The Putnam Thrust Plate, Idaho—Dismemberment and Tilting by Tertiary Normal Faults

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INTRODUCTION

The Putnam thrust is one of the major structures of the Idaho-Wyoming fold-and-thrust belt. It is exposed in the northern Portneuf Range, about 25 km northeast of Pocatello (Figs. 1 and 3), a region underlain by a thick sequence of Upper Proterozoic to Mesozoic rocks (Fig. 2). Detailed descriptions of these units are given by Link (1983), Link and others (1987), Kellogg and others (1989), Kellogg (1990), and Hladky and Kellogg (1990). At most localities, the Putnam thrust places Ordovician rocks above Permian and Pennsylvanian rocks of the Meade thrust plate, although near its southeastern extent, the thrust ramps laterally downsection and places Cambrian rocks above Mississippian (Hladky and others, 1992; Kellogg, 1992). The total stratigraphic offset across the thrust is as great as about 3,700 m. Hanging wall rocks include the oldest and most deeply buried sedimentary and volcanic rocks known in the entire Idaho-Wyoming-Utah thrust belt, brought up in the core of a major thrust culmination centered in the Bannock and Pocatello ranges near Pocatello (Fig. 1) (Trimble, 1976; Burgel and others, 1987; Rodgers and Janecke, 1992). These relationships require that the Putnam thrust ramp steeply downsection in the footwall somewhere to the west and south of Pocatello.

The Putnam thrust has been well known for years (Mansfield, 1920, 1927; Trimble, 1982), but the details of the complex upper-plate structures remained elusive until recent detailed mapping and structural analysis was completed at scales of 1:24,000 or more. (Hladky, 1986; Kellogg and others, 1989; Kellogg, 1990; Hladky and Kellogg, 1990; Hladky and others, 1992; Kellogg, 1992; Rodgers and Othberg, in press; McQuarrie and others, in press; Riesterer and Link, in press).

The age of movement on the Putnam thrust can only be inferred. The north end of the Paris thrust system, which is not shown on Figure 3, is about 40 km southeast of the eastern exposed trace of the Putnam thrust and is probably connected to the Putnam thrust by a thrust-transfer system (Kellogg, 1992; Rodgers and Janecke, 1992). This suggests that the age of movement on the Putnam thrust is probably coeval with that on the Paris thrust system. The Paris thrust is no younger than Early Cretaceous (Aptian) (DeCelles and others, 1993), and may be as old as Late Jurassic (Armstrong and Cressman, 1963). These ages most likely also constrain the age of the Putnam thrust and, by a somewhat more tenuous projection, contractional structures in its hanging wall.

Hanging Wall Structure of the Putnam thrust

Three subplates comprise the hanging wall of the Putnum thrust in the Pocatello Range and northern Portneuf Range (Figs. 3 and 5), although Neogene extension has profoundly modified the thrust geometry by block faulting and tilting. (The term *subplate* is used

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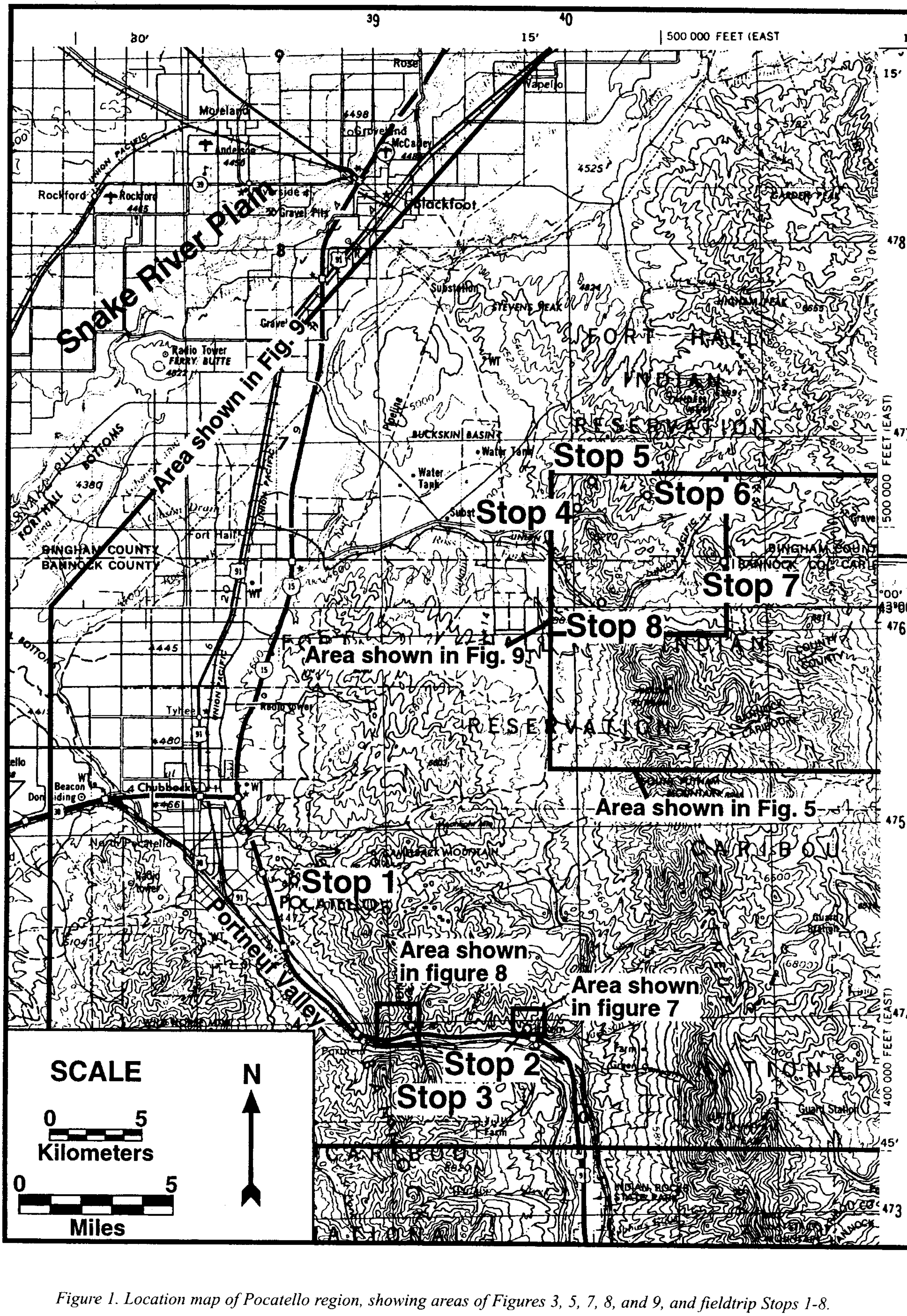


Figure 1. Location map of Pocatello region, showing areas of Figures 3, 5, 7, 8, and 9, and fieldtrip Stops 1-8.

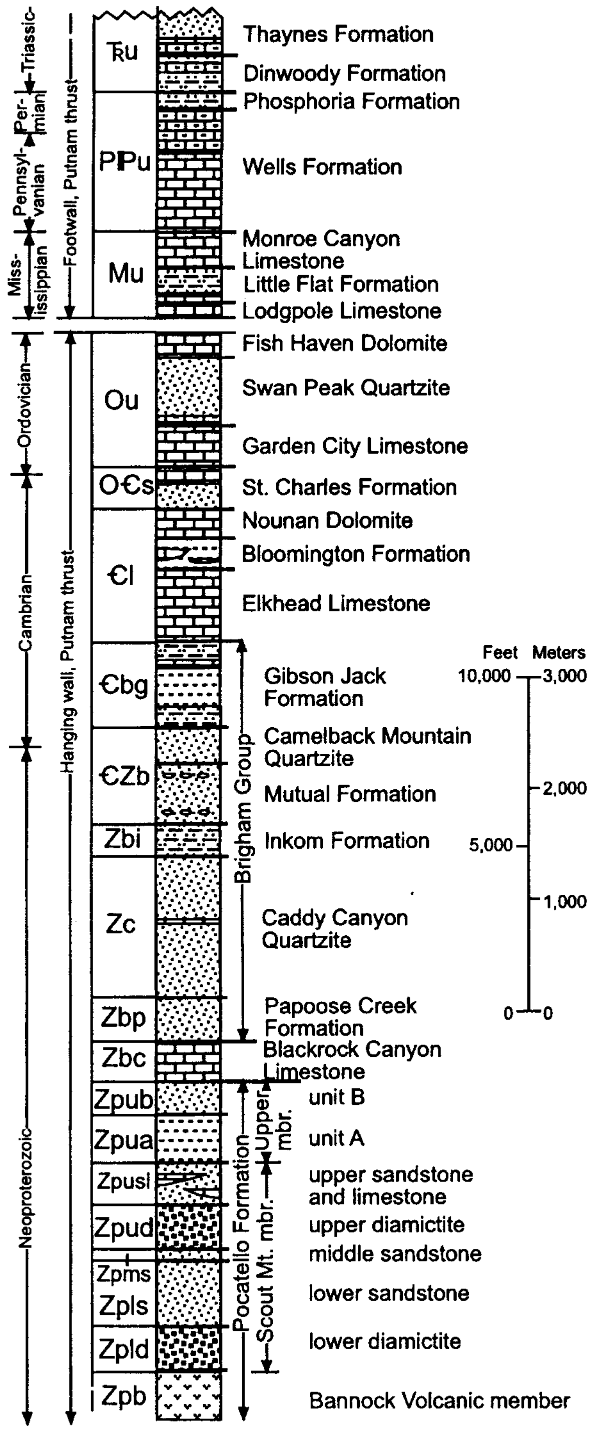


Figure 2. Stratigraphic column of rocks exposed in the northern Portneuf, Pocatello, and Bannock Ranges. Adapted from Kellogg (1992) and McQuarrie and others (in press).

to distinguish large thrust slices within the Putnam thrust plate.) The three subplates are, from structurally lowest to highest (and generally north to south), the Lone Pine subplate, the Narrows subplate, and the Bear Canyon-Toponce subplate (Fig. 5).

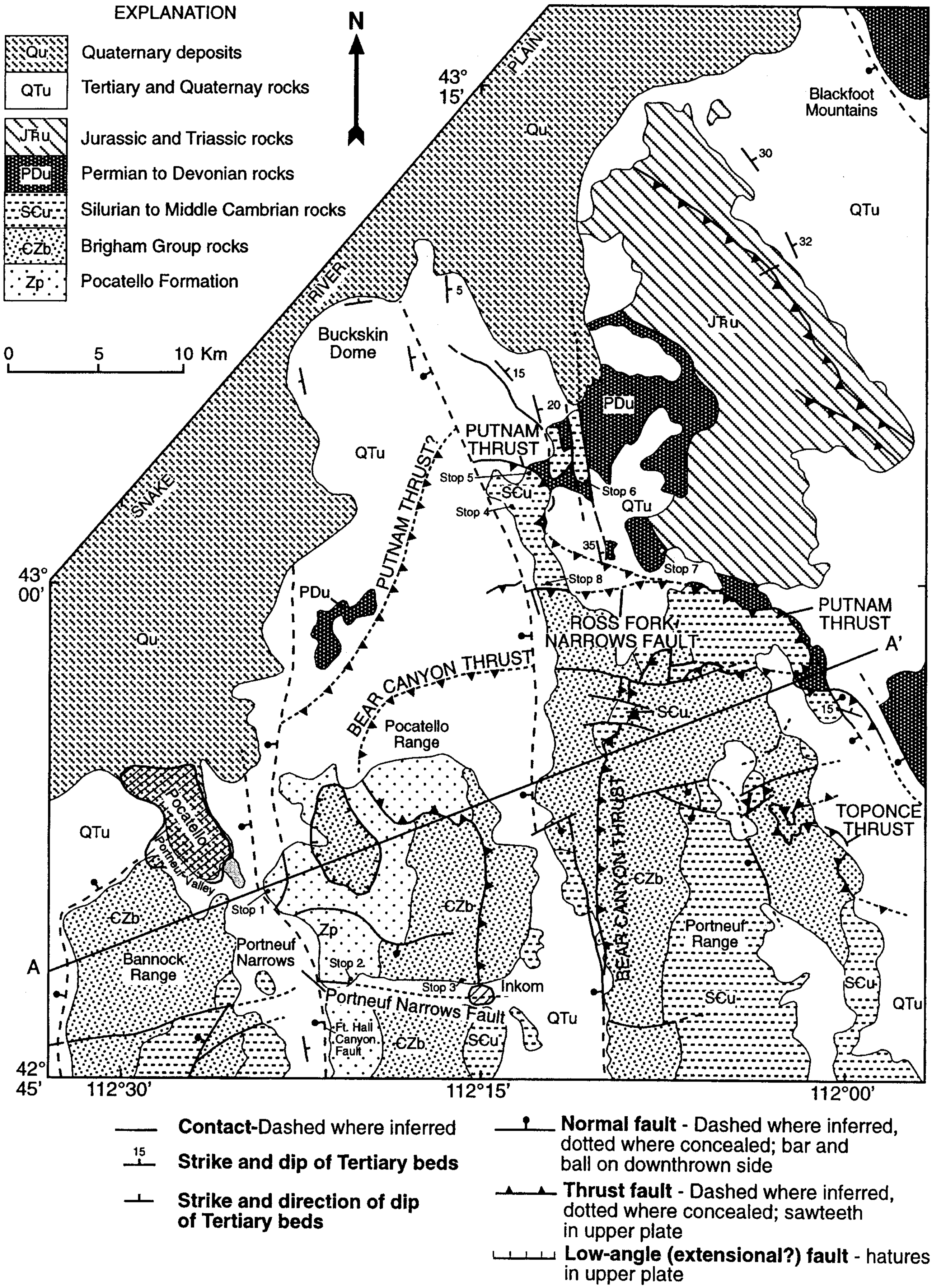
The Lone Pine subplate, composed of Ordovician and Cambrian rocks, and the Narrows subplate, composed mostly of Upper Proterozoic Brigham and Pocatello Groups (but locally containing rocks as young as Silurian), are juxtaposed across the steeply south-dipping Ross Fork Narrows fault, which is viewed as a steep lateral ramp (Kellogg, 1992; Trimble [1982] called it a "tear fault") although this interpretation may be a topic of lively discussions on the trip. Overlying the Narrows subplate and underlying the Bear Canyon-Toponce subplate is the Bear Canyon thrust, which dips eastward along the west side of the Portneuf Range and places mostly lower Brigham Group quartzite (Caddy Canyon Quartzite) above Cambrian limestone and upper Brigham Group rocks. The strongly folded Toponce thrust, on the east side of the Portneuf Range (Fig. 3), is believed to be an eastward extension of the Bear Canyon thrust (Kellogg, 1992). This thrust geometry is further complicated by (1) steep thrust ramps, both frontal and lateral, (2) numerous east-striking tear faults (compartmental faults of Brown, 1984), which accommodated different styles of shortening on either side of the fault (see Kellogg, 1990 for good examples), and (3) locally developed, tight S- and Z-shaped folds, each containing one gently-dipping overturned limb and a near-horizontal axial plane, which are particularly well developed in the Narrows subplate.

The Bear Canyon thrust is somewhat unusual in the Cordilleran thrust belt because it dips eastward. At least three explanations may account for this: (1) the thrust is a back thrust above the Putnam thrust and was west-directed, (2) the thrust, prior to Neogene extension, dipped west and was east-directed, but was subsequently tilted by down-to-the-east block tilting along large down-to-the-west normal faults, or 3) the thrust forms the roof of a large foreland-dipping duplex and was arched during duplex formation, so that its foreland side dips eastward.

We will present evidence that the latter two explanations both contributed to the eastward dip of Bear Canyon thrust and that the thrust is, indeed, an east-directed structure. The evidence is based mainly on the observation that the thrust ramps up-section to the east, both in the hanging wall and (particularly) in the footwall.

Eastward tilting of parts of the Portneuf, Pocatello, and Bannock Ranges by as much as 45° during Neogene extension certainly accounts for a large component of eastward dip of structures, but leaves room for an additional component of eastward dip induced by formation of the foreland-dipping duplex (Fig. 6; see Kellogg [1992] for a detailed discussion of this structure). The Narrows subplate is viewed as a large horse in the duplex, in which the Bear Canyon-Toponce thrusts define the roof thrust and the Putnam thrust defines the floor thrust. At the eastern end of the duplex, the roof thrust is nose down on the Putnam thrust and dips east. Beds are tectonically thickened and thinned within the Narrows subplate, reflecting a combination of bedding-plane slip, small-scale duplex stacking and thrust imbrication, and ductile flow. Outcrop- to map-scale, steeply overturned S- and Z-shaped folds, and a fanning of axial-plane cleavages by rotation during thrusting are common features in the Narrows subplate. In marked contrast to the foreland-dipping-duplex structure of the Narrows subplate, the Lone Pine and Bear Canyon-Toponce subplates contain mostly a moderately east-dipping sequence of relatively unsheared rocks.

Cambrian and Upper Proterozoic Brigham Group rocks and older rocks of the aerially extensive Narrows subplate were buried as deeply as about 15 km during Mesozoic contraction. The


EXPLANATION
Qu Quaternary deposits
QTu Tertiary and Quaternay rocks
JRu Jurassic and Triassic rocks
PDu Permian to Devonian rocks
SCu Silurian to Middle Cambrian rocks
CZb Brigham Group rocks
Zp Pocatello Formation
N
0 5 10 Km
43° 15'
43° 00'
42° 45'
112°30'
112°15'
112°00'
SNAKE RIVER PLAIN
Blackfoot Mountains
Buckskin Dome
PUTNAM THRUST
PUTNAM THRUST?
Stop 1
Stop 2
Stop 3
Stop 4
Stop 5
Stop 6
Stop 7
Stop 8
ROSS FORK NARROWS FAULT
BEAR CANYON THRUST
Pocatello Range
TOPONCE THRUST
A
A'
Pocatello
Portneuf Valley
Bannock Range
Portneuf Narrows
Portneuf Narrows Fault
Inkom
Ft. Hall Canyon Fault
Portneuf Range
BEAR CANYON THRUST
Contact-Dashed where inferred
Strike and dip of Tertiary beds
Strike and direction of dip of Tertiary beds
Normal fault - Dashed where inferred, dotted where concealed; bar and ball on downthrown side
Thrust fault - Dashed where inferred, dotted where concealed; sawteeth in upper plate
Low-angle (extensional?) fault - hatures in upper plate

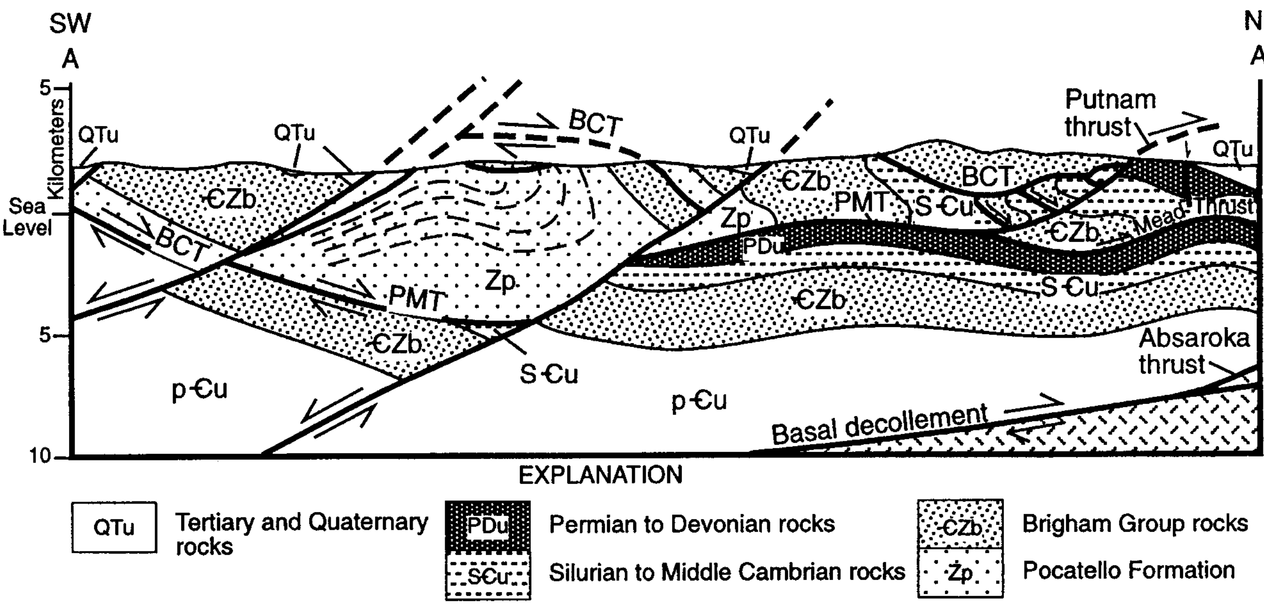


Figure 4. Cross section along line A-A' of Figure 3, modified from Kellogg (1992). All but largest range-front Tertiary faults have been removed. The cross section is largely schematic, due to lack of seismic and deep-well data for area, but depths to Meade thrust, Absaroka thrust, and magnetic basement are approximately known from Royse and others (1975). BCT is Bear Canyon thrust, PMT is westward extension of Putnam and Meade thrusts, and p€u is Precambrian undivided. Arrows show relative movement across major faults.

rocks were metamorphosed as high as upper greenschist facies. The deep burial (with associated quasi-ductile deformation), and formation of the duplex created many structures distinct from many other regions of the thrust belt. Large nappe-like folds are widespread (we will traverse one of these structures on the fieldtrip—the Blackrock Canyon fold at Stop 3).

Neogene Extension

Neogene extension has affected, to varying degrees, all of southeastern Idaho, producing numerous north-trending valleys and ranges characteristic of the Basin-and-Range Province. This extension is at least as old as about 16 Ma, the maximum-known age of valley-fill deposits in the region (Starlight Formation of Carr and Trimble [1963]), although a major pulse of normal faulting and basin filling culminated 6-8 Ma (Kellogg and Marvin, 1988; Rodgers and others, 1990). In addition, downwarping and extension adjacent to the Snake River Plain during late Miocene-Pleistocene time (post-7-10 Ma) has tilted rocks down to the northwest about northeast axes, producing a visible warping into the plain and numerous northeast-striking normal faults (Kirkham, 1931; Trimble, 1976, Zentner, 1989, Kellogg and others, 1994; Rodgers and Othberg, in press). Before some idea of the older thrust geometry can be appreciated, the effects of regional extension and tilting must be removed by restoring the Neogene normal faults back to their pre-extension position (we will examine one attempt to restore Neogene extension at Stops 5 and 6).

Figure 3. Generalized tectonic map of northern Portneuf Range, Pocatello Range, and northern Bannock Range. Map is modified from Kellogg (1992; refer to this reference for complete sources of geologic information), with additions based on recent unpublished mapping by Rodgers and Riesterer. Blackrock Canyon Limestone of Trimble (1976) is included with Pocatello Formation. Strikes and dips shown for Tertiary units only. Fold symbols and numerous normal faults are omitted from figure.

Field Trip – Overview

The fieldtrip will focus on major contractional structures in the hanging wall of the Putnam thrust and examine how these structures were modified by Neogene extension. At several localities, we will see how widespread overturning in the Narrows subplate, producing S- and Z-shaped folds with near-horizontal axial planes, characterizes the style of "ductile-thrust" deformation in these once deeply-buried rocks. We will discuss how the formation of a foreland-dipping duplex (Boyer and Elliott, 1982) may be associated with this style of deformation.

Three structurally distinct areas will be visited during the field trip (Fig. 1 and 3):

(1) The Narrows subplate near the Portneuf Narrows, where we will traverse a spectacular fold nappe involving the Pocatello Formation (Stop 3). We will revisit the Narrows subplate at our last stop (Stop 8) at the Ross Fork Narrows fault (not to be confused with the Portneuf Narrows fault).

(2) The Bear Canyon-Toponce subplate and the southern extent of the Bear Canyon thrust near Inkom, where Upper Proterozoic Caddy Canyon Quartzite overlies quartzite of Upper Proterozoic Mutual Formation (Stop 2). A new, more detailed understanding of the Brigham Group stratigraphy greatly facilitated the determination of some of these subtle thrust relationships (e.g., Link and others, 1987).

(3) The Lone Pine subplate, where an east-ramping section of Cambrian and Ordovician rocks directly overlies rocks as old as the Pennsylvanian Wells Formation and as young as the Triassic Dinwoody Formation (Stops 4-8). The Lone Pine subplate was extensively faulted and locally brecciated, during both Basin-Range and Snake River Plain extension, and contains exposed rocks as old as the Middle and Upper Cambrian Nounan Formation and as young as the Upper Ordovician part of the Fish Haven Dolomite (Hladky and Kellogg, 1990).

DAY 1

Total/Incremental Mileage

0.0		Leave parking lot of the Cavanaugh Motel and take southbound onramp (at exit 71) of Interstate 15.
2.0	2.0	Exit at first opportunity (Exit 69). Turn left through underpass and proceed east on Clark St.
2.1	0.1	On the left, Miocene gravels tilt east about 20°, reflecting the eastward tilt of the Portneuf Valley, a half graben typical of the Basin and Range. About 100 m farther east, a west-dipping normal fault, with slip of several 100 m, cuts the gravels.
2.3	0.2	Turn right on Hospital Way.
2.7	0.4	At the crest of the hill is the first good view south along the Portneuf Valley. The east side of the valley is bounded by a gently-dipping (about 30°) normal fault with an estimated 8 km of stratigraphic offset (Fig. 4). Both basin fill and bedrock have been tilted east.
3.1	0.4	Turn left on Buckskin Road. Along Buckskin Road, note the numerous cuts into the Miocene gravels, which have been locally oxidized and reddened.
4.3	1.2	At the top of the grade, park on the left (northwest) side. Walk to the crest of the hill.

STOP 1—Tilted Miocene beds and overview of regional geology.

Miocene basin fill underlies most of the eastern half of the Portneuf Valley. Basin fill consists of conglomerate and reworked rhyolite ash which now dip about 25° east, reflecting regional tilting associated with formation of the Portneuf Valley half graben. Immediately below us on the west side of the hill is a section of reworked ash beds, one of four distinct ash layers interbedded with conglomerate. This ash is the youngest one in the valley and yielded an $^{40}Ar/^{39}Ar$ age of 7.39±0.05 Ma (Rodgers and Othberg, in press). The oldest ash, located at the base of the basin fill, has an approximate age of 8.1 ± 0.5 Ma based on its chemical correlation to the informally named Inkom ash (Rodgers and Othberg, in press), thus bracketing half-graben basin filling to a short period in the late Miocene.

The Fort Hall Canyon Fault, a large range-bounding normal fault along which the valley tilted, is located about 500m to the east of us. The fault dips about 25° west beneath the valley and accommodated 6-8 km of dip slip, one of the largest offsets in the northeastern Basin and Range.

Upper Proterozoic rocks of the Pocatello Formation occupy the hills east of the Fort Hall Canyon Fault. These rocks record glaciation and initial rifting of the Cordillera (Link, 1983). The rocks are everywhere overturned in this region, forming the inverted limb of the Blackrock Canyon fold, a map-scale recumbent anticline which we will visit at Stop 3.

Tilted Proterozoic to Cambrian rocks crop out in the Bannock Range west of the Portneuf Valley. The approximate 45° east dip of the rocks reflects Basin-Range tectonics, although some tilting may be partially due to Sevier folding. Tilting is a major theme of the field trip: due to domino-style tilting of rocks and west-dipping normal faults, older west-dipping structural features may now be flat or east dipping, as we hope to show at Stop 2.

The Snake River Plain is visible to the north and northwest. In this region it consists of a ~1 km thick veneer of Pliocene-Pleistocene basalt lava and intercalated sediment, underlain by several kilometers of Miocene rhyolite. Rhyolite magmatism generally progressed from west to east across the Plain (Armstrong and others, 1975; Pierce and Morgan, 1992), with eruptions near Pocatello from about 10.2 to 7.9 Ma (Kellogg and others, 1994). One anomaly is the formation of several rhyolite buttes, which rise many hundreds of feet above the basaltic plain – these buttes are Late Pleistocene plugs or laccoliths which have ascended through Plio-Pleistocene basalt.

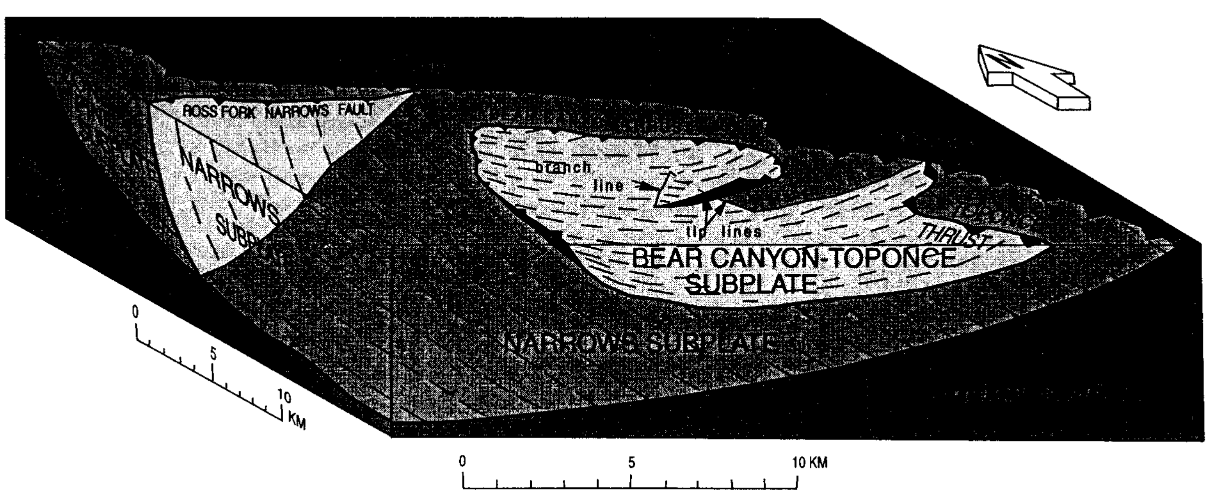


Figure 5. Diagramatic block diagram of northern Portneuf Range area showing the major structural elements, adapted from Kellogg (1992). The Narrows subplate extends west to and includes the northern Bannock Range. Its extent southward is unknown. Branch line and tip line are defined by Boyer and Elliott (1982).

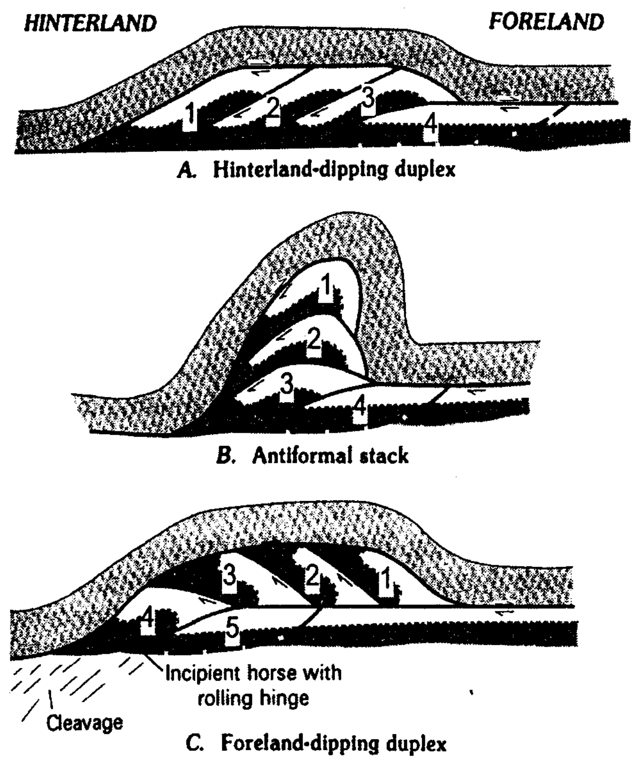


Figure 6. Schematic diagram showing the development of (A) hinterland-dipping duplex, (B) antiformal stack (a situation intermediate to a hinterland- and foreland-dipping duplex), and (C) foreland-dipping duplex. Relative order of formation of horses is indicated by numbers, 1 being first formed; note that relative order in hinterland-dipping and foreland-dipping duplexes is reversed. From Kellogg (1992), who adapted diagram from Boyer and Elliott (1982). Refer to Kellogg (1992) for more detailed explanation.

From this vantage the Snake River downwarp is well illustrated by the northward plunge of the Bannock Range. The timing and amount of subsidence along the margins of the downwarp encompass our most exciting areas of current research. We believe the Basin-Range and Cretaceous thrust belt once existed well north of its current border with the Plain, only to be buried by subsidence and accumulation of young basalts. Crustal subsidence along the north edge of the Plain amounts to 5-8 km (McQuarrie and Rodgers, 1998), but the amount near Pocatello is unknown at this time. Subsidence occurred at some time (shortly?) after 7 Ma, based upon the northward tilts of Miocene basin fill, and continues today as shown by tilted Plio-Pliestocene rocks (Houser, 1992).

Finally, the latest Pleistocene Bonneville Flood flowed through the Portneuf Valley after breaching a dam at Red Rock Pass near Preston, Idaho. With a peak discharge of about one million cubic meters per second that lasted for perhaps 8 weeks (Jarrett and Malde, 1987; O'Conner, 1993), it was of the largest floods ever recorded in geologic history. In the Portneuf Valley the flood produced scabland topography, a channel throughout downtown Pocatello filled with boulders as long as 3 m, and a delta deposit in northern Portneuf Valley where it widens and joins the Snake River Plain.

The trip will now return along Buckskin Road.

5.1	0.8	Turn left from Buckskin Road on Alvin Ricken Drive; proceed through an industrial park.
6.2	1.1	Turn right on Barton Road.
6.5	0.3	Camelback Mountain Quartzite and underlying Mutual Formation are strongly brecciated in the road cut and along the crest of Red Hill to the right. There is some controversy as to the origin of these rocks. They may either be part of a large pre-Pleistocene landslide that originated east of the Fort Hall Canyon fault that bounds the Pocatello Range (Trimble, 1976; Link and others, 1985), or (as Dave Rodgers believes), they are part of a separate normal-fault-bounded block that downdropped to the west into the Portneuf Valley.
6.7	0.2	At the stop sign on 5th Avenue, proceed straight ahead to 4th Avenue. Turn left on 4th Avenue.
7.0	0.3	Basalt of Portneuf Valley forms the small bluffs on the right (a local playground for the area's rock climbers). The basalt has been dated at 583 ± 104 ka (Scott and others, 1982).
7.4	0.4	Take southbound onramp to Interstate 15 (Exit 67). Drive on Basalt of Portneuf Valley.
11.4	4.0	The interstate bends left (east) and enters the Portneuf Narrows. The Pocatello Range is to the north, the Bannock Range is to the south, and the Portneuf Range is visible in the distance to the east. On the left, across the interstate, are Upper Proterozoic volcanic rocks (Bannock Volcanic Member of the Pocatello Formation) and diamictites (within the Scout Mountain Member of the Pocatello Formation). The diamictites have been interpreted as a mixed till and submarine flow deposit (Link, 1983). These rocks are cut by a south-dipping fault (Portneuf Narrows fault), out of view from here, which we will visit at Stop 3.

On the right is a steeply east-dipping homocline of diamictite, sandstone, conglomerate, and siltstone of the Scout Mountain Member of the Pocatello Formation, cut by a few normal faults with small offset.

16.4	5.0	At Inkom, take exit 58. Turn left under interstate and immediately turn right on Sorrelle Road.
16.8	0.4	Cross cattle guard and immediately turn left and park by gate.

STOP 2—The Bear Canyon thrust.

The Bear Canyon thrust, first identified by Pogue (1984) in the northern Portneuf Range, was soon recognized as a major structural feature of the region (Kellogg, 1990, 1992). The thrust was mapped southward along the west side of the Portneuf Range (Kellogg, 1990), and was predicted to crop out again in the Pocatello Range as a consequence of downdropping along the range-front normal fault bordering the west side of the Portneuf Range. Subsequent mapping in the Bonneville Peak (Riesterer and Link, in press) and Inkom areas (McQuarrie and others, in

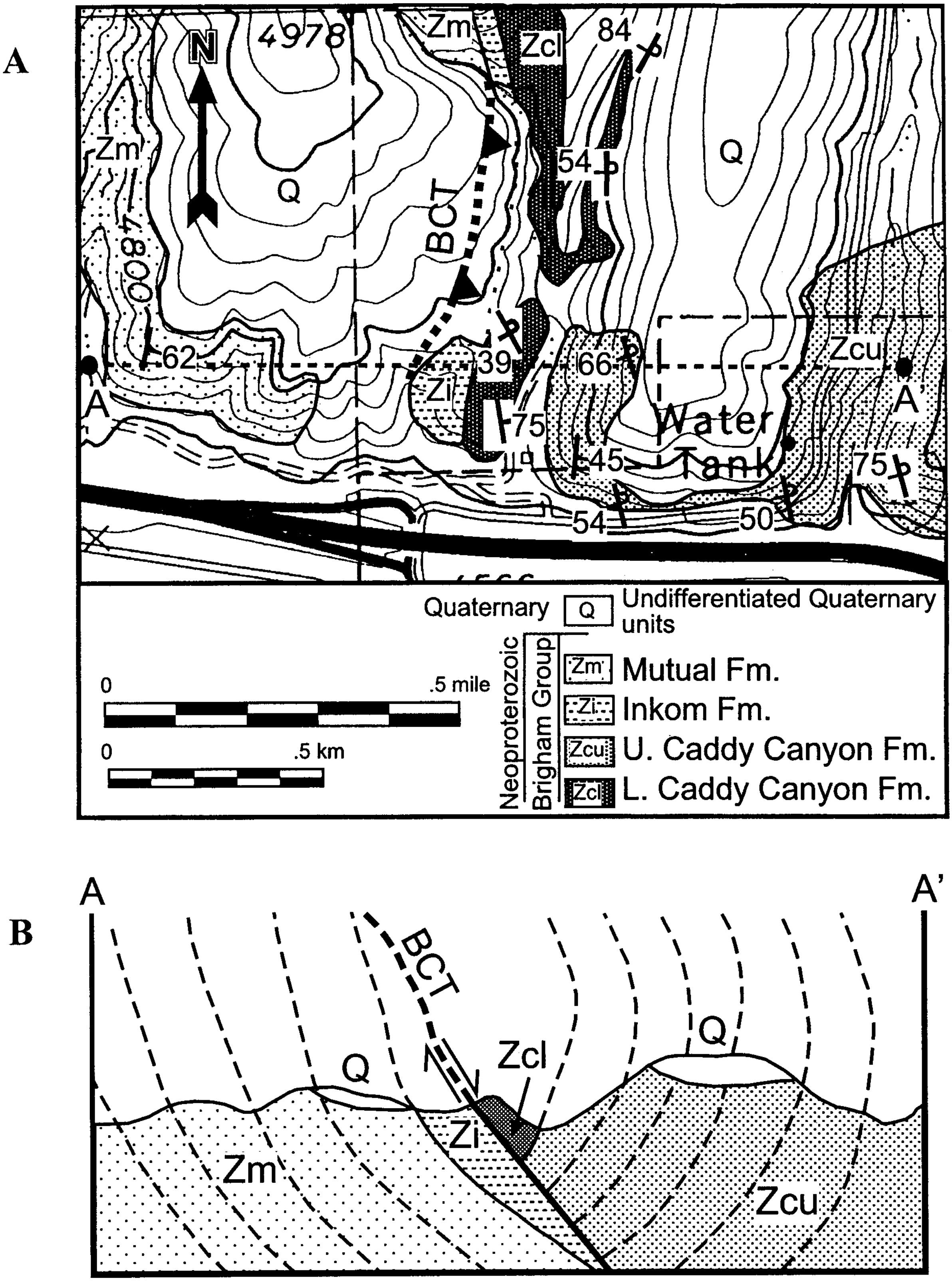


Figure 7. A, Geologic map of Stop 2, and B, cross section along A-A'. Bear Canyon thrust (BCT) separates a hanging wall of lower Caddy Canyon Quartzite (Zcl) and upper Caddy Canyon Quartzite (Zcu) from a footwall of Mutual Formation (Zm). Inkom Formation (Zi) is present in the fault zone and Quaternary units (Q) overlie all rocks and structures. Modified from Burgel (1986) and McQuarrie and others (in press).

press) has confirmed this prediction. This stop will examine the east-dipping Bear Canyon thrust.

A geologic map and cross-section of this stop are shown in Figure 7. Maroon quartzite (Mutual Formation) and brown to red quartzite (Caddy Canyon Quartzite) are juxtaposed, with slivers of green shale (Inkom Formation) locally in between. The Mutual Formation dips east whereas the Caddy Canyon Quartzite is subvertical to west-dipping (overturned) in most places. Burgel (1986) and Burgel and others (1987) interpreted the contact between quartzites as a west-dipping normal fault, but regional relations described above require the contact to be the Bear Canyon thrust fault, with Caddy Canyon Quartzite thrust over Mutual Formation. The map pattern indicates the unexposed thrust is moderately to steeply dipping, so we interpret it to be parallel to bedding in Mutual Formation (dipping 50°E). Immediately east of this stop the overturned Caddy Canyon Quartzite beds progressively unfold to become moderately east-dipping. Thus, the Bear Canyon thrust is interpreted to separate a hanging wall anticline from a footwall flat.

We will now drive west, back toward Pocatello. Turn right on Sorrell Road, then turn left and drive through interstate underpass.

17.0 0.2 Immediately past interstate offramp, turn right (west) onto Old Highway 91. Proceed west, parallel to Interstate 15.

21.1 4.1 Turn right (north) on Blackrock Canyon Road. To the north, all the prominently stratified rocks at the top of the ridge to the left are overturned Pocatello Formation rocks on the north side of the Portneuf Narrows fault. These overturned rocks form part of the inverted limb of a large east-vergent recumbent fold, the Blackrock Canyon fold (McQuarrie and others, in press).

Continue under I-15. Upright diamictite of the Scout Mountain Member of the Pocatello Formation crops out prominently in the hill directly ahead.

21.9 0.8 Pass phyllitic rocks of the upper member, Pocatello Formation.

22.2 0.3 Pavement ends as road enters Blackrock Canyon. The stratified rocks on the right are east-dipping (upright) Blackrock Canyon Limestone (Upper Proterozoic).

22.4 0.2 Park by west-trending gully on left.

STOP 3 – The Blackrock Canyon fold and the Portneuf Narrows fault.

Stop 3 provides an opportunity to traverse two regionally extensive structures that strongly influence the map pattern of rocks throughout the Pocatello Range. We will walk west and south through the hills, returning to Blackrock Canyon Road where it crosses beneath Interstate 15 (mile 21.9, above). The walk is about 1 mile long, involves 700' elevation gain, should take about 2 hours, and is shown on the accompanying geologic map and cross-section (Fig. 8).

Overturned rocks that comprise the Blackrock Canyon fold were recognized along the crest of the Pocatello Range (LeFebre, 1984; Link and others,1980), and interpreted in terms of an overturned limb of an east-vergent anticline-syncline pair. Burgel (1986) mapped local regions of overturned rocks east of Blackrock Canyon and proposed the existence of an east-vergent recumbent anticline, the Rapid Creek fold, which includes the crest of the Pocatello Range and projects to the east *above* the modern landscape (Burgel and others, 1987). More recent mapping by other graduate students at Idaho State University yielded a better map of rocks along the crest of the range, and a new interpretation that the east-vergent recumbent anticline projects east from the crest of the Pocatello Range *below* the modern landscape (McQuarrie and others, in press). To distinguish this new fold geometry and to associate the fold with its area of exposure, the latter authors proposed the name "Blackrock Canyon fold".

The Blackrock Canyon fold is a subhorizontal, north-trending map-scale fold whose axial plane is subhorizontal to gently east-dipping. The inverted limb, which crops out throughout the crest of the Pocatello Range, involves the Pocatello Formation, including the Bannock Volcanic Member, five informal units of the Scout Mountain Member, and the informal upper member. These overturned rocks typically dip 15-30° west, indicating 330°+ of tilting via folding (and superimposed Neogene tilting, see below). Outcrop-scale folds are not common except in the upper member of the Pocatello Formation, but small-scale deformation is illustrated by a pervasive axial planar cleavage, flattening of diamictite clasts, and marked thinning of some stratigraphic units in comparison to their upright equivalents.

The hinge region of the Blackrock Canyon fold is evident only at the mouth of Blackrock Canyon (along this traverse) where the upper member of the Pocatello Formation changes orientation from east-dipping to west-dipping. Elsewhere, the fold and its hinge are cut by faults; to the west, the inverted limb is cut by the Fort Hall Canyon normal fault (with 6-8 km of slip), to the east the fold is cut by the Blackrock Canyon normal fault (with 1-2 km of slip), and to the south the fold is cut by the Portneuf Narrows fault (Lefebre, 1984; McQuarrie and others, in press). Thus, the inverted limb is exposed in a horst flanked by downdropped, upright rocks that presumably formed the upright limb of the fold before faulting. Furthermore, the Blackrock Canyon fold was affected by regional tilting that accompanied normal faulting – removing a superimposed 45° eastward tilt would restore the fold to a north-trending, east-vergent anticline with a gently (30°) west-dipping axial plane.

The traverse at Stop 3 encounters several geometric elements of the Blackrock Canyon fold, as well as the Portneuf Narrows fault that abruptly transects the fold. Key outcrops are described below, and located on Figure 8.

3A Phyllite of upper member of the Pocatello Formation dips moderately east and contains a gently east-dipping axial planar cleavage. Although bedding dips more steeply than cleavage, these rocks are not overturned; after removing superimposed eastward tilting, cleavage would dip more steeply west than bedding.