Stratigraphic Notes, 1983

GEOLOGICAL SURVEY BULLETIN 1537-A

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CONTRIBUTIONS TO STRATIGRAPHY

GEOLOGICAL SURVEY BULLETIN 1537-A

Seven short papers describe changes in stratigraphic nomenclature in Alaska, Utah, New Mexico, North Carolina, South Carolina, Puerto Rico, and eastern North America; geologic time chart revised

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STRATIGRAPHIC NOTES, 1983

GEOLOGIC TIME CHART

The 1983 revision of the geologic time chart, "Major Geochronologic and Chronostratigraphic Units" (fig. 1) was prepared by the Geologic Names Committee for U.S. Geological Survey use. It supersedes the 1980 chart.

The chronometric subdivisions of the Precambrian, adopted by the Geological Survey in September 1982, are those recommended by the International Union of Geological Sciences Working Group on the Precambrian for the United States and Mexico, J. E. Harrison, Chairman. The age estimates for the major subdivisions of the Phanerozoic are those prepared for the 1980 chart and are suggested for Survey use. They were prepared at the request of the Geologic Names Committee by an ad hoc committee chaired by Z. E. Peterman.

Numerical ages of chronostratigraphic boundaries are subject to many uncertainties besides the analytical precision of the dating. The placement of boundary stratotypes and the achievement of international agreements on these ages is a slow process subject to much revision and review. Recent studies and revisions of the geologic time scale of especial interest are reported in "A Geologic Time Scale" by W. B. Harland, A. V. Cox, P. G. Llewellyn, C. A. G. Pickton, A. G. Smith, and R. Walters, 1982, Cambridge, Cambridge University Press, 132 p.; and in "The Decade of North American Geology 1983 Geologic Time Scale" by A. R. Palmer, 1983, Geology, v. 11, p. 503-504.

MAJOR GEOCHRONOLOGIC AND CHRONOSTRATIGRAPHIC UNITS

Subdivisions in use by the U.S. Geological Survey (map symbols)						Age estimates of boundaries in million years[1,5]	
Eon or Eonothem	Era or Erathem	Period or System		Epoch or Series			
Phanerozoic	Cenozoic (Cz)	Quaternary (Q)		Holocene		0.010	
Phanerozoic	Cenozoic (Cz)	Quaternary (Q)		Pleistocene		2	(1.7–2.2)
Phanerozoic	Cenozoic (Cz)	Tertiary (T)	Neogene Subperiod or Subsystem (N)	Pliocene		5	(4.9–5.3)
Phanerozoic	Cenozoic (Cz)	Tertiary (T)	Neogene Subperiod or Subsystem (N)	Miocene		24	(23–26)
Phanerozoic	Cenozoic (Cz)	Tertiary (T)	Paleogene Subperiod or Subsystem (Pɛ)	Oligocene		38	(34–38)
Phanerozoic	Cenozoic (Cz)	Tertiary (T)	Paleogene Subperiod or Subsystem (Pɛ)	Eocene		55	(54–56)
Phanerozoic	Cenozoic (Cz)	Tertiary (T)	Paleogene Subperiod or Subsystem (Pɛ)	Paleocene		63	(63–66)
Phanerozoic	Mesozoic (Mz)	Cretaceous (K)		Late	Upper	96	(95–97)
Phanerozoic	Mesozoic (Mz)	Cretaceous (K)		Early	Lower	138	(135–141)
Phanerozoic	Mesozoic (Mz)	Jurassic (J)		Late	Upper		
Phanerozoic	Mesozoic (Mz)	Jurassic (J)		Middle	Middle		
Phanerozoic	Mesozoic (Mz)	Jurassic (J)		Early	Lower	205	(200–215)
Phanerozoic	Mesozoic (Mz)	Triassic (Ѣ)		Late	Upper		
Phanerozoic	Mesozoic (Mz)	Triassic (Ѣ)		Middle	Middle		
Phanerozoic	Mesozoic (Mz)	Triassic (Ѣ)		Early	Lower	~240	
Phanerozoic	Paleozoic (Pz)	Permian (P)		Late	Upper		
Phanerozoic	Paleozoic (Pz)	Permian (P)		Early	Lower	290	(290–305)
Phanerozoic	Paleozoic (Pz)	Carboniferous Periods or Systems (C)	Pennsylvanian (ℙ)	Late	Upper		
Phanerozoic	Paleozoic (Pz)	Carboniferous Periods or Systems (C)	Pennsylvanian (ℙ)	Middle	Middle		
Phanerozoic	Paleozoic (Pz)	Carboniferous Periods or Systems (C)	Pennsylvanian (ℙ)	Early	Lower	~330	
Phanerozoic	Paleozoic (Pz)	Carboniferous Periods or Systems (C)	Mississippian (M)	Late	Upper		
Phanerozoic	Paleozoic (Pz)	Carboniferous Periods or Systems (C)	Mississippian (M)	Early	Lower	360	(360–365)
Phanerozoic	Paleozoic (Pz)	Devonian (D)		Late	Upper		
Phanerozoic	Paleozoic (Pz)	Devonian (D)		Middle	Middle		
Phanerozoic	Paleozoic (Pz)	Devonian (D)		Early	Lower	410	(405–415)
Phanerozoic	Paleozoic (Pz)	Silurian (S)		Late	Upper		
Phanerozoic	Paleozoic (Pz)	Silurian (S)		Middle	Middle		
Phanerozoic	Paleozoic (Pz)	Silurian (S)		Early	Lower	435	(435–440)
Phanerozoic	Paleozoic (Pz)	Ordovician (O)		Late	Upper		
Phanerozoic	Paleozoic (Pz)	Ordovician (O)		Middle	Middle		
Phanerozoic	Paleozoic (Pz)	Ordovician (O)		Early	Lower	500	(495–510)
Phanerozoic	Paleozoic (Pz)	Cambrian (Ꞓ)		Late	Upper		
Phanerozoic	Paleozoic (Pz)	Cambrian (Ꞓ)		Middle	Middle		
Phanerozoic	Paleozoic (Pz)	Cambrian (Ꞓ)		Early	Lower	~570[2]	
Proterozoic (P)	Late Proterozoic[3] (Z)					900	
Proterozoic (P)	Middle Proterozoic[3] (Y)					1600	
Proterozoic (P)	Early Proterozoic[3] (X)					2500	
Archean (A)	Late Archean[3] (W)					3000	
Archean (A)	Middle Archean[3] (V)					3400	
Archean (A)	Early Archean[3] (U)					(3800?)	
pre-Archean[4] (pA)						4550	

[1] Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age of boundaries not closely bracketed by existing data shown by ~. Decay constants and isotopic ratios employed are cited in Steiger and Jäger (1977).

[2] Rocks older than 570 Ma also called Precambrian (pꞒ), a time term without specific rank.

[3] Geochronometric units.

[4] Informal time term without specific rank.

[5] Age estimates for the Phanerozoic are by G. A. Izett, M. A. Lanphere, M. E. MacLachlan, C. W. Naeser, J. D. Obradovich, Z. E. Peterman, M. Rubin, T. W. Stern, and R. E. Zartman at the request of the Geologic Names Committee. Age estimates for the Precambrian are by International Union of Geological Sciences Working Group on the Precambrian for the United States and Mexico, J. E. Harrison, Chairman. The chart is intended for use by members of the U.S. Geological Survey and does not constitute a formal proposal for a geologic time scale. Estimates of ages of boundaries were made after reviewing published time scales and other data. Future modification of this chart will undoubtedly be required. The general references apply where references are not given for specific boundaries.

Geologic Names Committee, 1983

FIGURE 1.—Major geochronologic and chronostratigraphic units.

GENERAL REFERENCES

American Association of Petroleum Geologists, 1978, Studies in Geology 6, 388 p.
Berggren, W. A., 1972, Lethaia, v. 5, no. 2, p. 195-215.
Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964, American Journal of Science, v. 262, p. 145-198.
Geological Society of London, 1964, Quarterly Journal, v. 120S, 458 p.
Lambert, R. S., 1971, Geological Society of London, Special Publications 3, Part 1, p. 9-31.
Steiger, R. H., and Jager, E., 1977, Earth and Planetary Science Letters, v. 36, p. 359-362.

Holocene-Pleistocene boundary

Hopkins, D. M., 1975, Geology, v. 3, p. 10.

Pleistocene-Pliocene boundary

Haq, B. U., Berggren, W. A., and Van Couvering, J. A., 1977, Nature, v. 269, p. 483-488.
Selli, R., Accorsi, C. A., Bandini, M. M., Bertolani, M. D., Bigazzi, G., Bonadonna, F. P., Borsetti, A. M., Cati, F., Colalongo, M. L., D'onofrio, S., Landini, W., Menesini, E., Mezzetti, R., Pasini, G., Savelli, C., and Tampieri, R., 1977, Giornale di Geologica Bologna, ser. 2, v. 42, no. 1, book II, p. 181-204.

Pliocene-Miocene boundary

Cita, M. B., 1975, Micropaleontology, Special Publication 1, p. 1-30.
McDougall, I., and Page, R. W., 1975, Micropaleontology Special Publication 1, p. 75-84.
Tongiorgi, E., and Tongiorgi, M., 1964, Nature, v. 201, p. 365-367.
Van Couvering, J. A., 1972, in Bishop, W. W., and Miller, J. A., eds., Calibration of hominid evolution, Scottish Academic Press and University of Toronto Press, p. 247-271.

Miocene-Oligocene boundary

Van Couvering, J. A., 1978, Geology, v. 6, p. 169.
Van Couvering, J. A., and Berggren, W. A., 1977, in Kauffman, E. G., and Hazel, J. E., eds., Concepts and methods of biostratigraphy, Stroudsburg, Pa.; Dowden, Hutchinson, & Ross [New York]; exclusive distributor: Halstead Press, c. 1977.

Oligocene-Eocene boundary

Hardenbol, J., and Berggren, W. A., 1978, American Association of Petroleum Geologists Studies in Geology 6, p. 213-234.
Odin, G. S., Curry, D., and Hunziker, J. C., 1978, Journal of the Geological Society of London, v. 135, p. 481-497.

Eocene-Paleocene boundary

Berggren, W. A., McKenna, M. C., Hardenbol, J., and Obradovich, J. D., 1978, Journal of Geology, v. 86, p. 67-81.
Fitch, F. J., Hooker, P. J., Miller, J. A., and Brereton, N. R., 1978, Journal of the Geological Society of London, v. 135, p. 499-512.
Odin, G. S., Curry, D., and Hunziker, J. C., 1978, Journal of the Geological Society of London, v. 135, p. 481-497.

Paleocene-Cretaceous boundary

Lerbekmo, J. F., Evans, M. E., and Baadsgaard, H., 1979, Nature, v. 279, p. 26-30.
Obradovich, J. D., and Cobban, W. A., 1975, Geological Association of Canada Special Paper 13, p. 31-54.

Late-Early Cretaceous boundary

Folinsbee, R. E., Baadsgaard, H., and Cumming, G. L., 1963, National Research Council Publication 1075, p. 70-82.

Obradovich, J. D., and Cobban, W. A., 1970, Geological Association of Canada Special Paper 13, p. 31-54.

Cretaceous-Jurassic boundary

Lanphere, M. A., and Jones, D. L, 1978, American Association of Petroleum Geologists Studies in Geology 6, p. 259-268.

Jurassic-Triassic boundary

Armstrong, R. L., and Besancon, J., 1970, Eclogae Geologicae Helvetiae, v. 63, no. 1, p. 15-28.

White, W. H., Erickson, G. P., Northcote, K. E., Dirom, G. E., and Harakal, J. E., 1967, Canadian Journal of Earth Sciences, v. 4, p. 677-690.

Triassic-Permian boundary

Webb, A. W., and McDougall, I., 1967, Earth and Planetary Science Letters 2, p. 483-488.

Permian-Carboniferous boundary

Fitch, F. J., Miller, J. A., and Williams, S. C., 1970, International Congress on Stratigraphy and Carboniferous Geology, 6th, Sheffield, 1967, Compte Rendu, v. 2, p. 771-789.

Carboniferous-Devonian boundary

Fitch, F. J., Miller, J. A., and Williams, S. C., 1970, International Congress on Stratigraphy and Carboniferous Geology, 6th, Sheffield, 1967, Compte Rendu, v. 2, p. 771-789.

McDougall, I., Compston, W., and Bofinger, V. M., 1966, Geological Society of America Bulletin, v. 77, p. 1075-1088.

Talent, J. A., 1975, in Boucot, A. J., Evolution and extinction rate controls, Amsterdam, New York: Elsevier Scientific Pub. Co., p. 63.

Devonian-Silurian boundary

Ross, R. J., Jr., Naeser, C. W., Izett, G. A., Whittington, H. B., Hughes, C. P., Rickards, R. B., Zalasiewicz, J., Sheldon, P. R., Jenkins, C. J., Cocks, L. R. M., Bassett, M. G., Toghill, P., Dean, W. T., and Ingham, J. K., 1978, U.S. Geological Survey Open-File Rept. 78-701, p. 363-365.

Silurian-Ordovican boundary

Lanphere, M. A., Churkin, M., Jr., and Eberlein, G. D., 1977, Geological Magazine, v. 114, no. 1, p. 15-24.

Ross, R. J., Jr., Naeser, C. W., Izett, G. A., Whittington, H. B., Hughes, C. P., Rickards, R. B., Zalasiewicz, J., Sheldon, P. R., Jenkins, C. J., Cocks, L. R. M., Bassett, M. G., Toghill, P., Dean, W. T., and Ingham, J. K., 1978, U.S. Geological Survey Open-File Rept. 78-701, p. 363-365.

Precambrian subdivisions

Harrison, J. E., 1980, Geological Society of America Bulletin, v. 91, no. 6, p. 377-380.

Harrison, J. E., and Peterman, Z. E., 1982, American Association of Petroleum Geologists Bulletin, v. 66, no. 6, p. 801-802.

Proterozoic subdivisions

James, H. L., 1972, American Association of Petroleum Geologists Bulletin, v. 56, p. 1128-1133.

Proterozoic-Archean boundary

James, H. L, 1978, Precambrian Research, v. 7, no. 3, p. 193-204.

Archean

Goldich, S. S., and Wooden, J. L., 1978, in Smith, I. E. M., and Williams, J. G., eds., Proceedings of the 1978 Archean Geochemistry Conference, p. 285-318.

THE ARAPIEN SHALE OF CENTRAL UTAH—A DILEMMA IN STRATIGRAPHIC NOMENCLATURE

By Irving J. Witkind[1] and Clyde T. Hardy[2]

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[1]U.S. Geological Survey.
[2]Utah State University.

U.S. Geological Survey Bulletin 1537-A, 1984, p. A5-A20.

ABSTRACT

The Arapien Shale of Middle Jurassic age is widely exposed throughout central Utah. Regrettably, the name "Arapien Shale" is used differently by different groups. U.S. Geological Survey geologists use the name in its original sense: to identify a formation that consists of an upper Twist Gulch Member and a lower Twelvemile Canyon Member. Industry and university geologists use the name as a direct replacement for the term Twelvemile Canyon Member. This dual usage has caused much confusion. In an attempt to resolve this problem, we propose that the Twist Gulch Member be raised to formational rank, that the units now grouped as the Twelvemile Canyon Member be known as the Arapien Shale, and that the name Twelvemile Canyon Member be abandoned. Although this proposal infringes aspects of both the old and new codes of stratigraphic nomenclature, we believe that widespread and common usage argues persuasively for this change.

INTRODUCTION

The name "Arapien Shale" has been used differently by U.S. Geological Survey geologists on the one hand and by industry and university geologists on the other. Geological Survey geologists follow the original definition of the Arapien Shale (Spieker, 1946, p. 123-125): a Jurassic formation that consists of an upper Twist Gulch Member and a lower Twelvemile Canyon Member. Industry and university geologists use the name Arapien Shale as a direct replacement for the name Twelvemile Canyon Member. Much confusion has resulted from this dual usage. This geologic note explains how the confusion arose and proposes a solution to the problem.

HISTORY OF THE NAME "ARAPIEN SHALE"

Early workers commented on the widespread marine beds of Jurassic age in the Sanpete-Sevier Valley area of central Utah (fig. 1). Howell (1875, p. 236) first applied the term "shales" to these beds. Dutton (1880, p. 163) discussed "a narrow belt of rocks of Jurassic age" along the east side of the Sevier Valley between Gunnison and Salina. A half century later, Eardley (1933, p. 330-334), studying the southern Wasatch Mountains, remarked about the great thickness of these rocks, the great masses of evaporites, and the intense deformation (figs. 2 and 3), but none of the early geologists named or defined these units. Finally, in 1946, Spieker (p. 123-125), a longtime principal investigator in the Sanpete-Sevier Valley area, addressed the stratigraphic problem. He named these Jurassic beds the "Arapien shale" and recognized five different lithologic types (table 1). He described these as follows (Spieker, 1946, p. 124):

> "there are five different types of lithologic assemblage, in which the order of succession, beginning with the lowermost, is commonly but by no means regularly as follows: (1) Gray limestone, generally thin-bedded; (2) light-gray siltstone and shale, very thin-bedded, with occasional thin beds of finely rippled

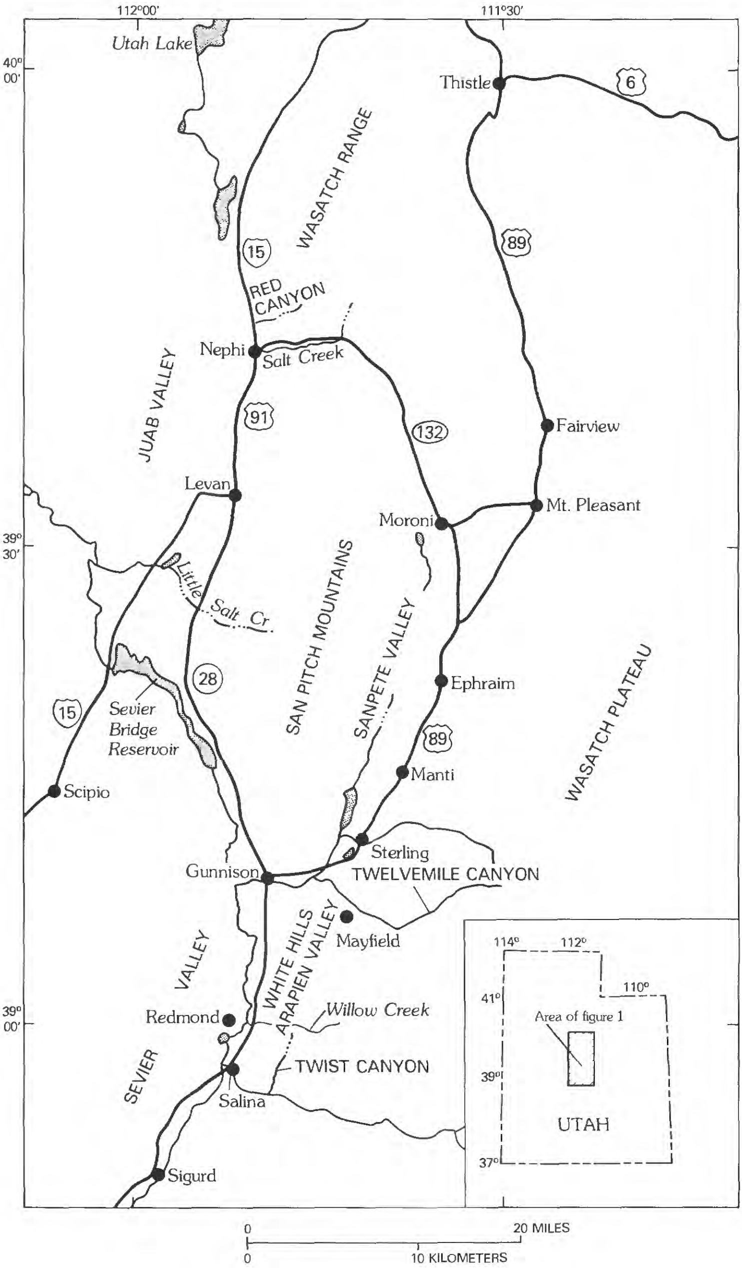

FIGURE 1.--Locations of features mentioned in the text.

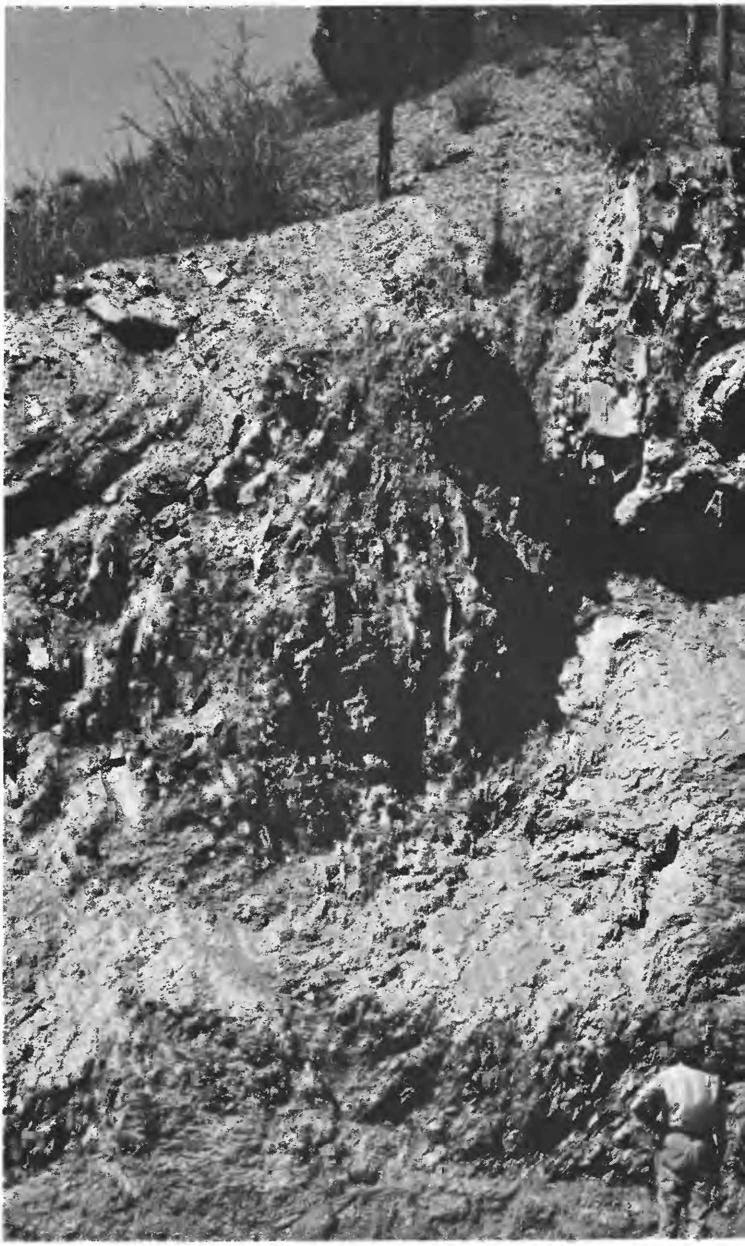

FIGURE 2.--Crumpled, contorted light-gray to gray calcareous mudstone and shaly siltstone beds of the Arapien Shale (formerly called the Twelvemile Canyon Member of Arapien) exposed along the north side of Utah Highway

132 about 5 km east of Nephi. Beds probably correlate with Hardy's unit C. Photograph by T. L. Brown.

FIGURE 3.—Overturned beds of the Arapien Shale (formerly called the Twelvemile Canyon Member of Arapien) exposed along Utah Highway 132 about 6 km east of Nephi. Comparable large-scale deformation is com-

mon throughout the Sanpete-Sevier Valley area. Consequently, thickness measurements of the Twelvemile Canyon Member (Arapien Shale of this report) probably are gross estimates at best.

sandstone; (3) gray shale, argillaceous and gypsiferous, with irregular red blotches, which locally become dominant; (4) compact red salt-bearing shale; (5) thin-bedded red siltstone and shale with many thin layers of greenish white siltstone and occasional zones of gray sandstone, some of which is fairly coarse grained. * * *"

Of these five lithologic types, only the uppermost, type 5, can be traced over long distances. Type 5 appeared to Spieker to be sufficiently consistent in lithology and appearance to warrant its being a named member. Therefore, he divided the five types of the Arapien Shale into two members: he named type 5 the "Twist Gulch member" and grouped the remaining four under the name "Twelvemile Canyon member."[3]

Table 1.--Existing terminology and proposed revisions in stratigraphic nomenclature of the Arapien Shale of Middle Jurassic age

[No lateral equivalency intended]

<table>
<tr><th colspan="2">European stages (Imlay, 1980)</th><th colspan="3">Spieker's (1946) original definition</th><th colspan="2">Hardy's (1952) proposed revision</th><th>This article</th></tr>
<tr><td rowspan="6">Middle Jurassic</td><td>Callovian</td><td rowspan="6">Arapien Shale</td><td>Twist Gulch Member</td><td>Type 5</td><td colspan="2">Twist Gulch Formation</td><td>Twist Gulch Formation</td></tr>
<tr><td rowspan="5">Bathonian</td><td rowspan="5">Twelvemile Canyon Member</td><td>Type 4</td><td rowspan="5">Arapien Shale</td><td>Unit E</td><td rowspan="5">Arapien Shale</td></tr>
<tr><td>Type 3</td><td>Unit D</td></tr>
<tr><td rowspan="2">Type 2</td><td>Unit C</td></tr>
<tr><td>Unit B</td></tr>
<tr><td>Type 1</td><td>Unit A</td></tr>
</table>

DESCRIPTION OF THE TWELVEMILE CANYON MEMBER

Bewildering lateral and vertical changes characterize the Twelvemile Canyon Member of the Arapien Shale. To understand these complexities better, Hardy, while he was one of Spieker's graduate students in the late 1940's, did a comprehensive study of the member chiefly where it is exposed along the east side of Sevier Valley. Hardy (1949, 1952) divided Spieker's original four types into five rock units and designated them A through E (table 1). He described these units, from youngest to oldest, as follows (1952, p. 15-16):

Unit E:

Brick-red silty shale, locally salt-bearing. The salt appears to be stratified and commonly contains a considerable amount of red clay.

Unit D:

Alternate layers of bluish-gray and red gypsiferous shale. Blotched appearance of the outcrop due to the lenticular nature of the beds, facies changes, and complex structure.

[3]The approved geographic name of the type locality of the Twist Gulch Member is "Twist Canyon."

Unit C:
: Bluish-gray calcareous shale with gray thin-bedded calcareous sandstone. Several resistant layers of arenaceous limestone with fossils. Massive lenticular beds of gypsum.

Unit B:
: Bluish-gray and red gypsiferous shale. Blotched appearance similar to unit D. Red gypsiferous shale in upper part is locally salt-bearing.

Unit A:
: Gray shale, gray thin-bedded limestone which weathers brown, red shale, gypsum in thin lenticular beds; or gray thin-bedded argillaceous limestone with massive lenticular beds of gypsum.

In general, unit A consists of Spieker's type 1, B of type 3, C of type 2, D of type 3, and E of type 4. Unit E is locally salt bearing.

These units, too, lack lateral continuity, are very heterogeneous, and range widely in lithology and appearance.

Although Howell (1875, p. 236), Richardson (1907, p. 8, 9), Spieker, and Hardy, among others, referred to some of these rock types as shales, almost none are shale in the commonly accepted sense (paper-thin laminae); most of the units are probably best described as calcareous mudstones. Picard (1980, p. 137) refers to the bulk of them as "micrite or clayey micrite."

No complete section of the Twelvemile Canyon Member is exposed anywhere in central Utah. Consequently, a specific type locality was not designated by Hardy.

Previous workers (Picard, 1980, p. 131; Spieker, 1949, p. 17; Moulton, 1977, p. 9) have suggested that the "Arapien shale" (that is, the Twelvemile Canyon Member) rests on the Navajo Sandstone, to which they assigned a Jurassic age. In Red Canyon, near Nephi, the Twelvemile Canyon Member is separated from the Navajo Sandstone by a series of beds, chiefly carbonate rock, that correlate with the lower and medial parts of the Middle Jurassic Twin Creek Limestone. The intercalated sequence includes the Gypsum Spring, Sliderock, Rich, Boundary Ridge, and Watton Canyon Members of the Twin Creek. This Gypsum Spring-Watton Canyon sequence of beds, separating the Twelvemile Canyon Member from the Navajo Sandstone, has been repeatedly cut by exploratory wells drilled by Placid Oil Company in the Juab and Sevier Valleys (Sprinkel, 1982). The Twelvemile Canyon Member most likely rests on one or another of these members of the Twin Creek Limestone throughout the Sanpete-Sevier Valley area.

A variety of units overlies the Twelvemile Canyon Member. In places, the Twelvemile Canyon Member is overlain with gradational contact by the Twist Gulch Member, but locally, as a result of either strip-thrusting (Billings, 1933) or sedimentary intrusive action (Witkind, 1982), the Twelvemile Canyon Member is overlain by beds of the Green River Formation (Eocene).

The Twelvemile Canyon Member is so severely deformed that its original thickness cannot be determined; estimates range from 1,220 to 3,960 m (Spieker, 1949, p. 17; Gilliland, 1948, p. 30; Hardy, 1949, p. 16, 17).

THE PROBLEM

During the course of his work, Hardy became convinced that the Twist Gulch and the Twelvemile Canyon Members were sufficiently distinct and widespread to warrant separate formational status. Spieker agreed, and consequently Hardy (1949, p. 8) noted: "* * * The nomenclature of the strata included in the Arapien shale by Spieker has recently been modified by Hardy and Spieker in order to set apart the Arapien and the Twist Gulch as separate formations (Hardy and Spieker, in preparation). * * *"

Hardy (1952, p. 14) subsequently reemphasized his and Spieker's general views:

> "* * * The Arapien shale was defined by E. M. Spieker in 1946, as a formation with two distinct members (Spieker, 1946, pp. 123-125). The term is now restricted to the strata formerly included in the Twelvemile Canyon member, and the Twist Gulch member is redesignated as a formation because of its great areal extent in central Utah (Hardy and Spieker, in preparation). * * *"

The Hardy-Spieker paper referred to in the above quotations was never published, but most subsequent authors seemingly assumed that the paper was in print, or simply accepted the reasonableness of Hardy's proposal, and used the term "Arapien shale" in a formational sense, much as proposed by Hardy, and as an exact replacement of the name "Twelvemile Canyon Member."

Hardy's redefinition of the Arapien Shale now infringes article 19 of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), which forbids using an original name for any of its divisions. In essence, the original name "Arapien shale" should not be employed for one of its divisions—the Twelvemile Canyon Member. As matters now stand, the term "Arapien Shale" has been and is being used in its original sense by some authors (Imlay, 1980; Witkind, 1982, 1983) and in its restricted sense by others (Moulton, 1977; Baer, 1976; Picard, 1980). Authors, therefore, are obliged to specify exactly what they mean by the term "Arapien Shale" if they are not to confuse their readers.

DISCUSSION AND PROPOSED SOLUTION

Dual usage of the term "Arapien Shale" should not continue. For 30 years most geologists have followed Hardy's redefinition of the Arapien Shale. Of some 25 significant papers dealing with the geology of the Sanpete-Sevier Valley area, 17 have conformed with Hardy's usage. Only a handful of authors, chiefly U.S. Geological Survey geologists (Imlay, 1964, 1967, 1980; Witkind, 1982, 1983), have followed Spieker's original usage.

The inherent logic of dividing the Jurassic marine strata of central Utah into the Twist Gulch Formation and the Arapien Shale is widely accepted, and most authors now use Hardy's revision. Although Hardy's redefinition of the name Arapien Shale violates the present code, his redefinition is entrenched in the literature, is widely used, and is unlikely to be dislodged.

The fact that Hardy's definition violates the code does not necessarily make it unacceptable. A few examples of comparable but generally accepted breaches of the stratigraphic code are listed in table 2. Many more could be cited. These examples demonstrate that long established common usage is a valid criterion for the formal acceptance of stratigraphic names.

Because the name "Arapien Shale" has become entrenched in the literature in its restricted sense as a substitute for the formal name "Twelvemile Canyon Member of the Arapien Shale," we recommend that the original Arapien Shale be divided into an upper Twist Gulch Formation and a lower Arapien Shale, and that the name Twelvemile Canyon Member be abandoned (table 1).

Table 2.—Examples of commonly accepted stratigraphic names that violate the stratigraphic code

[Source: M. E. Mac Lachlan, U.S. Geological Survey Geologic Names Committee Representative, written commun., 1982]

Name	Code violation	References
Wingate Sandstone	Sandstone at type locality (Fort Wingate, New Mexico) is Entrada Sandstone, not Wingate.	Harshbarger and others (1957, p. 8); Green (1974, p. D10).
Ocate Sandstone	Abandoned by U.S. Geological Survey, but still widely used in published literature.	Lessard and Bejnar (1976, p. 105).
Mesaverde Formation	Used for more than 70 years, in northwestern Colorado, eastern Utah, and southwestern Wyoming, for beds unlike those of the type section.	Gill and others (1970, p. 5).
Ojo Alamo Sandstone	In San Juan Basin, New Mexico, name has been used so commonly and consistently for beds now known to be Paleocene that the beds of the original type section (Cretaceous) have had to be excluded.	Brown (1910, p. 268); Baltz and others (1966, p. D14).

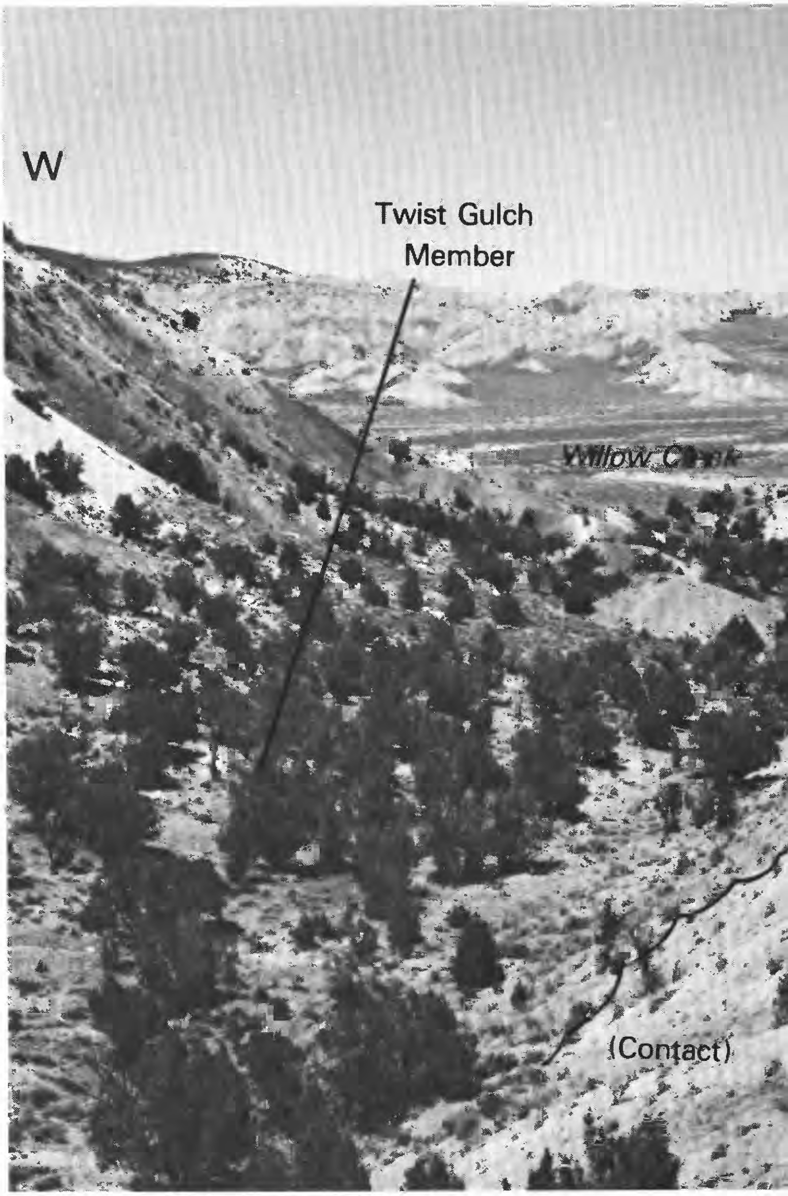

FIGURE 4.--View northward of the intricately dissected badland topography developed on the calcareous mudstones of the Arapien Shale (formerly called Twelvemile Canyon Member of Arapien) as exposed in the White Hills near Willow Creek, some 8 km northeast of Salina. Beds are part of Hardy's unit D--light-gray beds mottled irregularly with patches of light

red. Darker beds along left side of photograph are reddish-brown shaly siltstones and sandstones of the Twist Gulch Formation (formerly called Twist Gulch Member). Light-colored cap on ridge (near right side of photograph) consists of light-brown limestone fragments of the Green River Formation of Eocene age. Photograph by T. L. Brown.

FIGURE 5.--Vertical, interlayered, and much contorted dark reddish-brown amorphous mudstones and thin salt beds characteristic of Hardy's unit E of the Twelvemile Canyon Member (Arapien Shale of this report). Exposure is near Redmond. Beds of salt, as much as 60 m thick, are mined from these strata in this area.

PRINCIPAL REFERENCE LOCALITY, ARAPIEN SHALE

Most of the units that make up the Twelvemile Canyon Member crop out in several widely separated areas, and one of these areas is here designated as a principal reference locality of the Arapien Shale. This principal reference locality extends along the east flank of Sevier Valley as a belt 3 to 5 km wide and about 45 km long, from near Sigurd on the south to Sterling on the north. Hardy's units B through D are particularly well exposed in the White Hills, a range of low hills adjacent and parallel to the Arapien Valley near Mayfield (fig. 4). Unit E (red silty shale) is exposed about 8 km west of this belt near Redmond (fig. 5). Unit A (thin-bedded limestone) is not exposed in this reference locality of the Arapien.

A second area where Spieker's Twelvemile Canyon Member is well exposed is here designated a reference locality of the Arapien. This locality extends along the west and north flanks of the San Pitch Mountains and forms a belt, about 3 km wide and 30 km long, from near Little Salt Creek on the south to Salt Creek on the north. Limestone beds (unit A) are part of these exposures, but it is uncertain whether these limestone beds should be assigned to the Arapien or to the Twin Creek Limestone.

REFERENCES CITED

Baer, J. L., 1976, Structural evolution of central Utah--Late Permian to Recent, in Guidebook, 27th Annual Field Conference, Geology of Cordilleran hingeline: Denver, Colo., Rocky Mountain Association of Geologists, 1976, p. 37-45.

Baltz, E. H., Ash, S. R., and Anderson R. Y., 1966, History of nomenclature and stratigraphy of rocks adjacent to the Cretaceous-Tertiary boundary, western San Juan Basin, New Mexico: U.S. Geological Survey Professional Paper 524-D, p. D1-D23.

Billings, Marland, 1933, Thrusting younger rocks over older: American Journal of Science (Fifth series), v. 25, no. 146, p. 140-165.

Brown, Barnum, 1910, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus Kritosaurus: American Museum of Natural History Bulletin, v. 28, p. 267-274.

Dutton, C. E., 1880, Report on the geology of the high plateaus of Utah: U.S. Geographical and Geological Survey of the Rocky Mountain Region (Powell), 307 p.

Eardley, A. J., 1933, Stratigraphy of the southern Wasatch Mountains, Utah: Michigan Academy of Science Papers, v. 18, p. 307-344.

Gill, J. R., Merewether, E. A., and Cobban, W. A., 1970, Stratigraphy and nomenclature of some Upper Cretaceous and lower Tertiary rocks in south-central Wyoming: U.S. Geological Survey Professional Paper 667, 53 p.

Gilliland, W. N., 1948, Geology of the Gunnison quadrangle, Utah: Columbus, Ohio State University Ph.D. thesis, 178 p.

Green, M. W., 1974, The Iyanbito Member (a new stratigraphic unit) of the Jurassic Entrada Sandstone, Gallups-Grants area, New Mexico: U.S. Geological Survey Bulletin 1395-D, p. D1-D12.

Hardy, C. T., 1949, Stratigraphy and structure of the Arapien Shale and the Twist Gulch Formation in Sevier Valley, Utah: Columbus, Ohio State University, unpublished Ph.D. thesis, 85 p.

_______1952, Eastern Sevier Valley, Sevier and Sanpete Counties, Utah--with reference to formations of Jurassic age: Utah Geological and Mineralogical Survey Bulletin 43, 98 p.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geological Survey Professional Paper 291, 74 p.

Howell, E. E., 1875, Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico: U.S. Geographical and Geological Explorations and Surveys West of the 100th Meridian (Wheeler), v. 3, pt. 3, p. 227-301.

Imlay, R. W., 1964, Marine Jurassic pelecypods from central and southern Utah: U.S. Geological Survey Professional Paper 483-C, p. C1-C42, 4 pls.

_______1967, Twin Creek Limestone (Jurassic) in the western interior of the United States: U.S. Geological Survey Professional Paper 540, 105 p., 16 pls.

_______1980, Jurassic paleobiogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Lessard, R. H., and Bejnar, W., 1976, Geology of the Las Vegas area, in Guidebook of Vermejo Park, northeastern New Mexico: New Mexico Geological Society, 27th Field Conference, p. 103-108.

Moulton, F. C., 1977, Lower Mesozoic and Upper Paleozoic petroleum potential of the hingeline area, central Utah: Brigham Young University Geology Studies, v. 24, pt. 1, p. 1-11.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, p. 841-875.

Picard, M. D., 1980, Stratigraphy, petrography, and origin of evaporites in Jurassic Arapien Shale, central Utah, in Picard, M. D., ed., Henry Mountains symposium: Utah Geological Association Publication 8, p. 129-150.

Richardson, G. B., 1907, Underground water in Sanpete and central Sevier Valleys, Utah: U.S. Geological Survey Water-Supply Paper 199, 63 p.

Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, p. 117-160.

_______1949, The transition zone between the Colorado Plateaus and the Great Basin in central Utah: Utah Geological Society Guidebook to the Geology of Utah, no. 4, 106 p.

Sprinkel, D. A., 1982, Twin Creek Limestone-Arapien Shale relations in central Utah, in Nielsen, D. L., ed., Overthrust belt of Utah symposium: Utah Geological Association Publication 10, p. 169-179.

Witkind, I. J., 1982, Salt diapirism in central Utah, in Nielsen, D. L., ed., Overthrust belt of Utah symposium: Utah Geological Association Publication 10, p. 13-30.

_______1983, Overthrusts and salt diapirs, central Utah, in Miller, D. M., Todd, V. R., and Howard, K. A., eds., Tectonic and stratigraphic studies in the eastern Great Basin region: Geological Society of America Memoir 157, p. 45-60.

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U.S. Geological Survey, February 17, 1984.

STRATIGRAPHIC CLARIFICATION OF THE SHELIKOF FORMATION, ALASKA PENINSULA

By William H. Allaway, Jr., Robert L. Detterman, John W. Miller, and Leslie B. Magoon

INTRODUCTION

This paper clarifies the contact between the Shelikof Formation and the Kialagvik Formation so that both formations are mappable lithostratigraphic units.

The Shelikof Formation was named by Capps (1923, p.97) because "* * * it is the prevailing rock formation on the northwest shore of Shelikof Strait from Katmai Bay at least as far southwest as Kialagvik Bay [Wide Bay] * * *." Although Capps (1923, p. 97-98) did not designate either a type locality or type section for the formation, he did describe the unit as consisting of three members: a lower shale (siltstone) member, a middle sandstone member with minor shale and conglomerate, and an upper shale (siltstone) member. Capps placed the lower boundary of the Shelikof Formation at the base of a conglomerate bed that occurs at the base of the lower siltstone member on the northeast shore of Puale Bay (formerly Cold Bay). Capps considered that the thick siltstone unit immediately below this conglomerate was Early Jurassic, and that an unconformity separated the two. He recognized a similar unconformity at Wide Bay (formerly Kialagvik Bay) (fig. 1). He placed the upper contact at the base of the basal conglomerate of the Naknek Formation, which overlies the upper siltstone member in "nearly every normal section" (Capps, 1923).

If the lateral continuity of the three members as defined by Capps (1923) could be mapped throughout the Alaska Peninsula, then the Shelikof Formation would be a valid lithostratigraphic unit. However, our recent work (1979-81) indicates that many lateral changes in facies occur throughout the area and that vertical sections are quite different even if they are separated by short (0.5-1 km) distances. These changes in facies make the present definition of the Shelikof Formation incorrect. In addition, the lower and upper contact relations are not as simple as originally described by Capps.

Confusion arose over where to place the lower contact in the Wide Bay area when recent workers (Kellum and others, 1945; Westerman, 1964, 1969) used biostratigraphic or chronostratigraphic methods to define what should be a lithostratigraphic unit. In Capps' (1923) original description, the lower contact in this area was marked by a conglomerate which overlies with angular unconformity sandy siltstone of the Kialagvik Formation. This conglomerate, however, does not persist laterally and, as a result, subsequent workers (Kellum and others, 1945; Westerman, 1964, 1969) used fossil evidence to choose the contact where the conglomerate was not present. They reasoned that the disconformity between the lower Bajocian and the lower Callovian corresponded to the angular unconformity described by Capps (1923). However, the apparent hiatus between the lower or middle Bajocian and the lower Callovian has very little, if any, lithologic expression and therefore does not represent a mappable contact. In fact, our recent work suggests that in many places there may not be a hiatus. A literature

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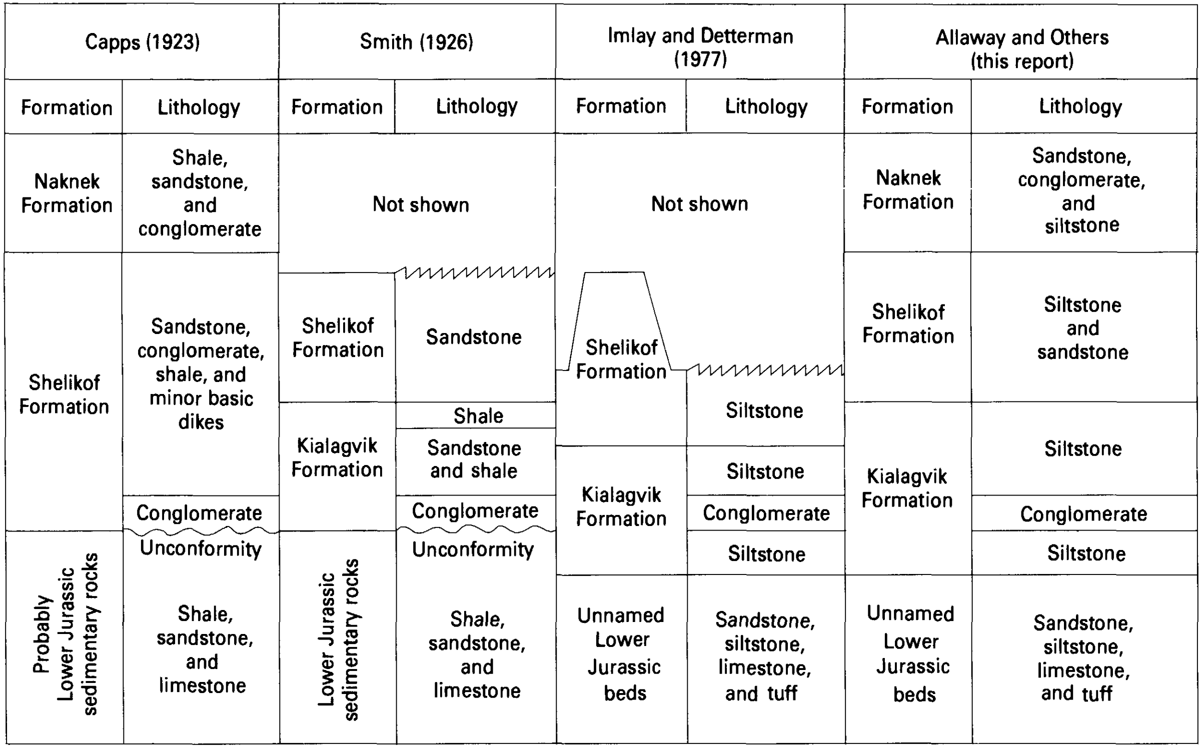

FIGURE 1.--Generalized columnar sections defined by various workers in Wide Bay-Puale Bay area. Thickness not to scale.

search conducted by J. H. Calloman (written commun., 1981) indicates that many fossils from the Shelikof Formation generally thought to be Callovian may range down into the Bathonian; thus the hiatus may be more a result of inadequate collecting or lack of fossils rather than of a period of nondeposition.

In the Puale Bay area, the Shelikof Formation has been redefined twice; it was redefined by Smith (1926), who reported fossils of Kialagvik age above the conglomerate. He redefined the lower contact to be the base of the massive sandstone approximately 457 m higher in the section. The second redefinition of the lower contact was made by Imlay and Detterman (1977) on the basis of fossil evidence; they placed the contact in the middle of the siltstone interval between the massive sandstone of Smith (1926) and the conglomerate of Capps (1923). Other workers (Martin, 1926; Burk, 1965) have referred back to Capps' original descriptions.

The upper contact is also more complex than originally described by Capps (1923). The basal unit of the Naknek Formation consists of two different lithofacies in the Puale Bay-Wide Bay area: a granite-pebble conglomerate and an arkosic sandstone that is commonly crossbedded, cross-laminated, or laminated with magnetite defining the laminations. These two lithofacies of the Naknek have been seen in contact with all the following three lithofacies of the Shelikof Formation: dark laminated and massive siltstone, volcanic-rich sandstone, and volcanic conglomerate. At Puale Bay, the upper contact consists of mainly Shelikof siltstone overlain by Naknek conglomerate as reported by Capps (1923). Locally, Shelikof siltstone is overlain by Naknek sandstone. In both the Alai Creek and Big Creek reference sections in the Wide Bay area (fig. 2), the contact is marked by

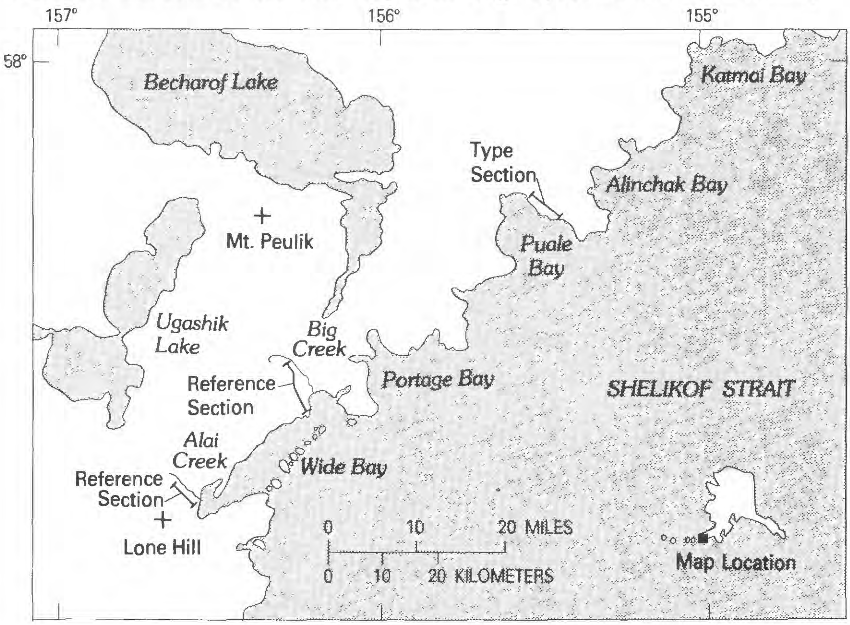

FIGURE 2.—The Wide Bay-Puale Bay area of the Alaska Peninsula showing the type and reference sections of the Shelikof Formation.

Shelikof conglomerate overlain by Naknek sandstone. In other places a conglomerate-on-conglomerate contact was observed, and in these cases the contact is gradational with a gradual upward decrease in volcanic rock clasts and an upward increase in plutonic rock clasts. Although lateral changes in lithology along the contact characterize both formations, the lithologic differences between the two make the contact relatively easy to identify.

The most easily mappable lithologic break useful in separating the two formations is at the base of the lowermost massive sandstone bed of the Shelikof Formation. This lithologic break conforms to the redefined contact proposed by Smith (1926). The type section, here designated, occurs along the northeast shore of Puale Bay (fig. 2) between the southern half of sec. 9, T. 28 S., R. 38 W. and sec. 19, T. 28 S., R. 37 W. in the Karluk C-4, C-5, and D-5 15-minute quadrangles. In addition, two reference sections (fig. 2) are designated in the Wide Bay area. The principal reference section is along the ridge southwest of Big Creek between sec. 5, T. 31 S., R. 43 W. in the Ugashik C-1 15-minute quadrangle and sec. 3, T. 32 S., R. 43 W. in the Ugashik B-1 15-minute quadrangle. The other reference section is along the ridge southwest of Alai Creek between sec. 13, T. 33 S., R. 46 W. and sec. 19, T. 33 S., R. 45 W. in the Ugashik B-2 15-minute quadrangle. The generalized sections in figure 3 show the variability of lithofacies and thickness in the Shelikof Formation, and the variety of its contacts with the Kialagvik Formation and the Naknek Formation.

LITHOLOGY

The type section of the Shelikof Formation (fig. 3) consists of approximately 1,402 m of sandstone, siltstone, and conglomerate. The contact with the underlying Kialagvik Formation is conformable. The lower half is mainly volcanic sandstone with lenses of conglomerate containing volcanic, sandstone, and calcareous sandstone clasts, interbedded with minor siltstone. The upper half consists of volcanic sandstone interbedded with massive and laminated siltstone whose upper part is a fining-upward sequence with mainly sandstone at its base and mainly siltstone with thin sandstone interbeds near its top. Naknek Formation conglomerate unconformably overlies this section.

The principal reference section (Big Creek) consists of approximately 1,524 m of conglomerate, sandstone, and siltstone. The lower contact with the Kialagvik Formation is an erosional unconformity marked by Shelikof conglomerate that fills paleochannels cut into Kialagvik siltstone. The lowermost part of the section consists of channel conglomerate with sandstone interbeds. The conglomerate clasts are mainly volcanic, but locally beds contain predominantly sedimentary clasts. The sandstone is volcanic and ranges from lithofeldspathic to lithic. The middle part of the section consists of siltstone and two thick intervals of sandstone and conglomerate. The upper part consists of volcaniclastic sandstone overlain by massive and channel conglomerate. The major clast type is volcanic; clasts composed of intrusive rocks are a minor component. The contact with the overlying Naknek Formation is defined by the presence of laminated and crossbedded arkosic sandstone.

The reference section along Alai Creek (fig. 3) shows that the Shelikof Formation thins considerably from almost 1,524 m at Big Creek to only 823 m. The lower contact of the Shelikof Formation with the Kialagvik Formation is conformable; massive, laminated, and crossbedded sandstone of

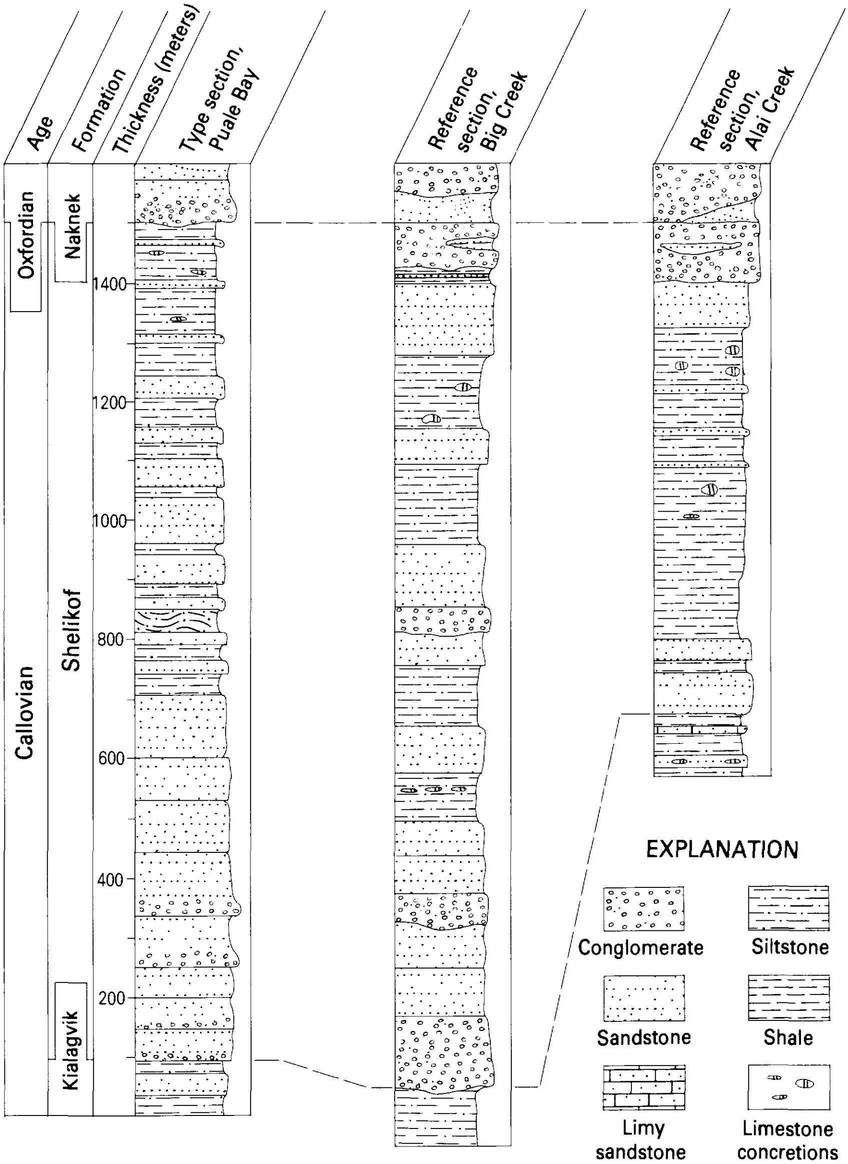

FIGURE 3.--Type and reference sections of the Shelikof Formation.

the lower part of the Shelikof overlies the laminated and massive siltstone here assigned to the Kialagvik. The sandstone is mainly volcanic lithofeldspathic to feldspatholithic graywacke and arenite. This sandstone is overlain by about 457 m of massive, laminated, and concretionary siltstone. The siltstone is locally calcareous but is mainly siliceous. The upper part consists of massive, laminated, and cross-laminated sandstone ovelain by massive and channel conglomerate with lenses of sandstone. The major clast type is volcanic with minor intrusive rock clasts. The upper contact of the Shelikof is characterized mainly by conglomerate overlain by massive, laminated, and crossbedded Naknek arkosic sandstone. At a few localities, Naknek conglomerate forms channel-fill deposits which overlie the Shelikof conglomerate, and where this occurs the contact is gradational through 7.6 m of section with a gradual upward increase of intrusive rock clasts and a corresponding decrease in clasts of volcanic rock.

AGE AND CORRELATION

The Shelikof Formation was dated, using fossil evidence, as earliest Late Jurassic by all the early workers (Capps 1923; Smith, 1926; Martin, 1926; Kellum and others, 1945; Imlay, 1953). Imlay (1953) was the first to assign the Shelikof Formation to the Callovian Stage. The Callovian Stage has since been assigned to the Middle Jurassic in accordance with the recommendations of the Luxemburg Colloquium of 1962 (Ager, 1963). Imlay (1975) further restricted the age of the Shelikof to the early through middle Callovian. The Shelikof Formation is considered to correlate with the Chinitna Formation in the Tuxedni Bay and Iniskin Bay areas by most workers (Capps, 1923; Smith, 1926; Martin, 1926; Kellum and others, 1945; Imlay, 1953, 1975; Burk, 1965; Detterman and Hartsock, 1966).

REFERENCES CITED

Ager, D. V., 1963, Jurassic stages: Nature, v. 198, no. 4885, p. 1045-1046.

Burk, C. A., 1965, Geology of the Alaska Peninsula--Island arc and continental margin: Geological Society of America Memoir 99, 249 p.

Capps, S. R., 1923, The Cold Bay district, in Brooks, A. H., and others, 1923, Mineral resources of Alaska: U.S. Geological Survey Bulletin 739, p. 77-116.

Detterman, R. L., and Hartsock, J. K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p.

Imlay, R. W., 1953, Callovian (Jurassic) ammonites from the United States and Alaska--Part 2. Alaska Peninsula and Cook Inlet regions: U.S. Geological Survey Professional Paper 249-B, p. 41-108, 30 pls.

________1975, Stratigraphic distribution and zonation of Jurassic (Callovian) ammonites in southern Alaska: U.S. Geological Survey Professional Paper 836, 28 p., 6 pls.

Imlay, R. W., and Detterman, R. L., 1977, Some Lower and Middle Jurassic beds in Puale Bay-Alinchak Bay area, Alaska Peninsula: American Association of Petroleum Geologists Bulletin, v. 61, no. 4, p. 607-611.

Kellum, L. B., Daviess, S. N., and Swinney, C. M., 1945, Geology and oil possibilities of the southwestern part of the Wide Bay anticline, Alaska: U.S. Geological Survey Open-File Report, 17 p.

Martin, G. C., 1926, The Mesozoic stratigraphy of Alaska: U.S. Geological Survey Bulletin 776, 493 p.

Smith, W. R., 1926, Geology and oil development of the Cold Bay district, in Smith, P. S., and others, 1926, Mineral resources of Alaska: U.S. Geological Survey Bulletin 783, p. 63-88.

Westerman, G. E. G., 1964, The ammonite fauna of the Kialagvik Formation at Wide Bay, Alaska Peninsula--Part 1, Lower Bajocian (Aalenian): Bulletin of American Paleontology, v. 47, no. 216, p. 329-503.

_______ 1969, The ammonite fauna of the Kialagvik Formation at Wide Bay, Alaska Peninsula--Part 2, Soninnia sowerby Zone (Bajocian): Bulletin of American Paleontology, v. 57, no. 255, 226 p.

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SUBDIVISIONS OF THE MENEFEE FORMATION AND CLIFF HOUSE SANDSTONE (UPPER CRETACEOUS) IN SOUTHWEST SAN JUAN BASIN, NEW MEXICO

By Ralph L. Miller

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ABSTRACT

In the La Vida Mission 7.5-minute quadrangle and adjacent quadrangles to the east and west, a threefold division of the Allison Member of the Menefee Formation is recognizable. The uppermost unit, a little more than 200 ft (61 m) thick, contains coal beds in its middle and upper parts. It is here designated the La Vida Beds of the Allison Member of the Menefee Formation. Below these beds is a sequence characterized by the presence of large calcareous concretions, here named the Juans Lake Beds of the Allison Member of the Menefee. This sequence is about 900 ft (275 m) thick. Underlying the Juans Lake Beds is the lower part or lower beds of the Allison member, about 760 ft (232 m) thick. Whether the underlying coal-bearing or Cleary Coal Member of the Menefee is present at depth beneath the Allison Member is not known, but in a drill hole near the La Vida Mission quadrangle, the Cleary was reported to be about 300 ft (91 m) thick. Total thickness of the Menefee Formation for this region is on the order of 2,200 ft (663 m).

Overlying the Menefee Formation is the Cliff House Sandstone, consisting of a lower cliff-making marine sandstone about 160 ft (49 m) thick and an upper cliff- and ledge-making marine sandstone more than 30 ft (9 m) thick. Between the two marine sandstone units is a tongue of Menefee consisting of continental sandstone and mudstone, which in some places contains coal beds. This tongue is as much as 54 ft (16 m) thick, but it thins to extinction just east of the east border of the La Vida Mission quadrangle. Similar tongues of Menefee, but in different stratigraphic positions, have been mapped by others east of the La Vida Mission quadrangle, but none are continuous with the one described above.

The above-mentioned six bedrock units of the Menefee and Cliff House Formations serve to characterize more specifically the Upper Cretaceous rocks in the region of the La Vida Mission quadrangle, and they permit more meaningful mapping and stratigraphic analysis of these rocks. The refinement presented herein should assist the exploration for additional resources of fossil fuels in the San Juan Basin.

INTRODUCTION

Upper Cretaceous stratigraphy of the San Juan Basin of northwest New Mexico has been the subject of much work and of many papers by numerous geologists since the years when rocks of this age could be encapsulated into three stratigraphic units; Dakota Sandstone (Meek, and Hayden, 1862); Mancos Shale (Cross and others, 1899) (or Group) (Bissell, 1952); and Mesa Verde Formation (or Group) (Holmes, 1877). The consensus is that the Late Cretaceous seas advanced from north to south across the San Juan Basin several times, retreating each time, which resulted in a complex stacking of marine and continental sediments. The sequences vary from locality to locality, and the lithologic units within the sequences vary greatly in thickness from locality to locality. Many writers have described parts of this complex for the areas of their studies in the San Juan Basin. Formal stratigraphic names have been applied to some of these stratigraphic units.

The complexity of the relations involving Mesaverde (changed to one word by Cross and others, (1899)) types of sediments may be judged in part by reference to the "Lexicon of Geologic Names of the United States" (Keroher and others, 1966) where 34 entries and 5 pages are devoted to the

Mesaverde Group (or Formation). Numerous additional papers published since 1960, the cut-off date for the lexicon, would swell the number of important papers considerably, but more recent lexicons have been almost entirely limited to new stratigraphic names. The proliferation of papers on the Mesaverde Group within the San Juan Basin is a measure (1) of the complexity of the interlayered and intertonguing relations; (2) of the numerous stratigraphic changes within relatively short distances within the basin; (3) of the large thicknesses of most mapped units whether formal or informal; (4) of the need to recognize thinner units and to apply names, whether formal or informal, in order to prepare meaningful bedrock geologic maps and sections; (5) of the economic importance of these rocks because of the resources of oil and gas, coal, and uranium in the basin; and (6) of the excellent preservation of sedimentary structures, trace fossils, and other evidence for paleodepositional environments in the basin.

Geologic mapping at the 1:24,000 scale has been expedited by the now almost complete coverage of the basin with topographic quadrangle maps at that scale. Recent emphasis on geologic mapping by the U.S. Geological Survey in the San Juan Basin has been on areas having known potential resources of coal and uranium. Reconnaissance geologic maps have been prepared for numerous quadrangles to assist the exploration for both these commodities.

In 1979, I began work mapping the geology of the La Vida Mission 7.5-minute quadrangle. This quadrangle was chosen in order to learn as much as possible about the stratigraphy, structure, and coal resources of the uppermost part of the Mesaverde Group in a typical quadrangle not previously covered by reconnaissance mapping. The quadrangle is located in the southwest part of the basin, about 46 mi (74 km) due south of Farmington and 57 mi (92 km) northeast of Gallup (fig. 1). Because of the length and frequent repetition of the name La Vida Mission quadrangle, it will be referred to as the LVM quadrangle.

Kelley has described a Central Basin subdivision of the San Juan Basin bordered on east, north, and west by structural uplifts and on the south "rather arbitrarily by the Chaco Slope * * * by this concept the Chaco Slope is only a subdivision of the San Juan Basin * * *" (Kelley and Clinton, 1960, p. 19). Figure 2, showing these relations, is slightly modified from Kelley's map (1951, p. 125). Recent drilling across the Chaco Slope (Kirk and others, 1981) and structural calculations in and near the LVM quadrangle (Miller, unpublished data) indicate no change between the inclination of and direction of dip of beds in the southern part of the Central Basin and the Chaco Slope. Nevertheless, the concept of a Central Basin and a larger San Juan Basin is useful, and Kelley's "arbitrary" southern border of the Central Basin is here accepted as shown in figure 2.

In the LVM quadrangle, only two bedrock formations are present at the surface, the Menefee Formation and the overlying Cliff House Sandstone, the uppermost formations of the Mesaverde Group. The Cliff House Sandstone is exposed in the northeast part of the LVM quadrangle and in one butte in the northwest part. The remainder of the quadrangle has rocks of the Menefee Formation at the surface. I was faced with the dilemma of mapping Menefee Formation, undivided, over more than three-fourths of the quadrangle, or finding mappable subdivisions of this thick heterogeneous formation. Likewise, it needed to be determined whether the overlying Cliff House Sandstone was a homogeneous unit or a unit having mappable subdivisions. This paper describes mappable subdivisions of the Menefee and of the Cliff House in the LVM and adjacent quadrangles that were found as the result of these studies.

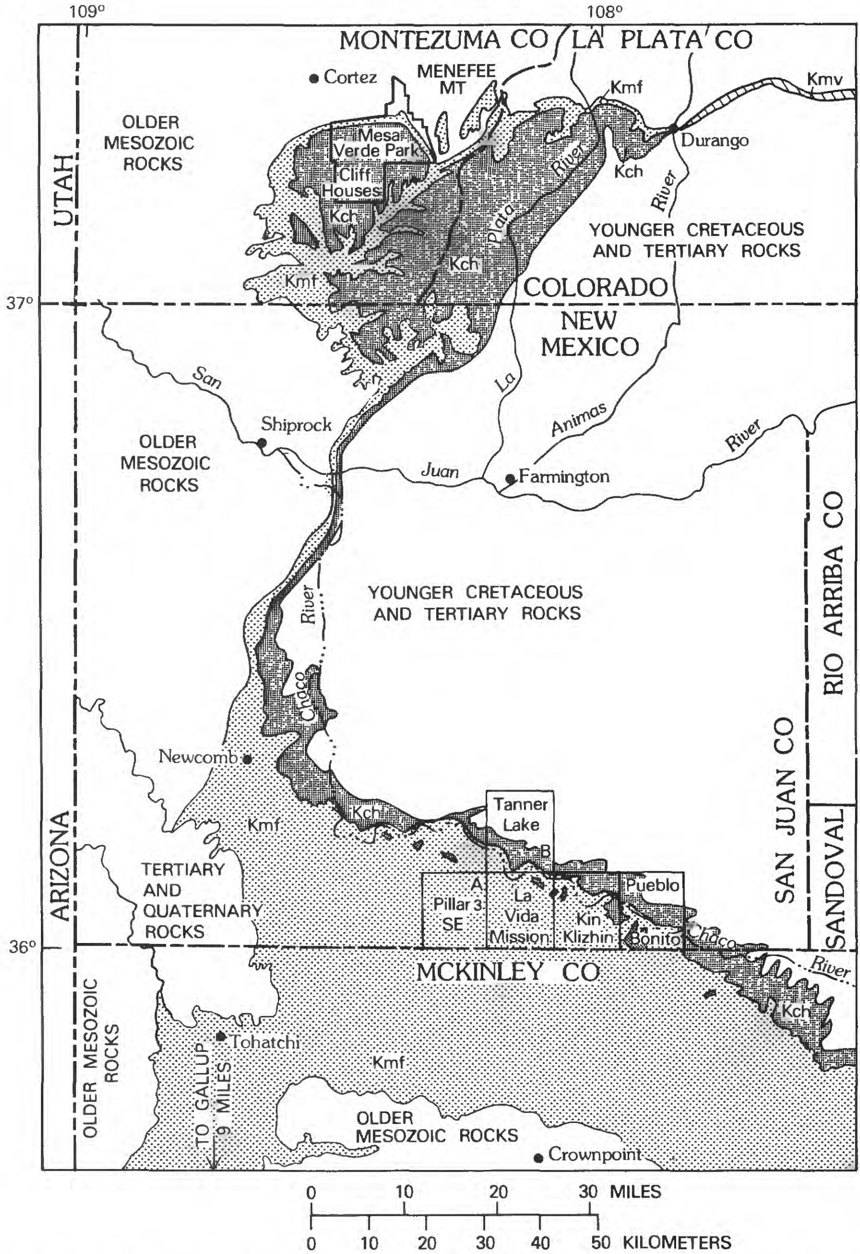

FIGURE 1.—Map of San Juan Basin, northwestern New Mexico and adjacent Colorado, showing locations of La Vida Mission and nearby quadrangles, outcrop areas of Cliff House (Kch) and Menefee (Kmf) Formations, and Mesaverde Formation (Kmv) east of Durango, and location of Red Hill - White Rock (A) and Tsaya Canyon (B) measured sections.

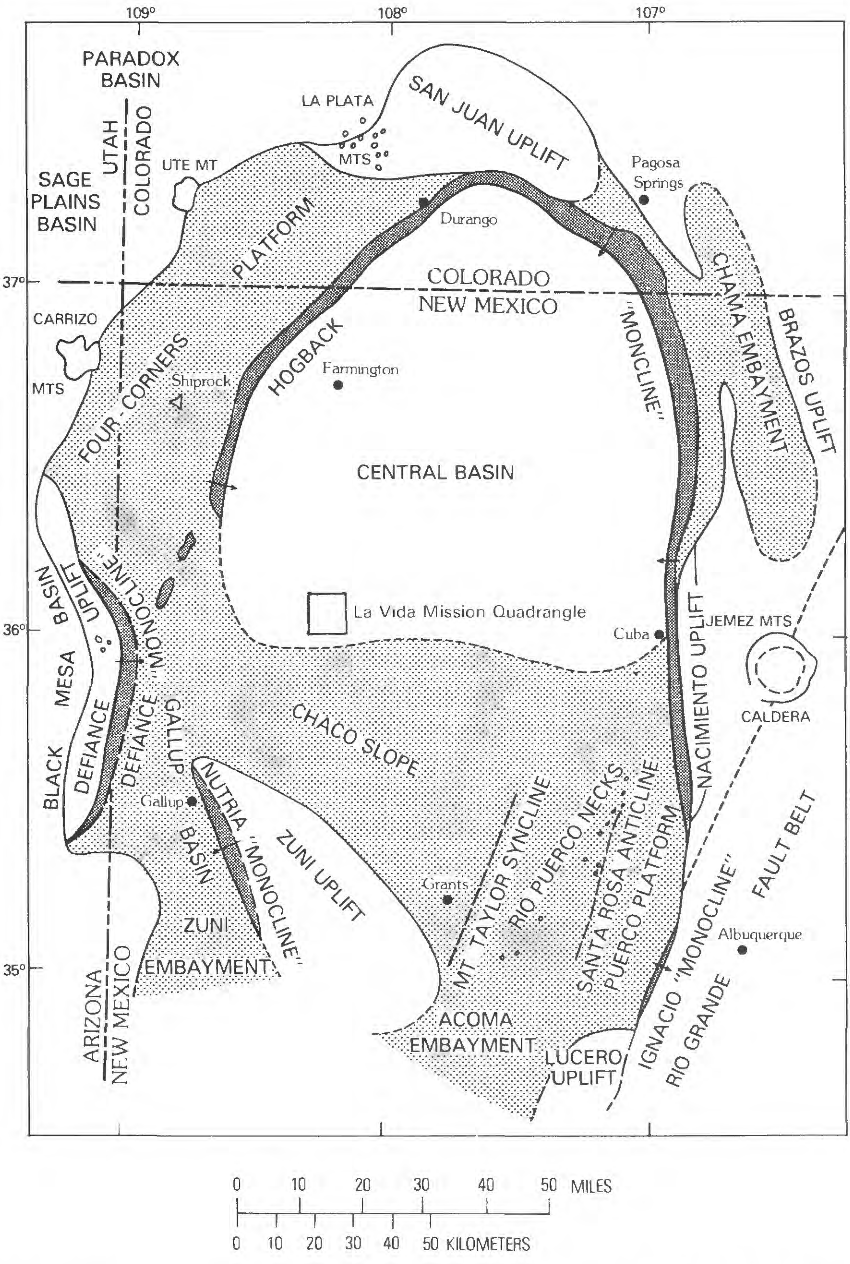

FIGURE 2.--Structural elements of the San Juan Basin (modifed from Kelley, V. C., 1951, New Mexico Geological Society Guidebook, no. 2, p. 125).

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MENEFEE FORMATION

The Menefee Formation is areally the most extensive Cretaceous formation at the surface in the New Mexico part of the San Juan Basin. It crops out in a narrow belt from the Colorado border southward for nearly 60 mi (97 km) past Shiprock (fig. 1) to the town of Sheep Springs, a tiny community 10 mi (16 km) south of Newcomb, on U.S. 666. From Sheep Springs the belt swings southeastward and widens out to nearly 25 mi (40 km). The LVM quadrangle is in the northern part of this wide belt (fig. 1). The rocks in this region dip very gently north to north-northeast, so only approximately the upper half of the formation is at the surface in the quadrangle area. The contact with the overlying Cliff House Sandstone is exposed in several places near the north border of the quadrangle.

History of Names

The Menefee Formation was named from Menefee Mountain (fig. 1) near the town of Mancos in the southwest corner of Colorado near the north margin of the San Juan Basin (Collier, 1919). In the type locality Collier described the formation as consisting of about 400 ft of beds of sandstone, shale, and coal in the ratio of 55 percent shale, 42 percent sandstone, and 2 to 3 percent coal. The coal is present "in many beds which vary greatly in thickness from place to place" (Collier, 1919, p. 296). In this area the formation overlies a massive sandstone which Collier named the Point Lookout Sandstone and underlies another sandstone which he named the Cliff House Sandstone. In southwest Colorado and in the region of the LVM quadrangle, these three formations constitute the Mesaverde Group, a name first proposed by W. H. Holmes (1877) in the form Mesa Verde Group.

In New Mexico many papers have dealt with the rocks assigned to the Menefee Formation, especially in the southern and southeastern parts of the San Juan Basin. The nomenclature applied by various authors, particularly Sears (1925, 1934), Dane (1936, 1948), Beaumont (1954), and others was reviewed and discussed by Beaumont and others (1956). From this analysis there resulted a nomenclatorial scheme in which the Menefee was divided into two members. A coal-bearing lower member was named the Cleary Coal Member. It is some 250 to 300 ft thick in its type locality. These beds had previously been called the "lower coal-bearing member of the Menefee" (Hayes and Zapp, 1955) in an area on the west side of the basin. They also constituted the upper part of the Gibson Coal Member of the Mesaverde Formation of Sears (1925) and of Dane (1936). The remainder of the Menefee, the so-called "barren" member, was to retain the name Allison Member, first proposed by Sears (1925). Sears states that the Allison Member is more than 500 ft thick in the Gallup area. Dane (1936, p. 95-96), in describing the La Ventana-Chacra Mesa coal field stated: "* * * As the top of the [Allison] member was not defined it seems a legitimate extension of the term to apply it to all the continental beds above the Gibson coal member and below the marine sandstone members [Cliff House Sandstone] at the top of the Mesaverde formation. This usage includes in the Allison some coal beds in the upper part of the member (pl. 41), whereas the member was originally defined as barren of coal. However, the coal-bearing part of the member does not have the stratigraphic continuity or thickness to warrant its separation as a member, and the coal-bearing beds belong genetically to the continental type of sediments of which the Allison is composed, not to the marine sandstones that overlie them. As a convenient and practicable terminology, therefore, the writer uses the name 'Allison Member' for all the continental beds of the Mesaverde Formation above the Gibson coal member. * * *"

Recently, Molenaar commented (1977, p. 164) "the upper part of the Allison is very carbonaceous and coaly. * * * This zone is sometimes referred to as the upper coal-bearing unit of the Menefee. * * *" In a companion paper in the same publication, Peterson and Kirk (1977, fig. 2), in a restored stratigraphic section, divide the Menefee into three members in the general area here considered. These are lower coal member, middle barren member, and upper coal member. In the same section the lower coal member is traceable southwestward into the Cleary Member, the middle member is traceable into the main part of Allison Member of the Menefee, and the upper member is shown forming the uppermost part of the formation but overlapping the barren part of the formation and pinching out in a southwest direction.

La Vida Beds of the Allison Member

The coal-bearing part of the Allison Member of the Menefee is well displayed in mesas in the northeast part of the LVM quadrangle, in buttes in a badlands area in the northwest corner of the quadrangle, and in the adjacent quadrangles to east and west. Sections measured at these localities consistently have a coal bed within a few feet of the top of the formation, and at least one and in some places several additional coal beds, most more than 1 ft (0.3 m) thick, in the underlying 200 ft (61 m) of beds. The coal beds are lenticular, so that measured sections in and near the quadrangle show a different spacing of coal beds below the uppermost coal. In many places the coals have burned, leaving a residue of white ash. In these places the original thickness of the coal bed can not be determined, but the ashy residue can in most places be found by digging at or close to the base of the red clinker zone resulting from the burn. Other writers have noted the coaly zone in the upper part of the Menefee over a wide area in the southern part of the San Juan Basin (Sabins, 1964, p. 302; Siemers and King, 1974, p. 268; Lease, 1971, p. 52-56; Siemers, 1977; Dane, 1936; Mytton, 1979, O'Sullivan and others, 1979; and others). This zone, however, has not been mapped as a separate part of the Menefee Formation because of the small scale of the mapping, because the distinction was not germane to the purpose of the investigations, or because no consistent base of the unit was apparent. This lack of a consistent base results from the lenticularity of the coal beds, which causes different stratigraphic locations of the lowest coal within relatively short distances.

This same problem of a consistent base to the coal-bearing beds exists in the LVM quadrangle. In searching for mappable units within the thick (approx 1,000 ft, or 305 m) sequence of Menefee beds present at the surface in the quadrangle, however, I noted a thick zone of Menefee sandstone and mudstone characterized by the presence of large limestone concretions. The top of this zone, approximately 100 ft (30 m) below the lowest coal noted in the quadrangle, proved mappable with moderate accuracy. This mapped horizon thus delimits a sequence of beds at the top of the Menefee that is distinguished in its middle and upper parts by coal beds. Thus, the "Allison barren member" of Sears (1925, p. 18) is not barren in its upper part, as Dane (1936) and others have recognized. It seems desirable to formalize the status of this upper coal-bearing unit. In order to avoid redefining and restricting the Allison Member, the coal-bearing unit is here named the La Vida Beds of the Allison Member, a name from La Vida Mission Indian School in the north part of the quadrangle. Excellent exposures of the middle and upper parts of the beds occur along the Chaco River north of the school and in the mesas south-southeast of the school. A full section of the La Vida Beds crops out in the badlands area dominated by Red Hill Butte and White Rock Mesa in the northeast part of The Pillar 3 SE quadrangle, which is adjacent to the LVM quadrangle on the west (fig. 1). The measured section in the Red Hill-White Rock region, described below, is therefore chosen as the type section of the La Vida Beds of the Allison Member.

The contact of the La Vida Beds of the Allison Member with the overlying Cliff House Sandstone is exposed in many places in the northeastern part of the La Vida Mission quadrangle and in adjacent quadrangles to the east, north, and west. Where exposed, the contact lies a few feet above the base of the cliff, which is formed by the resistant Cliff House Sandstone. Lengthy exposures of the contact are rare, however, because of the cover of talus that in most places blankets the lowest part of the cliff and the slopes below the cliff. In the majority of exposures the contact is sharp and clear cut, with very little channeling of the basal sands of the Cliff House into the mudstones and thin sandstones of the Menefee. Relief on the contact may be as little as a few inches up to a few feet. In other exposures, however, a transition zone as much as 20 ft (6.1 m) thick is present consisting of one or more tongues of Menefee-type mudstone within Cliff House-type sandstone units. In the type section of the La Vida Beds at White Rock in the northeast corner of The Pillar 3 SE 7.5-minute quadrangle, the transition zone is 17 ft (5.3 m) thick (units 26 and 25, table 1).

Coal beds have burned in many places, particularly on upper slopes where the coal has been exposed longer and has oxidized and caught fire. Coal beds close above drainages normally have not burned. Also, most beds of coal only a few inches thick have not burned. The base of the red clinker that results from baking the overlying mudstone marks the approximate position of a coal bed, and the nearly white ash remaining after burning can commonly be found with a little digging. Few residual ash beds exceed 1 ft (0.3 m) in thickness, and most are a few inches; in general, the thicker the coal bed the thicker the ash bed left after burning.

An additional lithology that is common in the La Vida Beds is a mudstone of dusky brown color, which normally contains abundant plant fragments. Many of the coal beds are underlain and (or) overlain by this dusky brown mudstone, but brown mudstone layers without associated coal beds are also numerous. The layers of brown mudstone stand out prominently in good exposures in contrast with the enclosing gray mudstone that makes up most of the argillaceous part of the Menefee. Most dusky brown mudstone layers are 1 to 3 ft (0.3 to 1 m) thick, but layers as thick as 10 ft (3 m) have been seen. This lithology is common in the upper part of the

Table 1.--Type Section of the La Vida Beds of the Allison Member of the Menefee Formation

[Measured by R. L. Miller and Mark Kirschbaum, June 22, 27-29, 1979]

[Section is located in the northeast part of The Pillar 3 SE 7.5-minute quadrangle. Section begins in the northeast corner of sec. 31, T. 22 N., R. 13 W. at the base of the steep slopes of a promontory marked 6,200 ft, and proceeds to the top of the promontory. From the crest it offsets on top of the sandstone capping the promontory 0.7 mi (1.1 km) in a direction N. 42° W. to a jog on an abandoned road at an elevation of 6,160 ft (1,880 m). From this point, measurements were continued in a direction N. 26° E. to the top of the southern tip of White Rock Mesa in the north-central part of sec. 30]

	Thickness Feet	Thickness Meters
Cliff House Sandstone		
27. Sandstone, very pale orange, fine-grained. Not measured in detail. Forms vertical cliff in many places. South tip of mesa is cut off from main mesa by an impassable crevasse. Higher Cliff House beds are present on main mesa	135+	41.2+
26. Sandstone, fine-grained, with mudstone interbedded. Poorly exposed	9.6	2.9
25. Basal zone of Cliff House Sandstone consisting of jumbled reworked lenses of mudstone and fine-grained sandstone. Much of sandstone is baked to a red color from burning of underlying coal. Units 25 and 26 form a transition zone of Menefee-type mudstone and Cliff House-type sandstone. In other places no transition zone exists, and contact between the two formations is sharp. Coal was probably present at base of this unit but burned, and the ash was not found	7.8	2.4
Total	152+	46+
Menefee Formation		
La Vida Beds of the Allison Member		
24. Mudstone, light-olive-gray, some baked red; some red coatings on bedding planes and joints. Gypsum crystals weather out	8.8	2.7
23. Mudstone, light-olive-gray, but some bands baked red, giving whole slope a reddish cast	17.3	5.3

Table 1.--continued.

	Feet	Meters
22. Siltstone and mudstone, light-olive-gray, interbedded in lower part, changing to mudstone in upper two-thirds. Thin sandstone, light-gray, at top. Nearly this entire unit shows "clinker" red colors	12.6	3.8
21. Predominantly mudstone, but now largely red clinker. Zone of ironstone concretions at top	7.5	2.3
20. Shale, dark-gray; some carbonaceous shale in upper part. Beds are at top of small knob, on the crest of which lay a burned coal bed, no longer present. This coal probably accounts for the burned colors of unit 21 and possibly of higher units	4.8	1.5
19. Mudstone, pale-brown	8.0	2.4
18. Mudstone, pale-brown, with a thin bed of sandstone in middle	8.0	2.4
17. Unit, poorly exposed, appears to be coal, about 2.2 ft (0.7 m) thick underlain by mudstone	3.9	1.2
16. Unit, poorly exposed, appears to be coal, about 2.2 ft (0.6 m) thick underlain by pale-brown mudstone with some red clinker, and with a thin coal at base. (Units 16 and 17 could not be dug out completely with equipment available)	3.2	1.0
15. Mudstone, pale-brown with a thin coal (burned to ash) at top. Probably same coal as base of unit 16	4.8	1.5
14. Mudstone, pale-brown, with a 1-foot (0.3 m) bed of white sandstone at top. Poorly exposed	12.1	3.7
13. Mudstone, dusky-brown, with 4-foot (1.2 m) slabby sandstone at top. Ironstone concretions 3 ft (0.9 m) above base and at top	18.7	5.7
12N Sandstone, light-gray, fine-grained, poorly exposed	3.0 } 6.8	0.9 } 2.1
11N Coal (14 in, 36 cm) overlain by carbonaceous shale (31 in, 79 cm). Locally cut out by overlying channel sandstone. Offset of 0.7 mi (1.1 km) between above section to north (11N, 12N) and below section to south (11S, 12S)	3.8	1.2
12S Sandstone, light-gray to white, fine-grained, with numerous iron-cemented sandstone concretions 1 in. (2.5 cm) to 3 in. (8 cm) in size. Forms nearly vertical cliff, shelving back at top.		

Table 1.--continued

	Feet	Meters
Because of its sheer cliff and nearly white color, it is most prominent unit in this vicinity. This sandstone has thinned to 3.8 ft (1.1 m) in unit 12N above --------------------	avg[1/] 35.0	10.7
	51.6	15.7
11S Sandstone, fine-grained in nodular masses with one or more lenses of brown mudstone. Forms lowest part of overlying cliff-making sandstone (unit 12S) ------------------	11.8	3.6
(51.6 + 11.8; 15.7 + 3.6)	63.3	19.3
10. Mudstone, dusky-brown, at base and top with plant debris (trash). Middle very poorly exposed; presumed largely or entirely similar mudstone. Gypsum veinlets at top ---------------	19.5	5.9
9. Sandstone, light-gray, fine-grained with low angle crossbedding. Upper part forms prominent ledges ---------	12.9	3.9
8. Mudstone, light-olive-gray, with scattered small ironstone concretions ---	12.3	3.8
7. Sandstone, light-gray, white-speckled, fine-grained, locally forms ledges; thins to 2 ft (0.6 m) nearby -------	8.9	2.7
6. Mudstone, light-olive-gray and brownish-gray with ironstone concretions and plant fragments -------------	4.0	1.2
5. Mudstone, dusky-brown, with plant trash; forms dark band -------------	0.5	0.2
4. Siltstone, light-gray, with some fine-grained sandstone ------------	9.2	2.8
3. Mudstone, dusky-brown, slightly carbonaceous at base. Forms prominent dark band --------------------	1.0	0.3
2. Sandstone, light-gray, fine-grained with interbedded mudstone. Basal unit of La Vida Beds ----------------	18.7	5.7
Total [2/]-------------------	231.7	70.7

Juans Lake Beds of the Allison Member

	Feet	Meters
1. Sandstone, light-gray, very fine grained, at base, overlain by light-olive-gray mudstone. Prominent zone of large calcareous concretions at top. Unit contains petrified wood ---------	10.9	3.3

1/ Averaged thicknesses of 11N-12N and 11S-12S.
2/ Reflects averaged thicknesses for 11N-12N and 11S-12S.

Menefee Formation and occurs both in the La Vida Beds and in the underlying beds with calcareous concretions. Siemers and Wadell (1977) have described these brown, organic-rich beds carefully, calling the beds "humate deposits."

Chunks of petrified wood are quite common in the La Vida Beds, but no in-place trunks were noted. The colors of the petrified wood are drab, mostly light gray and off-white. Bands of ironstone concretions are likewise common. Most ironstone concretions are a few inches in longest dimension but some are as long as 1 ft (0.3 m). In a few places, the concretions have coalesced to form a thin ironstone bed.

The thickness of the La Vida Beds at the type section is 232 ft (71 m). This thickness figure incorporates the average thickness of the sandstone (units 11-12, table 1); these units were 63.3 ft (19.3 m) thick in the southern subsection but only 6.8 ft (2.1 m) thick in the northern subsection. No other locality was found in or near the LVM quadrangle where base and top of the La Vida Beds are well exposed in quite close proximity to each other. Calculations derived from approximate elevations at mapped base and top of the La Vida Beds in several localities in the northeast part of the quadrangle, however, indicated thicknesses of about 200 ft (61 m).

The La Vida Beds were deposited in a fluvial distributary and interdistributary environment. In the channels, incursions of mud, silt, and fine sand were taking place. Between the channels, flood-plain deposits were interspersed with swamps, some of which were large enough and existed long enough to allow plant accumulation to form peat, later to become compacted into coal beds.

Juans Lake Beds of the Allison Member

The main body of the Menefee Formation in the LVM quadrangle below the La Vida Beds consists of a rather monotonous sequence of interbedded fine-grained sandstone and gray mudstone, similar to the rocks that make up most of the La Vida Beds. The principal difference between these rocks and the sandstone and mudstone of the La Vida Beds is the inclusion of numerous large calcareous concretions and the absence of coal beds. The concretions are spectacular, round, bun-shaped masses, many of them several feet in diameter, that occur in layers, mostly close above or close below one of the sandstone units. A few concretions occur in mudstone not near any sandstone bed, but these are rare. Circulation of water laden with calcium carbonate through the more pervious sandstone supplied abundant mineral matter to promote the growth of the concretions, probably not long after deposition of the sediments.

It needs to be emphasized that the concretions are not composed of sandstone cemented by calcium carbonate. They are dense, hard, and cryptocrystalline limestone, with a distinctive conchoidal fracture pattern. The fresh color of the limestone is a light gray, but the rock weathers to a light-yellowish-brown (grayish-orange 10 YR 7/4 on the rock color chart (Goddard and others, 1948)), which is easily recognized even at a distance. In places where the concretions are particularly abundant and where broad erosion surfaces have developed on the top of an underlying sandstone bed, the surface looks like a giant cabbage patch with spacing of a few tens of feet between the concretions.

The part of the Menefee having calcareous concretions forms the bedrock over most of the LVM quadrangle. The top of this zone is a mappable horizon that also delimits the base of the La Vida Beds. The concretions are present through hundreds of feet of beds, but are less abundant downward. The lowest ones stratigraphically are somewhat granular, rather than cryptocrystalline, but they are not sandy.

A lower limit to the part of the Menefee containing the concretions is more difficult to delineate than the upper limit because the concretions are more scarce downward, and because their presence is largely dependent on the presence of sandstone beds, which are also less numerous downward in the section. There is, however, a mappable lower cutoff of the beds containing concretions, though that cutoff is not consistently at the same stratigraphic horizon.

This part of the Menefee with calcareous concretions is here named the Juans Lake Beds of the Allison Member. The name is taken from Juans Lake in the northeast part of the La Vida Mission quadrangle. This lake is the largest body of water in the southern part of the San Juan Basin. The beds are known to be recognizable in the Kin Klizhin Ruins and The Pillar 3 SE quadrangles to the east and west respectively of the LVM quadrangle. How much farther in either direction the concretion-bearing sequence may persist has not been established.

The upper part of the Juans Lake Beds is well exposed in the badlands area near Red Hill, where a section of these beds was measured from the SE corner of sec. 6, T. 21 N., R. 13 W. (The Pillar 3 SE quadrangle) to the base of the La Vida Beds on the lower steep slopes of Red Hill in section 5. A total of 442 ft (135 m) of beds representing about the upper half of the calcareous concretion sequence was measured at this locality. This section is here designated the type section of the Juans Lake Beds (table 2). No measurements could be obtained at this locality for the thickness of the lower part of these beds below the base of the measured type section because of gentle dips and few outcrops in the area of low relief to the south. A rough measurement has been made on the basis of two regional dips calculated in the northern part of the LVM quadrangle. One was 1.7^{o} NNE, the other 1.0^{o} N. Using the mean of 1.35^{o}, approximately N. 10^{o} E., the lower part of the Juans Lake Beds would comprise an additional 464 ft (142 m), making a total thickness of about 900 ft (274 m) for the beds with calcareous concretions. The calculated thickness used here is tentative and subject to change as more data become available. Although no measured section of these lower beds was possible, evidence from scattered outcrops shows that they consist predominantly of fine-grained sandstone and mudstone similar to the beds in the type section. As previously noted, calcareous concretions are fewer. So also are zones of dusky brown mudstone. Sandstone units also are fewer and thinner. Ironstone concretions seem to be as abundant in these lower beds as in the upper beds in the type section.

The total thickness of the Menefee in this area has been calculated using three wells, two drilled for oil and one for water. Two of the wells are within the LVM quadrangle, and one is a mile to the west in The Pillar 3 SE quadrangle. The western well is in sec. 7, T. 21 N., R. 13 W. It spudded in the upper part of the Menefee and drilled into the underlying Point Lookout Sandstone. The well record showed that the well penetrated 1,533 ft (468 m) of Menefee from the surface to the top of the underlying Point Lookout. The section measured at Red Hill showed 672 ft (205 m) of Menefee from the lowest exposed beds to the base of the Cliff House. The base of the measured section was at almost the same elevation

Table 2.--Type Section of the Juans Lake Beds of the Allison Member of the Menefee Formation

[Measured by R. L. Miller and Mark Kirschbaum, June 22, 25-26, 1979]

[Section is located in the northeast part of The Pillar 3 SE 7.5-minute quadrangle. Section begins in the southwest corner sec. 6, T. 22 N., R. 13 W., at the base of a southwest-extending point alongside an abandoned road and proceeds northward and northeastward crossing the highway 600 ft (183 m) north of a corner labeled 5,943 ft. Thence it climbs eastward up the southernmost tributary ravine of a southwesterly flowing stream. Top of section is 15 ft (4.6 m) below the saddle between the two knobs of Red Hill in the northeast corner of the section at an elevation of about 6,240 ft (1903 m). Section begins 1.1 mi (1.8 km) west of the LVM quadrangle and ends 0.2 mi (0.3 km) west of the quadrangle]

	Thickness	
	Feet	Meters
Menefee Formation		
La Vida Beds of the Allison Member		
61. Mudstone, dusky-brown, carbonaceous in upper part with thin films of coal. Forms prominent dark-colored band on vertical cliffs ----------------	2.8	0.9
60. Sandstone, lower part a cliff-maker, mostly massive-bedded, but contains zones of planar laminated sandstone and of low angle crossbedded sandstone --------------------	37.9	11.6
59. Mudstone, light-olive-gray, and sandstone light-gray, white-speckled ----	13.5	4.1
58. Sandstone, white-speckled, medium-grained. Lower part makes ledge ---	17.0	5.2
Total ------------------	71.2+	21.8+
Juans Lake Beds of the Allison Member		
57. Sandstone, fine-grained, nonresistant. Large calcareous concretion at top --	7.0	2.1
56. Mudstone, light-olive-gray ---------	7.5	2.3
55. Sandstone, light-gray, fine-grained ----	5.5	1.7
54. Mudstone, light-olive-gray. Layer of ironstone concretions near top ----	24.4	7.4
53. Mudstone, gray, overlain by mudstone, dusky-brown with plant fragments. Forms prominent dark band on steep slopes --------------------	2.7	0.8
52. Mudstone, light-olive-gray. Two layers of ironstone concretions in lower part and two more in upper part. Carbon-		

Table 2.--continued.

	Feet	Meters
ized tree trunk, nearly upright, 7 in. (17.8 cm) in diameter near base. Forms very steep slopes in ravine --	26.0	7.9
51. Sandstone, light-gray, fine-grained. Lower part makes small ledge -----	9.6	2.9
50. Sandstone, light-gray, fine-grained, crossbedded in upper part. In upper part a zone 13 in. (33 cm) thick of dusky-brown mudstone, with calcareous concretions at top ---------	16.9	5.2
49. Mudstone, light-olive-gray. A few ironstone concretions in upper part ----	18.7	5.7
48. Sandstone, light-gray, white-speckled, fine-grained, nonresistant. Thin crossbedded zones. Calcareous concretions at base, many with cores of ironstone ------------------	11.5	3.5
47. Mudstone, pale-yellowish-brown in lower two-thirds; and sandstone, light-gray, very fine grained, above. Near top a zone of ironstone concretions is overlain by a zone of calcareous concretions ----------------	20.6	6.3
46. Mudstone, pale-yellowish-brown. Prominent zone of ironstone concretions and calcareous concretions at top -----	3.2	1.0
45. Shale, carbonaceous. Lenses of coals less than 1 in. (2.5 cm) thick at base. Abundant blebs of resin in some layers. Forms prominent dark unit in walls of ravine --------------	1.1	0.3
44. Sandstone, light-gray, fine-grained, nonresistant in lower two-thirds; mudstone, pale-yellowish-brown above, with a few ironstone concretions and one calcareous concretion -------	15.3	4.7
43. Sandstone, light-gray, fine-grained, slabby, nonresistant, with two zones of calcareous concretions -------	18.2	5.6
42. Mudstone, pale-yellowish-brown, with calcareous concretion at top. Poorly exposed ------------------	5.8	1.8
41. Mudstone, pale-brown with abundant dark-brown plant debris. Contains scattered angular coaly chips -----	0.9	0.3
40. Sandstone, very fine grained, with a few carbonaceous films -----------	11.5	3.5
39. Sandstone, light-gray, medium-grained, crossbedded, nonresistant. Thin bed of ironstone at top. Calcareous concretions and logs of gray petrified wood --------------------	25.2	7.7

Table 2.--continued.

	Feet	Meters
38. Sandstone, light-gray, fine-grained, changing to mudstone upward. Ironstone concretions near base ------	8.9	2.7
37. Mudstone, light-gray, slightly silty, and mudstone, grayish-orange, nonsilty. Beds of dusky-brown mudstone, 2 in. (5 cm) in middle, and another 6 in. (15 cm) at top. Numerous pedestals and pillars of mudstone capped by sandstone at this level ----------	16.7	5.1
36. Mudstone, gray, and mudstone, dusky-brown, with carbonaceous seams in lower half; sandstone crossbedded above --------------------	5.1	1.6
35. Sandstone, light-gray, white-speckled, crossbedded, becoming fine-grained upward. Contains a few very large oval ironstone concretions, largest is 6 ft (1.8 m) in longest dimension. Lenses out to east ------------	0-7.5 avg 3.8	0-2.3 1.2
34. Mudstone, pale-yellowish-brown, with ironstone concretions at two levels. Band of dusky-brown mudstone up to 10 in. (25.4 cm) thick at top ------	9.0	2.7
33. Lens of calcareous mudstone up to 1.5 ft (0.5 m) thick. Has conchoidal fracture --------------------	1.5	0.5
32. Sandstone, light-gray, fine-grained, nonresistant ------------------	4.5	1.4
31. Ironstone in coalescing nodules to form a bed. Colors range from pale brown, through grayish brown to dusky brown. Sheds abundant chips downslope -------------------	0.5	0.2
30. Sandstone, light-gray, fine-grained, even-bedded, grading upward into mudstone -----------------	7.0	2.1
29. Siltstone, calcareous, with zone of ironstone concretions at base -----	3.0	0.9
28. Sandstone, white-speckled, medium-grained, crossbedded in lower half; upper half fine-grained, even-bedded. Followed top of this unit 0.2 mi (0.3 km) toward Red Hill to base of unit 29 ------------------	5.7	1.7
27. Sandstone, very fine grained, even-bedded ------------------	1.7	0.5
26. Mudstone, gray. Ironstone bed at top --	1.1	0.3
25. Mudstone, brown, organic-rich, even-bedded ------------------	0.7	0.2
24. Mudstone, light-gray. Two layers of ironstone concretions ----------	3.5	1.1

Table 2.--continued.

	Feet	Meters
23. Sandstone, fine-grained ----------	0.5	0.2
22. Mudstone, light-gray. Zones of medium and large ironstone concretions at base and 2 ft (0.6 m) from top. Most concretions are flat ovals between 1 and 2 ft (0.3-0.6 m) in longest dimension --------------------	10.4	3.2
21. Mudstone, dusky-brown -----------	3.5	1.1
20. Mudstone, light-gray, with plant fragments. Very large ironstone concretion 5 ft x 1 ft (1.5 m x 0.3 m) at base	4.6	1.4
19. Shale, carbonaceous, with abundant plant fragments, some carbonized. Forms small bench ----------------	0.8	0.2
18. Lower half: mudstone, dusky-brown, organically rich; upper half: siltstone, yellowish-gray --------------	4.0	1.2
17. Covered, across highway. Calculated --	7.5 ±	2.3 ±
16. Sandstone, yellowish-gray, fine-grained, white-speckled, crossbedded. Contains petrified wood. Caps cliff just west of highway --------------	6.1	1.9
15. Sandstone, grayish-orange, very fine grained, and shale, light-olive-gray, with plant fragments. Shale contains veinlets of gypsum ------------	2.6	0.8
14. Mudstone, grayish-brown, organically rich ---------------------	2.0	0.6
13. Siltstone, poorly exposed, weathers yellowish-brown -------------	3.9	1.2
12. Mudstone, grayish-brown, with abundant plant fragments, with a 1-foot (0.3 m) sandstone bed in middle ---------	10.5	3.2
11. Covered, at base of bluff of mudstone -	3 ±	0.9 ±
10. Sandstone, fine-grained, poorly exposed below bluff of unit 12 ----------	3 ±	0.9 ±
9. Covered --------------------	10 ±	3.1 ±
8. Sandstone, grayish-yellow and pinkish-gray, fine-grained, subangular to subrounded. Clay films line some pores; strongly crossbedded, at angles up to 15 degrees. Contains oval iron-cemented sandstone concretions. On flat surfaces weathers reddish brown. Channel sandstone -------	10-24 avg 17	3.1-7.3 5.2
7. Siltstone, grading upward into gray shale. Upper half brown with two thin carbonaceous bands and ironstone concretions near top -----------	13.2	4.0
6. Sandstone, fine-grained; forms small ledge --------------------	0.8	0.2

Table 2.—continued.

	Feet	Meters
5. Mudstone, silty at base and top, greenish-gray; ironstone concretions near top ------------------	6.9	2.1
4. Shale, carbonaceous, dark-brown and brownish-black. Contains veinlets of coal and tiny pellets of amber resin -	0.8	0.2
3. Sandstone, fine-grained, interlaminated with shale at base, grading upward to gray and greenish-gray mudstone ---	10.3	3.1
2. Sandstone, light-gray, fine-grained, with plant fragments. Contains scattered ironstone concretions ----------	5.0	1.5
1. Lower half siltstone, medium-gray; upper half shale, brown, with carbonized fragments, one small carbonized log -	11.0	3.4
Total -------------------	442	135

as the well and only 1,700 ft (518 m) from it in the approximate direction of the regional strike. Thus, a total of 2,219 ft (677 m) of Menefee appears to be present in the Red Hill area.

The eastern well is in sec. 18, T. 21 N., R. 12 W., of the LVM quadrangle. According to the driller's log, it spudded in the Menefee and penetrated 1,491 ft (455 m) of beds to the top of the Point Lookout. No measured section from the well to the base of the Cliff House is possible at this site, but a calculated thickness using a regional dip and strike suggests that the well spudded 563 ft (172 m) below the base of the Cliff House, making a total thickness for the Menefee of 2,054 ft (626 m).

The third well is the water well at the Lake Valley Navajo School in sec. 6, T. 21 N., R. 12 W. It spudded in the upper part of the Menefee. A driller's log of the well indicates that the Point Lookout Sandstone was reached at 2,000 ft (610 m)—probably a rounded number. A calculated thickness for the beds from the ground level at the well to the base of the Cliff House Sandstone 0.95 mi (1.53 km) to the northeast gave an interval of 270 ft (82 m). Thus, the total thickness of the Menefee at the water well, based on available numbers, becomes 2,270 ft (692 m). The three thickness determinations (2,219, 2,054, and 2,270 ft) are close enough to give some confidence in reporting that the Menefee in this region is over 2,000 ft (610 m) thick, and it may be on the order of 2,150 to 2,200 ft (656 to 671 m). Thus, the thickness of the La Vida Beds and the Juans Lake Beds combined represent about the upper half of the whole Menefee Formation in this area. A generalized column for the area is shown in table 3.

In a well 12 mi (16 km) to the northeast, Fassett and others (1977a, well No. 1, fig. 2) records 1,850 ft (564 m) of Menefee. Fassett noted (written commun., 1982), however, that the Menefee is believed to thicken in the southwest direction from well No. 1 to the wells in the LVM quadrangle area; thus, thicknesses reported in the two areas are not necessarily discordant.

Table 3.--Generalized section of the Menefee Formation for the La Vida Mission region of the San Juan Basin

	Thickness	
	Feet	Meters
Cliff House Sandstone	>248	>76
Menefee Formation		
Allison Member		
La Vida Beds	232	71
Juans Lake Beds	900	274
Lower beds	760	232
Cleary Coal Member	300	92
Total	2,192	669
Point Lookout Sandstone (from the two oil company wells)	110	34

Lower beds of the Allison Member

Because I am here establishing a named coal-bearing unit (the La Vida Beds) for the uppermost part of the Allison Member of the Menefee Formation, and an underlying unit named the Juans Lake Beds, the remainder or lower beds of the Allison Member consist of those beds lying between the base of the Juans Lake Beds and the Cleary Coal Member of the Menefee. This sequence might still be considered as the barren beds of the Allison Member, now meaning barren both of coal beds and of calcareous concretions. Only the uppermost part of this sequence is exposed in the LVM quadrangle. The lower beds consist of interbedded fine-grained sandstone, siltstone, and mudstone similar to lithologies in the overlying calcareous concretion beds minus the concretions. The contact between the two mapped units lies at the base of the lowest occurrence of the concretions. The lower beds of the Allison Member have been calculated to be about 760 ft (232 m) thick. They form the bedrock and crop out sporadically in a wide belt from near the south border of the LVM quadrangle southward for nearly 15 mi (24 km).

Cleary Coal Member

The Cleary Coal Member (Beaumont and others, 1956) is not exposed in the LVM quadrangle. It has, however, been identified nearby in the cuttings of four drill holes. Holes 9 and 10 are less than 2 mi (3 km) south of the quadrangle (Kirk and others, 1981). In drill hole No. 10, the coal bed marking the top of the Cleary Coal Member was reached at a depth of about 750 ft (229 m) at an elevation of about 5,380 ft (1,640 m). The top of the underlying Point Lookout Sandstone was penetrated at a depth of about 1,055 ft (322 m), making a total thickness for the Cleary of about 300 ft (92 m).

The Cleary consists predominantly of mudstone and sandstone similar to the beds in the lower part of the Allison Member, but it is distinguished by its coal content. Three or more coal beds are present near the base of the Cleary in drill hole No. 9, and one or more others are present in the intervening beds below the topmost coal. "Traces" of coal in the cuttings (Kirk and others, 1981) at two or more levels in the beds high above the top of the Cleary must represent very thin coal beds in the lower beds of the Allison Member. The thickness of the coal beds in the Cleary cannot be determined from the logs or cuttings of the four drill holes that penetrated the Cleary in this region.

The Cleary probably underlies the entire La Vida Mission quadrangle. Because of the regional dip, which is consistently between 1^{o} and 1.5^{o}, the top of the member, which is at an elevation of about 5,380 ft (1,640 m) in drill hole No. 9, is expected to be at about 5,150 ft (1,570 m) at the south edge of the quadrangle and is progressively deeper northward.

CLIFF HOUSE SANDSTONE

The Cliff House Sandstone, which overlies the Menefee, was named by Collier (1919) in a report on a coal-bearing area near the town of Mancos in southwestern Colorado. The name is taken from the exposures "* * * On the southwest side of Mesa Verde where this formation, composed of hard sandstone, is very prominent, and forms the 'Upper Escarpment' of Holmes [1877]. * * *" He noted further that the cliff houses of Mesa Verde National Park were built along a shaly parting in the Cliff House Sandstone. At Mesa Verde, the Cliff House is about 400 ft (122 m) thick (Wanek, 1954).

In the La Vida Mission area the Cliff House likewise consists of hard sandstone, which forms prominent cliffs along the Chaco River and caps mesas and buttes south of the belt of outcrop. The sandstone is consistently clean and fine to very fine grained. Colors of the unweathered sandstone are off-white, very light gray, very pale orange, and other very light colors. Most of the sandstone is in units at least 10 ft (3 m) thick in which bedding is not visible or is indistinct, but thinner units have prominent horizontal bedding. Low-angle crossbedding is present in a few units but is not conspicuous. A few units fill channels in the underlying beds, but relief on these erosional surfaces is normally only a few feet. Sandstone concretions, cemented by calcium carbonate and (or) iron oxide are abundant in some layers. In some places the concretions weather out and litter the surface. Fossils are rare except for the burrow casts of *Ophiomorpha nodosa* Lundgren, a shrimp-like animal that favored shallow marine or intertidal environments. Marine mollusks, mostly pelecypods, have been found in a few places. Shaly sandstone units are rare and thin.

The name Cliff House Sandstone in the San Juan Basin has been the subject of discussion and controversy, inasmuch as various resistant sandstone units in different parts of the basin have been identified as Cliff House or as members or tongues of the Cliff House (Dane, 1936; Beaumont and others, 1956; Fassett, 1977). Mapping in the vicinity of the LVM quadrangle by several authors has consistently designated the massive sandstone overlying the Menefee Formation of this region as the Cliff House, on the basis of continuity of the unit northward around the west side of the Central Basin with the type Cliff House Sandstone in southwest Colorado (Zapp, 1949; Wanek, 1954; Hayes and Zapp, 1955; O'Sullivan and Beikman, 1963; O'Sullivan and Beaumont, 1957; O'Sullivan, 1955; Mytton, 1979; Tabet and Frost, 1979; Weide and others, 1979).

The sandstone lithology described above makes up the lower, major cliff-forming part of the Cliff House, which in the LVM quadrangle area is about 160 ft (49 m) thick. In the upper part of the formation, similar sandstone more than 30 ft (9 m) thick forms an upper small cliff and shelving ledges. Between the two is a slope-forming unit composed of gray mudstone, thin beds of sandstone, and in places including one or more coal beds. In a section measured at the mouth of Tsaya Canyon in the Tanner Lake 7.5-minute quadrangle, less than half a mile north of the LVM quadrangle (fig. 1*B*), this nonresistant (weak) unit is 54 ft (16 m) thick and includes four coal beds, the thickest being 4 ft (1.2 m) thick. The lithology of this unit is very similar to the lithology of the coal-bearing part of the La Vida Beds of the Allison Member of the Menefee Formation. Similar units within the Cliff House Sandstone have been mapped by O'Sullivan and others (1979) in a preliminary map of the Kin Klizhin Ruins quadrangle to the east and in unpublished mapping of the Tanner Lake quadrangle to the north.

I have mapped the unit in the northeast corner of the LVM quadrangle, resulting in a three-fold division of the Cliff House as shown in table 4.

Table 4.--Mapped divisions of the Cliff House Sandstone in and near the La Vida Mission quadrangle

	Feet	Meters
Upper cliff-making sandstone unit	33+	10.1+
Nonresistant (weak) unit	54-	16.5-
Lower cliff-making sandstone unit	161	49.1

I have also seen the weak unit at the surface in the Tanner Lake quadrangle at an elevation of 6,250 ft (1,906 m) near an abandoned house 2.5 mi (4 km) west northwest of Tsaya Canyon. Here it includes at least one coal bed and probably two. This belt of weak rocks has been traced almost continuously along the outcrop from the southeast corner of the Tanner Lake quadrangle, where it enters the La Vida Mission quadrangle, in a west-northwest direction to the border of Tanner Lake quadrangle with The Pillar 3 NE quadrangle (unpublished mapping of R. B. O'Sullivan and others). The weak unit has also been penetrated by a core hole 4 mi (6.4 km) northwest of Tsaya Canyon in sec. 34, T. 23 N., R. 13 W. (Lease, R. C., 1971). Here the unit is 26 ft (7.9 m) thick with a coal bed about 2 ft (0.6 m) thick at the base. Southwest of the belt of outcrop in Tanner Lake quadrangle, the unit is also present near the highest point of White Rock Mesa in the northeast corner of The Pillar 3 SE quadrangle. Here it is 17 ft (5 m) thick but does not contain any coal beds.

This mappable unit in the upper part of the Cliff House Sandstone is composed of rock types, including coal beds in most places, that are lithologically similar to the lithologies in the La Vida Beds of the Allison Member. In the LVM quadrangle this mappable unit is present at the top of the cliff-making lower member of the Cliff House Sandstone, but it has thinned to a few feet where it disappears beneath talus at the east edge of the quadrangle. It was not mapped in the Kin Klizhin Ruins 7.5-minute quadrangle to the east (O'Sullivan and others, 1979), but a similar unit 100 ft (30 m) stratigraphically lower begins 0.3 mi (0.5 km) east of the border with the LVM quadrangle. This lower unit, which thickens eastward, was mapped by O'Sullivan and others (1979) almost continuously across the Kin Klizhin Ruins quadrangle.

It thus appears that in the region of La Vida Mission there are two different tongues of Menefee-type sediments within the Cliff House Sandstone, one near the top of the formation and one approximately 100 ft (30 m) lower. These tongues serve for mapping purposes to divide the Cliff House Sandstone into upper and lower members, but these members are not the same in La Vida Mission, Tanner Lake, and The Pillar 3 SE quadrangles as they are to the east in the Kin Klizhin Ruins quadrangle. The unit of Menefee-type sediments in the Cliff House east of LVM quadrangle in the Kin Klizhin Ruins quadrangle has been interpreted by O'Sullivan and others (1979) as a northward-extending tongue of continental rocks of the Menefee Formation within the Cliff House, but with the connection with the main body of the Menefee to the south lost through erosion. Still farther east, Mytton (1979) in a geologic map of the Chaco Canyon quadrangle noted that the Cliff House Sandstone intertongues with the Menefee Formation. In the Tanner Lake, La Vida Mission, and The Pillar 3 SE quadrangles, the section is as shown in tables 4 and 5.

Table 5.—Cliff House Sandstone in the La Vida Mission, southern Tanner Lake, and northeastern Pillar 3 SE quadrangles

	Thickness	
	Feet	Meters
Lewis Shale (from core hole log of R.C. Lease, 1971, p.58) -----------	85	26
Cliff House Sandstone		
Upper sandstone unit -------------	18->33	5.5->10.0
Menefee-type mudstone, sandstone, and coal unit -----------------	>5-54	>1.5-16.5
Lower sandstone unit -------------	161	49
Menefee Formation		
Allison Member		
La Vida Beds -----------------	232	70.7

The upper unit of the Cliff House Sandstone at the Tsaya Canyon measured section was at least 33 ft (10 m) thick. Eroded beds at the top of the upper unit and below the Lewis Shale probably do not exceed 20 ft (6 m) and more likely amount to only a few feet. The member must thin to the northwest because in core hole 7a (R. C. Lease, 1971, p. 58) 4 mi (6.4 km) distant, the member is only 18 ft (5.5 m) thick.

The area here discussed is too small to trace the shoreline configuration between continental deltaic beds and swamps of the La Vida Beds or the near-shore marine sandstone beds of the Cliff House Sandstone. These regional relations have been described in Guidebook of San Juan Basin III in papers by Molenaar (1977), Peterson and Kirk (1977), and Fassett (1977), and in the guidebook road logs by Fassett and others (1977a,b).

SUMMARY

Mappable lithologic subdivisions of the thick Menefee Formation and of the Cliff House Sandstone in the southern part of the San Juan Basin have been described. Two of the mapped subdivisions are here named the La Vida Beds and the Juans Lake Beds of the Allison Member of the Menefee. These units have been mapped in the area of the La Vida Mission 7.5-minute quadrangle and are recognizable in the adjacent quadrangles to the east and west. They may persist much farther.

REFERENCES CITED

Beaumont, E. C., 1954, Preliminary geologic map of the Beautiful Mountain anticline, San Juan County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM-147, scale 1:48,000.

Beaumont, E. C., Dane, C. H., and Sears, J. D., 1956, Revised nomenclature of Mesaverde Group in San Juan Basin, New Mexico: American Association of Petroleum Geologists Bulletin, v. 40, no. 9, p. 2149-2162.

Bissell, H. J., 1952, Geology of the Cretaceous and Tertiary sedimentary rocks of the Utah-Arizona-Nevada corner: Utah Geological Society Guidebook to the Geology of Utah, no. 7, p. 69-78.

Collier, A. J., 1919, Coal south of Mancos, Montezuma County, Colo.: U.S. Geological Survey Bulletin 691K, p. 293-310.

Cross, C. Whitman, Spencer, A. C., and Purington, C. W., 1899, Description of the La Plata quadrangle [Colo.]: U.S. Geological Survey Geologic Atlas Folio 60: 14 p., maps.

Dane, C. H, 1936, Geology and fuel resources of the southern part of the San Juan Basin, New Mexico: U.S. Geological Survey Bulletin 860, part 3, The La Ventana-Chacra Mesa coal field, p. 81-166.

________ 1948, Geology and oil possibilities of the eastern side of San Juan Basin, Rio Arriba County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 78, scale 1:63,360.

Fassett, J. E., 1977, Geology of the Point Lookout, Cliff House and Pictured Cliffs Sandstones of the San Juan Basin, New Mexico and Colorado, in Fassett, J. E., (ed.), Guidebook of San Juan Basin III: New Mexico Geological Society Twenty-eighth Field Conference, Sept. 15-17, 1977, p. 193-198.

Fassett, J. E., Molenaar, C. M., Black, B. A., Jentgen, R. W., and Chenoweth, W. L., 1977a, First day; Road log from Farmington to Red Mountain oil field via Bisti, Crownpoint, Thoreau, Baca and Hospah, in Fassett, J. E., (ed.), Guidebook of San Juan Basin III: New Mexico Geological Society Twenty-eighth Field Conference, Sept. 15-17, 1977, p. 1-18.

Fassett, J. E., Jentgen, R. W., Black, B. A., Molenaar, C. M., and Woodward, L. A., 1977b, Second day; Road log from Red Mountain oil field to El Vado Lake via Pueblo Pintado Star Lake, Torreon, Cuba, and Llaves, in Fassett, J. E., (ed.), Guidebook of San Juan Basin III: New Mexico Geological Society Twenty-eighth Field Conference, Sept. 15-17, 1977, p. 19-38.

Goddard, E. N., and others, 1948, Rock-color chart: Washington, D. C., National Research Council; reprinted by Geological Society of America, 1951.

Hackman, R. J., and Olson, A. B., 1977, Geology, structure, and uranium deposits of the Gallup $1^{\circ} \times 2^{\circ}$ quadrangle, New Mexico and Arizona:

U. S. Geological Survey Miscellaneous Investigations Series Map I-981, scale 1:250,000.

Hayes, P. T., and Zapp, A. D , 1955, Geology and fuel resources of the Upper Cretaceous rocks of the Barker dome-Fruitland area, San Juan County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM-144, scale 1:62,500.

Holmes, W. H., 1877, Geological report on the San Juan District, Colorado: U.S. Geological and Geographical Survey of the Territories 9th Annual Report, 1875, p.241-194.

Kelley, V. C., 1951, Tectonics of the San Juan Basin, in Guidebook of the south and west sides of the San Juan Basin, New Mexico and Arizona: New Mexico Geological Society Second Field Conference, p. 124-131.

Kelley, V. C., and Clinton, N. J., 1960, Fracture systems and tectonic elements of the Colorado Plateau: University of New Mexico Publications in Geology, no. 6, p. 104.

Keroher, G. C., and others, 1966, Lexicon of geologic names of the United States: U.S. Geological Survey Bulletin 1200.

Kirk, A. R., and others, 1981, Lithologic descriptions, core and cutting samples, Mariano Lake-Lake Valley Drilling Project, McKinley County, New Mexico, Holes 1 to 10: U.S. Geological Survey Open-File Reports 81-1201 to 81-1210.

Lease, R. C., 1971, Chaco Canyon upper Menefee area, in Shomaker, J. W., Beaumont, E. C., and Kottlowski, F. E., Strippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Memoir 25, p. 56-64.

Meek, F. B., and Hayden, F. V., 1862, Descriptions of new Cretaceous fossils from Nebraska Terr: Academy of Natural Science, Phila., Proceedings, 1862, p. 415-447.

Molenaar, C. M., 1977, Stratigraphy and depositional history of Upper Cretaceous rocks of the San Juan Basin area, New Mexico and Colorado, with a note on economic resources, in Fassett, J. E., (ed.), Guidebook of San Juan Basin III: New Mexico Geological Society, Twenty-eighth Field Conference, Sept. 15-17, 1977, p. 159-166.

Mytton, J. W., 1979, Preliminary geologic map of Chaco Canyon 1^{o} x $1/2^{o}$ quadrangle, showing coal zones of Fruitland Formation, San Juan, Rio Arriba, and Sandoval Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1104, scale 1:100,000.

O'Sullivan, R. B., 1955, Preliminary geologic map of the Naschitti quadrangle, San Juan and McKinley Counties, New Mexico: U.S. Geological Survey Coal Investigations Series Map C-31, scale 1:62,500.

O'Sullivan, R. B., and Beikman, H. M., 1963, Geology, structure, and uranium deposits of the Shiprock quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-345, scale 1:250,000.

O'Sullivan, R. B., and Beaumont, E. C., 1957, Preliminary geologic map of western San Juan Basin, San Juan and McKinley Counties, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM-190, scale 1:125,000.

O'Sullivan, R. B., Scott, G. R., and Weide, D. L., 1979, Preliminary geologic map of the Kin Klizhin Ruins quadrangle, San Juan and McKinley Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1094, scale 1:24,000.

Peterson, F., and Kirk, A. R., 1977, Correlation of Cretaceous rocks in the San Juan, Black Mesa, Kaiparowits and Henry Basins, southern Colorado plateau, in Fassett, J. E., (ed.), Guidebook of San Juan Basin III: New Mexico Geological Society Twenty-eighth Field Conference, Sept. 15-17, 1977, p. 167-178.

Sabins, F. F., Jr., 1964, Symmetry, stratigraphy, and petrography of cyclic Cretaceous deposits in San Juan Basin: American Association of Petroleum Geologists Bulletin, v. 48, no. 3, p. 292-316.

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U.S. Geological Survey Bulletin 767, 53 p.

_______ 1934, Geology and fuel resources of the southern part of the San Juan Basin, New Mexico; part 1. The coal field from Gallup eastward toward Mount Taylor: U.S. Geological Survey Bulletin 860, p. 1-29.

Shomaker, J. W., Beaumont, E. C., and Kottlowski, F. E., 1971, Strippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Memoir 25.

Siemers, C. T., and King, N. R., 1974, Macroinvertebrate paleoecology of a transgressive marine sandstone, Cliff House Sandstone (Upper Cretaceous), Chaco Canyon, northwestern New Mexico: New Mexico Geological Society Guidebook, Twenty-fifth Field Conference, p. 267-277.

Siemers, C. T., and Wadell, J. S., 1977, Humate deposits of the Menefee Formation (Upper Cretaceous), northwestern New Mexico: Supplemental articles to San Juan Basin III, 1977, Twenty-eighth Field Conference, New Mexico Geological Society, p. 1-21.

Tabet, D. E., and Frost, S. J., 1979, Environmental characteristics of Menefee coals in the Torreon Wash area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File Report 102, 134 p.

Wanek, A. A., 1954, Geologic map of the Mesa Verde area, Montezuma County, Colorado: U.S. Geological Survey Oil and Gas Investigations Map OM-152, scale 1:63,360.

Weide, D. L., Schneider, G. B., Mytton, J. W., and Scott, G. R., 1979, Geologic map of the Pueblo Bonito quadrangle, San Juan County, New Mexico. U.S. Geological Survey Miscellaneous Field Studies Map MF-1119, scale 1:24,000.

Zapp, A. D , 1949, Geology and coal resources of the Durango area, La Plata and Montezuma Counties, Colorado: U.S. Geological Survey Oil and Gas Investigations Map OM-109, scale 1:31,680.

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NEWARK SUPERGROUP, A REVISION OF THE NEWARK GROUP IN EASTERN NORTH AMERICA

By A. J. Froelich[1] and P. E. Olsen[2]

The Newark Supergroup, a name proposed herein for adoption by the U.S. Geological Survey, includes the largely continental clastic rocks ("red beds") and interbedded basaltic flow rocks of Late Triassic and Early Jurassic age that crop out in discrete elongate basins parallel to the Appalachian orogen in eastern North America (fig. 1). The term "Newark Supergroup" was introduced by Van Houten (1977), referring to an unpublished manuscript by Olsen, to replace "Newark Group" (Redfield, 1856), a term that had been widely used but frequently misapplied in a time-stratigraphic sense (Klein, 1962). The use of Newark Supergroup preserves a well-established name (North American Stratigraphic Code, art. 7: c) which has increasingly been applied outside the U.S. Geological Survey to the rocks in all of the exposed basins (Geological Society of America, 1983, p. 156). The Newark Supergroup is a formal assemblage of related groups and formations (North American Stratigraphic Code, art. 29) with close lithologic and structural relationships that are implied through use of the supergroup designation. The term was clearly redefined by Olsen in 1978, but was expanded to include subsurface red beds of early Mesozoic age beneath the Atlantic Coastal Plain and Continental Shelf. As these subsurface rocks are poorly understood and apparently of diverse age, lithology, and origin, the term Newark Supergroup is here restricted to rocks that crop out, although we recognize that coeval strata are certainly concealed at depth beneath the Coastal Plain.

The Newark Supergroup strata in the exposed basins of eastern North America have variously been considered to be partly or solely of Early Jurassic age (Rogers, 1842; Lyell, 1847; Redfield, 1856), Permo-triassic (Emmons, 1857), Jurassic or Late Triassic (Fontaine, 1883), then solely of Late Triassic age, at first based on rare vertebrate and plant fossils (Ward, 1891; Eastman, 1913) and subsequently on vertebrate and plant fossils (Reeside and others, 1957) and radiometric ages of intercalated igneous rocks (Armstrong and Besancon, 1970). Some of the basins, however, have been determined to contain Lower Jurassic as well as Upper Triassic strata, as evidenced by spores, pollen, and well-preserved vertebrate remains in lacustrine mudstones (Cornet and others, 1973; Cornet, 1977; Olsen, 1978; Olsen and others, 1982) interbedded with basalt flows. The Lower Jurassic flows and interbedded strata can be considered informally as the "upper" Newark Supergroup and the Upper Triassic rocks as the "lower" Newark Supergroup.

The basins with only Upper Triassic rocks (with Group names where used) are the Wadesboro-Sanford-Durham (Chatham Group of Emmons, 1857)(1, 2, 3 on fig. 1); Davie County(4); Dan River and Danville (Dan River Group of Thayer, 1970)(5); Scottsburg(6); basins north of Scottsburg basin(7); Farmville(8); Richmond (Tuckahoe and Chesterfield Groups of Shaler and Woodworth, 1899)(9); Taylorsville(10); Scottsville(11),

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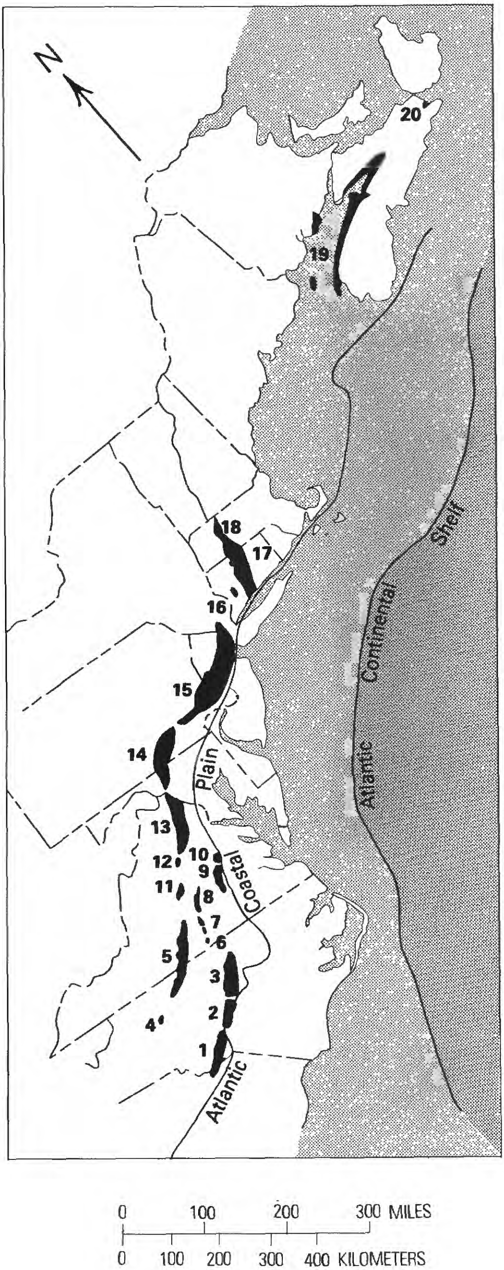

EXPLANATION

1. Wadesboro (N.C. – S.C.)
2. Sanford (N.C.)
3. Durham (N.C.)
4. Davie County (N.C.)
5. Dan River and Danville (N.C. – Va.)
6. Scottsburg (Va.)
7. Basins north of Scottsburg (Va.)
8. Farmville (Va.)
9. Richmond (Va.)
10. Taylorsville (Va.)
11. Scottsville (Va.)
12. Barboursville (Va.)
13. Culpeper (Va. – Md.)
14. Gettysburg (Md. – Pa.)
15. Newark (N.J. – Pa. – N.Y.)
16. Pomperaug (Conn.)
17. Hartford (Conn. – Mass.)
18. Deerfield (Mass.)
19. Fundy or Minas (Nova Scotia – Canada)
20. Chedabucto (Nova Scotia – Canada)

FIGURE 1.—Exposed basins of the Newark Supergroup in eastern North America.

and Barboursville (Culpeper Group of Lindholm, 1979)(12). The basins where Upper Triassic rocks are overlain by Lower Jurassic rocks are: the Culpeper (Culpeper Group of Lindholm, 1979)(13); Gettysburg (Conewago Group of Ashley, 1931)(14); Newark(15); Pomperaug(16); Hartford with Cherry Valley outlier (Meriden Group of Krynine, 1950)(17); Deerfield(18); Fundy or Minas (Fundy Group of Klein, 1962)(19); and Chedabucto(20).

Older Mesozoic strata of the lower Newark Supergroup (Upper Triassic, middle and upper Carnian), which are commonly coal-bearing, are preserved in the southern basins (1-10, fig. 1). Strata in two small, centrally located basins (11, 12, fig. 1) are mainly conglomerates and red beds that apparently lack diagnostic fossils but resemble Upper Triassic (upper Carnian and middle and upper Norian) rocks in adjacent basins to the north. Strata from the northern basins contain intercalated basalt flows and younger strata of the upper Newark Supergroup (13-18, fig. 1), span Late Triassic (Carnian and Norian) through Early Jurassic (Hettangian to Toarcian) time, and in the Hartford Basin (17, fig. 1), perhaps extend into Middle Jurassic (Bajocian) time. In the extreme northeast, the Fundy (Minas) Basin (19, fig. 1) is anomalous to this regional pattern because it contains Upper and possibly Middle Triassic (Ladinian) strata at the base and Lower Jurassic strata and basalt flows of the upper Newark Supergroup at the top.

As Olsen (1978) pointed out: "* * * Raising the rank of the term Newark to Supergroup preserves the original and familiar meaning of Redfield's designation, allows the formations of individual basins to be included in specific groups while remaining in a strictly rock-stratigraphic hierarchy, and permits the maximum amount of flexibility for future subdivision. * * *"

REFERENCES CITED

Armstrong, R. L., and Besancon, J., 1970, A Triassic time scale dilemma: K-Ar dating of Upper Triassic mafic igneous rocks, eastern U.S.A. and Canada and post-Triassic plutons, western Idaho, U.S.A.: Eclogae Geologicae Helvetiae, v. 63, p. 15-28.

Ashley, G. H., 1931, A syllabus of Pennsylvania geology and mineral resources: Pennsylvania Topographic and Geologic Survey, 4th Series, Bulletin no. G-1, 159 p.

Calver, J. L., 1963, Geologic map of Virginia: Virginia Department Conservation and Economic Development, Charlottesville, Scale 1:500,000.

Cornet, Bruce, 1977, The palynostratigraphy and age of the Newark Supergroup: Unpublished Ph.D Thesis, Pennsylvania State University, 506 p.

Cornet, Bruce, Traverse, Alfred, and McDonald, N. G., 1973, Fossil spores, pollen and fishes from Connecticut indicate Early Jurassic age for part of the Newark Group: Science, v. 182, p. 1243-1246.

Eastman, C. R., 1913, Notes on Triassic fishes belonging to the Families Catopteridae and Semionotidae: Annals of the Carnegie Museum, v. 9, p. 139-148.

Emmons, E. E., 1857, American Geology Pt. VI (III); X, 152, Albany.

Fontaine, W. M., 1883, Contributions to the knowledge of the older Mesozoic flora of Virginia: U.S. Geological Survey Monograph 6, 144 p.

Geological Society of America, 1983, Symposium: Advances in Paleontology and paleoecology—Newark Supergroup (Early Mesozoic): Northeastern Section, Abstracts with programs, v. 15, no. 3, p. 156.

Hitchcock, Edward, 1832, Report on the geology of Massachusetts: American Journal of Science, v. 22, p. 1-70.

Jansa, L. F., and Wade, J. A., 1975, Geology of the continental margin off Nova Scotia and Newfoundland in Volume 2, Offshore geology of Eastern Canada: Geological Survey of Canada Paper 74, 30, p. 51-105, Ottawa.

King, P. B., and others, 1944, Tectonic map of the United States: National Research Council, Division of Geology and Geography, Committee on Tectonics, American Association of Petroleum Geologists, 2 sheets, scale 1:2,500,000.

Klein, G. DeV., 1962, Triassic sedimentation, Maritime Provinces, Canada: Geological Society of America Bulletin, v. 73, p. 1127-1146.

Krynine, P. D., 1950, Petrology, stratigraphy, and origin of the Triassic sedimentary rocks of Connecticut: Geological and Natural History Survey Bulletin no. 73, 247 p.

Lindholm, R. C., 1979, Geologic history and stratigraphy of the Triassic-Jurassic Culpeper basin, Virginia: Geological Society of America Bulletin, (pt. 2, microfiche), v. 90, no. 11, p. 1702-1736.

Lyell, Sir Charles, 1847, On the structure and probable age of the coal field of the James River near Richmond, Virginia: Quarterly Journal of the Geological Society of London, v. 3, p. 261-280.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, p. 841-875.

Olsen, P. E., 1978, On the use of the term Newark for Triassic and Early Jurassic rocks of eastern North America: Newsletters on Stratigraphy, v. 7, no. 2, p. 90-95.

Olsen, P. E., McCune, A. R., Thomson, R. S., 1982, Correlation of the early Mesozoic Supergroup by vertebrates, principally fishes: American Journal of Science, v. 282, p. 1-44.

Redfield, W. C., 1856, On the relations of the fossil fishes of the sandstone of Connecticut and the Atlantic States to the Liassic and Oolitic periods: American Journal of Science (ser. 2) 22, p. 357-363.

Reeside, J. B., Jr., (Chairman, Triassic Subcommittee) and others, 1957, Correlation of Triassic formations of North America: Geological Society of America Bulletin, v. 68, p. 1451-1514.

Rogers, W. B., 1842, Report of the progress of the Geological Survey of the State of Virginia for the year 1841: 12 p., Richmond, Va. (reprinted in Geology of the Virginias, 1884, p. 537-546.)

Shaler, N. S., and Woodworth, J. B., 1899, Geology of the Richmond Basin, Virginia: U.S. Geological Survey Annual Report 19, 1897-1898, pt. 2, p. 385-515.

Thayer, P. A., 1970, Stratigraphy and geology of the Dan River Triassic basin, North Carolina: Southeastern Geology, v. 12, p. 1-37.

Van Houten, F. B., 1977, Triassic-Liassic deposits of Morocco and Eastern North America: Comparison: American Asssociation of Petroleum Geologists Bulletin, v. 61, no. 1, p. 79-99.

Ward, L. F., 1891, The plant-bearing deposits of the American Triassic: Science, v. 18, p. 287-288.

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STRATIGRAPHIC NOMENCLATURE IN THE KINGS MOUNTAIN BELT, NORTH CAROLINA AND SOUTH CAROLINA

By J. Wright Horton, Jr.

INTRODUCTION

Reconnaissance for a geologic map of the Charlotte $1^{\circ} \times 2^{\circ}$ quadrangle (Goldsmith and others, in press) and detailed mapping of selected areas within that quadrangle have indicated a need for revision of the names of rock units in the Kings Mountain belt of North Carolina and South Carolina.

The Kings Mountain belt was defined by King (1955, p. 350-352) as a highly compressed zone of distinctive metasedimentary rocks such as quartzite, conglomerate and marble, and mica schists that are partly volcanic in origin. Other features include high dip angles and a metamorphic grade lower than that of adjacent belts, but these features vary within and across the characteristic rock units. King stated that the belt begins near the Catawba River in North Carolina and extends southwest for about 80 km through the Gaffney area of South Carolina, and he noted marble occurrences along strike southwest of Gaffney. Overstreet and Bell (1965a, b) extended the Kings Mountain belt across South Carolina to the Savannah River near Lowndesville, mainly using the presence of sericite schist and amphibolite to define the belt. Kesler (1972) questioned the correlation of rocks in the Lowndesville area with those in the Kings Mountain belt and introduced the name Lowndesville belt. The Lowndesville belt is not continuous with the Kings Mountain belt in the type area, although the two belts have similar lithologies and tectonic positions. The stratigraphic nomenclature in this report is not intended to extend into the Lowndesville belt. To the north, this nomenclature is intended to extend as far as the termination of the Kings Mountain belt in Catawba and Iredell Counties, North Carolina, as mapped by Goldsmith and others (in press).

A key to understanding stratigraphic facing in the Kings Mountain belt is the South Fork antiform (fig. 1), which has been interpreted as a right-side-up anticline on the basis of several observations of graded bedding (Kesler, 1955; Espenshade and Potter, 1960; Horton and Butler, 1977; and Horton, 1981).

Formal rock-stratigraphic units recognized previously in the Kings Mountain belt include the Bessemer Granite of Keith and Sterrett (1917), the Blacksburg Schist and Gaffney Marble of Loughlin and others (1921), the Kings Mountain Quartzite and its Draytonville Conglomerate Member, and the Battleground Schist of Keith and Sterrett (1931). The Yorkville Quartz Monzonite of Espenshade and Potter (1960) (Yorkville Granite of Keith and Sterrett, 1931) also lies partly within the Kings Mountain belt. Most of these names have been avoided or used with discretion since the work of Kesler (1942; 1944; 1955) and Espenshade and Potter (1960), because of problems pointed out by them and by subsequent investigators.

The "Kings Mountain group" of Stuckey and Conrad (1958, p. 30-31), included all metasedimentary and metavolcanic rocks in the Kings Mountain belt but was never adopted for formal usage. Although appealing,

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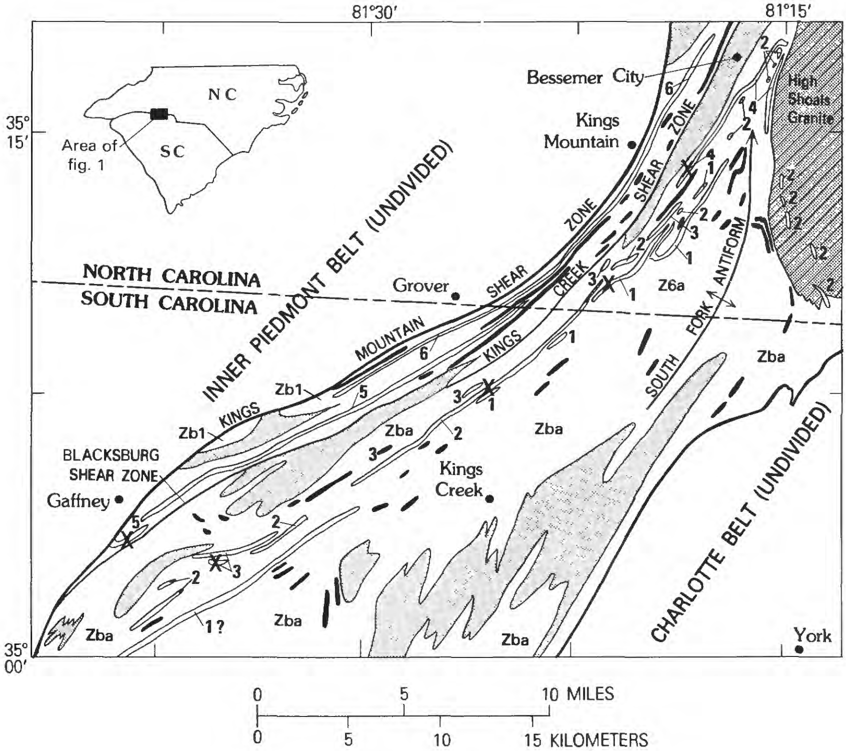

EXPLANATION

High Shoals Granite

Intrusive rocks (undivided)

Zba — Battleground Formation
1. Dixon Gap Metaconglomerate Member
2. Jumping Branch Manganiferous Member
3. Draytonville Metaconglomerate Member
4. Crowders Creek Metaconglomerate Member

Zb1 — Blacksburg Formation
5. Gaffney Marble Member
6. Marble member at Dixon Branch (informal)

Quartzite units in Blacksburg and Battleground Formations

Boundary of Kings Mountain belt

Contact

X Type locality defined in text

FIGURE 1.—Simplified geologic map of the Kings Mountain belt in the Gaffney, S.C., to Kings Mountain, N.C., area. Adapted from Horton (1981). Type localities defined in the text are marked by the symbol X.

it seems unwise to adopt such a group name at the present time because of the uncertain relationship between the Battleground and Blacksburg Formations (Horton, 1981).

KINGS MOUNTAIN QUARTZITE (ABANDONED)

The Kings Mountain Quartzite, originally defined by Keith and Sterrett (1931, p. 5) as a composite formation of quartz-pebble metaconglomerate (the Draytonville Conglomerate Member), kyanite quartzite, white nearly pure quartzite, and chloritic or sericitic quartzite, is here abandoned. It is a lithologic unit with no apparent stratigraphic significance. Quartzites which Keith and Sterrett (1931) mapped as Kings Mountain Quartzite occur at several stratigraphic positions within their Blacksburg Schist and within their Battleground Schist (Kesler, 1944; Horton and Butler, 1977; 1981). Quartz-pebble metaconglomerates which Keith and Sterrett (1931) mapped as the Draytonville Conglomerate Member of the Kings Mountain Quartzite occur at several stratigraphic levels within their Battleground Schist (Horton and Butler, 1977). Similarities and differences among some of the metaconglomerate units originally lumped as Draytonville are discussed by France and Brown (1981). Individual quartzite and conglomerate units, including the Draytonville, are herein assigned to the Battleground and Blacksburg Formations as discussed below.

BESSEMER GRANITE (ABANDONED)

The Bessemer Granite, named for Bessemer City in Gaston County, N.C., was originally described and mapped by Keith and Sterrett (1917, p. 129; 1931) as a strongly schistose muscovite-biotite granite. Much of the so-called Bessemer Granite was later found to consist of metavolcanic and metasedimentary rocks, and the remaining intrusive rocks are not granites (Espenshade and Potter, 1960; Horton and Butler, 1977; Butler, 1981; Murphy and Butler, 1981). The name Bessemer Granite is therefore abandoned. Informal descriptive names are recommended for the intrusive rocks, most of which are metatonalites and metatrondhjemites, until petrologic, geochemical, and isotopic studies clarify the relationships among them. The metavolcanic and metasedimentary rocks are now included in the Battleground Formation as defined below.

Biotite metatonalite plutons or hypabyssal intrusions previously mapped as Bessemer Granite are most abundant in the lower parts of the Battleground Formation (defined below). Their age is interpreted to be Late Proterozoic on the basis of preliminary uranium-lead isotopic data from zircons (J. W. Horton, Jr., and T. W. Stern, 1983, unpublished data). These sodium-rich rocks are generally more silicic but otherwise similar in major-element composition to pyroclastic rocks of the Kings Mountain belt (J. W. Horton, 1983, unpublished data). Murphy and Butler (1981) interpret the metatonalite bodies as shallow sills and plugs that intrude their own volcanic ejecta.

BATTLEGROUND FORMATION (REVISED)

The Battleground Schist was first mapped by Keith and Sterrett (1931, p. 4-5) and described as white to bluish-black, locally mottled sericite schist, including coarse sandy or quartzitic varieties, beds of conglomerate, and a unit of manganiferous schist informally called the "manganese schist member." The formation was named for its type area at the Kings Mountain battleground, the site of a Revolutionary War battle. The Battleground Schist is here redefined as the Battleground Formation and revised to include metavolcanic and metasedimentary rocks that were previously mapped as Bessemer Granite and units interlayered with the "schist" that were previously mapped as Kings Mountain Quartzite. A Late Proterozoic age is inferred from the above-mentioned uranium-lead isotopic data on metatonalite that has intruded the Battleground. The lower and upper contacts of the Battleground Formation are not known to be exposed. The present thickness of the formation on the west flank of the South Fork antiform is about 7 km, but an undetermined amount of this thickness is the result of stratigraphic repetition by folding and faulting.

Metavolcanic rocks, mostly dacitic to andesitic in composition, are interlayered with quartz-sericite schist in the lower part of the formation. The metavolcanic facies include hornblende gneiss, feldspathic biotite gneiss, and phyllitic or schistose volcaniclastic rocks (Horton, 1977). Murphy and Butler (1981) described some of these rocks in detail and interpreted them as moderately reworked crystal tuffs containing local beds of coarser pyroclastic material in the form of lapillistone. The metavolcanic rocks grade laterally and up the section into quartz-sericite schist, called locally "the schist of Kings Creek" by Murphy and Butler (1981), which represents a mixture of epiclastic or sedimentary material and extensively altered pyroclastic material. This schist grades upward into a sequence of metasedimentary rocks that includes quartz-sericite schist, high-alumina quartzite, at least three beds of quartz-pebble metaconglomerate (named below), and the Jumping Branch Manganiferous Member (described below). At least some of the quartzites, particularly those that grade laterally into quartz-pebble metaconglomerates, originated as clastic sediments; others may be metamorphosed cherts. The high-alumina (kyanite and sillimanite) quartzites probably formed by metamorphism of a mixture of aluminum-rich clays and quartz or by metamorphism of fine-grained silica and clay produced by hydrothermal alteration of volcanic or epiclastic material in hot springs or solfataras (Espenshade and Potter, 1960).

Dixon Gap Metaconglomerate Member (Named)

The Dixon Gap Metaconglomerate Member of the Battleground Formation is here named for usage in North Carolina and South Carolina. The unit is named for exposures at the type locality, here designated as the ridge crest of Kings Mountain at Dixon Gap (lat 35°10'27" N., long 81°21'46" W.) in Cleveland County, N.C., where secondary road 2245 crosses the ridge. The Dixon Gap Metaconglomerate Member was described at the type locality by Horton and Butler (1977, p. 130-132) and more generally under the informal name "bed C" by France and Brown (1981, p. 95). Although previously lumped with the Draytonville Conglomerate Member by Keith and Sterrett (1931), the Dixon Gap Metaconglomerate Member (unlike the Draytonville Metaconglomerate Member) is stratigraphically lower than the Jumping Branch Manganiferous Member.

Jumping Branch Manganiferous Member (Named)

Keith and Sterrett's (1931, p. 4-5) informal "manganese schist member" of the Battleground Schist is here named the Jumping Branch Manganiferous Member of the Battleground Formation for usage in North Carolina and South Carolina. The type locality is here designated as the Taylor clay pit (lat 35°07'59" N., long 81°25'17" W.) on the west side of secondary road 123 across from the western boundary of Kings Mountain National Military Park, Cherokee County, S.C. The name Jumping Branch is derived from a tributary of Kings Creek which crosses the unit 4.1 km S. 58° W. of the type locality. The unit has been described at other outcrops by White (1944), O'Neill and Bauder (1962), Horton and Butler (1977, p. 138-139), and Horton and others (1981, p. 241).

The Jumping Branch Manganiferous Member consists of fine-grained equigranular spessartine-almandine garnet and quartz rock (coticule or gondite) closely interlayered with fine-grained quartz-sericite schist or phyllite. Calcareous metasedimentary rocks adjacent to the unit suggest a marine origin (Horton and others, 1981). The manganese and associated iron may have been concentrated by chemical weathering and leaching of volcanic glass or as a distal volcanic-exhalative deposit of submarine hydrothermal vents (Horton and others, 1981). The dusky-brown color produced by secondary oxides and hydroxides of manganese and iron in weathered rock and saprolite makes the Jumping Branch Manganiferous Member one of the most distinctive marker units in the region.

Draytonville Metaconglomerate Member (Revised)

The Draytonville Conglomerate Member of the Kings Mountain Quartzite is here redefined as the Draytonville Metaconglomerate Member of the Battleground Formation and is restricted to the quartz-pebble metaconglomerate beds that can be correlated with exposures at the type locality on Draytonville Mountain (lat 35°02'46" N., long 81°35'18" W.) in Cherokee County, S.C. The unit has been described at Draytonville Mountain where the present thickness is about 20 m (Hatcher and Morgan, 1981), at a locality 1.5 km east-northeast of there where the thickness is about 8 m (Horton and others, 1981, p. 239-240), and in North Carolina under the informal name "bed D" (France and Brown, 1981). The Draytonville Metaconglomerate Member is stratigraphically higher than the Jumping Branch Manganiferous Member.

Crowders Creek Metaconglomerate Member (Named)

The Crowders Creek Metaconglomerate Member of the Battleground Formation is here named for usage in North Carolina. It has not been traced into South Carolina. Cliff exposures (lat 35°13'58" N., long 81°18'25" W.) at a bend in Crowders Creek 180 m N. 60° W. of its junction with Squirrel Branch (midway between Crowders Mountain and the town of Kings Mountain) in Gaston County, N.C., are here designated the type locality. The Crowders Creek Metaconglomerate Member was described in this area by France and Brown (1981, p. 96) under the informal name "bed E." An unnamed unit of micaceous quartzite along the crest of Yellow Ridge is stratigraphically lower than the Crowders Creek Metaconglomerate Member but higher than the Draytonville Metaconglomerate Member. The Crowders

Creek Metaconglomerate Member was mapped as the Draytonville Conglomerate Member by Keith and Sterrett (1931) and as "schistose conglomerate" by Espenshade and Potter (1960, pl. 7).

BLACKSBURG FORMATION (REVISED)

The Blacksburg Schist of Loughlin and others (1921, p. 73) is here redefined as the Blacksburg Formation and revised to include micaceous quartzite, marble, amphibolite, and calc-silicate rock interlayered with the sericite schist and phyllite. The Blacksburg Formation is equivalent to the informal "Blacksburg lithologies" of Horton (1977, p. 18). The marble layers suggest a marine sedimentary origin. Phyllite and schist of the Blacksburg Formation are commonly graphitic and generally more micaceous, less quartzose, and less plagioclase-rich than phyllite and schist of the Battleground Formation. The Blacksburg Formation is predominantly metasedimentary in origin, but the amphibolite lenses have basaltic compositions and may be metamorphosed sills or flows. The stratigraphic relationship between the Blacksburg and Battleground Formations is uncertain because of intervening faults and plutons (Horton, 1981). Because the formation is fault bounded, the lower and upper contacts are unknown. The age of the Blacksburg Formation is also unknown but is tentatively assumed to be Late Proterozoic(?). The present thickness of about 3 km has little significance since the Blacksburg is internally folded and faulted and is bounded by shear zones on both sides. Goldsmith and others (in press) have determined that the Blacksburg Formation does not wrap around the South Fork antiform.

Gaffney Marble Member (Revised)

The Gaffney Marble of Loughlin and others (1921, p. 23, p. 72-75) is here reduced in rank from a formation to a member of the Blacksburg Formation in which it occurs. The Gaffney Marble Member is here restricted to the marble unit that crops out on the east side of Gaffney, S.C., and is best exposed at the old Limestone Springs Quarry (lat 35°03'10" N., long 81°38'58" W.) at Gaffney. The Gaffney Marble Member appears to be locally dismembered and repeated by faulting; other marble occurrences in the Blacksburg Formation may or may not be equivalent. Use of the name Gaffney Marble Member for bodies not continuous with that marble in the type area hereafter implies a belief that such bodies are equivalent.

Marble Member at Dixon Branch (Informal)

The marble member at Dixon Branch is recommended as an informal name for the marble unit in the Blacksburg Formation exposed in quarries about 1 km south and southeast of Grover, N.C., and bordering the southern edge of the town of Kings Mountain, N.C. It is named for a linear segment of Dixon Branch in Cleveland County, N.C. The type locality is here designated as the Vulcan Materials quarry 1.4 km S. 44° E. of Grover, N.C., in Cherokee County, S.C. (lat 35°09'38" N., long 81°26'23" W.). The marble member at Dixon Branch is separated from the Gaffney Marble Member in the type area by a quartzite unit. Dixon Branch is an informal name because of the possibility that it might be the Gaffney Marble Member repeated by faulting.

HIGH SHOALS GRANITE (NAMED)

The informal High Shoals granitic gneiss of Horton and Butler (1977, p. 89) is here formally named the High Shoals Granite and adopted for usage in North Carolina. The excellent exposures at High Shoals, N.C., on the South Fork Catawba River (lat 35°23'48" N., long 81°12'05" W.) are designated the type locality. The High Shoals Granite is a coarse-grained, generally porphyritic, gneissoid biotite granite or granitic gneiss that occupies an area of batholithic size within the Kings Mountain belt (fig. 1). It was mapped as Yorkville Granite by Keith and Sterrett (1931, p. 6) and as Yorkville Quartz Monzonite by Espenshade and Potter (1960, p. 79-80). Horton and Butler (1977) introduced the name High Shoals to distinguish it from nonfoliated granites like the type Yorkville near York, S.C. Uranium-lead isotopic data on zircons from a sample collected at the type locality indicate a Pennsylvanian age of about 317 m.y. for the High Shoals Granite (Horton and Stern, 1983).

SUMMARY

Formal adoption of a group name to include all stratified rocks of the Kings Mountain belt is unfeasible at this time. The Battleground and Blacksburg Schists are redefined as the Battleground and Blacksburg Formations. Members of the Battleground Formation include the Dixon Gap Metaconglomerate Member, the Jumping Branch Manganiferous Member, the Draytonville Metaconglomerate Member, and the Crowders Creek Metaconglomerate Member. Members of the Blacksburg Formation include the Gaffney Marble Member and the informal marble member at Dixon Branch. The High Shoals Granite is adopted as a formal name. The Kings Mountain Quartzite and Bessemer Granite are abandoned as formal names. Intrusive units formerly in the Bessemer Granite can be referred to by informal descriptive names.

Table 1.--Summary of changes in nomenclature for the Kings Mountain belt

[(1) new name defined and adopted, (2) informal name, (3) change in age designation, (4) abandoned name, (5) change in lithologic designation, (6) stratigraphic revision, (7) assignment to another stratigraphic rank, (8) geographic extension or restriction]

Name	Changes
Blacksburg Formation	3,5,6
Gaffney Marble Member	3,6,7,8
Marble member at Dixon Branch	2
Battleground Formation	3,5,6
Crowders Creek Metaconglomerate Member	1
Draytonville Metaconglomerate Member	3,5,6,8
Jumping Branch Manganiferous Member	1
Dixon Gap Metaconglomerate Member	1
Kings Mountain Quartzite	4
Bessemer Granite	4
Yorkville Quartz Monzonite	6
High Shoals Granite	1

REFERENCES CITED

Butler, J. R., 1981, Geology of the Blacksburg South quadrangle, South Carolina, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 65-71.

Espenshade, G. H., and Potter, D. B., 1960, Kyanite, sillimanite, and andalusite deposits of the Southeastern States: U.S. Geological Survey Professional Paper 336, 121 p.

France, N. A., and Brown, H. S., 1981, A petrographic study of Kings Mountain belt metaconglomerates, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 91-99.

Goldsmith, Richard, Milton, D. J., and Horton, J. W., Jr., in press, Geologic map of the Charlotte $1^{\circ} \times 2^{\circ}$ quadrangle, North Carolina and South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I-1251-E, scale 1:250,000.

Hatcher, R. D., Jr., and Morgan, B. K., 1981, Finite strain and regional implications of the deformed Draytonville metaconglomerate near Gaffney, South Carolina, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 100-109.

Horton, J. W., Jr., 1977, Geology of the Kings Mountain and Grover quadrangles, North and South Carolina: Unpublished Ph.D. dissertation, University of North Carolina, Chapel Hill, 174 p.

________1981, Geologic map of the Kings Mountain belt between Gaffney, South Carolina, and Lincolnton, North Carolina, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 6-18.

Horton, J. W., Jr., and Butler, J. R., 1977, Guide to the geology of the Kings Mountain belt in the Kings Mountain area, North Carolina and South Carolina, in Burt, E. R., ed., Field guides for Geological Society of America, Southeastern Section Meeting, Winston-Salem, North Carolina: Raleigh, North Carolina Department of Natural and Economic Resources, p. 76-143.

________1981, Geology and mining history of the Kings Mountain belt - A summary and status report, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 194-212.

Horton, J. W., Jr., Butler, J. R., Schaeffer, M. F., Murphy, C. F., Connor, J. M., Milton, D. J., and Sharp, W. E., 1981, Field guide to the geology of the Kings Mountain belt between Gaffney, South Carolina, and Lincolnton, North Carolina, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 213-247.

Horton, J. W., Jr., and Stern, T. W., 1983, Late Paleozoic (Alleghanian) deformation, metamorphism, and syntectonic granite in the central Piedmont of the Southern Appalachians: Geological Society of America Abstracts with Programs, v. 15, no. 6, p. 599.

Keith, Arthur, and Sterrett, D. B., 1917, Tin resources of the Kings Mountain district, North Carolina and South Carolina: U.S. Geological Survey Bulletin 660-D, p. 123-146.

_______1931, Description of the Gaffney and Kings Mountain quadrangles [North Carolina-South Carolina]: U.S. Geological Survey Geologic Atlas Folio 222, 13 p.

Kesler, T. L., 1942, The tin-spodumene belt of the Carolinas--a preliminary report: U.S. Geological Survey Bulletin 936-J, p. 245-269.

_______1944, Correlation of some metamorphic rocks in the central Carolina Piedmont: Geological Society of America Bulletin, v. 55, p. 75-782.

_______1955, The Kings Mountain area, in Russell, R. J., ed., Guides to southeastern geology: New York, Geological Society of America, p. 374-389.

_______1972, Inner Piedmont belt of the southern crystalline Appalachians: Discussion: Geological Society of America Bulletin, v. 83, p. 1895-1896.

King, P. B., 1955, A geologic section across the southern Appalachians: An outline of the geology in the segment in Tennessee, North Carolina and South Carolina, in Russell, R. J., ed., Guides to southeastern geology: New York, Geological Society of America, p. 332-373.

Loughlin, G. F., Berry, F. W., and Cushman, J. A., 1921, Limestones and marls of North Carolina: North Carolina Geological and Economic Survey Bulletin 28, 211 p.

Murphy, C. F., and Butler, J. R., 1981, Geology of the northern half of the Kings Creek quadrangle, South Carolina, in Horton, J. W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas, Carolina Geological Society Field Trip Guidebook 1981: Columbia, South Carolina Geological Survey, p. 49-64.

O'Neill, J. F., and Bauder, R. B., 1962, Resource investigation and leaching study of manganiferous schists, Kings Mountain district, North and South Carolina: U.S. Bureau of Mines, Report of Investigation 6069, 12 p.

Overstreet, W. C., and Bell, Henry, III, 1965a, The crystalline rocks of South Carolina: U.S. Geological Survey Bulletin 1183, 126 p.

_______1965b, Geologic map of the crystalline rocks of South Carolina: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-413, scale 1:250,000.

Streckeisen, A. L., 1973, Plutonic rocks, classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks: Geotimes, v. 18, no. 10, p. 26-30.

Stuckey, J. L., and Conrad, S. G., 1958, Explanatory text for geologic map of North Carolina: Raleigh, North Carolina Division of Mineral Resources, Bulletin 71, 46 p.

White, W. A., 1944, Manganese deposits in North Carolina: North Carolina Division of Mineral Resources, Mineral Inventory 2, p. 1-4.

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REVISION OF THE ALBEMARLE GROUP, NORTH CAROLINA

By Daniel J. Milton

In their pioneer stratigraphic study in the Carolina slate belt, Conley and Bain (1965) established the Albemarle Group as a sequence of three formations: the Tillery Formation, a finely laminated meta-shale, at the base; the McManus Formation, a coarsely bedded argillite; and the Yadkin Graywacke at the top. Conley and Bain also established a Tater Top Group, comprising the Badin Greenstone and the Morrow Mountain Rhyolite, unconformably overlying the Albemarle Group.

Stromquist and Sundelius (1969) mapped a volcanic unit, their Flat Swamp Member, which provides an excellent stratigraphic marker that allowed them to divide the McManus Formation of Conley and Bain into a mudstone unit beneath and an argillite and siltstone unit above. They chose to abandon the McManus as a unit and to establish two new formations: the Cid Formation, comprising an unnamed mudstone member (the lower part of the old McManus Formation) as a lower unit and the Flat Swamp Member as an upper unit, and the Millingport Formation, comprising the Floyd Church Member (the upper part of the old McManus Formation) and the Yadkin Member. It is not evident why they considered the Floyd Church more closely related to the Yadkin than to the Cid mudstone (as the redivision of the Albemarle Group implies). In a later publication, Sundelius and Stromquist (1978) indicated an unconformity between the Floyd Church and the Yadkin Members.

Mapping by the present author in the Charlotte $1^{\circ} \times 2^{\circ}$ quadrangle (Goldsmith and others, in press) suggests that sequences less inclusive than either the McManus or the Millingport are the most natural formations. Accordingly, both names are abandoned and formation status is given to the Floyd Church and restored to the Yadkin, so that the Albemarle Group comprises four formations: Tillery Formation, Cid Formation, Floyd Church Formation, and Yadkin Formation (fig. 1). All four formations are predominantly sedimentary, but each contains volcanic intervals, or at least overwhelmingly tuffaceous beds, of which only the Flat Swamp Member, at the top of the Cid, has a formal name.

The formations from bottom to top correspond to environments of increasing depositional energy, although the pattern is complicated by the effect of volcanoes, which intermittently and locally flooded the basin with debris (Milton and Reinhardt, 1980). The Tillery Formation is characterized by continuous planar lamination of siltstone and mudstone on a scale of millimeters, suggesting deposition by distal turbidites. The Cid Formation is characterized by beds 10 to 40 cm thick, each composed of a lower ripple-cross-stratified siltstone interval and an upper interval with Tillery-like lamination. The Floyd Church Formation typically shows beds 20 to 60 cm thick, commonly with minor channeling at the base, composed of a planar-bedded basal interval, an overlying cross-stratified interval and, in many but not all beds, a thin poorly laminated upper interval. The Floyd Church also contains sections that show an alternation of massive and thinly laminated mudstone superficially similar to bedding in the Cid but distinguishable in that the lamination is more irregular and "wavy" and is accentuated by dark (graphitic?) partings. The Floyd Church commonly weathers pink or chalky

U.S. Geological Survey Bulletin 1537-A, 1984, p. A69-A72.

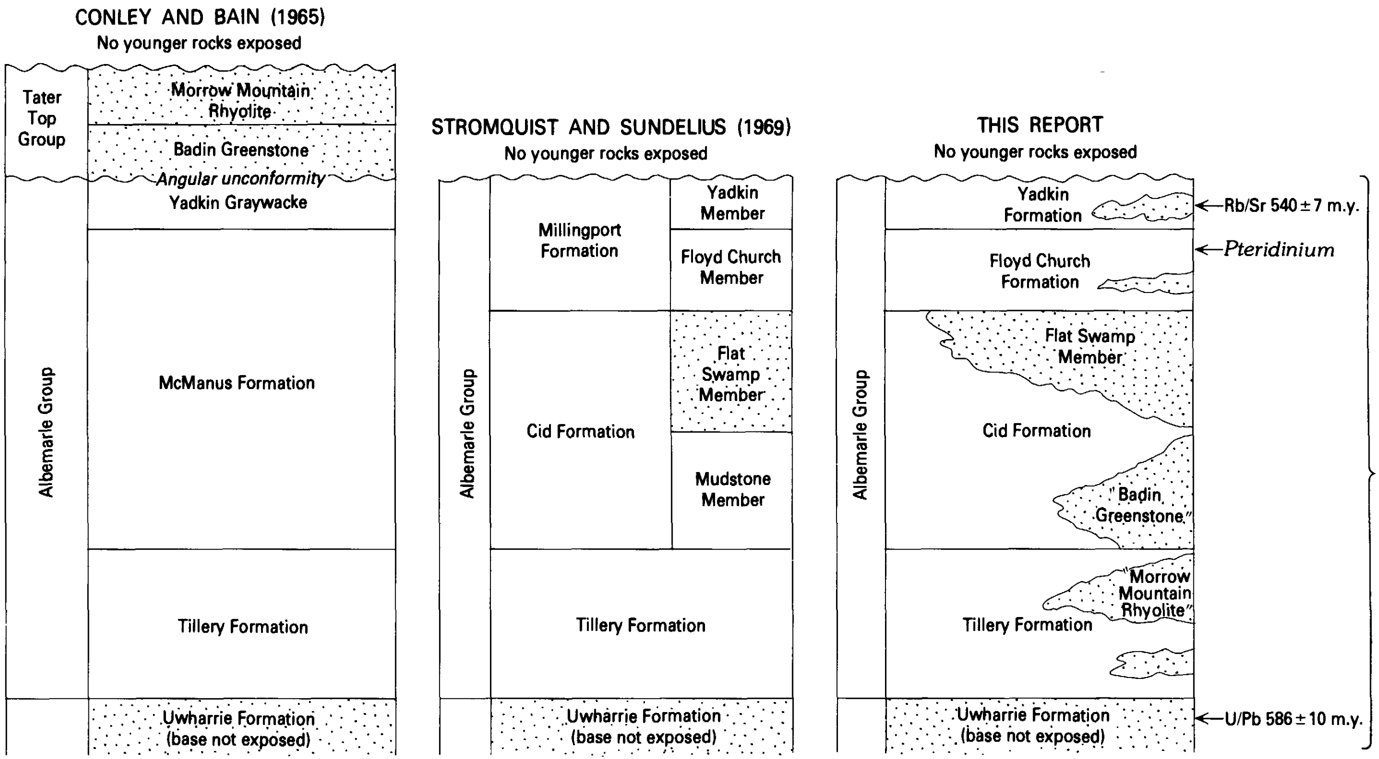

FIGURE 1.--Comparison of stratigraphic nomenclature proposed in this report with that of Conley and Bain (1965) and of Stromquist and Sundelius (1969). Approximate levels of fossils and radiometric dates and inferred ages are shown at right. Volcanic units indicated diagrammatically by pattern.

white, whereas the Cid typically weathers tan. The Floyd Church has a higher potassium content than the Cid mudstone, and areas underlain by the two formations show distinctly on maps of aeroradioactivity (Daniels and Zietz, 1982). The Yadkin Formation is characterized by poorly sorted sediments with an abundance of sand-sized particles of mafic volcanic provenance.

The nonexistence of the Tater Top as a distinct group is confirmed. As was shown by Stromquist and Sundelius (1969), Tater Top rocks of Conley and Bain (1965) comprise volcanics at various levels within the Albemarle Group and the underlying Uwharrie Formation. Morrow Mountain rhyolite and Badin greenstone may find use as informal terms for volcanic lentils at approximately the level of the upper Tillery and the mudstone member of the Cid, respectively, but are not proposed for reinstatement as formal stratigraphic names. Detailed mapping would be necessary to determine whether they are time equivalents of the sedimentary strata on strike, older sea mounts onto which these sediments lap or are in part younger intrusions (as suggested by Stromquist and Sundelius, 1975, for the Morrow Mountain rhyolite). If used, these terms should be restricted to occurrences continuous with the type localities and not extended on the basis of lithology. In particular, the "Badin Greenstone," for which Black (1978) obtained a Rb-Sr age of 540±7 Ma (recalculated for the newer value of the ^{87}Rb decay constant $\lambda = 1.42 \times 10^{-11}$ yr^{-1}), is a lentil in the Yadkin Formation.

The only datable fossils are *Pteridinium*, or a related genus, from three rock slabs, none in place but almost certainly from the middle or upper Floyd Church Formation (Gibson and others, 1984). The first of these to be found was erroneously described as a trilobite, *Paradoxides carolinaensis* (St. Jean, 1973), indicating a Cambrian, probably Middle Cambrian, age. *Pteridinium*, a frondlike metazoan with a form suggestive of a modern sea pen, however, is diagnostic of the soft-bodied Vendian or Ediacaran fauna of the uppermost Proterozoic.

Numerical dating of this part of the geologic time scale is poorly controlled. Estimates of the Proterozoic-Cambrian boundary range as much as 20 or 30 Ma on either side of the commonly accepted value of 570 Ma. Setting aside various radiometric dates on Albemarle and associated rocks done by older discredited techniques or of uncertain geologic interpretation, two radiometric dates appear to be directly relevant. The whole-rock Rb-Sr date mentioned above would put the Yadkin Formation into the Cambrian, but as the isochron has not been published and as volcanic rocks are highly susceptible to chemical disturbance that generally reduces the apparent Rb-Sr age, we disregard this date and assign the entire Albemarle Group to the Proterozoic. A U-Pb concordia-intercept date of 586±10 Ma for zircons from the uppermost level of the Uwharrie Formation (Wright and Seiders, 1980) does appear to be reliable. This date not only sets a maximum age limit for the Albemarle Group but must be considered in dating the Vendian-Ediacaran fauna worldwide.

A rich trilobite fauna of Middle Cambrian age has been discovered recently near the top of a 8-km-thick conformable sequence in the Carolina slate belt in central South Carolina (Secor and others, 1983). Intervening intrusive rocks and overlying Mesozoic strata preclude tracing of units to the Albemarle area. Comparison of lithologies, however, suggests that the correlative of the Albemarle Group in central South Carolina is an undated sequence distinct from and of undetermined relation to the fossiliferous sequence (D. T. Secor, Jr., written commun., 1982).

REFERENCES CITED

Black, W. W., 1978, Chemical characteristics and Rb/Sr ages of metavolcanics from the Carolina slate belt of North Carolina: Geological Society of America Abstracts with Programs, v. 10, p. 162-163.

Conley, J. F., and Bain, G. L., 1965, Geology of the Carolina slate belt west of the Deep River—Wadesboro Triassic Basin, North Carolina: Southeastern Geology, v. 6, p. 117-138.

Daniels, D. L., and Zietz, Isidore, 1982, Aeroradioactivity map of the Charlotte 1° x 2° quadrangle, North Carolina and South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I-1251-D, scale 1:250,000.

Gibson, G. G., Teeter, S. A., and Fedonkin, M. A., 1984, Ediacarian fossils from the Carolina slate belt, Stanly County, North Carolina: Geology, v. 12, no. 7, p. 387-390.

Milton, D. J., and Reinhardt, Juergen, 1980, Turbidites in the Albemarle Group, Carolina slate belt: Geological Society of America Abstracts with Programs, v. 12, p. 202.

St. Jean, Joseph, 1973, A new Cambrian trilobite from the Piedmont of North Carolina: American Journal of Science, v. 273-A, p. 196-216.

Secor, D. T., Jr., Samson, S. L., Snoke, A. W., and Palmer, A. R., 1983, Confirmation of the Carolina slate belt as an exotic terrane: Science, v. 221, p. 649-650.

Stromquist, A. A., and Sundelius, H. L., 1969, Stratigraphy of the Albemarle Group of the Carolina slate belt in central North Carolina: U.S. Geological Survey Bulletin 1274-B, p. B1-B220.

________1975, Interpretative geologic map of the bedrock showing radioactivity, and aeromagnetic map of the Salisbury, Southmont, Rockwell, and Gold Hill quadrangles, Rowan and Davidson Counties, North Carolina. U.S. Geological Survey Miscellaneous Investigations Series Map I-888, scale 1:48,000.

Sundelius, H. W., and Stromquist, A. A., 1978, Interpretative geologic map of the bedrock, Mount Pleasant quadrangle, Cabarrus and Stanly Counties, North Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I-1082, scale 1:48,000.

Wright, J. E., and Seiders, V. M., 1980, Age of zircon from volcanic rocks of the central North Carolina Piedmont and tectonic implications for the Carolina volcanic slate belt: Geological Society of America Bulletin, v. 91, p. 287-294.

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UPPER CRETACEOUS STRATIGRAPHY OF SOUTHWEST PUERTO RICO: A REVISION

By Richard P. Volckmann

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ABSTRACT

Recent detailed geologic mapping indicates a need for radical revision of the stratigraphic nomenclature of southwest Puerto Rico. Accordingly, the following changes are effected: the name San Germán Formation is abandoned, the lower part of that unit is named the Lajas Formation, and the overlying Cotui Limestone Member is raised in rank to Cotui Limestone. Basaltic lava underlying the Lajas is named the Boqueron Basalt, and the pyroxene-rich rocks above the Cotui are correlated with the Sabana Grande Formation. The name Brujo Limestone is abandoned, and the rocks so described are correlated with the Cotui Limestone; the El Rayo Volcanics are renamed the El Rayo Formation; the use of the terms Parguera Limestone and Melones Limestone are restricted; and the term Mayagüez Group is abandoned.

U.S. Geological Survey Bulletin 1537-A, 1984, p. A73-A83.

INTRODUCTION

Recent detailed geologic mapping (Volckmann, 1984a,b,c) and paleontologic study have resulted in new interpretations of structural and stratigraphic relationships in southwestern Puerto Rico and consequently in the need for a revision of the stratigraphic nomenclature of that area. This report suggests changes in the stratigraphic nomenclature in a succession of Cretaceous rocks in the Puerto Real, San Germán, Cabo Rojo, and Parguera 7.5-minute quadrangles of southwestern Puerto Rico.

Earliest geologic reconnaissance in southwestern Puerto Rico by Mitchell (1922, geologic map) indicated a seemingly simple sequence of east-west-striking shale, limestone, and tuff. More recent and more detailed work by Mattson (1960) and to some extent work of Slodowski (1956) had, until the present, served as the basis for geologic knowledge of the area. Mattson (1960) described from the base up (1) a complex of amphibolite, serpentinite, spillite, and silicified volcanic rock, (2) unconformably overlying andesitic lava of the Río Loco Formation of Slodowski (1956), (3) a complexly interbedded sequence of lithofacies comprising the Mayagüez Group, and (4) the unconformably overlying San Germán Formation of Mitchell (1922), as used by Slodowski (1956, p. 84). The Mayagüez Group was considered to be of Late Cretaceous (Cenomanian through early Maestrichtian) age, and the unconformably overlying San Germán Formation was considered of late Maestrichtian age. The Mayagüez Group was described by Mattson (1960, p. 329) as composed of seven lithofacies: the Parguera Limestone, Brujo Limestone, Melones Limestone, Yauco Mudstone, Sabana Grande Andesite, El Rayo Volcanics (El Rayo Formation), and Maricao Basalt. He noted that these lithofacies were irregularly interbedded and that stratigraphic relations of one unit to another might change greatly from one area to another. Mattson (1960, p. 340) also employed the term San Germán Formation in the Yauco area and described the formation as a thick sequence of andesitic volcanic rocks marked at the base by the Cabo Rojo Agglomerate Member and at the top by the Cotui Limestone Member. However, he mapped the Cotui as also overlain by andesitic volcanic rocks. The general stratigraphic relationship of thse units as interpreted by Mattson are diagramed in figure 1.

Volckmann (1984a,b,c) has shown that rocks of the San Germán Formation as used by Mattson (1960) do not overlie Mattson's Mayagüez Group but rather are equivalent to part of the group. Further, Volckmann's work indicates:

1) that the San Germán Formation is composed of three lithologically distinctive and mappable units: a thick basal unit of hornblende-andesite lava flows, flow breccia, and minor epiclastic rocks; a persistent massive limestone (the Cotui Limestone Member of Mattson); and an overlying thick sequence of pyroxene-rich tuff, tuff-breccia, epiclastic tuffaceous sandstone, and volcanic conglomerate, conglomerate lenses of massive limestone, and calcareous mudstone;
2) the Brujo Limestone of Mattson is stratigraphically continuous with and lithologically identical to his Cotui Limestone Member;
3) limestone thought by Mattson to be restricted to the top of the El Rayo Volcanics and assigned by him to the Melones Limestone in the Peñones de Melones area, is actually interbedded throughout the El Rayo;

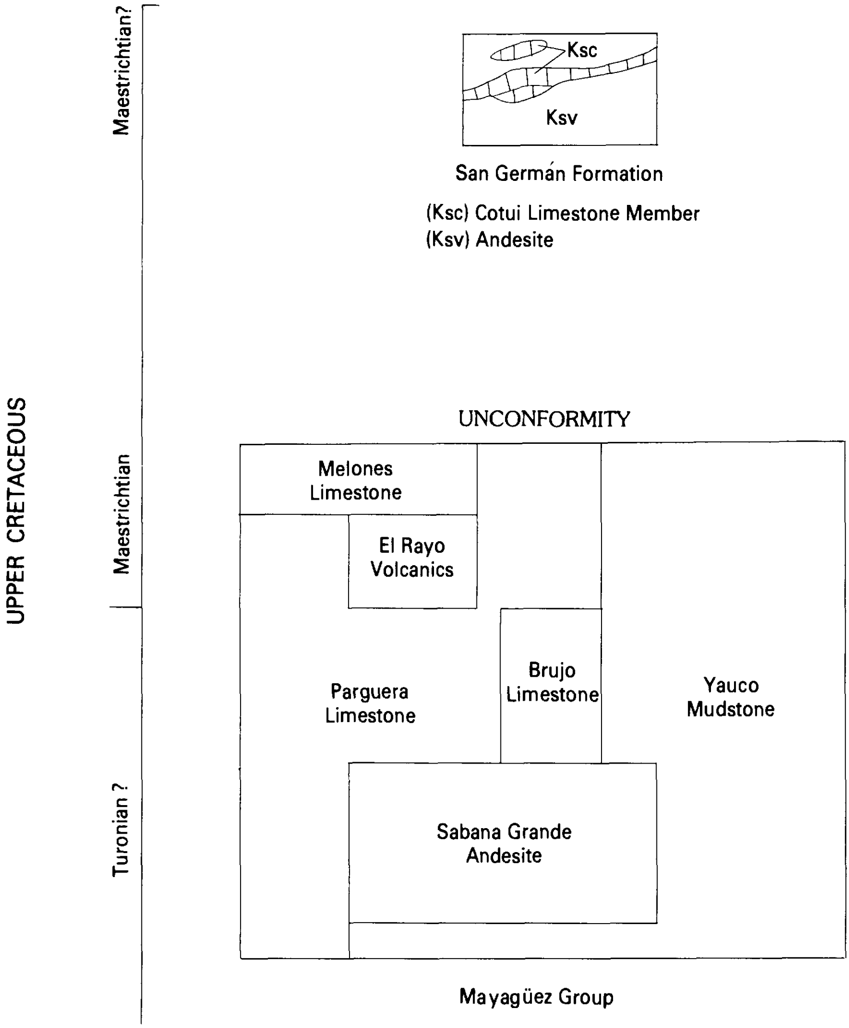

FIGURE 1.--Correlation chart showing relative stratigraphic positions and age ranges of layered rocks in the area of this report as interpreted by Mattson (1960).

4) the El Rayo Volcanics of Mattson are not stratigraphically within the Mayagüez Group as defined by Mattson but rather overlie rocks assigned by him to the San Germán Formation;
5) paleontologic evidence is now available to indicate the temporal equivalence of the upper part of the Cotui Limestone of this paper, the middle part of the Melones Limestone in the Peñones de Melones area, and the upper part of the Parguera Limestone; and
6) the Yauco Formation ranges from Cenomanian (not Turonian) to the Maestrichtian.

In light of the above relations, the following changes in the stratigraphic nomenclature are proposed:

1) Abandon the name San Germán Formation and its Cabo Rojo Agglomerate Member.
   a) Name its basal hornblende-bearing sequence the Lajas Formation;
   b) raise the rank of its Cotui Limestone Member to Cotui Limestone; and
   c) correlate the pyroxene-rich volcanic rocks overlying the Cotui Limestone and within the former San Germán Formation with the lithologically identical Sabana Grande Formation.
2) Abandon the name Brujo Limestone because rocks so named by Mattson are stratigraphically and lithologically identical to the Cotui Limestone.
3) Rename the El Rayo Volcanics the El Rayo Formation, and restrict use of the term Melones Limestone to exclude limestone interbedded throughout this unit.
4) Restrict the use of the name Parguera Limestone to the area south of the Lajas Valley, as rocks to the north are either identical to limestone in the Yauco Formation, or are significantly different from the Parguera in the type area.
5) Name the basaltic lava underlying the Lajas Formation in the Puérto Real quadrangle the Boqueron Basalt.
6) Abandon the name Mayagüez Group because it is no longer valid in the sense in which it was originally defined (Mattson, 1960, p. 329). Only two of the original lithofacies have survived without considerable redefinition. In addition, rocks included by Mattson in the group are now known to overlie other rocks of the group, and rocks assumed by Mattson to unconformably overlie the Mayagüez Group are now known to be identical with rocks in the group as defined by him.

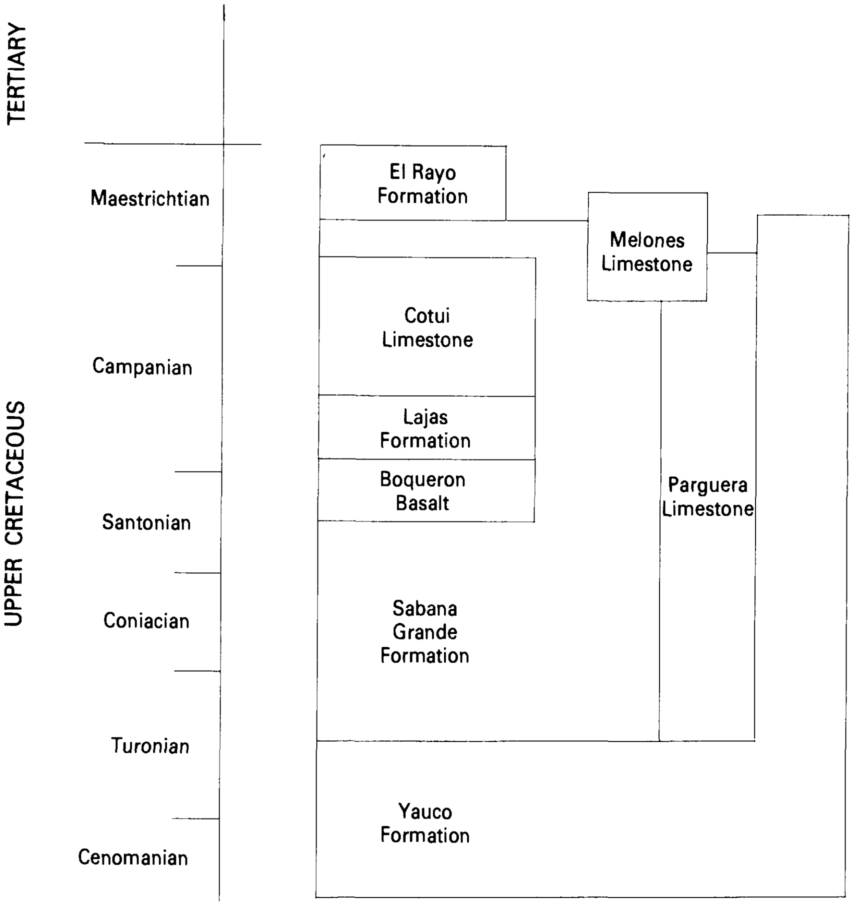

FIGURE 2.--Revised correlation chart showing relative stratigraphic positions and probable age ranges of layered rock units in the area of this report.

YAUCO FORMATION

The name Río Yauco Shale was first used by Mitchell (1922, p. 249) to describe mudstone, siltstone, and sandstone north of Yauco. He correlated "strongly bedded shale" in that sequence with "red shale around Mayagüez." The name Río Yauco Shale was changed to Río Yauco Series by Hubbard (1923, p. 29); Mattson (1960, p. 331), to avoid the misuse of the term shale and implications by use of the word series, changed the name to Yauco Mudstone. Mattson (1967, p. B20) adopted the name for U.S. Geological Survey use. Krushensky and Monroe (1979) changed the name to Yauco Formation because of the numerous lithofacies present.

The Yauco Formation crops out extensively in southwestern Puerto Rico. In the area of this report it consists of brownish-gray to black, thin- to medium-bedded, irregularly interbedded calcareous siltstone, argillaceous limestone, claystone, fine-grained tuff, and conglomerate. Detailed descriptions are given by Mattson for the Yauco in western Puerto Rico (1960, p. 331-333), by Krushensky and Monroe for the area between Yauco and Juana Diaz (1975, 1978, 1979), and by Volckmann for southwest Puerto Rico (1984a,b,c).

The age of the Yauco Formation in southwest Puerto Rico extends from the Cenomanian to the early Maestrichtian. Foraminifera from the Yauco where it overlies serpentinite on Route 2 in the San Germán quadrangle are, according to Pessagno (written commun., 1967), Cenomanian in age. Foraminifera from the Yauco where it is interbedded with the Sabana Grande Formation north of the Guanajibo Valley indicate, according to Mattson (1960, p. 332), a Turonian to Campanian age, and Foraminifera from the Yauco where it overlies the Cotui Limestone of this report are late Campanian and early Maestrichtian in age (see discussion of Cotui Limestone below). The known age range of the Yauco for this area is, therefore, Cenomanian to early Maestrichtian.

SABANA GRANDE FORMATION

The name Sabana Grande Formation was first used by Slodowski (1956, p. 15) to describe a sequence of "andesitic lava flows with subordinate dark, calcareous mudstones" in the area immediately north and northwest of the town of Sabana Grande on the network of roads leading north from Route 2. Mattson (1960, p. 338) used the name Sabana Grande Andesite to describe most of the same rocks. The unit is here renamed the Sabana Grande Formation to reflect the presence of significant amounts of limestone, conglomerate, and basaltic lava in the formation and is here adopted for U.S. Geological Survey usage. The Sabana Grande Formation, as here defined, underlies most of the mapped area north of the Guanajibo Valley. It also occurs south and southwest of San Germán and in the vicinity of the town of Cabo Rojo. The Sabana Grande is composed of gray, dark-greenish-gray and purplish-gray andesitic crystal lithic tuff, tuffaceous breccia, conglomerate, and locally of basaltic lava and breccia. Lens-like masses of limestone as much as 15 m thick and 100 m long are locally present. Typically these are light- to dark-gray, massive bioclastic calcarenite and calcirudite, composed chiefly of fragments of mollusks and Foraminifera. Detailed descriptions of the Sabana Grande Formation are given by Slodowski (1956, p. 16), Mattson (1960, p. 338-339), and Volckmann (1984a,b,c).

The upper part of the San Germán Formation as used by Mattson (1960, p. 340-344), or that which lies above the Cotui Limestone of this report, is lithologically identical with the Sabana Grande north of the Guanajibo Valley and is, therefore, correlated with the Sabana Grande Formation.

North of the Guanajibo Valley, Foraminifera from the Yauco, where interbedded with the Sabana Grande Formation, are of Turonian to Campanian age (Mattson, 1960, p. 332). South and west of the town of San Germán, limestone lenses contain the rudist *Barrettia gigas*, indicative of the Campanian-Maestrichtian boundary (N. F. Sohl, written commun., 1974). Foraminifera from limestone in the Sabana Grande near the northern border of the San Germán quadrangle range in age from Turonian through early Maestrichtian. Therefore, the Sabana Grande Formation ranges in age from Turonian through early Maestrichtian in the mapped area.

PARGUERA LIMESTONE

The Parguera Limestone was described by Mattson (1960, p. 333) as a buff to gray calcilutite and fragmental limestone, in part tuffaceous, which crops out north of the village of La Parguera. Almy (1965, p. 95-98) described three members. From the base up, they are: the Bahia Fosforescente Member, the Punta Papayo Member, and the Isla Magueyes Member. Krushensky and Monroe (1979) adopted the Parguera Limestone for use in the U.S. Geological Survey. Mapping in the Puerto Real and San German quadrangles (Volckmann, 1984b,c) indicates that rock mapped by Mattson (1960, pl. 1) as Parguera Limestone north of the Lajas Valley is either lithologically identical to the Yauco Formation, or shows lithologic associations significantly different from the Parguera in the type area. Therefore, application of the name Parguera Limestone is here restricted to the area south of the Lajas Valley. In mapping of the Cabo Rojo and Parguera quadrangles (Volckmann, 1984a), it was not possible consistently to separate lithofacies assigned by Almy to the Bahia Fosforescente and Punta Papayo Members. Those members will be referred to here as the lower member of the Parguera Limestone, and the Isla Magueyes Member of Almy will be referred to as the upper member of the Parguera Limestone.

The Parguera Limestone as limited in this study occurs south of the Lajas Valley in the Cabo Rojo and Parguera quadrangles and extends eastward into the Guanica and the Punta Verraco quadrangles. The lower member consists chiefly of bedded calcarenite, locally with volcanic lithic clasts, foraminiferal mudstone, thin lenses of glauconite, and beds of massive bioclastic limestone. A conglomerate, which contains sand- to cobble-size clasts of volcanic rock, chert, serpentinite, and amphibolite, is locally present. Calcarenite is the predominant lithic type in the lower part of the lower member, whereas calcareous mudstone is the predominant lithic type in the upper part of the lower member. The upper member consists of a coarse-grained massive bioclastic limestone, grading at the base into a volcaniclastic conglomerate. Gray to brown andesitic tuff is interbedded in the upper part of the upper member. Detailed descriptions of the Parguera Limestone are given by Mattson (1960, p. 333-334), Almy (1965, p. 58-95), and Volckmann (1984a).

The age of the Parguera Limestone, as with the Sabana Grande Formation, has been determined from contained Foraminifera. Almy (1965, p. 131) indicates that Foraminifera from his Bahia Fosforescente Member, the lower part of the lower member of the Parguera Limestone of this report, range from late Santonian through early Campanian, and that Foraminifera from his Punta Papayo Member, the upper part of the lower member of the Parguera Limestone of this report, range in age from early through late Campanian and possibly early Maestrichtian (Almy, 1965, p. 150). The lower member of this report, therefore, shows a possible age range of late Santonian through late Campanian and possibly early Maestrichtian. The upper member of this report contains abundant examples of the rudist *Barrettia gigas*, indicative (according to N. F. Sohl, written commun., 1974) of a late Campanian through early Maestrichtian age.

LAJAS FORMATION

Grayish-red to grayish-purple porphyritic lava and minor tuff that crop out at the abandoned railway station at the intersection of Roads 116 and 315 in the town of Lajas are here named the Lajas Formation. The rock so named includes the lower part of the San Germán Formation as defined by Mattson (1960, p. 340), that part below the Cotui Limestone. The Lajas Formation, at its easternmost limit, occurs between San Germán and Lajas and extends westward to Guanaquilla. Porphyritic lava and tuff of the Lajas consist chiefly of labradorite and oxyhornblende phenocrysts in a fine-grained matrix. Pseudomorphs of iddingsite and serpentine after olivine, and phenocrysts of partially to completely altered clinopyroxene and orthopyroxene are present locally and in varying amounts together with plagioclase and oxyhornblende. Apatite, biotite, zircon, and rarely quartz are accessory minerals. The matrix consists chiefly of fine needles or laths of plagioclase, minute irregular granules and octahedra of magnetite, and needles of hematite and actinolite; rarely the matrix consists chiefly of devitrified glass. The Lajas is generally massive, but flow-banding is apparent locally. The Lajas Formation is over 1,000 m thick. The base of the Lajas is exposed in the Puerto Real quadrangle where bedded tuff, characteristic of the Lajas, is interlayered with lava flows characteristic of the Boqueron Basalt. The contact between the Lajas and the overlying Cotui Limestone is marked by a sequence of epiclastic sandstone derived from the Lajas and interbedded with limestone of the Cotui. Lack of pillow structure in lava flows of the Lajas suggests that the unit was deposited subareally.

The age of the Lajas cannot be determined with any certainty because fossils have not been found in the formation. In as much as it is unconformably overlain by the Cotui, the lower part of which is middle Campanian, the Lajas is presumed to be middle Campanian or older.

COTUI LIMESTONE

The Cotui Limestone Member of the San Germán Formation was described by Mattson (1960, p. 340) as a massive, rarely thick-bedded limestone near and within the top of the San Germán Formation best exposed in quarries along the south edge of the Guanajibo Valley. The Cotui is here raised to formation rank as the Cotui Limestone and adopted for U.S. Geological Survey usage. The formation is best exposed in Barrio Cotui along Road 314, 1.25 km south of Sabana Eneas, 350 m northeast and 150 m southwest of the intersection of Road 314 with an unnumbered road from the south. It is a medium-gray to brownish-gray, thick-bedded to massive bioclastic limestone containing abundant mollusk fragments, chiefly rudistid, in an abundant micritic to sparry cement. Locally the Cotui contains fecal pellets, larger Foraminifera, and rare oolites. Authigenic quartz, glauconite, and hematite are local and minor constituents. Rudists present include *Radiolilidae*, *Durania* sp., *Barrettia gigas*, *Barrettia rusae*, and *Pseudovaccinites* sp. Locally the Cotui contains concentrations of whole specimens of the large gastropod *Trochocteon* sp. The Cotui is generally cavernous, and shows surfaces with well developed karren or lapies. Typically the limestone ranges in thickness from 10 to 75 m.

The Cotui Limestone overlies the Lajas Formation with an apparently slight disconformity and is conformably overlain by the Sabana Grande Formation. The age of the Cotui, as indicated by *Barrettia rusae* from the lower part of the unit and *Barrettia gigas* from the upper part, is, according to N. F. Sohl (written commun., 1974), latest early Campanian through early Maestrichtian. The Brujo Limestone of Mattson (1960, p. 337) is lithologically identical to and laterally continuous with the Cotui Limestone. Therefore, it is suggested that the name Brujo Limestone be abandoned, and the rock called Brujo Limestone by Mattson is here assigned to the Cotui Limestone.

MELONES LIMESTONE

The Melones Limestone was described by Mattson (1960, p. 335) as a sequence of argillaceous limestone, mudstone, volcanic sandstone, conglomeratic volcanic sandstone, calcilutite, and argillaceous limestone exposed in the center of the Sierra Melones in the Peñones de Melones. Although the type area of the Melones was mapped by Mattson (1960, pl. 1) as a syncline, detailed mapping by Volckmann revealed that a normal fault existed along the length of the "syncline"; Volckmann also found cross-bedding that indicated both "limbs" were upright. Together these structures indicate a northward-dipping sequence repeated by normal faulting. Although Mattson (1960, p. 335) included lenses occurring in the El Rayo Volcanics (El Rayo Formation of this report) in the type Melones limestone, the limestones themselves, as well as their associations with other rocks and their ages, are quite dissimilar. The term Melones Limestone, is therefore restricted and applied only to the sequence described in the Peñones de Melones and is here adopted for U.S. Geological Survey usage. The presence of *Barrettia gigas* in the lower part of the Melones as here redefined, and the rudists *Parastroma guitarti* and *Titanosarcolites* sp. indicate that the lower part of the formation may be late Campanian through early Maestrichtian in age and that the upper part of the Melones is probably no younger than middle Maestrichtian in age.

EL RAYO FORMATION

Slodowski (1956, p. 26) described the El Rayo Formation as a feldspathic olivine basalt porphyry with interbedded lenses of volcanic conglomerate and dark massive limestone. Mattson (1960, p. 339) renamed the unit the El Rayo Volcanics and assigned the interbedded limestone lenses to his Melones Limestone. The basalt and interbedded limestone sequence is here renamed the El Rayo Formation, following Slodowski's original usage, and is adopted for U.S. Geological Survey usage. The use of the name Melones to describe the interbedded limestone is here abandoned.

The El Rayo Formation, as here defined, crops out in the vicinity of Lajas Arriba and extends eastward into the Sabana Grande 7.5-minute quadrangle and its type locality south of Sabana Grande. It is named for Quebrada de El Rayo, a small stream located 2.5 km south of Sabana Grande. The formation consists chiefly of dark-grayish-purple to black, massive or brecciated, porphyritic andesitic and basaltic lava and tuffaceous breccia. Lava and breccia fragments commonly contain abundant phenocrysts of andesine or labradorite, green hornblende, clinopyroxene, olivine, and rarely euhedral oxyhornblende. The matrix is composed of plagioclase needles, chloritized mafic minerals, and magnetite in a chloritized glass. Interstices between clasts in tuff breccia are calcite. Limestone interbedded with the lava flows and breccias is light to dark gray, locally light-yellowish-brown weathering, thin-bedded to massive, locally argillaceous, bioclastic calcarenite composed of rudist fragments in a sparry to micritic matrix.

The El Rayo Formation commonly contains rudists of the genera *Titanosarcolites*, *Distefanella*, *Parastroma*, and *Chiopasella*. *Titanosarcolites* is diagnostic of the middle to late Maestrichtian.

BOQUERON BASALT

The Boqueron Basalt is here named for pyroxene, olivine, and oxyhornblende-bearing basaltic lava that crops out from Morales Díaz on the eastern border of the Puerto Real 7.5-minute quadrangle to the town of Boqueron on the Bahia (Bay) of Boqueron in the west. Mattson (1960, pl. 1) mapped some of these rocks as the San Germán Formation and others as undifferentiated Cretaceous(?) volcanic rocks. The Boqueron Basalt consists of dark-gray-brown to dark-greenish-brown or very dark gray porphyritic, locally amygdular, basaltic lava together with minor breccia and tuff. Lava and volcaniclastic rocks contain phenocrysts of labradorite, clinopyroxene, olivine, and rarely oxyhornblende. The matrix is a fine-grained to aphanitic mass of plagioclase needles, epidote, and abundant anhedral hematite grains in a chloritized mass. Some outcrops show a poorly developed flow banding; pillows have not been seen in any outcrops. North of Boqueron, thin, discontinuous, and dark-gray limestone lenses occur at the top of the basalt. The Boqueron Basalt is overlain by an epiclastic sandstone, compositionally identical to the Boqueron, which is interbedded with hornblende-rich volcanic sandstone or tuff identical to the overlying Lajas Formation lava flow and tuff units. The Boqueron and Lajas apparently are both products of subaerial deposition, as lava flows in both lack pillow structure. The limestone sequence at the top of the Boqueron apparently represents a local(?) flooding by the sea. The age of the Boqueron Basalt is only imperfectly known because diagnostic fossils have not been recovered from the limestone lenses at the top of the formation. The Boqueron appears to be overlain by the Lajas with only a very minor disconformity, if in fact a disconformity is present.

REFERENCES CITED

Almy, C. C., Jr., 1965, Parguera Limestone, Upper Cretaceous Mayaguez Group, Southwest Puerto Rico: University Microfilms, Ann Arbor, Mich., Rice University Ph.D. thesis, 203 p.

Hubbard, B., 1923, The geology of the Lares district, Porto Rico: New York Academy of Sciences, Scientific Survey of Porto Rico and the Virgin Islands, v. 2, pt. 1, p. 1-115.

Krushensky, R. D., and Monroe, W. H., 1975, Geologic map of the Ponce quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Investigations Series Map I-863, scale 1:20,000.

_______1978, Geologic map of the Penuelas and Punta Cuchara quadrangles, Puerto Rico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1042, scale 1:20,000.

_______1979, Geologic map of the Yauco and Punta Verraco quadrangles, Puerto Rico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1147, scale 1:20,000.

Mattson, P. H., 1960, Geology of the Mayaguez area, Puerto Rico: Geological Society of America Bulletin, v. 71, p. 319-362.

_______1967, Cretaceous and lower Tertiary stratigraphy in west-central Puerto Rico: U.S. Geological Survey Bulletin 1254-B, p. B1-B35.

Mitchell, G. J., 1922, Geology of the Ponce district, Porto Rico: New York Academy of Sciences, Scientific Survey of Porto Rico and the Virgin Islands, v. 1, pt. 3, p. 229-300.

Slodowski, T. R., 1956, Geology of the Yauco area, Puerto Rico: University Microfilms, Ann Arbor, Mich., Princeton Unviersity Ph.D. thesis, 177 p.

Volckmann, R. P., 1984a, Geologic map of the Cabo Rojo and Parguera quadrangles, southwest Puerto Rico: U.S. Geological Survey Miscellaneous Investigatons Series Map I-1557, scale 1:20,000 (in press).

_______1984b, Geologic map of the Puerto Real quadrangle, southwest Puerto Rico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1559, scale 1:20,000 (in press).

_______1984c, Geologic map of the San Germán quadrangle, southwest Puerto Rico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1558, scale 1:20,000 (in press).

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