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Geology and Economic Potential of the Muddy Ranch Inlier, North-Central Oregon

Mustafa Kamal

ABSTRACT

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by

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There has been confusion for many years regarding the lithology and age of the rocks exposed in the Muddy Ranch Inlier in north-central Oregon. Taylor (1960) referred to these rocks as metasediments and informally named them the "Muddy Ranch phyllite". My studies indicate the inlier consists of weakly metamorphosed siltstone, mudstone, and less abundant sandstone.

Due to the absence of fossil evidence, it was not possible to determine the age of these rocks. However, from the stratigraphic setting and correlation with similar rocks exposed along structural trend to both the northeast and southwest, rocks of the Muddy Ranch Inlier may be Early Eocene in age, as reported for the "Hay Creek Formation" by Wareham (1986). The depositional environment of these rocks is uncertain but is interpreted to be a submarine fan based on the presence of turbidites and lithologic similarities to the "Hay Creek Formation".

As potential petroleum source rocks the organic-rich siltstones of the "Muddy Ranch Formation" are overmature. However, this may only indicate that these rocks have produced oil or gas in the past. Occurrences of asphalt and

shows of both oil and gas in wells in the vicinity indicate the possibility of commercial quantities of hydrocarbons. Besides petroleum, the Muddy Ranch also has potential to produce metallic minerals such as copper, gold, silver, and cinnabar. In addition, bentonitic clay deposits in the Clarno Formation show promise for commercial production.

LOMA LINDA UNIVERSITY

Graduate School

GEOLOGY AND ECONOMIC POTENTIAL OF THE MUDDY RANCH INLIER, NORTH-CENTRAL OREGON

by

Mustafa Kamal

A Thesis in Partial Fulfillment

of the Requirements for the Degree

Master of Science in Geology

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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INTRODUCTION

General Statement

North-central Oregon is covered by a blanket of Tertiary volcanic and volcaniclastic rocks with only a few erosional windows (Fisk and Fritts, 1987; see Figure 1) which expose Cretaceous and Early Tertiary sedimentary and metasedimentary rocks. These erosional windows through the volcanic cover are properly termed inliers. An inlier is an area or group of rocks surrounded by rocks of a younger age, e.g., an eroded anticlinal crest (Bates and Jackson, 1980). Many questions regarding the age, stratigraphy, tectonic significance, and petroleum potential of these inliers remain unsolved (Fisk and Fritts, 1987).

One inlier that has attracted only limited attention in the past is the Muddy Ranch Inlier (Figure 1). Most geologists believe that this particular inlier is composed of metamorphic rocks of late Paleozoic or early Mesozoic age. For instance, Taylor (1960) considered these rocks to be Permo-Triassic phyllite and informally named them the "Muddy Ranch phyllite". Others (e.g., Kleinhans and others, 1984; Sidle and Richers, 1985; and Fisk and Fritts, 1987) have referred to these exposures as either Cretaceous or Tertiary sedimentary or metasedimentary rocks. These conflicting descriptions have created confusion and basic misunderstanding over the lithology, age, and economic potential of the rocks composing the Muddy Ranch Inlier.

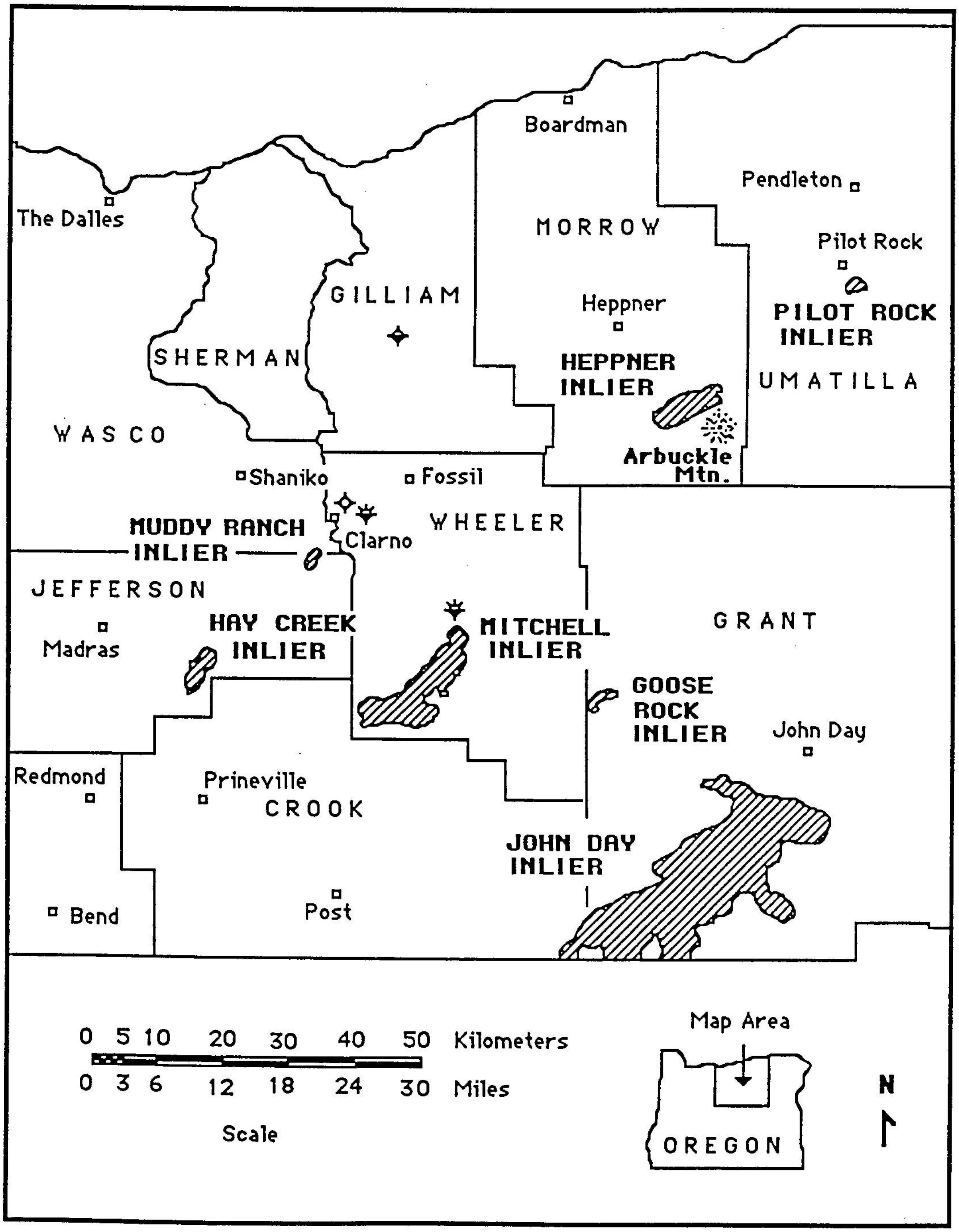

Figure 1. Map of the pre-volcanic inliers of north-central Oregon (modified from Fisk and Fritts, 1987).

Purpose and Scope

The purpose of my thesis research was to attempt to resolve the conflicting interpretations of the rocks of the Muddy Ranch Inlier by mapping the area in detail and determining the stratigraphic setting, lithology, and age of the rocks exposed in the vicinity. In addition, the prospect of economic minerals and hydrocarbon generation from the Muddy Ranch rocks was also explored.

Geographic Setting

The thesis area lies within the Muddy Ranch located in the Arrastra Butte and Muddy Ranch Quadrangles (1:24,000) astraddle the Wasco and Jefferson county boundary in north-central Oregon (Figure 2). The main outcrops of the Muddy Ranch Inlier lie 14 miles by road southeast of the village of Antelope and about 150 miles southeast of Portland.

The Muddy Ranch area is characterized by gentle slopes at higher elevations with steep canyons in deeply dissected areas near the John Day River. The topographic high in the thesis area is 2564 feet in the northwestern corner and the low is 1400 feet near the confluence of Muddy Creek and the John Day River. The area is drained by three major streams: Muddy, Currant, and Dry Creeks. Only the John Day River and these major tributaries have flat-bottomed valleys with alluvial fill. Rocks of the Muddy Ranch Inlier are exposed as rounded hills (Figure 3) at the junction of Muddy and Currant Creeks. The nearest climatological station to the

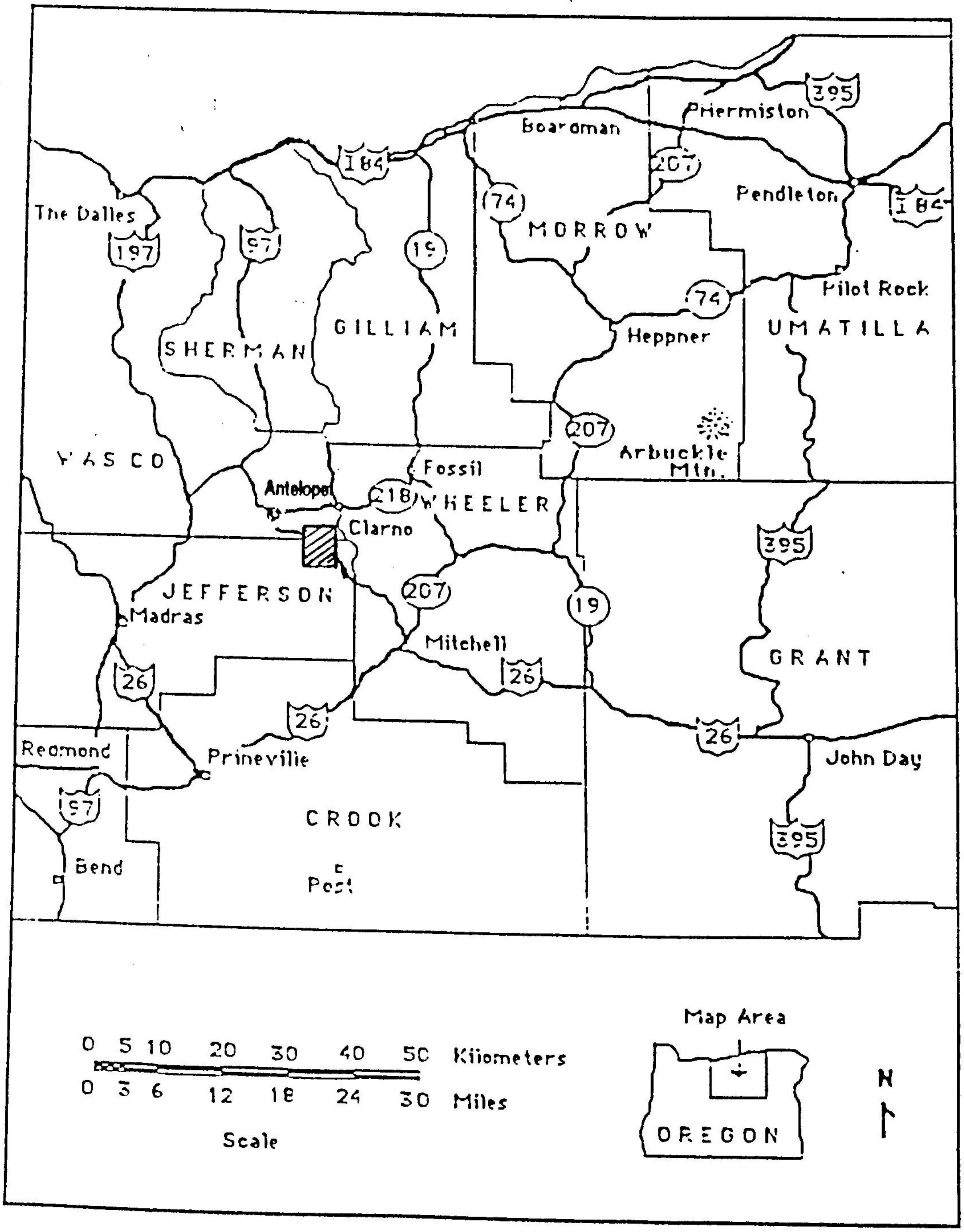

Figure 2. Road map of north-central Oregon showing the location of the study area on the Muddy Ranch (modified from Fisk and Fritts, 1987). The research area is indicated with a rectangle.

Figure 3. Panoramic view showing the rounded hills of the Creeks.Muddy Ranch Inlier. Photo was taken facing NNW.

Big Muddy Ranch is at Antelope where the climate consists of warm, dry summers and cool, moist winters (Anonymous, 1982). The mean annual temperature recorded is 48.4° F with an average maximum of 63° F and an average minimum of 35° F. The average annual precipitation is 12.97 inches and average annual snow fall is 22.4 inches. Juniper, sage brush, and native bunch grass sparsely cover the hills of the ranch, and introduced grasses have been planted in the valleys.

Previous Work

Merriam (1901) was the first geologist to write about the rocks of the Muddy Ranch Inlier. He wrote: "On several occasions, as the parties have been passing through the region, search has been made for fossils, but so far no traces of them have been found. Judging from the appearance of this formation it is older than the [Cretaceous] Knoxville shales". Taylor (1960) in his unpublished master's thesis described the Muddy Ranch outcrops as pre-Cretaceous metamorphic rocks. Swanson and Robinson (1968) mapped the Muddy Ranch rocks as undifferentiated sedimentary and metasedimentary rocks of pre-Tertiary age. Robinson (1975) mapped the area as pre-Tertiary phyllite, shale, and graywacke, correlative with Cretaceous strata in the Mitchell Inlier (Figure 1); however, the latter he identified as unmetamorphosed conglomerate, sandstone, and shale. Kleinhans and others (1984) and Sidle and Richers

(1985) considered the Muddy Ranch outcrops to be Cretaceous in age.

Cretaceous rocks closest to the Muddy Ranch are exposed in the Mitchell area about 30 miles to the southeast. The Cretaceous rocks at Mitchell have been described by Wilkinson and Oles (1968), Oles and Enlows (1971), Jarman (1973), Kleinhans and others (1984), Kleinhans (1987), and Little (1986). Oles and Enlows (1971) interpreted the sandstones and conglomerates of the Gable Creek Formation to be fluvial-deltaic deposits interfingering with marine mudstones of the Hudspeth Formation. Fossils indicate that the age of these beds are largely Middle Cretaceous ranging from Albian to Cenomanian (Wilkinson and Oles, 1968; Kleinhans and others, 1984). Recently Kleinhans and others (1984), Fritts and Fisk (1985a and b), Sandefur (1986), Kleinhans (1987), and Fisk and Fritts (1987) have interpreted these rocks to be submarine fan deposits. In addition, these authors (with the exception of Kleinhans and others, 1984) have informally referred to the Cretaceous rocks at Mitchell collectively as the "Mitchell Formation".

Another group of rocks which are very similar to those exposed on the Muddy Ranch occur in the Hay Creek Inlier approximately 18 miles to the southwest. While describing the geology of the Hay Creek area, Hodge (1942) wrote: "Mesozoic formations occur at two places within the area; one is near Mitchell and the other lies three townships east of Culver and is represented by a hill of folded and crushed rock, the top of which has been exposed. Its surface has been searched for fossils without success, and its exact age is unknown. The rocks, their degree of folding and mineralization, resemble known nearby Triassic formations". Wareham (1986) in his unpublished master's thesis correlated the rocks of the Hay Creek Inlier with those of the Muddy Ranch Inlier. The rocks of the Hay Creek Inlier, informally named the "Hay Creek Formation" by Wareham (1986), had previously been mapped as pre-Tertiary or "Mesozoic-Paleozoic undivided" by earlier workers (Peck, 1964; Swanson and Robinson, 1968; Swanson, 1969; Robinson, 1975; Walker, 1977). However, Wareham (1986) reported calcareous nannoplankton from the "Hay Creek Formation" and suggested that these rocks may be Early to Middle Eocene in age.

Fisk and Fritts (1987) considered the rocks exposed in the Muddy Ranch Inlier to be probably Tertiary in age and possibly equivalent to the "Hay Creek Formation" of Wareham (1986). The interpreted wide distribution of these organic-rich sedimentary rocks beneath the blanket of Tertiary volcanic and volcaniclastic rocks led Fisk and Fritts (1987) to suggest that these rocks may have in the past been important source rocks for petroleum generation. Fisk and Fritts (1987) also suggested that the Muddy Ranch rocks may have been the source of asphaltic dikes in the region, such as those exposed in a roadcut along Highway 218 near Clarno, and also the oil and gas shows in the Clarno Oil Company Burgess No. 2 well in the Clarno area.

METHODS OF STUDY

Field Methods

An area of 20 square miles centered on the Muddy Ranch Inlier was mapped in the field during the Summer of 1988 and field checked during the Summer of 1989. Mapping was done on a 1:24,000 scale U.S. Geological Survey topographic base map prepared by combining the eastern part of the Arrastra Butte and the western part of the Muddy Ranch quadrangles. Aerial photos of several scales (1:40,000, 1:24,000, and 1:20,000) from the U.S. Geological Survey and U.S. Department of Agriculture were also used to aid field reconnaissance. Attitudes of beds were measured with a 360° Brunton compass. About 50 samples of rocks were collected for later laboratory analyses.

Laboratory Methods

Three intrusive volcanic rock samples were sent to Geochron Laboratories Division of Krueger Enterprises, Inc., for K-Ar age determinations. Twelve rock samples (including the three basalts sent for K-Ar age determination) were thin sectioned by Cal Brea Geological Services. These thin sections were petrographically studied and described by using a Zeiss polarizing microscope. Photomicrography of thin sections was done with an Aus Jena POL-U photomicroscope.

Twelve rock samples were sent to Conoco for petroleum source rock analyses and a duplicate set plus five additional samples were sent to Unocal for source rock and microfossil analyses. When the first twelve microfossil samples were found to be barren, an additional five samples of calcareous siltstone were collected in April of 1989 and sent to Unocal. Unfortunately, the second set of samples were also barren. In addition to the above, I personally processed ten samples from the Muddy Ranch Inlier for palynomorphs using standard laboratory techniques (Gray, 1964; Doher, 1980); those from the Muddy Ranch Inlier were also barren.

STRATIGRAPHY

Strata exposed in the general vicinity of the research area have been previously referred to four mappable units, from oldest to youngest, "Muddy Ranch phyllite" (Taylor, 1960), Clarno Formation, John Day Formation, and Columbia River Basalt Group (Figure 4). The rocks Taylor (1960) called "Muddy Ranch phyllite", I have informally renamed the "Muddy Ranch Formation". The thesis area contains only rocks of the "Muddy Ranch Formation" and Clarno Formation. Quaternary alluvium, consisting of unconsolidated gravel and sand deposits, are also present along the courses of the main streams. Figure 5 is a generalized geological map of the thesis area and a detailed geologic map at 1:24,000 scale can be found in the pocket at the back of the thesis. The individual map units will be described below, from oldest to youngest.

"Muddy Ranch Formation"

The rocks of the "Muddy Ranch Formation", the oldest rocks exposed in the research area, cover an area of approximately two and one half square miles. The upper boundary of this unit is an angular unconformity with volcaniclastic rocks of the Clarno Formation and the lower contact is not exposed. The total exposed thickness of the "Muddy Ranch Formation" is approximately 1800 feet (not 5000 feet as estimated by Taylor, 1960).

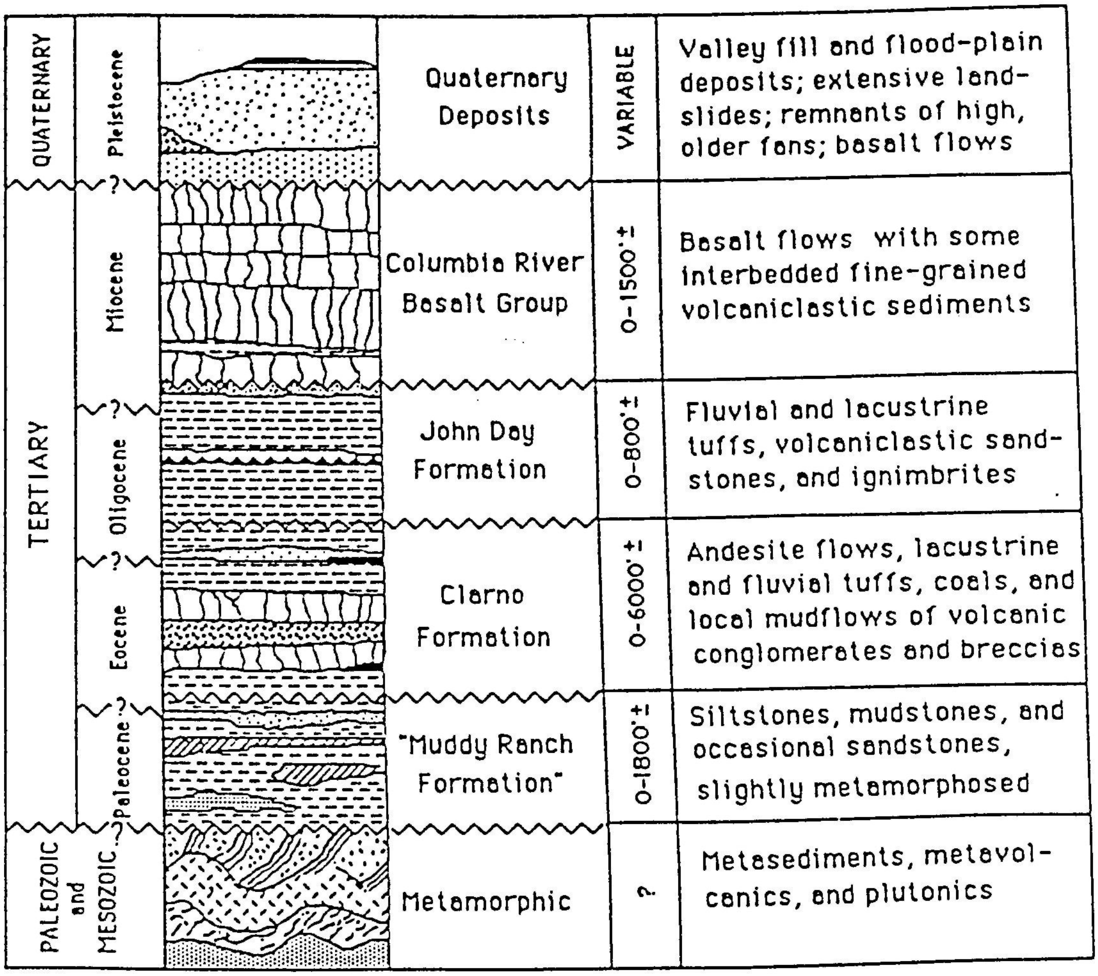

Figure 4. Generalized stratigraphic column of rocks exposed in the vicinity of the Muddy Ranch (modified from Fisk and Fritts, 1987).

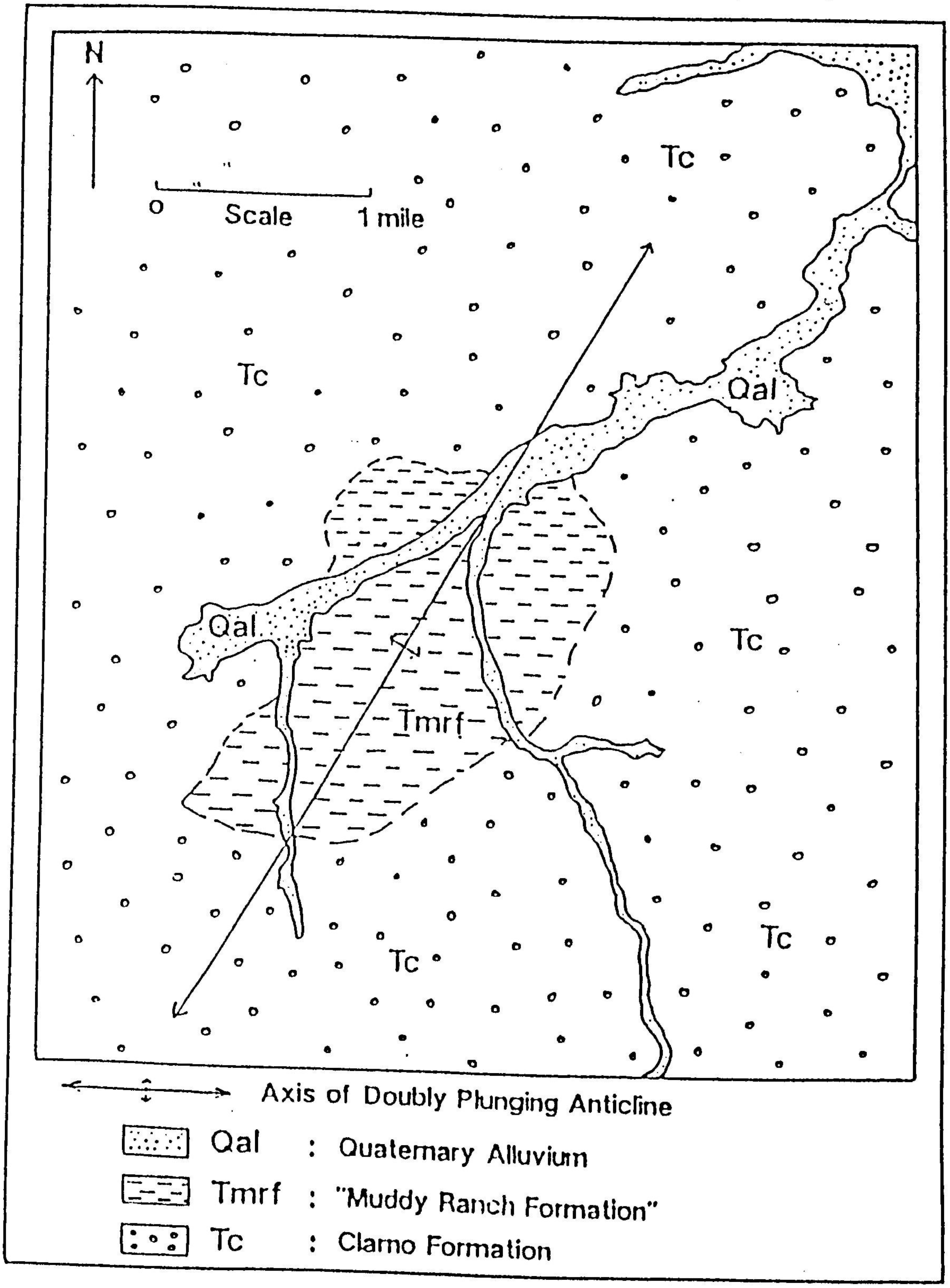

Figure 5. Generalized geologic map of the Muddy Ranch Inlier and vicinity.

Nomenclature: Taylor (1960) was the first geologist to name the rocks of the Muddy Ranch Inlier, informally referring to them as "Muddy Ranch phyllite". Most earlier and later workers (e.g., Merriam, 1901; Peck, 1964; Robinson 1973, 1975; Kleinhans and others, 1984; and Sidle and Richers, 1985) referred to these exposures as pre-Cretaceous or Cretaceous rocks without naming them. Because these rocks vary in lithology and some outcrops are not phyllitic, I suggest that the informal name "Muddy Ranch Formation" (MRF) be used to refer to rocks of the entire inlier.

Physiographic Expression: The "Muddy Ranch Formation" crops out as low, rounded hills surrounded by more deeply-eroded, valley-forming rocks of the Clarno Formation (see Figure 3). This topographic expression is due to a higher resistance to weathering of the lithologies of the "Muddy Ranch Formation". Muddy and Currant Creeks cut through the outcrop, dividing it into separate, smooth, rounded hills (Figures 3 and 5).

Lithology: The "Muddy Ranch Formation" is composed of siltstone, mudstone, and rarely sandstone, light brown to dark gray and black in color when fresh but weathering to gray and silver gray with a shining lustre. Thin sections of seven MRF rocks were studied under the microscope. Detailed petrographic descriptions are included in Appendix A and the mineralogical composition of all seven samples is presented in Table 1. The MRF rocks are composed

Table 1. Estimated mineral composition (in percent) of seven samples of "Muddy Ranch Formation" siltstone, sandstone, and weakly metamorphosed pelitic rock.

Constituent	Sample Number						
	MRF2	MRF4	MRF7	MRF8	MRF13	MRF16	MRF18
Quartz	40	32	41	46	60	35	14
Clay	40	49	46	35	20	42	38
Organics	9	5	5	7	10	5	15
Plagioclase	--	--	--	1	--	--	2
Sericite	5	4	3	7	5	13	2
Iron oxide	4	5	4	2	3	3	1
Biotite	1	1	--	--	--	--	--
Muscovite	1	2	1	1	2	2	1
Calcite	--	2	--	--	--	--	25
Lithic fragments	--	--	--	1	--	--	2

predominantly of quartz and argillaceous (clay) minerals. From the thin section studies only two samples, MRF-4 (Figure 6) and MRF-16 (Figure 7), show signs of low-grade metamorphism, including an incipient schistose texture and a preferred orientation of phyllosilicate minerals. The remaining five samples show only sedimentary textures (Figures 8-12). Thus, the whole "Muddy Ranch Formation" is not "phyllite" as implied by the name "Muddy Ranch phyllite" applied by Taylor (1960).

Level of Metamorphism: Rocks of the "Muddy Ranch Formation" have been subjected to very low grade metamorphism with the development of incipient cleavage in the siltstones which often break into elongated polygonal fragments known as "pencil structures" (Figure 13). These

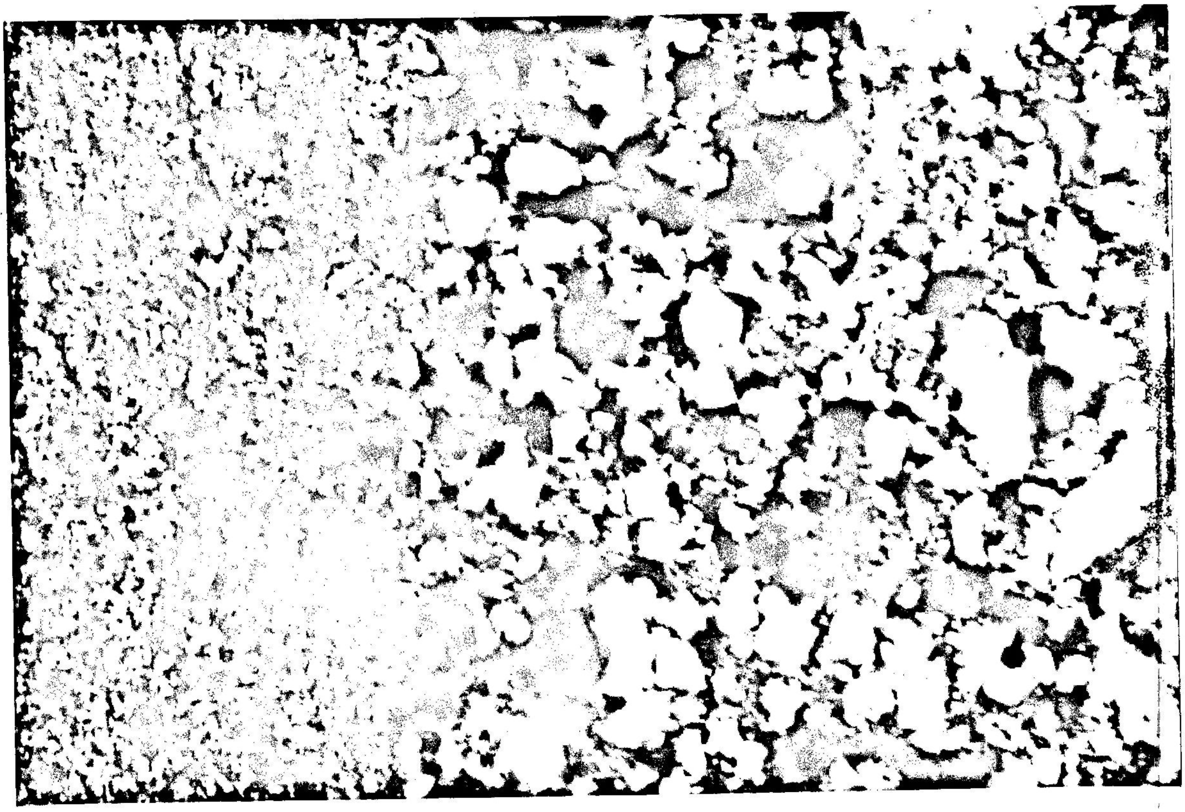

Figure 6. Photomicrograph of sample MRF-4 composed of weakly metamorphosed sandstone and siltstone with a sharp contact between them. The sandstone is normally graded and the siltstone shows faint planar lamination as a result of the alignment of organic debris (cross polarized light, approximately 400X).

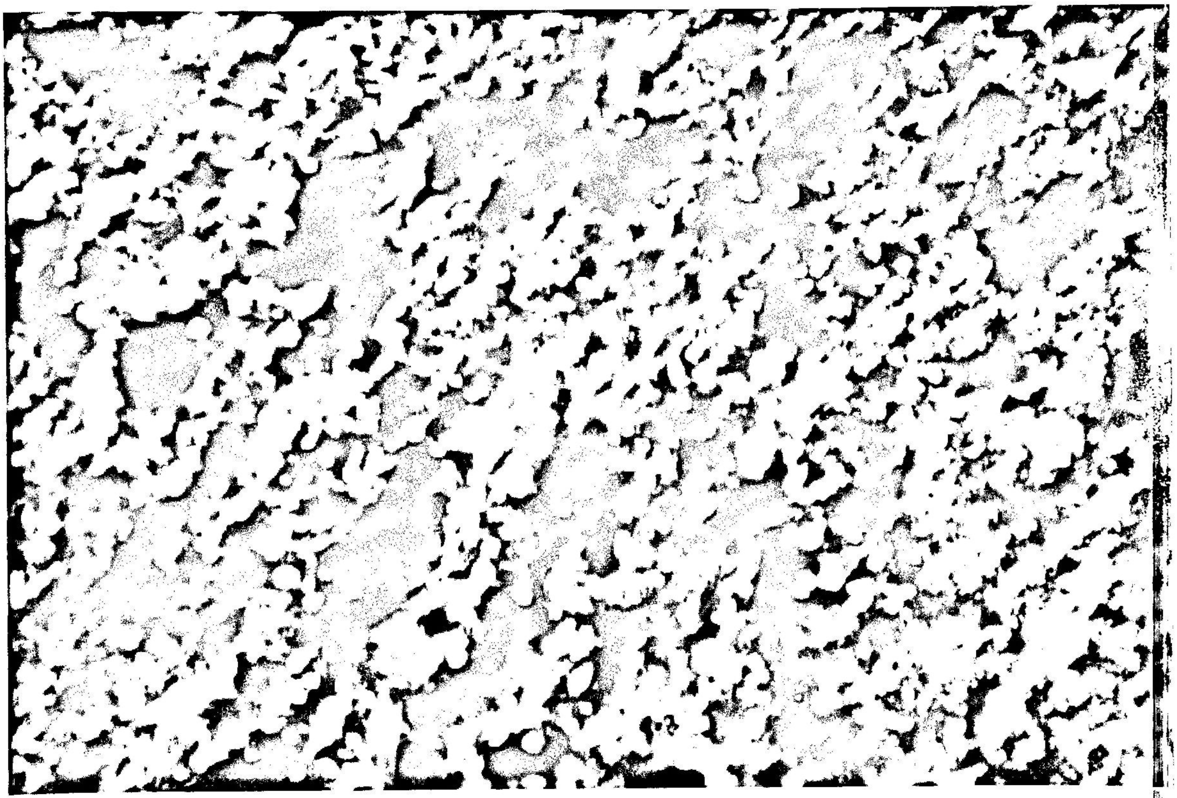

Figure 7. Photomicrograph of sample MRF-16, a weakly metamorphosed siltstone with a phyllitic texture (ordinary polarized light, approximately 400X).

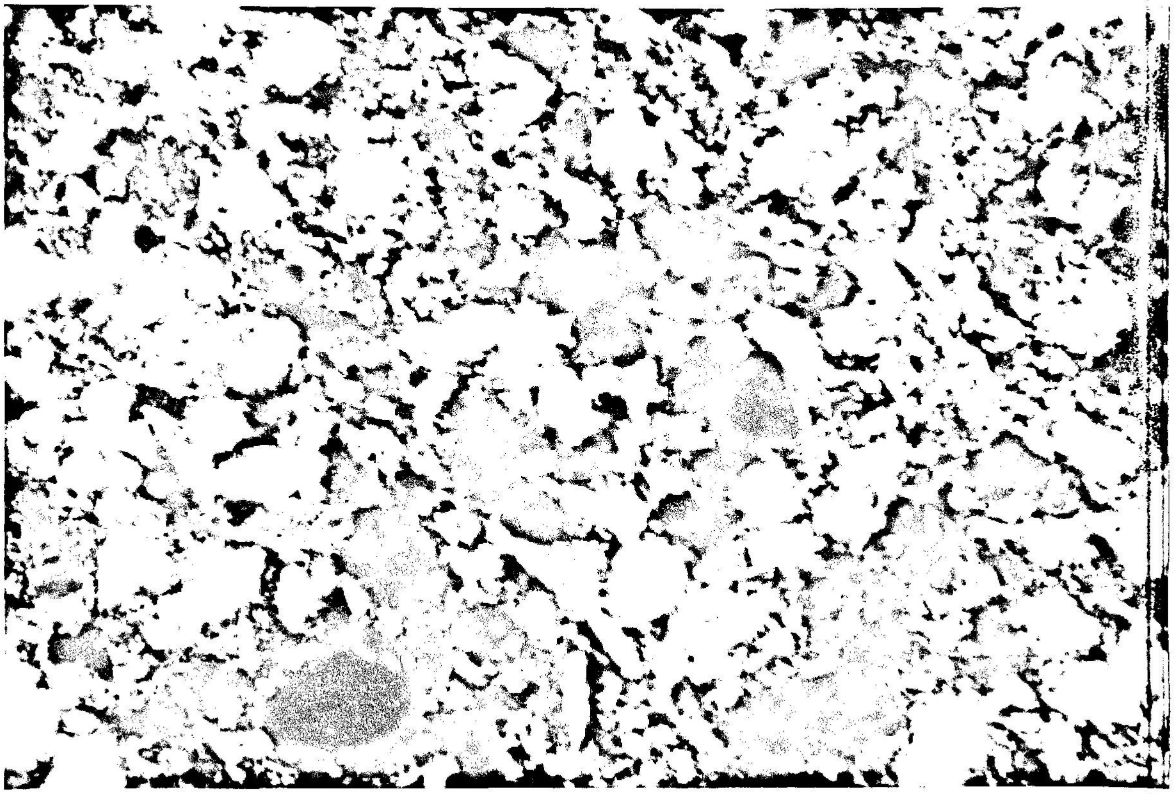

Figure 8. Photomicrograph of sample MRF-2, a silty sandstone. Organics are black; the subrounded, light-colored grains are quartz; and matrix is clay (cross polarized light, approximately 400X).

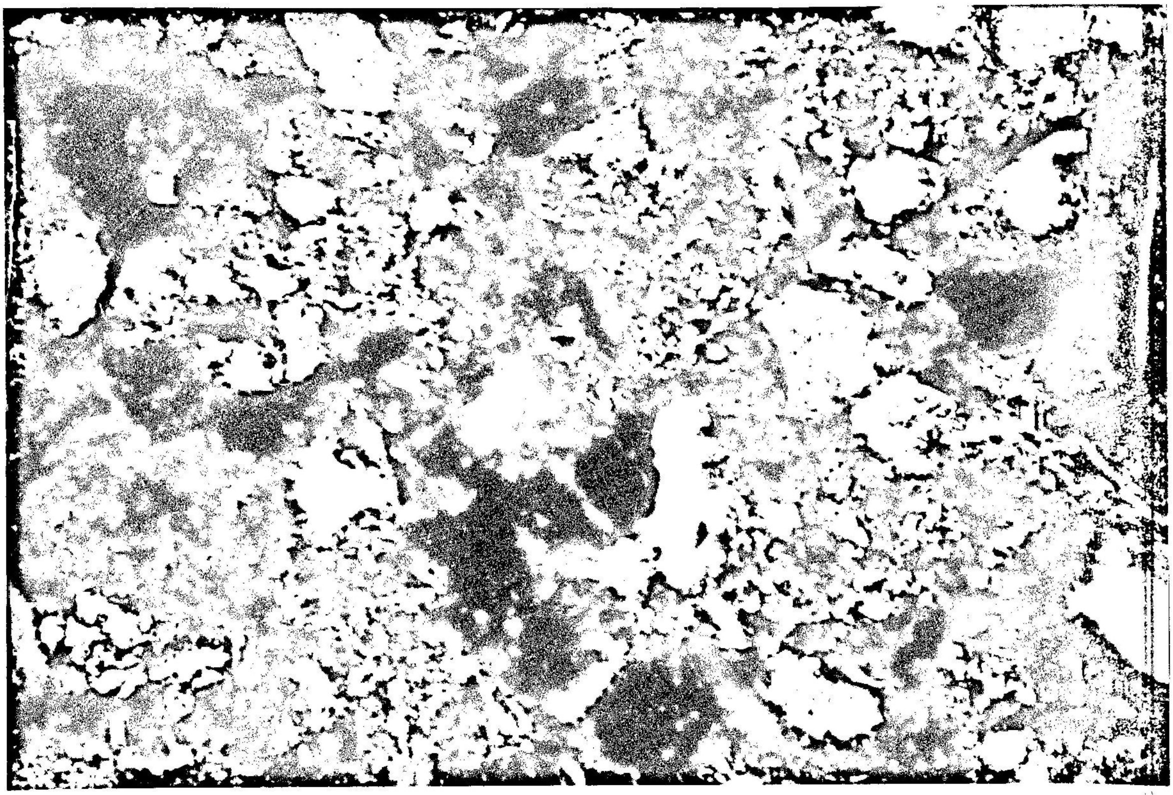

Figure 9. Photomicrograph of sample MRF-7, a sandy siltstone. Organics are black; quartz is light-colored; and matrix is clay (ordinary polarized light, approximately 400X).

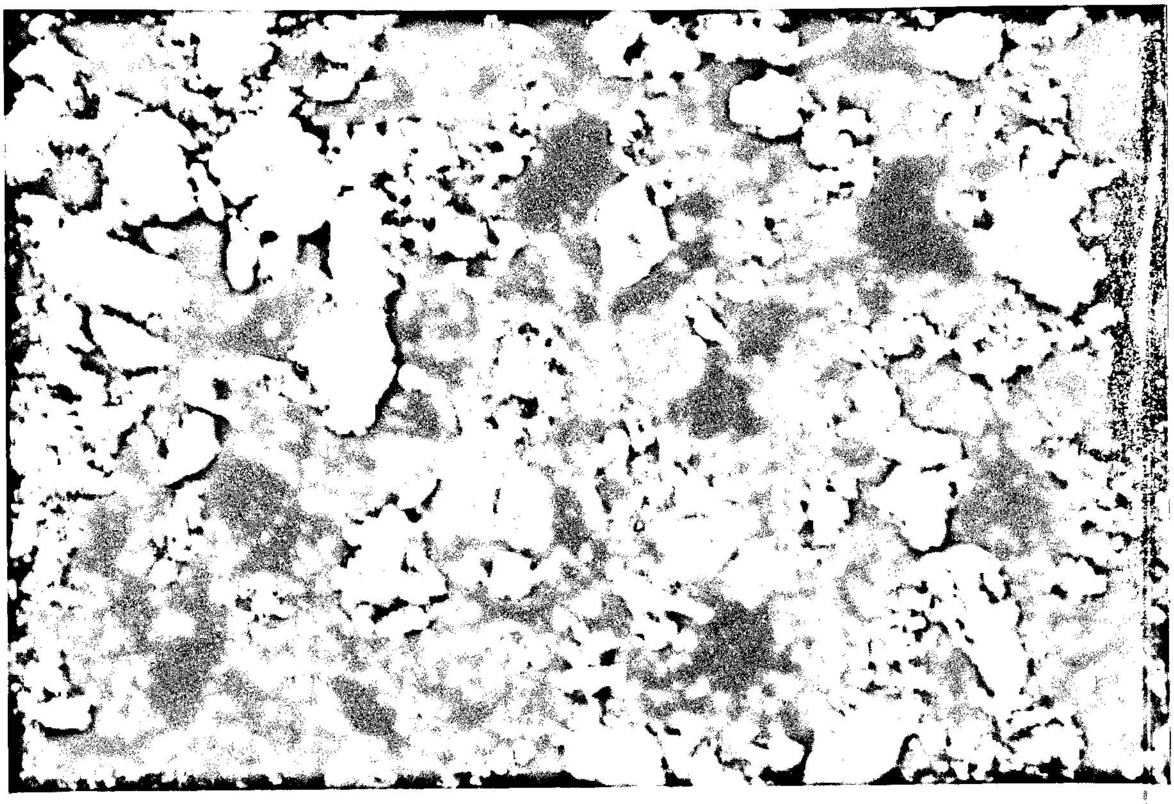

Figure 10. Photomicrograph of sample MRF-8, a siltstone. Organics are black; quartz is light-colored; and matrix is clay (cross polarized light, approximately 400X).

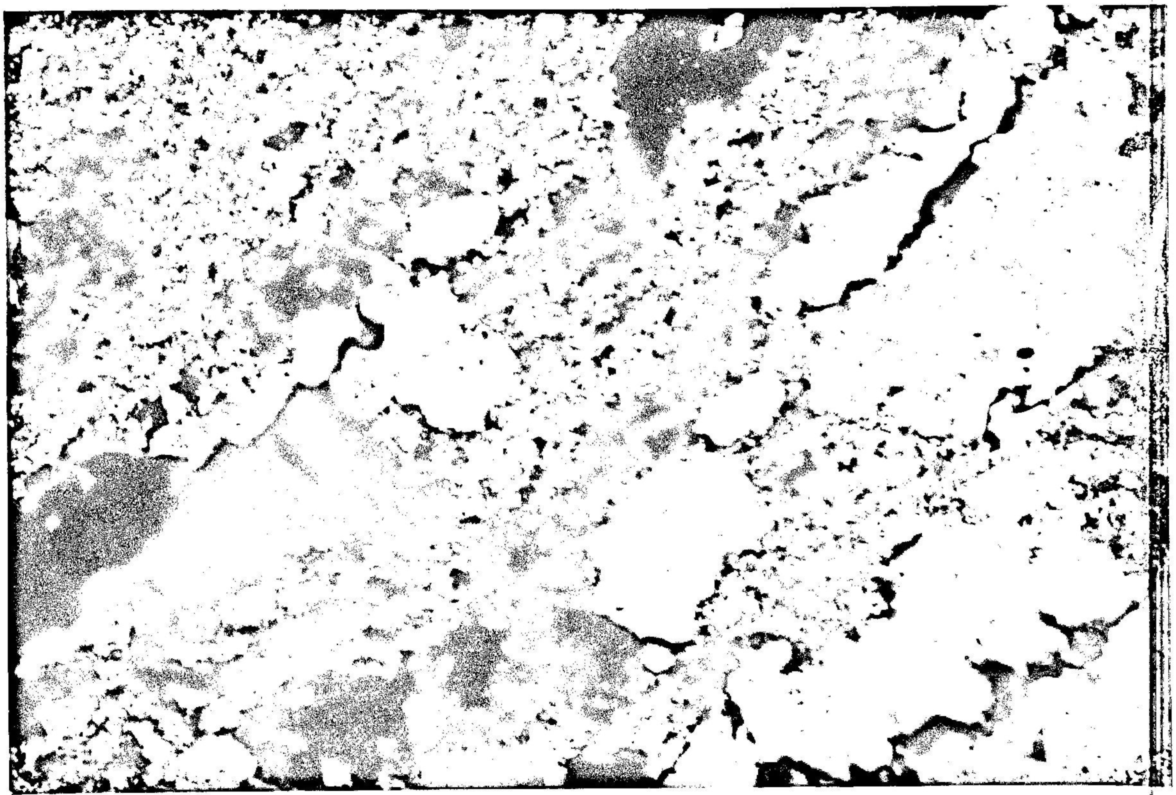

Figure 11. Photomicrograph of sample MRF-13, a mudstone with quartz vein (cross polarized light, approximately 400X).

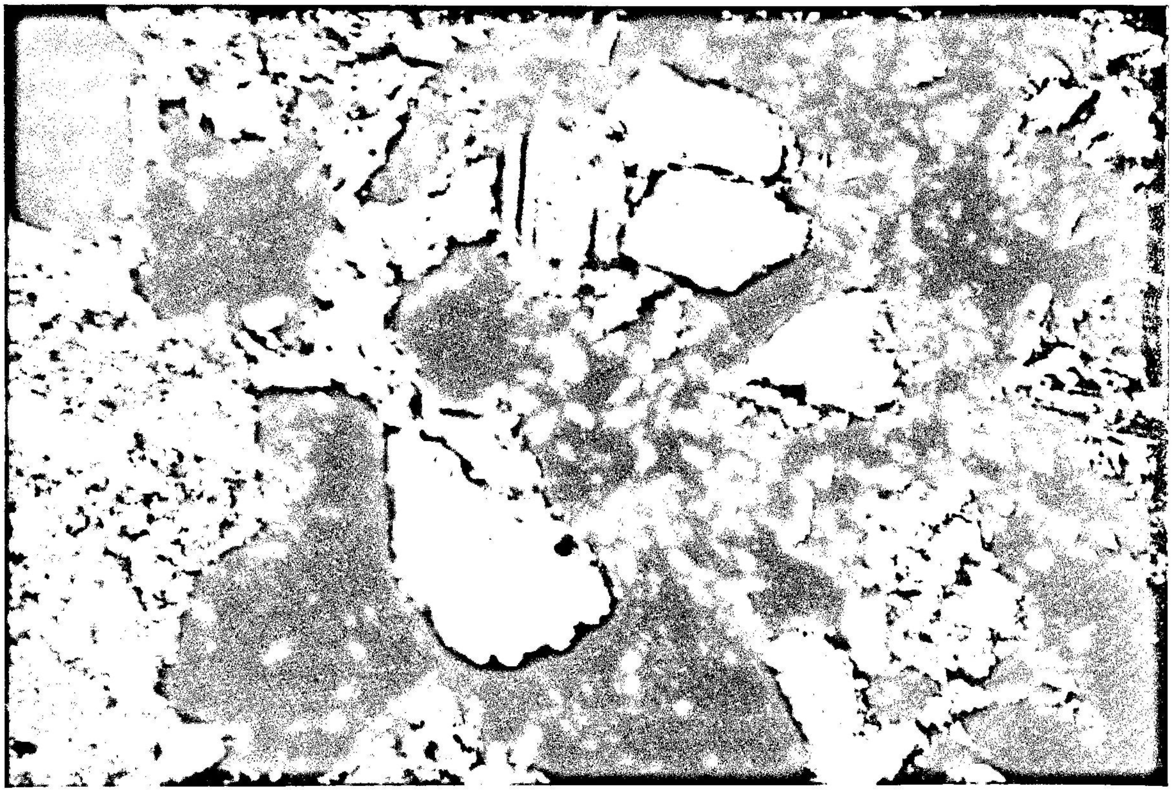

Figure 12. Photomicrograph of sample MRF-18, a calcareous siltstone (cross polarized light, approximately 400X).

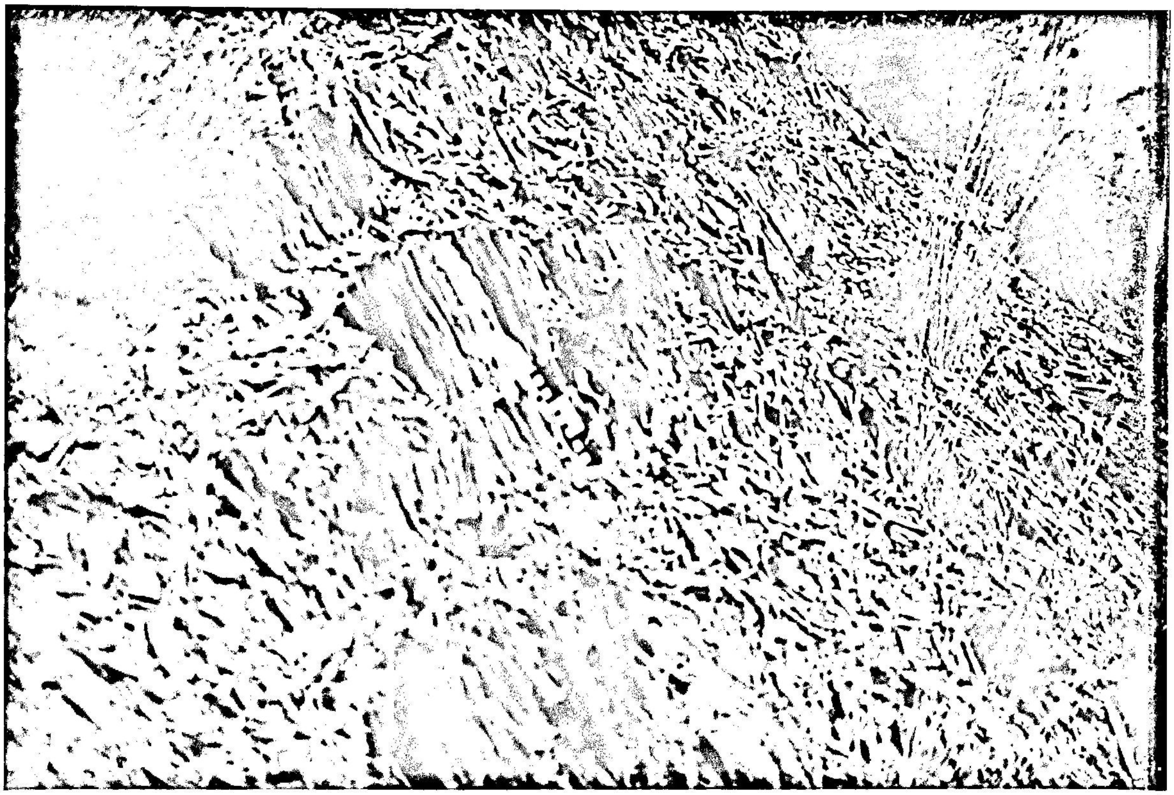

Figure 13. Pencil structure in a siltstone bed of the "Muddy Ranch Formation", located in the NE 1/4 of Section 31, T. 8 S., R. 19 E.

are best developed in the NE 1/4 of Section 31 in T. 8 S.,R. 19 E. This feature has also been termed "pencil cleavage" by Graham (1978) and Engelder and Gieser (1979). Pencil structures are formed by the intersection of bedding fissility and cleavage (Reks and Gray, 1982). Bedding fissility is formed by alignment of clay particles normal to the vertical maximum principal lithostatic stress resulting from the weight of the overlying strata (Hatcher, 1990).

Progressive development of tectonic cleavage in fine-grained sedimentary rocks has been divided by Ramsay and Huber (1983) into six stages of increasing tectonic strain. Those stages with slight modification by Hatcher (1990) are summarized as follows:

A. Undeformed condition - Bedding fissility develops.

B. Earliest deformation stage - Loss of volume, from reorientation of grains and expulsion of water, enhances bedding fissility.

C. Pencil structure - Elongate pencil-like fragments are produced by the intersection of bedding and cleavage, with no continuously organized planer cleavage. Such structure is best shown by homogeneous silty shales. Pencils generally parallel fold axes. This stage may be found in unmetamorphosed fine-grained rocks.

D. Embryonic cleavage stage - Weak, poorly developed cleavage parallel to fold axial surfaces results from pressure solution of silty carbonate or argillaceous rocks.

Minor recrystallization of new minerals such as illite, quartz, or calcite. This stage is most likely to be found in unmetamorphosed rocks.

E. Cleavage stage - A strong planar fabric results from pressure solution, reorientation of platy minerals, or incipient recrystallization of clays. Rocks displaying this cleavage stage range in metamorphic grade from anchizone to lower greenschist facies (chlorite zone).

F. Strong cleavage with mineral lineation - Slaty cleavage is better developed than earlier stages and a faint mineral elongation lineation appears on the cleavage. This is the highest stage of cleavage development and may occur throughout the chlorite zone of regional metamorphism; sometimes cleavage persists into the biotite zone.

The development of pencil cleavage is found in the third stage (C) which is associated with unmetamorphosed rocks. The development of pencil cleavage indicates that most of the "Muddy Ranch Formation" has undergone transformation to only the third stage and thus is composed of unmetamorphosed or only very weakly metamorphosed rocks. However, some samples (e.g. MRF-16) have been subjected to very low grade metamorphism as evidenced by the development of a slight phyllitic texture.

<u>Timing of Metamorphism</u>: Metamorphism of the "Muddy Ranch Formation" possibly occurred only after deposition of the Clarno Formation. Unmetamorphosed clastic dikes of

MRFintruded into the overlying sediments of the Clarno Formation supports this interpretation (Figure 14).

<u>Paleontology, Age, and Stratigraphic Position</u>: There have been no previously reported occurrences of fossils in the "Muddy Ranch Formation". During my fieldwork some burrow-like structures were found in the exposures near Post Pile Rock in the NE 1/4 of Section 31, T. 8 S., R. 19 E. but they were neither identifiable nor age diagnostic. To determine the relative age of the formation, 17 rock samples were collected for microfossil studies and sent to Unocal's Paleo/Stratigraphic Section for biostratigraphic age determination. Unfortunately all the samples were barren. Another ten samples were studied for palynomorphs but these were also barren. Due to the absence of any fossil evidence, it was not possible to determine the age of the "Muddy Ranch Formation".

At this time, all that is possible to say with certainty about the age of the "Muddy Ranch Formation" is that from stratigraphic relations it is older than the Clarno Formation. Similarities in lithology and the fact that the Muddy Ranch outcrops occur along the same structural trend as outcrops of the "Hay Creek Formation" suggest that they may be the same age, possibly Early Eocene according to Wareham (1986).

Taylor (1960) compared the rocks of the Muddy Ranch Inlier with cuttings from the Oregon Petroleum Company

Figure 14. Photograph showing unmetamorphosed clastic dikes of "Muddy Ranch Formation" intruded into the overlying rocks of the Clarno Formation located in the SW 1/4 SW 1/4 of Section 29, T. 8 S., R. 19 E.

Clarno No. 1 well drilled about five and a one half miles to the northeast. He concluded, based on the degree of metamorphism, that the cuttings of sedimentary rocks immediately underlying the Clarno Formation were younger than the rocks of "Muddy Ranch Formation". As the cuttings were unmetamorphosed, he suggested that the siltstones and shales penetrated by the well were probably Cretaceous in age and correlated them with Cretaceous outcrops near Mitchell. At greater depth, this well encountered very low grade metamorphic rocks which Taylor correlated with the "Muddy Ranch phyllite" and inferred a Permo-Triassic age. Although rocks of the "Muddy Ranch Formation" have been weakly metamorphosed, they do not show the higher grade metamorphism found in the most of Permo-Triassic rocks exposed elsewhere in Central Oregon. According to Fisk and Fritts (1987), black mudstones discovered below 2,000 feet in the Oregon Petroleum Company Clarno No. 1 and Clarno Oil Company Burgess No. 2 wells may be equivalent to the Paleocene to Early Eocene "Herren Formation" of Shorey (1976). Similar rocks in the "Hay Creek Inlier" have been dated as Early Eocene by Wareham (1986).

Judging from similarities in lithology, intensity of metamorphism, and stratigraphic position, I agree that the rocks of the "Muddy Ranch Formation" may be Paleocene to Early Eocene in age, equivalent to the "Herren Formation" of Shorey (1976) and/or the "Hay Creek Formation" of Wareham

(1986). However, due to the absence of both fossil evidence and radiometric dates, these correlations could be erroneous.

Depositional Environment: The rocks of the "Muddy Ranch Formation" could have been deposited in a variety of environments either marine or nonmarine. Taylor (1960) suggested that these rocks were deposited in a marine environment and cited as evidence the well-developed bedding, the fineness and constancy of grain size, the lack of high oxidation, and the similarity with metamorphosed marine sediments at Tony Butte. Kleinhans and others (1984) were of the opinion that the rocks of "Muddy Ranch Formation" were submarine fan turbidites. Due to the absence of any definitive criteria indicating a lacustrine environment (Picard and High, 1972) and the presence of graded beds, some sediments of the "Muddy Ranch Formation" were probably deposited by turbidity currents and presumably into a deep water offshore marine environment. The turbidite sequence consists of rhythmically bedded, dark gray to black siltstones to fine-grained sandstones, 2-3 cm. thick, showing graded bedding with small current ripples at the base and planar lamination in the upper part (Figure 15) characteristic of facies C and D of the classic Bouma sequence (Bouma, 1962). Similar turbidites to those of the "Muddy Ranch Formation" are exposed to the southwest in the Hay Creek Inlier. They were interpreted by Wareham (1986)

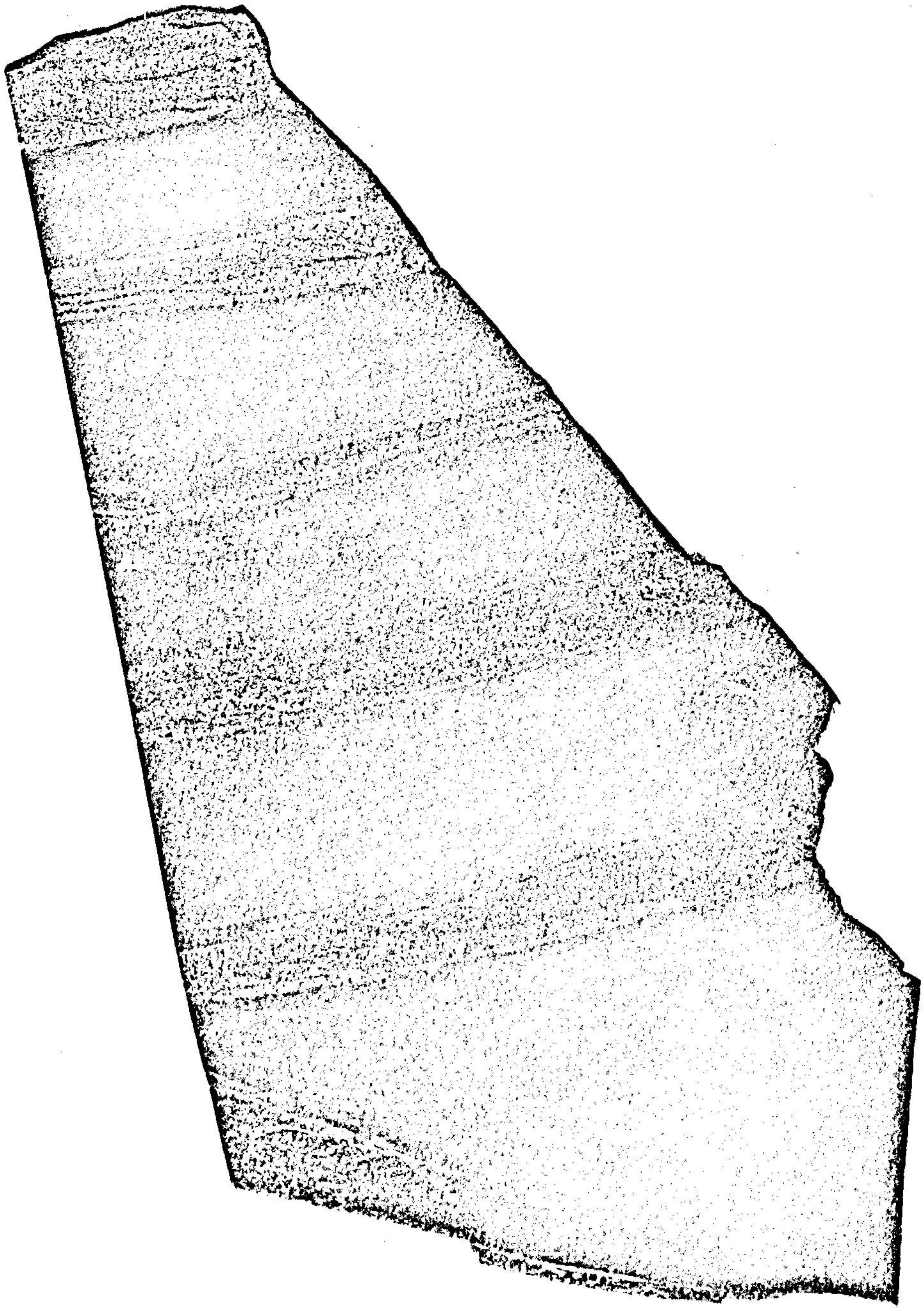

Figure 15. Photograph of a polished slab showing a sequence of turbidites in the "Muddy Ranch Formation". Note the small current ripples. Well exposed in the NE 1/4 of Section 31, T. 8 S., R. 19 E. (actual size).

as being deposited on a submarine fan complex near a shallow marine shelf. The provenance of sediments for the deposition of "Muddy Ranch Formation" could possibly be from Blue Mountains terranes to the east and southeast. Sandefur(1986) found that the submarine fan complex at Mitchell had a predominantly northwesterly paleocurrent direction during Cretaceous time.

Clarno Formation

Volcaniclastic rocks of the Clarno Formation overlie the "Muddy Ranch Formation" with an erosional and angular unconformity. This formation was named by Merriam (1901) for outcrops near the community of Clarno about five miles northeast of the research area. A thick sequence of Clarno volcanic and volcaniclastic strata measuring 5800 feet (Swanson and Robinson, 1968) is exposed in the vicinity of the Horse Heaven Mine approximately ten miles south of my research area. In the vicinity of the Muddy Ranch the sequence is much reduced presumably due to deposition on a topographic high represented by outcrops of the "Muddy Ranch Formation".

Physiographic Expression: The topography surrounding the Muddy Ranch Inlier is a deeply dissected highland. The hill summits have convex tops with steep slopes. Vertical ciffs with talus are not uncommon. At lower elevations lacustrine beds of semiconsolidated and unconsolidated tuff compose the valleys and gentle slopes. The physiographic expression of the hill tops on the southeastern part of the research area have a "stepped plateau" appearance which could be due to ancient landslides (Anonymous, 1982). Elsewhere on the hill slopes sometimes hoodoo structures (Figure 16) are found.

Lithology: The Clarno Formation in the research area is composed of tuffs, tuff breccias, andesite intrusions and flows, volcaniclastic conglomerates and sandstones, and rarely shaley coal. Where weathered, tuffaceous siltstones form bentonitic swelling clays. Red saprolitic clay zones are also present in the Clarno sequence; these have been interpreted as paleosols by Retallack (1981).

Paleontology, Age, and Stratigraphic Position: The Clarno Formation is well known for its diverse flora and fauna (Scott, 1954; Hergert, 1961; Arnold, 1963, 1964; McKee, 1970; Hanson, 1973; Manchester and Dilcher 1980; and Manchester 1981). The described flora includes fan palms, cycads, magnolias, grapes, and a diversity of other plants (Manchester, 1981). While describing the fossil plants of the Clarno "nut beds" near Camp Hancock about five miles northeast of Muddy Ranch, Manchester (1981) gave a list of identified plant remains which included 140 genera. Manchester concluded that the age of this fossil flora was Middle Eocene. During field mapping, fossil leaves were found at two localities in my research area: in laminated lacustrine shales in the SW 1/4 SE 1/4 of Section 32, T. 9

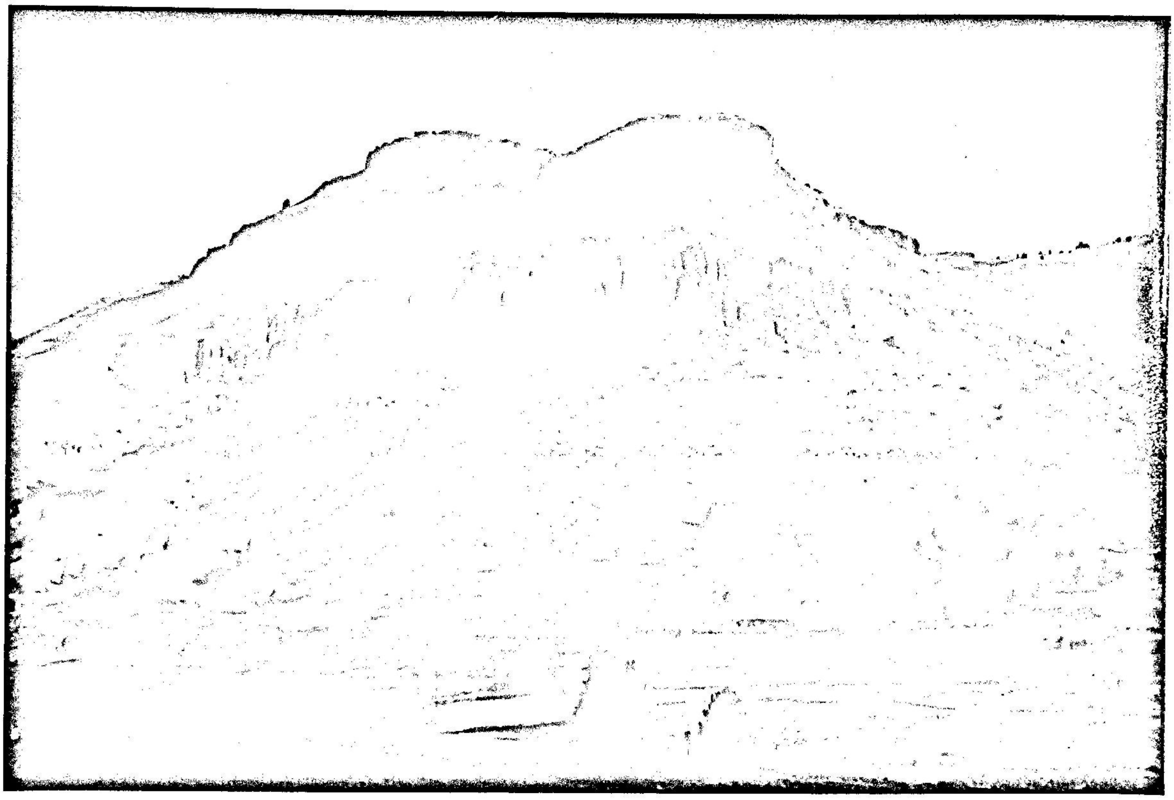

Figure 16. Hoodoo forming conglomerate in the Clarno Formation. Photograph was taken on well exposed outcrop on the eastern bank of John Day River, east margin of the research area.

S., R. 19 E. and in channel-fill sandstone (Figure 17) in the SW 1/4 NW 1/4 of Section 29, T. 8 S., R. 19 E. Leaf impressions were identified by Dr. Lanny H. Fisk as Ginkgo, Typha or Cycad, Equisetum, Asplenium (?) fern, and a member of the family Juglandaceae. Although not well preserved, these florules deserve further study.

Samples of carbonaceous shale collected from small isolated outcrops in the Clarno Formation yielded an age-diagnostic palynoflora (Table 2) including Caryapollenites veripites indicative of a Middle Eocene age.

Three intrusive rock samples were dated by the potassium-argon whole rock technique (Appendix B). Two samples gave dates within the range of ages previously reported for the Clarno Formation -- 29.0 $\pm$ 1.7 and 42.4 $\pm$ 2.0 million years. The date of 42.4 $\pm$ 2.0 million years came from Post Pile Rock, an intrusion into the "Muddy Ranch Formation" (Figure 18). The third sample gave an anomalously old date of 69.8 $\pm$ 3.9 million years. Its discordance is probably due to excess argon possibly resulting from intrusion into Clarno lacustrine sediments. A fission track age of about 44 million years (average of 5 ages ranging from 46.1-42.7 million years) was reported on tuffs from the Muddy Ranch area by Vance (1988). From these radiometric dates, the age range of Clarno Formation strata exposed in the research area is roughly between 46 and 30 million years .

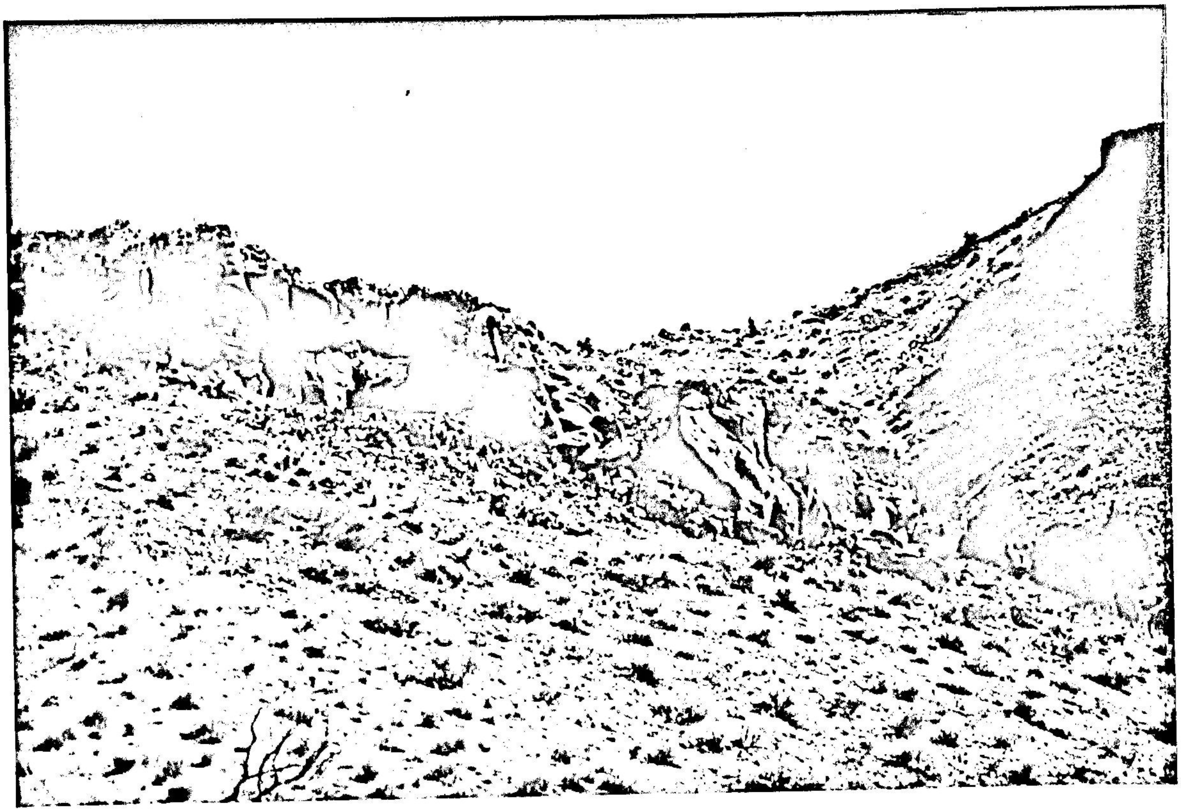

Figure 17. Outcrop photograph of the leaf-bearing, channel-fill, tuffaceous sandstone in the Clarno Formation located in the SW 1/4 NW 1/4 of Section 29, T. 8 S., R. 19 E.

Table 2. List of palynomorphs identified from carbonaceous shales of the Clarno Formation outcropping in the NE 1/4 NW 1/4 of Section 31, T. 8 S., R. 19 E. and in the SE 1/4 NW 1/4 of Section 20, T. 8 S., R. 19 E.

Osmundacidites sp.
Betulapollenites sp.
Alnipollenites sp.
Ulmipollenites sp.
Caryapollenites veripites
Momipites sp.

Depositional Environment: Taylor (1960) interpreted the thick mudflow conglomerates, tuffs, and tuffaceous shales of the Clarno Formation to have been deposited on a broad flood plain. Finely laminated tuff beds (Figure 19), freshwater fish (Cavender, 1968), and carbonaceous shale provide evidence of a lacustrine origin. Channel-fill sandstones indicate that fluvial environments were also present. The fossil flora of the Clarno Formation indicates that the lakes and streams were surrounded by a tropical rain forest (Manchester, 1981; Retallack, 1981).

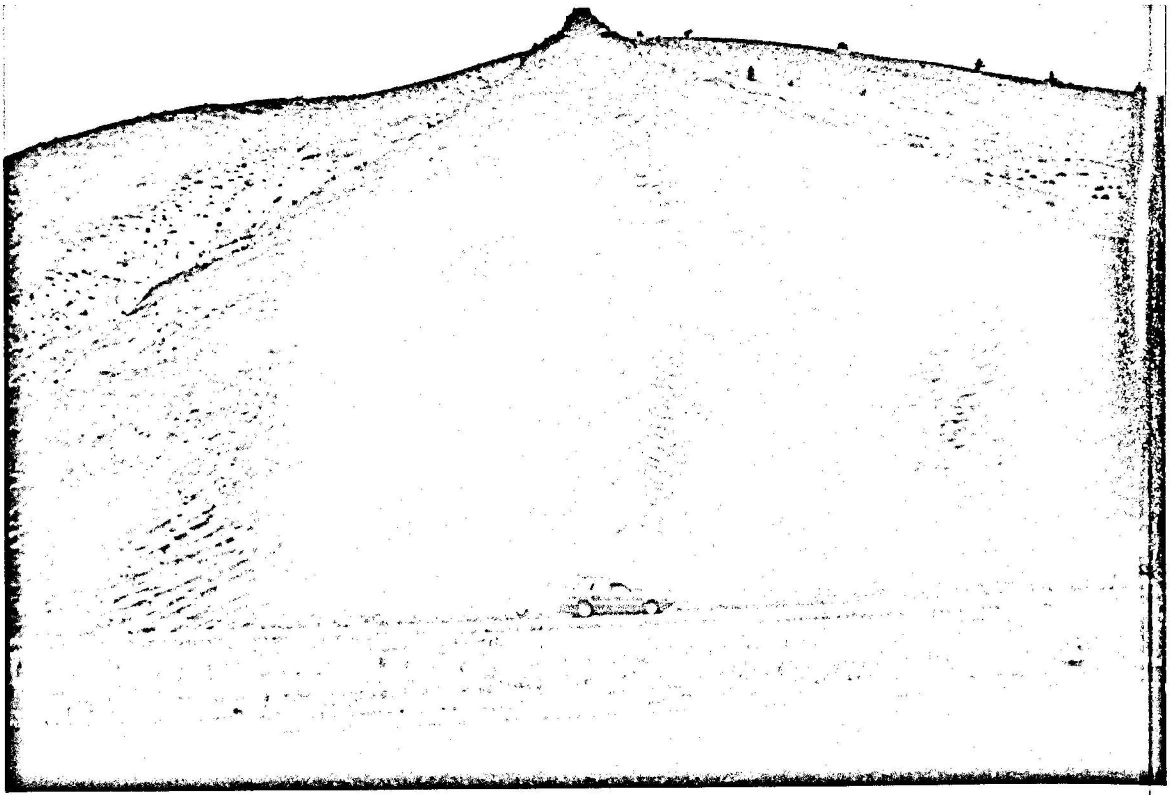

Figure 18. Post Pile Rock, a Clarno age basaltic intrusion into rocks of the "Muddy Ranch Formation", located in the SW 1/4 NE 1/4 of Section 31, T. 8 S., R. 19 E.

Figure 19. Photograph showing lake beds of the Clarno Formation located in the SE 1/4 SE 1/4 of Section 36, T. 8 S., R. 18 E.

STRUCTURE

The rocks of the Muddy Ranch Inlier are exposed along the breached axis of a doubly-plunging anticline (Figure 5), here informally named the "Muddy Ranch Anticline" which forms part of the Blue Mountains Anticlinorium. The axis of the "Muddy Ranch Anticline" trends NNE-SSW. Uplift and folding occurred after deposition of the Clarno Formation but probably before the end of John Day time (Fisher, 1967).

GEOLOGIC HISTORY

The rocks exposed on the Muddy Ranch record an incomplete history of events and changing environments during Tertiary time. The sedimentary rocks of the "Muddy Ranch Formation" were probably deposited in Paleocene or early Eocene time in a marine environment. Coarse- to fine-grained sediments were deposited in this marine basin primarily by turbidity currents. The provenance of these sediments was possibly to the east and southeast where prograding deltas of the "Herren Formation" (Shorey, 1976; Fisk, in preparation) received sediments from metamorphic and crystalline highlands further to the east and southeast. Sometime during the Early Eocene the area was uplifted, the seas withdrew, and a period of erosion followed. During Middle Eocene time this region was an alluvial plain containing shallow streams and lakes interspersed with numerous active volcanoes. Intense volcanic activity resulted in the deposition of volcaniclastic sediments of various composition inter-layered with lacustrine and fluvial deposits. The bulk of the Clarno Formation was formed from air-borne ash and ash falling into water. Reworking by water formed thick deposits of tuffaceous sediments, including mudflow conglomerates and breccias, siltstones, claystones, and minor sandstones. Periodically the volcaniclastic sediments were covered by andesitic and basaltic lava flows and intruded by dikes and pipes.

Magmatic fluids and intense heat associated with the late Clarno intrusions caused low grade metamorphism of the underlying siltstones and sandstones of the "Muddy Ranch Formation". Later tectonic activities uplifted the area and erosion cut through the entire pile eventually exposing the weakly metamorphosed rocks of the "Muddy Ranch Formation".

The Blue Mountains Anticlorium was formed during Pliocene time (Fisher, 1967) due to northwest-southeast crustal compression. As a result of such forces, the "Muddy Ranch Formation" with the overlying Clarno rocks were further uplifted. During Pleistocene and Holocene time erosion removed the overlying Clarno rocks to expose the lower parts of the Clarno Formation and the Muddy Ranch Inlier. These eroded materials with other sediments were deposited in valleys and stream beds to form Quaternary alluvium.

PETROLEUM POTENTIAL

For petroleum generation and accumulation to occur in the vicinity of Muddy Ranch all the following requirements must be present: (1) organic rich, thermally mature, source rocks, (2) porous and permeable reservoir rocks, (3) seals to prevent generated petroleum from escaping to the surface, and (4) traps to accumulate hydrocarbons in commercial quantities. Petroleum seeps and shows in oil wells drilled in the area could provide direct evidence that some, if not all, of these requirements have been met.

Source Rock Analyses

Thirteen samples of carbonceous siltstone from the "Muddy Ranch Formation" and four samples of carbonaceous siltstone from the Clarno Formation were analyzed for petroleum source rock potential by Conoco and Unocal. The results of these source rock analyses, along with those published by Sidle and Richers (1985), will be discussed below.

Total Organic Carbon: This value is a simple measure of organic richness and is used to determine if samples contain sufficient organic material to produce petroleum upon heating. The general rule of thumb is that samples with less than 0.5% total organic carbon (TOC) cannot yield sufficient petroleum to form commercial petroleum deposits and therefore are considered non-source rocks. Samples containing between 0.5 and 1% TOC are rated as having marginal to good source quality and samples with greater than 1.0% TOC have excellent source rock quality.

TOC measurements by Unocal and Conoco are given in Table 3. The TOC content of the thirteen MRF samples ranges from 0.15 to 3.17 weight percent with a mean of 0.81 percent. These quantities indicate that MRF siltstones have poor to excellent potential for petroleum generation. The four samples of Clarno Formation siltstone yielded a TOC range of 1.76 to 3.63 percent, indicating excellent source rock potential.

Kerogen Analysis: The acid-insoluble organic matter found in rock samples is known as kerogen. Identifying the kind of kerogen present in a source rock can indicate the type of petroleum that it would have generated when it was heated. Thomson and Dembicki (1986) have classified kerogen into AA, amorphous type A (oil prone); AC, amorphous type C (gas prone); AD, amorphous type D (oil or gas prone); H, herbaceous; W, woody; and V, vitrinite. The last three types are all gas prone. Conoco provided visual kerogen analysis on eight samples from the "Muddy Ranch Formation" (Table 4). All eight were dominated by amorphous type C kerogen and are gas prone. In the four samples from the Clarno Formation, the kerogen composition ranged from AA to V, indicating oil to gas prone (see Table 4).

Table 3. Total organic carbon measurements from thirteen samples of "Muddy Ranch Formation" (MRF) and four samples of Clarno Formation (CFt) carbonaceous siltstones.

Sample Number	TOC from Conoco (wt.%)	TOC from Unocal (wt.%)
MRF-9	0.46	0.60
MRF-10	0.61	1.15
MRF-11	0.26	1.19
MRF-12	0.15	0.86
MRF-14	3.17	3.10
MRF-15	0.40	0.76
MRF-20	0.66	1.15
MRF-23	0.59	1.03
MRF-25	-	0.17
MRF-26	-	0.18
MRF-27	-	0.18
MRF-28	-	0.17
MRF-29	-	0.17
CFt-6	1.85	1.76
CFt-8	2.40	2.57
CFt-9	3.63	3.11
CFt-10	2.55	2.63

Table 4. Visual kerogen analyses of potential petroleum source rocks from "Muddy Ranch Formation" (MRF) and Clarno Formation (CFt). Data kindly provided by Conoco.

Sample	Kerogen Composition* (in volume %)					
Number	AA	AC	AD	H	W	V
MRF-9	-	100	-	-	-	-
MRF-10	-	100	-	-	-	-
MRF-11	-	100	-	-	-	-
MRF-12	-	95	-	-	5	-
MRF-14	-	95	-	5	-	-
MRF-15	-	100	-	-	-	-
MRF-20	-	100	-	-	-	-
MRF-23	-	100	-	-	-	-
CFt-6	20	-		50	-	30
CFt-8	-	-	30	20	-	50
CFt-9	-	85	10	5	-	-
CFt-10	-	100	-	-	-	-

*Kerogen classification follows Thomson and Dembicki (1986): AA = Amorphous Type A (oil prone); AC = Amorphous Type C (gas prone); AD = Amorphous Type D (oil or gas prone); H = Herbaceous; W = Woody; V = Vitrinite.

Thermal Maturity: The thermal maturity of a petroleum source rock may be determined in several ways. By visually examining kerogen under the microscope, it is possible to quantitatively judge their maturation level by color and subjectively assign samples a number on the thermal alteration index (TAI) scale (Staplin, 1982). The lowest level on the TAI scale (1) is indicated by pale yellow, the mid-level (2.5) by brown, and the highest (5) by black. Kerogen in the TAI range of 1-2 have not been heated to levels sufficient to generate thermogenic petroleum and are considered immature. When heated in the color range 2-4 (orange brown to brown black) kerogen produce oil and gas and thus are termed mature. TAI levels above 4 indicate overmature kerogens which have already produced all the petroleum that they are capable of generating.

In the palynology samples I prepared, all the kerogens from the "Muddy Ranch Formation" were overmature with colors of brown black to black and TAI levels of 4.5-5. However, kerogens from the Clarno Formation ranged from orange brown to brown black in color (TAI = 2-4) and were mature for oil and gas generation.

Thermal maturity of kerogen can also be obtained by measuring the percentage of light reflected by microscopic vitrinite particles. Vitrinite reflectance in oil (R_0) measurements provide a quantitative measure by which TAI data can be calibrated and checked. Oil generation starts at R_o values of about 0.65 percent and ends approximately at 1.30 percent; gas generation continues above 1.30 percent. Table 5 contains R_o measurements for seven samples from the "Muddy Ranch Formation" and four from the Clarno Formation. The R_o for the MRF samples ranges from 2.14 to 4.28 percent indicating that they are overmature for oil generation and all but one sample are in the latest stage of gas generation. The four Clarno samples yielded R_o values of 0.75 to 1.53, indicating that they have been heated to the oil generating stage with one sample in the early gas stage. These results are in agreement with and confirm my subjective TAI determinations discussed above.

A third measure of thermal maturity is T_{max}, the temperature in degrees Centigrade at which the maximum quantity of hydrocarbons are generated from kerogen in a sample during Rock Eval pyrolysis. Using this measure, the "oil window" extends from approximately 435° to 470° C (depending on kerogen type). T_{max} values less than 435° C indicate insufficient maturity for significant petroleum generation and those exceeding 470° C are overmature for oil generation but have generated thermogenic gas.

The T_{max} value for eleven samples from the "Muddy Ranch Formation" are included in Table 5. T_{max} ranges from 353° to 589° C indicating that samples are immature to overmature for oil and gas generation. Four Clarno samples yielded T_{max}

Table 5. Thermal maturation data from samples of carbonaceous siltstone from the "Muddy Ranch Formation" (MRF) and Clarno Formation (CFt). Data kindly provided by Conoco (R_o and T_{max}) and Unocal (T_{max}). ND indicates no data.

Sample Number	R_o (in %)	Conoco T_{max}	Unocal T_{max}
MRF-9	4.08	445?	ND
MRF-10	4.26	503?	542
MRF-11	4.26	524?	382
MRF-12	ND	463?	364
MRF-14	2.14	589?	494
MRF-15	4.28	522?	407
MRF-20	4.13	584?	419
MRF-23	4.23	483?	356
MRF-25	ND	ND	449
MRF-26	ND	ND	431
MRF-27	ND	ND	ND
MRF-28	ND	ND	456
MRF-29	ND	ND	353
CFt-6	0.95	519	494
CFt-8	0.75	521	447
CFt-9	1.05	585?	505
CFt-10	1.53	573?	497

ranges from 447° to 585° C indicating that these samples are mature to overmature for oil and gas generation.

<u>Rock Eval Pyrolysis</u>: Rock Eval pyrolysis is done to determine if potential source rocks have the capability of generating, or already have generated, oil and gas. In this laboratory test a 100 mg. sample of rock is pyrolysed at 300° C for 3-4 minutes then the pyrolyzation temperature is raised to 550° C at the rate of 25 degrees per minute. During heating the hydrocarbons produced by pyrolysis are both qualitatively and quantitatively analyzed. Rock Eval pyrolysis data provided by Conoco and Unocal are given in

Table 6. Guidelines for interpretation and use of these data are given below.

Table 6. Rock-Eval pyrolysis data for samples from the "Muddy Ranch Formation" (MRF) and Clarno Formation (CFt). All data were provided by Conoco (C) or Unocal (U). ND indicates no data were provided.

Sample Number	Lab	S_1 (mg/g)	S_2 (mg/g)	S_3 (mg/g)	S_2/S_3	HI	OI	PI	RCI (%)
MRF-9	C	0.00	0.08	0.10	0.80	17	22	0.00	1.74
MRF-9	U	0.10	0.05	ND	ND	8	ND	0.67	2.5
MRF-10	C	0.00	0.06	0.18	0.33	10	30	0.00	0.98
MRF-10	U	0.09	0.02	ND	ND	2	ND	0.82	0.96
MRF-11	C	0.00	0.10	0.13	0.77	38	50	0.00	3.85
MRF-11	U	0.09	0.01	ND	ND	1	ND	0.90	0.84
MRF-12	C	0.00	0.06	0.32	0.19	40	213	0.00	4.00
MRF-12	U	0.09	0.01	ND	ND	1	ND	0.90	1.16
MRF-14	C	0.02	0.08	1.61	0.05	3	51	0.20	0.32
MRF-14	U	0.10	0.03	ND	ND	1	ND	0.77	0.42
MRF-15	C	0.01	0.17	0.12	1.42	43	30	0.06	4.50
MRF-15	U	0.08	0.04	ND	ND	5	ND	0.67	1.58
MRF-20	C	0.00	0.05	0.29	0.17	8	44	0.00	0.76
MRF-20	U	0.14	0.03	ND	ND	3	ND	0.82	1.48
MRF-23	C	0.00	0.07	0.05	1.40	12	8	0.00	1.19
MRF-23	U	0.09	0.02	ND	ND	2	ND	0.81	1.07
MRF-25	U	0.05	0.01	ND	ND	6	ND	0.83	3.53
MRF-26	U	0.06	0.03	ND	ND	17	ND	0.67	5.00
MRF-27	U	0.07	0.02	ND	ND	11	ND	0.78	5.00
MRF-28	U	0.07	0.03	ND	ND	18	ND	0.70	5.88
MRF-29	U	0.06	0.02	ND	ND	12	ND	0.75	4.70
CFt-6	C	0.01	0.53	2.18	0.24	29	118	0.02	2.92
CFt-6	U	0.08	0.11	ND	ND	6	ND	0.42	1.08
CFt-8	C	0.01	0.58	2.00	0.29	24	83	0.02	2.92
CFt-8	U	0.14	0.69	ND	ND	27	ND	0.17	3.20
CFt-9	C	0.00	0.12	3.09	0.04	3	85	0.00	0.33
CFt-9	U	0.07	0.06	ND	ND	2	ND	0.54	0.42
CFt-10	C	0.00	0.02	1.86	0.01	1	73	0.00	0.08
CFt-10	U	0.10	0.04	ND	ND	2	ND	0.71	0.53

The first measurement obtained during Rock Eval pyrolysis is termed S_1. It represents the quantity of hydrocarbons (bitumen) present in the sample prior to heating. This parameter is useful in determining the presence of hydrocarbons previously generated and not yet migrated out of a sample. S_1 is reported in milligrams of hydrocarbons per gram of rock. The S_1 quantity for all the samples I collected were very low, indicating that they contained only trace amounts or no free hydrocarbons.

The second parameter measured during the Rock Eval pyrolysis is S_2, the quantity of hydrocarbons released by kerogen during pyrolysis. S_2 is directly related to the source rock potential; samples with values less than 2.5 mg/g are considered poor source rocks; values in the range of 2.5 to 5.0 mg/g are considered marginal; and values greater than 5.0 mg/g suggest that the sample has good to excellent petroleum source possibilities. Using this scale, S_2 values of the samples from my research area, ranging from 0.01 mg/g to 0.69 mg/g, indicate that they all have poor source rock potential. However, I suspect that these S_2 values are low because most samples are thermally overmature and are not capable of generating further quantities of hydrocarbons.

The ratio S_2/S_3 can be used as a general indication of the kerogen type (i.e., whether the organic matter is prone to generate either oil or gas). As a general rule S_2/S_3 ratios less than 5.0 are more prone to gas generation;

values greater than 10.0 are suggestive of primarily oil generation. Between 5.0 and 10.0 is an indeterminate zone,

The third parameter measured during Rock Eval pyrolysis, S_3, is a measure of the amount of organic matter in a sample which is incapable of generating hydrocarbons. S_3 can be used to assess the organic facies of the sample being tested and like S_1 and S_2 is reported in mg/g usually described as the "wet gas" or condensate zone. The S_2/S_3 values for the samples from my research area range from 0.01 to 1.42, indicating that they are prone to gas generation.

The Productivity Index ($PI = S_1/S_1 + S_2$) is a measure of the overall hydrocarbon-generating potential of a sample. The PI is a function of both maturity and migration since as a source rock matures, more and more of the hydrocarbon-prone kerogen (S_2) will be converted to free hydrocarbons (S_1). Very high relative concentrations of free hydrocarbons (high productivity indices) suggest the presence of migrated oil. As anticipated, all of the outcrop samples yielded a very low PI since none of them would be expected to produce migrated oil.

The Reactive Carbon Index ($RCI=(S_1 + S_2) \times 10^{-2}/TOC$) describes the proportion of total organic carbon present as either free hydrocarbons (S_1) or kerogen with petroleum generating potential (S_2). The RCI can vary considerably for petroleum source rocks (10 to 100 percent); samples with values less than 10 percent are considered poor source rocks. All of the samples from my research area yielde/d RCI values less than 10% but, since S_1 and S_2 values were so low, the RCI is not a good measure of the true source rock potential but instead is a function of thermal maturity.

The Hydrogen Index (HI = S_2/TOC x 10^{-1}) in Table 6 is a comparison of the hydrogen richness of the kerogen in each sample relative to the amount of total organic carbon in the sample. The Oxygen Index (OI = S_3/TOC x 10^{-1}) is a measure of the oxygen richness of the kerogen, measured by monitoring the carbon dioxide released during pyrolytic decomposition. When HI is plotted against OI on a Van Krevelen-type diagram, additional information on kerogen type and maturity can be obtained (Figure 20). From the Van Krevelen-type diagram it can be seen that all the samples are over mature and contain Type III, gas prone kerogen.

<u>Summary and Discussion</u>: The petroleum source rock analyses of the "Muddy Ranch Formation" samples indicate that these rocks have sufficient gas-prone kerogen to be good hydrocarbon source rocks. However, thermal maturity indicators show that they are post-mature for oil generation and are in the latest stage of gas generation. Overmaturity of these rocks indicates that they probably have generated hydrocarbons in the past.

These results differ somewhat from those reported by Sidle and Richers (1985), who analysed the petroleum source rock potential of one sample from the Muddy Ranch Inlier.

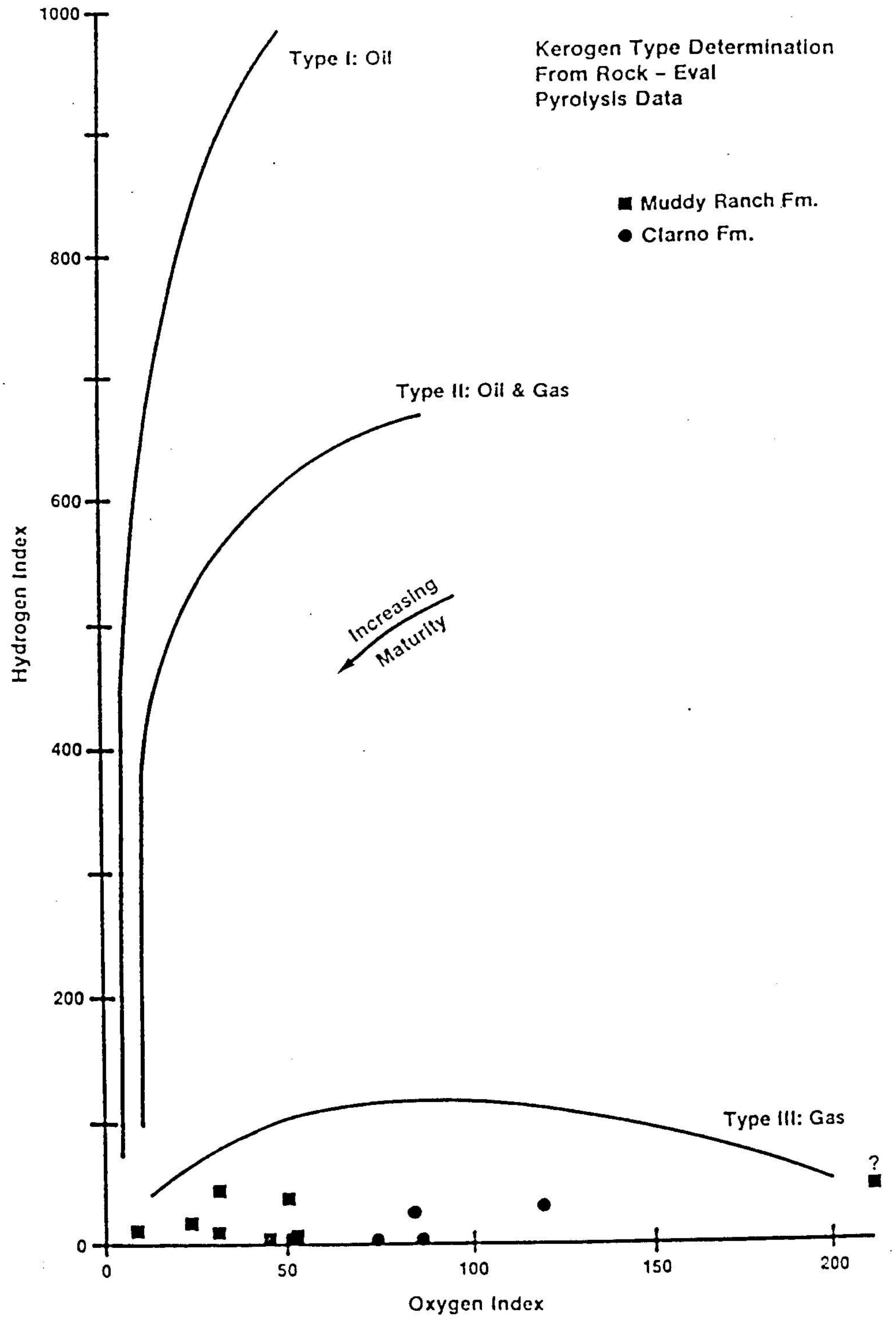

Figure 20. A plot of hydrogen index (HI) versus oxygen index (OI) for samples from the "Muddy Ranch Formation" and Clarno Formation. Data are from Conoco.

The TOC value for that sample was higher than values obtained in this study (1.82% vs. 0.81% average). In addition, the Rock Eval pyrolysis data reported by Sidle and Richers (1985) indicated that their sample contained mature "type II (mixed marine) oil-prone kerogen" whereas all my samples appear to contain over-mature type III, gas-prone kerogen. These differences may be due to differences in either sampling or laboratory techniques. The latter is very likely considering the significant differences in Rock Eval data from portions of the same samples analyzed for me by Conoco and Unocal laboratories (see Table 6). Despite the differences between my data and those of Sidle and Richers (1985), we are in agreement that the rocks of the Muddy Ranch Inlier are potential petroleum source rocks and therefore may have generated significant quantities of petroleum during maturation.

Rock samples of Clarno Formation were found to be good to excellent source rocks, oil prone, and mature for oil generation. Hydrocarbons generated from these petroleum source rocks could have migrated and been trapped in overlying reservoir rocks.

Potential Reservoir Rocks

For a rock to act as a petroleum reservoir it must possess two essential properties: it must have pores to contain oil or gas and these pores must be connected to allow the movement of these fluids. In other words, the rock must have both porosity and permeability (Selley, 1985). Porosity is expressed in percentage and is the ratio of voids to the volume of solid rock. There are two kinds of porosity: primary porosity developed during sedimentation and retained during diagenesis, and secondary porosity which forms after deposition, during diagenesis, due to the dissolution of intergranular cement or individual grains and the formation of fractures.

In addition to either or both primary and secondary porosity, a good reservoir rock must also have adequate permeability, the ability of fluids to pass through a porous medium. The unit of permeability is the Darcy, which is defined as the permeability that allows a fluid of one centipoise (cP) viscosity to flow at a velocity of one centimeter per second for a pressure drop of 1 atm/cm (Selley, 1985). As reservoir permeability is most often less than one Darcy, the millidarcy (md) is commonly used.

No direct porosity or permeability measurements were made on potential reservoir rocks from the "Muddy Ranch Formation". However, thin section porosity of "Muddy Ranch Formation" samples is poor, usually less than one percent (Appendix A). At depth MRF sandstones may have developed sufficient secondary porosity due to fracturing or grain dissolution to make them adequate reservoir rocks for natural gas; however, this is doubtful.

Volcaniclastic sandstones and fractured silicified tuffs and flows in the Clarno Formation could be fair to good petroleum reservoir rocks. Riddle (1990) has found that the porosity of 14 sandstone samples from the Clarno Formation range from 4 to 38 percent with an average of 17.4 percent. Permeability values for these same samples ranged up to 43 millidarcies with an average of 8.13 millidarcies, indicating that Clarno sandstones are potential petroleum reservoirs. The presence of fracture zones in the Clarno Formation which serve as aquifers capable of yielding up to 6380 barrels of water per day (200 gallons of water per minute; Anonymous, 1982) is good evidence that these rocks could even be excellent petroleum reservoir rocks.

Seeps and Shows:

The oil and gas shows in the Clarno Oil Company Burgess No. 2 well in the Clarno area located about five and one half miles north of the Muddy Ranch is direct evidence that hydrocarbons have been generated. Asphaltic dikes found along Highway 218 in the Clarno area is another direct evidence of hydrocarbon generation (Fisk and Fritts, 1987). The presence of asphaltite in veins and fractures along Dry Creek (Buwalda, 1921) on the north edge of my research area (Figure 21) and the presence of a hydrocarbon anomaly in the soil in the northeastern part of the Muddy Ranch (Sidle and Richers, 1985) indicate that in the subsurface reservoir rocks could contain commercial quantities of hydrocarbons.

Figure 21. Exposures of brown calcite, possibly due to asphalt inclusions. Exposure is located along the south side of Dry Creek in the SE1/4 NW1/4 of Section 20, T. 8 S., R. 19 E.

Conclusions: The thermally overmature siltstones of the "Muddy Ranch Formation" can be categorized as good to excellent petroleum source rocks which in the past may have produced large quantities of hydrocarbons. As potential reservoir rocks the MRF sandstones have poor primary porosity. However, the possibility of diagenetic andfracture porosity development at depth cannot be ruled out. Carbonaceous siltstones in the Clarno Formation volcanic and volcaniclastic rock sequence overlying the "Muddy Ranch Formation" are excellent petroleum source rocks and sandstones and fracture zones in the sequence could serve as good reservoir rocks. The presence of a structure like the "Muddy Ranch Anticline" and impervious clay beds which could act as seals to trap accumulated oil or gas indicate that the Muddy Ranch area does have petroleum potential. To test this potential will require drilling one or more wildcat wells which just might discover commercial hydrocarbon deposits.

MINERAL RESOURCE POTENTIAL

Metallic Minerals

No detail studies have previously been published on the mineral potential of the Muddy Ranch. During field work minor amounts of silver and cinnabar (the mineral ore of mercury) were observed in some quartz and calcite veins (Figure 22). The possibility of enrichment of these minerals into ore bodies with gold and lead as was found in the Copiapo volcanic complex in Chile (Mulja and Zentilli, 1987) cannot be ruled out. Cinnabar was commercially mined for many years from the Horse Heaven Mine south of Muddy Ranch. These deposits are associated with a rhyolite plug (Swanson and Robinson, 1968). East of my research area in the Spring Basin Wilderness Study Area in Wheeler County, Ach and others (1988) reported low level geochemical anomalies indicating a potential for mercury resources. Occurences of copper mineralization (Figure 23) were also found in my research area.

Non-metallic Minerals

There is a good prospect for commercial production of bentonite from altered lacustrine tuffs of the Clarno Formation in the Muddy Ranch area. According to Patterson and Murray (1983), bentonite is formed in three different ways. The first type, most important from a commercial point of view, is formed from bedded air-fall volcanic ash that was deposited in a marine or alkaine-lake environment

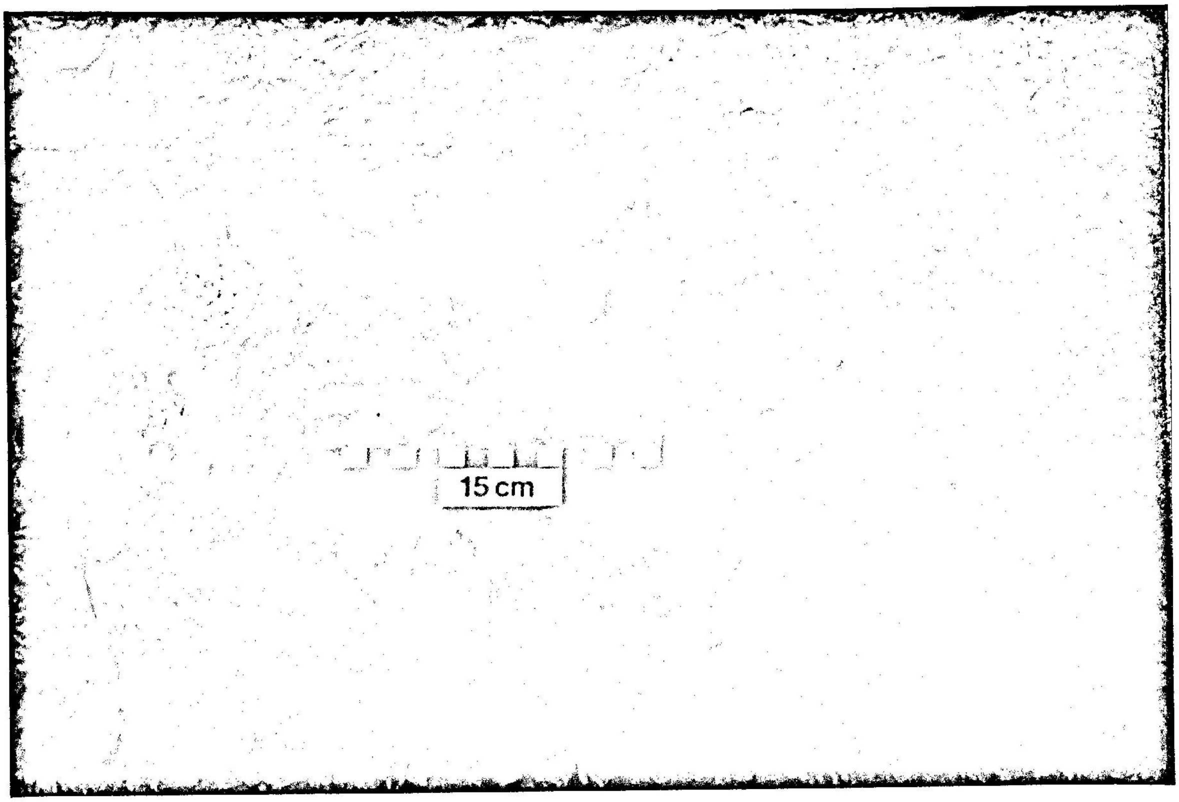

Figure 22. Photograph of calcite veins in a tuff bed of Clarno Formation located in the NW 1/4 of Section 1, T. 9 S., R. 18 E.

Figure 23. Outcrop photograph of copper-bearing tuff bed in Clarno Formation located in the SE 1/4 NW 1/4 of Section 32, T. 8 S., R. 19 E.

and subsequently altered to bentonite. The most common parent volcanic rock is andesite to rhyolite in composition. The second type is a transported deposit, not formed in-situ, and the third type of bentonite is formed by hydrothermal alteration. The bentonite deposits found on the Muddy Ranch are either of the first or third category. Gray and others (1989) reported geochemical analyses of two samples of Clarno altered tuff collected from the SW 1/4 SW 1/4 of Section 35 and the SW 1/4 SW 1/4 of Section 36, T. 8 S., R. 18 E. These samples yielded an expansion percentage of 380 and 420 respectively in an "as received" condition and after treatment with soda ash both samples yielded an expansion percent of 820. Sample treated with soda ash which show expansion greater than 800 percent are considered to be commercial grades of Na-bentonite. The terms "sodium bentonite" and "calcium bentonite" are commonly used by the bentonite industry to refer to swelling and non-swelling clays respectively. The highly expansive sodium bentonite clays of the Muddy Ranch could be mined and produced as a commercial product.

Thin lenses of coaly deposits were found in volcaniclastic sediments of the Clarno Formation at three locations: SE 1/4 NE 1/4 of Section 20, T. 8 S., R. 19 E.; SW 1/4 SE 1/4 of Section 6, T. 9 S. R. 19 E.; and S/W 1/4 NE 1/4 of Section 29, T. 8 S., R. 19 E. (Figure 24). The latter locality was visited by Collier (1914) and described

Figure 24. Shaly coal in the Clarno Formation located at S/W 1/4 NE 1/4 of Section 29, T. 8 S., R. 19 E.

as being mined or at least prospected as a potentially commercial deposit. The coal is mostly shaley and powdery. The average thickness of the coaly seams is less than one foot and the total thickness of carbonaceous shale does not appear to exceed three feet. Thus it is unlikely that commercial quality or quantities of coal are present on the Muddy Ranch.

SUMMARY AND CONCLUSIONS

The Muddy Ranch Inlier is composed of sedimentary and metasedimentary rocks informally named the "Muddy Ranch Formation" exposed along the axis of a deeply breached northeast-southwest trending anticline. The dominant lithologies of these, the oldest rocks exposed in the area, are siltstones, mudstones, sandstones, including some turbidites. These sedimentary rocks were weakly metamorphosed to very low- to low-grade metamorphism probably by heat from magmatic fluids accompanying late Clarno volcanic intrusions.

The age of the "Muddy Ranch Formation" is unknown. If these outcrops are correlative with either the deltaic "Herren Formation" to the northeast (Fisk and Fritts, 1987) or with the "Hay Creek Formation" to the southwest (Wareham, 1986) as suggested by these authors, then they could be Paleocene to Lower Eocene in age. Considering the similarities in stratigraphic position, lithology, grade of metamorphism, and the fact that they are exposed along the same structural trend on the same anticline (Hay Creek uplift of Hodge, 1931) as the "Hay Creek Formation", I am in agreement with Fisk and Fritts (1987) and Wareham (1986) that the most probable age of the "Muddy Ranch Formation" is Early Tertiary. Precise age determination was not possible, however, due to the absence of fossils or any geochronologic method not affected by later heating. The dark gray color of siltstones, persistency of bedding, and the presence of graded beds suggest that the depositional environment of the "Muddy Ranch Formation" could have been a submarine fan, similar to that interpreted for the "Hay Creek Formation" (Wareham, 1986).

There is a good possibility of hydrothermal enrichment of metallic minerals such as gold, silver, and mercury into commercial deposits in the Muddy Ranch area. Swelling bentonite clay deposits in the Clarno Formation also hold potential for commercial production. There is also a good possibility of hydrocarbons either in the "Muddy Ranch Formation" itself, or in the Clarno Formation where petroleum may have migrated after generation. The presence of a suitable structural trap, the "Muddy Ranch Anticline", and impervious clay beds to act as a seal increase this potential. Shows of both oil and natural gas in the Clarno Basin Oil Company Burgess No. 2 well drilled about five and one half miles north of the Muddy Ranch, the presence of asphaltite in veins and fractures along Dry Creek on the north edge of the ranch (Buwalda, 1921), and the presence of a hydrocarbon soil anomaly over the northeastern part of the ranch (Sidle and Richers, 1985) are all good evidence that the area could contain commercial quantities of hydrocarbons.

LITERATURE CITED

Ach, J. A., S. A. Minor, J.G. Frisken, R.J. Blakley, R.A. Winters, and T.J. Peters, 1988, Mineral resources of the Spring Basin Wilderness Study Area, Wheeler County, Oregon: U.S. Geological Survey Bulletin 1743-C, p. 1-16.

Anonymous, 1982, City of Rajneeshpuram comprehensive plan: Research and analysis: Report to the Wasco County Planning Commission, v. 1., 335 p.

Arnold, C. A., and L. H. Dauherty, 1963, The fern genus Acrostichum in the Eocene Clarno Formation of Oregon: Contributions from the Museum of Paleontology, University of Michigan, v. 18, no. 13, p. 205-227.

Arnold, C. A., and L. H. Dauherty, 1964, A fossil dennstaedtioid fern from the Eocene Clarno Formation of Oregon: Contributions from the Museum of Paleontology, University of Michigan, v. 19, no. 6, p. 65-88.

Bates, R. L., and J. A. Jackson, 1980, Glossary of Geology, second edition: American Geological Institute, Falls Church, Virginia, 751 p.

Bouma, A. H., 1962, Sedimentology of flysch deposits: A graphic approach to facies interpretation: Elsevier, NY, 168 p.

Buwalda, J. P., 1921, Report on oil and gas possibilities of eastern Oregon: Oregon Bureau of Mines and Geology, The Mineral Resources of Oregon, v. 3, no. 2, 47 p.

Cavender, T. M., 1968, Freshwater fish remains from the Clarno Formation, Ochoco Mountains of north-central Oregon: Ore Bin, v. 30, p. 125-141.

Collier, A. J., 1914, The geology and mineral resources of the John Day region: Oregon Bureau of Mines and Geology, The Mineral Resources of Oregon, v. 1, no. 3, 47 p.

Doher, L. I., 1980, Palynomorph preparation procedures currently used in the Paleontology and Stratigraphy Laboratories, U. S. Geological Survey: U.S.Geological Survey Circular 830, 29 p.

Engelder, J. T., and P. Geiser, 1979, The relationship between pencil cleavage and lateral shortening within the Devonian section of the Appalachian Plateau, New York: Geology, v. 7, p. 460-464.

Fisk, L. H., in preparation, Stratigraphy, age, and petroleum potential of Cretaceous and Paleogene rocks in north-central Oregon: Unpublished Ph.D. Dissertation, Michigan State University, Lansing, MI, 217 p.

Fisk, L. H., and S. G. Fritts, 1987, Field guide and roadlog to the geology and petroleum potential of north-central Oregon: Northwest Geology, v. 16, p. 105-125.

Fritts, S. G., and L. H. Fisk, 1985a, The Columbia Basin-1: implications for oil and gas potential of north central Oregon: Oil and Gas Journal, v. 83, no. 34, p. 84-88.

Fritts, S. G., and L. H. Fisk, 1985b, The Columbia Basin-2: structural evolution of south margin, relation to hydrocarbon generation: Oil and Gas Journal, v. 83, no. 35, p. 85-90.

Gray, J. J., R. P. Geitgey, and G. L. Baxter, 1989, Bentonite in Oregon--analysis and economic potential: Department of Geology and Mineral Industries, State of Oregon, Special Paper 20, 16 p.

Graham, R. H., 1978, Quantitative deformation studies in the Permian rocks of the Alpes-Maritimes: Goguel Symposium, Bureau de Recherches Geologiques et Minieres, Memoir 91, p. 219-238.

Gray, J., 1965, Palynological techniques: p. 470-481, in B. Kummel and D. Raup (editors), Handbook of paleontological techniques: W. H. Freeman and Company, San Francisco, CA, 852 p.

Hanson, C. B., 1973, Geology and vertebrate faunas in the type area of the Clarno Formation, Oregon: Geological Society of America Abstracts with Programs, v. 5, no. 1, p. 50.

Hatcher, R, D. Jr., 1990, Structural geology: principles, concepts, and problems: Merrill Publishing Company, Columbus, Ohio, 531 p.

Hergert, H. L., 1961, Plant fossils in the Clarno Formation, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 23, no. 6, p. 55-62.

Hodge, E. T., 1931, Geologic map of north central Oregon and text: University of Oregon Publications, Supplement to Geology Series, v. 1, no. 5, 7 p.

Hodge, E. T., 1942, Geology of north central Oregon: Studies in Geology, no. 3, Oregon State College, Corvallis, Oregon, 6 p.

Jarman, C. B., 1973, Clay mineralogy and sedimentary petrology of the Cretaceous Hudspeth Formation, Mitchell, Oregon: Unpublished Ph.D. dissertation: Oregon State University, Corvallis, Oregon, 173 p.

Kleinhans, L. C., E. A. Balcells-Baldwin, and R. E. Jones, 1984, A paleogeographic reinterpretation of some Middle Cretaceous units, north central Oregon, evidence for a submarine turbidite system: p. 239-257, in T. H. Nilsen (editor), Geology of the Upper Cretaceous Hornbrook Formation , Oregon and California: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 42, 257 p.

Kleinhans, L. C., 1987, Cretaceous rocks of the Mitchell Inlier north-central Oregon--field trip guidebook: Northwest Petroleum Association, 1987 Spring Symposium, Bend, Oregon, 54 p.

Little, S. W., 1986, Stratigraphy, petrology and provenance of the Cretaceous Gable Creek Formation, Wheeler County, Oregon: Unpublished M.Sc. Thesis, Oregon State University, Corvallis, Oregon, 133 p.

Manchester, S. R., 1981, Fossil plants of the Eocene Clarno nut beds: Oregon Geology, v. 43, no. 6, p. 75-81.

McKee, T. M., 1970, Preliminary report on fossil fruits and seeds from the mammal quarry of the Clarno Formation: Ore Bin, no. 32, p. 117-132.

Merriam, J. C., 1901, A contribution to the geology of the John Day Basin: University of California, Bulletin of the Department of Geology, v. 2, p. 269-314.

Mulja, T., and M. Zentilli, 1987, Hydrothermal alteration and gold mineralization in the Copiapo volcanic complex, Chile: Geological Society of America, Memoir 19, 781 p.

Oles, K. F., and H. Enlow, 1971, Bedrock geology of the Mitchell Quadrangle, Wheeler County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin, v. 72, p. 1-61.

Patterson, S. H., and H. H. Murray, 1983, Clays: p. 585-651, in S. J. Lefond, and others, (editors), Industrial Minerals and Rocks (nonmetallics other than fuels), 5th edition: Society of Mining Engineers of AIME, Salt Lake City, Utah, v. 1, p. 670.

Peck, D. L., 1964, Geologic reconnaissance of the Antelope-Ashwood area, north-central Oregon: U.S. Geological Survey Bulletin 1161-D, 26 p.

Picard, M.D., and L. R. High, 1972, Criteria for recognizing lacustrine rocks: p. 108-145 in J. K. Rigby and W. K. Hamblin, Recognition of Ancient Sedimentary Environments: Society of Economic Paleontologists and Mineralogists Special Publication no. 16, 340 p.

Ramsay, J. G., and M. I. Huber, 1983, The techniques of modern structural geology, Volume 1: Strain analysis: Academic Press, London, 307 p.

Retallack, G., 1981, Preliminary observation on fossil soils in the Clarno Formation (Eocene to early Oligocene) near Clarno, Oregon: Oregon Geology, v. 43, p.147-150.

Reks, I. J., and D. R. Gray, 1982, Pencil structure and strain in weakly deformed mudstone and siltstone: Journal of Structural Geology, v. 4, p. 161-176.

Riddle, A., 1990, Potential petroleum reservoir rocks in the Cretaceous to Tertiary strata of north-central Oregon: Unpublished M.Sc. Thesis, Loma Linda University, Riverside, CA, 120 p.

Robinson, P. T., 1975, Reconnaissance geologic map of the John Day Formation in the southwestern part of the Blue Mountains and adjacent areas, north-central Oregon: U.S. Geological Survey Miscellaneous Investigations Map I-872.

Sandefur, C. A., 1986, Paleocurrent analysis of the Cretaceous Mitchell Formation, north-central Oregon: Unpublished M.S. Thesis, Loma Linda University, Riverside, CA, 80 p.

Scott, R. A., 1954, Fossil fruits and seeds from the Eocene Clarno Formation of Oregon: Palaeontographica, v. 96, part B, p. 66-97.

Selley, R. C., 1985, Elements of petroleum geology: W. H. Freeman and Company, New York, NY, 449 p.

Sidle, W. C., and D. M. Richers, 1985, Geochemical reconnaissance of Cretaceous inliers in north-central Oregon: American Association of Petroleum Geologists Bulletin, v. 69, p. 412-421.

Shorey, E. F., 1976, Geology of part of southern Morrow County, north-east Oregon: Unpublished M.S. Thesis, Oregon State University, Corvallis, OR, 128 p.

Staplin, F. L., 1982, Determination of Thermal Alteration Index from color of exinite (pollen, spores): Society of Economic Paleontologist and Mineralogist, Short Courseno. 7, Tulsa, OK., p. 7-11.

Swanson, D. A., 1969, Reconnaissance geologic map of the east half of the Bend Quadrangle, Crook, Wheeler, Jefferson, Wasco, and Deschutes counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Map I-568.

Swanson, D. A., and P. T. Robinson, 1968, Base of the John Day Formation in and near the Horse Heaven Mining District, north central Oregon: U.S. Geological Survey Professional Paper 600-D, p. D154-D161.

Taylor, E. M., 1960, Geology of the Clarno basin, Mitchell Quadrangle: Unpublished M.Sc. Thesis, Oregon State College, Corvallis, OR, 173 p.

Thompson, C. L., and H. Dembicki Jr., 1986, Optical characteristics of amorphous kerogens and the hydrocarbon generating potential of source rocks: International Journal of Coal Geology, v. 6, p. 229-249.

Vance, J. A., 1988, New fission track and K-Ar ages from the Clarno Formation, Challis age volcanic rocks in north-central Oregon: Geological Society of America, Abstracts with Programs, v. 20, no. 6, p. 473.

Walker, G. W., 1977, Geologic map of Oregon east of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Map I-902.

Wareham, S. I., 1986, Geology and petroleum potential of Hay Creek Anticline, north-central Oregon: Unpublished M. Sc. Thesis, Loma Linda University, Riverside, CA, 65 p.

Wilkinson, W. D., and K. F. Oles, 1968, Stratigraphy and paleontology of Cretaceous rocks, Mitchell Quadrangle, Oregon: American Association of Petroleum Geologists Bulletin, v. 52. p. 129-161.

APPENDICES

APPENDIX A

Petrographic Descriptions Of Thin Sections

Sample Number: MRF-2.

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collectors: L. H. Fisk and M. Kamal
Map Unit: MRF
Location: SW1/4 NW1/4 of Section 32, T.8 S., R.19 E.

II. NAME: Siliceous siltstone

III. COLOR:
Fresh: Light gray
Weathered: Brownish gray
Internal Color Controls: Organic content

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.025 mm.
Largest Grains: 0.12 mm.
Sorting: Well sorted
Roundness: Sub-rounded
Sphericity: Sub-prismoidal

V. SEDIMENTARY STRUCTURE: Organic - inorganic banding, organic bands have light/dark lamellae.

VI. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 40%
Argillaceous Minerals: 40%
Organics: 9%
Sericite: 5%
Iron Oxide: 4%
Biotite: 1%
Mica: 1%

VII. DIGENETIC FEATURES:
Lithification: Well-indurated
Cement: Silica
Porosity: Very low; fracture porosity has been nullified by sericite fill.

VIII. BIOGENIC CONSTITUENTS:
Fine-grained, laminated zones contain elongated curved patches which are probably relict organic features.

Sample Number: MRF-4.

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collectors: L. H. Fisk and M. Kamal
Map Unit: MRF
Location: SW1/4 SW1/4 of Section 32, T.8 S., R.19 E.

II. NAME: Weakly metamorphosed siltstone with sandstone

III. COLOR:
Fresh: Dark gray
Weathered: Dark brown to brownish gray

1V. TEXTURE:
The rock is composed predominantly of very fine grain argillaceous minerals with a faint schistose texture. It shows a sharp contact with normally graded sandstone.

V. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 32%
Argillaceous Minerals: 49%
Organics: 5%
Sericite: 4%
Iron Oxide: 5%
Biotite: 1%
Muscovite: 2%
Calcite: 2%

VI. DIGENETIC FEATURE:
Porosity: Very low

Sample Number: MRF-7

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collector: M. Kamal
Map Unit: MRF
Location: SW1/4 NW1/4 of Section 5, T.9 S., R.19 E.

II. NAME: Siltstone

III. COLOR:
Fresh: Light gray
Weathered: Brownish gray
Internal Color Controls: Organic content and opaque minerals

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.035 mm.
Largest Grains: 0.16 mm.
Sorting: Poor
Roundness: Sub-rounded
Sphericity: Sub-prismoidal

V. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 41%
Argillaceous Minerals: 46%
Organics: 5%
Sericite: 3%
Iron Oxide: 4%
Mica: 1%

VI. DIGENETIC FEATURES:
Lithification: Well-indurated
Cement: Silica
Porosity: Very low

VII. BIOGENIC CONSTITUENTS:
None

Sample Number: MRF-8

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collectors: L. H. Fisk and M. Kamal
Map Unit: MRF
Location: NE1/4 SW1/4 of Section 6, T.9 S., R.19 E.

II. NAME: Siltstone

III. COLOR:
Fresh: Light gray
Weathered: Greenish gray
Internal Color Controls: Organic content and opaque minerals

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.08 mm.
Largest Grains: 0.15 mm.
Sorting: Poor
Roundness: Sub-angular to sub-rounded
Sphericity: Sub-prismoidal

V. FABRIC:
Grain Orientation: Random and haphazard; both grain and matrix supported

VI. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 46%
Argillaceous Minerals: 35%
Organics: 7%
Plagioclase: 1%
Sericite: 7%
Iron Oxide: 2%
Mica: 1%
Lithic Fragments: 1%

VII. DIGENETIC FEATURES:
Lithification: Well-indurated
Cement: Silica
Porosity: Very low; fracture porosity has been nullified by sericite fill.

VIII. BIOGENIC CONSTITUENTS:
None

Sample Number: MRF-13

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collector: M. Kamal
Map Unit: MRF
Location: SE1/4 NW1/4 of Section 31, T.8 S., R.19 E.

II. NAME: Mudstone with quartz veins

III. COLOR:
Fresh: Dark gray
Weathered: Steel gray
Internal Color Controls: Silica content

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.05 mm.
Largest Grains: 0.2 mm.
Sorting: Poor
Roundness: Sub-angular
Sphericity: Prismoidal to sub-prismoidal

V. FABRIC:
Veins of microcrystalline quartz have prismatic crystals which are oriented perpendicular to vein walls.

VI. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 60%
Argillaceous Minerals: 20%
Organics: 10%
Sericite: 5%
Iron Oxide: 3%
Mica: 2%

VII. DIGENETIC FEATURES:
Lithification: Well-indurated
Cement: Silica
Porosity: Poor

VIII. BIOGENIC CONSTITUENTS:
Dark areas of rock contain abundant unrecognizable organic matter.

Sample Number: MRF-16

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collector: M. Kamal
Map Unit: MRF
Location: NW1/4 NW1/4 of Section 5, T.9 S., R.19 E.

II. NAME: Weakly metamorphosed argillaceous siltstone

III. COLOR:
Fresh: Light gray
Weathered: Yellowish gray

1V. TEXTURE:
The rock is composed predominantly of very fine-grained argillaceous minerals with a trachytoid texture.

V. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 35%
Argillaceous Minerals: 42%
Organics: 5%
Sericite: 13%
Iron Oxide: 3%
Muscovite: 2%

VI. DIGENETIC FEATURE:
Cryptocrystalline argillaceous minerals

Sample Number: MRF-18

I. GENERAL:
Formation: "Muddy Ranch Formation"
Collector: M. Kamal
Map Unit: MRF
Location: SW1/4 SW1/4 of Section 32, T.8 S., R.19 E.

II. NAME: Calcareous sandstone

III. COLOR:
Fresh: Gray
Weathered: Silver gray
Internal Color Controls: Calcite

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.01 mm.
Largest Grains: 0.22 mm.
Sorting: Well-sorted
Roundness: Sub-angular to sub-rounded
Sphericity: Sub-prismoidal

V. SEDIMENTARY STRUCTURE:
Very finely laminated, normally graded

VI. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 14%
Argillaceous Minerals: 38%
Organics: 15%
Plagioclase: 2%
Sericite: 2%
Iron Oxide: 1%
Mica: 1%
Calcite: 25%
Lithic Fragments: 2%

VII. DIGENETIC FEATURES:
Lithification: Well-indurated
Cement: Calcite
Porosity: Poor

VIII. BIOGENIC CONSTITUENTS:
None

Sample Number: TCt-29

I. GENERAL:
Formation: Clarno Formation
Collectors: L. H. Fisk and M. Kamal
Map Unit: Clarno lower tuff (unit #1)
Location: SW1/4 NW 1/4 of Section 29, T.8 S., R.19 E.

II. NAME: Siliceous tuff

III. COLOR:
Fresh: Tan
Weathered: Yellowish tan
Internal Color Controls: Organic content and iron oxide

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.0024 mm.
Largest Grains: 0.01 mm.
Sorting: Well-sorted
Roundness: Sub-angular to sub-rounded
Sphericity: Sub-prismoidal

V. SEDIMENTARY STRUCTURE:
Normally graded laminae, 0.5 to 10 mm. thick

VI. MINERAL COMPOSITION:
Estimated Percentages:
Quartz: 40%
Argillaceous Minerals: 50%
Organics: 2%
Iron Oxide: 6%
Volcaniclastic Fragments: 2%

VII. DIGENETIC FEATURES:
Lithification: Well-indurated
Cement: Silica
Porosity: Poor

VIII. BIOGENIC CONSTITUENTS:
Burrows and leaf impressions

Sample Number: TCb - 1

I. GENERAL:
    Formation: Clarno
    Collector: M. Kamal
    Map Unit: Clarno intrusion, "Post Pile Rock"
    Location: SW1/4 NE1/4 of Section 31, T.8 S., R.19 E.

II. NAME: Basalt

III. COLOR:
    Fresh: Black
    Weathered: Dark gray
    Internal Color Controls: Ferro-magnesium mineral content

1V. TEXTURE:
    Grain Size:
        Average Groundmass: 0.15 mm.
        Phenocrysts:
            Plagioclase: 0.15 mm.
            Olivine: 0.3 mm.
    Crystal Shape:
        Plagioclase: Euhedral to sub-hedral
        Olivine: Anhedral

V. FABRIC:
    Grain Orientation: Non-trachytic

VI. MINERAL COMPOSITION:
    Estimated Percentages:
        Glass: 36%
        Chlorite: 15%
        Plagioclase: 35%
        Olivine: 7%
        Iron Oxide: 3%
        Serpentine: 4%

VII. DIGENETIC FEATURE:
    Ferro-magesium minerals altered to iron oxide and chlorite

Sample Number: TCb - 2

I. GENERAL:
Formation: Clarno Formation
Collectors: L. H. Fisk and M. Kamal
Map Unit: Clarno
Location: NE1/4 SE1/4 of Section 1, T.9 S., R.18 E.

II. NAME: Basalt

III. COLOR:
Fresh: Black
Weathered: Black
Internal Color Controls: Plagioclase mineral content

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.15 mm.
Phenocrysts:
Plagioclase: 0.4 mm.
Olivine: 1 mm.
Crystal Shape:
Plagioclase: Sub-hedral
Olivine: Anhedral

V. FABRIC:
Grain Orientation: Sub-trachytic

VI. MINERAL COMPOSITION:
Estimated Percentages:
Glass: 40%
Plagioclase: 43%
Olivine: 5%
Iron Oxide: 2%
Horneblende: 3%
Clay: 7%

VII. DIGENETIC FEATURES:
Glass is altered to clay and feldspar is clean with no alteration. Larger feldspar grains are fractured and filled with clay minerals.

Sample Number: TCb - 3

I. GENERAL:
Formation: Clarno Formation
Collectors: L. H. Fisk and M. Kamal
Map Unit: Clarno
Location: SW1/4 NE1/4 of Section 11, T.9 S.,R.18 E.

II. NAME: Olivine basalt

III. COLOR:
Fresh: Black
Weathered: Gray
Internal Color Controls: Ferro-magnesium mineral content

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.15 mm.
Phenocrysts:
Olivine: 1.4 mm.
Augite: 0.78 mm.
Crystal Shape:
Olivine: Euhedral
Augite: Euhedral
Plagioclase: Sub-hedral

V. FABRIC:
Grain Orientation: Non-trachytic

VI. MINERAL COMPOSITION:
Estimated Percentages:
Glass: 40%
Plagioclase: 35%
Olivine: 10%
Augite: 10%
Iron Oxide: 3%
Serpentine: 2%

VII. DIGENETIC FEATURE:
Olivine altered to serpentine and magnetite

Sample Number: TCb - 5

I. GENERAL:
Formation: Clarno Formation
Collector: M. Kamal
Map Unit: Clarno
Location: SE1/4 SW1/4 of Section 24, T.8 S., R.18 E.

II. NAME: Olivine basalt

III. COLOR:
Fresh: Black
Weathered: Dark gray
Internal Color Controls: Ferro-magnesium mineral content

1V. TEXTURE:
Grain Size:
Average Groundmass: 0.026 mm.
Phenocrysts:
Plagioclase: 0.1 mm.
Olivine: 1.5 mm.
Xenoliths: 3.5 mm.
Crystal Shape:
Plagioclase: Sub-hedral
Olivine: Euhedral

V. FABRIC:
Grain Orientation: Sub-trachytic

VI. MINERAL COMPOSITION:
Estimated Percentages:
Glass: 57%
Plagioclase: 30%
Olivine: 10%
Horneblende: 2%
Xenoliths: 1%

VII. DIGENETIC FEATURES:
Ferro-magnesium minerals are altered to iron oxide. Fine-grain volcanic material which lacks ferro-magnesium minerals interfingers with olivine basalt and contains about 5% sanidine. It may represent a separate concurrent magma interfingering with the olivine basalt.

APPENDIX B

Potassium Argon Dates

Data for K-Ar dates from three basalt sample from the Clarno Formation of the Muddy Ranch, north-central Oregon.

Material: Unweathered basalt, whole-rock analysis, field no. CFb-1, analysis by Geochron Laboratories in 1989 (sample R-8566)
Location: S/W 1/4 of NE 1/4, Section 31, T.8 S., R.19 E.
Stratigraphy: Clarno Formation basalt intrusion; "Post Pile Rock"
Age: 42.4 ± 2.0 m.y.
Argon Analyses:

^{40}Ar, ppm	$^{40}Ar/Total^{40}Ar$	Avg. ^{40}Ar, ppm
.003669	.499	.003758
.003847	.555	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
1.271	1.265	1.509
0.405		

Material: Unweathered basalt, whole-rock analysis, field no. CFb-2, analysis by Geochron Laboratories in 1989 (sample R-8567)
Location: NE1/4 SE1/4 of Section 1, T.9 S., R 18 E.
Stratigraphy: Clarno Formation basalt intrusion
Age: 29.0 ± 1.7 m.y.
Argon Analyses:

^{40}Ar, ppm	$^{40}Ar/Total^{40}Ar$	Avg. ^{40}Ar, ppm
.001571	.303	.001600
.001628	.216	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
0.790	0.789	0.941
0.788		

Material: Unweathered basalt, whole-rock analysis, field no. CFb-3, analysis by Geochron Laboratories in 1989 (sample R-8570)
Location: SW1/4 NE1/4 of Section 11, T.9 S., R.18 E.
Stratigraphy: Clarno Formation basalt dike
Age: 69.8 ± 3.9 m.y.
Argon Analyses:

^{40}Ar, ppm	$^{40}Ar/Total^{40}Ar$	Avg. ^{40}Ar, ppm
.001766	.152	.001782
.001798	.271	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
0.350	0.362	0.431
0.373		