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SUMMARY OF GEOLOGIC DATA OBTAINED FROM BOREHOLE GB-1, PROJECT GASBUGGY[1]

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INTRODUCTION

On a clear sunny day, Sunday, December 10, 1967, about 300 people were standing, momentarily hushed, on a small mesa in northwestern New Mexico awaiting the detonation of a 26-kiloton nuclear explosive at a depth of 4,240 feet. For a few seconds after the countdown reached zero nothing happened; then suddenly the ground was rocked by a double shock wave and a low rumbling roar was heard in the distance. The explosion completed the most dramatic phase of Project Gasbuggy—an experiment designed to determine the practicability of increasing gas production by fracturing low permeability sandstones with nuclear explosives.

Project Gasbuggy is a joint venture of the U.S. Atomic Energy Commission, the El Paso Natural Gas Co., and the U.S. Bureau of Mines. The site chosen by the participants for the experiment is in sec. 36, T. 29 N., R. 4 W., New Mexico principal meridian, Rio Arriba County, N. Mex., about 55 miles east of Farmington, N. Mex. (fig. 1). This site was chosen because (1) the Pictured Cliffs Sandstone, the target formation, is thicker (nearly 300 feet) than in any other part of the San Juan Basin, (2) the Pictured Cliffs Sandstone is gas-bearing but it does not have sufficient permeability to yield commercial quantities of gas, (3) the formations above the Pictured Cliffs do not contain large amounts of water, and (4) the area is far from population centers.

BOREHOLE GB-1

Borehole GB-1 (Gasbuggy 1) was the first test hole drilled for Project Gasbuggy. The primary purpose of drilling the hole was to obtain for laboratory analyses core samples of the rocks which would be affected by the nuclear explosion. The test hole is located 1,324 feet from the south line and 1,614 feet from the west line of sec. 36 at a surface elevation of 7,200.19 feet. Drilling was begun on February 11, 1967, and a depth of 3,436 feet was reached on February 21, 1967. All depths herein referred to were measured from the Kelly bushing whose elevation was 7,210.09 feet. The hole was cored from 3,436 feet to 4,316 feet; 5¼-inch core was cut from 3,436 to 3,880 feet, and 3½-inch core was cut from 3,880 to 4,316 feet. Coring was completed on March 16, 1967. The hole was mud-drilled from the surface to 3,880 feet and gas-drilled from 3,880 feet to the total depth.

Coring started in the lowermost part of the Paleocene Nacimiento Formation and continued, in descending order, into the Paleocene Ojo Alamo Sandstone and the Upper Cretaceous Fruitland Formation, Pictured Cliffs Sandstone, and upper part of the Lewis Shale. The author examined and described the core segments (Fassett, 1968) as they were brought to Farmington from the well and later examined in detail chips of the cores with a stereomicroscope. The core chips were subsequently sent to R. S. Tschudy of the U.S. Geological Survey for pollen and spore analyses.

GEOLOGY

The electric log and a lithologic column based on the core description from the cored portion of borehole GB-1 are shown in figure 2. Each of the units shown is discussed below in ascending order. The brief discussion of the environment of deposition and the regional relationships of each of these units is based on data accumulated by the author and J. S. Hinds during several years of study of these units, on the surface and in the subsurface, throughout the San Juan Basin. The results of this study are soon to be published.

Lewis Shale.—The upper part of the Lewis Shale, which

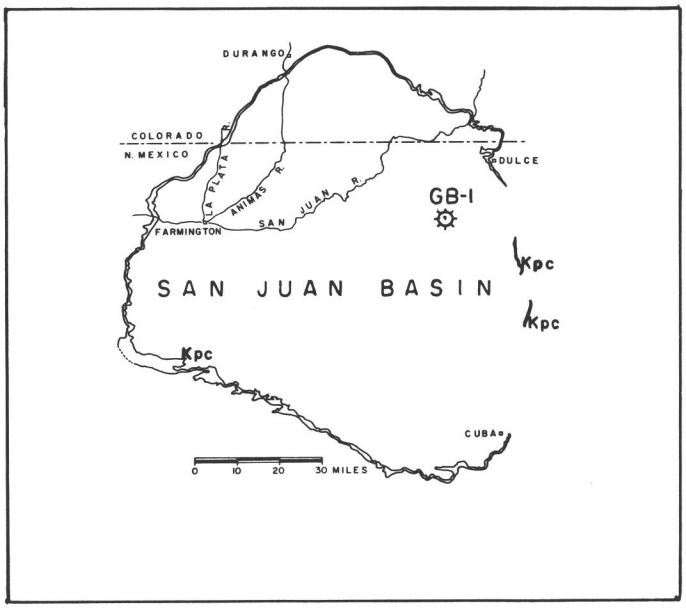

FIGURE 1.
Index map of the San Juan Basin showing the location of borehole GB-1; Kpc, Pictured Cliffs Sandstone.

1. Publication authorized by the Director, U.S. Geological Survey.

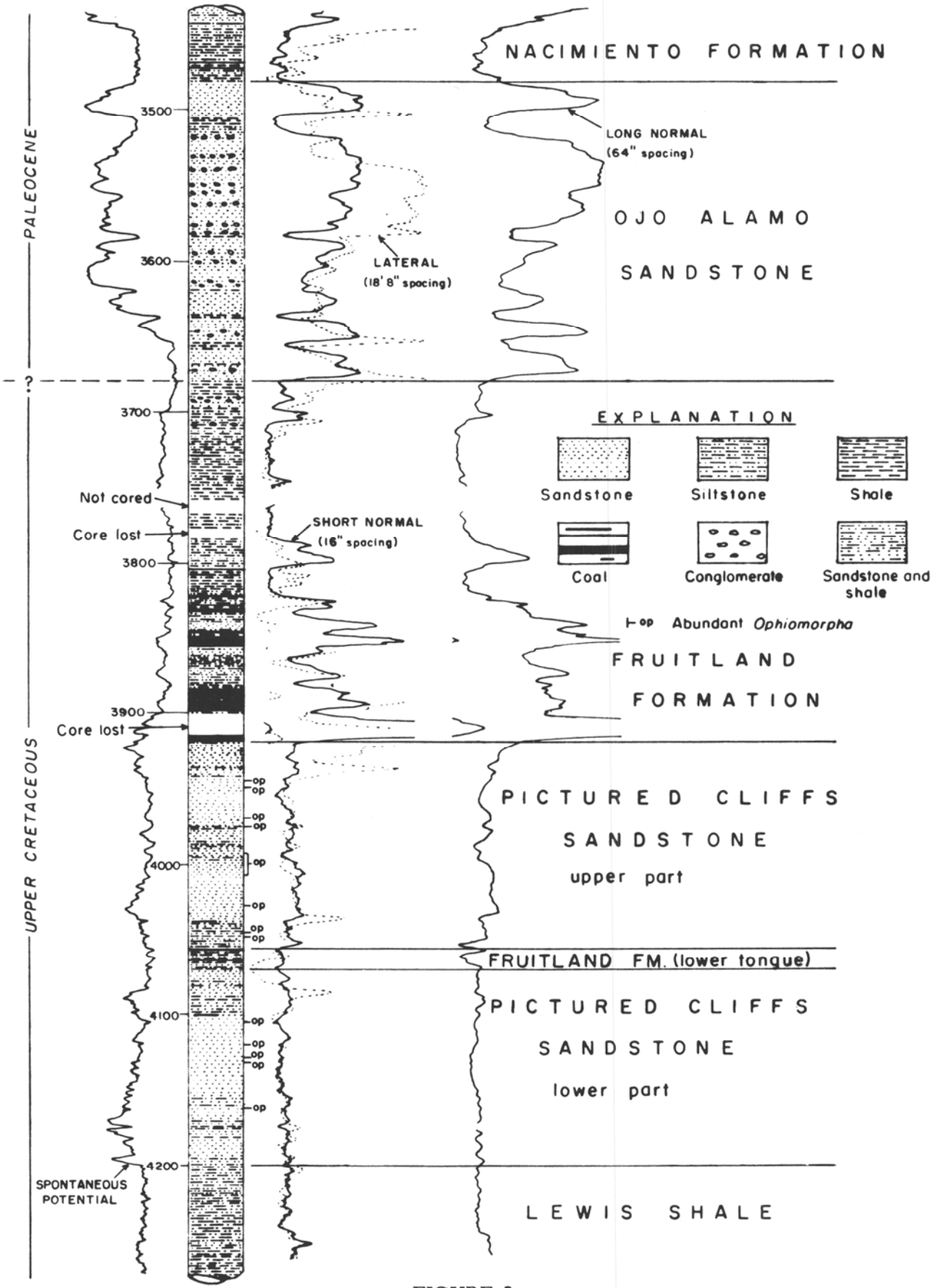

FIGURE 2.
Electric log and lithologic column of the cored portion of borehole GB-1.

was cored from 4,200 to 4,316 feet, is composed of interbedded very fine grained sandstone, siltstone, shale, and silty shale. The amount of sandstone decreases and the amount of black silty massive brittle shale increases downward. The grain size decreases downward from very fine sandstone to siltstone. The lowermost shale units contain a relatively high amount of silt-size material and many cylindrical bodies of sandstone and siltstone about dime-size in cross section.

The portion of the Lewis Shale cored was deposited in a shallow marine environment; the finer grained material at the base of the core represents the deepest water and the greatest distance from the shore.

Pictured *Cliffs Sandstone, lower* part.—The lower part of the Pictured Cliffs Sandstone, which occurs between 4,072 and 4,200 feet, primarily consists of very fine grained to fine-grained sandstone composed of fairly well sorted quartz grains and a small amount of dark grains which include glauconite, mica, and carbonaceous shale. The dark grains give the sandstone a salt-and-pepper appearance. The average grain size of the sandstone decreases downward from fine to very fine at the top to very fine at the base. Many black shale interbeds as much as 0.65 foot thick are present in the lower part of the unit but the interbeds become fewer and thinner upward to about 4,170 feet where they disappear. Thin papery streaks of carbonaceous material occur at the top and decrease in number downward to about 4,100 feet where they disappear. The entire sequence contains casts and molds of Ophiomorpha (fig. 2). The lower part of the Pictured Cliffs fingers out into the Lewis Shale to the northeast.

The lower part of the Pictured Cliffs Sandstone represents a regressive shoreline environment of deposition. The uppermost part of the formation was deposited at or near the beach, whereas the lower part was deposited seaward of the beach in somewhat deeper water. At the time of deposition of the sandstone, the Pictured Cliffs shoreline trended northwest.

Fruitland Formation, *lower* tongue.—A thin tongue of the Fruitland Formation is present between 4,055 and 4,072 feet. It is composed of interbeds of coal, siltstone, shale, carbonaceous shale, and carbonaceous sandstone. The thickest coal bed is at the top of the sequence and is 1.15 feet thick.

The lower tongue of the Fruitland was deposited in a coastal swamp environment. It wedges out into the Pictured Cliffs Sandstone to the northeast and thickens southwestward where it merges with the main body of the Fruitland Formation.

Pictured Cliffs Sandstone, upper part.—The upper part of the Pictured Cliffs Sandstone occurs between 3,918 and 4,055 feet (fig. 2) and is primarily composed of fine to very fine grained sandstone similar to the lower part of the Pictured Cliffs. The lower part of this unit contains thin shale interbeds up to about 4,038 feet. Between 3,970 and 3,995 feet thin black shale interbeds as much as 0.65 foot thick are present. In the upper part another interval of very thin shale and carbonaceous sandstone partings occurs between 3,935 and 3,943 feet. There does not seem to be a consistent gradation in grain size throughout the sandstone of the upper part of the Pictured Cliffs as there is in the lower part. Casts and molds of Ophiomorpha occur throughout most of this unit.

The sediments of the upper part of the Pictured Cliffs were deposited in a marine littoral and beach environment. Because this unit is both underlain and overlain by coal beds of continental origin, it must represent a transgressive phase at the bottom and a regressive phase at the top. The shale interbeds just above 4,000 feet may represent deeper water deposition after maximum transgression, followed by the final regression of the sea. Several other relatively minor cycles of transgression and regression probably occurred during the time that the upper part of the Pictured Cliffs was being deposited.

The upper part of the Pictured Cliffs Sandstone was deposited along a northwest-trending shoreline. It thins and wedges out into Fruitland rocks toward the southwest where the main body and the lower tongue of the Fruitland Formation merge. To the northeast the lower part of the upper part of the Pictured Cliffs fingers out into the Lewis Shale.

Fruitland Formation.—The main body of the Fruitland Formation occupies the interval of rock between 3,680 and 3,918 feet and is composed of sandstone, siltstone, shale, claystone pebble conglomerate, coal, and carbonaceous shale, siltstone, and sandstone. The coal beds are chiefly in the lowermost part of the formation. Thin coal beds occur as high as 3,716 feet. The lowermost coal zone which includes a few thin partings of silty shale has an aggregate thickness of 34 feet. This thickness includes 10 feet of lost core which from interpretation of the electric log seems to be coal. A coal bed 6.4 feet thick above the lowermost coal zone is between 3,858 and 3,884.4 feet. Most of the other rocks in the Fruitland are thinly laminated and intermixed. The thickest discrete unit, other than coal, is a 6.1-foot-thick bed of siltstone and fine-grained sandstone located between 3,837.9 and 3,844 feet. Based on the core information, the most abundant lithologic rock type in the Fruitland is siltstone. Sandstone grain size ranges from very fine to very coarse. The claystone pebbles in the upper part of the Fruitland are as much as 1 inch or more in diameter. Most of the pebbles are flattened; they are gray, green, and red-brown.

The Fruitland was deposited in a coastal swamp environment which graded to a river and flood-plain environment farther landward. The largest and longest enduring swamps were closest to the shore.

Ojo Alamo *Sandstone.—The* Ojo Alamo Sandstone is present between 3,480 and 3,680 feet. It is composed of poorly sorted arkosic sandstone and a few thin shale interbeds and papery carbonaceous partings. Beds of claystone pebbles as much as 0.3 foot in diameter occur at random throughout this unit. A few alert pebbles as much as 0.1 foot in diameter were seen. Grain size of the sandstone ranges from very fine to very coarse. Some parts of the formation contain as much as 20 percent feldspar.

The Ojo Alamo Sandstone was deposited by streams of relatively high energy. The streams may have had a source to the northwest or west. Basinwide subsurface studies (J. E. Fassett and J. S. Hinds, unpublished data, 1968) in-

dicate that the Ojo Alamo Sandstone was deposited on an erosion surface from which possibly thousands of feet of sediment were removed. The sediment thickness between the Ojo Alamo Sandstone and the Pictured Cliffs Sandstone on the outcrop in the northwestern part of the basin is more than 2,000 feet. This same interval is only 238 feet thick at GB-1. The Cretaceous-Tertiary boundary is shown with a query on figure 2 because, although this boundary is believed to be located at the base of the Ojo Alamo Sandstone throughout most of the San Juan Basin, in some areas it has been located in the shales below the base of the Ojo Alamo.

Nacimiento Formation.—The lowermost part of the Nacimiento Formation occupies the interval from 3,436 feet to 3,480 feet. This part of the Nacimiento is composed of interbedded poorly sorted arkosic sandstone, siltstone, shale, and carbonaceous shale. The sandstone contains as much as 40 percent feldspar and ranges from very fine to very coarse.

The rocks comprising the Nacimiento in this part of the basin are probably mainly fluvial in origin and had a northern source. These fluvial beds grade southward into lakebed deposits.

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