Structural geology of the Swift Reservoir culmination, Sawtooth Range, Montana
by Donald Scott Singdahlsen

A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Northwest trending, west dipping thrust—faulted and folded rocks of Paleozoic and Mesozoic age comprise the Sawtooth Range of northwestern Montana. The configuration of crystalline basement may have controlled the development and geometry of the Sawtooth Range, a part of the Northern Disturbed Belt. Primary influences include the Sweetgrass Arch and a series of northeast trending features which may reflect a fundamental structural grain in the Precambrian basement. Timing of Sevier-style deformation within the Northern Disturbed Belt is bracketed to have occurred primarily during the Paleocene.

The Swift Reservoir culmination is defined by a doubly-plunging thrust sheet anticlinorium which is structurally higher than adjacent areas along strike. Fold axes within the culmination plunge away from the culmination center. Kinematic development of the culmination is a result of polyphase deformation of the Backbone thrust sheet. Uplift, rotation, and folding of the Backbone thrust by footwall imbrication and potential duplex formation is responsibe for development of the Swift Reservoir culmination.

Major structures within the culmination include thrust faults, tear faults, and folds. Thrust faults are dominantly bedding-plane thrusts with their location strongly controlled by stratigraphic zones of weakness. Concentric folding by flexural-slip mechanisms is the dominant folding style. Folds are commonly asymmetric with vergence in the direction of tectonic transport.

Deformational style and intensity within the culmination are controlled by lithologic variability and structural level of development. Ductility contrasts and mechanical behavior of different lithostratigraphic packages partition thrust sheet deformation within the Swift Reservoir area. Because of these factors, the Cambrian lithostratigraphic package exhibits the greatest deformational intensity as penetrative structures are developed. Orogenic shortening across the Swift Reservoir culmination due to structural thickening is approximately 64%. Development of penetrative fabrics such as boudinage, pencil structure, and axial-planar solution cleavage accounts for an estimated 10 to 25% internal shortening superimposed on the translational shortening observed for the culmination.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Purpose

The Northern Disturbed Belt of northwestern Montana forms the eastern margin of the foreland portion of the structurally complex Cordilleran Fold and Thrust Belt (Figure 1). The Sawtooth Range is part of the Montana Disturbed Belt and consists of closely spaced imbricate thrust faults. The purpose of this study is to provide a structural analysis of the Swift Reservoir culmination located within the northern Sawtooth Range. This analysis will then be applied to an interpretation of the structural development of both the study area and the Sawtooth Range. In addition to the structural analysis, this project will include detailed geologic mapping, interpretation of timing of deformation, mechanical significance of deformation, and evaluation of hydrocarbon potential in the region.

Study Area

The Sawtooth Range is located directly south of Glacier National Park and forms the front ranges of the Rocky Mountains in northwestern Montana. The study area is 15 miles (24 km) west of the town of Dupuyer, Montana, and is bounded on the north by Swift Reservoir - Birch Creek and on the south by the North Fork of Dupuyer Creek (Figure 2). The map area is contained within portions of the United

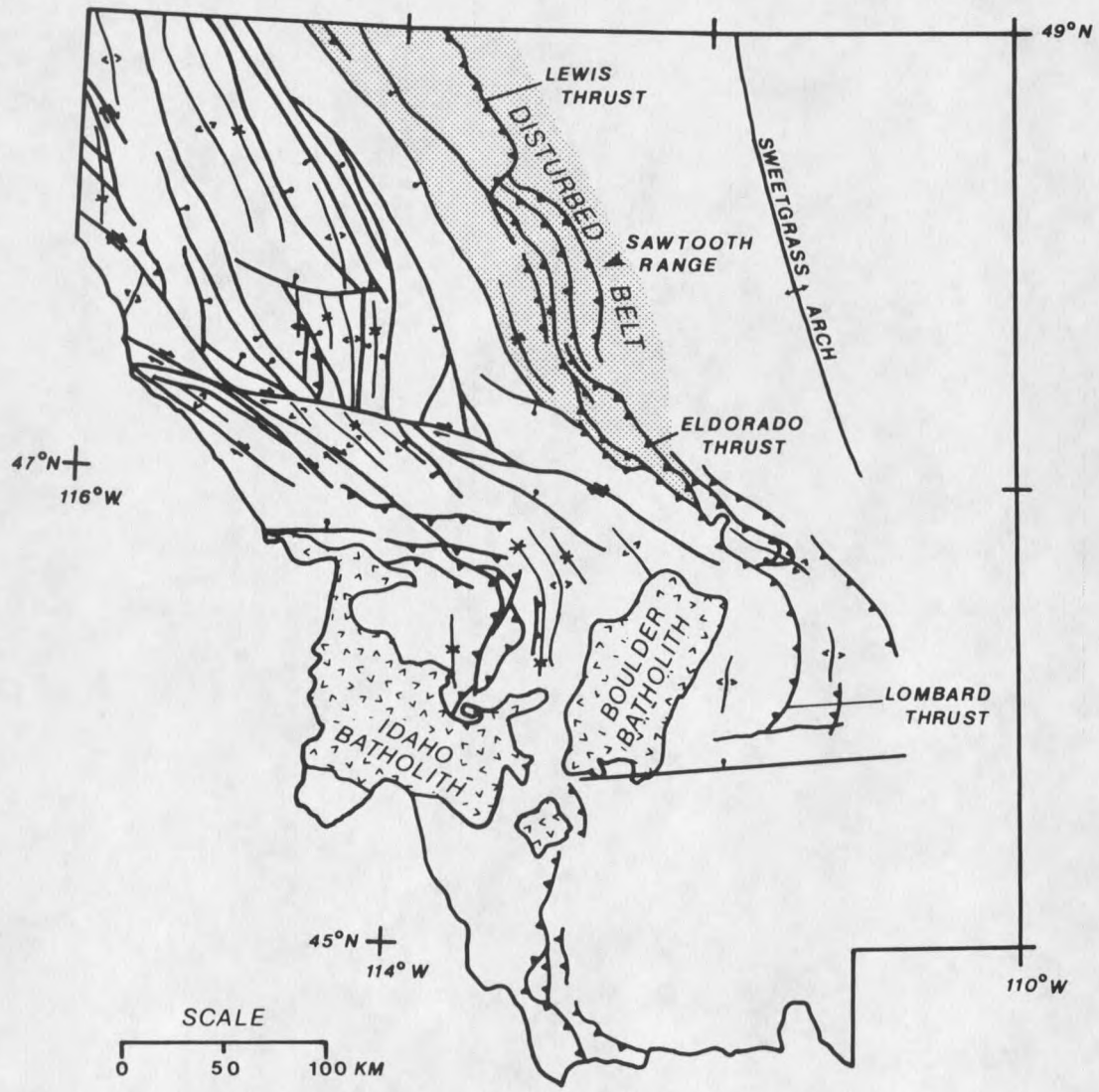

Figure 1. Generalized tectonic map of northwest Montana (after Harrison et al, 1974; Bregman, 1976).

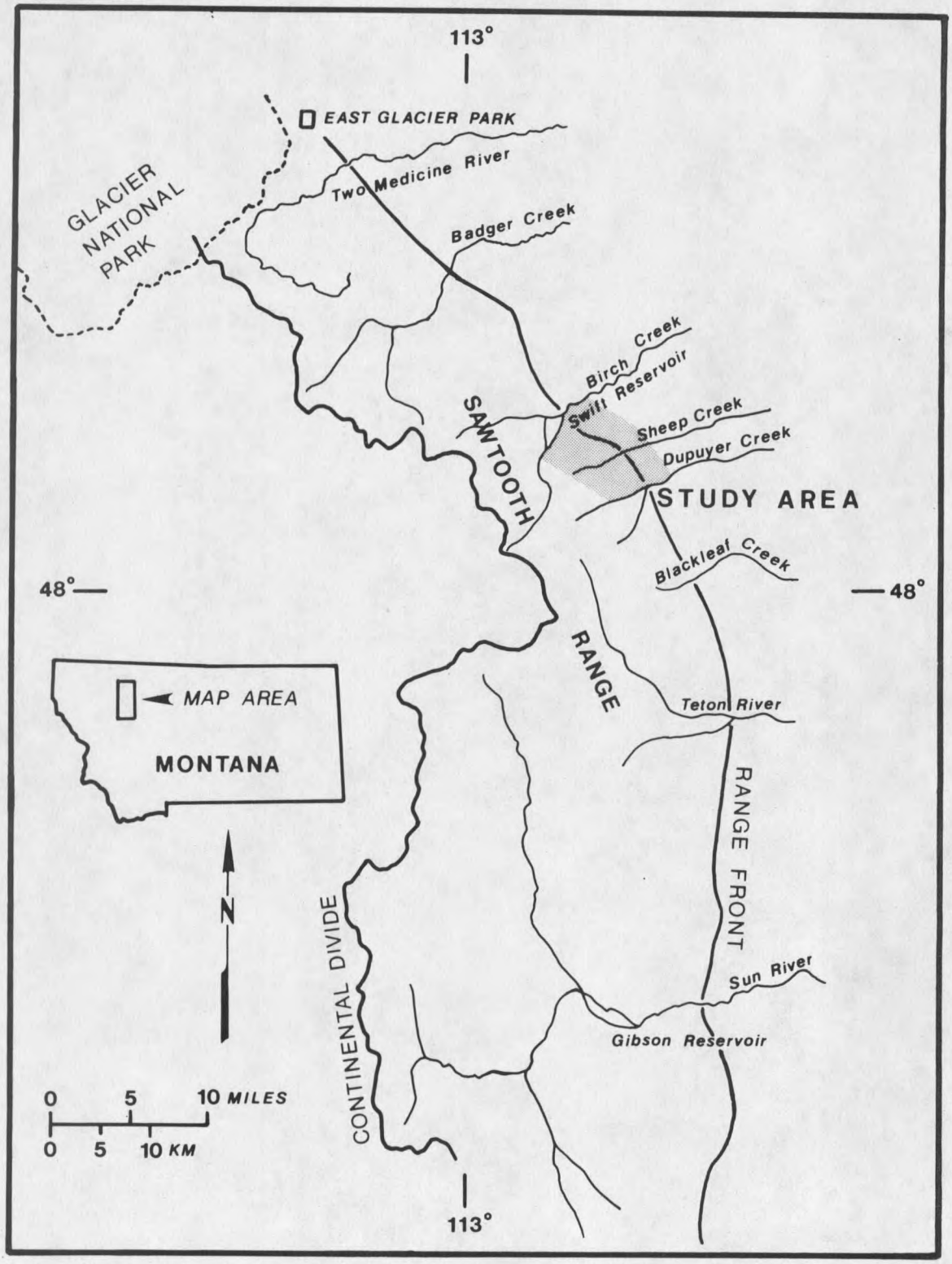

Figure 2. Study area location map, Sawtooth Range.

States Geological Survey 7.5 minute topographic quadrangles of Fish Lake, Swift Reservoir, Volcano Reef, and Walling Reef, Montana.

Access to the area is provided by an improved dirt road that leads to the dam site at Swift Reservoir. Although the region has considerable topographic relief, numerous foot and horse trails provide access.

Field Methods

Approximately 65 days during the summer of 1983 were spent in the field conducting stratigraphic reconnaisance and geologic mapping. An area of 36 square miles (93 km^2) was mapped at a scale of 1:24,000. Geologic contacts and structural elements were recorded on USGS 7.5 minute topographic quadrangles based on field inspection. Some geologic contacts were extended or inferred based on air photo interpretation and field checking.

Stratigraphic reconnaisance was undertaken prior to field mapping to facilitate stratigraphic differentiation in the field. No stratigraphic sections were measured within the map area during this study. Rather, previous stratigraphic studies completed in the area were relied on to enable differentiation of mappable units and to determine stratigraphic position within units.

Previous Investigations

Previous geologic studies in the Sawtooth Range and surrounding areas have allowed for a better understanding of the regional geology. Stratigraphic studies, primarily by Deiss (1939, 1943a), Cobban (1945,

1955), Mudge and others, (1962), and Mudge (1972a) have delineated mappable units and lithologic characteristics of Precambrian, Paleozoic, and Mesozoic strata.

Geologic mapping by the United States Geological Survey in the Gibson Reservoir - Sun River Canyon area and the Northern Disturbed Belt (Mudge, 1966a, 1966b, 1967, 1968; Mudge and Earhart, 1983; and Mudge et al, 1982) provide an understanding of the structural framework for the Sawtooth Range. Stebinger (1918), Deiss (1943b), Alpha (1955), Weimer (1955), Childers (1963), Mudge and Earhart (1980), and Mudge (1970, 1972b, 1977, 1982) provide additional knowledge of the structural geology in the Sawtooth Range and surrounding area. These publications form the basis for much of the structural interpretation of development and evolution of the Sawtooth Range.

A number of master's theses have been completed in the Swift Reservoir region. A study of the area west of Swift Reservoir was done by Feucht (1971). His work was largely descriptive and emphasized stratigraphy and deformational style. Egan (1971) studied the area east of the range front from Badger Creek southward to Birch Creek. This study mainly emphasized Mesozoic stratigraphy and deformation observed within this strata. To the south of Swift Reservoir, Ore (1959), Hansen (1962), and Osborne (1963) have completed theses in the Blackleaf Canyon area. These theses mainly emphasize stratigraphy and deal with structural geology of the map areas in a generalized and descriptive manner.

CHAPTER 2

STRATIGRAPHY

The lithologic character of the various stratigraphic units exposed in the Sawtooth Range plays an important role in determination of the location and nature of thrust belt deformation in the Disturbed Belt. Because many faults in the Disturbed Belt are low angle bedding plane thrusts, a working knowledge of stratigraphy is necessary for detailed structural mapping. In order to resolve possible conflicts in prior work, the stratigraphy of the study area is discussed in relation to field mapping.

Strata of Proterozoic, Paleozoic, and Mesozoic age are exposed in the Sawtooth Range, but only Paleozoic and Mesozoic sequences are present in the Swift Reservoir study area. Figure 3 shows a generalized stratigraphic column for the Swift Reservoir area.

Paleozoic

The Paleozoic sequence within the Sawtooth Range is comprised of up to 4000 feet (1200 m) of predominantly carbonate strata with minor amounts of fine-grained clastic rocks (Mudge, 1972a). Cambrian, Devonian, and Mississippian age rocks are present within the range. Regional unconformities account for gaps in the Paleozoic stratigraphic record in northwestern Montana.

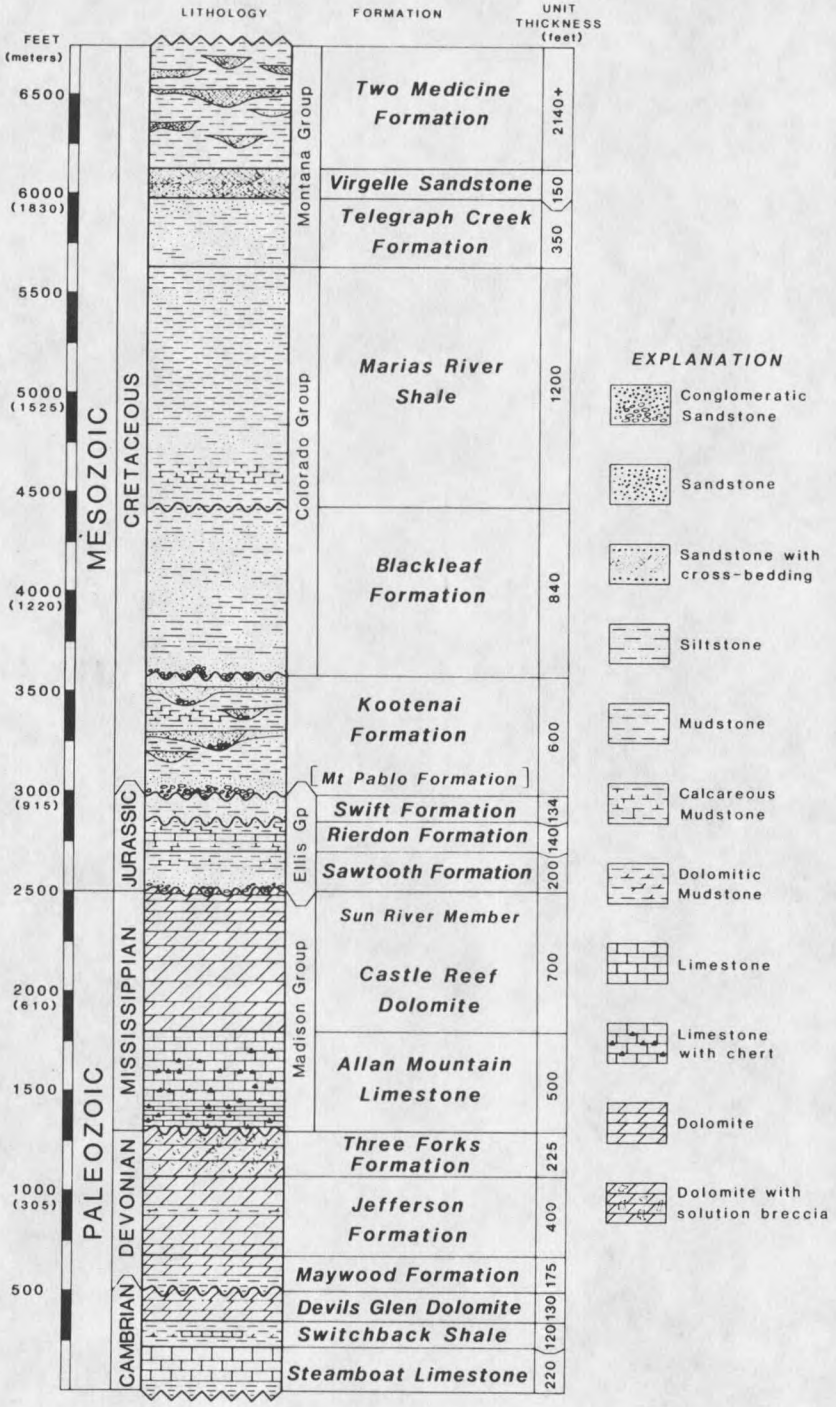

Figure 3. Generalized stratigraphic column of the Swift Reservoir area, northern Sawtooth Range (after Mudge, 1972a).

Cambrian

Rocks of Middle and Late Cambrian age are the oldest strata exposed within the Swift Reservoir study area. Deiss (1939, 1943a) divided the Cambrian section into nine formations within the Lewis and Clark Range. In the Swift Reservoir area, only the Middle Cambrian Steamboat Limestone, and Upper Cambrian Switchback Shale and Devils Glen Dolomite are present.

Steamboat Limestone. The Steamboat Limestone consists primarily of thinly bedded micritic and dolomitic limestone. The limestone is grayish-brown in color and commonly contains yellow-orange quartz silt grains on bedding surfaces. Intraformational conglomerate layers, 1 to 6 inches (25 - 150 mm) thick, occur locally within the limestone units. These conglomerates are comprised of shingled flat micrite pebbles and may have resulted from strong storm-generated waves or currents. Approximately 220 feet (70 m) of Steamboat Limestone is present within the study area.

The basal part of the Steamboat Limestone is a greenish-gray shale unit that Feucht (1971) assigned to the Pentagon Shale. Mudge (1972a) states that the Pentagon Shale as described by Deiss (1939) is of local extent and is not present in the Sun River Canyon area. The unit assigned by Feucht (1971) to the Pentagon is herein considered a shaly facies of the Steamboat Limestone, since it contains many interbeds and lenses of calcareous siltstone and limestone similar to shaly units within the Steamboat in the Sun River Canyon area as described by Mudge (1972a).

The Steamboat Limestone is the most commonly exposed Cambrian unit within the study area. The base of this unit is not observed in the study area since it likely forms the major decollement surface within the Cambrian section.

Switchback Shale. The Switchback Shale rests conformably upon the Steamboat Limestone with a sharp and distinct contact (Mudge, 1972a). It is typically poorly exposed beneath covered areas between the underlying Steamboat and overlying Devils Glen Dolomite when associated with folds.

The Switchback is predominantly a noncalcareous, light-green shale that weathers to a buff color, and contains thin interbeds of dolomitic limestone and conglomerate. The yellowish color is commonly imparted to the soil in covered areas. Mudge (1972a) interprets one of the conglomerate layers to represent the Middle-Upper Cambrian boundary.

No well-exposed section of Switchback Shale is present within the study area. Deiss (1939) states that the Switchback ranges in thickness from 70 to 250 feet (20-80 m) in northwestern Montana. The estimated thickness of the Switchback within the study area is approximately 120 feet (40 m), a value consistant with the thicknesses of Feucht (1971) and Deiss (1943b).

Devils Glen Dolomite. The Devils Glen Dolomite is the youngest Cambrian unit within the Sawtooth Range. An intraformational conglomerate, up to 3 feet (1 m) thick, marks the base of the Devils Glen Dolomite (Feucht, 1971), and appears to rest conformably upon the Switchback Shale (Mudge, 1972a). Where exposed, the Devils Glen

Dolomite is a distinctive thick-bedded, white to light gray dolomite that forms massive light colored ledges stratigraphically above the Switchback Shale. Faint cross-lamination is locally apparent on well-weathered surfaces of some of the dolomite beds (Mudge, 1972a).

Thickness of the Devils Glen varies widely in northwestern Montana, ranging from 179 to 565 feet (55-172 m) (Deiss, 1939). A thickness of 130 feet (40 m) was measured by Feucht (1971) within the study area.

Devonian

A major unconformity representing a time span from Late Cambrian to Middle Devonian exists at the base of Devonian strata in the Sawtooth Range. Sloss and Laird (1947) described strata of the Devonian System in central and northwest Montana using Devonian terminology from the Logan area of south-central Montana. Wilson (1955) measured a complete Devonian section at Featherwoman Mountain approximately four miles (6 km) north of the study area. Wilson's measured section of 800 feet (240 m) is used herein as an average thickness of Devonian strata for the study area. Thickness of Devonian strata varies widely in the Sawtooth Range due to unconformities that exist at the bottom and top of the section.

Devonian rocks of the Sawtooth Range are divided into, in ascending order: the Maywood, Jefferson, and Three Forks Formations. In the study area, Devonian rocks were mapped as a single undifferentiated unit because of lack of stratigraphic control and exposed complete sections. The gray-brown Devonian rocks contrast sharply

with the underlying light gray Upper Cambrian Devils Glen Dolomite and overlying gray to dark gray rocks of the Mississippian Madison Group.

Maywood Formation. The Middle and Upper Devonian Maywood Formation is divided into two members: a lower mudstone member and an upper limestone member (Mudge, 1972a). The lower member consists primarily of greenish-gray to reddish-gray dolomitic mudstone and shale. Interbeds of dolomitic limestone and dolomite are common. The upper member is thinly bedded, gray to brown dolomitic limestone and dolomite. Most beds have a mottled appearance due to silty inclusions (Mudge, 1972a).

Jefferson Formation. The Jefferson Formation is a dark brown dolomite which consists of two members: an unnamed lower member and the overlying Birdbear Member (Mudge, 1972a). The lower member consists of thickly bedded, dark brown dolomite and lesser dolomitic limestone that has a sucrosic texture. Massive stromatoporoids are widespread throughout, and a strong fetid odor is characteristic. The overlying Birdbear Member is mostly thin to medium bedded, finely crystalline dolomite that forms a yellowish-gray slope above the dark brown lower member of the Jefferson Formation (Mudge, 1972a). The upper portion of the upper member locally exhibits well developed solution breccia.

Three Forks Formation. The Three Forks Formation within the northern Sawtooth Range consists almost entirely of dolomite and evaporite solution breccia. The breccia is composed of angular blocks of fine to medium crystalline, brown dolomite and dolomitic limestone (Mudge, 1972a). It is usually well cemented with carbonate, but

locally may be very porous and contain large cavities. Commonly, the upper portions of solution breccias contain fragments and blocks of Lower Mississippian rock. These relations require dissolution of evaporite beds within the Three Forks Formation to have occurred after the Early Mississippian.

Mississippian

The most resistant strata in the Sawtooth Range are Mississippian Madison Group rocks. These rocks act as a structural beam and form many of the high, northwest trending ridges that comprise the Sawtooth Range. Mudge and others (1962) describe in detail the reference section of Madison strata in the Sun River Canyon area. In the Sawtooth Range, the Madison Group is subdivided into two formations: the Lower Mississippian Allan Mountain Limestone, and the Lower to Upper Mississippian Castle Reef Dolomite (Mudge et al, 1962). Nichols (1984) has revised the stratigraphic nomenclature for the upper part of the Madison Group in the Sawtooth Range, based on recognition of primary depositional units. Figure 4 shows the revised nomenclature for the Madison Group within the Sawtooth Range. In this investigation, the existing formal stratigraphic nomenclature of Mudge and others (1962) was used in mapping because of simplicity and ease of unit differentiation.

Thickness of the Madison Group in the Sawtooth Range ranges from 1200 to 1700 feet (370-520 m). The variation in thickness appears to be the result of pre-Jurassic erosion at the top of the Mississippian section (Mudge, 1972a). An average thickness of 1200 feet (370 m) for