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Spencer G. Lucas

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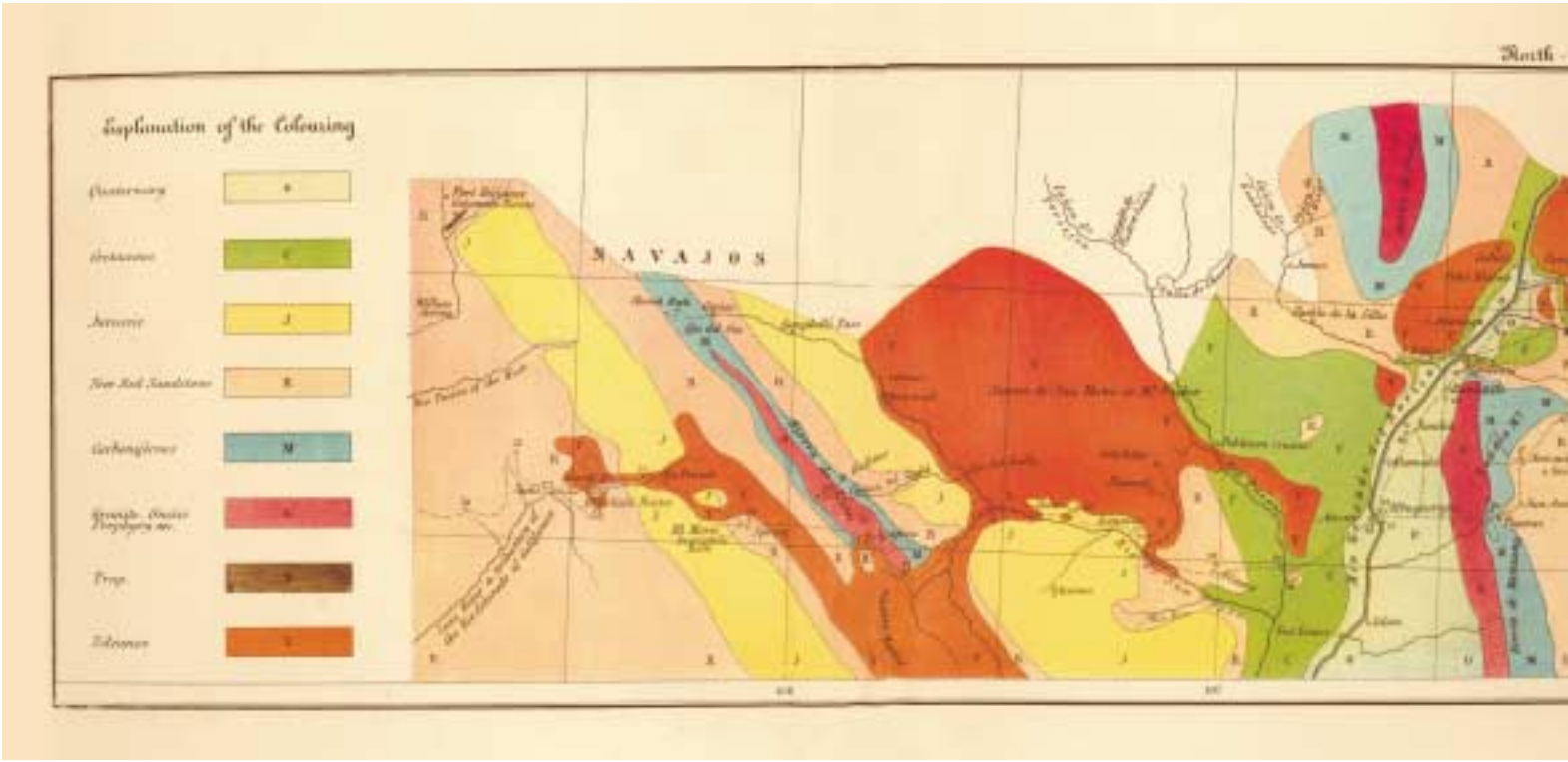
Spencer G. Lucas, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, New Mexico 87104

Introduction

In 1858 the French geologist Jules Marcou (1824–1898) published the first geologic map of New Mexico. This map was a product of Marcou's 1853 traverse of the New Mexico Territory as the geologist of the Whipple expedition to determine a route for a transcontinental railroad (Fig. 1; Kues, 1985a). Marcou's map (Fig. 2) is not a complete geologic map of the territory (nor of the current state)—it encompasses about one degree of latitude around 35°N. Nevertheless, it was the first map explicitly titled "Geological Map of New Mexico." It predates, by about 70 yrs, the first published, statewide maps of Ellis (1925) and Darton (1928). Indeed, Blake's (1856) geologic map of Marcou's route is a crude effort based on Marcou's data by somebody who never visited the state (Kues, 1985a).

Marcou's map is little known to geologists working in New Mexico today, largely because of the rarity of the book in which it first appeared as an approximately 63 x 14 cm (25 x 6 inch) color foldout (Marcou, 1858, pl. 8). Kelley and Northrop (1975, fig. 8), Hook and Cobban (1979, fig. 2), and Kues (1985a, fig. 11; 1985b, fig. 7) reproduced parts of the map in black and white. DeFord (1972) also discussed some aspects of Marcou's map. Here, I re-publish Marcou's entire map in color at about half of its original size (Fig. 2). My text is in four parts—a brief overview of the context of Marcou's map, an explanation of the geologic units Marcou mapped, a summary of the map, and a brief evaluation of its strengths and weaknesses.



Context of Marcou's map

In 1853 Marcou served as chief geologist of the Army Corp of Topographical Engineers' Survey of the 35th Parallel Route for the Pacific Railroad, under the leadership of Lieutenant Amiel Whipple (Goetzmann, 1959). This survey was authorized and funded by the U.S. Congress and traversed from Fort Smith, Arkansas, to Los Angeles, California, between July 1853 and March 1854 (Fig. 1). As survey geologist, one of Marcou's (1853, p. 58) primary goals was "to synchronize the sedimentary rocks of America with those of Europe." The results of Marcou's efforts were geologic maps of the United States that placed him among a competitive group of compilers of such maps, including James Hall, Edward Hitchcock, and Henry Rogers, who worked in the decades immediately preceding the Civil War (Nelson, 1999).

Indeed, as Goetzmann (1959, p. 311) noted, Marcou "published the first geologic map of the West, which made him a controversial figure in American scientific circles for most of his later career." Much of the controversy focused on Marcou's work in New Mexico, where he identified vast expanses of Triassic and Jurassic strata, particularly under the southern High Plains (e.g., Goetzmann, 1959; Kues, 1985b; Nelson, 1989, 1999).

Marcou's stratigraphy

Born in Salins, France, near the Jura Mountains, Marcou first studied mathematics and then trained in geology. His outstanding talent brought him a professorship in mineralogy at the Sorbonne in 1846 and a curatorship (in fossil conchology) at the Jardin de Plantes in 1847. He subsequently traveled to the United States, married into a wealthy family, and ultimately spent

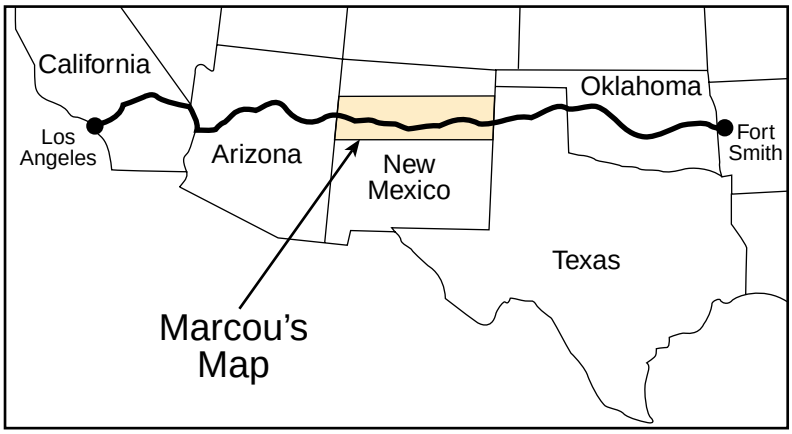


FIGURE 1—Route of the Whipple expedition of 1853, and area included in Marcou's (1858) geological map of New Mexico (Fig. 2; after Goetzmann, 1959).

Marcou's map employs eight cartographic units, three of igneous or metamorphic rocks and five of sedimentary rocks. In temporal order (oldest to youngest), they are:
(1) Granite, Gneiss, Porphyry, etc. (G);
(2) Carboniferous (M for Mountain Limestone);
(3) New Red Sandstone (R);
(4) Jurassic (J);
(5) Cretaceous (C);
(6) Volcanos (sic) (V);
(7) Trap (T); and
(8) Quaternary (O).

FIGURE 2—Jules Marcou's geologic map of New Mexico (from Marcou, 1858, pl. 8).

most of his later life in this country (Lurie, 1974). In reviewing Marcou's geologic map of New Mexico, we should realize that, although Marcou was an all-round geologist in the best tradition of his times, his research and expertise focused on sedimentary rocks and fossils. Indeed, Sarjeant (1980, p. 1648) appropriately labeled Marcou a "stratigrapher, structural geologist and invertebrate paleontologist."

Like most European geologists of the early nineteenth century, Marcou expected to find a close correspondence between the rock formations already delineated in western Europe and those in North America (see quote from Marcou, 1853 above). Thus, his 1858 text abounds in close comparison of the European and North American rock successions, tinged with clear satisfaction when a close correspondence/correlation is established. This is well reflected by Marcou's ready use of European names such as "Mountain Limestone" and "New Red Sandstone" for New Mexican strata. And, where he judged lithologic similarity to be less close, Marcou proposed direct correlation of the New Mexican units to their European equivalents; for example, his correlation of the marine Cretaceous strata of north-central New Mexico to the European "White Chalk."

Granite, gneiss, porphyry, etc.

Based on his observations in the Sangre de Cristo and Sandia Mountains, Marcou (1858, pp. 20–21) noted that "masses of *Granite*…form the centre of the line of dislocation of the Rocky Mountains." He further observed (p. 21) that in the Sandia Mountains (Tijeras Canyon) he encountered a succession of "quartzose metamorphic rocks," then "serpentine," and then granite. However, Marcou provided no further information on these basement rocks, probably because his interests and expertise lay elsewhere.

Carboniferous

Based on what he'd seen of the European section, Marcou would have expected the New Mexican Carboniferous to consist of a lower, limestone-dominated interval and an upper, coal-bearing interval. Marcou applied the British terms "Mountain Limestone" (in Europe these strata form mountains) and "Coal Measures" to these rocks. In New Mexico, Marcou's most detailed examination of these rocks was in the Sandia Mountains (Tijeras Canyon) where he described them as "grayish blue limestone, containing a great quantity of fossils" (p. 20). Above them are a "black slate" or "black schistose clay" assigned to the "coal measures" but not mapped separately (p. 20). Marcou states the Mountain Limestone in New Mexico has a mean thickness of 700 ft (p. 21). His assessment of the fossils he collected and described (mostly brachiopods) led him to incorrectly assign the New Mexican Mountain Limestone to the Early Carboniferous. But, as Newberry (1861) first determined, and as stressed by Kelley and Northrop (1975, pp. 35–44), who reviewed Marcou's Carboniferous fossils in detail, they are all Pennsylvanian in age.

New Red Sandstone

During the early 1800s British geologists referred to most of the strata between the Carboniferous and Lower Jurassic (Liassic) as the New Red Sandstone (Wilmarth, 1925). In Europe, these are largely Permian and Triassic red beds, with some intervals of evaporites and marine limestone. Marcou applied the term New Red Sandstone in a similar way in New Mexico, but there is no evidence that he considered any of these strata to be Permian (or Dyas in age, a term Marcou preferred to Permian; Marcou, 1892) in age. Marcou assigned the New Mexican New Red Sandstone a Triassic age and described it as mostly red sandstone, but including beds of gypsum and dolomite. According to Marcou, these strata are 4,000–5,000 ft thick in New Mexico (p. 10).

Jurassic

Marcou's identification of Jurassic strata in New Mexico was his most controversial conclusion (DeFord, 1972; Kues, 1985b). Marcou stated that these rocks are as much as 400 ft thick on the Llano Estacado in eastern New Mexico, where they are mostly white and yellow sandstone, minor limestone, and a "blue clay" with a characteristic Jurassic invertebrate fauna that includes the bivalves "*Gryphaea*" (now termed *Texigryphaea*) and *Ostrea* (p. 20). This "blue clay," the Tucumcari Shale of current usage, is now assigned an Early Cretaceous age. The "white and yellow sandstone" Marcou assigned to the Jurassic is mostly the Entrada Sandstone, now recognized across the state and known to be of Middle Jurassic age.

Cretaceous

Marcou gave no thickness for these rocks and described them (p. 22) as mostly a white, friable sandstone that is horizontally stratified with index fossils of the Cretaceous, including *Inoceramus*, "*Ammonites*," and *Scaphites*. The shark tooth found near Galisteo in these strata that Marcou named *Ptychodus whipplei* was the first vertebrate fossil described from New Mexico. Marcou correlated the New Mexican Cretaceous to the White Chalk (Craie Blanche) of France. He also stated (p. 22) that "the discordance of stratification of the Upper Cretaceous of New Mexico, with all the sedimentary rocks found there, indicates that this formation was deposited *after* the principal dislocation of the Rocky Mountains, which took place at the *end of the American Jurassic period*." This repudiation of basic principles led Marcou to an erroneous conclusion, as the Cenozoic uplift of the Rocky Mountains postdates the Cretaceous strata that are, in part, dislocated by the Rocky Mountain orogeny, not the reverse!

Volcanos (sic)

Marcou mapped volcanic rocks across large parts of north-central and west-central New Mexico. His text offers brief descriptions of volcanoes near Galisteo, San Felipe Pueblo, Mount Taylor, and east of Zuni Pueblo. He was particularly impressed by "immense overflowings of lava" (p. 22) in west-central New Mexico, and noted that the lava flows "are destitute of vegetation, and give to the country, where they are found, an arid and desolate aspect, named by the Mexicans, very appropriately, *Mal Pais*" (pp. 22–23).

Trap

Marcou used the term trap to refer to dikes formed by dark-colored igneous rocks. He mapped such dikes in the Galisteo area and near Fort Defiance on the western edge of the map. Marcou offered no discussion of these rocks, but did note near Galisteo (p. 56) "a trap dyke, direction 30° east-east-north and 30° west-west-south, cutting through the strata of the New Red Sandstone."

Quaternary

Marcou termed the youngest sediments he saw in New Mexico Quaternary (in the text, "Quarternary" [sic]). He noted (p. 22) "the plain of the Rio Grande del Norte, where the Granite is found covered with *Drift* and *Alluvium*, which form the whole plain as far as the right bank of the river…." Marcou, however, offered no detailed description of these rocks, which he probably assumed to be very young because of their coarse-grained and unconsolidated textures.

Summary of the map

Four pages of explanatory text (Marcou, 1858, pp. 54–57) accompany Marcou's geologic map. This text begins with a short introduction, concluded by a disclaimer: "This map must be regarded as a first essay upon a country about which the geological notions have hitherto been very vague, and I publish it only as a first attempt upon a *terra incognita*." The remaining text is structured as a narrative organized by Marcou's 38 camps in New Mexico and the traverses between these camps. Here, I divide Marcou's map into three geographic portions—east-central, north-central, and west-central New Mexico.

East-central New Mexico

Marcou traversed east-central New Mexico from east to west, just north of the 35th parallel, and stayed at ten camps. The geologic map across this traverse identifies only two stratigraphic units—lowlands of New Red Sandstone and uplands of Jurassic strata.

Marcou's observations at Pyramid Mountain (pp. 18–21; Fig. 3), between camps 4 and 5, proved critical to these determinations (DeFord, 1972; Kues, 1985b). Here, Marcou collected gryphaeid bivalves from shales near the butte summit. *Gryphea* is a characteristic Jurassic bivalve in Marcou's native Jura Mountains region, so he reasonably inferred a Jurassic age for the New Mexico fossils and assigned a Jurassic age to all of the strata defending the Llano Estacado and its erosional outliers. But, these fossils are not true *Gryphaea* and instead belong to a closely related Early Cretaceous taxon, now called *Texigryphaea*. Thus, the shale strata at Pyramid Mountain are actually of Cretaceous age, and Marcou's error engendered a lengthy debate that was never resolved in his lifetime (Lurie, 1974; Kues, 1985b). Marcou's assignment of the underlying rocks to the Triassic lacked a paleontological basis; instead, stratigraphic position and similarity to the nonmarine Keuper (Upper Triassic) strata of Europe provided the principal basis for Marcou's determination.

From Camp 1 (near present San Jon) to Camp 7 (near present-day Santa Rosa), the lowland country is largely Upper Triassic red beds (now Chinle Group). But as Marcou traversed northwestward, up the Pecos River (Camps 8–10), he failed to recognize, as distinct, the underlying Permian strata. Indeed, on Marcou's map, all the nonmarine red beds are New Red Sandstone, including strata now distinguished as Permian (Abo, Yeso, and

Glorieta Formations), Triassic (Moenkopi Formation and Chinle Group), and Eocene (Diamond Tail and Galisteo Formations). And, at some locations (notably Tijeras Canyon in the Sandia Mountains), Marcou even included in the New Red Sandstone strata now known to be Jurassic.

North-central New Mexico

North-central New Mexico encompasses the area from Marcou's camps 11 (Galisteo River) to 26 (just southwest of Albuquerque). Marcou correctly identified Cretaceous strata just east of Galisteo, based in large part on their fossil content, which included inoceramid bivalves and ammonites known to him to be Late Cretaceous fossils in Europe. He also identified volcanic rocks of the Gold Hills–Ortiz Mountains, which are now known to be mid-Cenozoic (primarily Oligocene) in age. Understandably, having no way to determine precise ages, Marcou included basalts of late Cenozoic age he encountered just west of the Rio Grande (Cerros del Rio volcanic field, Santa Ana basalts) in the same cartographic unit of volcanic rocks. Furthermore, lack of attention to lithologic detail probably also explains why Marcou included all igneous rocks, other than a few dikes, in one map unit.

Marcou identified the relatively young sediments along the Rio Grande valley (now mostly Santa Fe Group of Miocene–Pleistocene age) as Quaternary. Marcou's mapping of these sediments differentiates the Española basin outcrop belt from the Albuquerque basin outcrop belt and even shows the northward right shift of the rift basins, although Marcou attributed no significance to these patterns.

After Marcou reached Albuquerque, he went east and northeast through the Sandia Mountains and up to Pecos in the Sangre de Cristo Mountains ("Rocky Mountains" on Marcou's map). In the Sandias he first encountered rocks he correctly identified as Carboniferous, assigning them (based largely on their fossil content) to the Mountain Limestone, which in current terminology would be Mississippian (they are actually Pennsylvanian). Marcou recognized the granitic cores of the Sandia and Sangre de Cristo Mountains, and their principal sedimentary cover as marine strata of Carboniferous age. He thus reasonably (but incorrectly) extrapolated this structure onto the Jemez Mountains, which he did not visit. Doubtless, if he had, he would have immediately recognized their volcanic origin. Indeed, the eastern flank of the Jemez Mountains as depicted by Marcou—broad outcrop belts of Carboniferous, New Red Sandstone, and Cretaceous—is one of the more significant errors on his map.

West-central New Mexico

Here, west-central New Mexico refers to Marcou's camps 27–38, a traverse from Albuquerque westward across the Rio Puerco, south of Mount Taylor, around the southeastern edge of the Zuni Mountains and on to El Morro, Zuni Pueblo, and what is now Arizona. On this traverse, Marcou assigned the rocks to units already encountered to the east.

FIGURE 3—Mesozoic strata of Pyramid Mountain viewed from the east.

He thus identified the Mount Taylor and Zuni–Bandera volcanic fields, assigning them to his general cartographic unit "Volcanos." This again underscores Marcou's expertise in sedimentary rocks and fossils, for he failed to differentiate the very young lava flows in west-central New Mexico from the older and lithologically different igneous rocks in the Galisteo area of north-central New Mexico. Furthermore, Marcou's map shows a broad area of volcanic rocks east of Mount Taylor extending east of the Rio Puerco. No such volcanic rocks exist; probably they are an unwarranted extrapolation by Marcou of the Albuquerque volcanoes and basalts westward to meet the Mount Taylor field.

In west-central New Mexico, Marcou identified vast expanses of Jurassic strata, mostly the yellow cliff-forming sandstones now called the Entrada Sandstone. A significant omission is Marcou's failure to identify Cretaceous strata in west-central New Mexico. Indeed, in his text (p. 57) he claims to have found *Gryphaea dilatata* var. *tucumcarii* near Camp 30 (near present-day Cubero), which must be an error for one of the common and superficially similar Cretaceous bivalves now assigned to *Pycnodonte* (though long assigned to *Gryphaea*).

Marcou's map gives little or no hint of the presence of the San Juan Basin, which in its broadest sense begins on the northeastern flank of the Zuni Mountains. Indeed, Marcou's portrayal of the Zuni Mountains is not completely correct. On his map the Zunis are similar to the Jemez Mountains—a linear welt of granite flanked on both sides by Carboniferous New Red Sandstone, and Jurassic strata. In fact, the basement-cored Zunis are overlain to the northeast by sedimentary strata (as Marcou depicts, though very little Carboniferous rock is actually present) but separated on the southwest from Mesozoic strata by faults that dip to the west-southwest, away from the range. Limestone-dominated strata of the Permian San Andres Formation in the Zuni Mountains evidently were mistaken by Marcou for his "Mountain Limestone."

Conclusion—strengths and weaknesses of the map

The great strength of Marcou's map is its accurate depiction of the basic geologic structure of part of New Mexico—southern High Plains mantled by largely flat-lying Mesozoic strata, basement-cored block-faulted mountains in central New Mexico draped with Carboniferous marine strata, Rio Grande valley filled with young Cenozoic sediments, and southern Colorado Plateau covered in large part by Jurassic strata and extensive volcanic fields. The most significant weaknesses of the map are its evident errors: misidentification of Lower Cretaceous strata on the southern High Plains as Jurassic, incorrect basic structure of the Jemez and Zuni Mountains, and failure to identify Cretaceous strata in west-central New Mexico. Yet, in spite of its flaws, Marcou's geologic map of New Mexico represents a remarkable first effort. Thereby, it not only laid a foundation for subsequent work, but the controversy it engendered drew greater geologic attention to New Mexico.

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