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Paleoenvironmental interpretation of Tertiary carbonates in western Montana

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PALEOENVIRONMENTAL INTERPRETATION
OF
TERTIARY CARBONATES
IN
WESTERN MONTANA

by

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Paleoenvironmental Interpretation of Tertiary Carbonates
in Western Montana (99 p.)

Director: Graham T. Thompson

Tertiary carbonate deposits in western Montana have long been interpreted as lacustrine limestones. Examination of the textural, mineral, floral, faunal, and chemical aspects of Tertiary carbonates in the upper Ruby, Jefferson, and Avon Valleys suggests their depositional environments were quite diverse. The interpreted depositional environments include: ephemeral alkaline lakes, and ponds; alkaline or hydrothermal springs; and caliche soils.

Facies relationships between the upper Ruby Valley carbonates and their related sediments were determined by measuring three stratigraphic sections. The mineral, floral, faunal, and chemical components of the carbonate samples and their related sediments in the upper Ruby, Jefferson, and Avon Valleys were determined by x-ray diffraction, x-ray fluorescence, petrographic and SEM analyses to interpret the physical, chemical, biological and climatic factors controlling carbonate deposition during Tertiary time in western Montana. Sedimentary, vertebrate fossil, and mineralogical evidence in the upper Ruby, Jefferson and Avon Valleys in western Montana indicate the prevailing climate during carbonate deposition in the Renova Formation was arid to semi-arid.

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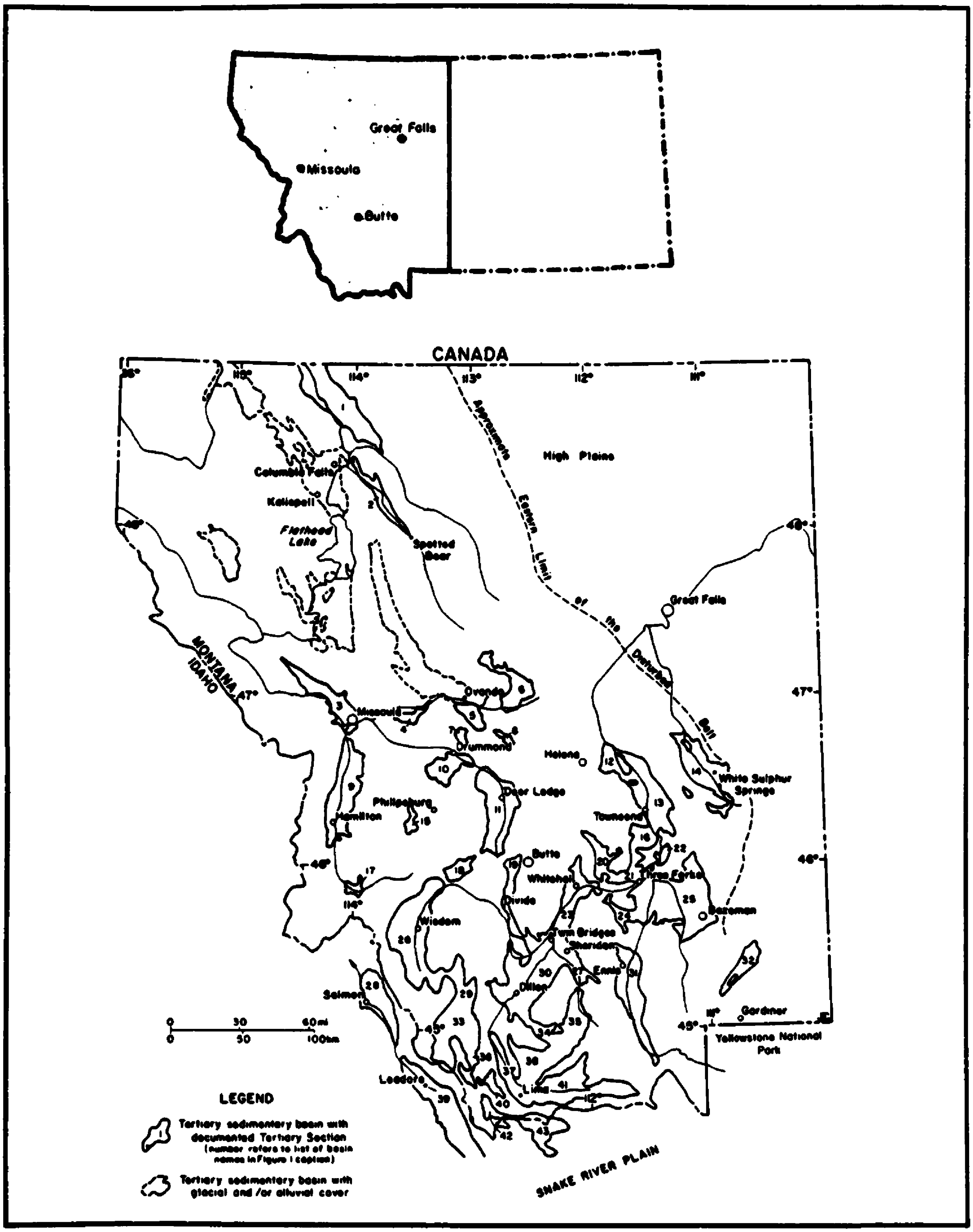
INTRODUCTION

Scope and Purpose

Terrestrial deposits in western Montana's Tertiary basins (Fig. 1) contain a minor carbonate component, the origin of which has been attributed to lacustrine sedimentation (Kuenzi, 1966; Rasmussen 1969, 1977; Kuenzi and Fields, 1971; Monroe, 1976; Axelrod, 1984). Monroe (1976) additionally recognized travertine deposits in the upper Ruby basin. The primary depositional environments for lacustrine carbonates include saline lakes and playa flats in arid regions, and brackish and freshwater lakes in humid regions (Kelts and Hsü, 1978). Carbonate sediments may be composed of allocthonous grains, biologically produced tests, or inorganically precipitated crystals. The bulk of lacustrine carbonates consists of inorganic calcite. Precipitation of inorganic calcite may be biologically or chemically induced and is largely controlled by environmental factors (Kelts and Hsü, 1978). Although most authors generally agree the carbonates in western Montana's Tertiary basins were deposited in lacustrine systems, none have considered the environmental factors controlling carbonate precipitation. This study focuses on the mineral, floral, faunal, and chemical components of Tertiary

Figure 1. Index map of intermontane basins in western Montana and eastern Idaho (Fields et al., 1985). Basin names: 1. Kishenehn, 2. South Fork-Flathead, 3. Missoula, 4. Potomac, 5. Blackfoot, 6. Lincoln, 7. Douglas Creek, 8. Avon-Nevada Creek, 9. Bitterroot, 10. Flint Creek, 11. Deer Lodge, 12. Helena, 13. Townsend, 14. Smith River, 15. Philipsburg, 16. Toston, 17. East Fork-Bitterroot, 18. French Gulch, 19. Divide, 20. North Boulder, 21. Three Forks, 22. Clarkston, 23. Jefferson River, 24. Norris, 25. Madison-Gallatin, 26. Big Hole, 27. lower Ruby River, 28. Salmon, 29. Grasshopper, 30. Beaverhead, 31. upper Madison, 32. upper Yellowstone (Paradise), 33. Horse Prairie, 34. Blacktail Deer, 35. upper Ruby River, 36. Medicine Lodge, 37. Red Rock River, 38. Sage Creek, 39. Lemhi, 40. Muddy Creek, 41. Centennial, 42. Nicholia, 43. Lake Hollow.

Figure 1. Index Map of Western Montana's Tertiary Basins.



carbonates and their related sediments, as well as their vertical and lateral facies relations, to interpret the physical, chemical, biological and climatic factors controlling carbonate deposition during Tertiary time in western Montana.

Carbonate deposits discussed in this report are exposed in the upper Ruby, Jefferson and Avon Valleys (Figs. 2, 3, and 4). Samples were collected from each of these basins.

Regional Tertiary Tectonics

In 1963, Robinson, working in the Three Forks basin raised doubt that Montana's Tertiary basins share a similar geologic history. His concern was founded upon the differing interpretations of Peale (1896), Atwood (1916), Perry (1934), Pardee (1950), Alden (1953), and McMannis (1955). Their disagreements included whether the basins were formed by structural or erosional processes, whether their formation began in the Paleocene or the Oligocene, and whether the regional drainage was to the west or the east. Since 1963, numerous studies have been conducted which indicate the basins do share similar geologic histories (Kuenzi, 1966; Robinson, 1967; Konizeski et al., 1968; Rasmussen, 1969,1973,1977; Hoffman, 1971; Petkewich, 1972; Monroe, 1976, 1981; Constenius, 1981, 1982; Fields, 1981;

Figure 2. Upper Ruby Valley (modified after Monroe, 1976).

LEGEND

Quaternary		Qa	Alluvium
Quaternary Tertiary		TQhs	Hot spring deposits
Tertiary		Tv	Tertiary volcanics age unknown
		Sixmile Creek Formation	
	Pliocene	Tsq	Quartzite Member
		Tsf	Fanglomerate Member
		Tsm	Metamorphic Member
		Renova Formation	
	Miocene	Trp	Passamari Member
	Oligocene	Trd	Dunbar Creek Member
	Eocene	Trc	Climbing Arrow Member
Paleozoic		Ps	Sedimentary rocks
Precambrian		PЄm	Metamorphic basement

Contact; dashed where approximated, dotted where inferred.

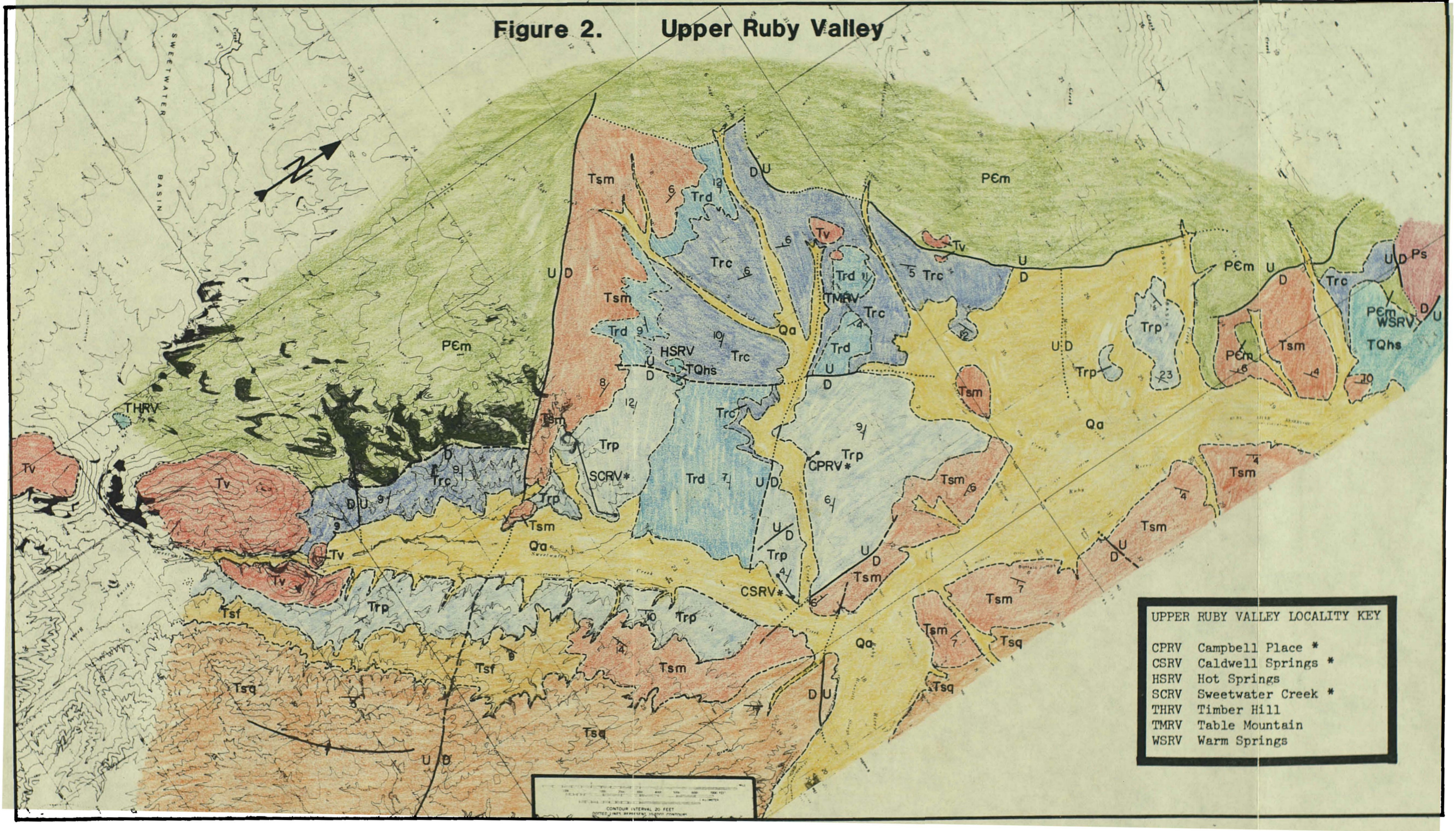
23┤ Strike and dip

U
D
Normal fault; dashed where approximated dotted where concealed; U upthrown side; D downthrown side.

Measured Section

SCRV Sampled Locality; * follows measured sections

Figure 2. Upper Ruby Valley



UPPER RUBY VALLEY LOCALITY KEY

CPRV	Campbell Place *
CSRV	Caldwell Springs *
HSRV	Hot Springs
SCRV	Sweetwater Creek *
THRV	Timber Hill
TMRV	Table Mountain
WSRV	Warm Springs

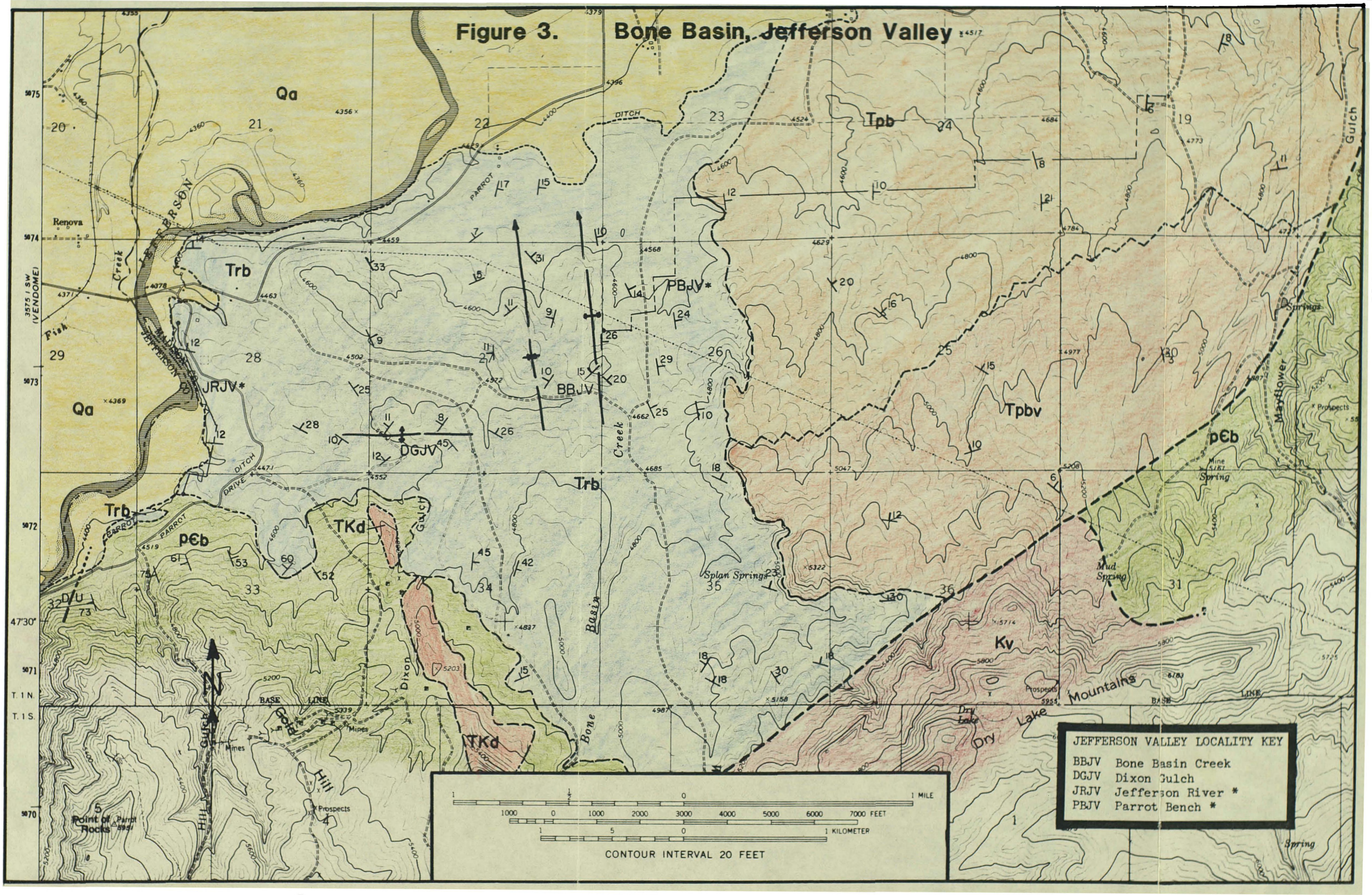
Figure 3. Bone Basin, Jefferson Valley (after Kuenzi, 1966).

LEGEND

Quaternary	Qa	Alluvium
Tertiary		Sixmile Creek Formation
	Tpb ? Tpbv	Parrot Bench Member Volcanic Fanglomerate Member
		Renova Formation
	Trb	Bone Basin Member
Tertiary Cretaceous	TKd	Dacite
Cretaceous	Kv	Elkhorn Volcanics
Precambrian	P€b	Belt Rocks

	Contact; dashed where approximated, dotted where inferred, zig-zagged where gradational.
23┤	Strike and dip
U D	Normal fault; dashed where approximated, dotted where concealed; U upthrown side; D downthrown side.
	Measured Section
BBJV	Sampled Locality; * follows measured sections.

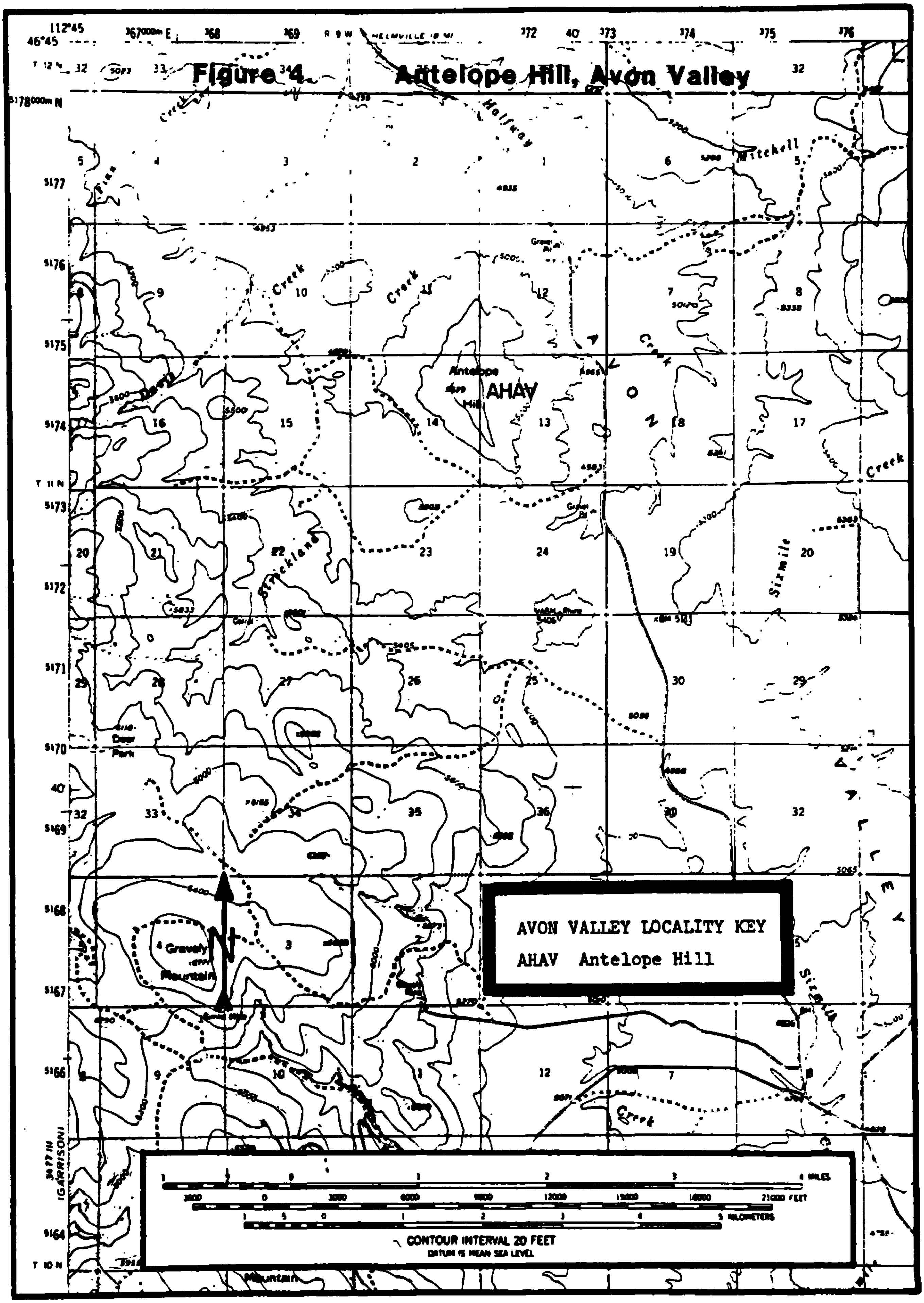
Figure 3. Bone Basin, Jefferson Valley



JEFFERSON VALLEY LOCALITY KEY

BBJV	Bone Basin Creek
DGJV	Dixon Gulch
JRJV	Jefferson River *
PBJV	Parrot Bench *

Figure 4 Antelope Hill, Avon Valley



AVON VALLEY LOCALITY KEY

AHAV Antelope Hill

Hanneman and Nichols, 1981; Dunlap, 1982; Lofgren, 1986; Runkel, 1986).

Fields et al. (1985) give an excellent summary of the tectonic origin and development of Tertiary basins in western Montana and eastern Idaho. The intermontane basins in western Montana are bounded by approximately north south trending listric normal faults and filled with Tertiary volcaniclastic sediments. Most workers agree extensional faulting is the primary mechanism of basin development.

Deposition of Tertiary deposits began during the middle Eocene and ended in the middle to late Miocene (Fields et al., 1985). As indicated by the enormous thickness of Bozeman Group sediments in some valleys, sedimentation rates must have been high. Active volcanism in western Montana, eastern Idaho, and Oregon during the Oligocene could have contributed to the large volume of rhyolitic ash (Fields et al., 1985). Possible sources for the volcaniclastic sediments include reworked Cretaceous Elkhorn volcanics, Eocene Challis, and Lowland Creek volcanics and their equivalents (Fields et al., 1985). Numerous ponds and shallow lakes are interpreted to have formed when streams became choked with sediment and through flowing drainage was impeded by basin development (Kuenzi, 1966; Monroe, 1976).

METHODS

Sample Collection

One hundred forty eight samples of Tertiary carbonates and their related sediments were collected from fifteen localities in the upper Ruby, Jefferson, and Avon Valleys in western Montana, during the summer of 1986. Three stratigraphic sections were measured in the upper Ruby Valley, using a Jacob's staff and Brunton Pocket Transit, to develop a stratigraphic framework for sampling. Samples were collected at every major lithologic horizon. Where stratigraphic data could not be obtained carbonate samples were collected as available in outcrop. Collecting localities are shown on Figures 2, 3, and 4.

Clay Mineral Analyses

Clay mineral content of forty five samples was determined by x-ray diffraction. The samples were crushed using a ceramic mortar and pestle and then disaggregated in deionized water using an ultrasonic probe. Na-metaphosphate was added as a dispersant. The less than 0.5 micron fraction was separated for analysis by centrifugation. Glycol-solvated, oriented samples were analysed using a Philips Norelco x-ray diffractometer with CuKα radiation and a graphite crystal monochrometer. X-ray patterns were run with the x-ray tube operated at 30 Kv and 30 Ma. Randomly oriented bulk powder samples were additionally analysed by x-ray diffraction. To determine the presence of attapulgite, six samples with intense dolomite peaks at 2.89Å were treated with 1 N Na-acetate (pH=5.0) for carbonate removal (Jackson, 1969) and then the glycol-solvated, oriented slides were analyzed by x-ray diffraction.

Chemical Analyses

Twenty carbonate and shale samples were chosen for bulk chemical analysis of silicon, aluminium, titanium, iron, manganese, calcium, magnesium, potassium, sodium, and phosphorous. Dr Peter R. Hooper, of Washington State University, conducted the analysis by x-ray fluorescence with matrix corrections. Results were normalized on a volatile-free basis with total iron expressed as FeO. Analytical precision using x-ray florescence is: SiO_2 0.55%, Al_2O_3 0.31%, Fe_2O_3 0.35%, MgO 0.15%, K_20 0.03%, CaO 0.22%, Na_2O% 0.16.

Petrographic and SEM Analyses

Mineral, floral, and faunal contents of the carbonate samples were determined with a Zeiss petrographic scope and a Zeiss Novascan 30 scanning electron microscope. Ninety four thin sections cut from fifty six samples were studied under the petrographic scope. Eleven untreated bulk samples were examined under the scanning electron microscope.

Folk's (1959) carbonate classification was used to describe carbonate rock types. In some cases, because of the clastic content, Folk's classification was not adequate and a modified classification was necessary for description.

DATA

Upper Ruby Valley

HISTORY OF INVESTIGATION

Dorr and Wheeler (1964) first described the fossil content and stratigraphy of Tertiary Bozeman Group sediments in the upper Ruby Valley. They recognized two unconformably bounded, lithologically distinct formations: the Passamari Formation and overlying "Madison Valley equivalent". Kuenzi and Fields (1971) revised Bozeman Group nomenclature following the rules of the American Commission of Stratigraphic Nomenclature (1961, p. 649, article 4b) to standardize nomenclature of Tertiary deposits in western Montana based on their geographic and temporal proximity, lithologic similarity and homotaxial stratigraphic positions. In accordance with Kuenzi and Fields' (1971) proposed classification, Becker (1973) and Monroe (1976) revised Dorr and Wheeler's stratigraphy of the upper Ruby Valley. The Passamari Formation was relegated to a member of the Renova Formation and the Madison Valley equivalent was established as the Sixmile Creek Formation (Fig. 5). Plant and vertebrate fossils in the upper Ruby Valley suggest age ranges of Early Oligocene (Chadronian) to Early Miocene (latest Arikareean - earliest Hemingfordian) for the Renova Formation, and Late Miocene (Barstovian to Hemphillian) for the Sixmile Creek Formation (Monroe, 1976).

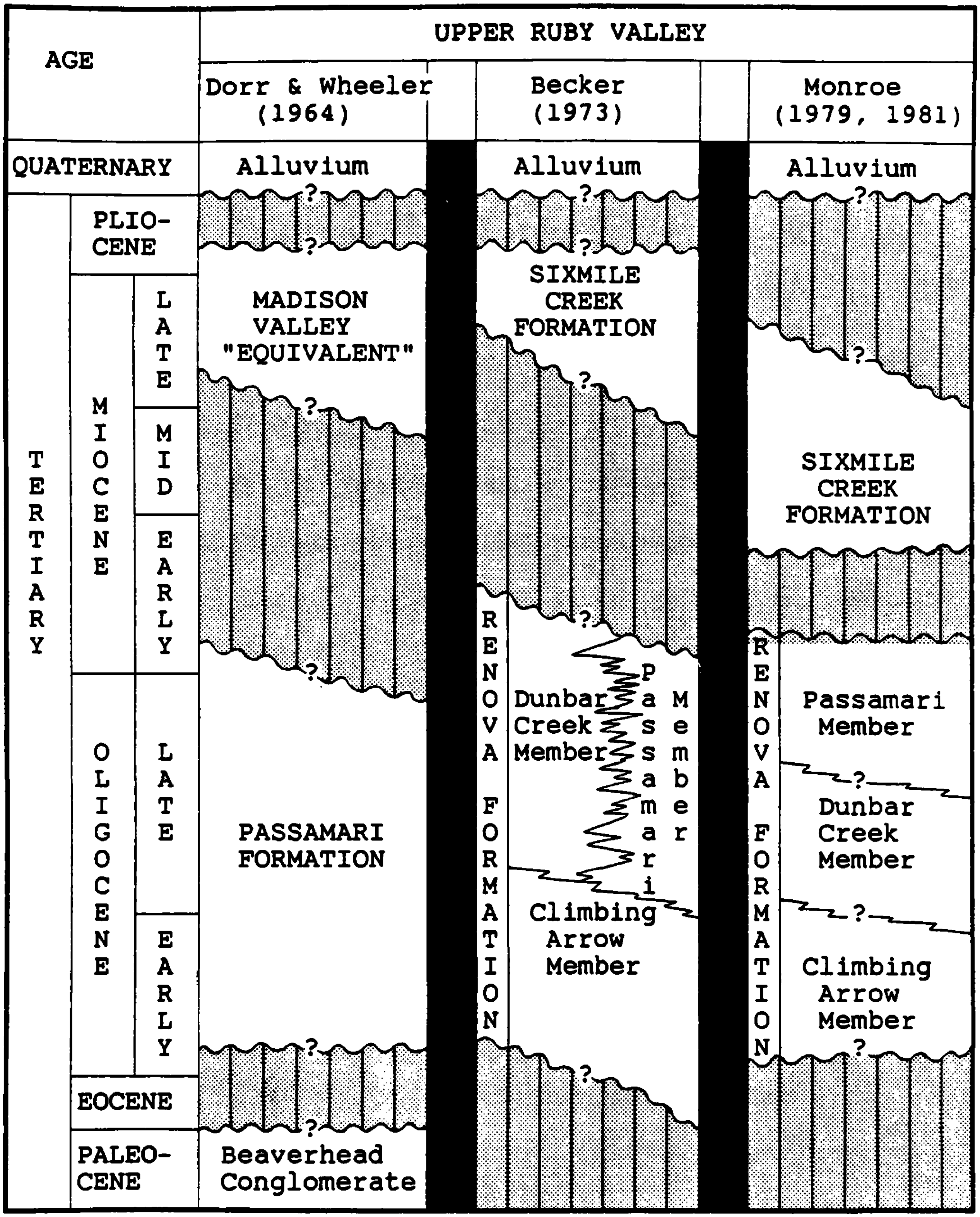


Figure 5. Time stratigraphic chart for the Bozeman Group, upper Ruby Valley (Monroe, 1981).

Monroe (1976) recognized three mappable members in the Sixmile Creek Formation and three in the Renova Formation in the upper Ruby Valley. The members present in the Renova Formation are similarly recognized in other Tertiary basins and are assigned the formal stratigraphic names Climbing Arrow Member (Robinson, 1963), Dunbar Creek Member (Robinson, 1963), and Passamari Member (Petkewich, 1972). Members of the overlying Sixmile Creek Formation occur only in the upper Ruby Valley and are assigned the informal stratigraphic names metamorphic fanglomerate member, feldspathic sandstone member, and quartzite pebble conglomerate member. Limestone units occur in all of the Bozeman Group members in the upper Ruby Valley, but significant deposits (>1.0% of the total member) exist only in the Dunbar Creek and Passamari Members of the Renova Formation. Monroe (1976) interpreted the Dunbar Creek limestones as travertine deposits and the Passamari limestones as lake marls.

DESCRIPTIONS

Sedimentary Features

Three stratigraphic sections were measured in the upper Ruby Valley. The sections were chosen because they represent different facies within the Passamari Member, they are well exposed, and contain varying amounts of carbonate. Monroe

(1976) originally measured and described the Sweetwater Creek (SCRV), Caldwell Springs (CSRV), and Campbell Place (CPRV) Sections. They were remeasured for this study, concentrating on the stratigraphic relationship between the carbonate and clastic sediments and on the sedimentary structures which they contain, to determine the environment and processes of deposition. Section localities are illustrated on Figure 2, and illustrated columns and their descriptions are given in Appendix A.

The Sweetwater Creek Section, measured one mile west of Conley Ranch from the SE$\frac{1}{4}$ sec. 22 to the NW$\frac{1}{4}$, SE$\frac{1}{4}$ sec 21, T.8S., R.5W., contains 118 meters of the Passamari Member. The section does not contain the base of the Passamari Member. The Passamari Member consists of 66% paper shale, 19% siltstone, 5% mudstone, 5% limestone, 4% sandstone, and less than 1% tuff in the Sweetwater Creek Section. The upper 63 meters are dominated by interbedded flat laminated paper shales and silts, whereas the lower 55 meters are dominated by repeated cycles of ripple and trough cross stratified siltstone, flat laminated paper shale, crenulated biolithite, and massive intradismicrite. The repeated sedimentary packages of the lower 55 meters vary somewhat, but in general consist of basal trough cross stratified tuffaceous silts and sands which interbed with flat laminated paper shales and are overlain by laminated biolithites. The sedimentary

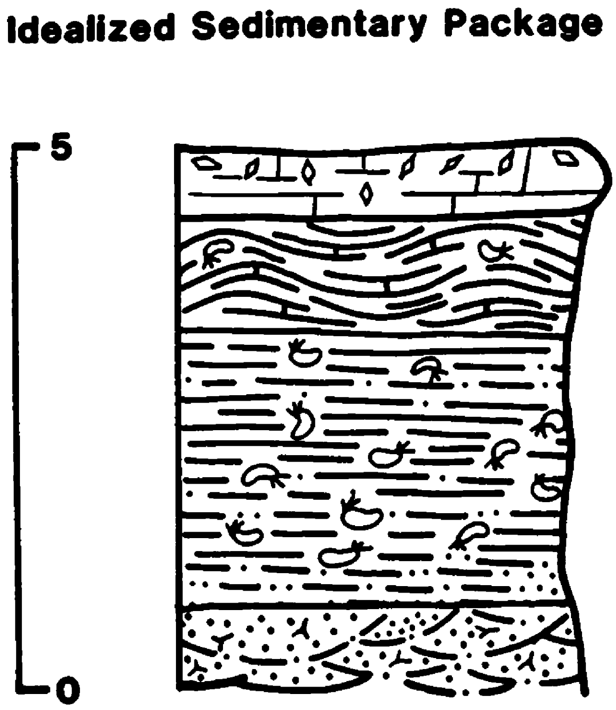


Figure 6. Repeated sedimentary package in the Sweetwater Creek Section. Scale in meters. See Appendix A for explanation of symbols.

packages are capped by intradismicrites which contain calcite psuedomorphs of gypsum (Fig 6). Some of the basal silts contain ash shards (Plate 1). Thin gypsum layers (0.5-4.0 cm thick) run parallel to and across bedding in silty shale units 23, 24, and 38 (see Appendix A). Occasional mudcracks of uncertain origin occur in the paper shales and collapse breccias occur in the intradismicrites (Plate 2). Diamond shaped crystal molds occur near the tops of all the intradismicrite units; in some of these units the original crystals have been replaced by sparry calcite (Plate 2). Planed oscillation ripples occur on bedding surfaces of coarse (0.05-2.0 cm diameter), trough cross stratified pebble-sands in Unit 37.

The Caldwell Springs Section, located in the west center of sec 13, T.8S., R.5W., represents a coarser facies of the Passamari Member than does the Sweetwater Creek Section. Neither the base nor the top of the Passamari Member is exposed in the Caldwell Springs Section. Fine sands and silts compose up to 72% of the total 41 meters, while paper shales compose 38% of the section. A variety of sedimentary structures is present throughout the section, including planar laminations (0.1-2.0 cm thick), channel scours (3.0-10.0 cm high, 10.0-5.0 cm wide), load structures, flame structures, and mud diapirs (1.0-2.0 m high). Lenticular beds of coarse, rip up clast sands repeatedly occur in the section. The pebble sized rip up clasts (0.5-4.0 cm diameter) are composed of calcareous silts and clay. Occasional mudcracks and gypsum layers (1.0-2.0 cm thick) occur in the calcareous paper shales of Unit 7.

The Campbell Place Section, in the NW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 11, T.8S., R.5W., represents the coarsest facies of the Passamari Member in the upper Ruby Valley. The section measures 32 meters and contains neither the base nor the top of the Passamari Member. Poorly sorted sands make up 90% of the section while conglomerates comprise 10%. Paper shale is not present in the Campbell Place Section. Isolated cobble to boulder sized, basalt clasts commonly occur "floating" in a

Plate 1.

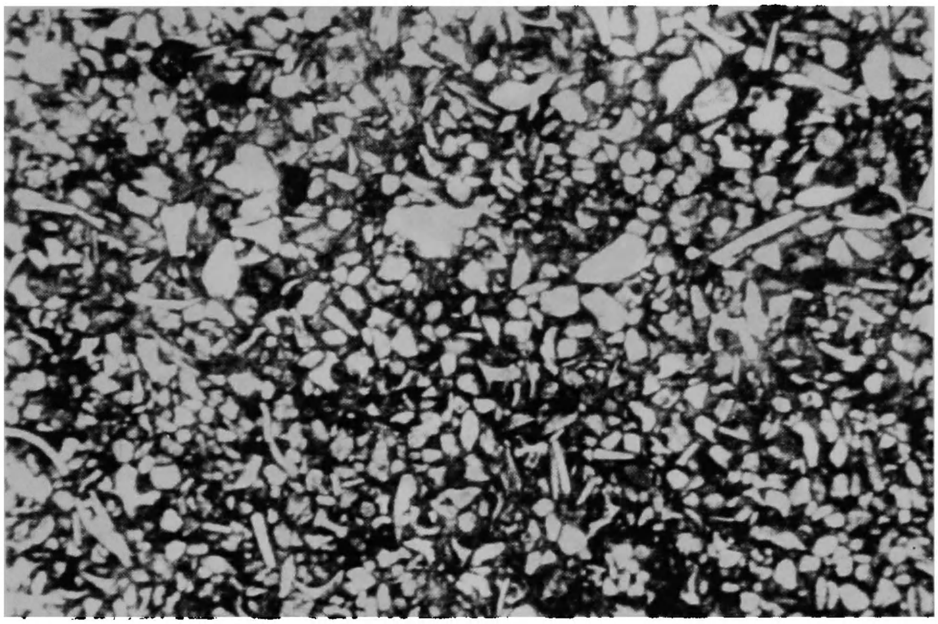


Figure 1. Photomicrograph of tuffaceous silty sand (SCRV-23) x10, plane light.

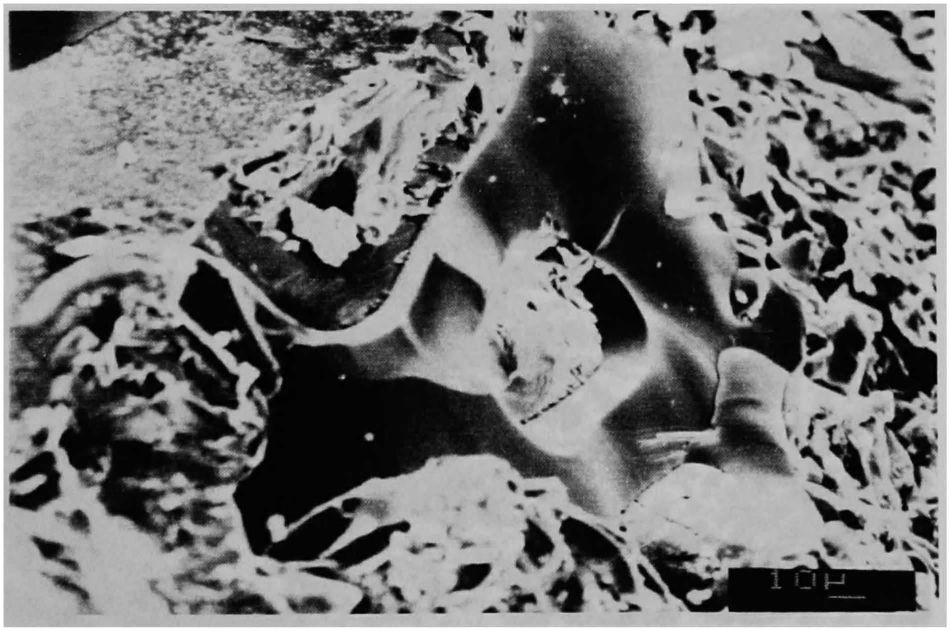


Figure 2. SEM photograph of volcanic glass shard (SCRV-23) x1K.

Plate 2.

Figure 1. Photomicrograph of calcite psuedomorphs after gypsum (SCRV-19) x10, plane light.

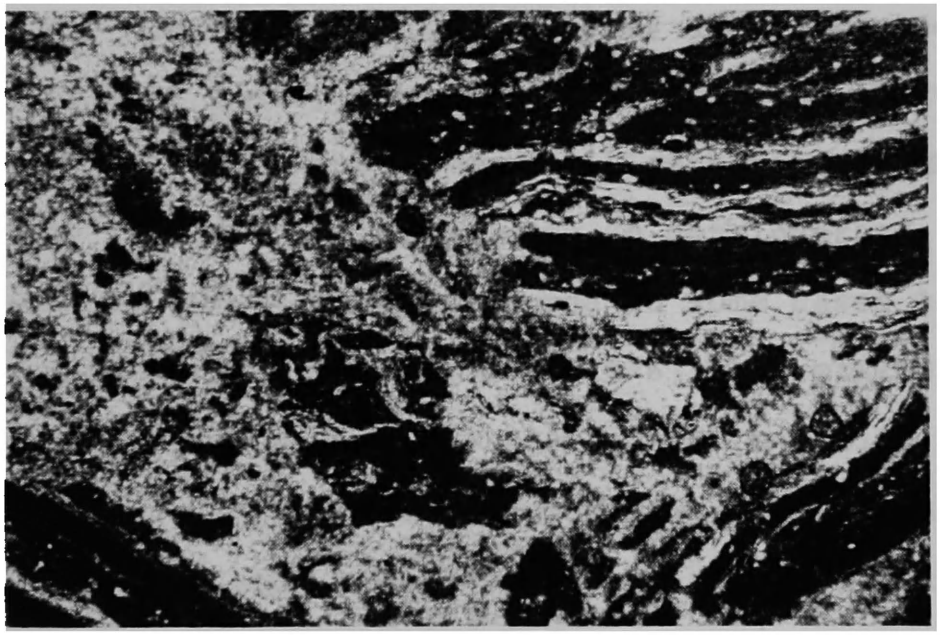


Figure 2. Photomicrograph of brecciated micrite (SCRV-19) x10, plane light.

matrix of massive sands. Poorly developed conglomeratic channel lenses (5.0-10.0 cm high, 1.0-2.0 m wide) also occur in the massive sands. Four lenticular beds (0.5-1.0 m thick) of cobble conglomerates alternate with the poorly sorted sand units. Well developed channel scours (10.0-50.0 cm high, 3.0-10.0 m wide) cut into the sands. Conglomeratic beds low in the section are matrix supported, whereas those higher in the section are clast supported.

Massive carbonate deposits occur in the upper Ruby Valley near the present basin margins (Fig. 2). These deposits include: the Warm Springs carbonates (WSRV) located in secs. 12 and 13, T.7S., R.5W., and secs 7, 8, 17, and 18, T.7S., R.4W.; Table Mountain carbonates (TMRV) in secs. 3, 4, and 10, T.8S., R.5W.; Hot Springs carbonates (HSRV) in sec 16, T.8S., R.5W.; and Timber Hill carbonates (THRV) in sec. 7, T.9S., R.5W. The carbonates do not interbed extensively with clastic deposits and in some cases they occur in isolated patches. Monroe (1976) interpreted the deposits as calcareous tufa and travertine resulting from hot spring activity. Internal structures are not apparent in field exposures or hand samples, however petrographic analysis reveals algal laminations and abundant ostracod shells (Plates 3 and 9). All of the travertine biosparites and biolithites have been neomorphosed (Plates 3 and 9).

Plate 3.

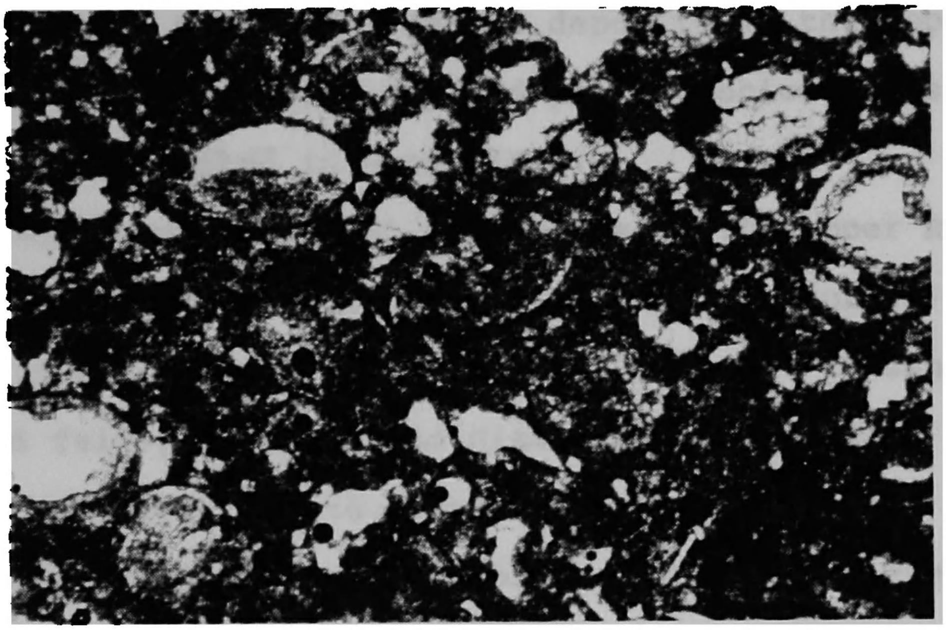


Figure 1. Photomicrograph of ostracod biosparite (THRV-14) x10, plane light. Note geopetal structure and neomorphic spar.

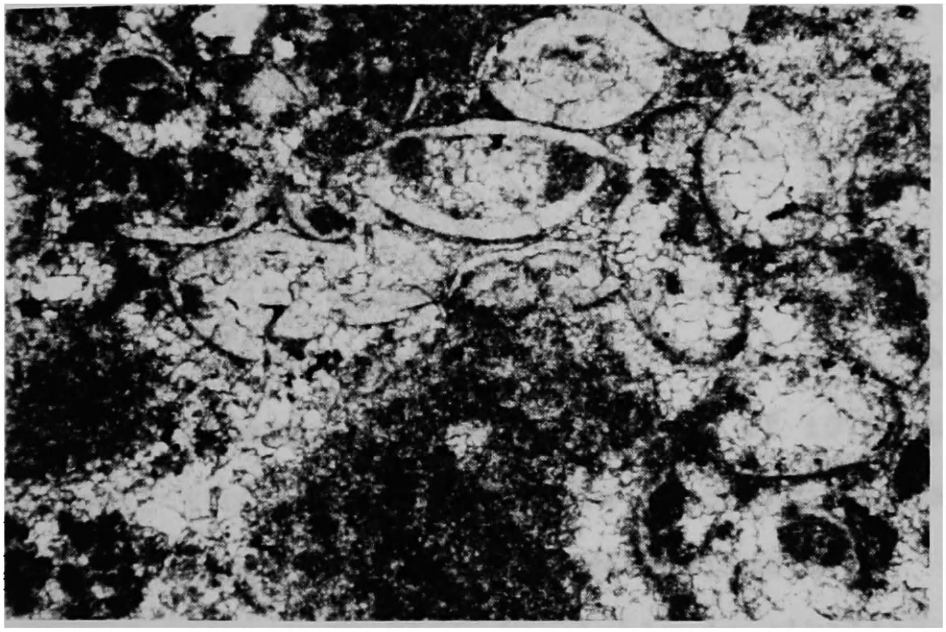


Figure 2. Photomicrograph of ostracod biosparite (HSRV-1) x10, plane light. Note neomorphic spar.

Mineral Content

The mineral content of Renova deposits in the upper Ruby Valley was determined by x-ray and petrographic analyses. Mineral data is listed in Appendix B.

The most common mineral assemblage in the upper Ruby Valley consists of smectite, calcite, rhyolitic glass (Monroe, 1976), quartz, and feldspar. The silt to sand sized quartz and feldspar grains and glass shards are all allogenic, whereas calcite occurs as an endogenic precipitate. Allochthonous Paleozoic and Mesozoic carbonate clasts do not occur in any of the upper Ruby Valley deposits.

Dolomite, gypsum, halite, illite, and attapulgite are present in some horizons. The most common occurrence of these minerals is in the lower 80 meters of the Sweetwater Creek Section (Appendix A). Halite and illite also occur in the Caldwell Springs Section.

A 10.5 Å d-spacing reflection was detected in two x-ray diffraction patterns from the Sweetwater Creek Section (SCRV-8 and SCRV-15). Although a (110) d-spacing of 10.5 is not a definitive test, its presence suggests attapulgite (Carroll, 1970). Attapulgite is a magnesium silicate ($(Mg,Al_2)Si_4O_{10}(OH) \cdot 4H_2O$) that is stable in alkaline environments (Carroll, 1970). Aluminum inhibits formation of attapulgite in favor of smectite (Weaver and Pollard, 1973). To overcome the influence of aluminum, magnesium concentrations must be high.

X-ray diffraction patterns of the less than 0.5 micron clay fraction indicate a randomly interstratified mixed-layer illite-smectite (I/S) in the Sweetwater Creek and Caldwell Springs Sections. Smectite layers in the I/S range from 75 - 100 percent as determined using the techniques of Reynolds and Hower (1970).

The dominant mineral assemblage of the Warm Springs, Hot Springs, Table Mountain, and Timber Hill carbonates consists of smectite and calcite. Chalcedony is present in these carbonates as a secondary mineral. Glass shards and quartz and feldspar grains occur in a few of the Table Mountain and Timber Hill samples.

Chemical Content

Chemical content of 12 samples from the upper Ruby Valley was determined by x-ray fluorescence (Table 1). The samples chosen for analysis include calcareous paper shales (SCRV-33 and SCRV-40), silty micrites (SCRV-16 and SCRV-27), micrites (SCRV-20, SCRV-21, SCRV-26, SCRV-30, and SCRV-32) and sparites (THRV-13, TMRV-2, and WSRV-3). Results of chemical analyses are listed in Table 1 and Appendix C.

Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
SCRV-33	37.43	8.48	.471	3.30	.288	45.16	1.77	1.57	1.23	.287
SCRV-40	35.88	6.80	.354	2.53	.979	50.73	1.45	1.32	0.35	.289
SCRV-16	38.73	8.15	.446	1.70	.246	46.36	1.47	1.59	1.17	.157
SCRV-27	36.84	7.77	.375	2.22	.244	49.12	1.35	1.91	0.76	.185
SCRV-20	16.66	3.18	.180	1.59	.282	49.95	27.72	0.61	0.27	.219
SCRV-21	17.86	3.03	.180	1.04	.244	72.98	3.71	0.64	0.09	.219
SCRV-26	13.31	2.71	.211	1.19	.390	80.25	1.23	0.55	0.07	.111
SCRV-30	12.26	1.72	.123	0.46	.273	83.86	0.87	0.32	0.00	.120
SCRV-32	7.32	1.11	.123	0.34	.085	57.32	32.84	0.20	0.42	.256
THRV-13	2.04	0.29	.057	0.00	.160	97.01	0.38	0.00	0.00	.078
TMRV-2	20.57	3.95	.250	1.32	.042	70.16	2.24	0.98	0.37	.097
WSRV-3	3.12	0.57	.065	0.00	.001	94.67	1.49	0.07	0.00	.030

Table 1. Chemical data from the upper Ruby Valley listed in weight percent. See text for sample information.

Paper shales and silty micrites contain the highest percentage of silicon and aluminum in the upper Ruby Valley samples. Aluminum and silicon oxide values are interpreted to represent the clay mineral assemblage. Titanium, magnesium, iron, and potassium all increase with increasing silicon and are interpreted to occur with the clay fraction (see variation diagrams Appendix C). The sparites (THRV-13, and WSRV-3) contain the lowest percentage of silica which is consistent with the clastic content of these samples.

Norm calculations were conducted to describe semiquantitatively the mineral content of the twelve upper Ruby Valley samples (Table 2). Before proceeding with the calculations several assumptions were made: 1. all the magnesium was used to make dolomite; 2. all the remaining calcium was used to make calcite; 3. all the aluminum was used to make smectite; 4. all octahedral cations in the smectite are aluminum; and 5. all the sodium was used to make halite. Total normative percentages exceeded one hundred by approximately 20 percent probably because the clay characterization was oversimplified and gypsum was not included in the calculation. Using this approach the highest clay content was determined at 34 percent (SCRV-33) and the lowest was less than 1 percent (WSRV-3). Calcite contributions range from 15 to 126 percent. Halite never exceeds 1 percent and silica (allogenic glass and quartz) never exceeds 19 percent of the total mineral assemblage. The normative calculations give only a rough estimation of the mineral content of the samples analyzed, but corroborate petrographic analysis.

Sample	Calcite	Dolomite	Clay	Free Silica	Halite
SCRV-33	63.90	6.82	33.05	17.20	1.00
SCRV-40	72.90	5.53	26.45	18.72	0.29
SCRV-16	67.80	5.72	32.58	6.06	0.90
SCRV-27	72.00	5.35	30.69	17.62	0.58
SCRV-20	16.80	94.76	1.13	7.87	0.18
SCRV-21	96.70	13.46	11.33	9.35	0.06
SCRV-26	107.36	4.24	1.21	8.98	0.06
SCRV-30	115.30	3.13	6.14	6.95	0.00
SCRV-32	15.30	110.98	3.78	3.77	0.29
THRV-13	126.00	1.29	0.94	1.11	0.00
TMRV-2	96.00	8.30	14.64	10.26	0.29
WSRV-3	122.00	4.98	1.89	0.02	0.00

Table 2. Results of norm calculations listed in percent. See text for discussion of sample rock types.

Fossil Content

Floral and faunal studies conducted in the upper Ruby Valley focus primarily on the macrofossil content. Becker (1960, 1961, 1972, 1973) recognized four Tertiary floras in the valley only one of which, the Paper Shale flora, he placed in the Passamari Member. The Paper Shale flora (Late Oligocene) occurs south of Peterson Creek in Fossil Basin (secs. 23, 24, 25, 26, T.7S., R.5W.) and contains well preserved plant leaves, flowers, stems, and seeds, as well as insect and fish (Teleostei, cf. *Amia*) remains. Species of fir (*Abies*), spruce (*Picea*), pine (*Pinus*), dawn redwood (*Metasequoia*), maple (*Acer*), birch (*Betula*), hackberry (*Celtis*), beech (*Fagus*), ash (*Fraxinus*), Oregon grape (*Mahonia*), poplar (*Populus*), rose (*Rosa*), elm (*Ulmus*), and keaki tree (*Zelkova*) genera contribute to the flora. The Paper Shale flora does not occur anywhere else in the Passamari Member therefore its stratigraphic relationship to measured sections is questionable.

Monroe (1976) recognized five faunas in the upper Ruby Valley only one of which, the Belmont Park fauna, occurs in the Passamari member. The Belmont Park fauna (latest Arikareean - earliest Hemingfordian) includes ancestral beavers (*Palaeocastor*), rabbits (*Palaeolagus*), horses (*Parahippus*, *Anchitherium*), tragulids (*Nannotragulus*, cf. hypertragulid), deer (*Blastomeryx*), camels (*Oxydactylus*), and oreodonts (Ticholeptus, Phenacocoelus, Merychyus).

Microfossils present in the Passamari Member include ostracods (Plate 4), diatoms (Plates 5, 6, 7, and 8), and foraminifera. Van Nieuwenhuise (1986) cited the presence of three species of benthonic foraminifera (Elphidium) in a limited horizon (Monroe, 1976, Unit 28) of the Sweetwater Creek Section. Monroe's Unit 28 tentatively correlates with Unit 34 in this report based on lithologic descriptions, but no evidence of a foram horizon was found.

Ostracod molds and impressions are abundant in the Sweetwater Creek and Caldwell Springs paper shales. They also occur in some of the Sweetwater Creek biolithites and intradismicrites, but are not as numerous in these rock types. Ostracod identification is difficult due to poor preservation. Dorr and Wheeler (1964, p. 302) identified some of the ostracods as Candona. Ostracods in the Warm Spring, Table Mountain, Hot Spring, and Timber Hill travertine deposits are recognized only in thin section (Plate 3).

Coccoid green algae occur throughout the Sweetwater Creek Section. The algal spheres (Plates 7, 8 and 9), similar to Chlorellopsis coloniata from the Green River Formation (Bradley, 1929), dominate the biolithites and occur scattered throughout the intradismicrites. Chlorellopsis coloniata is an extinct unicellular green

Plate 4.

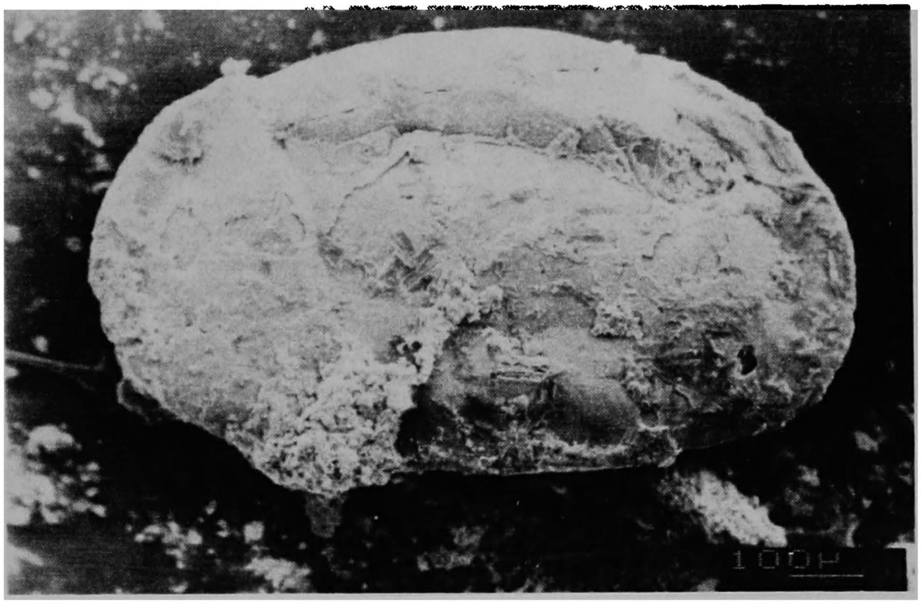


Figure 1. SEM photograph of ostracod (SCRV-31) x50.

Figure 2. SEM photograph of ostracods (SCRV-32) x50.

Plate 5.

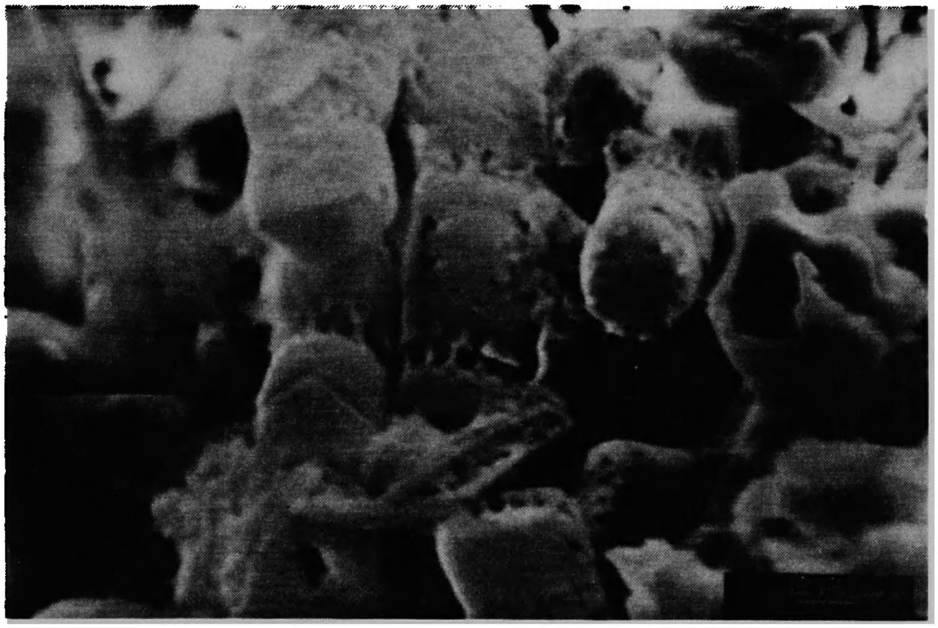


Figure 1. SEM photograph of the diatom ? <u>Melosira</u> (SCRV-32), x5K.

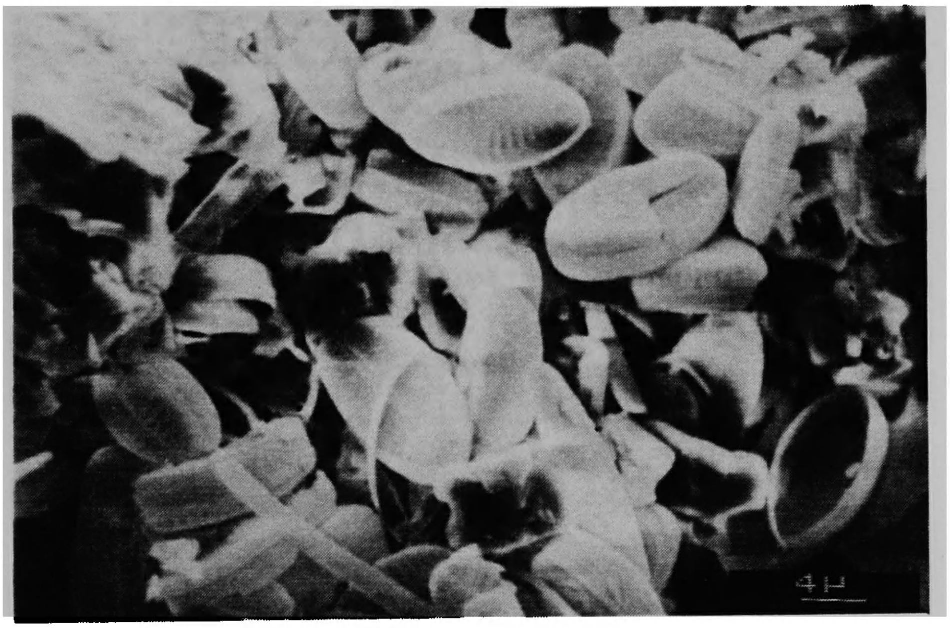


Figure 2. SEM photograph of the diatom ? <u>Navicula</u> (SCRV-32), x2.5K.

Plate 6.

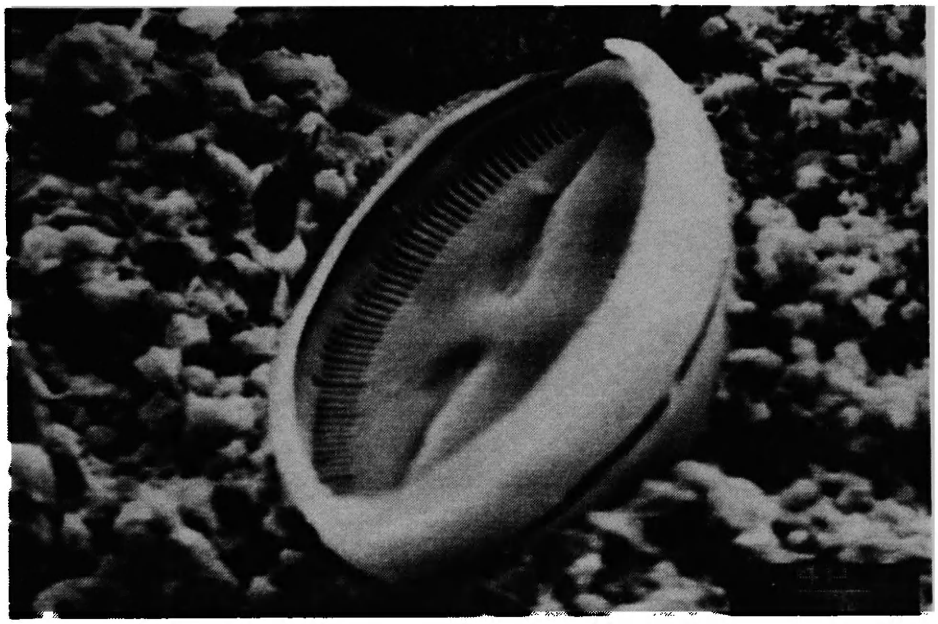


Figure 1. SEM photograph of the diatom ? <u>Mastogloia</u> (SCRV-32), x2.5K.

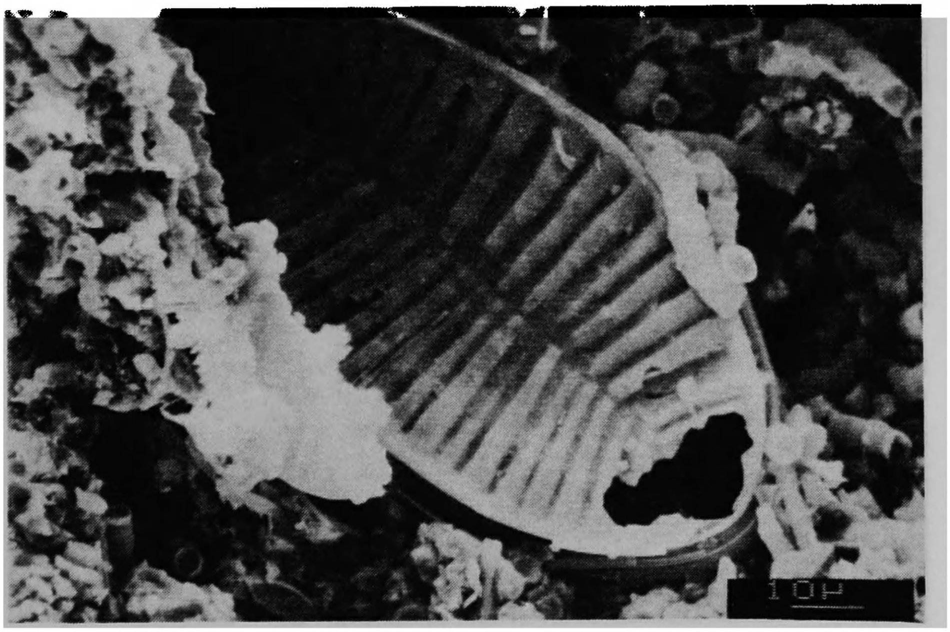


Figure 2. SEM photograph of the diatom ? <u>Surirella</u> (SCRV-32), x1K.

Plate 7.

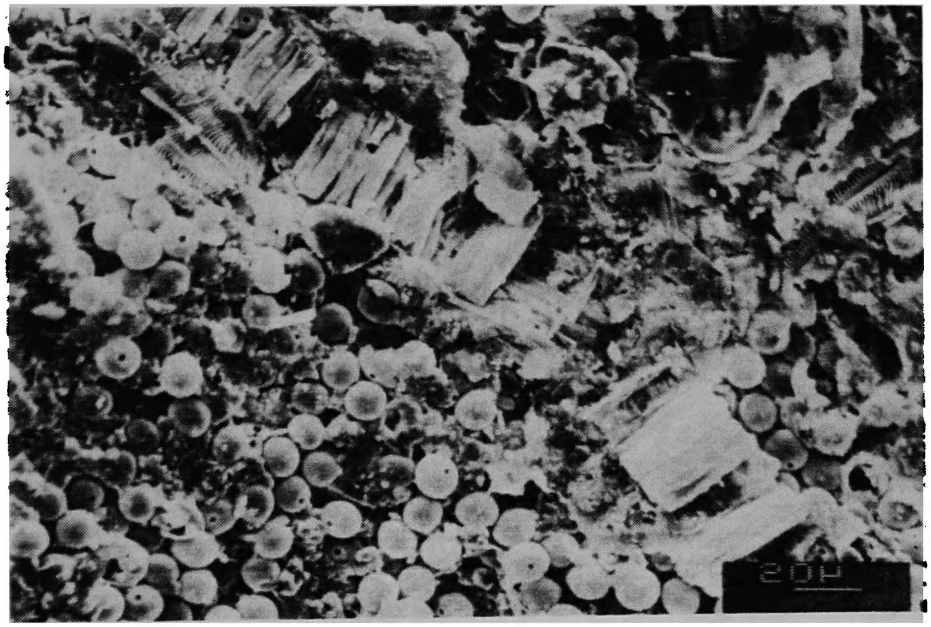


Figure 1. SEM photograph of diatom colony and coccoid green algae (SCRV-40), x500.

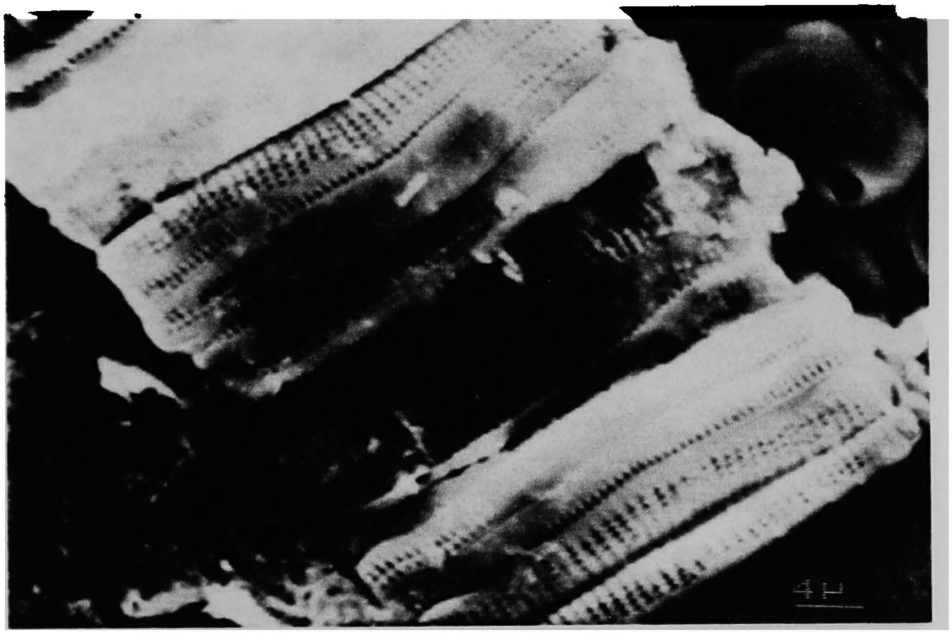


Figure 2. Close up photograph of diatom colony (SCRV-40), x2.5K.

Plate 8.

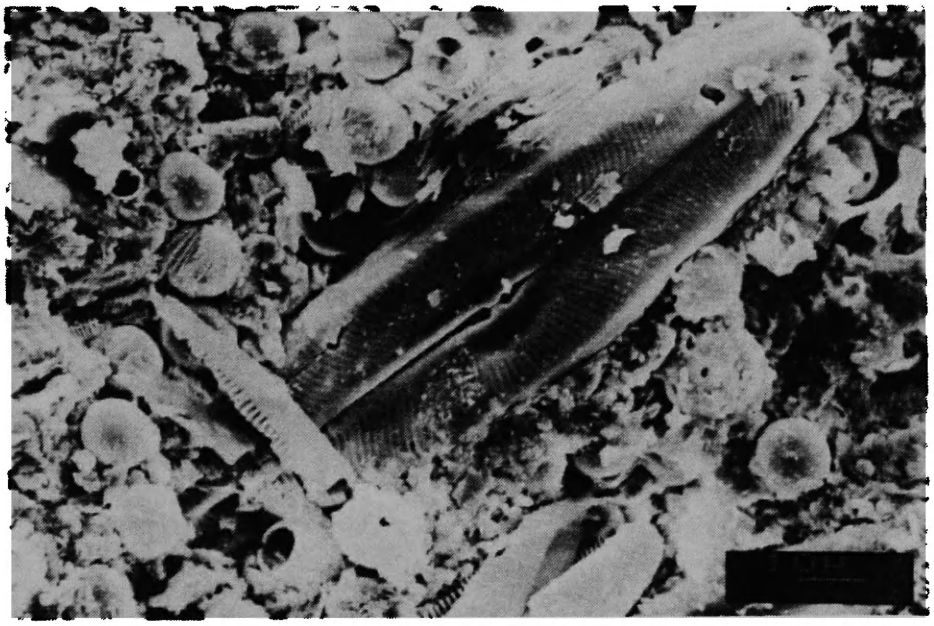


Figure 1. SEM photograph of the diatom *Navicula* and coccoid green algae (SCRV-40), x1K.

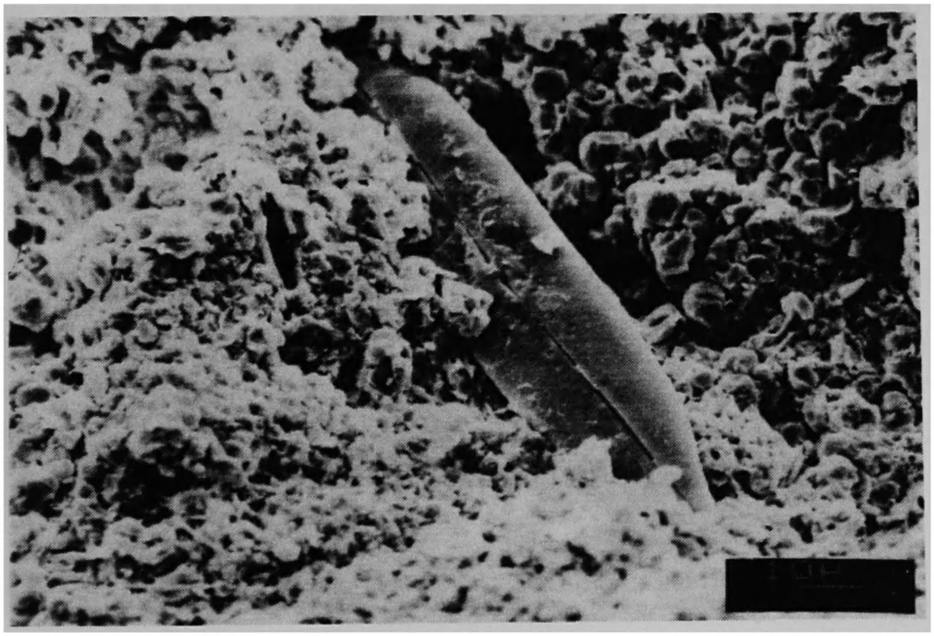


Figure 2. SEM photograph of the diatom *Navicula* (SCRV-32) x1K.

Plate 9.

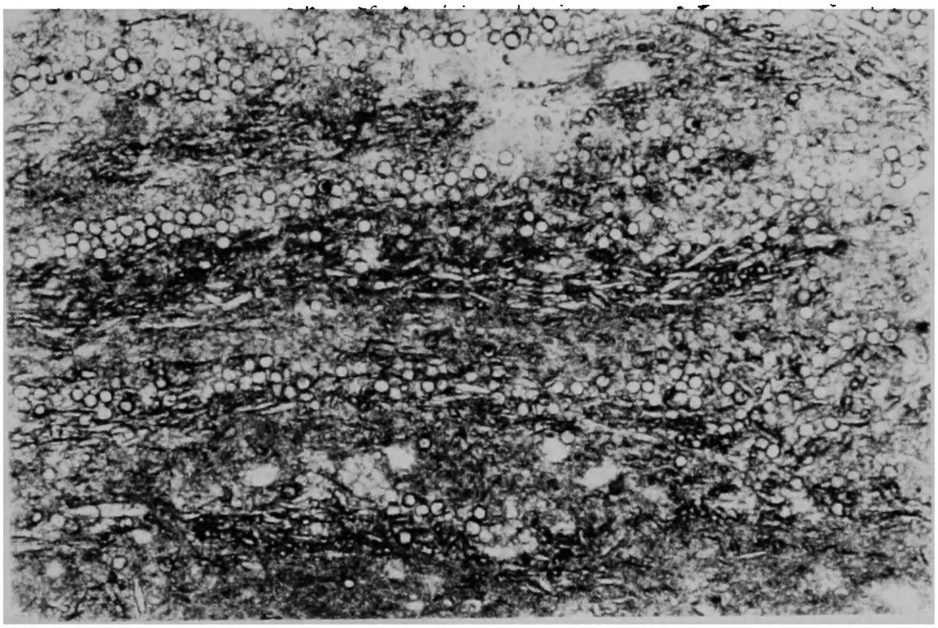


Figure 1. Photomicrograph of coccoid green algae (SCRV-30) x10, plane light.

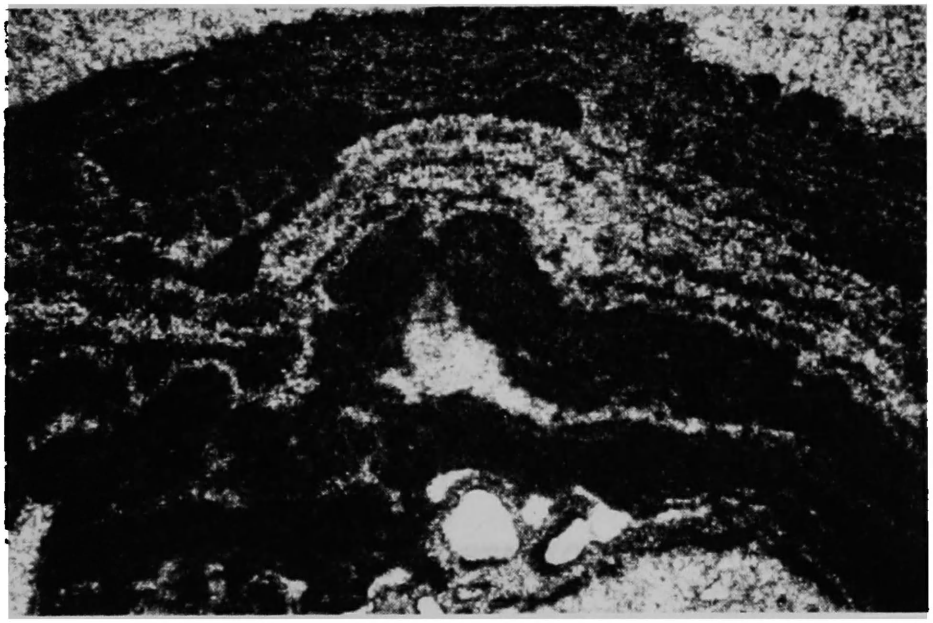


Figure 2. Photomicrograph of algal laminations in spring deposit (TMRV-4) x10, plane light.

algae similar to the modern genus Chlorella. Coccoid green algae in the Sweetwater Creek carbonates differ from Chlorellopsis coloniata in size and growth habit. Individual spheres of Chlorellopsis coloniata range in diameter from 110-140 microns, and form algal heads 0.7-1.7 meters high and 0.6-0.7 meters in diameter, whereas algal spheres from the Sweetwater Creek section range from 8-10 microns in diameter and form laminated mats 5.0-10.0 centimeters thick. The Sweetwater Creek algae are probably not the same species as Chlorellopsis coloniata, but they may belong to the same genus.

Numerous and varied forms of diatoms occur in the Sweetwater Creek shales, biolithites, and intradismicrites. The genera present include Navicula, ? Surirell, ? Melosira, and ? Mastogloia (Plates 5, 6, 7, and 8). Monroe (1981) cited the presence of a 0.3 meter thick diatomite bed in the Passamari lacustrine facies. A pure diatomite bed was not found in the Sweetwater Creek Section, but many of the units are diatomaceous.

INTERPRETATION

The Sweetwater Creek, Caldwell Springs, and Campbell Place Sections each display different textural fabrics, sedimentary structures, mineral assemblages, and fossil assemblages. Monroe (1976, 1981) interpreted these three sections respectively as lacustrine, deltaic, and alluvial fan facies of the Passamari Member. Monroe (1976, 1981) suggested the Sweetwater Creek limestones precipitated in a shallow perennial lake (Lake Passamari) which occupied a closed basin. Reexamination of the Sweetwater Creek Section leads to a slightly different interpretation of the lacustrine environment. The presence of desiccation cracks, collapse breccias, halite, attapulgite, pseudomorphs of calcite after gypsum, and a flora and fauna restricted to ostracods and algae suggest the carbonates were precipitated in an ephemeral, saline lacustrine environment. This interpretation is supported by the repeated sedimentary packages of silts, paper shales, biolithites, and intradismicrites which are interpreted to record recurrent flooding and desiccation of ancient Lake Passamari.

Monroe (1976) interpreted the Tertiary carbonates at the Warm Springs, Table Mountain, and Hot Springs localities as travertine deposits resulting from hot spring activity. The Timber Hill carbonate deposits of this report can also be included in this category. This is a reasonable interpretation given the mineral, faunal, and textural aspects of these deposits. Travertine deposits are commonly associated with perennial and ephemeral lacustrine environments in arid regions (Hardie, et al., 1978; Smoot, 1978; Esteban and Klappa, 1983).

Trona is a common evaporite mineral in the Wilkens Peak Member of the Eocene Green River Formation in Utah (Eugster and Hardie, 1975; Smoot, 1978) and in modern Lake Magadi in Africa (Eugster and Hardie, 1975), but is absent in the Passamari Member of the Renova Formation in western Montana. The absence of trona ($NaHCO_3 \cdot Na_2CO_3 \cdot H_2O$) in the evaporite mineral assemblage indicates Lake Passamari waters either never became concentrated enough to precipitate trona or that they were slightly depleted in bicarbonate relative to calcium. Bicarbonate is less soluable in alkaline environments (Eugster and Hardie, 1978), and any free bicarbonate probably reacted with calcium to precipitate calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). A 25-fold brine concentration is required after precipitation of gypsum ($CaSO_4$) for halite to precipitate and an additional 250-fold brine concentration is needed for trona to precipitate (Eugster and Hardie, 1978). The absence of trona in the Passamari Member indicates either the evaporative brine in ancient Lake Passamari never reached a 250-fold increase after gypsum precipitation or that the system was highly alkaline and depleted with respect to bicarbonate.

Pebble and cobble compositions in coarse grained facies of the Campbell Place and Caldwell Springs sections indicate metamorphic basement and basalt were the primary source rocks for Passamari deposits. Exposed bedrock surrounding the upper Ruby Valley today consists of Precambrian Cherry Creek Group gneiss, schist, marble, and quartzite (Monroe, 1976). Precambrian Belt rocks are not present in the region. Solutes necessary for precipitation of calcite, dolomite, halite, and gypsum could have been supplied from chemical weathering of the carbonate and silicate minerals present in the gneiss, schists, marble, and basalt (Eugster and Hardie, 1978).

Illite in the lacustrine and deltaic facies may be detrital, but its association with gypsum, halite, and dolomite in the Sweetwater Creek and Caldwell Springs Sections and exclusion from other sections implies a genetic relationship. Jones and Weir (1983) described the chemical transformation of smectite to illite in a modern alkaline, lacustrine environment in Oregon. Eberl et al. (1986) suggest the smectite to illite transformation may result from frequent periods of wetting and drying and from chemical reaction in high pH environments.

The fossil assemblage in the upper Ruby Valley Passamari facies further supports an ephemeral alkaline lacustrine interpretation. Ostracods dominate the fossil assemblage, occurring primarily in the laminated paper shales. The paper shales are interpreted as quiet water deposits laid down after flooding events. Ostracod abundance declines in the biolithites and intradismicrites. Forester (1983, 1986) states ostracod occurrence is determined by dissolved anion concentrations, and that ostracod species are anion-specific. Without knowing what ostracod species are present in the Passamari Member it is impossible to determine what specific anion limited their occurrence to the paper shales, but evidence of their decline in the biolithites and intradismicrites suggests chemical conditions in the lake were changing.

Pulmonate gastropods are terrestrial snails that live in freshwater environments. The complete absence of land snails in the upper Ruby Valley deposits suggests the lake and spring waters were too alkaline, or in the case of the springs, too warm.

The abundance of algae in the Sweetwater Creek biolithites may indicate that initial carbonate precipitation was enhanced by biological extraction of carbon dioxide. As evaporation continued, biological activity declined, as indicated in the declining flora and fauna of the intradismicrites, and calcite precipitated chemically.

Two carbonate depositional environments are interpreted in the upper Ruby Valley. They are an ephemeral, alkaline, saline lake represented by the Sweetwater Creek, Caldwell Spring and Campbell Place localities; and alkaline or hydrothermal springs represented by the Warm Spring, Table Mountain, Hot Spring, and Timber Hill localities. The processes resulting in carbonate deposition include direct precipitation from loss of carbon dioxide in spring waters and evaporative concentration of solutes in alkaline lakes. Biological activity may have induced carbonate precipitation in the upper Ruby Valley by extracting carbon dioxide from the water column.

Jefferson Valley

HISTORY OF INVESTIGATION

Tertiary sediments in the Jefferson Valley range from late Eocene to late Miocene based on vertebrate fossil data (Kuenzi, 1966). Kuenzi (1966) first described the stratigraphy in the Jefferson Valley recognizing two units: the basal Renova Formation and the overlying Parrot Bench Formation. In 1971, Kuenzi and Fields revised Tertiary nomenclature in the Jefferson Valley to standardize similar stratigraphic units. In doing so they formalized the Renova Formation and designated Kuenzi's (1966) Parrot Bench Formation as a member of the Sixmile Creek Formation. The type section for the Renova Formation (Kuenzi, 1966) is approximately 1.25 miles southeast of Renova, along the east bank of the Jefferson River from the NW$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 33, T.1N., R.4W. to the NW¼, NW¼, sec. 28, T.1N., R.4W. (Figure 3). The top of the Renova Formation is not exposed at the type locality (Jefferson River Section) and all rock types included in the formation are not present. Kuenzi (1966) measured three principal sections to include the Pipestone Springs Member, Easter Lily Member, and top of the Bone Basin Member in the Renova Formation.

The type section for the Bone Basin Member is the same as the type Renova section. The Lower Parrot Bench Section (secs. 23, 26, 27, T.1N., R.4W.) is a principal section of the Renova Formation which includes the upper contact between the Bone Basin Member and overlying Sixmile Creek Formation (Fig. 3). The Bone Basin Member is the only member of the Renova Formation in the Jefferson Valley that contains significant limestone. Kuenzi (1966) interpreted the Bone Basin carbonates as chemical precipitates deposited in shallow lakes and ponds on a low lying flood plain.

The Jefferson River and Lower Parrot Bench Sections were not remeasured for this study. Stratigraphic data was obtained from Kuenzi (1966) and field checked. All of the carbonate samples from the Jefferson Valley used in this study were obtained from the Bone Basin Member in Bone Basin at the north east corner of the Tobacco Root Mountains (Fig. 3).

DESCRIPTIONS

Sedimentary Features

Kuenzi (1966) suggested a probable thickness for the Bone Basin Member of greater than 296 meters based on the cumulative thickness of the Jefferson River and Lower Parrot Bench sections. The composite sections consist of 31% limestone and marl, 25% mudstone, 19% sandstone, and 17% siltstone. Limestone beds occur throughout the member. Some of the limestone units contain an abundant invertebrate fauna and are very calcareous (>60% CaO), whereas other carbonate units are strongly silicified (>30% SiO_2) and contain a sparse ostracod fauna and abundant root casts.

Most of the silicified limestone units show transitional lower boundaries with underlying tuffaceous silts and sands, and display sharp upper bounding surfaces. Silicified and calcified root casts (Plate 10) commonly occur near the tops of these units. The ashy-sand to silicified limestone units range from 0.5-5.0 meters thick. The original micrite in these units has been replaced by chalcedony, chert, and opal giving the "limestones" a porcelain-like quality. They are aphanitic, hard, break with a conchoidal fracture, and display a dull luster. Petrographic analysis of one of the limestones (PBJV-7) reveals interlocking irregularly shaped "ooids" of micrite

Plate 10.

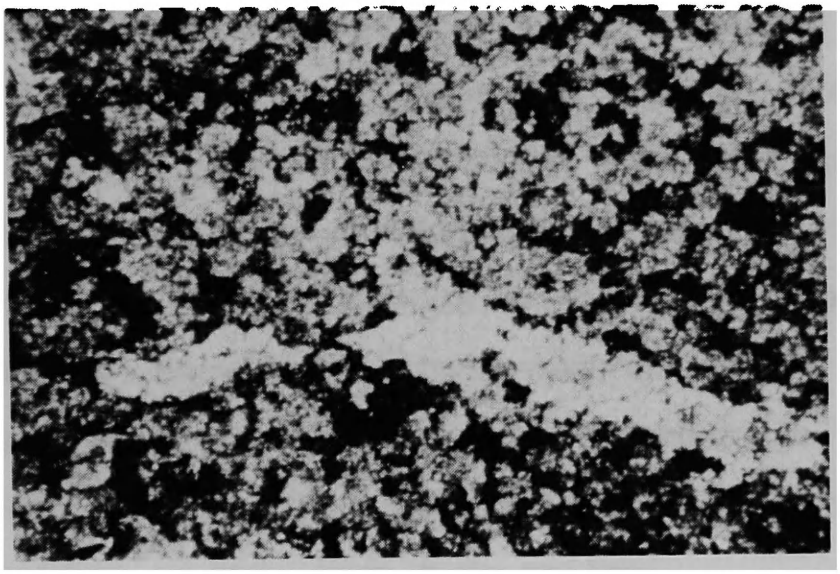


Figure 1. Photomicrograph of silicified root cast (PBJV-7) x10, crossed nicols.

Figure 2. Photomicrograph of "ooids" (PBJV-7) x10, plane light.

cemented with chalcedony (Plate 10). The term "ooid" is used to describe these grains primarily because of their shape and size; it is not meant to imply a genetic origin.

Clastic sediments in the Bone Basin Member are predominantly fine grained, tuffaceous sands and silts. Most of the clastic units are massive, however Kuenzi (1966) notes trough cross stratification in some sandstone units. The sands exhibit poor to moderate textural and compositional maturity. The Bone Basin Member in the Jefferson Valley is slightly more tuffaceous than the Passamari Member in the upper Ruby Valley.

Mineral Content

The most common mineral assemblage in Bone Basin consists of smectite, calcite, glass, quartz, chalcedony, opal, and feldspar. Evaporite minerals, illite, and dolomite are completely lacking. Glass shards, quartz, and feldspar occur as allogenic grains; calcite occurs as an endogenic precipitate; and chalcedony and opal occur as authigenic cements.

Chemical Content

Four samples from the Jefferson Valley were analyzed to determine their chemical content (Table 3). The samples chosen for analysis include one micrite (DGJV-7) and three silicified micrites (PBJV-5, PBJV-7, and PBJV-12). Variation diagrams for the Avon Valley analyses are illustrated in Appendix C.

Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
DGJV-7	21.14	1.42	.132	0.58	.164	75.28	0.99	0.20	0.00	.096
PBJV-5	32.44	4.45	.218	1.23	.186	58.97	1.06	1.09	0.29	.053
PBJV-7	40.45	1.37	.110	1.00	1.30	54.36	1.00	0.23	0.00	.182
PBJV-12	55.50	1.39	.116	0.38	.298	41.20	0.80	0.18	0.00	.100

Table 3. Chemical data for the Jefferson Valley listed in weight percent. See text for information of sample rock type.

Silicon and calcium oxide values content are inversely related in the Jefferson Valley carbonates (see variation diagrams). Aluminum, titanium, magnesium, manganese and potassium oxide weight percentages are fairly constant in these samples indicating the clay content is fairly uniform. The decrease in silica relative to calcium is probably the result of secondary silica replacing calcite.

Dolomite and halite minerals were not detected in any of the x-ray diffraction patterns or thin sections of the Jefferson Valley samples and were not included in the norm calculations. Norm calculations were overestimated by nearly 20 percent for the Jefferson Valley samples (Table 4). Calcite content ranges from 63 (PBJV-12) to 100 (DGJV-7) percent, clay content ranges from 5 (DGJV-7) to 17 (PBJV-5) percent, and free silica content ranges from 19

(DGJV-7) to 45 (PBJV-12) percent. High aluminum, iron, titanium, and magnesium values for PBJV-5 correlate with its higher clay content. Abnormally high iron and manganese oxide percentages in PBJV-7 are probably a result of stronger oxide staining in this sample. PBJV-7 is the only sample from the Jefferson Valley with a brown coloration, everything else is a creamy tan color.

Sample	Calcite	Clay	Free Silica
DGJV-7	100.0	5.0	19.0
PBJV-5	85.0	17.0	19.5
PBJV-7	79.0	5.2	31.7
PBJV-12	63.0	5.7	45.0

Table 4. Results of norm calculations listed in percent.

Fossil Content

Kuenzi (1966) first collected and described the invertebrate and vertebrate fossil content of the Bone Basin Member. Invertebrate fossils occur in a few of the limestone and marl units and include ostracods, gastropods and pelecypods. Pelecypods occur only in one limestone unit which also contains an abundant gastropod fauna (Kuenzi, 1966). Ostracod shells are present in most of the calcareous limestone units, but are sparse in the silicified limestones.

Vertebrate fossils are not numerous in the Bone Basin Member. The assemblage collected by Kuenzi (1966) includes ancestral rabbits (Palaeolagus), camels (?Poebrotherium), horses (Mesohippus), rhinoceros (?Caenopus or Trigonias), tragulids (Leptomeryx), mustelids (cf. Daphoencyon), oreodonts (Merycoidon), titantotheres (? Brontothere), and anthracotheres (? Anthracothere). The vertebrate assemblage implies an early Oligocene (Chadronian) age for the Bone Basin Member which is older than the Passamari Member in the upper Ruby Valley.

INTERPRETATION

Kuenzi (1966) and Axelrod (1984) interpreted the Bone Basin Member carbonates as representing deposition in shallow lakes and ponds on a low lying floodplain. This interpretation is adequate for the carbonate units that contain an abundant invertebrate fossil assemblage and high calcite content, but it fails to account for the irregularly shaped "ooids" and massive clastic units (0.7-12.0 m thick) which become increasingly more lithified toward their tops and are capped by silicified, rhizolithic carbonates.

Axelrod (1984, p. 39) interpreted the "ooids" in the Parrot Bench Section as ooliths which formed by "agitation in extensive lake margin flats". The nature of the "ooids":

their irregular sizes and shapes; their lack of radial fibrous textures; and the lack of associated sedimentary structures indicative of wave action, excludes such an interpretation.

The textures present in the Bone Basin Member's silicified carbonates are indicative of caliche. Most of the world's massive caliche deposits occur in Tertiary, fluvial sands and gravels (Reeves, 1976) and typically are silica cemented and display increasing lithification toward the tops of units, concretionary glaebules, massive bedding, and rhizolithic mats (Reeves, 1976). Esteban and Klappa (1983) believe rhizoliths (root casts) are reliable indicators of subaerial exposure.

A few of the limestones in Bone Basin, Jefferson Valley are interpreted to have precipitated in shallow ponds. The occurrence of trough cross stratified sands lower in the Jefferson River Section suggests that the ponds formed on or adjacent to a fluvial flood plain. The shallow ponds supported a limited invertebrate fauna and never became saline enough to precipitate evaporite minerals. Caliche development on fluvial flood plains in arid environments is common (Reeves, 1976).

The Bone Basin Member of the Renova Formation is exposed only in Bone Basin in the Jefferson Valley. Whether these deposits were associated with a much larger lacustrine system can not be determined from the section.

Avon Valley

HISTORY OF INVESTIGATION

Tertiary sedimentary deposits in the Avon Valley (Fig. 1) have not been studied extensively. Fields (1983) first described silicified carbonates in the Avon Valley in a geologic reconnaissance report to the Montana Historical Society. The purpose of that study was to determine source areas of usable material for making stone tools and weapons to obtain information about ancient native American Indians.

Poor exposure of the Tertiary carbonates in the Avon Valley makes them difficult to study. The best exposures occur on Antelope Hill and Rhine Point in secs. 11, 12, 13, 14, 24 and 25, T.11N., R.9W. (Fig. 4). Samples for this study were collected from the Antelope Hill locality in badger hole tailings, ancient indian excavating quarries, and occasional outcrop exposures.

The Antelope Hill carbonates are actually silicified marls. The age of these deposits has not been determined but is presumed to be Tertiary (Fields, 1983).

The environmental processes resulting in deposition of the Avon Valley carbonates is not well understood, because stratigraphic relationships are difficult to determine, and less field time was spent in this area than in the upper Ruby or Jefferson Valleys.

DESCRIPTIONS

Sedimentary Features

Tertiary deposits in the Avon Valley are poorly exposed. Where outcrop exposures do exist sedimentary structures are lacking. Fields (1983) suggested a possible thickness of ± 130 meters for the Tertiary silicified marls in the Avon Valley. Silica replacement of the marl deposits is irregular and varies in degree vertically and laterally.

Silicified carbonate (porcellanite) is the dominant rock type found on Antelope Hill. These rocks are hard, aphanitic, break with a conchoidal fracture, contain abundant plant, gastropod and ostracod fossils, and appear mottled from silica replacement. Color of the porcellanites ranges from black to brown to red to tan. Weathered surfaces display a white chalky rind.

The Antelope Hill marls are fine grained muddy micrites that, when struck, emit a petroliferous odor and contain occasional cherty nodules. Visible sedimentary structures are lacking, but some samples break along preferred parting surfaces. Plant impressions occur on these surfaces.

Occasional exposures of medium grained, clastic sands occur on the eastern slope of Antelope Hill. The sand units are poorly exposed and their relationship with the marls and porcellanites remains undetermined. Hand samples show faint evidence of stratification. The sands units are calcite cemented and composed predominantly of poorly sorted, angular clasts of Precambrian Belt quartzite.

Paper shales are exposed in a road cut approximately 5 miles north east of Antelope Hill in the NE$\frac{1}{4}$, NE$\frac{1}{4}$ sec. 28, T.12N., R.9W. (0.5 miles east of Dalton Pass Road and Jefferson Creek). The stratigraphic relationship of these shales to the Antelope Hill marls and porcellanites is unknown, but their similarity to the Ruby Valley paper shales suggests a lacustrine origin.

Mineral Content

The mineral content of carbonate deposits in the Avon Valley was primarily determined by petrographic analysis. X-ray analysis was conducted on one of the samples (Appendix B).

The most common mineral assemblage in the Avon Valley Tertiary marls consists of smectite, calcite, chalcedony, and amorphous silica. Allochthonous quartz, feldspar, and reworked Precambrian Belt grains are additionally present in the sand facies. Most of the original endogenic and biogenic carbonate has been replaced by silica. Silica replacement is irregular, and commonly patchy. Detailed preservation of cellular plant structures indicates silicification occurred soon after deposition (Plate 11).

Chemical Content

Four samples were analyzed from the Avon Valley (Table 5). These samples include micrite (AHAV-2), "porcellanite" (AHAV-10), and sparite (AHAV-5 and AHAV-6). Variation diagrams of oxide values from the Avon Valley samples are illustrated in Appendix C.

The Avon Valley marls and porcellanites contain much higher silicon values and much lower aluminum, magnesium, potassium, and manganese values than either the upper Ruby or Jefferson Valley carbonates. The high silicon values are interpreted to reflect secondary silica replacement of primary carbonate minerals. Low values for the other oxides indicate that clay mineral contributions are minor in these rocks.

Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
AHAV-2	71.42	1.00	.065	0.27	.075	26.68	0.29	0.12	0.00	.068
AHAV-10	80.01	0.42	.039	0.23	.022	18.83	0.37	0.50	0.00	.028
AHAV-5	1.69	0.27	.069	0.00	.007	97.59	0.36	0.00	0.00	.019
AHAV-6	1.77	0.22	.048	0.42	.025	97.23	0.25	0.00	0.00	.037

Table 5. Chemical data from the Avon Valley listed in weight percent. See text for sample information.

Plate 11.

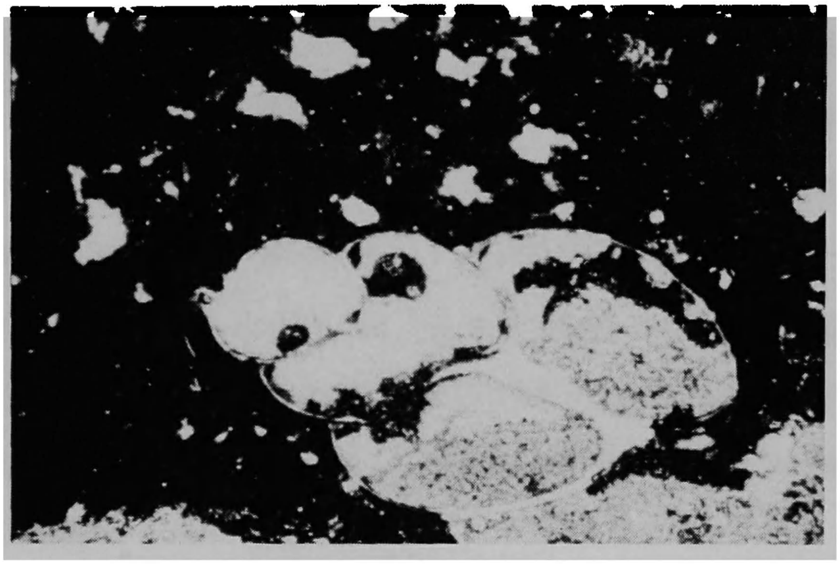


Figure 1. Photomicrograph of silicified gastropod in porcellanite (AHAV-10) x10, plane light. Note relict calcite in lower right corner of the photograph.

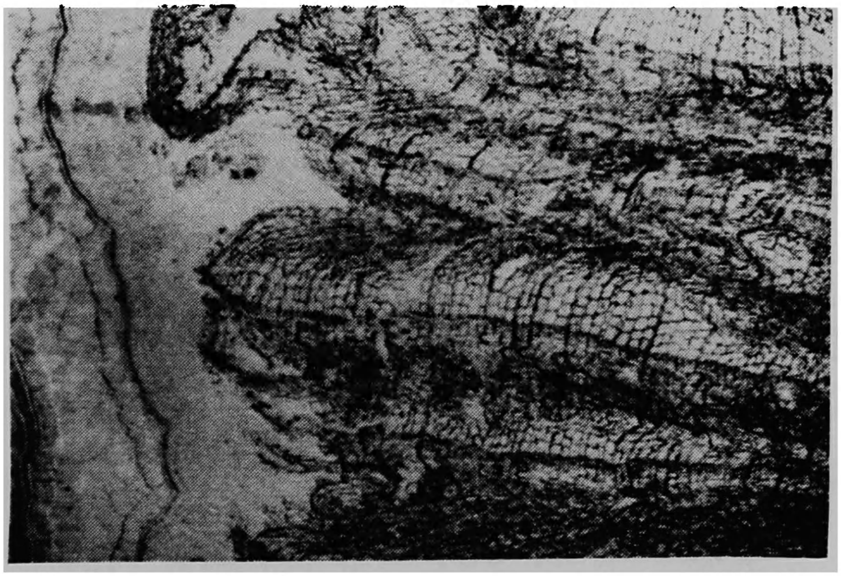


Figure 2. Photomicrograph of silicified wood (AHAV-10), x10 plane light.

Norm calculations indicate that clay contributes from less than 1 percent (AHAV-5) up to 4 percent (AHAV-2) to the Avon Valley carbonates (Table 6). Secondary silica has replaced up to 72 percent of some of the carbonates (AHAV-10). Carbonate content ranges from 31 percent (AHAV-10) to 132 percent (AHAV-5, AHAV-6). Norm calculations are overestimated by as much as 32 percent for some of the Avon Valley samples. Those samples with high calcium oxide values show the most error, probably due to inadequate characterization of calcium.

Sample	Calcite	Clay	Free Silica
AHAV-2	43.00	4.30	62.50
AHAV-10	31.00	1.88	72.62
AHAV-5	132.00	0.94	0.87
AHAV-6	125.00	0.47	1.07

Table 6. Results of norm calculations listed in percent.

Fossil Content

The Avon Valley marls and porcellanites are extremely fossiliferous, containing a diverse assemblage of pulmonate gastropods, ostracods, and woody plant material (Plate 11). All of the gastropod forms belong to the Order Basommatophora, which includes all fresh water gastropods. Most of the fossils are permineralized, infilled or replaced by silica (chalcedony and chert). Some parent gastropod shell material remains.

Fossilized vascular plant material in the Avon Valley is abundant. Silicified stems display detailed preservation of cellular structures (Plate 11). Impressions of stems are also present in some of the marls. No fossil leaves were found.

Ostracod, gastropod, and plant taxa preserved in the Avon marls and porcellanites have never been fully described. Identification of the flora and fauna could indicate a more exact age for these deposits.

INTERPRETATION

Fields (1983) interpreted the Avon marls and porcellanites as representing deposition is shallow lakes or ponds. Limited stratigraphic information available in the Avon Valley makes a paleoenvironmental interpretation difficult. The presence of paper shales several miles to the north east of Antelope Hill indicates the marls and porcellanites could have been deposited near the margins of a lake.

The abundance of gastropods and lack of evaporite minerals in the Antelope Hill marls and porcellanites suggests the water never reached extreme salinities (Raup and Stanley, 1971, p. 265). Early silica permineralization of woody cell structures indicates the environment was alkaline and saturated with respect to silica. Silica is soluable at a pH greater than 8 (Krauskopf, 1979, p. 133). Carbonate was probably produced either by evaporation or biological activity in standing water with a pH slightly below 9. If silica saturated, alkaline waters encroached on fresher water silica would precipitate out of solution and carbonate would become soluable. The Avon marls are interpreted to have been replaced by silica near a hydrologic front between fresh and alkaline water. The fresh water supported a diverse invertebrate fauna and was probably supplied by a small stream located near the margins of an alkaline lake. This interpretation accounts for the patchy replacement of silica for carbonate, the associated paper shales, and the abundant gastropod fauna.

DISCUSSION

Depositional Processes and Environments

Tertiary carbonates in western Montana display a variety of textural and compositional features indicating deposition in diverse environments. Textural features include algal laminations, evaporite mineral molds, collapse breccias, neomorphic spar, root casts, glaebules, and patchy silica replacement. Compositional variation includes the presence or absence of evaporite minerals, fossils, silica cements, and magnesium and potassium clay minerals. The interpreted Tertiary environments resulting in carbonate deposition include: ephemeral alkaline lakes and ponds, alkaline or hydrothermal springs, and caliche soils. Evidence of similar Tertiary environments is not restricted to western Montana. Lacustrine, and hydrothermal carbonates occur in the Eocene Green River Formation in Utah and Wyoming (Bradley, 1929; Eugster and Hardie, 1975; Surdam and Wolfbauer, 1975; Smoot, 1978, 1983); and lacustrine and pedogenic carbonates occur in the Late Arikareen Harrison Formation in Nebraska and Wyoming (Hunt, 1985).

The bulk of Tertiary carbonate deposits in western Montana are primary precipitates. No allogenic Paleozoic or Mesozoic carbonate clasts were found in any of the basins. The carbonates are interpreted to have precipitated from organic and inorganic processes. Organically produced carbonate tests make up only a fraction of Tertiary carbonate deposits. The interpreted processes resulting in inorganic precipitation of carbonate minerals include evaporative concentration of solutes, biological extraction of carbon dioxide from the water column, and a physical release of carbon dioxide from the water column.

Paleoclimate

The Green River and Harrison Formations represent deposition influenced by arid (Smoot, 1978) to semi-arid (Hunt, 1985) climatic conditions. Thompson et al. (1982) suggested the climate in western Montana during deposition of the Renova Formation was also arid to semi-arid. Vertebrate fossil data, sedimentary data, and mineral data in Tertiary deposits in the upper Ruby, Jefferson, and Avon Valleys support an arid to semi-arid climatic interpretation.

Cursorial, grazing animals dominate Tertiary vertebrate fossil assemblages in the upper Ruby and Jefferson Valleys. To date no fossil study has been conducted in the Avon Valley, but the vertebrate fossil assemblage would probably be similar to other faunas found in the Renova Formation. Related modern forms of horses, camels, deer, and tragulids generally live on grassy steppes and plains characterized by arid to semi-arid climates. Fields et al. (1985) stated the trend in mammalian faunas through Renova time was toward adaptations suited for aridity.

Sedimentary structures present in the Renova Formation support an arid to semi-arid climatic interpretation. Trough cross stratified beds are the most common sedimentary feature and are interpreted to represent braided stream channels. Braided stream channels form when sediment load is high and bank resistance is low (Reineck and Singh, 1980, p. 260). Braided streams are common in arid climates because vegetation is sparse and not capable of stablizing stream banks and soil horizons.

Inorganic calcite contributes to the bulk of Tertiary carbonate deposits in western Montana. Kelts and Hsü (1978) state inorganic carbonate may precipitate in alkaline and saline lakes in arid regions or in fresh to brackish water lakes in humid regions. The alkaline nature of Tertiary carbonate environments in western Montana is reflected by their mineral content and implies that the climate was influenced by arid to semi-arid conditions. Caliche soil development also implies arid to semi-arid climatic conditions.

CONCLUSIONS

Tertiary carbonate deposits in western Montana have long been interpreted as lacustrine limestones (Kuenzi, 1966; Monroe, 1976, 1981; Axelrod, 1984). Reexamination of the textural, mineral, floral, faunal, and chemical aspects of Tertiary carbonates in the upper Ruby, Jefferson, and Avon Valleys suggests their depositional processes and environments were quite diverse. Three carbonate depositional processes are interpreted to have operated in these basins. The first process operative in the upper Ruby, Jefferson, and Avon Valleys involved deposition due to evaporative concentration of solutes in shallow ephemeral saline lakes, ponds, marshes and caliche soils which lead to supersaturation and precipitation of carbonate minerals. The second process occuring in all of the valleys involved biological extraction of carbon dioxide from the water column leading to precipitation of carbonate minerals. The last process occured in the upper Ruby Valley alkaline or hydrothermal spring environments from the physical release of carbon dioxide.

Timing of deposition in each of these basins varies, but the carbonates all developed sometime during deposition of the Renova Formation (20 to 42 mya). Sedimentary data, vertebrate fossil data, and mineral data indicate the prevailing Renova climate was arid to semi-arid.

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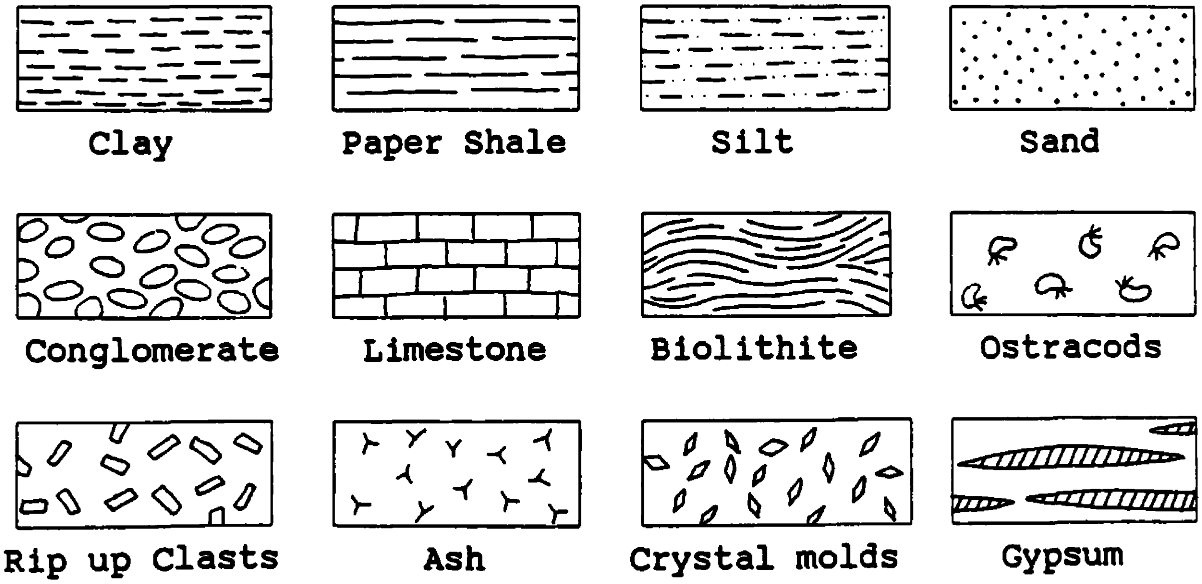
APPENDIX A

Measured Sections

Three stratigraphic sections were measured and described in the upper Ruby Basin; these include the Sweetwater Creek (SCRV), Caldwell Springs (CSRV), and Campbell Place Sections (CPRV). The following descriptions were compiled from field observations, thin section descriptions, and x-ray diffraction patterns. Sample designations are highlighted in the text and listed in the form locality abbreviation-sample number. Small case t's follow sample designations if a thin section was cut and described. Illustrated stratigraphic columns follow each section's description depicting unit numbers, thicknesses, and sampled horizons. All stratigraphic sections were measured in meters.

Legend for Stratigraphic Columns



Section 1 - Sweetwater Creek

SCRV

The Sweetwater Creek Section, originally measured by J.S. Monroe, 1976, is the type section of the Passamari Member of the Renova Formation. The section was measured one mile west of the Conley Ranch (formerly the Belmont Park Ranch) from the center of the SE¼ sec. 22 to the NW¼, SE¼ sec. 21., T.8S., R.5W. (Fig. 2). The Passamari Member totals 117.7 meters in this section.

Unit	Unit Thickness (meters)	Total Thickness (meters)

SIXMILE CREEK FORMATION

43	20.0+	137.7

Well indurated, poorly sorted, massive, pebble conglomerate. Individual clasts <3.0 cm diameter. Matrix supported. Calcareous siltstone matrix. Black oxide stained conglomeratic lenses throughout the unit. SCRV-38.

PASSAMARI MEMBER, RENOVA FORMATION

42	5.0	117.7

Sandy siltstones interbedded with shales. Individual beds 1.0-10.0 cm thick. Shales contain ostracods.

41	1.0	112.7

Similar to Unit 37. Poorly sorted sandstone. Grains 1.0-3.0ϕ, angular to rounded. Calcareous cement. Comp.: VRF's 55-60%, spar 20%, MRF's 5-10%, quartz and feldspar 5-10%, micrite clasts 1-5%, ash 0-40% in some horizons. N55W6SW. SCRV-37 t.

40	30.0	111.7

Unconsolidated silts and paper shales. Some medium-coarse grained, lithified sandstone lenses occur within Unit 40 and display planed oscillation ripples.

39 3.0 81.7

Unconsolidated, red-brown, silty clay. Unit is not resistant. SCRV-36.

38 3.0 78.7

Similar to Unit 14. Poorly exposed buff tan silts and paper shales. Ostracods occur in paper shales. 1.0-4.0 cm thick gypsum beds occur throughout the unit and occasionally cut across bedding. SCRV-35. X-ray: smectite, illite.

37 1-2 72.7

Poorly sorted sandstone. Dark grey to reddish tan color. Coarse grains are matrix supported. Trough cross stratification. Grains range from 1.0-4.0ϕ and are angular to subrounded. Slabby weathering. Comp.: MRF's 40%, intraclasts 10-20%, micrite 10-15%, spar 5-10%, glass shards 5-10%, quartz 5%, feldspar 5%, limonite <1%. SCRV-34 t.

36 1.0 70.7

Covered.

35 7.0 69.7

Interbedded calcarous shales and shaley limestones. Abundant ostracods. Shales are crenulated in some areas. Calcarous shale layers are more resistant to weathering. Shales weather into slabs and blocks (1cm^3 to 3x10x20 cm^3). Black lichen prefer shaley limes. E-W5S. SCRV-33. X-ray: smectite, illite.

34 7.5 62.7

Mostly covered by pediment gravels. Occasional exposures consist of ostracod bearing paper shales. SCRV-40.

33 1.0 55.2

Fine-grained micrite. Creamy color. Upper portion contains diamond shaped minerals (gypsum?). Unit fizzes with HCL. Powdery texture. Strongly oxidized zones run through unit generally following bedding. SCRV-32 t. X-ray: smectite, calcite.

32 6.0 54.2

Fissile calcareous paper shale. Similar to Unit 31. Contains ostracods and organic fragments. Not as calcareous as some of the zones in Unit 31. Parting surfaces are flat and even. Comp.: microspar 55%, glass shards 40%, limonite 1-2%, quartz <1%, ostracods <1%. SCRV-31 t. X-ray: smectite, illite, halite.

31 6.5 48.2

Mostly covered, but in places calcareous paper shales are exposed. Carbonate content varies throughout the unit and a well lithified calcareous paper shale caps the unit. Contains ostracods and organic fragments. SCRV-30 t upper calcareous shale. SCRV-29 paper shale. X-ray: smectite, illite, calcite.

30 0.5 41.7

Similar to Unit 29, but shalier. Unit weather into slabbier pieces. Slabs have crenulated texture (laminated). Not quite fissile enough to be a calcareous paper shale. SCRV-28. X-ray: smectite, calcite, gypsum.

29 0.5 41.2

Well lithified silty limestone. Grains well sorted, 3.0-4.0ϕ, angular. Creamy gray color. Black lichen. Unit looks mottled. Thin irregular stringers (<0.5 cm) of sparry calcite throughout unit. Comp.: micrite 40%, intraclasts 40%, ash 5%, microspar 1-5%. SCRV-27 t. X-ray: smectite, calcite.

28 3.0 40.7

Mostly covered. Primarily composed of interbedded, unconsolidated silts and shales. Similar to Units 23 and 26, but doesn't contain bedded gypsum or paper shales. SCRV-39.

27 0.8 37.7

Cream colored intramicrite. Abundant MnO_2 and Fe_2O_3 staining the unit black and red. Vugs filled with calcite. Intraclasts range from <0.5-3.0 cm. Angular intraclasts. Some areas of unit appear laminated. Blocky to slabby weathering. Comp.: micrite 70-80%, intraclasts 5-20%, spar 5-10%, quartz and feldspar (3.0-4.0ϕ) 1-3%, algae 1%. SCRV-26 t. X-ray: smectite, calcite.

26 4.0 36.9

Clayey siltstones grade up and interbed with organic paper shales. Both lithologies are a buff tan color with abundant oxide stains. Unit is similar to Unit 23, but it's not as tuffaceous and doesn't contain gypsum beds. The paper shales are slightly crenulated . Calcareous cement. SCRV-25. X-ray: smectite, calcite, gypsum.

25 3.0 32.9

Covered. Float material indicates interbedded silts and paper shales. Abundant organic fragments.

24 1.5 29.9

Similar to Unit 23 except that 0.5-4.0 cm thick gypsum beds occur throughout. Gypsum beds are associated with red oxidation zones. SCRV-24. X-ray: smectite, dolomite, gypsum, halite. Dolomite and halite lacking in lower portion of unit.

0.03 28.4

Brown, tabular tuffaceous sandstone bed separates tuffaceous siltstones from overlying paper shales. Calcite cemented. SCRV-23 t.

23 3.0 28.4

Interbedded tuffaceous silts, shales, and sands. Ash and silts make up major component of the unit with minor paper shales and sands. Unit forms cream colored bluff. Individual bed thicknesses range from 1.0-15.0 cm. Channel cross bedding is very shallow. Bed thickness undulates and internal bedding is planar. Basal scouring is evident. Thin gypsum beds (0.5-2.0 cm) occur near top of the unit. The gypsum beds occur with red silty layers (hardpans?). SCRV-22. X-ray: smectite, glass, dolomite, gypsum.

22 3.0 25.4

Covered. Float material indicates interbedded silts and paper shales.

21 0.3 22.4

Repeat of Unit 19. Unit is strongly disrupted by secondary mineral growth. Vugs filled with calcite. Color varies from buff tan to light grey. No oxide stains on upper grey portion. Comp.: micrite 95%, spar 3-5 %, algae 1%, ash <1%, quartz and feldspar <<1% (<4.0ϕ). SCRV-21 t. X-ray: smectite, calcite, dolomite.

20 1.0 22.1

Repeat of Unit 18.

19 0.3 21.1

Calcareous siltstone. Similar to Units 5, 8, and 11. Grains <4.0ϕ, angular to subrounded. Diamond shaped voids (0.5-2.0 mm length). Fe_2O_3 stains give unit mottled appearance. Weathers a buff tan color. Blocky weathering. No internal structure. Comp.: micrite 95%, voids 5%, quartz and feldspar <1%, limonite <1%, algae 1%. N75W8SW. SCRV-20 t.

18 1.0 20.8

Fissile organic rich paper shale. Cream colored with iron oxide staining. Some areas appear crenulated (thin sections reveal algal laminations). Calcite fills cracks and voids. Comp.: micrite 98%, sparite 1-2%, limonite <1%. SCRV-19 t. X-ray: smectite, illite, calcite, dolomite.

17 1.5 19.8

Interbedded silts, clay, and ash. Similar to Unit 14. Unit 17 contains a paleosol: ~4.0 cm of oxidized silty clay. Red soil underlain by brown silty clay.

16 0.2 18.3

Medium grey siltstone. Platy weathering. No apparent cross bedding. Unit is not calcareous. Some holes exist which may be weathered out gypsum crystals.

15 0.2 18.1

Unconsolidated grey ash. Forms slightly resistant unit. SCRV-18. X-ray: smectite, glass.

14 1.0 17.9

Interbedded silts and clays. Beds range from 1.0-4.0 cm. Clay layers are grey and silty layers are red. The unit is not well lithified. Blocky weathering.

13 0.5 16.9

Calcareous tuff. Grains 1.0-4.0ϕ (mostly 3.0-3.5ϕ), angular to subrounded. Thin layers of calcite (<0.5 cm) run throughout. In some places voids are filled with calcite. Slabby weathering (1.0-4.0 cm thick). Weathers buff brown-tan. Black and orange lichen. Comp.: micrite 75%, glass 10%, MRF's 5%, quartz 1-5%, spar 2%, limonite 1-2 %, biotite 1%. SCRV-17 t. X-ray: smectite, calcite, dolomite, gypsum, halite.

12 2.5 16.4

Calcareous ashy mudstone. Similar to Unit 9. Light tan color on dry weathered surface. Poorly exposed. N64W5SW.

11 0.5 13.9

Pale cream colored, silty micrite. Glass shards. Diamond shaped vugs 0.5-1.0 mm (gypsum?). Blocky weathering. Vugs filled with calcite. Comp.: micrite 55-60%, spar 40-45%, glass and quartz <1%. SCRV-16 t. X-ray: smectite, calcite, halite, glass.

10 2.0 13.4

Blocky calcareous silty mudstone. Tan color (bleached appearance). Weathers into small blocks (1.0x2.0x3.0 cm^3). Bedding isn't apparent. MnO_2 and Fe_2O_3 stains occur on weathered surfaces. Calcite cement. SCRV-15. X-ray: smectite, palygorskite, dolomite.

9 2.0 11.4

Unconsolidated ashy sands, silts, and clays. Thin layer of ash (5.0-10.0 cm thick) found in unit which contains euhedral biotite crystals. Clay content increases toward the top of the unit. Ash layer is light grey to white, silty sands are reddish brown, and clayey silt is olive green. All the lithologies grade into one another with no distinct boundaries. SCRV-12 t ash, SCRV-13 sandy siltstone (bottom), SCRV-14 clayey siltstone (top). X-ray: smectite.

8 0.5 9.4

Similar to Unit 5. Blocky calcareous mudstone. Buff tan color. Numerous platy and diamond shaped holes indicate weathered out crystal. Comp.: micrite 40%, voids 30%, limonite 1-2%, quartz and feldspar <1%, spar <1%. SCRV-11 t. X-ray: smectite, illite, dolomite.

7 2.5 8.9

Light buff tan paper shale. Very fissile. Unlike Unit 4, the parting planes are even. Unit breaks into small plates (2.0x2.0x0.05cm^3). Clay rich. SCRV-10.

6 0.5 6.4

Light grey tuffaceous sand. Fresh surfaces sparkle (glass shards). Occasional sand grains, matrix is very fine ashy. Doesn't fizz with HCL. Blocky weathering. SCRV-9. X-ray: smectite, illite.

5 0.5 5.9

Blocky calcareous mudstone/shale. Unit grades up from paper shale to calcareous mudstone. It weathers to a buff tan and shows no internal structure. Calcite cement. Blocky weathering ~1.0-6.0 cm^3. Platy and diamond shaped holes in mudstone. SCRV-8. X-ray: smectite, palygorskite, dolomite.

4 2.0 5.4

Crenulated buff tan calcareous paper shale. Ostracod bearing. Shaley layers break into <0.5 cm^2 chips. MnO_2 stain occurs along joints perpendicular to bedding, but not along partings. SCRV-6, SCRV-7. X-ray: smectite, illite, calcite.

3 0.4 3.4

Calcareous siltstone. Grains 2.5-4.0ϕ, angular to subrounded. Tan color. Fe_2O_3 and MnO_2 staining. Calcite cement. Blocky weathering. No internal structures. Comp.: micrite 40-50%, MRF's 20%, quartz 10-15%, glass shards 10%, SRF's 5%, feldspar 5%. SCRV-5 t. X-ray: smectite, illite, dolomite.

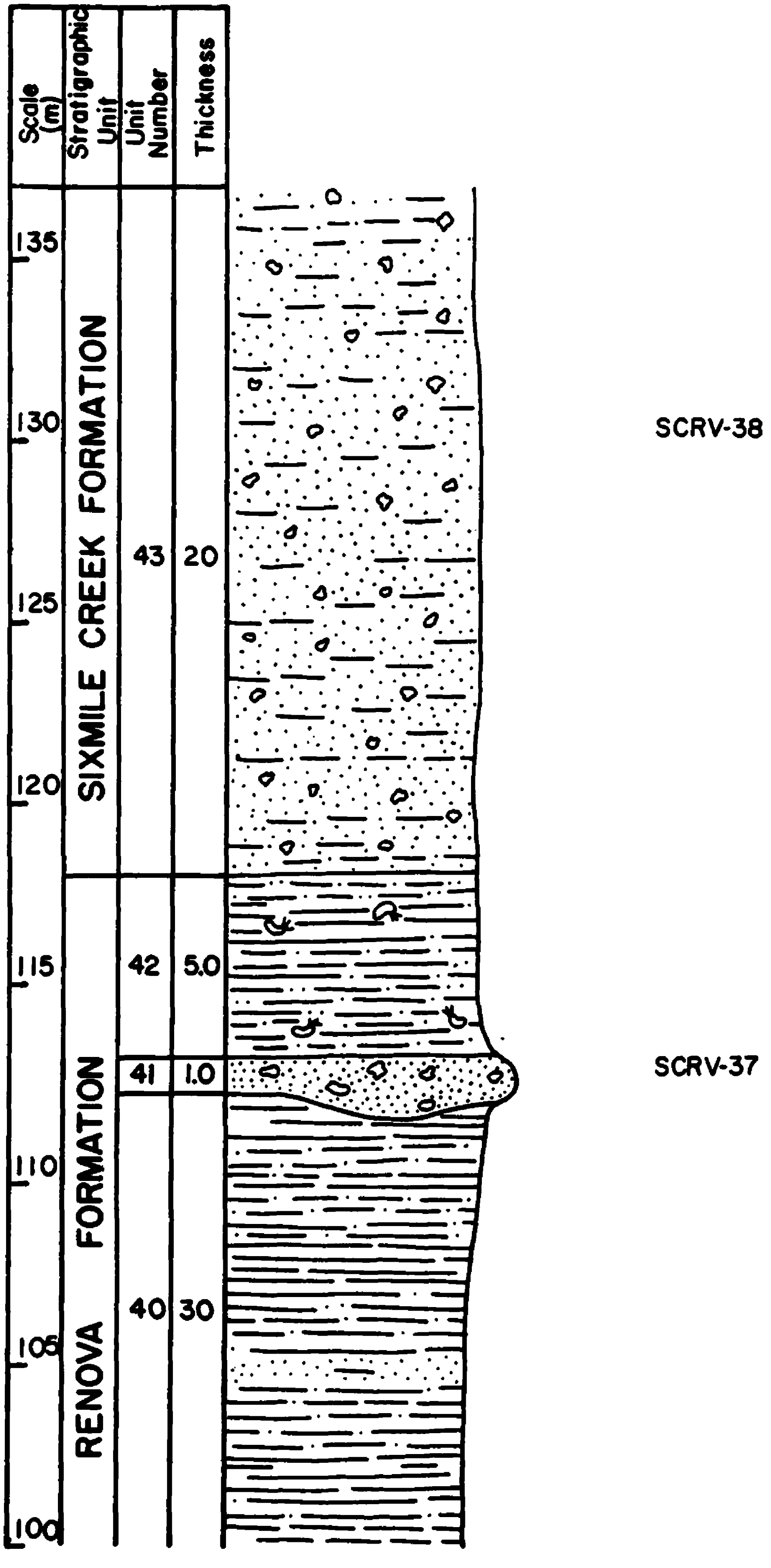
2 1.5 3.0

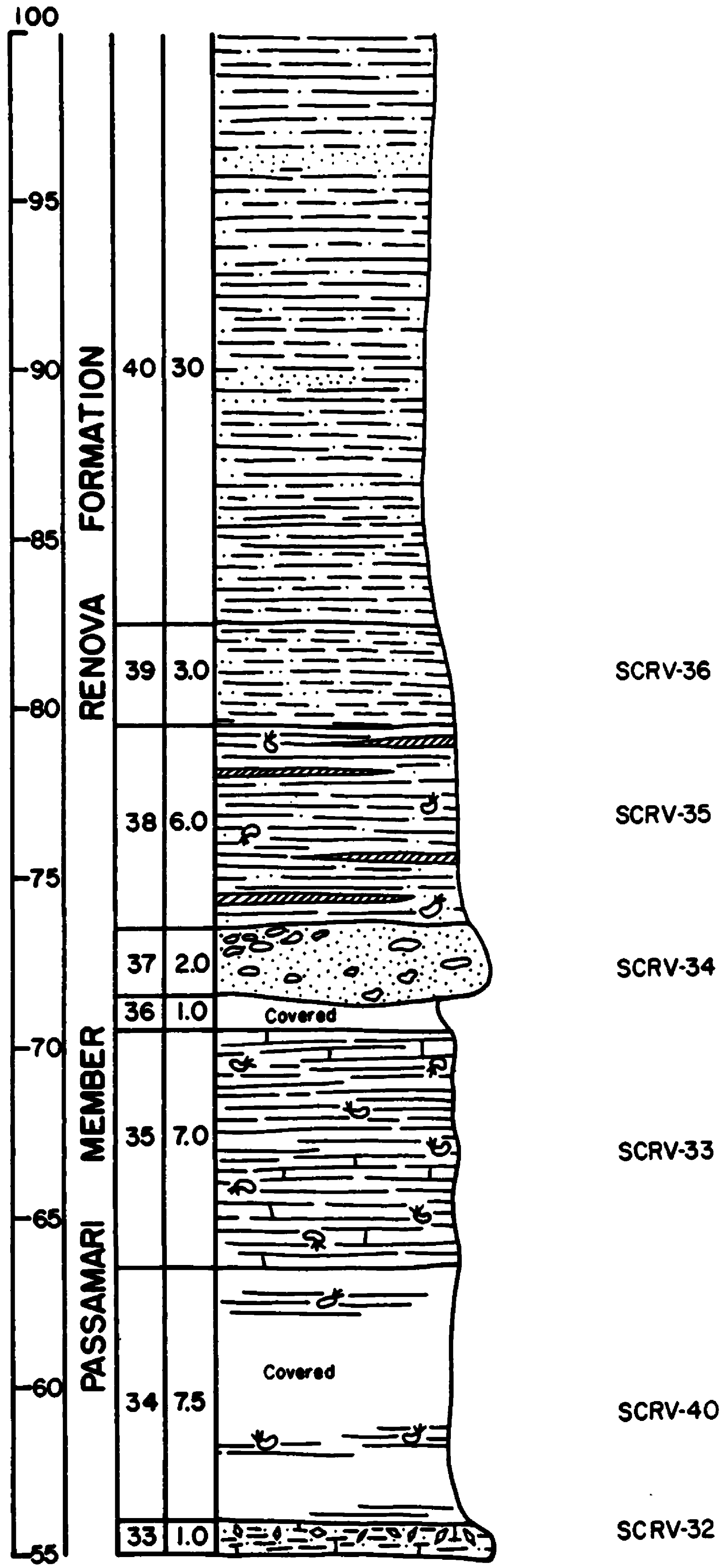
Reddish brown sandstone interbedded with thin (1.0-2.0 cm) siltstone layers. Siltstone is light grey. Fe_2O_3 staining. Shallow channel cross beds. Most cross beds are planar. Beds 1.0-5.0 cm thick.

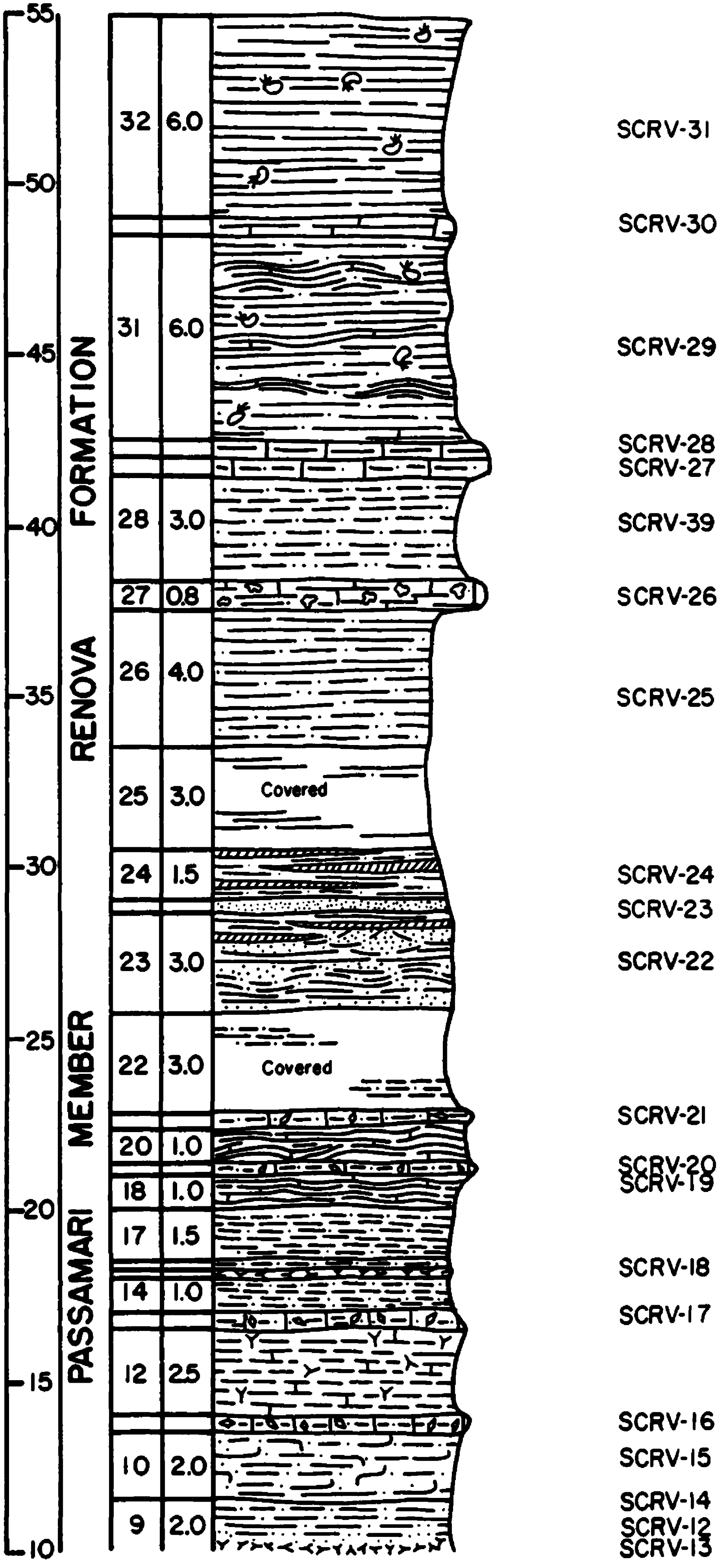
1 1.5 1.5

Light grey siltstone. Platy weathering. Unit is mostly silt but contains some clay. N50W10SW. SCRV-4. X-ray: smectite, illite, dolomite.

SWEETWATER CREEK




100
95
90
85
80
75
70
65
60
55
RENOVA FORMATION
PASSAMARI MEMBER
40 30
39 3.0
38 6.0
37 2.0
36 1.0
35 7.0
34 7.5
33 1.0
Covered
Covered
SCRV-36
SCRV-35
SCRV-34
SCRV-33
SCRV-40
SCRV-32


55
50
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15
10
PASSAMARI MEMBER
RENOVA FORMATION
32 6.0
31 6.0
28 3.0
27 0.8
26 4.0
25 3.0
Covered
24 1.5
23 3.0
22 3.0
Covered
20 1.0
18 1.0
17 1.5
14 1.0
12 2.5
10 2.0
9 2.0
SCRV-31
SCRV-30
SCRV-29
SCRV-28
SCRV-27
SCRV-39
SCRV-26
SCRV-25
SCRV-24
SCRV-23
SCRV-22
SCRV-21
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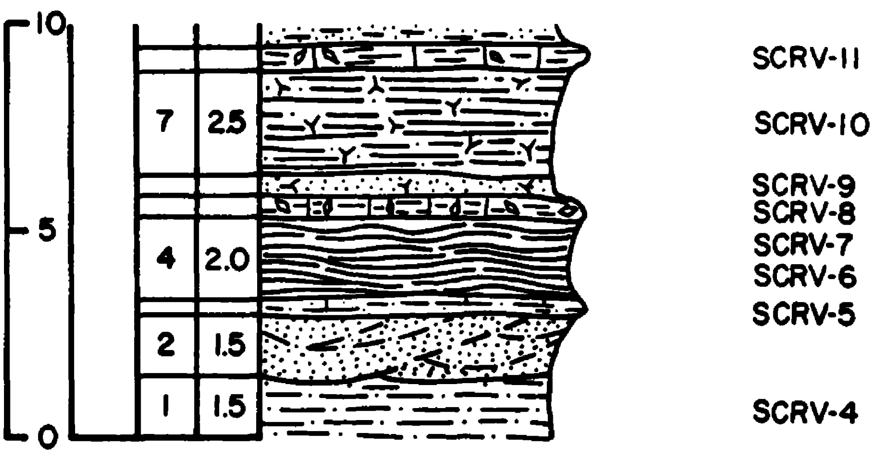
SCRV-12
SCRV-13


10
5
0
7
2.5
4
2.0
2
1.5
1
1.5
SCRV-11
SCRV-10
SCRV-9
SCRV-8
SCRV-7
SCRV-6
SCRV-5
SCRV-4

Section 2 - Caldwell Springs

CSRV

The Caldwell Springs Section, originally measured by J.S. Monroe, 1976, represents a prograding deltaic sequence in the Passamari Member. The section was measured in the west center of sec. 13, T.8S., R.5W. (Fig. 2) and totals 41.0 meters.

Unit		Unit Thickness (meters)	Total Thickness (meters)
PASSAMARI MEMBER, RENOVA FORMATION			
21	Similar to Unit 19. Mostly covered by pediment gravels. CSRV-22.	7.5	41.0
20	Similar to Units 12 and 14. CSRV-21.	0.1	33.5
19	Interbedded silts and sands. Unconsolidated. Contains organic fragments. CSRV-20. X-ray: smectite, illite, halite.	1.1	33.4
18	Similar to Units 12 and 14. CSRV-19.	0.1	32.3
17	Similar to Unit 11. Fissile calcareous paper shale. Some areas are more strongly cemented than other. Unit contains ostracods and organic fragments. CSRV-18.	1.6	32.2
16	Similar to Units 12 and 14. Calcareous cement. Contains rip up clasts of Unit 15. CSRV-17. X-ray: smectite, halite.	0.4	30.6

15 3.2 30.2

Interbedded silts and sands. Planar laminations, ripple cross beds, trough cross beds, and soft sediment deformation. Upper surface cut by channel scours. Iron oxide stains occur throughout unit. Calcareous cement. Interbeds range from 1.0-20.0 cm. and are lenticular. Isolated vesicular basalt cobbles (1.0-3.0 cm diameter) occur floating in matrix. CSRV-16, CSRV-15. X-ray: smectite, halite.

14 0.3 27.0

Channeled coarse-grained sandstone. Unit grades up and contains coarse pebbles and rip up clasts. Cross beds range from 3.0-10.0 cm. Amplitude 10-50 cm. CSRV-23.

13 1.5 26.7

Fine-grained silty sand. Creamy buff color. Scour surfaces evident throughout. Oxidation is stronger in some beds. Rip up clasts occur throughout unit. Bedding features range from 3.0-10.0 cm thick and up to 30.0 cm wide. Foresets alternate between coarse and fine grain layers. CSRV-13.

12 0.3-0.5 25.2

Coarse grained sandstone similar to Unit 10. Rip up clasts in Unit 12 are more angular than those in Unit 10. Clasts are also larger (1.0-3.0 cm). CSRV-12.

11 1.0 24.7

Calcareous paper shale. Similar to Unit 7. Upper portion of unit is fissile; lower portion is slabby. Unit weathers to a creamy white and locally has iron oxide staining. CSRV-11.

10 7.5 23.7

Interbedded sands, silts, and clay clast conglomerates. Most of the unit is composed of sediments similar to Unit 3, however the beds display a higher degree of trough cross stratification. Individual beds are 5.0-20.0 cm thick with foresets ranging from <0.05 cm to 1.0 cm. Coarse conglomerates are resistant to weathering and are composed of lithified sands and pebble sized (rounded) rip up clasts of clay. Scour marks occur at the base of the rip up clast layers. These layers weather to a reddish brown and contrast with the grey rip up clasts. Thickness of rip up clast layers ranges from 10.0-50.0 cm. Calcareous cement. CSRV-9 rip up clast unit, CSRV-10 sandy-silty unit. X-ray: smectite, calcite, halite.

9 0.5 16.2

Sandy lime or limey sand. Well lithified. Coarse-fine sand grains. Mostly quartz grains. Blocky weathering habit. CSRV-8.

8 1.5 15.7

Unconsolidated silts and sands. Similar to Unit 3.

7 6.0 14.2

Interbedded calcareous paper shales and shaley limestones. Ostracods occur in both lithologies. Some silty layers occur throughout unit. Creamy color. MnO_2 stains occur throughout especially on shaley limes. Stains occur on fracture surfaces. Limonite stains prefer the shales. Some of the limes weather slabby and some (the upper limes) weather blocky. Silt content increases up the unit. Mudcracks and 1.0-2.0 cm thick gypsum layers seen. CSRV-6 shale, CSRV-7 limestone.

6 3.5 8.2

Unconsolidated silts, and ashy sands. Low angle trough stratification. Some areas more lithified. Slabby weathering habit when lithified. Calcite cement. Thin (0.5 cm) clay layers occur as stringers throughout unit. Unit weathers to a light reddish tan. N5W10SW. CSRV-5.

5 1.3 4.7

Paper shales interbedded with silts and sands. Paper shales are creamy tan color and contain ostracods. Shales and sands both fizz with HCL. Upper portion of unit is capped by coarser grained sandstone with individual clasts up to 1 cm diameter. Load structures occur at the top of Unit 5. CSRV-4.

4 0.1 3.4

Tuff. Whitish grey color. Contains euhedral biotite flakes. Unit is fine grained. CSRV-3. X-ray: smectite, illite calcite, dolomite.

3 1.5 3.3

Thinly bedded (1.0-3.0 cm) silts and sands. Tan-orange color. Grey ashy layers found throughout. Unit moderately indurated. Bedding is wavy and layers show grading. Mica flakes concentrated in upper portion. Mica concentrations act as parting surfaces. Unit doesn't fizz with HCL. Occasional coarse quartz grains occur in the silty-sandy layers. Sand grains 30% VRF's, 69% MRF's. CSRV-2.

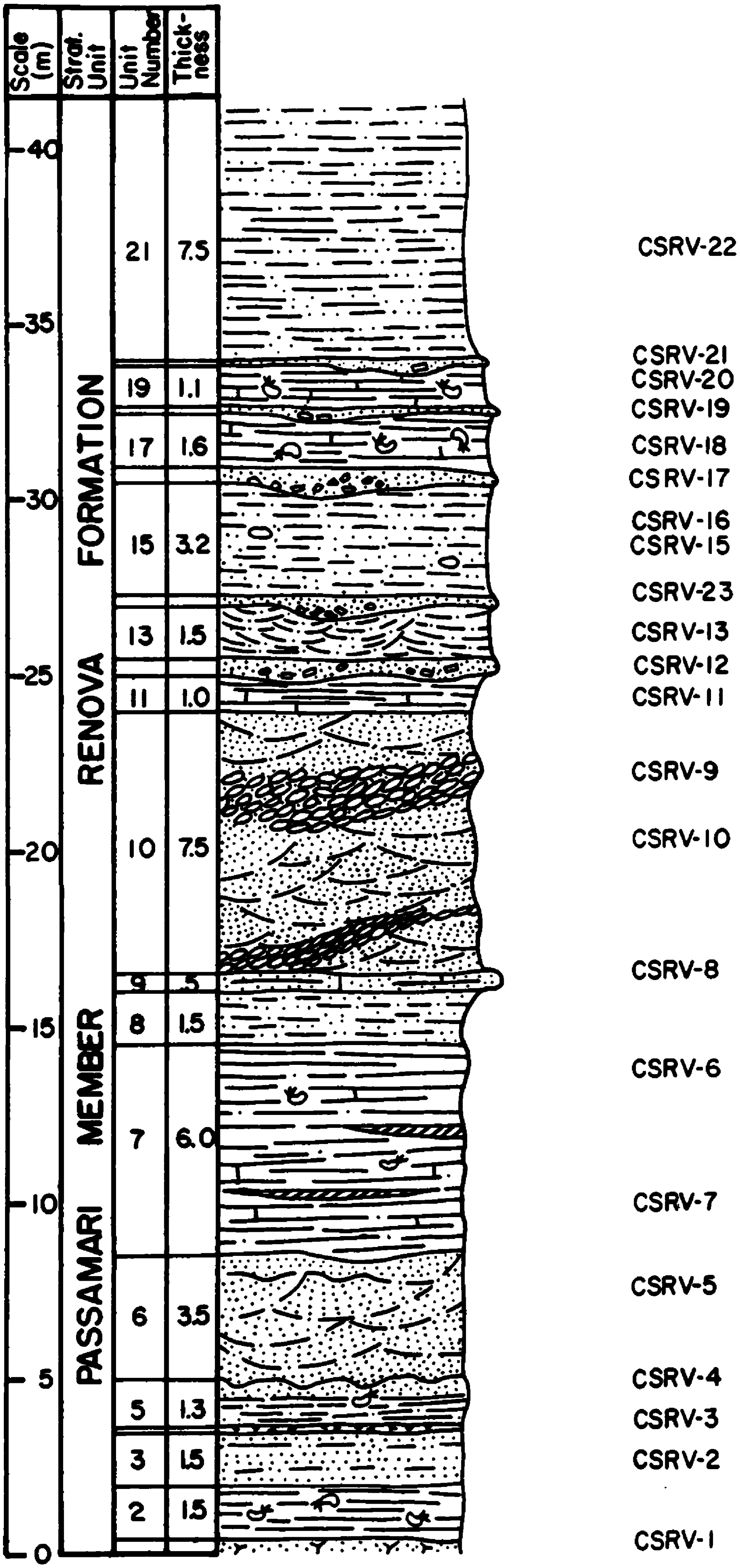
2 1.5 1.8

Mostly covered. Consists of ostracode bearing, creamy white to olive green paper shales.

1 0.3 0.3

Fine-grained tuffaceous sandstone. Contains glass shards. Possibly some fossils? Horizontally stratified. Light grey color. Individual layers <0.5-2.0 cm. N15W6SW. CSRV-1 t. X-ray: smectite, calcite, dolomite, gypsum, halite.

CALDWELL SPRINGS



Section 3 - Campbell Place

CPRV

The Campbell Place Section, originally measured by J.S. Monroe, 1976, was measured in the NW¼, SW¼ sec. 11, T.8S., R.5W. (Fig. 2). The section represents a coarse facies of the Passamari Member and totals 31.9 meters.

Unit	Unit Thickness (meters)	Total Thickness (meters)

PASSAMARI MEMBER, RENOVA FORMATION

8	7.0	31.9

Mostly covered. Exposed sections similar to Units 2, 4, and 6. CPRV-8. X-ray: smectite.

7	0.5	24.9

Clast supported conglomerate similar to Unit 5. CPRV-7.

6	7.0	24.4

Mostly covered with pediment gravels. Exposed areas are similar to Units 2 and 4. None of the units 2,4, or 6 form resistant outcrops. Best exposures occur directly under the more resistant conglomeratic lenses. The overlying conglomerates occur as channel deposits which have scoured into the friable medium grained sands. Small channel deposits can be seen in Units 2, 4, and 6, but they are not well developed and appear not to have actively migrated. CPRV-6. X-ray: smectite.

5	0.2-0.7	17.4

Clast supported, coarse cobble conglomerate. Similar to Unit 1. Poorly sorted gravels. Imbricated clasts. Poor textural and compositional maturity. Calcite cement. CPRV-5.

4	5.0	16.7

Medium grained sandstone. Similar to Unit 2. 0.5-1.0 cm diameter clay rip up clasts occur throughout. Occasional conglomeratic lenses. Numerous isolated basalt clasts occur "floating" in the sandy matrix. Pink quartzite clasts also occur as isolated clasts. Bedding difficult to see. Matrix grains are poorly sorted and angular to subrounded. Conglomerate clasts are subrounded to angular with poor sphericity. CPRV-4.

3 1.0 11.7

Grain supported conglomerate. Similar to Unit 1. Numerous channels and scouring. Clasts show imbrication. Channel scours cut each other. Channels 5.0-10.0 cm high, 0.5-1.0 m wide. Resistant unit. CPRV-3.

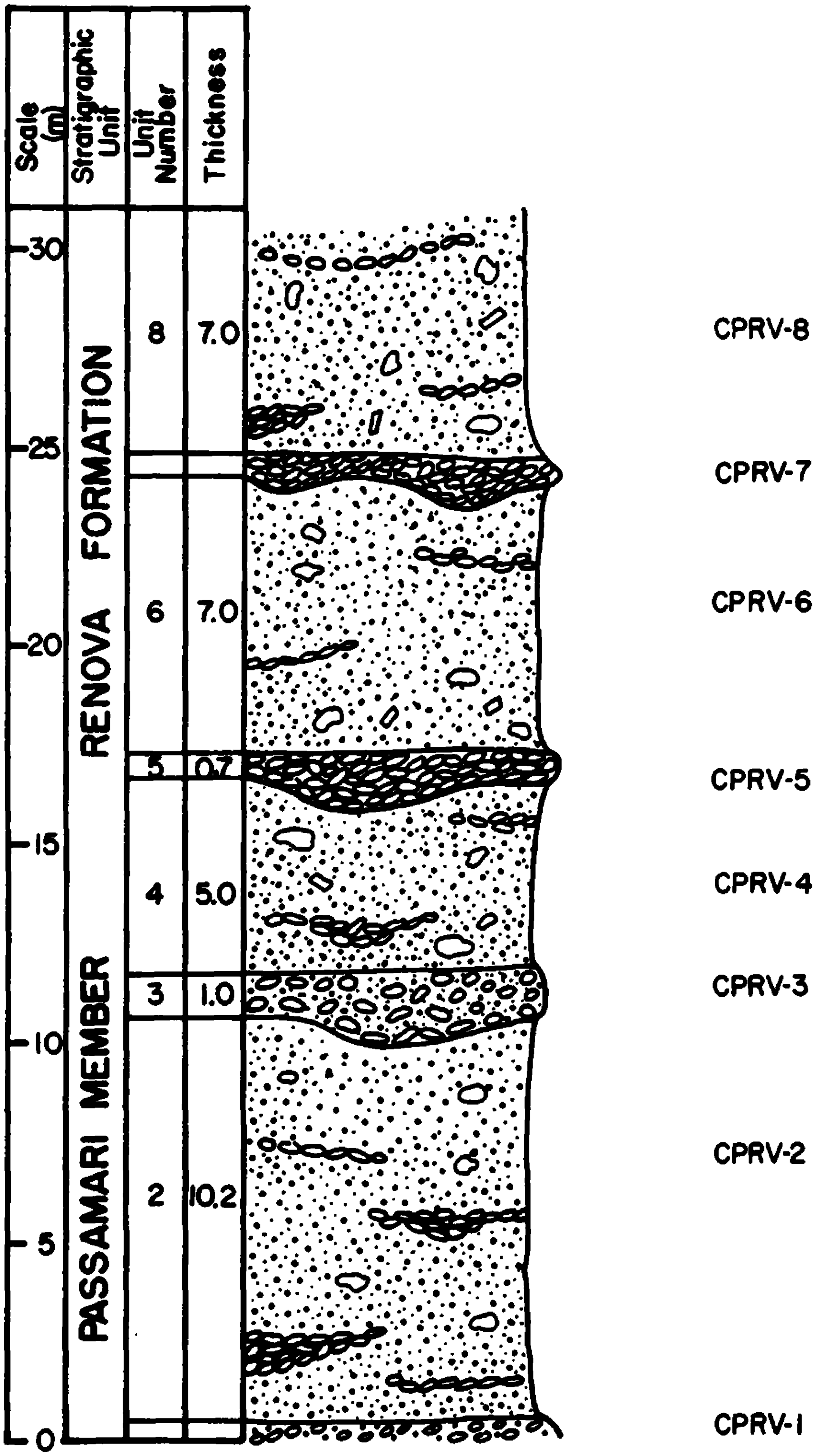
2 10.2 10.7

Medium-fine grained, ashy sands. Grains are poorly sorted and angular. Composed predominantly of MRF's. Internal bedding difficult to see. The unit is massive. Coarse conglomeratic lenses composed of basalt and metamorphic rock clasts occur throughout the unit . The conglomeratic lenses range from 5.0-10.0 cm high and 1.0-2.0 m wide. Calcite cement. Blocky weathering character. Clay rip up clasts (0.1-3.0 cm diameter) occur near the top of the unit. CPRV-2. X-ray: smectite.

1 0.5 0.5

Coarse matrix supported conglomerate. Framework clasts range from 1.0-20.0 cm length, are angular to rounded and poorly sorted. Coarse sand matrix. Trough cross stratification. Lenticular beds. Calcite cement. Channels 0.1-0.5 m high and 3.0-10.0 m wide. Clasts composed of basalt and metamorphic basement rocks. CPRV-1.

CAMPBELL PLACE



APPENDIX B

Mineral Data

Mineral data was obtained from petrographic examination of thin sections and x-ray diffraction patterns. Results of analyses were compiled and are listed below.

Abbreviations

SCRV	Sweetwater Creek, Ruby Valley
CSRV	Caldwell Springs, Ruby Valley
CPRV	Campbell Place, Ruby Valley
TMRV	Table Mountain, Ruby Valley
THRV	Timber Hill, Ruby Valley
HSRV	Hot Springs, Ruby Valley
WSRV	Warm Springs, Ruby Valley
BCJV	Bone Basin Creek, Jefferson Valley
PBJV	Parrot Bench, Jefferson Valley
AHAV	Antelope Hill, Avon Valley

I	illite	Sm	smectite	P	palygorskite
C	calcite	D	dolomite	G	gypsum
A	glass	Cd	chalcedony	Q	quartz
F	feldspar	H	halite	O	opal
*	x-ray data	t	thin section data		
B	base	T	top		

Upper Ruby Valley

Sample	I	Sm	P	C	D	G	A	Cd	Q	F	H	O	*	t
SCRV-4	X	X			X								X	
SCRV-5	X	X		X			X		X	X			X	X
SCRV-6	X	X		X									X	
SCRV-7	X	X		X									X	
SCRV-8		X	X		X								X	
SCRV-9	X	X											X	
SCRV-11	X	X			X								X	X
SCRV-12		X					X		X	X			X	X
SCRV-13		X											X	
SCRV-14		X											X	

Upper Ruby Valley

Sample	I	Sm	P	C	D	G	A	Cd	Q	F	H	O	*	t
SCRV-15		X	X		X								X	
SCRV-16		X		X					X		X		X	X
SCRV-17		X		X	X	X	X		X		X		X	X
SCRV-18							X						X	
SCRV-19	X	X		X	X								X	X
SCRV-20				X										X
SCRV-21		X		X	X		X						X	X
SCRV-22		X		X	X	X	X		X	X			X	X
SCRV-23				X			X							X
SCRV-24 B		X				X							X	
SCRV-24 T	X		X	X	X					X			X	
SCRV-25		X		X		X							X	
SCRV-26		X		X					X	X			X	X
SCRV-27		X		X			X		X	X			X	X
SCRV-28		X		X		X							X	
SCRV-30	X	X		X									X	X
SCRV-31	X	X					X		X		X		X	X
SCRV-32		X		X			X		X	X			X	X
SCRV-33	X	X											X	
SCRV-34				X			X		X	X				X
SCRV-35		X											X	
SCRV-36		X											X	
SCRV-37				X			X		X	X				X
CSRV-1		X		X	X	X	X		X		X		X	X
CSRV-3	X	X		X	X								X	
CSRV-6	X	X									X		X	
CSRV-8		X		X		X					X		X	
CSRV-10		X		X							X		X	
CSRV-11		X		X							X		X	
CSRV-14		X		X									X	
CSRV-15		X									X		X	
CSRV-16	X	X									X		X	
CSRV-17		X									X		X	
CSRV-20	X	X									X		X	
CPRV-2		X											X	
CPRV-6		X											X	
CPRV-7		X									X		X	
CPRV-14		X											X	
WSRV-2				X										X
WSRV-3				X										X
WSRV-4				X										X

Upper Ruby Valley

Sample	I	Sm	P	C	D	G	A	Cd	Q	F	H	O	*	t
TMRV-1								X						X
TMRV-2				X			X		X	X				X
TMRV-3				X				X	X	X				X
TMRV-4				X				X	X					
HSRV-1				X										X
THRV-13				X										X
THRV-14				X			X		X	X				X

Jefferson Valley

Sample	I	Sm	P	C	D	G	A	Cd	Q	F	H	O	*	t
BCJV-2		X		X									X	
BCJV-3		X											X	
BCJV-11				X					X	X				X
PBJV-2				X				X						X
PBJV-5		X					X							X
PBJV-7							X	X	X			X		X
PBJV-9		X											X	

Avon Valley

Sample	I	Sm	P	C	D	G	A	Cd	Q	F	H	O	*	t
AHAV-7		X		X										X

APPENDIX C

Chemical Data

Chemical content of carbonate and shale samples from the upper Ruby, Jefferson, and Avon Valleys was determined by x-ray flourescence. Results of the analyses were normalized on a volatile free basis. See text for discussion of data, variation diagrams and sample types.

UPPER RUBY VALLEY

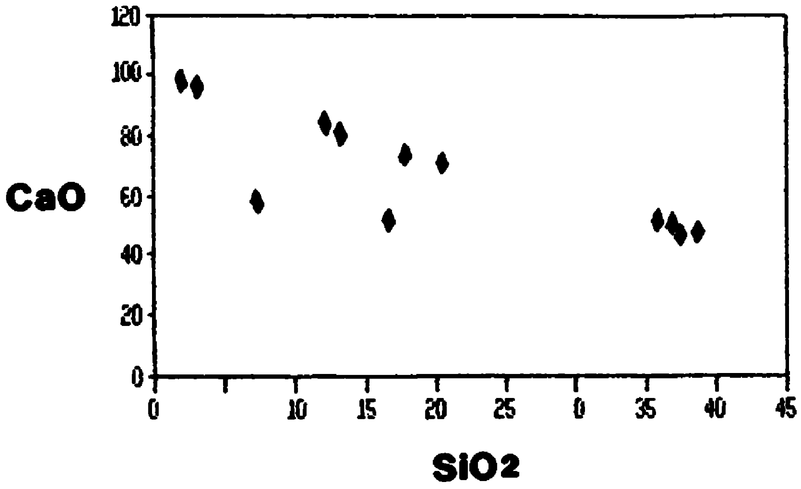
Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P
SCRV-33	37.43	8.48	.471	3.30	.288	45.16	1.77	1.57	1.23	.
SCRV-40	35.88	6.80	.354	2.53	.979	50.73	1.45	1.32	0.35	.
SCRV-16	38.73	8.15	.446	1.70	.246	46.36	1.47	1.59	1.17	.
SCRV-27	36.84	7.77	.375	2.22	.244	49.12	1.35	1.91	0.76	.
SCRV-20	16.66	3.18	.180	1.59	.282	49.95	27.72	0.61	0.27	.
SCRV-21	17.86	3.03	.180	1.04	.244	72.98	3.71	0.64	0.09	.
SCRV-26	13.31	2.71	.211	1.19	.390	80.25	1.23	0.55	0.07	.
SCRV-30	12.26	1.72	.123	0.46	.273	83.86	0.87	0.32	0.00	.
SCRV-32	7.32	1.11	.123	0.34	.085	57.32	32.84	0.20	0.42	.
THRV-13	2.04	0.29	.057	0.00	.160	97.01	0.38	0.00	0.00	.
TMRV-2	20.57	3.95	.250	1.32	.042	70.16	2.24	0.98	0.37	.
WSRV-3	3.12	0.57	.065	0.00	.001	94.67	1.49	0.07	0.00	.

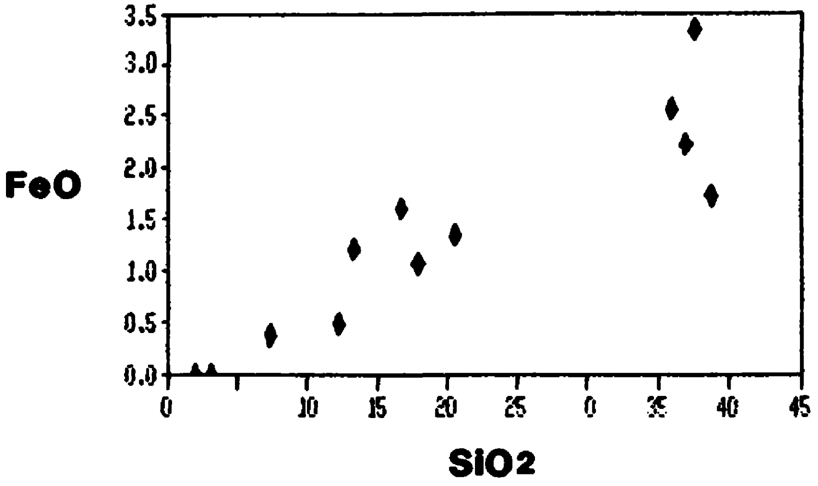
JEFFERSON VALLEY

Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P
DGJV-7	21.14	1.42	.132	0.58	.164	75.28	0.99	0.20	0.00	.
PBJV-5	32.44	4.45	.218	1.23	.186	58.97	1.06	1.09	0.29	.
PBJV-7	40.45	1.37	.110	1.00	1.30	54.36	1.00	0.23	0.00	.
PBJV-12	55.50	1.39	.116	0.38	.298	41.20	0.80	0.18	0.00	.

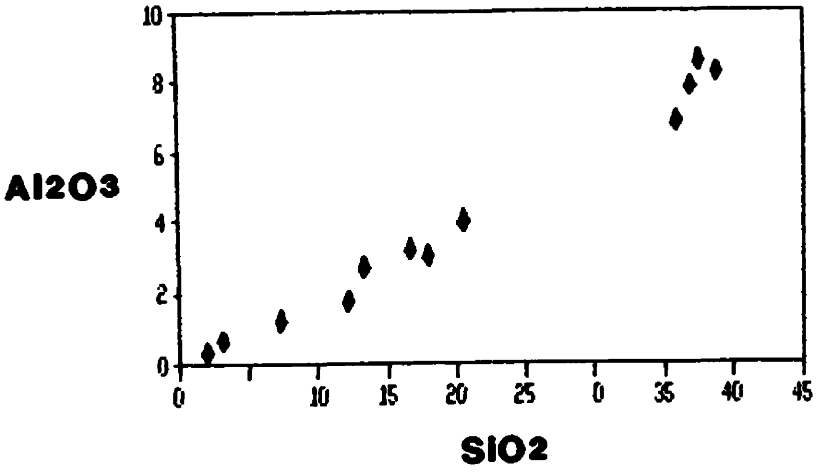
AVON VALLEY

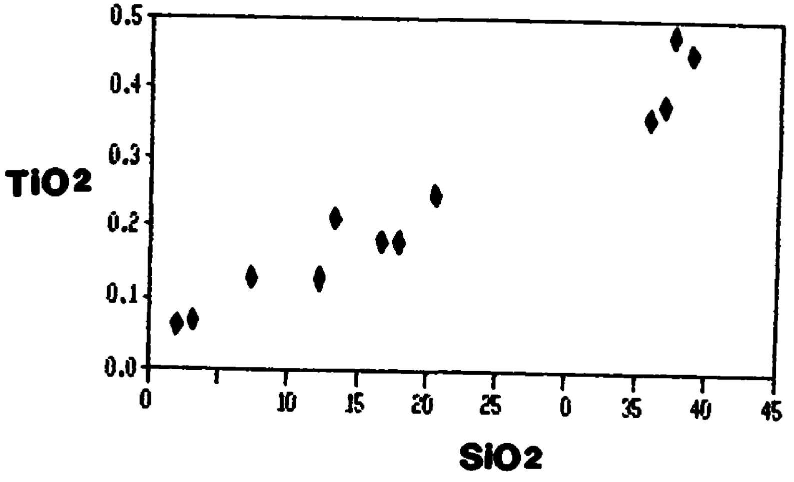
Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P
AHAV-2	71.42	1.00	.065	0.27	.075	26.68	0.29	0.12	0.00	.
AHAV-10	80.01	0.42	.039	0.23	.022	18.83	0.37	0.50	0.00	.
AHAV-5	1.69	0.27	.069	0.00	.007	97.59	0.36	0.00	0.00	.
AHAV-6	1.77	0.22	.048	0.42	.025	97.23	0.25	0.00	0.00	.

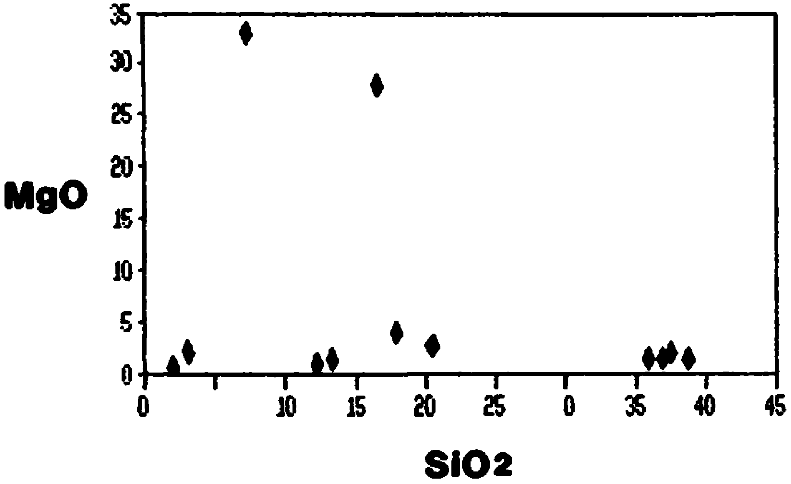


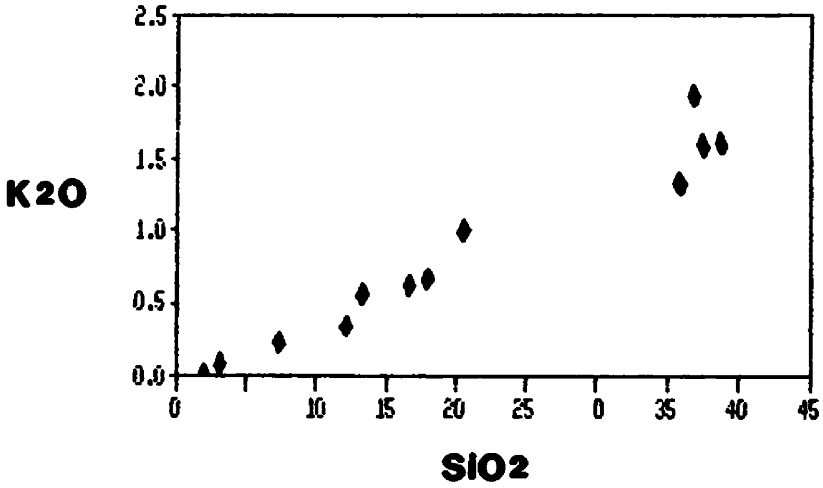


Variation Diagrams Upper Ruby Valley

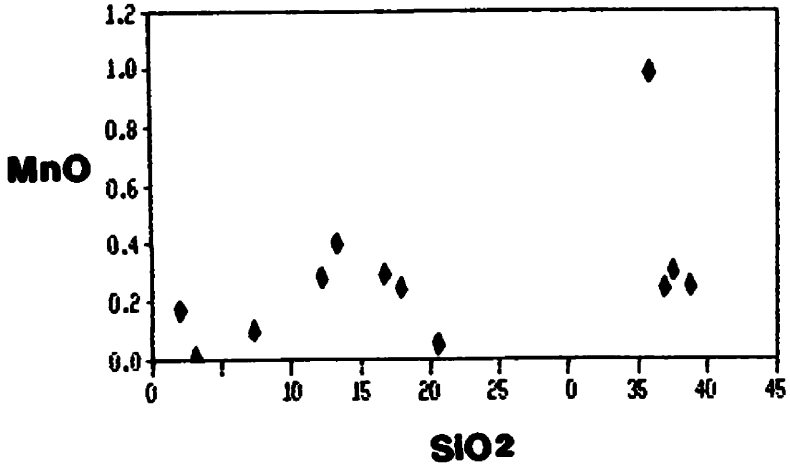


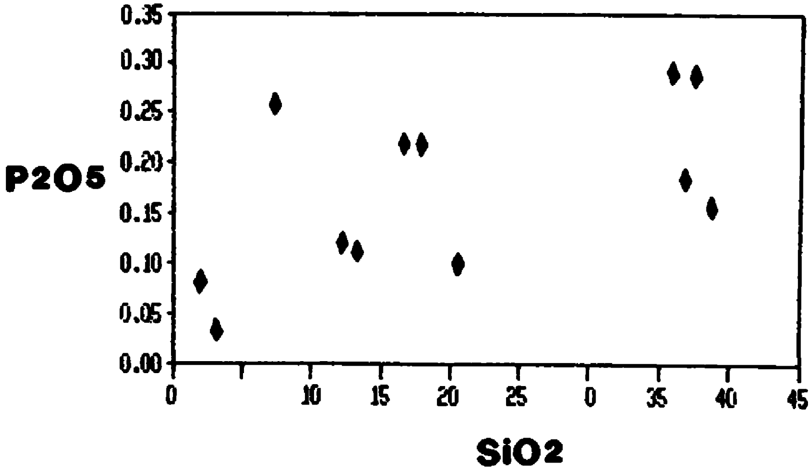


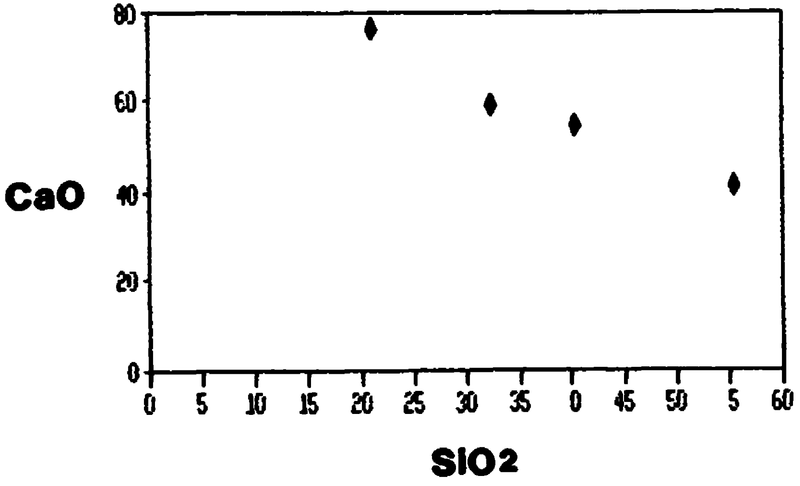


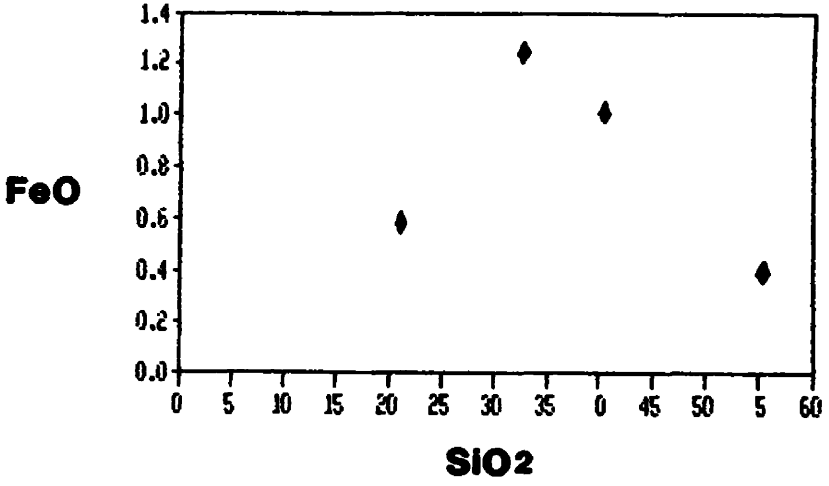


Variation Diagrams Upper Ruby Valley

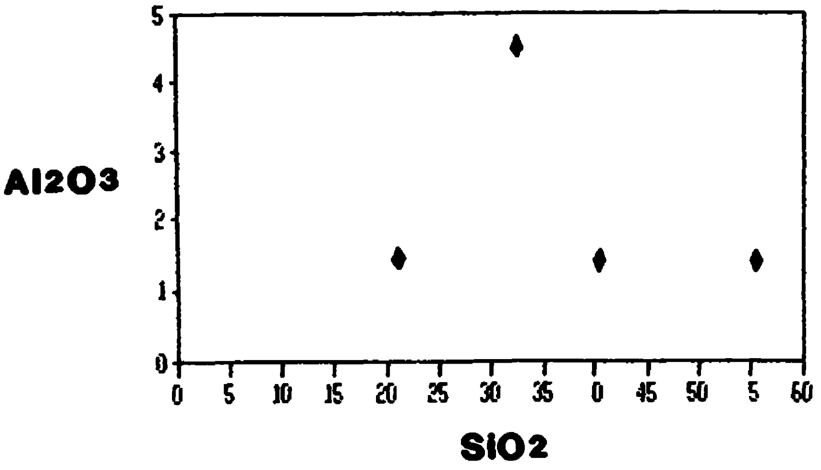


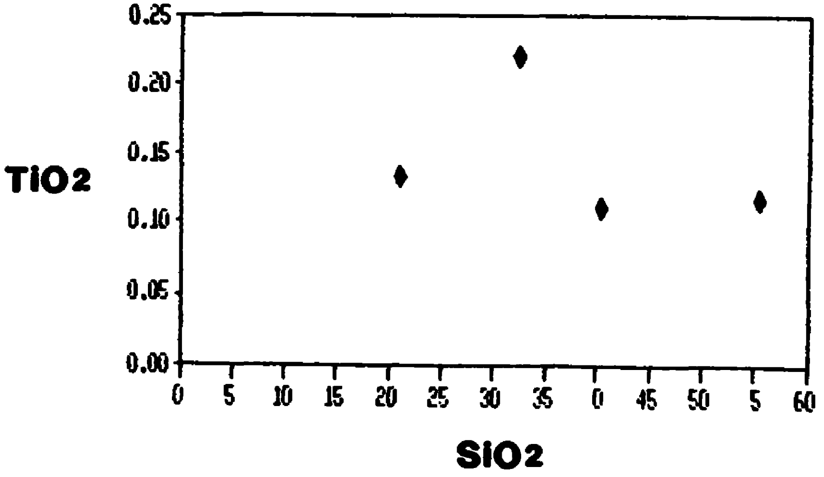


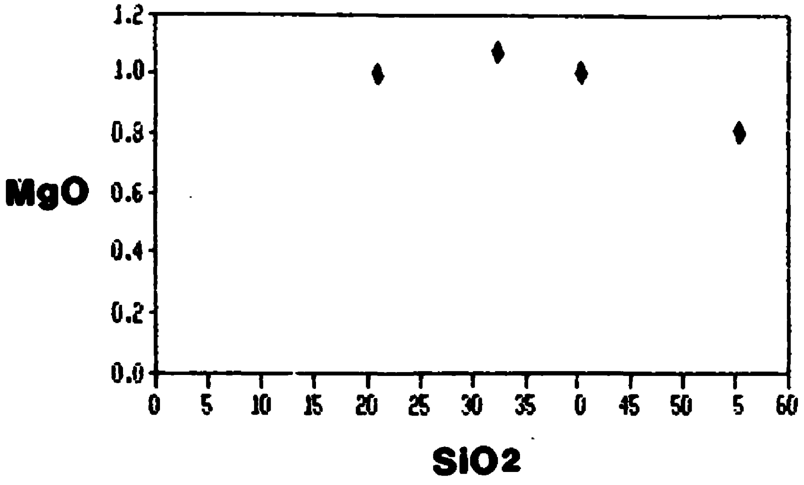


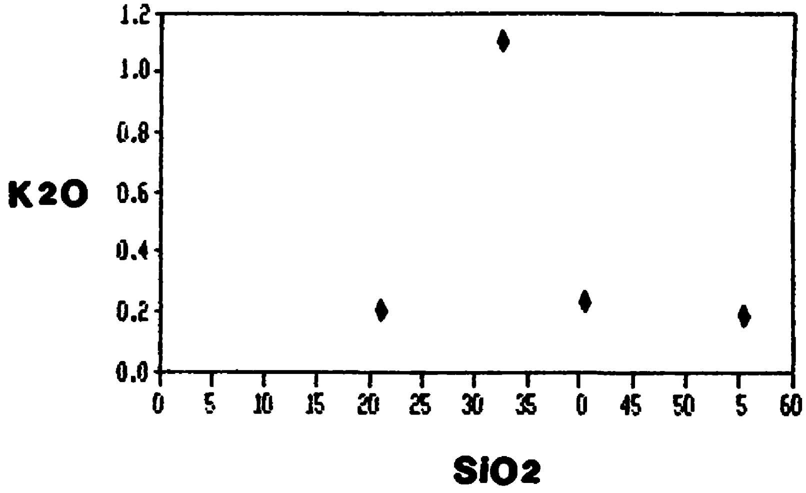


Variation Diagrams   Jefferson Valley

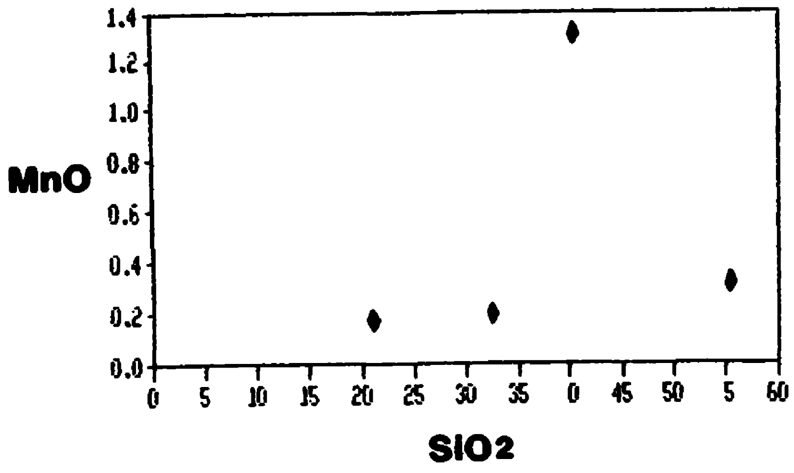


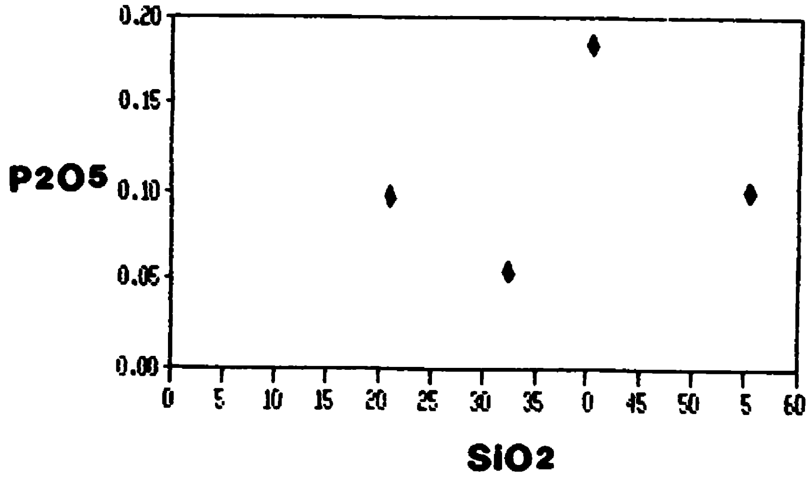


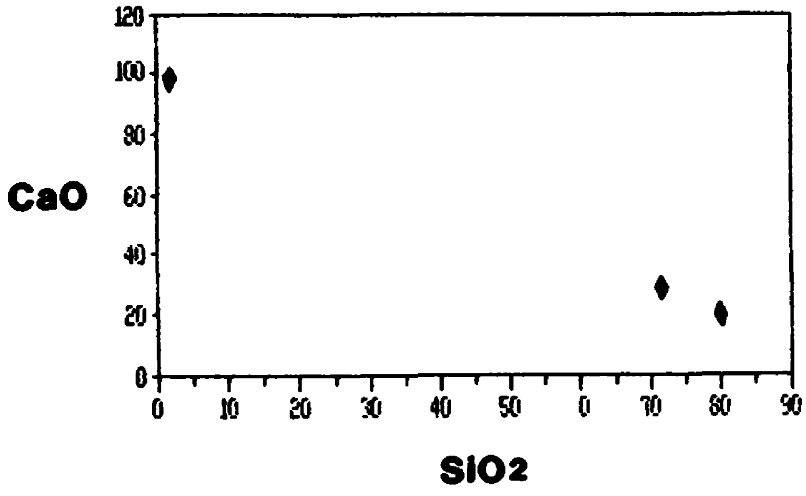


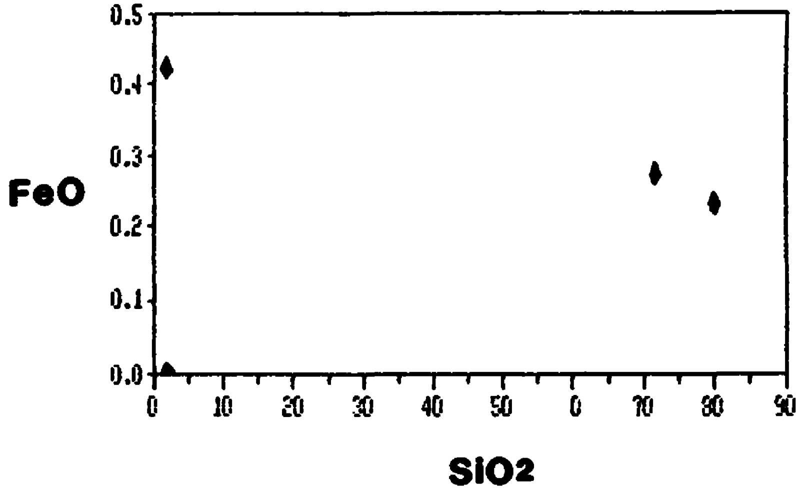


Variation Diagrams Jefferson Valley

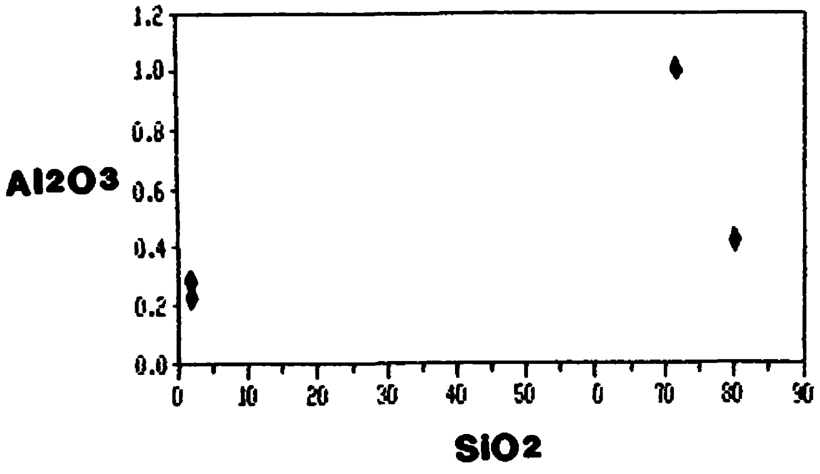


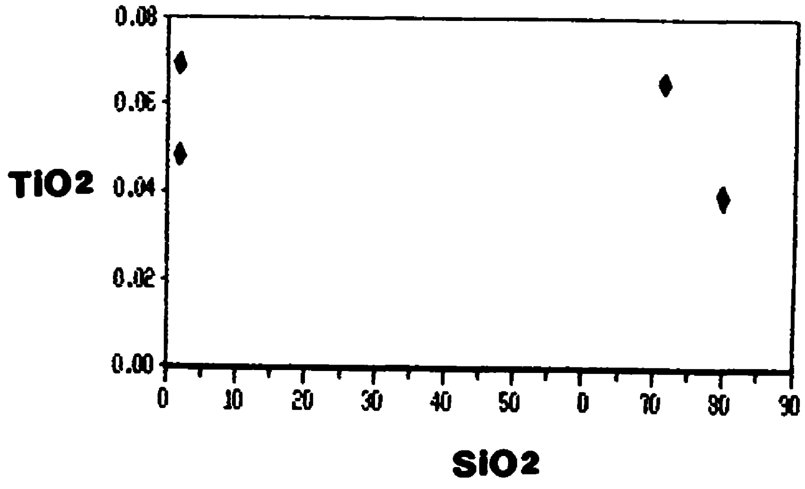


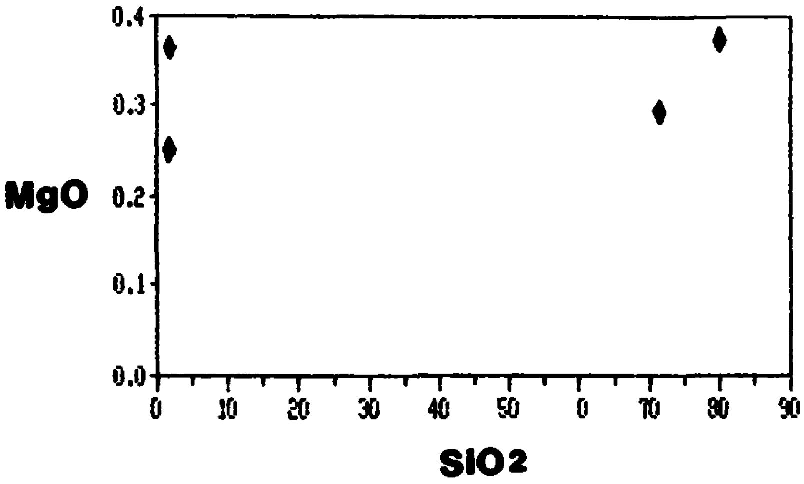


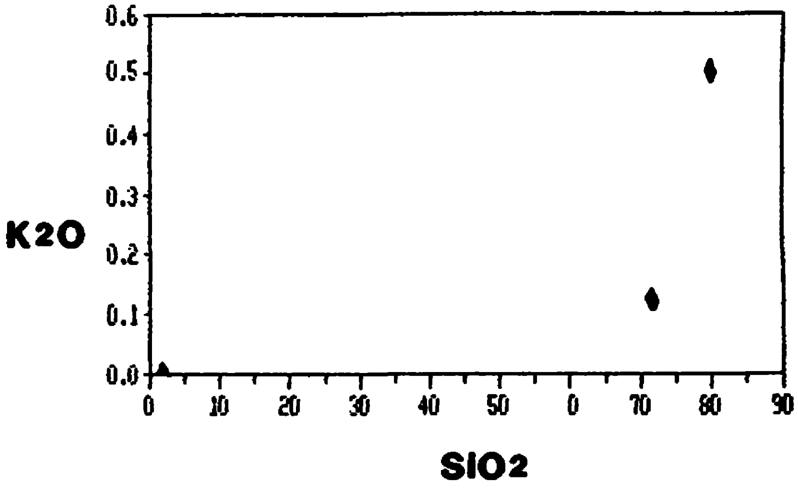


Variation Diagrams Avon Valley









Variation Diagrams Avon Valley