accumulated. One result of the arching was complete removal of the Jurassic strata locally and widespread removal of parts of the sequence.

Late Cretaceous or late early Cretaceous seas finally advanced across this arch and deposited approximately 200 feet of transgressive beds of the Dakota group on the truncated Jurassic strata. After this transgression, which was from the east and southeast, the dark marine calcareous muds that constitute the Mancos shale were widely deposited. The Mancos reaches a maximum thickness of more than 2,000 feet. To the west and southwest of the present San Juan Basin, rising mountains shed debris that was deposited in coastal swamps and deltas and formed sandstone, carbonaceous shale, and coal beds that interfinger with the marine shale. These coal-bearing sequences are the Mesaverde formation and are a result of several minor

retreats and advances of the strand line. In the Gallup area the Mesaverde group is at least 3,500 feet thick.

Mesaverde deposits in the San Juan Basin are overlain by the dark, marine Lewis shale which is as much as 1,700 feet thick in some places, and records the final widespread marine transgression in Montana time. The eastward retreat of the sea was marked by the deposition of the regressive Pictured Cliffs sandstone, which is locally 275 feet thick. The superjacent Fruitland and Kirtland formations are as much as 1,000 feet thick and are records of swamp and floodplain conditions that prevailed immediately afterwards.

As the Cretaceous period drew to a close increasing orogenic activity accompanied by sporadic vulcanism caused the area of the San Juan Basin to be flooded with detritus from rising source areas to the north and northeast. Thus while the sea retreated eastward or southeastward great thicknesses of terrestrial materials were deposited in the western and central parts of the basin. These deposits constitute the McDermott formation and a part of the Animas formation as well as the Ojo Alamo sandstone.

Cenozoic Era

It is apparent from the preceding account of Cretaceous history in the San Juan Basin area that the Laramide orogeny began in late Cretaceous time and is recorded in the McDermott and Animas formations. Vulcanism accompanied by deposition of andesitic detritus of the Animas formation continued well into Paleocene time in the northern part of the San Juan Basin, whereas farther south sands and silts containing no notable quantities of volcanic detritus were deposited under fluviatile conditions. These latter deposits constitute the Nacimiento group, which, in the vicinity of Cuba, is 1,400 feet thick.

The "Wasatch" (San Jose of Simpson) formation of Eocene age overlies the Animas formation in the northeastern part of the San Juan Basin; elsewhere it rests on the Nacimiento group. It constitutes a sedimentary record of a late episode in Laramide mountain building in the area and consists of at least 2,500 feet of alternating sandstone and variegated shale that were derived from rising fold belts, the Sierra Nacimiento on the east, the folded ranges of the San Juan Mountain group on the north, and the Defiance and associated uplifts on the west. The "Wasatch" formation of the San Juan Basin is, in fact, a basin-filling deposit.

At this time of late Laramide orogeny most of the striking structural features of the basin rim appear to have been initiated, including the Gallup basin and associated anticlines, the Defiance asymmetrical anticline, the hogback, the several small anticlines that lie between the north-plunging axis of the Defiance anticline and the south-facing hogback, the Archuleta anticlinorium, and the Sierra Nacimiento.

In somewhat later Cenozoic time volcanic outbursts accompanied by emplacement of intrusive bodies added debris to the northern rim of the basin and locally deformed the strata. The great quantities of pyroclastics and flows that thus accumulated were then carved into the present San Juan Mountains. The sedimentary products of this erosional cycle, however, were removed from the basin by the active streams that now drain the area.

Contemporaneous with this volcanic activity epeirogenic movements elevated the entire area, and late Cenozoic orogeny in the adjacent Basin and Range country to the south and southeast locally expanded into the basin rims, thus modifying the early geologic structure.

Extensive glaciation during the Pleistocene epoch finally carved the San Juan Mountains into their present bold features, and outwash from the glaciers beveled and locally covered the older strata of the northern rim.

Geologic events since then have been those of erosion. The present landscape, characterized by picturesque mesas and buttes in the basin and by rugged hogbacks and ridges on the rim, is a result of the action of water and wind on a sparsely vegetated country.