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Geology of the Butler Basin, Grant and Wheeler Counties, Central Oregon

Martin R. Aguirre

ABSTRACT

GEOLOGY OF THE BUTLER BASIN,
GRANT AND WHEELER COUNTIES, CENTRAL OREGON

by

Martin R. Aguirre

The Butler Basin lies along the John Day River in Central Oregon, astraddle the boundary of Wheeler and Grant counties. Strata exposed in this geomorphic basin, formed by an erosionally breached anticline, range in age from Permo-Triassic to Neogene. The basement rocks of the basin are poorly exposed but lithologically similar to the Permo-Triassic Blue Mountains island-arc rocks which crop out to the south and southeast of the basin in the John Day Inlier. Overlying the basement rocks are Early Cretaceous conglomerates with lenses of sandstone and siltstone informally named the "Goose Rock Conglomerate." Pebble and cobble lithologies present in the conglomerate indicate that the source was terranes of the John Day Inlier. A sparse and poorly preserved terrestrial palynoflora recovered from siltstone lenses suggest that the conglomerates are pre-Albian in age and older than the well-known mid-Cretaceous rocks of the neighboring Mitchell Inlier. Sedimentary structures along with the terrestrial palynoflora indicate a fluvial depositional system with a south-westerly paleocurrent trend. Based on a whole-rock K-Ar date of 49 million years and lithostratigraphy of the region, the basalt flow and unreworked red tuffs immediately overlying the "Goose Rock Conglomerate" belong to the lower Clarno Formation. The overlying John Day, Picture Gorge Basalt, Mascall, and Rattlesnake formations are only

briefly reviewed since they have been the emphasis of many previous works. The large-scale (1:24,000) geologic map of the Butler Basin produced from this study has resulted in the addition of detail and refinement to the stratigraphic and structural relationships in the Butler Basin.

LOMA LINDA UNIVERSITY

Graduate School

GEOLOGY OF THE BUTLER BASIN, GRANT AND WHEELER COUNTIES, CENTRAL OREGON

by

Martin R. Aguirre

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.

Lanny H. Fisk, Associate Professor of Geology, Chairman

H. Paul Buchheim, Professor of Geology

Ivan E. Rouse, Professor of Physics

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GEOLOGY OF THE BUTLER BASIN, GRANT AND WHEELER COUNTIES, CENTRAL OREGON

INTRODUCTION

General Statement

The stratigraphic succession of rocks and fossils found in Central Oregon has attracted geologists and paleontologists since the mid-1800's. In the early investigations of this region, many researchers emphasized the vertebrate fossils of the Oligocene-Miocene John Day Formation because of their abundance and excellent preservation. Later studies emphasized plant fossils from the John Day Formation and underlying Eocene-Oligocene Clarno Formation.

Pre-John Day strata have received far less emphasis and often only reconnaissance study. In some areas, the age, stratigraphic position, structural relations, and depositional environments of the rocks are not yet known or interpretations are conflicting. Such an area is Butler Basin (Figure 1), a geomorphic erosional basin (Figure 2) containing a well-exposed stratigraphic sequence of Permo-Triassic, Cretaceous, and Tertiary rocks; see Figure 3 for the stratigraphic sequence.

Purpose

The purpose of this research was to produce a 1:24,000 scale geologic map of Butler Basin, to resolve the interpretational controversy over the structure of the Basin, to determine the ages of the pre-John Day Formation rocks, to define the age-boundaries of some of the controversial formations, and to interpret the depositional

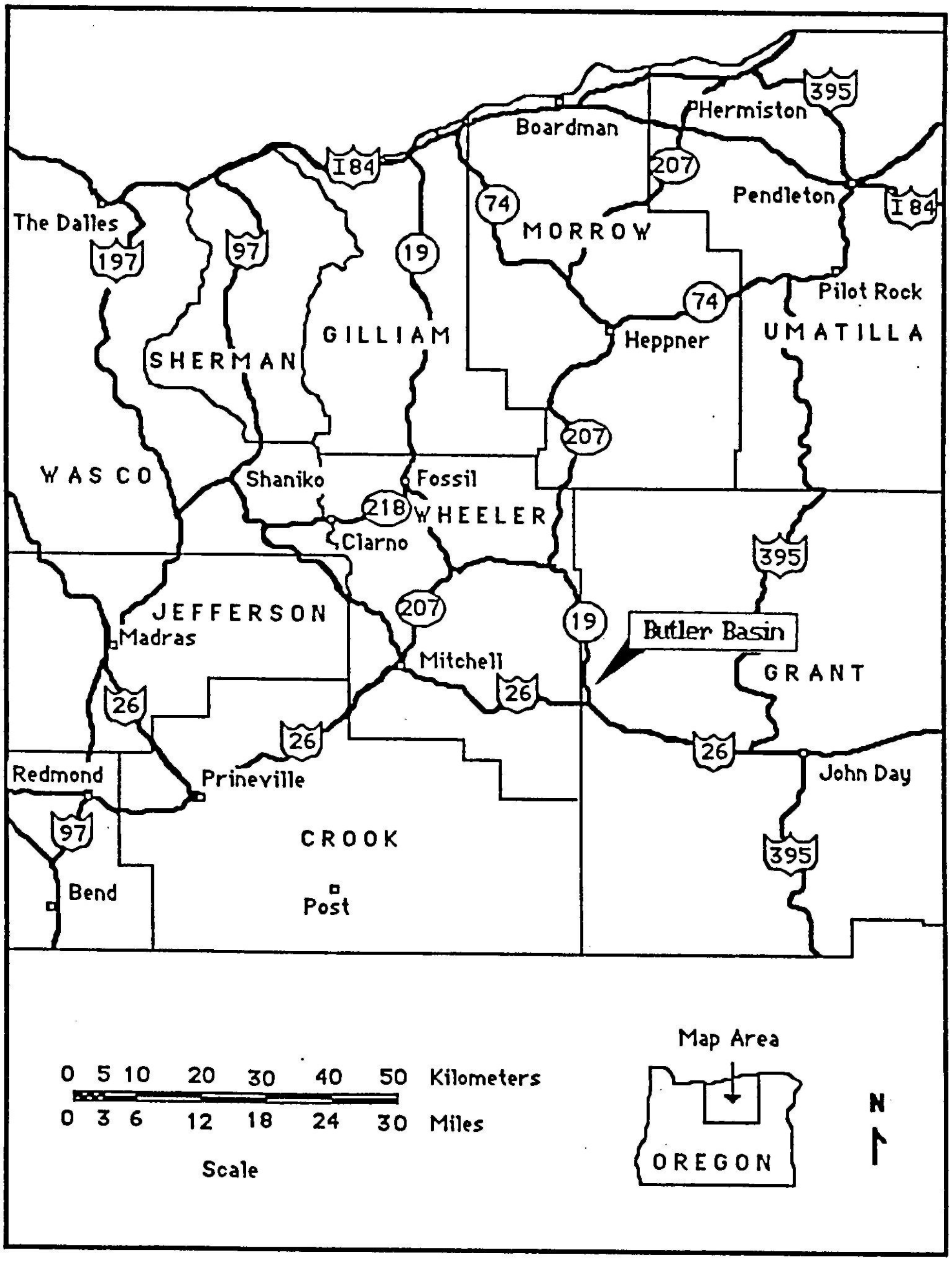

Figure 1. Highway map of north-central Oregon showing the location of Butler Basin just north of the junction of US Highway 26 and Oregon Highway 19 (modified from Fisk and Fritts, 1987).

Figure 2. Aerial photograph of the Butler Basin and vicinity in Central Oregon (1:62,500 scale). The John Day River flows from the lower right corner to the top center of the photo. The steeply eroded canyon at the junction of the John Day River with Rock Creek is Picture Gorge.

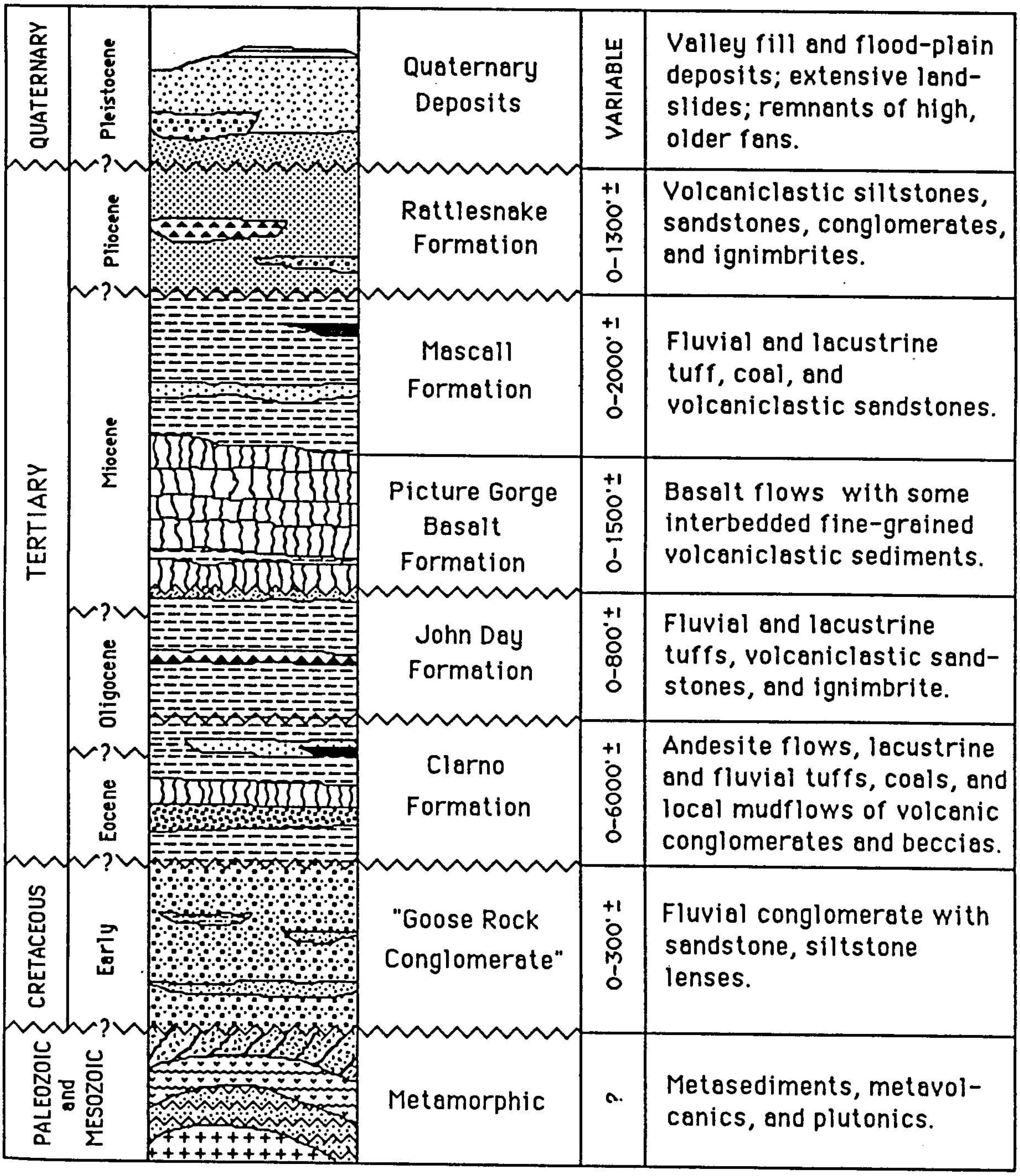

Figure 3. Generalized stratigraphic column of the Butler Basin of Central Oregon (modified from Wilkinson and Oles, 1968; Fisk and Fritts, 1987).

environments of the pre-Tertiary rocks. The emphasis throughout was on the pre-John Day Formation rocks which have previously received less study in this area.

Location of Study Area

Butler Basin is located between latitude 44° 32' and 44° 35' and longitude 119° 36' and 119° 42' 30" in the Picture Gorge Quadrangle (1:62,500 scale), astraddle the boundary of Wheeler and Grant counties, Oregon. The basin lies at the northern end of Picture Gorge near the junction of Highway 26 (east/west) and Highway 19 (north/-south); see Figure 1. Butler Basin includes an area of approximately ten square miles and is bisected by the John Day River and Highway 19. Located within Butler Basin is the Sheep Rock Unit of the John Day Fossil Beds National Monument, including a visitor center in the James Cant National Historic District.

Previous Investigations

The first published geologic investigation of the John Day Country was by Thomas Condon, amateur geologist and Congregational minister of The Dalles, Oregon (Condon, 1871). The primary emphasis of Condon's early work was the collection of vertebrate fossils, although he also interpreted the depositional environment of the fossil-bearing strata as lacustrine deposits of a huge lake. Most of Condon's (1871) vertebrate fossil collections were from exposures of the John Day Formation along the John Day River in the Butler Basin, Big Basin, and Artman Basin areas of the Picture Gorge quadrangle.

The first professional and comprehensive geologic and paleontologic investigations of the Butler Basin and vicinity were by Merriam (1900, 1901a and b), Calkins (1902), and Merriam and Sinclair (1907). The emphasis of these studies was also the fossil-bearing John Day Formation. Unlike Condon (1871), Calkins (1902) interpreted the depositional environment of the John Day Formation as subaerial rather than lacustrine. More recently, the geology and paleontology of the John Day Formation in the vicinity of Butler Basin has been described further by Fisher (1963, 1964, 1966, 1967, 1968), Fisher and Rensberger (1972), and Fremd (1988).

Several publications have described the geology and paleontology of the overlying Miocene Mascall and Pliocene Rattlesnake Formations exposed on the south margin of the Butler Basin (Le Conte, 1874; Collier, 1914; Merriam, 1901b; Calkins, 1902; Merriam and others, 1925; Chaney, 1948, 1956; Downs, 1956; Campbell and others, 1958; Davenport, 1971; Enlows, 1973, 1976; Kuiper, 1988).

Coleman (1949) and White (1964) described the general geology of Butler Basin with emphasis on the John Day Formation in unpublished Master of Science theses completed at Oregon State University. They contributed detailed petrographic descriptions, geologic maps (at 1:28,000 and 1:62,500 scales, respectively), and preliminary interpretations of depositional environments.

Besides Coleman and White, several other geologists have provided intermediate- and small-scale geologic maps which have included the Butler Basin area (e.g., Fisher, 1964 at 1:100,000 scale; Brown and Thayer, 1966 at 1:250,000 scale; Fisher and Rensberger, 1972 at 1:100,000 scale). Buwalda (1929) indicated that he was undertaking the mapping of the Picture Gorge quadrangle; however, subsequent literature contains no further mention of the project nor a map. On some geologic maps of the area, the north/south structure of Butler Basin has been interpreted as a syncline (Coleman, 1949; White, 1964; Brown and Thayer, 1966; Newcomb, 1970; Walker, 1977), while others have interpreted the structure as an anticline (Baldwin, 1976; Thayer, 1977a).

MATERIALS AND METHODS

To achieve the purposes of this study, I mapped the ten square miles centered on the Butler Basin in Picture Gorge Quadrangle at 1:24,000 scale. The overall structure of the basin was also determined, since there are conflicting interpretations in the literature. This was accomplished by dip and strike measurements of minimally disturbed strata throughout the basin. North-south and east-west cross-sections were prepared from the field data.

In the conglomerates exposed at Goose Rock, paleocurrent and depositional environment were studied by measuring pebble imbrication and macrofabric sedimentary features. Nearly three hundred imbrications were measured using a 360° Brunton compass corrected for local magnetic declination. Particular care was taken to measure imbrication on two or more pebbles inclined or shingled on one another (Sandefur, 1986). Macrofabric measurements consisted of directional current features, such as cross-bedding, channels, and ripples. All structures from every possible bed were recorded with no limit to the number of readings taken. Location descriptions, photographs, and map coordinates were recorded for each of the features measured. The directional data from all collection sites were plotted on a rose diagram to indicate the paleocurrent trend.

The geologic age and depositional environment of the Goose Rock conglomerates were determined using palynological analyses of four fine-grained siltstone lens. Standard palynological laboratory techniques were used to prepare, extract, mount, and study the palynomorphs (Gray, 1965; Doher, 1973). Pertinent literature was used to identify the individual taxa and draw paleoenvironmental and age conclusions from the palynoflora (e.g., Burden and Hills, 1989).

The age of four basalt samples were determined from whole-rock potassium-argon dating done by Geochron Laboratories Division of Krueger Enterprises, in Cambridge, Massachusetts. Following the recommended procedures of Evernden and James (1964), the basalts were also petrographically thin-sectioned and studied microscopically to check for any diagenetic alteration that might affect the accuracy of the potassium-argon age determinations.

STRATIGRAPHY

General Statement

Strata outcropping in the Butler Basin range in age from Permo-Triassic to Recent and in lithology range from metamorphic (schist, phyllite, quartzite, and marble) to volcanic/volcaniclastic (trachyte, dacite, basalt, andesite, and rhyolite as tuffs, mudflows, breccias, ignimbrites, and flows) to sedimentary (siltstones, sandstones, and conglomerates). Figure 4 is a generalized geologic map of the area; a detailed, 1:24,000 scale, geologic map can be found in the pocket in the back of the thesis. The individual map units will be described below, from oldest to youngest, with emphasis on the older pre-John Day Formation units.

Metamorphic Rocks

The oldest rocks exposed in Butler Basin are Permo-Triassic metamorphic rocks (schist, phyllite, quartzite, and marble) found just east of Middle Mountain on the northeast margin of the basin (Coleman, 1949; Fisher, 1964, 1968; Fisher and Rensberger, 1972; and others). These rocks are similar to and assumed to be the same age as the Permo-Triassic rocks described by Thayer (1963, 1977b), Thayer and Brown (1964), Avé Lallemant (1976), and others which crop out to the southeast of Butler Basin in the Aldrich Mountains and form part of the "Central Melange Terrane" of Thayer (1977b), Brooks and Vallier (1978), Brooks (1979), and Dickinson (1979). This lithostratigraphic/tectonic terrane forms an east-west belt of outcrops in central and eastern Oregon, Idaho, and Washington (Figure 5) which have been

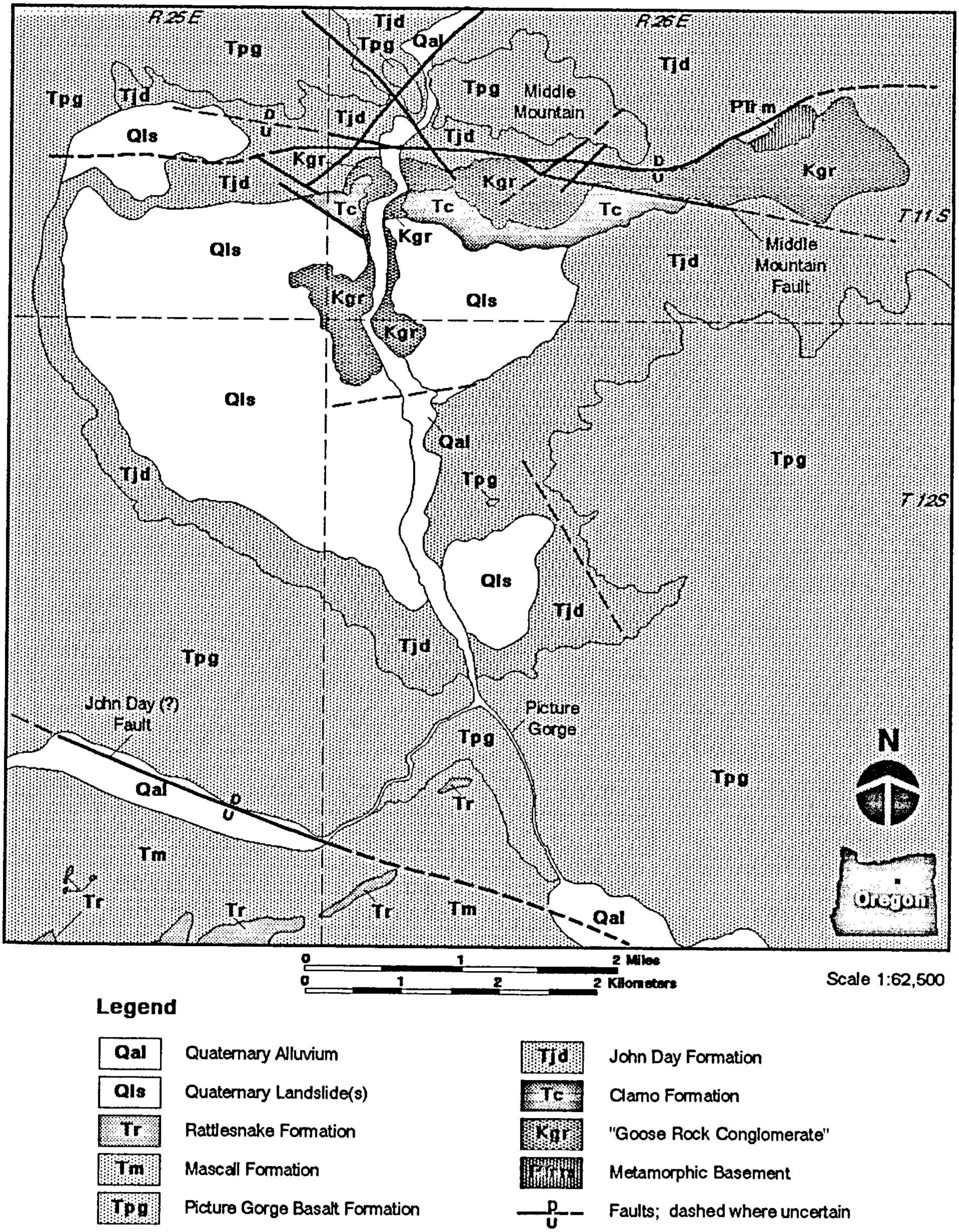

Figure 4. Generalized geologic map (at approximately 1:62,500 scale) of the Butler Basin. Compare with the aerial photograph in Figure 3.

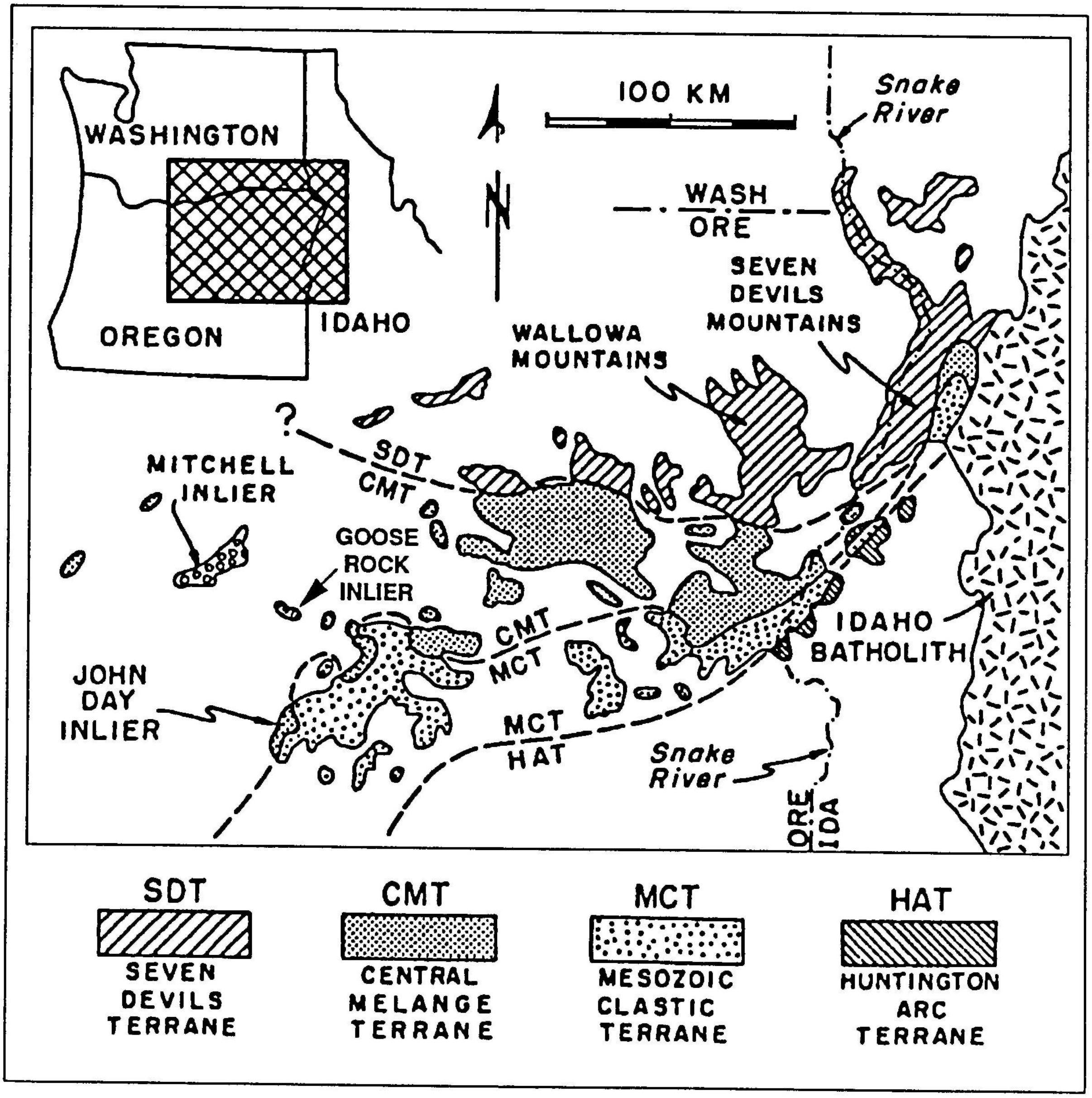

Figure 5. Map of the areal destribution of the four lithostratigraphic/tectonic terranes of Oregon, Idaho, and Washington (modified from Dickinson, 1979).

interpreted as dismembered oceanic crust that was completely accreted to the North American Plate by mid-Cretaceous time (Dickinson and Thayer, 1978; Dickinson, 1979, Avé Lallemant and others, 1980). Continual accretion during Late Jurassic time resulted in major east trending thrust faults and folds which control the present distribution pattern of these rocks (Brooks and Vallier, 1978; Avé Lallemant and others, 1980).

"Goose Rock Conglomerate"

Unconformably overlying the metamorphic basement rocks is a sequence of predominantly conglomerates with lesser amounts of sandstones and siltstones which crop out in the northern and central portion of the Butler Basin (Figure 4). The outcrop pattern is an east-west strip parallel to and along the south-side of the Middle Mountain Fault and a north-south strip along both sides of the John Day River. The total outcrop exposure of these conglomerates is about one-half mile wide by three and one-half miles long along the Middle Mountain Fault and about one-third mile wide by one and one-half miles long along the John Day River; see geologic map in back map pouch. The thickest exposure of the conglomerates is approximately 300 feet (Figure 6). The best exposures are the cliffs along the east side of the John Day River approximately one and one-half miles north of the Cant Ranch Visitors Center on Highway 19 (Figure 7).

Nomenclature: No formal formation name has been assigned to the conglomerates exposed in Butler Basin. Previous authors have referred to this group of

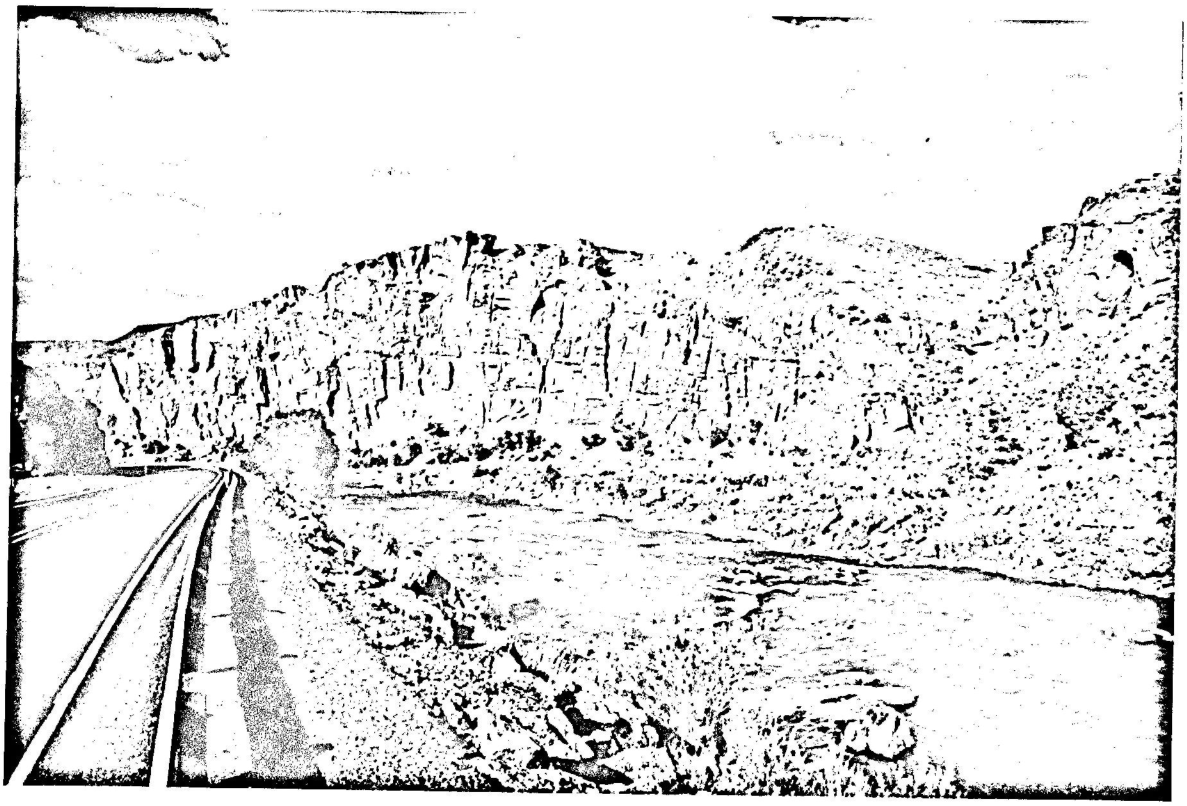

Figure 6. Photograph of Goose Rock in Butler Basin, from Highway 19, looking north-east.

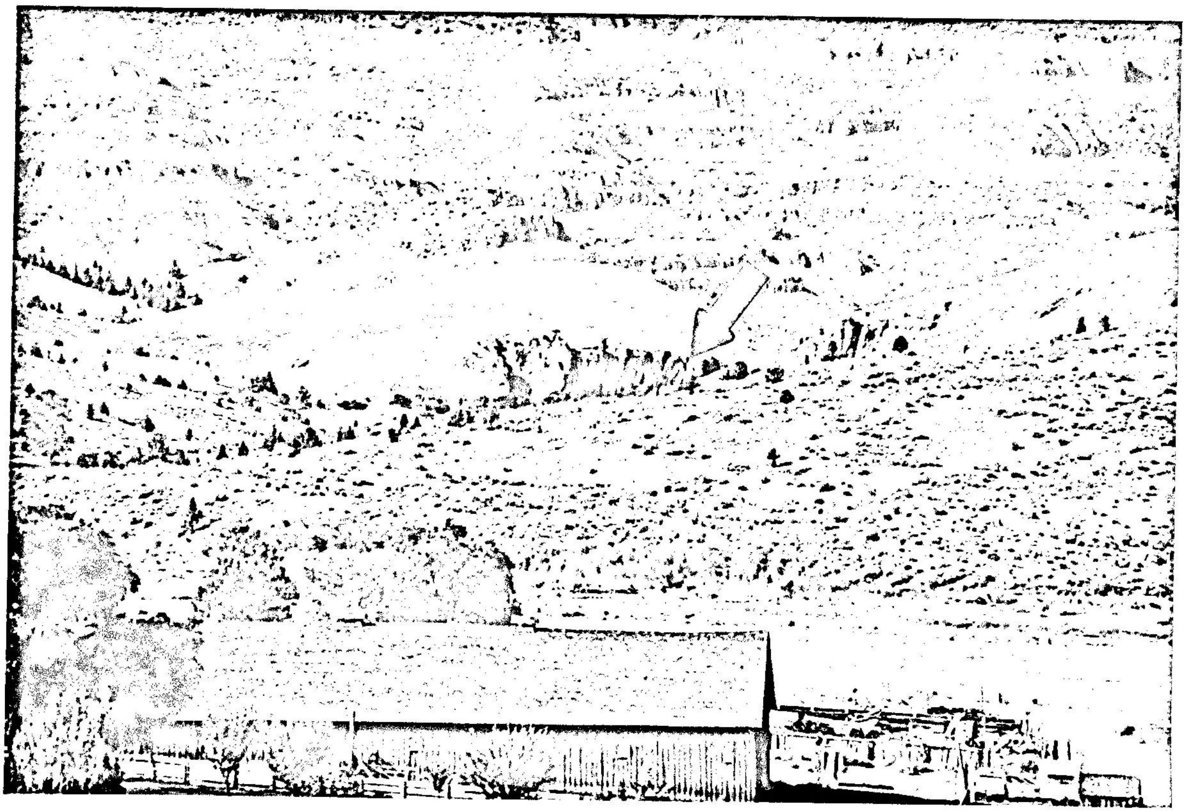

Figure 7. Photograph of principal outcrops of the "Goose Rock Conglomerate" (low rounded hills with cliffs along the river; see arrow); view toward the north-northwest, with the Cant Ranch barn in the foreground. Strata exposed beyond the "Goose Rock Conglomerate" outcrops are basalt flows of the Picture Gorge Basalt Formation, Columbia River Basalt Group, exposed on the down-thrown side of the Middle Mountain Fault.

rocks as "Cretaceous(?) conglomerates" (Coleman, 1949), "Cretaceous conglomerates" (White, 1964; Fisher, 1964, 1967, and 1968; Fisher and Rensberger, 1972), "conglomerate of Goose Rock" (Thayer, 1977a), "Cretaceous strata near Goose Rock" and "Cretaceous sequence near Goose Rock" (Kleinhans and others, 1984), and "Cretaceous sedimentary rocks at Goose Rock" (Little, 1986). I will use the informal name "Goose Rock Conglomerate" throughout this thesis. This name is derived from the conglomeratic cliff exposure along the John Day River (Figure 6) specifically named Goose Rock. This geographic feature appears on topographic maps of the area.

Lithology: The "Goose Rock Conglomerate" consists of buff to gray (fresh color) to rust (weathered color due to iron oxide staining), unsorted, sub-rounded to rounded, cobble- to pebble-sized clasts with medium-sized sand matrix. Pervasive siliceous cement has created well-indurated outcrops. Interbeds in the conglomerate sequence are relatively uncommon but where they exist they are predominantly medium- to coarse-grained sandstone. Pebbly sandstone interbeds are also present. Small laminated, fossiliferous or carbonaceous, coarse-grained siltstone or silty claystone interbeds are even less common. Many of the sandstone and some of the siltstone interbeds display cross-bedding or climbing-ripple lamina (Figure 8).

A wide variety of lithotypes are represented in the "Goose Rock Conglomerate" clasts. According to Little (1986,1987), the dominate lithologies are chert (34%), trachyte (34%), rhyolite (16%), and granite (5%) with minor quartzite and some mafic volcanic rocks also present. The heterolithology of the unit supports the interpretation that the clast provinance was the Blue Mountains island-arc terrane and associated

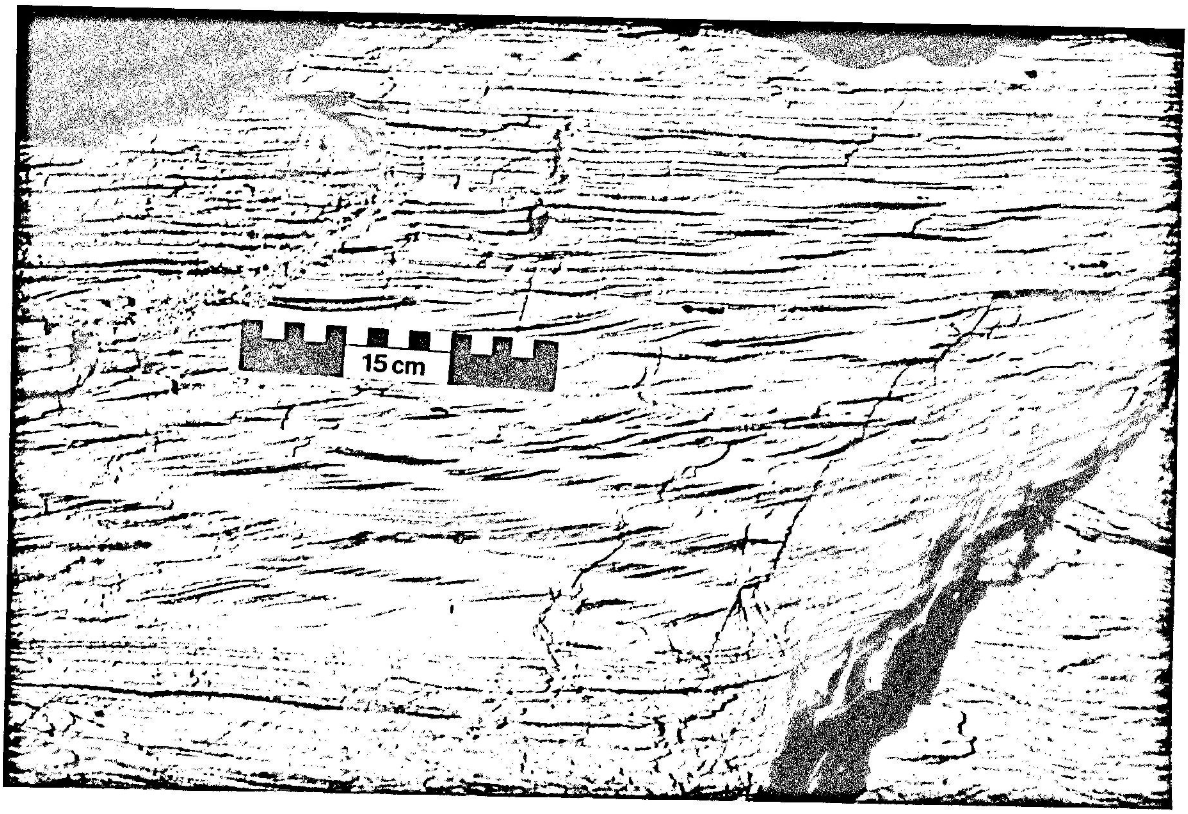

Figure 8. Photograph of a climbing-ripple laminated sandstone lens in the "Goose Rock Conglomerate".

Jurassic-Cretaceous plutons. Some examples of nearby Central Melange Terrane rocks are the ophiolitic Canyon Mountain Complex (Avé Lallemant, 1976; Thayer 1978) to the southeast of Butler Basin and further to the east are the supracrustal assemblage of Permo-Triassic Elkhorn Ridge Argillite and the Burnt River Schist (Gilluly, 1937). The ophiolite complex consists of quartz diorite, albite granite, and ultramafic rocks like peridotite, serpentinite, and gabbro (Thayer, 1963). The Elkhorn Ridge Argillite consists of interbedded chert, argillite, tuff, basalt, and minor amounts of limestone and conglomerate, while the Burnt River Schist consists of quartz phyllite, greenschist, greenstone, phyllitic quartzite, and marble (Gilluly, 1937). Of these three examples, the ophiolitic Canyon Mountain Complex appears to be the primary provinance rocks for the "Goose Rock Conglomerate" clasts, with perhaps some input from related terranes.

Age: The age of the "Goose Rock Conglomerate" has been variously interpreted as "middle" Cretaceous (Coleman, 1949; White, 1964; Beaulieu, 1972) and Late Cretaceous (Baldwin, 1976; Kleinhans and others, 1984; Little, 1986). Coleman (1949) concluded, "until a complete paleontological and petrographic study of the Cretaceous in the John Day Basin is made the age of the conglomerates . . . will remain questionable." Beaulieu (1972) suggested that the extensive Cretaceous outcrops near Mitchell "undoubtedly belong to the same unit". The Mitchell outcrops have been assigned an Albian to Cenomanian age (Wilkinson and Oles, 1968). Baldwin (1976) stated that since similar conglomerates are not "known to be present in the Clarno or younger

Tertiary formations of this area . . . an inferred Cretaceous, perhaps late Cretaceous, age has been assigned."

Thayer (1977a) briefly concluded that the sandstones and conglomerates of the Blue Mountains region, including those at Goose Rock, were deposited during a Cretaceous marine transgression following erosion and exposure of the Blue Mountains granites and early Mesozoic metasediments to the south and east of Butler Basin.

Kleinhans and others (1984) stated that due to the absence of fossil fauna in the Goose Rock strata "its Cretaceous age appears to be suspect." However, in their paleogeographic reconstruction of the area, these authors labelled the Goose Rock exposures as "Post mid-Cretac.?". Little (1986) stated that the "paucity of fossils" in the Cretaceous sedimentary rocks at Goose Rock "makes accurate determination of the age . . . difficult".

Palynology: Two of the four siltstone lens sampled from the "Goose Rock Conglomerate" yielded poorly preserved yet datable pollen and spore floras. Table 1 (see page 20) is a taxonomic list of the palynomorphs identified. This taxonomic list suggests a Late Jurassic to Early Cretaceous age, in contrast with previous age interpretations of Middle to Late Cretaceous.

The lack of similarity between the Goose Rock palynoflora and the Early Cretaceous (mid-Albian to Cenomanian) "Mitchell Formation" palynoflora (Fisk, personal communication, 1989) is of special interest. The Goose Rock palyno-flora is characteristic of pre-middle Albian palynofloras which have distinctive trilete spores and lack the tricolpate angiosperm pollen Clavatipollenites hughesii that has been identified from

Table 1. Taxonomic list of the palynomorphs identified from carbonaceous siltstones in the "Goose Rock Conglomerate" of Butler Basin, Central Oregon.

Appendicisporites sp.
Cicatricosisporites sp.
Cyathidites sp.
Foveosporites sp.
Laevigatosporites ovatus
?Lygodium sp.
Neoraistrickia truncata
Osmundacidites wellmanii
Tripalnosporites sp.
Vitreosporites pallidus

the "Mitchell Formation". On this basis, Aguirre and Fisk (1987) argued that the "Goose Rock Conglomerate" is probably Aptian in age and older than most of the "Mitchell Formation", although it may be equivalent in age to the "Basal Member" of the Mitchell Cretaceous sequence which also may be pre-Albian (Kleinhans and others, 1984). Further study of the Goose Rock palynoflora and comparisonswith that of other Cretaceous outcrops in the area may yield even closer refinement of its age.

Depositional Environment: In their paleogeographic reconstruction of Central Oregon (see Figure 9), Kleinhans and others (1984) placed the "Goose Rock Conglomerate" at the margin of an oceanic basin with the Cretaceous rocks exposed near Mitchell being forearc submarine fan deposits. Fritts and Fisk (1985a and b), Sandefur (1986), Little (1986, 1987), Kleinhans (1987), and Fisk and Fritts (1987) have all recently studied the Mitchell outcrops and also concluded that they represent a submarine turbidite fan complex deposited in a deep marine basin.

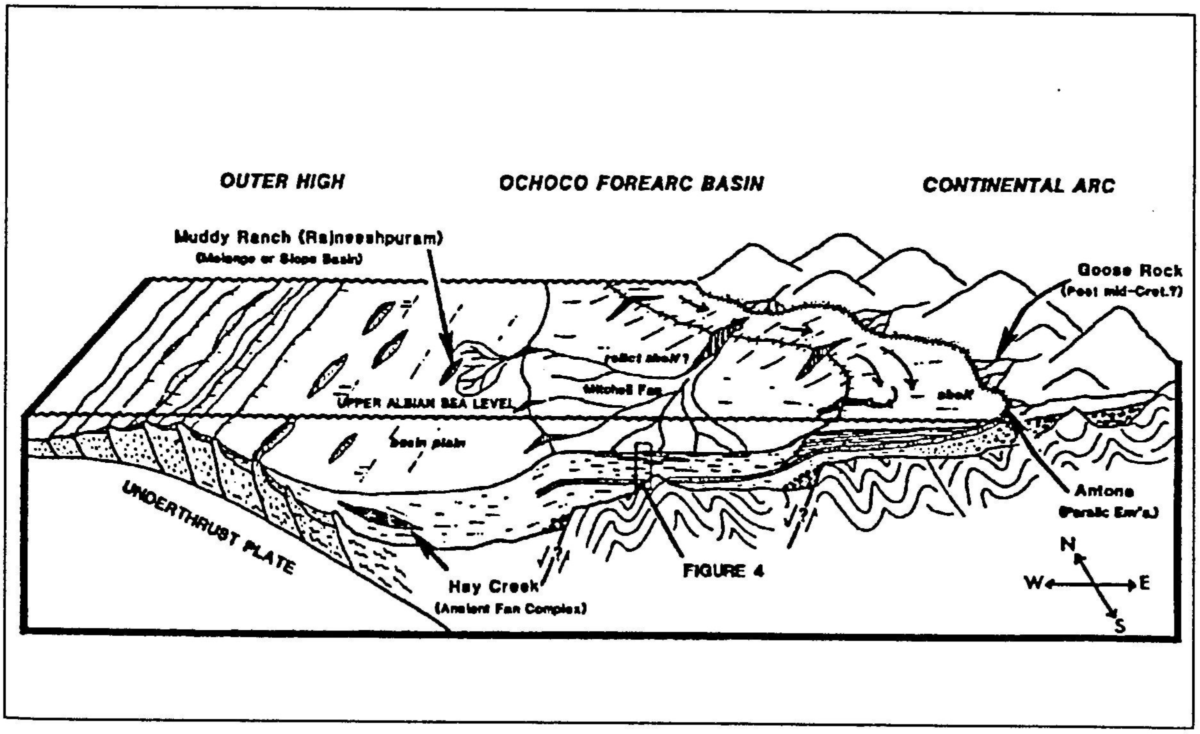

Figure 9. Paleogeographic model for Cretaceous outcrops in Central Oregon (reproduced from Kleinhans and others, 1984). Note these authors' interpretation of the depositional environment of the Goose Rock outcrops to the right.

Little (1986) did petrologic comparisons of all the known Cretaceous conglomerates of Central Oregon. He concluded that there are two major conglomerate petrofacies representing two depositional environments: the submarine turbidite fan deposits in the Mitchell area named the Gable Creek Formation and Hudspeth Formation by Wilkinson and Oles (1968) and the nonmarine to shallow marine environments of the basin margins to the south and east of Mitchell. He interpreted the sedimentary rocks at Goose Rock as being deposited in a "nonmarine setting" based on the absence of dark mudstones and marine fossils. I am in agreement with Little (1986) that a fluvial depositional environment best fits the available sedimentologic and paleontologic data from the "Goose Rock Conglomerate". The coarse-grained, well-rounded, and poorly-sorted nature of the conglomerates are indicative of a high-energy, near-source, fluvial system. The coarse-grained, ripple-laminated, arkosic sandstone and siltstone lenses are also indicative of a fluvial system. Further, the palynoflora recovered from these siltstone lenses contained only pollen and spores from terrestrial plants; no marine dinoflagellates were present.

The general transport direction for Cretaceous sediments in Central Oregon has been controversial. McKnight (1964) concluded a northwest transport direction for the Cretaceous outcrops at Mitchell. However, Wilkinson and Oles (1968), Jarman (1973), Kleinhans and others (1984), Little (1986, 1987), and Kleinhans (1987) have all argued for a southerly or southwesterly transport. Little (1986) concluded, based on only 40 paleocurrent observations, that the paleocurrents of the Mitchell inlier were predominantly towards the southwest with a "subordinate northwesterly trend." In contrast, Sandefur (1986) determined, based on approximately 3,000 individual paleocurrent measurements, that the Mitchell turbidites showed a predominant northwesterly paleocurrent trend, in agreement with McKnight (1964), with a few minor or subordinate west and southwest trends.

For the "Goose Rock Conglomerate", Little (1986) collected "limited" paleocurrent direction data from cross-bedded sandstones and again concluded that the paleocurrent direction was southwest. My nearly 300 paleocurrent measurements collected from the "Goose Rock Conglomerate" are summarized in Figure 10. In agreement with Little (1986, 1987), this rose diagram clearly indicates a predominantly southwesterly direction of transport. Thus, although during Early Cretaceous time a northwesterly regional paleoslope may have existed (McKnight, 1964; Swanson, 1969; Fritts and Fisk, 1985a and b; Sandefur, 1986), the "Goose Rock Conglomerate" represents a southwesterly-flowing fluvial channel system.

Clarno Formation

The "Goose Rock Conglomerate" is unconformably overlain by basalt flows and volcaniclastic rocks which have been variously referred to either the Clarno Formation or the basal member of the John Day Formation. For reasons outlined below, I have referred and mapped these rocks as Clarno Formation.

Boundary Problem: With the exception of Fisher (1968), Fisher and Rensberger (1972), Thayer (1977a), and Fisk and Fritts (1987), most previous workers have not recognized the presence of the Clarno Formation in Butler Basin (e.g.,

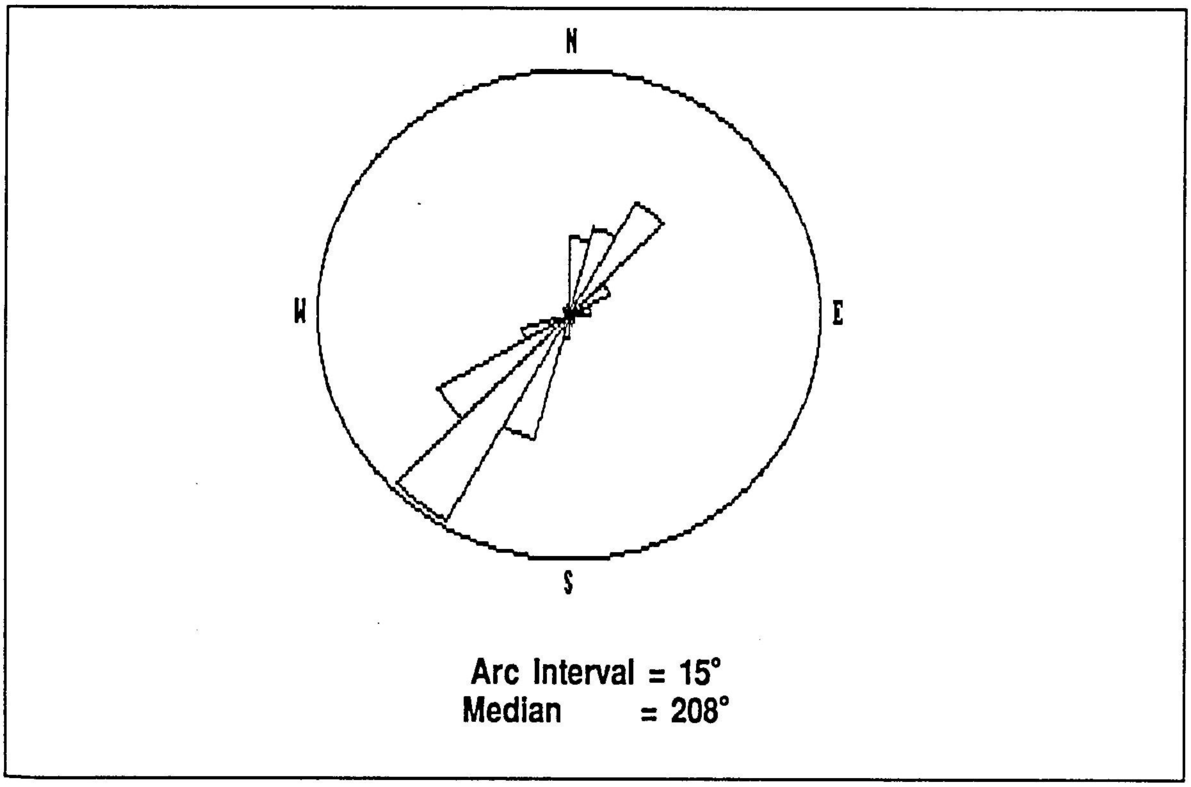

Figure 10. Rose diagram of 296 individual paleocurrent azimuth measurements from the "Goose Rock Conglomerate".

Coleman, 1949; White, 1964; Fisher, 1964; Baldwin, 1976). Part of the reason for the problem centers around whether a researcher accepts the presence of basalts in the lower John Day Formation (e.g., Hay, 1962, 1963; Robinson, 1969) or not (e.g., Taylor, 1960; Fisk and Fritts, 1987; Riseley, 1989; Fisk, in preparation).

Basalts, basaltic andesites, and andesitic basalts are abundant in the Clarno Formation (Merriam, 1901b; Taylor, 1960). Many contemporary workers choose to place the boundary between the Clarno and John Day Formations at a "post-Clarno"/pre-John Day Formation "soil" zone (Waters and others, 1951; Hay, 1962; Peck, 1964; Fisher, 1964, 1967, 1968; Fisher and Rensberger, 1972). Other workers have included this "post-Clarno" paleosol as part of the Clarno Formation but have not included associated basalts which have instead been referred to the lower John Day Formation (Swanson and Robinson, 1968; Swanson, 1969a; Beaulieu, 1972; Robinson, 1973, 1977).

I am in agreement with Taylor (1960) and Fisk (in preparation) that there is no good reason for placing these basalts into the lower John Day Formation but rather include them in the upper Clarno Formation where basalts are common. Taylor (1960), Oles and Enlows (1971), Noblett (1981), and Fisk (in preparation) place the Clarno-John Day Formation contact at the weathered surface of the uppermost Clarno flow (either basalt or ignimbrite) overlain by red, tan, and white John Day Formation tuffs.

Lithology: In the Butler Basin, the basalts, siliceous shales, and red tuffs which have not been reworked and are immediately overlying the "Goose Rock

Conglomerate" belong to the Clarno Formation. In places, the Clarno-age red tuffs have been reworked into the basal John Day Formation, thus giving the youngest John Day tuffs their red color and obscuring the boundary between the two formations (see also Hay, 1962; Fisher, 1964; Robinson and Brem, 1981; Robinson, 1987; and Fisk and Fritts, 1987).

Age: To determine the age of the basalts immediately overlying the Goose Rock outcrops (Figure 11), a whole-rock potassium-argon age determination was done; this is the only potassium-argon date known from this outcrop. The basalt sample (sample # GRC_{c1}; see Table 2, page 28) yielded an age of 49.0 $\pm$ 2.2 million years. This date clearly documents that this basalt belongs to the Clarno Formation and in fact is one of the oldest dates reported for lower Clarno Formation flows (Walker and others, 1974; Fiebelkorn and others, 1983; Vance, 1988). Previously reported ages for the Clarno Formation range from 50 million years (Robinson in Noblett, 1981) to 29.3 million years (Enlows and Parker, 1972). There have been and continue to be conflicting interpretations of the age of the Clarno Formation. Enlows and Parker concluded that the age range is 46 to 30 million years. However, based on personal communication from Robinson, Noblett (1981) concluded that the Clarno was as old as 50 million years but "in no case has a sample been younger than 41 m.y.".

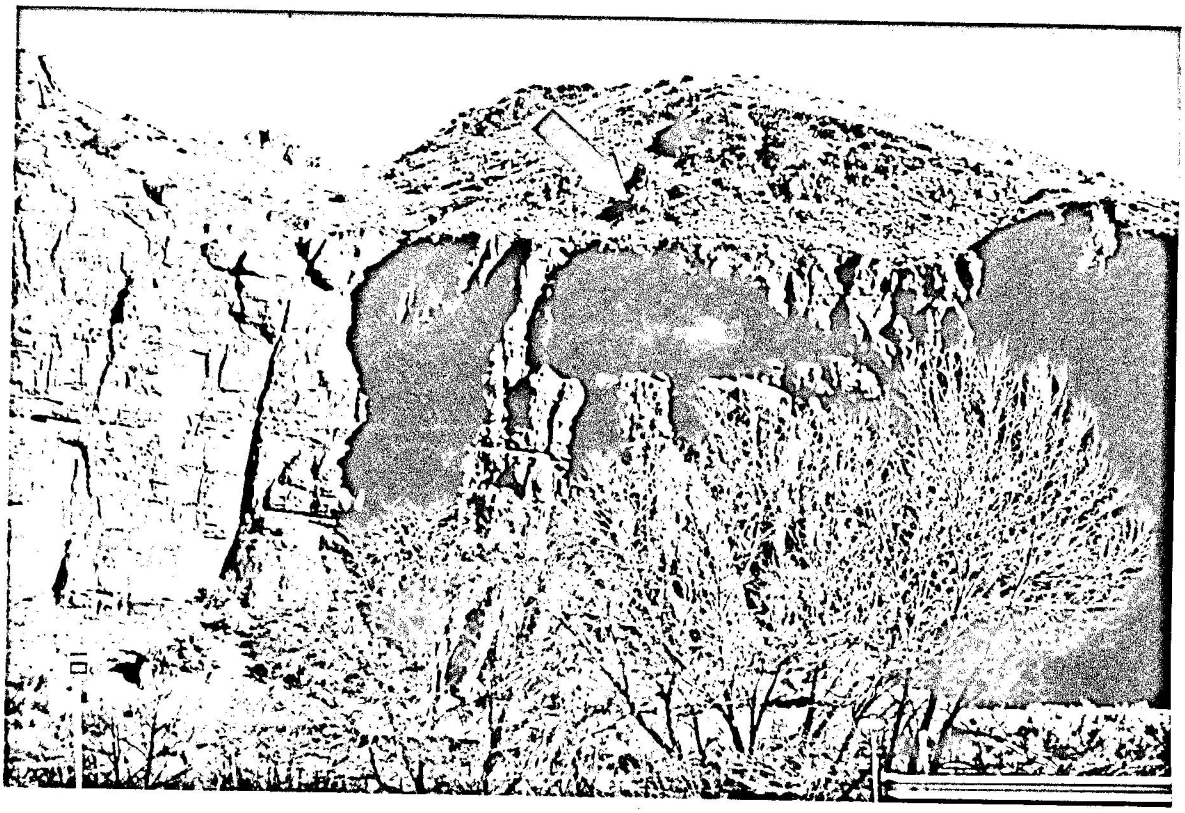

Figure 11. Photograph of Clarno Formation basalt (see arrow) overlying the "Goose Rock Conglomerate" at Goose Rock. The K-Ar dated sample came from the outcrop at the arrow.

Table 2. Data for a whole-rock K-Ar date of a basalt unconformably overlying the "Goose Rock Conglomerate" at Goose Rock. Analyses by Geochron Laboratories 1988 (sample R-8183).

Material: unweathered basalt, whole-rock analysis, field no. GRC_{C1}.

Locality: basalt outcrop capping Goose Rock

Stratigraphy: lowermost Clarno Formation

Age: 49.0 ± 2.2 m.y.

Argon Analyses:

^{40}Ar, ppm	$^{40}Ar/Total^{40}Ar$	Avg. ^{40}Ar, ppm
.005487	.325	.005359
.005264	.498	
.005327	.418	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
1.594	1.556	1.857
1.513		
1.562		

I suggest that the age-of-the-Clarno conflict is in part due to differences in interpretation of exactly where to draw the contact between the John Day and Clarno Formations and in part due to poor samples or sample collecting techniques. I am in agreement with Fisk (in preparation and personal communication, 1989) that the age range of the Clarno Formation is approximately 50 to 30 million years (i.e, Middle Eocene to Early Oligocene). This age span includes the full range of radiometric dates available for the Clarno Formation and is in close agreement with the biostratigraphic age ranges of both fossil plants and mammals (Fisk, in preparation).

John Day Formation

The Clarno Formation is unconformably overlain by the varicolored tuffs of the Oligocene-Miocene John Day Formation (Figure 12), the most scenic and most studied formation in the region. Merriam (1901b) was the first to comprehensively describe the John Day Formation. He did not designate a type section but concentrated his work along the John Day River in the section from Picture Gorge to Kimberly, now generally accepted as the type area. In Butler Basin, the John Day Formation is about 800 thick and sparsely fossiliferous. To the west, the formation has a thickness ranging from 2700 to 4000 feet (Hay, 1963; Peck, 1964).

The stratigraphy of the John Day Formation has been modified and described in detail most recently by Fisher and Rensberger (1972). They recognized the following four subdivisions of the John Day Formation, from oldest to youngest. Unconformably overlying the hilly erosional surface of the Clarno Formation basalt and saprolitic tuffs is the Big Basin Member (equivalent to Merriam's (1901b) lower division) which consists of red to tan to white, diagenetically altered, locally lacustrine, air-fall tuffs. This unit is the thinnest and least fossiliferous of the four members (Fisher and Rensberger, 1972). Transitionally overlying the Big Basin Member is the blue-green to green to gray, massive, diagenetically altered, lower zeolitized tuff facies (equivalent to Merriam's (1901b) middle division) and an upper, gray to buff, thick, unzeolitized fresh glass facies of the Turtle Cove Member (Fremd, 1988; personal communication). This unit is the thickest and most fossiliferous member of the John Day Formation (Fisher and Rensberger, 1972). The widespread Picture Gorge

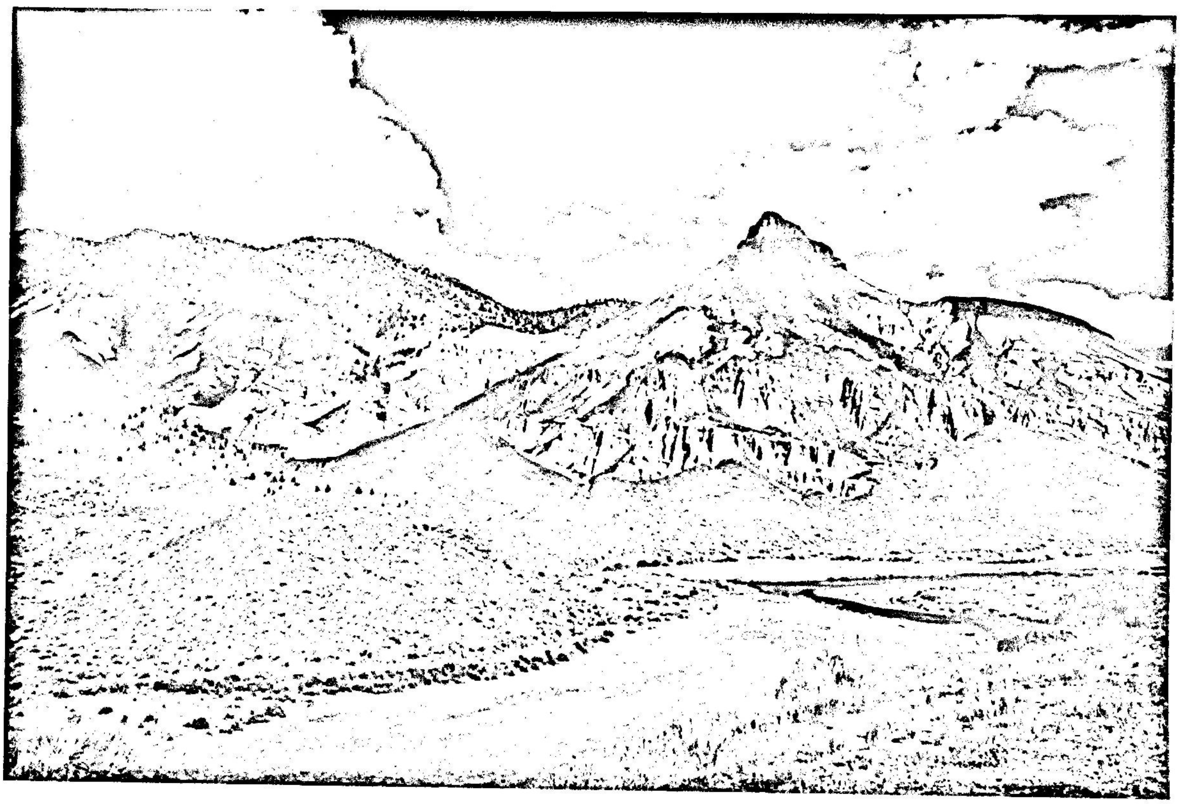

Figure 12. Photograph of "Sheep Rock" in the Sheep Rock Unit of the John Day Fossil Beds National Monument consisting of John Day Formation tuffs capped by Picture Gorge Basalt.

Ignimbrite (Fisher, 1966) which occurs within the lower half of this member is an excellent stratigraphic marker bed and has yielded, from near its base north of Mitchell, a potassium-argon age of 25.3 million years (Evernden and others, 1964b; Enlows and Parker, 1972; Fiebelkorn and others, 1983). The third or "upper" division of Merriam (1901b) has been subdivided by Fisher and Rensberger (1972) into the Kimberly and Haystack Valley Members. The gray, greenish gray and buff, unzeolitized, massive tuffs of the Kimberly Member are diagenetically transitional with the unzeolitized upper Turtle Cove Member. The Kimberly Member is very fossiliferous. The uppermost unit, named the Haystack Valley Member, is composed of gray to greenish-gray and buff, unzeolitized, conglomerate, sandstone, and lacustrine tuffs interbedded with abundant massive air-fall tuffs. This unit is erosionally unconformable with the Kimberly Member (Fisher and Rensberger, 1972). In Butler Basin, only the Big Basin, Turtle Cove, and Kimberly Members are present.

Age: Due to the Clarno-John Day boundary problem discussed earlier, the age range of the John Day Formation is uncertain. Since the Big Basin Member red beds contain reworked Clarno Formation red saprolitic tuffs (Hay, 1962; Fisher, 1964; Robinson and Brem, 1981; Fisk, in preparation and personal communication, 1989), samples from this unit yield erroneously old ages. In addition, since the so-called "lower John Day basalts" actually belong to the Clarno Formation (Fisk, in preparation and personal communication, 1989; also see discussion above), I do not accept potassium-argon dates of these basalts as valid ages of the basal John Day Formation. Considering these problems in stratigraphy and geochronology, the most likely age range for the John Day Formation is roughly 30 to 17 million years (i.e., Late Oligocene to Early Miocene).

Picture Gorge Basalt Formation

Unconformably overlying the John Day Formation is the Miocene Picture Gorge Basalt Formation, the lowermost unit of the Columbia River Basalt Group (Waters, 1961; Swanson, 1969b; Swanson and others, 1979). These tholeiitic flood basalt flows form the "rim rock" of the Butler Basin and are the youngest strata exposed on the margin of the Basin. In Picture Gorge, the type location, the Picture Gorge Basalts are approximately 1500 feet thick (Waters, 1961; Swanson and others, 1979).

Three basalt samples (field numbers GRC_{D1}, GRC_{D7}, and GRC_{D8}, Table 3) were collected from the central portion of Butler Basin and their potassium-argon age was determined by Geochron. All three samples yielded ages of approximately 17 million $\pm$ 2 million years, within the age range previously reported for Picture Gorge Basalts (Evernden and James, 1964a and b; Watkins and Baksi, 1968; Baksi, 1972; Walker and others, 1974; Fiebelkorn and others, 1983). Although several hundred feet below the basalt rim and in the central part of the basin, these basalts can be explained as slump blocks of Picture Gorge Basalts carried on landslides driven by swelling clays in John Day Formation (Fisher, 1964). All previous workers have mapped these basalts as Quaternary landslides (e.g., Coleman, 1949; Fisher and Rensberger, 1972).

Table 3. Data for whole-rock K-Ar dates from three basalts sampled from the center of Butler Basin. Analyses by Geochron Laboratories in 1989.

Material: unweathered basalt, whole-rock analysis, field no. GRC_{D1}. Geochron Laboratories sample no. R-8571.
Locality: landslide in SE 1/4, NE 1/4, Sec. 6, T12S, R26E
Stratigraphy: lower Picture Gorge Basalt
Age: 16.2 ± 1.8 m.y.
Argon Analyses:

^{40}Ar, ppm	^{40}Ar/Total ^{40}Ar	Avg. ^{40}Ar, ppm
.000470	.125	.000464
.000458	.086	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
0.419	0.412	0.492
0.405		

Material: unweathered basalt, whole-rock analysis, field no. GRC_{D7}. Geochron Laboratories sample no. R-8568.
Locality: landslide in SW 1/4, NE 1/4, Sec. 6, T12S, R26E
Stratigraphy: lower Picture Gorge Basalt
Age: 17.8 ± 1.9 m.y.
Argon Analyses:

^{40}Ar, ppm	^{40}Ar/Total ^{40}Ar	Avg. ^{40}Ar, ppm
.000390	.229	.000395
.000401	.196	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
0.321	0.320	0.381
0.318		

Material: unweathered basalt, whole-rock analysis, field no. GRC_{D8}. Geochron Laboratories sample no. R-8569.
Locality: landslide in SW 1/4, SW 1/4, Sec. 32, T11S, R26E
Stratigraphy: lower Picture Gorge Basalt
Age: 16.9 ± 1.7 m.y.
Argon Analyses:

^{40}Ar, ppm	^{40}Ar/Total ^{40}Ar	Avg. ^{40}Ar, ppm
.000491	.231	.000554
.000638	.335	
.000676	.074	
.000410	.100	

Potassium Analyses:

% K	Avg. % K	^{40}K, ppm
0.470	0.472	0.562
0.473		

Mascall Formation

Conformably overlying the Picture Gorge Basalts is exposed a series of late Miocene fluvial and lacustrine volcaniclastic sandstones and siltstones named the Mascall Formation by Merriam (1901b). The type locality is near the Mascall Ranch just south and east of my study area. The Mascall rocks are lithologically similar to those of the John Day Formation. The type section is 1340 feet although this unit ranges in thickness from 400 to 2000+ feet (Merriam, 1901b; Enlows, 1973; Kuiper, 1988) and contains fossil pelecypods, leaves, and mammals of Hemingfordian and Barstovian age (Merriam and others, 1925; Chaney, 1956; Downs, 1956). The Mascall Formation has recently been studied in depth by Kuiper (1988).

Rattlesnake Formation

Overlying the Mascall Formation with angular unconformity is the Pliocene Rattlesnake Formation consisting of a thick sequence of fanglomerates separated near the middle by a relatively thin (41 foot) rhyodacite ignimbrite. The type-section of the formation, on the Rattlesnake Ranch (Merriam, 1901b) at the south edge of my study area, has a total thickness of 629 feet but a composite formation thickness of 1350 feet has been recognized by Enlows (1976). The Rattlesnake Formation is composed primarily of pebble- to cobble-size clasts and coarse sandstones with some mudstones (Enlows, 1973; Enlows, 1976). Mammal remains collected and studied by Merriam (1901b), Merriam and others (1925), and Davenport (1971) and fossil leaves collected and identified by Chaney (1948 and 1956) both yield a Pliocene age for the

Rattlesnake Formation. Enlows (1973) reported several K-Ar date determinations indicating a 6.4 million year age for the Rattlesnake Formation.

STRUCTURE

On some geologic maps, the Butler Basin has been interpreted as a syncline with a north-south axis (Coleman, 1949; White, 1964; Brown and Thayer, 1966; Newcomb, 1970; Walker, 1977). Others have interpreted the structure as a southward plunging anticline (inferred from the north-south cross-sections of Baldwin (1976) and Thayer (1977a)). In agreement with the latter authors, I interpret the structure of Butler Basin as a shallow southward plunging anticline with the axis trending north-south (Figure 13; see geologic map in back pocket for east-west and north-south cross-sections). Extensive landsliding and large slumped blocks of Picture Gorge Basalt along the margins of the basin give a false impression that the strata dip toward the basin center and explain why the structure has in the past been misinterpreted as a syncline. The true anticlinal structure is documented by dips measured in the John Day Formation and Picture Gorge Basalt on the margin of Butler Basin.

The north-south trending anticline through the basin is superposed on an east-west trending monoclinal flexure in the Picture Gorge Basalt (Calkins, 1902). The dip slope of this monocline strikes ESE-WNW, parallel to the John Day Fault, a down-to-the-north normal fault, which is the primary structural control on the east-west trending John Day River Valley (see Figure 4). The trace of the John Day Fault is located in the southwest corner of my study area.

The second major fault in the Butler Basin area is the Middle Mountain Fault which forms the northern boundary of the Butler Basin (Figure 14; also note that this

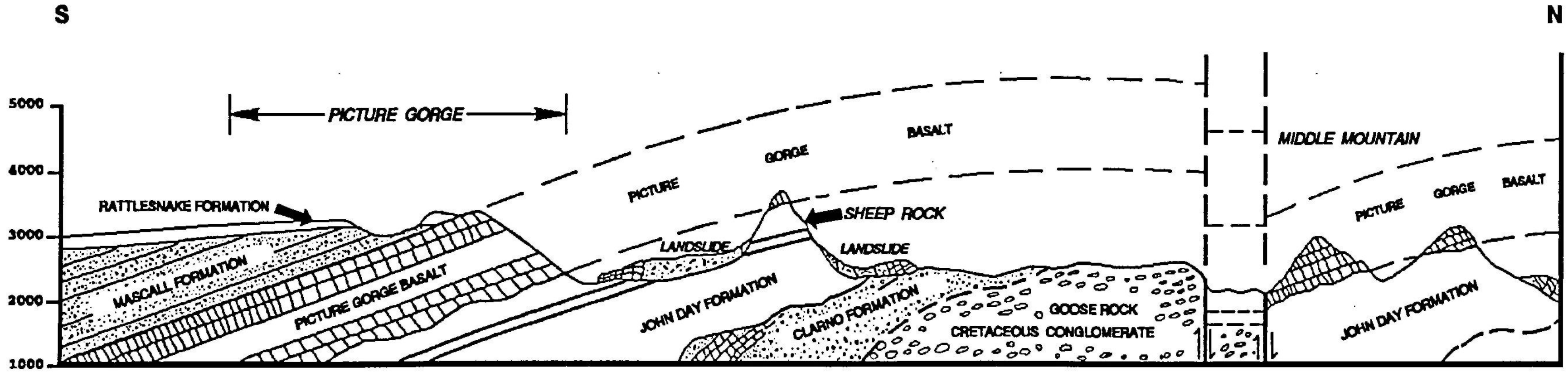

Figure 13. North-south cross-section through the middle of Butler Basin parallel to the John Day River (modified from Thayer, 1977a).

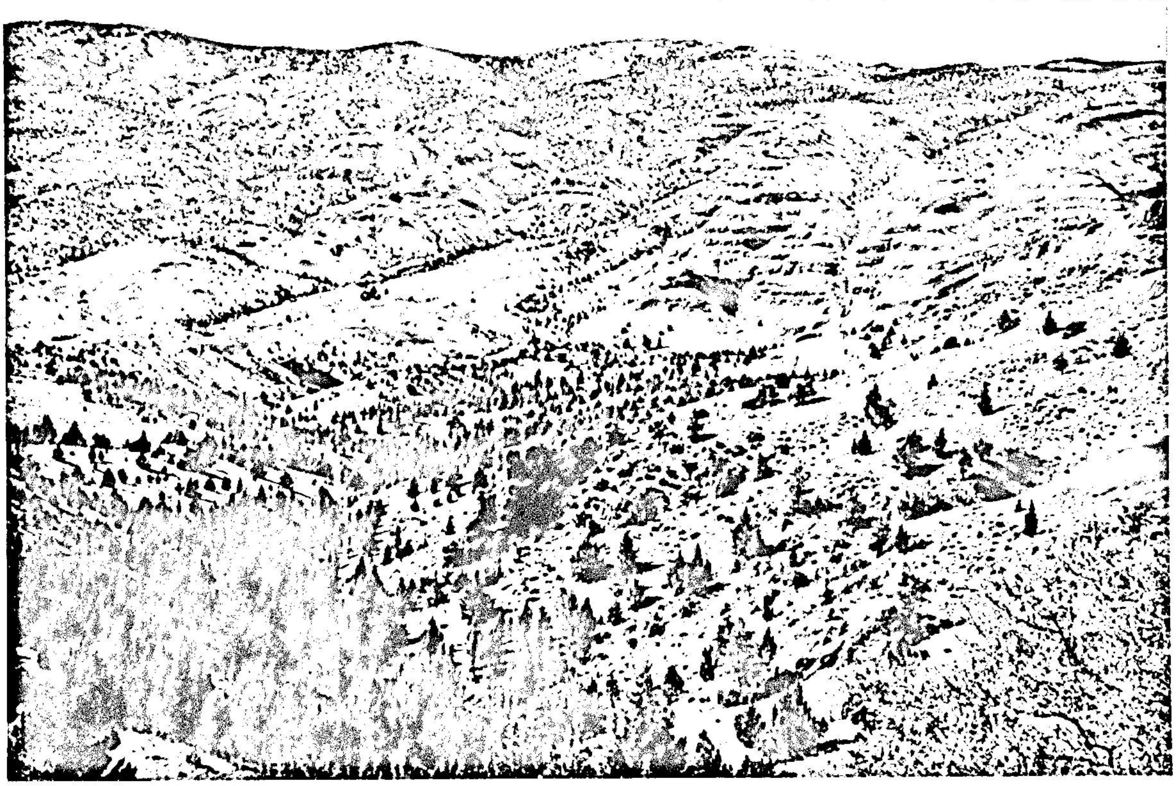

Figure 14. Photograph taken along the trend of the Middle Mountain Fault; view is from the east-side of Butler Basin, looking west. Middle Mountain is on right.

feature is clearly visible in the aerial photo in Figure 4). This east-west trending, down-to-the-north, normal fault is sub-parallel to and has the same sense of movement as the John Day Fault and is probably the same age.

Stratigraphic relationships document that movement on the John Day Fault was primarily post-Picture Gorge Basalt but pre-Mascall (inferred from the angular unconformity at its base and its deposition restricted to the John Day River Valley). Rejuvenated fault activity is evidenced by uplift and tilting of the Mascall beds, an angular unconformity at the contact with the overlying Rattlesnake Formation, the presence of angular unconformities and the deposition of extensive coarse conglomerates within the Rattlesnake Formation, and further post-depositional uplift and tilting of the Rattlesnake Formation. These relationships are easily viewed in a scenic panorama of the southern portion of my study area (Figure 15).

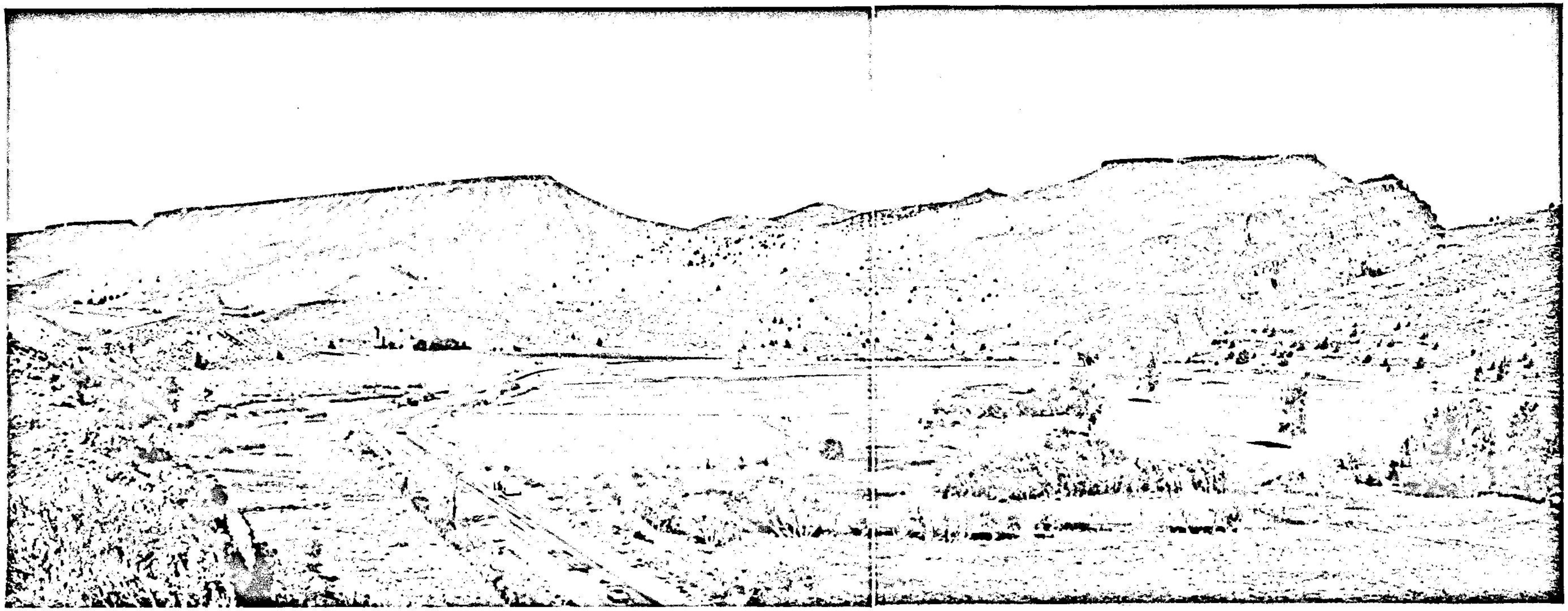

Figure 15. Panoramic view of the John Day River Valley, looking northwest toward the south entrance of Picture Gorge (the cliff exposures near the right edge of the photograph). The light-colored, steeply dipping strata on the left are Mascall Formation and the shallower dipping, table-top unit at the skyline is the Rattlesnake ignimbrite.

SUMMARY AND CONCLUSIONS

Butler Basin is an erosional breach in a north-south trending, south-plunging anticline which exposes Permo-Triassic through Neogene strata. Permo-Triassic metamorphic rocks (schist, phyllite, quartzite, and marble) are poorly exposed as a weathered fault sliver along the Middle Mountain Fault. These rocks are lithologically similar to those which crop out to the southeast of Butler Basin along the John Day Fault and in the Aldrich Mountains.

The overlying Early Cretaceous, post-accretionary Goose Rock conglomerates are composed of pebble- to cobble-sized clasts with lenses of sandstone and some siltstone. Lithologies represented in the clast population indicate that the conglomerate was derived from the accreted island-arc terranes of the John Day Inlier. A sparse and poorly preserved palynoflora recovered from the Goose Rock siltstones, suggests that the conglomerates are pre-Albian in age and older than the Cretaceous rocks of the Mitchell Inlier. Thus, the "Goose Rock Conglomerate" may represent the earliest deposition following accretion and suturing of Blue Mountain terranes. A more specific age (i.e., more specific than pre-Albian) cannot be assigned to the "Goose Rock Conglomerate" at this time. More abundant and better preserved palynomorphs that are age-diagnostic of a shorter biostratigraphic age range are required to assign a more precise age to this unit. Sedimentary structures in the "Goose Rock Conglomerate", along with the entirely terrestrial palynoflora, document a fluvial depositional system with a southwesterly paleocurrent trend.

The basalt flow and unreworked red tuffs immediately overlying the "Goose Rock Conglomerate" are referable to the lower Clarno Formation, based on a whole-rock K-Ar date on the basalt of 49 million years. The overlying John Day, Picture Gorge Basalt, Mascall, and Rattlesnake formations have been only briefly reviewed since they have been the emphasis of much previous work.

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