RECONNAISSANCE GEOLOGY
OF THE ELK CITY REGION, IDAHO

by

Rolland R. Reid

IDAHO BUREAU OF MINES AND GEOLOGY
MOSCOW, IDAHO
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>3</td>
</tr>
<tr>
<td>Purpose of the investigation</td>
<td>3</td>
</tr>
<tr>
<td>Geography</td>
<td>3</td>
</tr>
<tr>
<td>Location</td>
<td>3</td>
</tr>
<tr>
<td>Access</td>
<td>3</td>
</tr>
<tr>
<td>Topography</td>
<td>3</td>
</tr>
<tr>
<td>Summary of previous work</td>
<td>4</td>
</tr>
<tr>
<td>Field and laboratory procedures</td>
<td>4</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>5</td>
</tr>
<tr>
<td>DESCRIPTIVE GEOMORPHOLOGY</td>
<td>7</td>
</tr>
<tr>
<td>Land forms in the area</td>
<td>7</td>
</tr>
<tr>
<td>Fault control of major valleys</td>
<td>8</td>
</tr>
<tr>
<td>South Fork of the Clearwater Valley</td>
<td>8</td>
</tr>
<tr>
<td>American River Valley</td>
<td>8</td>
</tr>
<tr>
<td>Newsome Creek Valley</td>
<td>9</td>
</tr>
<tr>
<td>Crooked River Valley</td>
<td>9</td>
</tr>
<tr>
<td>Red River Valley</td>
<td>9</td>
</tr>
<tr>
<td>Elk Creek Valley</td>
<td>10</td>
</tr>
<tr>
<td>Relation of Tertiary deposits to the bedrock and to present landforms</td>
<td>10</td>
</tr>
<tr>
<td>Newsome Creek deposits</td>
<td>10</td>
</tr>
<tr>
<td>Elk Creek deposits</td>
<td>12</td>
</tr>
<tr>
<td>GEOMORPHIC HISTORY</td>
<td>15</td>
</tr>
<tr>
<td>Summary of earlier concepts of the Idaho peneplain</td>
<td>15</td>
</tr>
<tr>
<td>Work in adjacent areas</td>
<td>16</td>
</tr>
<tr>
<td>Older views on the origin of the Tertiary gravels</td>
<td>17</td>
</tr>
<tr>
<td>Postulated geomorphic sequence</td>
<td>17</td>
</tr>
<tr>
<td>ROCK TYPES</td>
<td>21</td>
</tr>
<tr>
<td>DESCRIPTIVE STRUCTURAL GEOLOGY</td>
<td>23</td>
</tr>
<tr>
<td>Tight isoclinal folds</td>
<td>23</td>
</tr>
<tr>
<td>Open isoclinal folds</td>
<td>25</td>
</tr>
<tr>
<td>General description</td>
<td>25</td>
</tr>
<tr>
<td>Granitic stringers</td>
<td>25</td>
</tr>
<tr>
<td>Lineation</td>
<td>29</td>
</tr>
<tr>
<td>Relict folds</td>
<td>31</td>
</tr>
<tr>
<td>Combination folds</td>
<td>33</td>
</tr>
<tr>
<td>Boudinage structure</td>
<td>33</td>
</tr>
<tr>
<td>Gentle folds</td>
<td>33</td>
</tr>
<tr>
<td>Cross folds</td>
<td>33</td>
</tr>
<tr>
<td>Microchevron folds</td>
<td>35</td>
</tr>
<tr>
<td>Compiled structural data</td>
<td>35</td>
</tr>
<tr>
<td>The geologic map</td>
<td>37</td>
</tr>
<tr>
<td>Structural cross-sections</td>
<td>39</td>
</tr>
<tr>
<td>PETROGRAPHY</td>
<td>43</td>
</tr>
<tr>
<td>Megascopic description of rocks</td>
<td>43</td>
</tr>
<tr>
<td>Microscopic rock description</td>
<td>45</td>
</tr>
<tr>
<td>Biotite gneiss</td>
<td>45</td>
</tr>
<tr>
<td>Biotite quartzite</td>
<td>47</td>
</tr>
<tr>
<td>Augen gneiss</td>
<td>47</td>
</tr>
<tr>
<td>Granitic rocks</td>
<td>48</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Index map of the Elk City region, Idaho</td>
</tr>
<tr>
<td>2.</td>
<td>Geologic map of the Elk City region, Idaho</td>
</tr>
<tr>
<td>3.</td>
<td>Structural cross-section map of the Elk City region, Idaho with axial planes of the No. 2 folds</td>
</tr>
<tr>
<td>4.</td>
<td>Tight isoclinal fold in biotite gneiss</td>
</tr>
<tr>
<td>5.</td>
<td>Tight isoclinal folds in biotite quartzite</td>
</tr>
<tr>
<td>6.</td>
<td>Tight isoclinal fold in biotite quartzite</td>
</tr>
<tr>
<td>7.</td>
<td>Tight isoclinal fold with axial plane foliation</td>
</tr>
<tr>
<td>8.</td>
<td>Isoclinal fold in biotite quartzite</td>
</tr>
<tr>
<td>9.</td>
<td>Sketch of a portion of a stream boulder of quartzite</td>
</tr>
<tr>
<td>10.</td>
<td>Isoclinally folded compositional layering in biotite quartzite</td>
</tr>
<tr>
<td>11.</td>
<td>Folded foliation in biotite quartzite</td>
</tr>
<tr>
<td>12.</td>
<td>Tightly folded foliation in biotite gneiss</td>
</tr>
<tr>
<td>13.</td>
<td>Folded foliation in biotite gneiss</td>
</tr>
<tr>
<td>14.</td>
<td>Folded foliation in biotite quartzite</td>
</tr>
<tr>
<td>15.</td>
<td>Gentle fold in foliation</td>
</tr>
<tr>
<td>16.</td>
<td>Folded granitic stringer in biotite gneiss</td>
</tr>
<tr>
<td>17.</td>
<td>Biotite gneiss with folded foliation</td>
</tr>
<tr>
<td>18.</td>
<td>Folded granitic stringer in biotite quartzite</td>
</tr>
<tr>
<td>19.</td>
<td>Tight folding of a granitic stringer in biotite gneiss</td>
</tr>
<tr>
<td>20.</td>
<td>Differential folding of granitic stringers</td>
</tr>
<tr>
<td>21.</td>
<td>Folded granitic stringer in gneiss</td>
</tr>
<tr>
<td>22.</td>
<td>Vertical face in biotite gneiss</td>
</tr>
<tr>
<td>23.</td>
<td>Rolled fold crest in biotite gneiss</td>
</tr>
<tr>
<td>24.</td>
<td>Granitic stringer in biotite gneiss</td>
</tr>
<tr>
<td>25.</td>
<td>Folded granitic stringer in biotite quartzite</td>
</tr>
<tr>
<td>26.</td>
<td>Folded foliation in biotite gneiss</td>
</tr>
<tr>
<td>27.</td>
<td>Granitic rock in biotite gneiss</td>
</tr>
<tr>
<td>28.</td>
<td>Granitic rock in biotite gneiss</td>
</tr>
<tr>
<td>29.</td>
<td>Gneiss traversed by a granitic sill with a cross-cutting offshoot</td>
</tr>
<tr>
<td>30.</td>
<td>Augen gneiss cut by irregular granitic rock</td>
</tr>
<tr>
<td>31.</td>
<td>Folded foliation in biotite quartzite</td>
</tr>
<tr>
<td>32.</td>
<td>Intersecting drag folds causing wave interference effects</td>
</tr>
<tr>
<td>33.</td>
<td>An exposure of biotite quartzite</td>
</tr>
<tr>
<td>34.</td>
<td>Partly cross-cutting, partly concordant granitic rock.</td>
</tr>
<tr>
<td>35.</td>
<td>Horizontal outcrop surface</td>
</tr>
<tr>
<td>36.</td>
<td>Boudinage structure developed in a granitic sill</td>
</tr>
<tr>
<td>37.</td>
<td>A boudin of augen gneiss in biotite quartzite</td>
</tr>
<tr>
<td>38.</td>
<td>Granitic stringer in biotite quartzite</td>
</tr>
<tr>
<td>39.</td>
<td>Drag folds consisting of folded foliation</td>
</tr>
<tr>
<td>40.</td>
<td>Folded foliation and folded granitic stringers</td>
</tr>
<tr>
<td>41.</td>
<td>Large isoclinal fold of biotite schist in augen gneiss</td>
</tr>
<tr>
<td>42.</td>
<td>A vertical exposure in biotite gneiss</td>
</tr>
<tr>
<td>43.</td>
<td>Structure exposed in biotite gneiss</td>
</tr>
<tr>
<td>44.</td>
<td>Thin granitic sills or stringers in biotite quartzite</td>
</tr>
<tr>
<td>45.</td>
<td>Pegmatite dike in biotite quartzite</td>
</tr>
<tr>
<td>46.</td>
<td>Non-folded cross-cutting intrusive</td>
</tr>
<tr>
<td>47.</td>
<td>Intrusive unfolded granitic dikes</td>
</tr>
</tbody>
</table>
48. A high-angle granitic dike
49. A section in biotite gneiss
50. Composite sketch to illustrate structure exposed in biotite gneiss
51. Stereogram to show formation of granitic stringers
52. Lineation map showing orientation of No. 1 fold axes
53. Lineation map showing orientation of No. 2 fold axes
54. Lineation map showing orientation of No. 3 fold axes
55. Plot of No. 1 fold axes on Schmidt stereonet
56. Contoured plot of No. 2 fold axes on Schmidt stereonet
57. Plot of No. 3 fold axes on Schmidt stereonet
58. Stereogram to show relations of all three lineations
59. Contoured modified beta-diagram on poles to foliation
60. Contoured modified beta-diagram on poles to axial planes of the No. 2 folds
61. Contoured quartz axis diagram from a No. 1 fold
62. Contoured quartz axis diagram from a No. 2 fold
63. Sketch of a No. 1 fold with an inset quartz axis diagram
64. Sketch of a No. 2 fold with an inset quartz axis diagram
65. Highly generalized diagrammatic sketch to illustrate concept of fold structures
FOREWORD

In addition to gold, the sands of central Idaho placer deposits contain, from place to place, potentially economic concentrations of minerals which contain thorium, uranium, and other metals. As part of a program of research on these placer deposits initiated in 1957 by this Bureau, R. R. Reid has spent two field seasons in the Elk City region.

It quickly became apparent, in the first few weeks of the Elk City project, that the nature and history of the bedrock from which the placer minerals came are fully as important in the localization of the placer deposits as is the presence of streams of suitable gradient. Consequently, in addition to studying the placer deposits, Mr. Reid examined the bedrock of the region as carefully as time and availability of outcrops permitted. The results of the bedrock investigation are set forth in this paper and constitute a valuable contribution to the knowledge of Idaho geology.

The results of the placer study will be published separately, as Pamphlet 121. Anyone wishing the full picture of the placer deposits and their geologic environment should have both Pamphlets 120 and 121.

E. F. COOK, Director
Idaho Bureau of Mines and Geology
RECONNAISSANCE GEOLOGY OF THE

ELK CITY REGION, IDAHO

by

Rolland R. Reid

ABSTRACT

Belt-equivalent (?) northwest-trending gneisses, quartzites, and schists in the Elk City region contain four lineation sets (axes of small folds), representing four postulated regional metamorphic episodes, and three sets of major superposed folds.

All three sets of folds developed about axes that trend N 10⁰–20⁰ W on the average. The fact that the axes in individual outcrops are not parallel, means that the rock has triclinic symmetry. This conclusion is borne out by preliminary quartz fabric studies.

Nonfolded quartz diorite to granodiorite dikes, showing the dilation offset characteristic of dikes produced by liquid magmatic injection, cut the above-described structures. These dikes are tentatively correlated with the emplacement of the magmatic part of the Idaho batholith. (The suggestion, made earlier by others, of a replacement origin for parts of the Idaho batholith, is renewed herein.) Although all three metamorphic episodes appear to be pre-Idaho batholith in age, it is not known whether 1, 2, or 3 orogenies are represented.

Cataclastic microchevron folds, present locally, reflect the fourth metamorphic episode, tentatively assigned to the Laramide.

Erosion in post-Challis, pre-Columbia River basalt time produced the Idaho "peneplain". Later faulting, perhaps in the Miocene, produced basins in which gravels and other basin deposits accumulated. During and after post-gravel faulting, major portions of the principal streams in the area gained their courses along northwest-trending fault zones. Renewed uplift has rejuvenated these streams, perhaps in the later part of the Tertiary.
INTRODUCTION

PURPOSE OF THE INVESTIGATION

A study of the placer deposits in the Elk City region was made by the Idaho Bureau of Mines and Geology in the summers of 1957 and 1958 to determine the mineral content of the deposits and to extend earlier studies made in this area by the Bureau and the U. S. Geological Survey.

Because the study of the origin of the heavy minerals involves the bedrock in the region, the bedrock geology was mapped, largely by reconnaissance, in conjunction with the study of the placer deposits, which are described in a companion report to this paper, Idaho Bureau of Mines and Geology Pamphlet No. 121.

GEOGRAPHY

Location

The Elk City region is in the drainage of the upper South Fork of the Clearwater River, Idaho County, Idaho (Fig. 1). Field mapping on this project was confined almost entirely to the South Fork drainage, including lower Red River, Newsome Creek, American River, and Crooked River north of Orogrande. Approximately 330 square miles are included within the map boundaries (Fig. 2), although not all of this area was mapped.

Access

This region may be reached most conveniently from Kooskia or Grangeville along an all-weather, narrow, graveled highway leading eastward up the South Fork of the Clearwater. During the summer one may drive to Elk City from Selway Falls (on the Selway River to the north) over a single track forest road. A small airstrip is maintained a short distance southwest of Elk City.

Off the main highway, except for the road leading beyond Elk City along Red River and the road up Crooked River to Orogrande, four-wheel drive vehicles are desirable for travel. Most of the forest roads can be traversed in July and August by automobiles with good clearance. In most years, a heavy snow cover is present during the winter months.

Topography

As several authors have emphasized, the Elk City region lies within a rather high, dissected upland with broadly accordant ridge levels. The local relief is only a few hundred feet over most of the eastern part of the area. Along Newsome Creek and Crooked River it may be a thousand feet or more. Most of the
ridges are steep-sided, slopes of 20° to 30° being common. From high points within the area, such as Elk Summit, the area has a broad, rolling aspect. Driving along the South Fork of the Clearwater River, one has the impression of steep, mountainous terrain because of the steep walls of the canyon.

SUMMARY OF PREVIOUS WORK

The earlier work done in the Elk City region on general geology and on the placer deposits has been largely of reconnaissance nature. Lindgren (1904) made a number of observations on the bedrock geology and on the placer deposits that have proved to be accurate and, for the placer deposits, very helpful in the present investigation. Thomson and Ballard (1924) made a few general observations on the bedrock geology during a study of the gold mines in north-central Idaho. Anderson (1930) prepared a geologic map that is overlapped on the north by the geologic map prepared in this investigation. Shenon and Reed (1934a, 1934b) made a rather thorough geologic reconnaissance in an area that overlaps the present map considerably and extends for some distance to the south of it. Their excellent map has proved helpful for further mapping. Reed (1934) dealt with the geology of the placer deposits of the Elk City region in some detail. Lorain and Metzger (1938) discussed the economics and extent of the gold placers. Capps (1941) examined fault relations in part of the district in connection with a study of faulting in western Idaho. Anderson (1948) briefly described vein relations in the district.

FIELD AND LABORATORY PROCEDURES

Field data were mapped on air photographs (scale 1:20,000) obtained from the U. S. Soil Conservation Service. U. S. Forest Service planimetric maps served as a base for compilation of data, as well as for the geologic map (Fig. 2).

Orientation data were obtained on foliation, fold axes (three sets), axial planes of folds (two sets), boudins, and rarely, upon oriented augen and hornblende grains. The Wulff stereonet (Bucher, 1944; Lowe, 1945) was found exceedingly helpful in mapping those outcrops on which desired orientation data could not be measured directly, but on which sufficient measurements could be made to permit computation of the desired data.

Sixty-seven thin sections were studied with the petrographic microscope. The Schmidt equal-area stereonet was used in conjunction with the universal stage for statistical determination of quartz grain orientation in oriented thin sections. The Schmidt net was used also in preparing the modified beta-diagrams and the lineation plots (b-diagrams). Because of the paucity of the statistical data analyzed, a two percent area counter was used in contouring all the diagrams.
Fig. 1 — INDEX MAP OF THE ELK CITY REGION, IDAHO.
ACKNOWLEDGMENTS

As is usual in a study of this kind, several persons have contributed materially to the report. John Beeder and Richard Kopp each provided one month of high-quality field assistance and, in many field discussions, contributed to the development of the ideas on the bedrock geology. Bruce Brogoitti and Stuart Hill each did significant portions of the heavy mineral analyses under my supervision. Dr. E. F. Cook, director of the Idaho Bureau of Mines and Geology, in critical discussions and reading, made several suggestions that resulted in material improvement.

The excellent geologic map prepared by Shenon and Reed (1934a) has been consulted freely during the course of this work. Further, because it did not seem necessary, nor was there time to remap placerless ground covered by them, many geologic contacts have been transferred directly from their map to the present map (Fig. 2) with a special line symbol to show which contacts are their work. Most of the contacts transferred lie in the southwest quarter of the present map. It follows that the present work does not supplant that of Shenon and Reed, but rather extends and elaborates upon it. Needless to say, I bear full responsibility for any and all errors that may be present.
LAND FORMS IN THE AREA

Standing on the Elk Summit forest lookout, one may look for miles in each direction across a broad, rolling surface at elevations of 5000-8000 feet, cut by narrow, sharp canyons. Across the area the South Fork of the Clearwater has cut an east-west canyon that is 1000 feet deep west of Crooked River, and considerably shallower and more subdued east of Crooked River as it heads at the confluence of American and Red Rivers.

The northwest part of the area is dominated by Newsome Creek valley, a valley different in form from the narrow, sharp canyons already mentioned. Viewing this canyon from Pilot Knob, one has the impression of a rather broad basin, the bottom of which is considerably dissected. The basin is bounded on the west by the Reed Mountain-Pilot Knob-Baldy Mountain ridge, much of which is higher than 6000 feet in elevation, and on the east by the Elk Summit-Iron Mountain ridge, much of which is also higher than 6000 feet. Between these two ridges is an area 3 miles wide by 10 miles long that is perhaps 4200 feet in average elevation. Into this broad area, Newsome Creek cuts a sharp, narrow canyon that is about 200 feet deep near Old Newsome and about 400 feet deep at the South Fork. The relatively low, flat area extends south of the South Fork between Buckhorn Creek and Rabbit Creek, sloping upward toward Nipple Mountain.

The southwest part of the area is flat overall, sloping upward to the south, with only the sharp canyons of Tenmile Creek and Crooked River cutting into the surface. A rather prominent topographic low extends along Crooked River from Orogrande to Relief Creek. Beyond Relief Creek, the low continues northeasterly into Deadwood Creek, and Crooked River flows in a sharp, steep canyon that cuts across the high area west of the topographic low. This topographic low can be seen particularly well from the Elk Summit forest lookout.

East of the Elk Summit-Iron Mountain ridge extends a broad, relatively low area bounded on the east by the Green Ridge-Anderson Butte-Blackhawk Mountain ridge. Much of this low lies within the drainage basins of Elk Creek, American River, and Red River. From the Selway River-American River divide, this topographic low slopes down to the south as far as Elk City. Beyond Elk City, the low surface, dissected by Red River and its tributaries, rises gradually toward the south to the Salmon River divide, and beyond into the Dixie area. This portion of the topographic low, referred to by Capps (1939, p. 5), lies mostly below 6500 feet in elevation.

The streams that dissect the area are youthful in their overall habit: steep-sided with narrow valley bottoms no wider than the channel width of the streams. At places along the streams,
the valleys widen out, still steep-sided, into flood plains that range from only slightly wider than the channel of the stream to more than one-half mile wide, partly covered by alluvium from the valley sides. These flats generally, but not invariably, have a lesser gradient than the stream bed both above and below.

**Fault control of major valleys**

At the placer mining operation of Mr. Clair Johnson on Red River, large quantities of massive, strongly foliated blue clay were brought up from the bedrock by the dragline. Bits of mica and crushed rock are present in this clay. In short, it is a heavy fault gouge. Similar clay was brought up in Crooked River by Mr. Lester Strack's dragline in one of the sharpest, narrowest parts of the canyon. Weathered masses of such foliated clay are present in the old dredge gravels along other parts of Crooked River, Newsome Creek, American River, and Little Elk Creek. The small creek below the ranch of Mr. A. York, tributary to and on trend with Little Elk Creek, has been placer mined so that bedrock is well exposed over some area. The whole bedrock is intensely sheared and altered and high in limonite content. Such sheared, limonite-stained bedrock is common in the dredge gravels in the above-mentioned streams. Therefore, it appears that large parts of Crooked River, Newsome Creek, Little Elk Creek, American River, and Red River lie along north-south to northwest-southeast fault zones.

Profiles of these valleys are figured in Pamphlet 121. The overall form of these profiles, combined with the evidence above and general evidence on the Idaho peneplain, indicates that the present valleys have been controlled in their formation partly by pre-existing faults and partly by rejuvenation due to uplift.

**South Fork of the Clearwater Valley**

Within the map area, the South Fork of the Clearwater has a gradient of about 50 feet per mile between Golden and Santiam Creek, where the valley is narrow and sharp. Between Santiam Creek and Rabbit Creek, the gradient is about 15 feet per mile, through a narrow flood plain. This part of the stream crosses the Newsome Valley topographic low described earlier. Above Rabbit Creek, the gradient is about 35 feet per mile, and the valley is narrow and sharp to the Crooked River bridge. Beyond Crooked River, the stream is within the Elk Creek topographic low, the gradient is about 21 feet per mile, and a flood plain of moderate width has developed.

**American River Valley**

At the confluence of American River and Red River, and continuing along American River, the gradient steepens slightly to 26 feet per mile; and, as far as Kirk's Fork, although the valley bottom narrows in places, flood plain gravels and accompanying placer deposits are thick and even enough that the whole length
of the stream could be dredged. All of this part of the South Fork and American River lies in the Elk Creek topographic low. Between Kirk's Fork and Baboon Gulch the stream is narrow and rocky with a gradient of about 54 feet per mile. Above Baboon Gulch, a wide floodplain with a gradient of 28 feet per mile extends to about 1/2 mile beyond the Flint Creek trail. The profile was not drawn farther, but after another steep, narrow portion, an area of wide flood plain (undredged) extends well up the West Fork, up Limber Lake Creek, and up Lick Creek.

The distribution of flood plains in the upper part of American River is repeated on a small scale in virtually every small stream, and some of the large ones, in the area. A narrow, steep valley forms the lower part of most minor streams, just above the main valley stream. This feature may correspond in a general way to the steep part of American River between Kirk's Fork and Baboon Gulch. Above the lower, steep part of the valley is an area of flood plain, another steep area, another area of flood plain, and then the steep headwater section of the stream.

Newsome Creek Valley

Newsome Creek differs somewhat from the average profile configuration. Lower Newsome Creek lies in a sharp, narrow valley with an average gradient of about 63 feet per mile. Above Bear Creek, the gradient on a well-developed, broad flood plain is about 48 feet per mile. Although the valley narrows at the entry of Pilot Creek and Baldy Creek, the smooth part of the profile continues uninterrupted to Radcliff Creek, where the valley narrows and steepens in the headwater section.

Crooked River Valley

Crooked River also differs from the average profile for the smaller streams. The lower, steepest part of the valley has the highest gradient among the larger streams in the area, 96 feet per mile, and a relatively wide flood plain. About two miles above the mouth, the stream flows in a narrow, sharp canyon with a gradient of 61 feet per mile. In this part of its course, the stream lies athwart the ridge west of the Crooked River topographic low described earlier. From a point about two miles below the mouth of Relief Creek, the stream is within the topographic low and has a rather broad flood plain with a gradient of about 43 feet per mile. As the flood plain extends upstream to Fivemile Creek, it steepens rather abruptly to about 86 feet per mile at a point about 1/2 mile below Sawmill Creek.

Red River Valley

Red River flows in a narrow, bouldery gorge in its lower portion, with a gradient of about 40 feet per mile. Above French Gulch, the valley broadens abruptly to a flood plain 1/2 mile wide and about 3 miles long, with a gradient of about 25 feet per mile. Above this area, the valley narrows abruptly for a distance, then
opens out into another flood plain 1/2 mile wide and more than a
mile long. Perhaps "meadow" is a better term to use than "flood
plain" because much of the area is underlain by alluvium deposited
from the valley sides. It is not known how many of these gently
sloping alluvial surfaces along the valley sides are underlain by
gravels at present flood-plain level, by low terrace gravels, or
by weathered bedrock. The entire flat probably owes its existence
to stream cutting.

**Elk Creek Valley**

No profile was drawn along Elk Creek. The entire lower part
of this stream flows in a broad meadow similar in overall appear-
ance to the Red River meadows. Little Elk Creek flows in a meadow
much the same as Big Elk Creek. From the appearance of these
meadows it seems likely that their profiles are continuous into
their headwaters without any major breaks in gradient.

**RELATION OF TERTIARY DEPOSITS TO THE BEDROCK**

AND TO PRESENT LANDFORMS

The Tertiary gravels have been discussed by most of the geo-
logists who have worked in this area (Lindgren, 1904, p. 27; Shenon
and Reed, 1934a, p. 22; Reed, 1934, p. 2). Lindgren thought that
damming of an ancient Clearwater canyon (probably in the Miocene)
cause the accumulation of the Tertiary gravels upstream, in the
Elk City region. Shenon and Reed, on the other hand, thought
that "Warping and faulting of the partly dissected Idaho pene-
plain appear to have resulted in the formation of Newsome and Elk
Creek basins..." in which the Tertiary gravels were deposited.
The scanty work done on these gravels in the present investigation
can add but little to conceptions regarding their geologic signi-
ficance.

**Newsome Creek deposits**

The Newsome Creek topographic low contains rather extensive
Tertiary gravels (Fig. 2), underlying the aforementioned surface
at 4200 feet elevation. The west contact of these gravels has
been examined near the New York mine, on the West Fork of Newsome
Creek, and on the ridge between Pilot and Baldy Creeks. Because
the relations in the West Fork are typical, its description will
illustrate the entire west contact. In the creek bottom one passes
abruptly from stream gravel rich in white, well-rounded quartz cob-
bles and boulders, characteristic of the Tertiary gravels, to
stream gravel with large angular boulders of gneiss and quartzite,
characteristic of the eroded country rock. In the zone of transi-
tion between gravel types in the stream bottom, rather sharp north-
south gullies are present in the valley side. The west side of the
gully on the south side of the creek has a gneiss bedrock, whereas
directly across the gully to the east a few feet away, no bedrock
is visible. The soil there contains well-rounded quartz cobbles.
These relations are present all the way up the gully to the top of the ridge between Legget Creek and the West Fork. Standing on this ridge, one sees a rather prominent north-south escarpment, sloping up steeply to the west. This scarp is visible also on the air photos and is shown on the Buffalo Hump topographic sheet. Quartzite a short distance up the creek is strongly sheared and broken, with high-angle shear joints. This evidence suggests the presence of a high-angle fault. Thus, tentatively, the west contact of the Tertiary along Newsome Creek is considered to be a fault contact.

The east contact of the Tertiary, west of Newsome Creek, is rather irregular and has the overall appearance of the trace of a flat surface—the base of the Tertiary gravels. The base of the Tertiary gravels is at about 4000 feet elevation near the South Fork and at about 4200 feet in the upper part of Haysfork Creek. The gravels (Fig. 2) are shown as continuous over the whole distance, although they were not traced foot by foot. Because of heavy soil and forest cover, it was necessary to rely on float gravel in the streams and on scattered hydraulic placer pits. Newsome Creek is incised to depths of 200-400 feet below the base of the Tertiary gravels, which range in thickness from a few inches to about 600 feet. The highest gravel is at an elevation of about 4600 feet on the west side of Newsome Creek.

The base of the Tertiary seems to be rather flat along the Newsome Creek topographic low, although locally there may be fifty feet or more of relief beneath the gravels, as in the Moose Creek placer pit. Slopes on the bedrock surface beneath the Tertiary gravels are gentle. The bedrock is thoroughly and deeply decayed beneath the Tertiary gravels; even at depths of thirty feet or more, pieces of the bedrock can be disintegrated to grain size by crushing in the hand, and the clay content is high. Details of the rock structure are preserved in spite of the intense decay.

Present in lesser volume on the east side of Newsome Creek, the Tertiary gravels are higher, with the exception of the Moose Creek placer, than those on the west side. A small patch of gravel is present with base at about 4500 feet elevation in the head of Vicory Creek. A somewhat larger patch occurs in the vicinity of the old Iron Crown mine, again at about 4500 feet. A small patch also outcrops in the divide between the two forks of Mule Creek, along the Mule Creek trail. All these patches appear to have relatively flat bases at about the same elevation. Geologic relations along their east sides (small saddle in the ridge at the contact and abrupt change from quartz cobble float to bedrock float) suggest a common fault contact. Although time did not permit further search to be made, the presence of quartz cobbles in the gravels of Nugget Creek and Radcliff Creek leads to the surmise that Tertiary gravels are present at about 4500 feet in elevation on the ridge between Nugget and Beaver Creeks and on the ridge between Mule Creek and Radcliff Creek. A small patch of Tertiary gravel occurs also at about 4500 feet elevation south of the Clearwater across from the Legget Creek placer, between Santiam
Creek and Rabbit Creek. This gravel was probably with the gravel north of the river at some past time.

**Elk Creek deposits**

The map pattern of the Tertiary gravels in the Elk Creek topographic low, at least near Elk City, indicates somewhat more relief on the bedrock beneath the gravels than at Newsome Creek. The west contact of the Tertiary gravels is similar in every respect to the contact on the west side of Newsome Creek. Lindgren (1904, p. 95) observed a fault contact between bedrock and the Tertiary gravels in the Buffalo Hill placer, which confirms the inference drawn from other field relations. The scarp on the west side of the Tertiary outcrop is more subdued than the one in Newsome Creek and trends a little south of east between the Beartrap Ranch and the Buffalo Hill placer. South of the river, it swings westerly to form a southwest-trending ridge along the west side of the Crooked River topographic low.

The base of the Tertiary gravel is at about 4000 feet elevation at several places near Elk City. To the southwest, it rises to about 4100 feet on the ridge between lower Deadwood Creek and Campbell Creek, and to about 4600 feet elevation in the divide between Relief Creek and Deadwood Creek, which divide lies on the axis of the Crooked River topographic low.

North of Elk City, much of Erickson Ridge north of the old Forest Service airstrip is covered with a thin layer of Tertiary gravels. The geologic relations along Little Elk Creek strongly indicate a fault under Little Elk Creek that is downthrown to the southwest. The relatively high gravel at the old Tiernan Hill placer may lie east of this fault. Also, the geologic relations along Big Elk Creek, near the Beartrap Ranch, seem to indicate a fault that is downthrown to the southwest. Tertiary gravel that extends from Mother Lode Hill to the Cal-Idaho placer between American River and Red River was not traced out in detail; the map pattern is based on an exposure at the Cal-Idaho pit, one in the road along the north side of Mother Lode Hill, and two intervening traverses across the ridge, each of which disclosed Tertiary gravels in old placer prospects in gullies in the upper part of the ridge. Some float quartzite boulders observed at old placer operations near the mouth of Siegel Creek, may be indicative of the presence of Tertiary gravels along the lower slopes east of Red River. Time did not permit checking this possibility.

No Tertiary gravels were observed east of American River. However, Lorain and Metzger (1938, p. 21) reported the presence of Tertiary gravels of small extent in the head of Baboon Gulch. These gravels are considerably higher than those along Erickson Ridge.

The gravels on Erickson Ridge slope gently up to the northwest along the ridge to an elevation of about 4500 feet at the north end of their outcrop belt. The surface of Erickson ridge does not lie far from the base of the Tertiary gravels at any point.
The base of the Tertiary gravels, over the whole district, has the general configuration of a gentle syncline, with an east-west axis coincident generally with the trend of the canyon of the South Fork of the Clearwater.

The boulders, cobbles, and pebbles in the Tertiary gravels are composed partly of massive, white vein-quartz; and partly of massive, white quartzite of a type that, as far as observed, occurs only in the quartzite belt that runs north-south through Golden. Well-rounded quartzite cobbles are sparsely scattered in the soil on the ridge south of Anderson Butte, at an elevation probably higher than 5500 feet. Although less abundant, and not to be confused with sub-angular to sub-rounded, residual vein-quartz boulders, they are present also in the soil along the Elk Summit ridge.
SUMMARY OF EARLIER CONCEPTS OF THE IDAHO PENEPLAIN

Shenon and Reed (1934a, p. 22) make several pertinent remarks regarding the development of the topography in the Elk City region:

The most ancient topographic features of the present landscape of the area are the remnants of an old peneplain or erosion surface which... may be the so-called "summit" or Idaho peneplain, whose age and manner of development are subjects of controversy. ... Warping and faulting of this peneplain appear to have resulted in the formation of certain basins such as those of Elk and Newsome Creeks...

The present work can add nothing new to the Idaho peneplain discussion, but a brief review of the work of others seems helpful not only to provide a background for the discussion of topographic development but also to show, through the confusion present in the literature, how little is yet known of the Idaho peneplain. Lindgren (1900, p. 234) was one of the earliest persons to remark upon the age of the high level erosion surface:

The age of this old gentler topography (at Florence) is not established beyond doubt, but for many reasons it seems probable that it decidedly antedates the Miocene...

Umpleby (1912, p. 144) considered that the peneplain was of Eocene age. Blackwelder (1912, p. 414) thought that Umpleby's evidence could also be interpreted to indicate a post-middle Miocene age for the summit peneplain. Umpleby (1913, p. 224) considered at least a part of Blackwelder's interpretation to be inadmissible. Here the matter rested until Rich (1918, p. 129, 135) pointed out that the supposed Eocene erosion surface cuts Challis volcanics as well as older rocks; he concluded that this relation indicates a probable late Miocene or Pliocene age for the surface. These remarks brought Lindgren (1918, p. 487), with some lively remarks about armchair geologists, to Umpleby's defense:

... nobody has a right to assert a Pliocene or Miocene age of the high peneplain without having critically examined the relations of the Columbia River lava to that surface, as exposed in the region of the western margin of the Clearwater Mountains. ... The evidence is complete that the molten lavas in successive floods buried the foothills and dammed the rivers...

Livingston (1918) made several remarks in the same vein. Anderson (1929, p. 760, 761) proposed the existence of three peneplains in northern Idaho: a summit peneplain of late Cretaceous age; a sub-summit peneplain of Eocene age; and an old valley surface "... carved and also dissected before the deposition of the Latah..."
The subsummit peneplain of Anderson may well correspond to the summit peneplain of south-central Idaho. It would then be of probable late Tertiary age. The youngest surface discussed by Anderson would probably correspond to the numerous broad basins of south-central Idaho and hence would probably be Pliocene or Pleistocene.

Anderson (Ross and others, 1930, p. 651) proposed in turn that Ross's correlation should be changed so as to relate the summit peneplain of south-central Idaho to the youngest erosion surface (old valley surface) in the northern part of the state. And there the matter rests. The Elk City region lies approximately halfway between the controversial areas. The consensus appears to be that a high peneplain, partly dissected in pre-Columbia River lava time, is present in northern Idaho and that a high peneplain of post-Challis age is present in south-central Idaho.

WORK IN ADJACENT AREAS

The work done in nearby areas may cast some light on the geomorphic history of the Elk City region. Both the Warren and Seecess mining districts (Capps, 1939), south of the Salmon River, have rocks identical to and perhaps correlative with the Tertiary gravels at Elk City--highly quartzitic gravels upon a deeply decayed bedrock. The beds are tilted so that their present dips are 12° to 28°. Capps (1939, p. 12) further states:

The Tertiary sedimentary rocks are overlain by deeply decomposed Pleistocene morainal deposits that are much older than the moraines of the Wisconsin stage, and that are probably of early Pleistocene age. Moreover, they occupy structural valleys that had been faulted down to their present position before the early Pleistocene glaciers advanced down them.

Capps also states that these beds are clearly older than the post-Latah faulting that Reed (1938, p. 21) discussed briefly. The highly quartzitic gravels, present also at Florence on a deeply weathered surface (Reed, 1939, p. 10), are perhaps also correlative with those in the Elk City region. According to Reed, "the gravel is closely associated with flows of Columbia River lava and locally at least appears to be interbedded with it." Reed (1934) indicates that such quartzitic gravels occur at several other places, including Big Creek, the head of American Creek, Adams Ranger Station, Whitebird Station, Peasley Creek-Silver Creek divide, Meadow Creek, the head of Johns Creek, and at Blacktail Butte where they are said to be interbedded with lava. Reed (1934, p. 15) also mentions fossil leaves of probable Miocene age from Meadow Creek basin. Shenon and Reed (1934, p. 9) remark that "In
one place [in the Tertiary rocks] about four feet of tuffaceous material is exposed." This exposure might indicate an age closer to the Challis volcanics than to the Columbia River lavas.

OLDER VIEWS ON THE ORIGIN OF THE TERTIARY GRAVELS

Views regarding the origin of the Tertiary beds are somewhat divergent. Lindgren (1904, p. 27) advanced the view that the gravels accumulated in the upper parts of stream valleys when the lower parts of the valleys were dammed by lava in the Miocene. Reed (1934, p. 11) considered that the Elk Creek and Newsome basins were formed by Miocene faulting. Capps (1939, p. 11) proposed that in the Dixie district, just south of Elk City, the following post-basalt events occurred: block faulting and minor folding of the plateau surface; uplift, resulting in filling of basins; erosional formation of a surface, beveling the basin deposits; and finally, canyon cutting by the major streams. Capps (1941) thought the block faulting may have occurred in the Pliocene. His remark (1941, p. 13) that the high erosion surface was developed in post-Challis and pre-Columbia River basalt time, tends to reconcile the divergent views of Ross and Anderson cited earlier (Ross and others, 1930).

Lindgren's view that the gravels filled Miocene valleys dammed by lavas, seems untenable. It does not account satisfactorily for the presence, as in the Elk City region, of very poorly sorted basalt conglomerates, with quartz and quartzite boulders up to five feet in diameter on a deeply weathered surface. Some layers of these gravels have certain of the aspects of mudflow deposits: very poor sorting, virtually no internal stratification, presence of very large boulders, and high mud-silt content. Further, on this hypothesis, the white quartzite that seems to be present in the bedrock on the west side of the area only, could not get across Elk Summit to the gravels in the Elk Creek topographic low.

The concept of small individual basins, held more or less jointly by Reed and Capps, does not seem to explain satisfactorily the presence of well-rounded quartz and quartzite cobbles that have a Tertiary "look" to them high on Elk Summit and Anderson Butte; the strong similarity of the sediments at widely separated places; and the presence of sediments in aligned continuous topographic lows both north and south of the South Fork-American River-Red River system. I have seen no evidence to support Reed's (1934, p. 2) proposed pediment-like surface.

POSTULATED GEOMORPHIC SEQUENCE

Although no evidence has been found relating to the age of the more recent geologic events in the Elk City region, a geomorphic sequence differing somewhat from those suggested earlier, can be proposed on the basis of present evidence.
The earliest geomorphic event recorded was the formation of an erosion surface of low to moderate relief, with thorough rock decay to considerable depth. Next was an episode of faulting that probably occurred rather rapidly, perhaps with local uplift present only in the vicinity of the Reed Mountain-Pilot Knob-Baldy Mountain ridge, which would account for the abundance of white quartzite boulders present everywhere in the gravels. Relatively rapid uplift seems necessary to account for sufficient local relief to produce the poorly sorted, mudflow-like deposits with their large boulders. From this ridge and others, a blanket of gravel buried the countryside to the east and southeast for some distance beyond Anderson Butte, although judging from the peat beds, the center of the basin may have been near Elk City.

Faulting, following gravel deposition, formed the Newsome Creek and Elk Creek topographic lows and the Elk Summit and Anderson Butte ridges. One fault, presumably the one along which Newsome Creek now lies, was thrown down to the west so that the gravels on the west side of Newsome Creek are about 300 feet lower than those on the east side. Similar faults under Little Elk Creek and American River are responsible for the uplift of gravels on Erickson Ridge above those west of Little Elk Creek, and for the uplift of the gravels in the head of Baboon Gulch above those on Erickson Ridge. Presumably, further movement occurred along the original faults that formed the basins, for example, along the fault west of Newsome Creek.

Newly formed streams (Newsome Creek, Elk Creek, American River, Red River, and Crooked River in part) gained their courses either as consequent streams in fault-line depressions or as subsequent streams eroding headward along faults; perhaps both mechanisms were locally operative. Evocation of one or the other of these mechanisms seems necessary to explain why each of the major streams lies in a fault zone. Certainly all the streams, if flowing randomly, whether on a continuous gravel surface over the whole region or in individual basins, would not cut down through the gravel in such a way as to flow along a pre-gravel fault zone. This is not to say that the fault zones along which the streams lie are entirely post-gravel; rather it is thought that in post-gravel time renewed movement occurred along some or all of the older faults, some of which have been mineralized in varying degree and are therefore older than the time of ore deposition in this region. Those parts of the streams that lie in strong fault zones where the bedrock has been "softened", have been able to cut rather wide flood plains. The broad meadows of Elk Creek may be broad because the stream is cutting in soft, easily eroded Tertiary gravels.

On the other hand, the lower parts of Red River, American River, and the middle part of Crooked River seem to have gained their present courses through superposition onto the bedrock from the old gravel surface. If superposition is the correct explanation for the course of the middle part of Crooked River across the ridge west of the Crooked River topographic low, the gravels there
may have been considerably thicker than 600 feet. Yet, the presence of fault gouge under the creek, even in the narrow part of the canyon, argues against superposition.

The suggestion of a blanket of gravels is not new (Shenon and Reed, 1934a, p. 23), but it is not clear if those authors thought that the gravels were as widespread as here proposed. If gravel has been spread over most of the Elk City region, it is not easy to understand how the South Fork gained its present course. Perhaps the syncline formed by the base of the Tertiary gravels is post-gravel and pre-faulting, or contemporaneous with faulting; and perhaps the South Fork is essentially consequent along the axis of the syncline. Though I propose to disregard for the present the problem of how the river got across the postulated Pilot Knob quartzite ridge, Capps' (1941, p. 1) proposal of antecedence, coupled with a suggestion of temporary damming or defeat, suggests a solution.

If one indulges in a bit of pure speculation, it seems possible that the entire north-central Idaho region, extending south of the Salmon River, may have had spread over it a more or less continuous blanket of gravel at some time in or about the Miocene. If so, the present gravel deposits are infaulted remnants of the original gravel blanket. Serious problems arise from this hypothesis regarding the origin of the courses of the major streams of the region.

After the post-gravel faulting, the streams in the Elk City region appear to have developed mature profiles and rather broad flood plains, as in upper Newsome Creek, upper Crooked River, upper Red River, and upper American River. Then, upon a relative lowering of base level, the South Fork cut down rapidly and caused corresponding downcutting and steepening of profile in the lower part of its tributaries, a process still actively under way.
ROCK TYPES

Although considerable diversity in rock type is found in the Elk City region, a diversity due to inter-gradation among the principal rock types, the rocks present fall into four broad groups: quartzite, biotite gneiss, augen gneiss, and granitic rocks. Scattered andesite dikes are so rare that andesite is virtually negligible in volume. Amphibolite occurs in scattered thin sills except for the area northeast of Elk City, in which one rather large sill occurs.

Quartzite includes biotite quartzite, most abundant; pure white quartzite; muscovite quartzite, relatively rare; and feldspathic biotite quartzite, transitional into biotite gneiss. The present, widely variable thickness of quartzite layers ranges from a few hundred feet to perhaps several thousand feet. Much of their apparent thickness is no doubt caused by repetition in tight folds. Biotite gneiss, including minor amounts of feldspathic biotite schist, is rather uniform in composition and in appearance. This rock is the most abundant in the area. The thickness of individual units is no doubt many thousand feet; however, no reliable estimate of thickness can be given because of much repetition in tight folds. Augen gneiss, minor in amount, occurs at only a few localities in the area. Granitic rocks, including rocks that have the composition of quartz diorite, granodiorite, and quartz monzonite, are intimately intermixed with the metamorphics, in places making up perhaps more than half the volume of the rock. However, in most places, the rock retains an overall metamorphic aspect and has been arbitrarily mapped as metamorphic rock. A few thin, concordant layers of lime-silicate rock were seen on Newsome Creek. Generally, however, this rock type is rare or absent in the map area.

The age of these rocks is not known with certainty, although they are generally considered to be equivalent to Beltian rocks to the north and to the northwest. Shenon and Reed (1934a, p. 15) point out that "... these rocks ... correspond structurally and lithologically with the Belt series ..." On the same page, these authors attribute the formation of the granitic rocks in the area to the intrusion of the Idaho batholith.

All of the metamorphic rocks in the area exhibit a variety of large to small folds in places. Based on geometry of the small folds, three classes of folds are present: (1) tight isoclinal folds, (2) open isoclinal folds, (3) gentle folds. The following description of the folds follows this tentative classification.

Because granitic rocks are thoroughly intermixed with the metamorphics, a separate discussion is difficult, if not unrealistic. Many features of these rocks are discussed in the various sections on structure.
An important feature of the granitic stringers in the metamorphic rocks needs to be emphasized, however (Fig. 45). Whether the granitic stringers are parallel to the foliation, folded along the foliation, folded across the foliation, or parallel to the No. 2 axial plane direction, biotite is almost invariably concentrated along their edges (Figures 4, 17, and 19 illustrate this feature).

Pegmatites are relatively rare and small over the whole Elk City area, except for the Elk Summit ridge, on which they are rather common. Figure 46 shows the relationship of many pegmatites to the country rock. Where structures in the bedrock can be traced across a pegmatite dike, they go straight across, with complete absence of dilation offset (Goodspeed, 1940).

Certain granitic dikes are different from those described above. They are non-folded in individual outcrop, so far as can be seen; their walls are straight; and they contain rotated inclusions of country rock (Fig. 47). Cutting folded granitic stringers with distinct dilation offset (Fig. 48), the dikes may have distinct mineral alignment parallel to their walls and to elongate inclusions of country rock (Fig. 49).

Certain pegmatites have different relations to the country rock from those pegmatites described above. Garnet-bearing pegmatites cut folded granitic stringers or earlier pegmatites with distinct dilation offset. None of the pegmatites that exhibit dilation offset have concentration of biotite along their walls; on the other hand, virtually all of those pegmatites that have no dilation offset do have biotite zones along their walls in the country rock.
DESCRIPTIVE STRUCTURAL GEOLOGY

TIGHT ISOCININAL FOLDS

Tight isoclinal folds include all folds in which the limbs are almost parallel and in which the hinges are so sharp that the amplitude is very much greater than the wavelength. In these folds, compositional layering has been folded, and a strong axial plane foliation (or schistosity) (Fairbairn, 1935, p. 592) is present. Because exposures are not good in the map area, it seems desirable to illustrate and describe the several examples found. Figure 4 shows rather typical biotite gneiss with a thin layer of biotite quartzite. Biotite grains are aligned parallel to the axial plane of the fold. Thus the rock has a well-developed axial plane foliation. Granitic sills along the foliation cut across the compositional layering at a small angle in the crestal portion of the fold. Figure 5 shows biotite quartzite with an interlayering of two varieties of quartzite. The gray quartzite is deformed into a rather complex synclinal trough, almost a miniature synclinorium. Axial plane foliation is strongly developed. Figure 6 shows a tight isoclinal fold of compositional layering in biotite quartzite. Axial plane foliation is strongly developed, and a granitic sill parallel to the foliation cuts across compositional layering at a small angle in the crestal portion of the fold. In Figure 7, a tight isoclinal fold has a concordant granitic sill in its crestal portion. Axial plane foliation is strongly developed in this fold also. In a close view (Fig. 8) of one of these folds, the alignment of biotite grains parallel to the axial plane direction of the fold can be clearly seen.

The foregoing folds are all on the scale of individual hand specimens. However, the same kind of fold is present on larger scale. Figure 9 portrays one in a large boulder. Figure 10 portrays one on outcrop scale. Close examination with the hand lens was required to ascertain that the foliation is parallel to the axial plane of the fold. Superficially, the structure looks very much like bedding foliation or schistosity. The rock in Figure 5 was taken from the trough of this fold. Parallel to the axis of this fold is a crinkly lineation, presumably formed at the same time as the fold. On a scale larger than that of the individual outcrop (Fig. 11), isoclinal folds with strong axial plane foliation are still present. In this kind of structure, the foliation parallels the compositional layering only where the limbs of the folds are parallel. Where the limbs are slightly divergent, even at some distance from the hinge, foliation cuts across the compositional layering at a small angle. This cutting may not be seen readily in the individual outcrop. The structure shown in Figure 11 is visible only because of almost complete exposure in a cirque. Henceforth, tight isoclinal folds will be called No. 1 folds. The compositional layering will be called $s_1$ and the axial plane foliation (or schistosity), $s_2$. 
FIG. 4

Tight isoclinal fold of compositional layering (with strong axial plane foliation) in biotite gneiss. Note concentration of biotite along edges of granitic stringers along foliation.

FIG. 5

Tight isoclinal folds of compositional layering (with strong axial plane foliation) in biotite quartzite.

FIG. 6

Tight isoclinal fold (with strong axial plane foliation) in biotite quartzite near Pilot Knob. A granitic sill very nearly parallel to the foliation cuts across one limb of the fold at a small angle. The plunge of the fold is oblique to the sloping outcrop surface.

FIG. 7

Tight isoclinal fold with axial plane foliation in biotite quartzite near Pilot Knob. A tightly folded granitic stringer of probable replacement origin occupies the crestal portion of the fold.
OPEN ISOCLINAL FOLDS

General description

Open isoclinal folds are those folds in which the limbs are parallel to nearly parallel, and which perhaps might better be classified as tight concentric folds. Though the amplitude and the wavelength are not significantly different, the hinge is broad and round, rather than sharp as in the tight isoclinal folds. Foliation (or schistosity) is the structural element deformed in these folds, as first noted by Thomson and Ballard (1924, p. 25).

Figure 12 shows this structure on the scale of the individual hand specimen in biotite quartzite. As a hand specimen containing one of these folds is rotated, continual reflections from biotite cleavage surfaces indicate that biotite grains are tangential to the fold surface both on the limbs and the crest. Examination of an outcrop surface that is normal to the axis of one of these folds confirms that foliation is the folded structural element. Figure 13 shows the same structure in a large boulder. In Figure 14, a concentric fold with gentle flexure above, grading into tight flexure below is shown. It must be emphasized that this structure is folded foliation (or schistosity), not folded compositional layering.

Folds involving folded foliation occur on a still larger scale, as in Figure 15. Much larger folds may be viewed at several places in the canyon of the South Fork of the Clearwater River. Whether the folds be large or small, it is clear upon close inspection that foliation, rather than sedimentary bedding, has been folded. Sedimentary bedding has previously been deformed into tight isoclinal folds with sharp axial plane foliation.

Folds involving folded foliation will henceforth be called No. 2 folds to aid in their distinction from other folds. Small drag folds on the flanks of larger No. 2 folds have the same geometry as the larger folds (Fig. 23). Their axes and axial planes are more or less parallel to the axes and axial planes of the larger folds. Also, the drags on each limb show the correct direction of transport with respect to the larger folds.

Granitic stringers

Where the foliation is planar, abundant thin granitic sills are present. These sills were first noted by Lindgren (1904, p. 20) and later by Thomson and Ballard (1924, p. 26). Their relationship to the No. 1 folds has been shown in Figure 6. Generally, No. 1 fold hinges are not visible or not present, and the granitic stringers lie parallel to the foliation. Less commonly, they cut across the foliation. Where the foliation is folded, the sills appear to be as abundant as elsewhere. A gentle fold involving a granitic sill is shown in Figure 16. The granitic sill, coarsened in grain size in the crestal portion of the fold, indicates incipient pegmatite development. In places, these pegmatite bodies attain several feet in diameter in fold crests, have gradational
FIG. 8

Isoclinal fold in biotite quartzite near Pilot Knob. Biotite is strongly aligned in the axial plane direction, forming strong axial plane foliation.

FIG. 9

Sketch of a portion of a stream boulder of quartzite in Little Moose Creek, vertical to the plunge of a tight isoclinal fold with nearly parallel limbs. Biotite grains, shown diagrammatically, were ascertained with the aid of a lens to be parallel to the axial plane of the fold. Sketch from field notes.

FIG. 10

Isoclinally folded compositional layering in biotite quartzite along the South Fork of the Clearwater River near the Crooked River bridge. Strong axial plane foliation is present. A well-developed crinkly lineation is parallel to the axis of the fold.

FIG. 11

Folded foliation in biotite quartzite.
contacts into the adjacent sill material, and contain small amounts of schorlite. Augen gneiss is cut by granitic stringers that bear the same relation to it as that described for the granitic stringers in biotite gneiss and quartzite. The granitic stringers have concentrations of biotite along their edges and are in places pytistically folded.

In some places where the bulk of the foliation is planar, the granitic sills are rather tightly folded (Fig. 17). This may be caused by shortening along the foliation in which the granitic sill acts as a relatively competent unit. Further, the size of the folds produced depends, in part, on the thickness of the granitic stringers. It is well known that the amplitude of a fold depends on the thickness of the rock unit being folded (De Sitter, 1956, p. 190). Figure 18 illustrates tiny folds formed in a thin granitic stringer and larger folds in thicker granitic stringers. Figure 19 illustrates a rather tight fold in a somewhat thicker granitic stringer. Close examination with a hand lens of favorable areas in the core of the fold, showed that some of the mica grains are parallel to the folded foliation and that some of them are parallel to the axial plane of the fold. Figure 20 illustrates some closely spaced folds in weakly foliated biotite gneiss. In other rocks, however, granitic layers of about equal thickness may be folded with rather different intensity (Fig. 21). Perhaps this difference is caused by stronger differential movements in some layers than in other closely adjacent layers.

Not uncommonly, granitic stringers that cut across the foliation more or less steeply are folded sharply into pytistic folds with axial planes parallel to the foliation (Fig. 22). These folds have seemingly been formed by differential movements along the foliation planes. Foliation (weak) in the granitic stringers is generally parallel to the foliation in the enclosing rock.

Rarely, the crestal portion of smaller folded granitic stringers may undergo still more deformation (Fig. 24). Differential movement along the foliation rotates the fold crest much as a porphyroblast may be rotated, rolling it into an involute form. With more intense rolling, the fold crest may become "homogenized;" producing granitic "knots" on otherwise thin granitic stringers (Fig. 25). All transitions may be observed in outcrop. Partly rolled fold crests may form complex-appearing pytistic folds where exposed in outcrop faces oblique to the fold axes.

Figure 26 shows the result of folding of a granitic stringer where it cuts across the crestal portion of some No. 1 folds. The folds in the granitic stringer seem clearly to be due to differential movements along the foliation.

Figure 27 illustrates a fairly common structure associated with the No. 2 folds: a granitic stringer coincident with the axial plane of the fold. Ramsay (1958, p. 293) has recently reported similar structures in Scotland. It will be observed that the granitic stringer lying along the axial plane is
FIG. 12

Tightly folded foliation in biotite gneiss.

FIG. 13

Folded foliation in biotite gneiss, showing folding on concentric principle, with gentle flexure above and tighter flexure below.

FIG. 14

Folded foliation in upper Kirk's Fork Creek in biotite quartzite. Note that the axial plane of the fold is nearly horizontal. Sketched from a color photograph.

FIG. 15

Gentle fold in foliation. Note coarsened quartz and feldspar in the crestal portion of the fold—incipient pegmatite development. The rock is biotite gneiss. The pegmatite is beginning to form in a granitic stringer or thin sill.
continuous with one that lies parallel to the foliation on the flank of the fold. As mentioned above, relatively tight No. 2 folds have the beginnings of an axial plane foliation. This kind of axial plane foliation will be called $s_3$. Still tighter folds have a narrow axial zone of axial plane foliation cutting across the older folded foliation. In folds that have an axial plane granitic stringer or dike, a thin zone of axial plane foliation is commonly visible in outcrop. Figure 28 shows a somewhat similar structure. Where the No. 2 folds are very tight, they are transitional into shear folds, and the secondary axial plane foliation somewhat modifies the folded foliation. Such structures are subordinate.

In many places, granitic rock is rather abundant, making up a large part of the rock. Rather large areas of granitic rock, mapped by Shenon and Reed (1934a), in the southwest part of the map area, were not studied in more than the most general reconnaissance. Figure 29 shows the appearance of the mixed rock. Figure 30 shows still more detail. Although it may not be true of the larger bodies of granitic rock, the smaller bodies almost invariably have a weak foliation parallel to that in the host rock, whether the granitic rock is in sills or in dikes. Inclusions of gneiss are not rotated and still have foliation parallel to gneissic country rock, whether the invaded rock is quartzite, biotite gneiss, or augen gneiss (Fig. 31). Along restricted shear zones bounding a body of granitic rock, a weak foliation parallel to the walls of the shear may be present (Fig. 31).

**Lineation**

The presence of many small No. 2 folds in places forms a distinct lineation in the rock, a lineation defined by the axes of the No. 2 folds. In order to map this lineation, it was necessary to establish criteria by which No. 2 folds could be distinguished from other folds present in the rock. These criteria are: (1) foliation is tightly folded, generally with concentric fold pattern; (2) locally, these folds have a narrow axial zone of $s_3$; (3) pytymatic drag folds of granitic stringers have their axes parallel to the axes of nearby No. 2 folds and can therefore be mapped as No. 2 folds; (4) drag folds on limbs of larger folds have correct direction of transport with respect to larger folds; (5) granitic stringers may lie along the axial plane of the fold; (6) tighter No. 2 folds, doubtful at first, plunge parallel to nearby undoubted No. 2 folds; (7) crinkly lineation parallel to the fold crest is absent, a negative criterion to be used with some caution.

No. 1 folds are rather easily distinguished from No. 2 folds: (1) their hinges are sharp, almost angular, rather than round; (2) they have ubiquitous, strongly developed, axial plane foliation; (3) crinkly lineation parallels the fold crest. Not all the criteria for recognition of a particular type of fold will be found in one outcrop.

The augen in augen gneiss exhibit a linear arrangement of their long axes, probably formed at the time of augen growth.
This arrangement can be seen only in exposures parallel to the foliation (rare). The bearing and plunge of this lineation change rather rapidly over short distances. Hornblende grains in amphibolite similarly may have strong preferred orientation. In the few places where augen and hornblende orientation could be compared to nearby lineations, they were found to parallel crinkly lineation. Such crinkly lineation is parallel to the axes of the No. 1 folds.

Figure 32 illustrates an outcrop in which a No. 2 fold with an axial plane granitic stringer occurs in combination with crinkly lineation. It will be observed that the crinkly lineation is not parallel to the crest of the No. 2 fold, but rather lies across it at a low angle, about 15°. Observation of the bearing of the crinkly lineation on either limb of the No. 2 fold shows that the bearing is different on each limb and that the crinkly lineation has therefore been folded during the development of the No. 2 fold. Crinkly lineation is not everywhere exposed, but is etched into relief by weathering on favorable foliation surfaces. In the microscope, no trace of it can be seen, even in rocks in which it is most strongly developed. Presumably, subsequent metamorphic recrystallization has annealed mineralogic evidence of such crinkly lineation. In Figure 33, the relationship of crinkly lineation to two sets of intersecting folds is shown. The two sets of folds, both bearing differently from the crinkly linea-
tion, intersect at a low angle so that the one causes troughs and swells along the crests of the other, creating wave-interference effects. Where the two sets of intersecting folds are developed in about equal strength, as shown in Figure 33, the outcrop appearance is rather complex. Wave-interference forms characterize broken, weathered rock over the entire Elk City region.

Figure 34 shows in one picture all three structures seen in the last two illustrations. Three lineations are present in the outcrop, all plunging southerly. Crinkly lineation bears about N 15° W, the No. 2 fold axes bear about north-south, and the third set of folds (in the right hand side of the picture) bears about N 15° E. Crinkly lineation (parallel to No. 1 fold axes) is folded by both sets of folds. Very thin granitic stringers parallel to the No. 2 axial plane direction are gently folded by the northeast-bearing folds, hereafter to be called No. 3 folds.

Recllct folds

The granitic rock in places encloses earlier structures. A particularly well-developed example (Fig. 35) occurs in lower Tenmile Creek. It differs from the ordinary inclusions in that the inclusion is not bounded by sharp borders as is the one, say, in Figure 30. The form of a tight isoclinal fold with axial plane foliation parallel to foliation in the country rock is present in granitic rock, outlined by thin zones of biotite grains. It fades out gradually into the granitic rock. Granitic rock, similar in appearance and composition to that outside, also occupies the interior portion of the fold between the biotite grain layers.
FIG. 20

Differential folding of granitic stringers in biotite gneiss in closely adjacent layers.

FIG. 21

Folded granitic stringer in gneiss with largely planar foliation. The dark streaks inside the stringer are concentrations of coarse biotite. Upper Red Horse Creek. Sketch from field notes.

FIG. 22

Vertical face in biotite gneiss along the South Fork of the Clearwater River near Moose Creek. Both foliation and a granitic stringer are folded in this fold. The axes of the drag folds are parallel to the axis of the larger fold, and the drag folds on each limb have the correct movement sense with respect to the fold as a whole. The geometric form of the drag folds is similar to that of the larger fold. Sketch from field notes.

FIG. 23

Rolled fold crest in biotite gneiss. The fold crest in the granitic stringer has been rotated much as a porphyroblast.
Fig. 20

Fig. 21

SW

NE

Quartz monzonitic stringer

Coarsely foliated biotite gneiss

1 ft

Fig. 22

1 ft

Fig. 23

Folded foliation

Biotite gneiss

Granitic stringer
If the biotite grains were to be removed, the fold would not be visible.

**Combination folds**

A combination fold involving both a No. 1 and a No. 2 fold is shown in Figure 36. The No. 1 fold, folded compositional layering or folded s1, has strongly developed axial plane foliation (a2). The axial plane foliation has been refolded to make a No. 2 fold. Outcrops showing this structural relationship are relatively rare.

**Boudinage structure**

Boudinage structure is not common. Figure 37 illustrates one variety of boudinage structure that is perhaps most common. A granitic sill has been stretched subsequent to its formation. The few boudins well enough exposed that their orientation could be measured, have their long dimension parallel to the axes of nearby No. 2 folds. Figure 38 shows a boudin of augen gneiss in biotite quartzite with thin inclusions of biotite quartzite. The thin inclusions are planar and parallel to the main foliation.

**GENTLE FOLDS**

In many outcrops, the foliation is folded by relatively gentle folds that do not meet the criteria for No. 2 folds. Where they occur in combination with No. 2 folds, they invariably have a different bearing and plunge. In Figure 39 is a No. 2 fold that is overturned to the southwest at about 60° and that bears about N 30° W. It lies on the crest of a gentle fold that has a vertical axial plane and that bears about N 15° W. The tightly compressed fold on the left limb has the wrong direction of transport with respect to the gentle fold. Gentle folds of this sort are called No. 3 folds (see also Fig. 34).

Where circumstances are favorable (Fig. 40), the No. 3 folds are expressed as folds of the No. 2 axial planes. This may lead to rather complex-appearing structures (Fig. 41). Drag folds related to the No. 2 folds may be warped into new orientations on the limbs of No. 3 folds. Then they appear to go the "wrong" way; they have the wrong direction of transport with respect to the fold in which they at present occur (Fig. 42). Further, the axes of the drag folds bear differently from the axis of the larger fold with which they are associated. In a few favorable places (Fig. 43), folded No. 1 and No. 2 axial planes are exposed in the same outcrop. In a very few outcrops (Fig. 44), structures relating to all three fold sets can be seen. Axial plane foliation is warped by No. 2 folds that have a particular orientation and by No. 3 folds that have a different orientation from the No. 2 folds.

In summary, the criteria used in recognition of No. 3 folds for mapping purposes are that (1) these folds are relatively gentle; (2) drag folds on the flanks have both the wrong direction
FIG. 24

Granitic stringer in biotite gneiss in lower Legget Creek. Sketched from a color photograph.

FIG. 25

Folded granitic stringer in biotite quartzite on Anderson Butte. The tight folds in the quartzite have axial plane foliation. Both sets of folds plunge obliquely into the face, but the plunge of neither could be measured. Sketch from field notes.

FIG. 26

Folded foliation in biotite gneiss with a granitic stringer along the axial plane of the fold. Note the concentration of biotite in a thin zone along the borders of the granitic stringer.

FIG. 27

Granitic rock in biotite gneiss in lower Ten-mile Creek. Weak development of granitic stringers along the axial plane direction has occurred during the formation of granitic rock in this fold crest. Sketched from a color photograph.
Fig. 24

Granitic stringer

Biotite gneiss

1 ft

Fig. 25

Granitic stringer

Compositional layering—axial plane foliation is present but not shown.

1 ft

Fig. 26

Fig. 27

Granitic rock

Biotite gneiss

1 ft
of transport with respect to the main fold, and different geometry from that of the large fold; (3) in combination with No. 2 folds, their axes bear and plunge differently; (4) axes of drag folds are not parallel to the axis of the large fold; (5) these folds warp axial planes (and axial plane dikes) of No. 2 folds; (6) they fold foliation; (7) an axial zone of axial plane foliation or an axial plane dike is absent (a negative criterion to be used with considerable caution).

CROSS FOLDS

In sections parallel to the fold axes so far described, a cross-folding is visible. Figure 50 shows the only example of this thus far encountered. It is not known whether the rarity of such folds is caused by lack of favorable exposures, failure to search closely for this kind of structure, or whether the structure is uncommon.

MICROCHEVRON FOLDS

In scattered outcrops, a lineation is present that looks very much like the crinkly or No. 1 lineation. However, close examination with a hand lens shows that this structure consists of microscopic (one or two millimeter wave length and amplitude) chevron folds. Thin section study shows that these are cataclastic shear folds. In two outcrops where microchevron folds were found in combination with No. 1 folds, they have there a different orientation from that of the No. 1 folds. Some caution is necessary in mapping to avoid confusing these two types of lineation.

COMPILED STRUCTURAL DATA

Figure 52 illustrates the distribution and orientation of No. 1 fold axes measured in the Elk City region. This diagram shows that the bearing and plunge of No. 1 axes change rapidly from place to place. Figures 53 and 54 illustrate the distribution and orientation of No. 2 and No. 3 axes respectively. No. 2 fold axes are, at least locally, more constant in bearing and plunge than are the No. 1 fold axes. No. 3 fold axes, on the other hand, exhibit greater variation in bearing and plunge than either the No. 1 or the No. 2 fold axes. The reason for this is not understood. Perhaps further work may reveal another set of fold axes.

In Figure 54, the 26 No. 1 fold axes that were measured were plotted on the Schmidt stereonet. This diagram is a bdiagram (Fairbairn, 1949, p. 194, a point diagram of fold axes). The fold axes are distributed over the whole map area. In view of the rather broad area covered, the preferred orientation of these axes is fairly strong. They bear predominantly northwesterly and
FIG. 28
Granitic rock in biotite gneiss in lower Tenmile Creek. It is partly concordant and partly cross-cutting. Sketched from a color photograph.

FIG. 29
Gneiss traversed by a granitic sill with a cross-cutting offshoot. Elongate inclusions of gneiss have foliation parallel to that in the country rock and are non-rotated. The granitic rock has a weak foliation parallel to that in the country rock. The exposure is nearly vertical to the strike of the gneiss and is on the south side of Red River. Sketch from field notes.

FIG. 30
Augen gneiss near Pilot Knob cut by irregular granitic rock. The granitic rock has a weak foliation generally parallel to that in the augen gneiss, except for restricted cross-cutting shear zones as in the upper left hand part of the sketch, in which foliation is parallel to the wall of the shear. Sketched from a color photograph.

FIG. 31
Folded foliation in biotite quartzite near Rabbit Creek on the highway along the South Fork of the Clearwater River. Note the granitic stringer along the axial plane of the fold. Note also the fine crinkly lineation that cuts across the axis of the fold; this lineation is folded by the large fold.
plunge both northerly and southerly in about equal numbers. So few of these axes were mapped that it seemed unnecessary to contour the diagram.

The 87 No. 2-fold axes that were measured were plotted and contoured on the Schmidt stereonet. The larger number of the axes bear about N $10^\circ$ W with north-plunging and south-plunging axes about equal in number. It will be observed that the axes statistically form a partial girdle inclined to the east (Fig. 55).

The 25 No. 3-fold axes that were measured were also plotted on the Schmidt stereonet (Fig. 56). While south-plunging axes are fairly strongly aligned at about S $15^\circ$ E, north-plunging axes exhibit virtually no preferred orientation, or if a preferred orientation is present, it cannot be detected through plotting the few axes that were found.

Figure 57 is a stereogram showing the relation among the three sets of fold axes exposed in one outcrop. Although they are not far from parallel, they have distinctly different orientations. Similar relations obtain in every outcrop in which two or more lineations are present.

Figure 58 is a modified beta-diagram. Beta-diagrams were defined by Sander (1942, cited in Fairbairn, 1949, p. 194). The modified beta-diagram employed here is a contoured plot of poles to the foliation and corresponds to the $\tau$-diagram of Weiss and McIntyre (1957, p. 587). Poles to the foliation have been plotted for the 189 attitudes measured on foliation over the entire map area. Poles to the foliation form a broad northeast-trending vertical girdle with a pronounced maximum of poles plunging at about $45^\circ$ southwesterly. The beta-axis lies at about N $20^\circ$ W. A beta-axis is a statistical axis of folding—a horizontal axis approximately normal to the principal stress. A modified beta-diagram on fifty-two poles to the axial planes of the No. 2 folds shows a northeast-trending partial girdle with a maximum of poles plunging along west-southwest. The beta-axis lies at about N $20^\circ$ W (Fig. 59).

THE GEOLOGIC MAP

A first glance at the geologic map (Fig. 2) yields the impression of broad northwest-trending belts of rock. Biotite gneiss is predominant, granodiorite and quartzite roughly equal in amount, and augen gneiss subordinate. Strikes and dips on foliation are not generally parallel to the trend of the outcrop belt; rather they are widely variable, ranging from northwesterly to northeasterly.

The blank areas are those that, for lack of time, were not traversed in this investigation. The large granodiorite masses lie in outcrop belts roughly parallel to the outcrop belts of
FIG. 32

Intersecting drag folds causing wave interference effects; "hills" and "valleys" along the bearing of a particular set of folds. A crinkly lineation cuts across both of the intersecting fold directions and is folded by both.

FIG. 33

An exposure of biotite quartzite near Rabbit Creek on the highway along the South Fork of the Clearwater River. A crinkly lineation that appears as very fine striations (in the picture) on the foliation planes is folded by both sets of folds present. The larger fold (with the man at its base) has a granitic stringer along its axial plane. The smaller folds (seen in the right hand side of the picture) also fold the larger folds, creating wave interference effects. The axes of the two sets of folds plunge differently from each other and from the crinkly lineation.

FIG. 34

Partly cross-cutting, partly concordant granitic rock in biotite gneiss in lower Tenmile Creek. A relict tight isoclinal fold is preserved in the granitic rock. It has axial plane foliation and is visible largely because of thin zones of biotite grains. Sketched from a color photograph.

FIG. 35

Horizontal outcrop surface in upper Pilot Creek. The gentler fold plunges vertically. The plunge of the tight isoclinal folds of the compositional layering could not be measured. Orientation of biotite flakes, parallel to the axial planes of the isoclinal folds, is shown diagrammatically. The foliation strikes northeasterly. Sketch from field notes.
gneiss and quartzite. The extensive quartzite on the west side of the area is a rather pure, white variety, whereas the quartzite on the east side of the area is dark colored and high in biotite.

Structural relations do not appear to make much sense. A large tight isoclinal fold (No. 1) may exist in the Deadwood Creek-Elk City-Red Horse Creek area, as suggested by the convergence of outcrop belts. Although most outcrop belts are continuous, certain ones are not. South of Elk City, for instance, a thick biotite gneiss unit strikes directly toward a thick augen gneiss unit in Relief Creek. Just to the west, a thick augen gneiss unit strikes directly toward a thick biotite gneiss unit in Relief Creek. Shenon and Reed (1934a) emphasize transitional relations of these rocks along strike. The present investigation has produced no evidence either to support or to deny this transition. A very thick quartzite unit extends from Wigwam Creek to Flint Creek, a distance of about seven miles. No doubt much thickened by folding, this unit's present width across average strike is about 16,000 feet. Three miles beyond Flint Creek, in Limber Lake Creek, no quartzite occurs directly along strike. From evidence in hand, no decision can be made on the mode of disappearance of the quartzite, whether by transition into gneiss along strike, or by steep plunge of folds. One outcrop on Limber Lake Creek was observed in which No. 2 folds plunge 80° southerly, but it is so small that it is doubtful whether it is in place or is a float boulder. The complexity of the deformation of these rocks, as deduced from small-scale structures, no doubt explains the difficulty of interpreting and understanding the larger structures revealed by the geologic map.

In mapping the Tertiary basin gravels, considerable use was made of the air photos by employing the assumption of a relatively flat base for the travels. The contact lines drawn by photogeology were field checked at a number of places. In ridges capped by the Tertiary gravels, there is a change of slope at the contact. Also, the Tertiary rocks support evergreen trees of somewhat different appearance from those on the metamorphics.

STRUCTURAL CROSS-SECTIONS

In order to interpret the cross-sections (Fig. 3), it is helpful to study Figure 64, although this interpretation anticipates, in some degree, material in later pages. It will be observed that in No. 3 anticlines, axial planes of the No. 2 folds diverge in dip, whereas in No. 3 synclines, axial planes of the No. 2 folds converge in dip. The structural cross-sections are highly generalized and no doubt somewhat incorrect, partly because of the scarcity of outcrops and structural data, and partly because of the complexity of the structures. Figure 41 will give a further idea of the detail that should be present in some parts of the cross-sections. Apparent simplicity in a portion of a cross-section is probably a result of data shortage.
Fig. 40 Folded foliation and folded granitic stringers in lower Legget Creek. Note that the axial planes of the folds themselves have been folded. The exposure face is near vertical. The plunge could not be measured. Sketch from field notes.

Fig. 41 Large isoclinal fold of biotite schist in augen gneiss near Pilat Knob. Strongly developed axial plane foliation cuts across the compositional layering at a small angle. Superficially, in a small outcrop, it might appear that the foliation is parallel to the compositional layering. The outcrop is not far from horizontal, in the bottom of a small cirque. Sketch from field notes.
A fairly persistent anticline is present in the quartzite north of Golden. It may be of either No. 2 or No. 3 age. In the rocks east of Newsome Creek, a fairly persistent No. 3 anticline and a syncline appear to be present. In the vicinity of Elk City, another large No. 3 anticline and a No. 3 syncline appear to be present. A considerable number of No. 2 folds are present, as indicated by numerous drag folds. The cross-sections in their lack of detail do not permit delineation of any major No. 2 structures. The rapid changes in strike and dip of the No. 2 axial planes deserve note (Fig. 3).
FIG. 42

A vertical exposure in biotite gneiss along the South Fork of the Clearwater River. Small drag folds are shown in a larger gentle fold. The small drag folds are partly folded foliation and partly folded granitic stringers with incipient development of granitic material along the axial planes of the drag folds. The axes of the drag folds bear north-south and plunge 10° north whereas the axis of the larger gentle fold bears N 30° W and plunges 45° northerly. The drag fold on the right hand side of the larger fold has the wrong movement sense with respect to the larger fold, and the geometric form of the drag fold is different from that of the larger fold. Sketch from field notes.

FIG. 43

Structure exposed in biotite gneiss in a roadcut on the road between Legget Creek and the West Fork of Newsome Creek. The tighter fold has strong axial plane foliation, whereas the gentler fold consists of folded foliation. Note that the axial plane of the tighter fold has been deformed in the folding of the (axial plane) foliation. Note also that the axial plane of the gentler fold has itself been gently folded. The axis of the gentler fold bears N 45° E horizontal. Sketch from field notes.

FIG. 44

Thin granitic sills or stringers along foliation in biotite quartzite. Note concentration of biotite along edges of the granitic stringers.

FIG. 45

Pegmatite dike in biotite quartzite near Pilot Knob. Note that a biotite-rich layer in the upper part of the sketch is not offset by the pegmatite. Sketched from a color photograph.
PETROGRAPHY

MEGASCOPIC DESCRIPTION OF ROCKS

Outcrops are relatively scarce over much of the Elk City area. The best exposures are along the South Fork of the Clearwater River, where much of the highway is cut in solid rock, and along Red River and American River. Excellent exposures occur near Pilot Knob, in the northwestern part of the area. Fair exposures occur along the valley bottoms of the larger tributary streams to the South Fork of the Clearwater, American River, and Red River. Apart from these places, soil and forest cover are heavy so that exposures are rare to absent, and deeply weathered where they do occur. For example, one does not find exposures along the ridges or along the bottoms of the smaller creeks.

The granitic rocks and augen gneiss weather to rounded outcrops. Because of this rounding, it is generally difficult to get attitudes on augen gneiss. The granitic rocks weather to a smooth, clean, gray surface, with a few protuberances caused by large feldspar grains. Augen gneiss weathers to a rather rough, grainy, gray surface with a weak parallel alignment of biotite grains and large, lenticular feldspar grains. In hand specimen, the granitic rocks are different shades of gray, even-grained, medium-grained, and commonly, weakly foliated. Augen gneiss is gray, coarse-grained, and weakly to moderately foliated with parallel biotite and lenticular feldspar grains. Pegmatite has about the same characteristics as have granitic rocks, except that it is much coarser grained.

Because of their relatively strong foliation, biotite gneiss and biotite quartzite weather to gray, strongly angular outcrops. Weathered surfaces are clean, dark to light gray, and generally devoid of moss, except on north-facing exposures in narrow, heavily forested gullies. Biotite gneiss outcrops are generally massive whereas biotite quartzite weathers to a more slabby structure. In hand specimen as well as in outcrop, biotite gneiss has the appearance of very strong foliation because its thin dark layers, rich in biotite, contrast strongly with thin light layers, rich in quartz and dull white feldspar. Biotite quartzite, although fairly strongly foliated, appears to be less foliated than biotite gneiss, and is fairly uniform in appearance. Hand lens examination shows a preponderance of clear gray quartz over mica and feldspar. Because all mineralogic transitions from biotite quartzite to biotite gneiss occur, one finds all textural gradations in hand specimen from biotite quartzite to biotite gneiss.

Pure, white quartzites weather to massive outcrops. In hand specimen, white quartzite has a markedly vitreous appearance and appears to be completely non-foliated. If minor amounts of mica are present, then the rock is moderately foliated. Amphibolite weathers to rounded, massive, rather rough-textured, black
FIG. 46

Non-folded cross-cutting intrusive (dike) with a small xenolith of gneiss partly rotated into the interior of the dike. Sketched from a color photograph.

FIG. 47

Intrusive unfolded granitic dikes cutting folded granitic stringers in folded foliation. Note that dilation offset is present. Lower Legget Creek. Sketched from a color photograph.

FIG. 48

A high-angle granitic dike with an internal foliation parallel to its walls. A later pegmatite has formed inside the dike. The biotite gneiss xenoliths are not visibly rotated. Bending of foliation at the contact probably indicates that the dike was emplaced along a shear zone. This occurrence is near Newsome Creek, along the South Fork of the Clearwater River. Sketch from field notes.

FIG. 49

A section in biotite gneiss parallel to the axial direction of tightly folded foliation. Differential folding in moderate degree has occurred.
outcrops from which it is difficult or impossible to get an attitude on foliation. In hand specimen, amphibolite is dark-gray to black and moderately to strongly foliated and/or lineated. More or less biotite may be present in addition to hornblende and plagioclase. Lime-silicate rocks weather to a dull greenish, strongly pitted surface caused by the relatively rapid corrosion of garnet contrasted to corrosion of epidote and diopside. Andesite weathers to a dark-green to dull black, very smooth surface with small shallow pits where feldspar phenocrysts have been etched out by weathering.

MICROSCOPIC ROCK DESCRIPTION

In this section, the major rock types are described separately, with detailed descriptions of each of the major minerals. Emphasis is placed on the textural relations.

Biotite gneiss

In biotite gneiss, most of the minerals are about the same size, one to two mm, the average diameter. Average biotite gneiss has perhaps 20-30 percent each of quartz, potassium feldspar, plagioclase, and mica. Other minerals comprise only a few percent of the rock.

Quartz is rather irregular xenoblastic in habit and has undulatory extinction in many rocks. Less commonly, mortar zones may be present.

Plagioclase in most biotite gneisses lies in the composition range An23 to An31. One rock has plagioclase with composition An6. Against potassium feldspar, plagioclase is partly myrmekitic and has thin oligoclase (An13-15) rims a few microns thick. Plagioclase includes small quartz grains, biotite grains parallel both to $s_2$ and to $s_3$, muscovite grains, and it also partly replaces both biotite and muscovite grains. Grains of plagioclase are locally sheared and bent.

Microcline and untwinned potassium feldspar (submicroscopic-ally twinned microcline? orthoclase?) occur together in irregular, ill-defined intergrowths or separately, in different rocks. Both varieties of potassium feldspar have the same textural relations to other minerals. They include biotite and muscovite oriented parallel both to $s_2$ and to $s_3$, quartz, hornblende, sphene, plagioclase, apatite, ilmenite, and zircon. Both are non-micropertithic to weakly micropertithic. Locally, microcline replaces plagioclase, forming intricate intergrowths. Both microcline and orthoclase partly replace oriented mica grains. Certain gneisses are completely devoid of potassium feldspar.

Biotite is strongly aligned parallel to $s_2$ and less strongly aligned parallel to $s_3$. It is commonly arranged in fold patterns (folded $s_2$) with axial plane biotite present also ($s_3$). In some
rocks it forms very good polygonal arcs that consist of a number of closely spaced mica grains arranged in a well-defined microfold in which individual grains are not bent, but rather have unbroken crystal form. Polygonal arcs indicate simultaneous folding and recrystallization (Misch, personal communication, 1952). Biotite is locally bent into tiny cataclastic microfolds.

Muscovite is partly parallel to the biotite trends and partly transverse to them. The transverse grains have no preferred orientation as far as can be seen without a statistical study of grain orientation. Muscovite includes fibrolite that is arranged in tiny isoclinal fold patterns with axial planes parallel to \( \sigma_2 \); some fibrolite is parallel to \( \sigma_3 \). The transverse muscovite includes oriented biotite and muscovite, both \( \sigma_2 \) and \( \sigma_3 \). Muscovite grains locally are cataclastically bent. Fibrolite occurs in scattered, irregular clusters and microfolds, associated with and included in muscovite. These may have formed when muscovite replaced biotite. Sillimanite occurs but rarely in these rocks. Garnet occurs as scattered, small, xenoblastic, inclusion-free grains. Epidote occurs as discrete, xenoblastic, moderately pleochroic grains that appear to belong to the main mineral assemblage rather than to be plagioclase alteration products. Green hornblende is rare in biotite gneiss, occurring in small amounts in only one rock studied. Hornblende grains are aligned parallel to the foliation but are not themselves parallel within the foliation.

Accessory minerals identified include magnetite, zircon, apatite, monazite, sphene, allanite, ilmenite, ilmenite rimmed by sphene, thorite, and tourmaline (schorlomite). Alteration products identified include hematite and goethite after magnetite; clay minerals after microcline, orthoclase, and plagioclase; pennine after biotite; epidote after plagioclase and hornblende; and calcite (hydrothermal?).

Thorite that occurs in minor amounts in biotite gneiss deserves special mention. The thorite is closely associated with magnetite. Both appear to replace biotite and perhaps to be contemporaneous with plagioclase.

**Biotite quartzite**

Biotite quartzite is fairly even-grained, most minerals having diameters of one or two mm. Quartz is by far predominant. It is irregular xenoblastic and, in various rocks, exhibits different degrees of cataclasis; weak to strong undulatory extinction, sutured quartz grains, mortar zones, and microbreccia. Locally, it is almost completely mylonitized.

Plagioclase lies mostly in the range of composition from An18 to An30 and has albite rims against potassium feldspar. One rock studied has plagioclase of composition An4 with virtually pure albite rims against potassium feldspar. Xenoblastic plagioclase includes quartz and mica and is partly myrmekitic adjacent
Fig. 50 Composite sketch to illustrate structure exposed in biotite gneiss in lower Legget Creek. The outcrop face is about ten feet high and nearly vertical to the strike. Note that the two drag folds developed through folding of the foliation have different movement sense, differently oriented axial planes, differently oriented axes, and different geometric form. The tight isoclinal folds are still different from the other two. Sketch from field notes.

Fig. 51 Stereogram to show formation of granitic stringers along shears conjugate to the No. 2 axial plane direction.
to potassium feldspar. In certain rocks, the grains are strongly bent and sheared. Generally present only in small amounts, it does not occur in some quartzites.

Non-microperthitic to weakly microperthitic, irregular, microcline-untwinned potassium feldspar intergrowths; or microcline; or untwinned potassium feldspar alone, occur in minor amounts as a sort of meshwork among the quartz grains, suggestive of replacement. Potassium feldspar does not occur in certain quartzites, and some quartzites have no feldspar at all. Both microcline and untwinned potassium feldspar appear to include and to replace quartz, biotite, plagioclase, and muscovite. In certain rocks, potassium feldspar has been cataclastically sheared and broken.

Biotite is moderately well-aligned parallel to $s_2$, less well aligned parallel to $s_3$, and small in amount in all quartzites. Some have no biotite; some others have no mica. Muscovite, generally minor in amount and moderately well-aligned, is absent in many quartzites. Aligned principally in the $s_3$ direction, it has only a weak preferred orientation parallel to $s_2$. It replaces, cuts across, and includes biotite. Transverse muscovite cuts randomly across both $s_2$ and $s_3$.

Accessory minerals identified in biotite quartzite are thorite, rutile, zircon, apatite, magnetite, zoisite, garnet, tourmaline, epidote, ilmenite, and allanite, all relatively rare. Alteration products identified are clay after the feldspars, sericite after plagioclase and pennine after biotite, and hematite and goethite after magnetite.

Augen gneiss

Augen gneiss has a bulk composition like that of quartz monzonite, with an average grain size of one to two mm. except for augen, which occur either as lenticular grains from four to eight cm. across or as lenticular clusters of grains in which individual grains are one-half to one cm. in diameter. Quartz is irregular xenoblastic and has undulatory extinction in some rocks. Plagioclase, in the composition range An25 to An29, has thin oligoclase rims against microcline. Also xenoblastic, plagioclase encloses small, oriented biotite grains and is myrmekitic against microcline.

Microcline is non-microperthitic and encloses small, strongly-altered, plagioclase grains, oriented biotite flakes, and quartz. Biotite exhibits a fair alignment parallel to $s_2$, although a few transverse ($s_3$?) grains are present. Amoeba-shaped grains of muscovite in optical continuity cut across microcline grains of different optical orientations. Some muscovite parallels $s_2$, but most of it is transverse and may be parallel to $s_3$. It replaces and includes biotite. Accessory minerals identified are magnetite, ilmenite, zircon, apatite, pyrite, and allanite. Alteration products identified are sericite after
plagioclase, clay after plagioclase and microcline, pennine and epidote after biotite, and hematite after magnetite.

**Granitic rocks**

The granitic rocks in the folded granitic stringers and in the axial plane dikes of the No. 2 folds have petrographic features and relationships distinctly different from those of the granitic rocks in dikes showing dilation offset. The term "granitic rock" is used throughout this report with only descriptive significance. Included in the term are light-colored, quartzose-feldspathic, medium- to coarse-grained, and homogeneous rocks that may be of broad compositional variation and diverse origins. These rocks are of somewhat coarser grain than the biotite gneisses, lying mostly in the range from two to three mm. They are not far from average biotite gneiss in composition, containing 30-40 percent of each of the major minerals. Biotite content, however, is very much lower in the granitic rocks than in the biotite gneisses, so that many of the granitic rocks should really be called leucogranitic rocks. Apart from the lower mica content, the granitic rocks are mineralogically and texturally similar to the biotite gneisses that they traverse. Only garnet, present in the biotite gneiss, does not occur in the granitic stringers.

Irregular xenoblastic, quartz in the granitic rocks has locally undulatory extinction, sutured grain boundaries, and minor mortar zones. Based on estimation of volume percent, quartz is rather more abundant in the granitic stringers cutting biotite quartzite than in those cutting biotite gneiss.

The plagioclase in those granitic stringers thus far studied lies in the composition range An23 to An29. Through use of the a-normal method for plagioclase identification (Winchell, 1951, p. 285), the plagioclase composition was found to correspond closely to the plagioclase composition in the adjacent biotite gneiss. In a rock in which plagioclase in the biotite gneiss is An24, the plagioclase in the granitic stringer is An24. Where the plagioclase in the biotite gneiss is An27, the plagioclase in the granitic stringer is An27. Grain habit is xenoblastic; the plagioclase grains in the granitic stringers have the same texture as the plagioclase grains in the adjacent biotite gneiss. Plagioclase may be the only feldspar present in the granitic stringer, which has then the composition of quartz diorite. In the adjacent biotite gneiss as well, plagioclase is the only feldspar present. Plagioclase in the granitic stringers has thin albic (An9-11) rims against microcline. Plagioclase includes intricate fibrolite microfolds that have their axial planes parallel to z2. Two plagioclase grains in one granitic stringer show what seems to be a rather significant relationship. Xenoblastic plagioclase of composition An24 includes and is in crystallographic continuity with a smaller plagioclase grain of composition An29. Plagioclase in the country rock is also An29. The grain of An29 has a thin, sharply defined rim of An24 against the including An24, then an inner, less well-defined zone of An34 against the outer rim of
Fig. 52—LINEATION MAP SHOWING ORIENTATION OF
No. 1 FOLD AXES, ELK CITY REGION, IDAHO.

Bearing & plunge of No. 1 lineation (fold axes)

Bearing of horizontal No. 1 lineation (fold axes)
An₂⁶, then the relatively large homogeneous inner core of An₂⁶. These relations are interpreted as evidence for two generations of plagioclase. The An₄₄ has an albite rim against microcline.

Microcline may be totally absent, about equal to plagioclase in amount, or predominant over plagioclase. The feldspar ratio in the granitic stringers appears to correspond rather closely to that in the country rock: where the biotite gneiss is quartz monzonitic, the granitic stringer is quartz monzonitic; where the biotite gneiss is granitic, the granitic stringer has the composition of granite. Microcline in the granitic stringers tends generally to be coarser-grained than in the country rock. It is xenoblastic and weakly microperthitic to non-microperthitic. It includes fibrolite clusters arranged in tiny microfolds that have their axial planes parallel to a3. Large microcline grains enclosing clusters of smaller microcline grains of different orientations as well as patchy, sericitized, plagioclase grains, may be indicative of two generations of microcline. Unzoned potassium feldspar was not observed in any of the granitic stringers.

Biotite in the granitic stringers is in small amounts and is mostly aligned parallel to a2, but not so strongly as in the biotite gneiss. Where concentrated in the biotite gneiss along the edges of granitic sills, it also is aligned parallel to a2. One thin section studied contains a continuous granitic stringer that is a small sill in one part and passes into an axial plane dike in the other part. In the sill part, the stringer includes biotite oriented parallel to a2. In the dike part, it includes biotite oriented parallel both to a2 and to a3. Biotite concentrated along the edges of the granitic stringers in adjacent biotite gneiss is oriented in the same way.

Muscovite is absent or present in only small amounts. It is coarser-grained than in adjacent biotite gneiss, includes and partly replaces biotite, and is partly transverse, but mostly parallel to a2.

Accessories identified are apatite, zircon, magnetite, epidote, tourmaline, allanite, and thorite. The accessories in each granitic rock seem to be about the same as those in adjacent biotite gneiss, but in lesser amounts. Only thorite is more abundant in the granitic rocks than in the biotite gneiss. Alteration products identified are sericite after plagioclase and clay after plagioclase and microcline.

**Quartz diorite**

Quartz diorite dike rock has a fairly strong internal parallelism of euhedral andesine laths that exhibit strong normal zoning. Hornblende, quartz, and minor biotite and microcline make up the balance of the rock. Accessories, in small amounts, are zircon, sphene, apatite, and epidote. Granodiorite dike rock that exhibits dilation offset and no folding in rather similar in appearance and mineralogy to the quartz diorite. It contains more microcline, but plagioclase orientation is not so well developed.
Amphibolite

Amphibolite is rather variable in composition, ranging from virtually pure hornblendite to normal amphibolite containing roughly equal amounts of hornblende and plagioclase. Hornblende is strongly to weakly aligned, parallel, so far as was observed, to the No. 1 lineation. Plagioclase is xenoblastic and, in the rocks studied, lies in the composition range An35 to An59. Small amounts of quartz and biotite are present in some amphibolites. Accessories of magnetite, apatite, and sphene aggregate in tiny lenticular grains scattered randomly throughout the rock. Alteration products are leucoxene after sphene, hematite after magnetite, pennine along shear zones in hornblende, and epidote (rare) after plagioclase. Plagioclase is locally bent and microfaulted.

Phyllite (Phyllonite?)

A phyllite was discovered in one outcrop in the northeasternmost part of the area, interlayered concordantly with biotite gneiss. Almost certainly some sort of a diaphtorite, retrogressive after biotite gneiss, it exhibits certain puzzling features that cannot at present be reconciled with the other rocks. The minerals present are clinochlore, sericite, muscovite, and quartz. Clinochlore and sericite, which are predominant, are deformed in very tight microfolds (folded foliation). What is puzzling is that fold crests are included in large, non-oriented, undeformed, muscovite grains. Do the sericite and clinochlore represent selective alteration of biotite enclosed in muscovite? Or have the clinochlore and sericite really persisted as bent grains while the muscovite grew? Data in hand are not adequate to answer these questions. This rock must be regarded as a unique exception to the paragenetic scheme proposed in following pages.

Partly phyllonitic zones are sub-parallel or parallel to foliation in large volumes of rock throughout the district. In thin section, lenticular phyllonitic zones are seen arranged en echelon, connected by relatively thin microshear zones. Within the phyllonitic zones, muscovite and biotite are bent into microfolds, and plagioclase is sheared and locally bent. Abundant sericite and pennine have formed, so that each little lens is really a diaphtorite included in the body of the biotite gneiss. This deformation (cooler epizone) has taken place roughly parallel to the foliation and probably correlates with the microchevron folding, in which deformation has occurred across existing foliation and in which considerable sericite and chlorite have also formed along the microshears that give rise to the microchevron folds.

Andesite

Two northeast-trending, vertical, andesite dikes were found in mapping. The andesite is holocrystalline and contains hornblende, sericite aggregates after plagioclase(?7) phenocrysts, tiny laths of trachytic groundmass plagioclase, minor chlorite, and apatite. It is weakly amygdaloidal; the vesicles are filled with quartz.
Fig. 53 - Lineation map showing orientation of No. 2 fold axes, Elk City region, Idaho.

- Bearing & plunge of No. 2 lineation (fold axes)
- Bearing of horizontal No. 2 lineation (fold axes)
- Vertical No. 2 lineation
TENTATIVE SILICATE PARAGENESIS

The following interpretation of paragenesis is considered to have the highest degree of probability. The \( s_2 \) foliation direction, the \( s_3 \) foliation direction, non-oriented muscovite, and low-temperature minerals are useful reference points, points to which one may attempt texturally to refer the other minerals in the rock, as regards their time or times of crystallization. In this fashion, the paragenesis can be deduced more or less independently of external considerations.

**Early:** Biotite No. 1—parallel to \( s_2 \).
- Quartz
- Rutile
- Sillimanite (rare, mostly fibrolite)
- Magnetite No. 1
- Zircon
- Apatite
- Plagioclase No. 1--based on inclusions of more calcic plagioclase in more sodic plagioclase. This relation is found only in the granitic stringers.
- Microcline No. 1--based on a few small grains of microcline included in larger grains of microcline. Cut by muscovite. These relations occur in the granitic stringers and in augen gneiss respectively.
- Hornblende
- Labradorite
- Sphene
- Ilmenite

**Early intermediate:** Biotite No. 2—parallel to \( s_3 \).

- Plagioclase No. 2--definitely formed in the granitic stringers at this time, and perhaps in the biotite gneiss in part.
- Microcline No. 2--definitely formed in the granitic stringers at this time. Includes oriented muscovite. Microcline is probably a little later than plagioclase.
- Muscovite No. 1--partly parallel to \( s_2 \), partly parallel to \( s_3 \).
- Magnetite No. 2--definitely grew in parts of the rock at this time in association with thorite. It replaces biotite.
- Thorite—associated with magnetite No. 2 in schist, occurs also as an accessory mineral in granitic stringers that formed at this time.
- Tourmaline—associated with granitic rocks that formed at this time.
Later intermediate:

Muscovite No. 2—non-oriented.
Epidote—may have grown at this time. Evidence not available so far.
Allanite—partly associated with epidote and may have grown at the same time.

Late:

Sericite—after feldspars, mica.
Clay—after feldspars.
Chlorite—after biotite, hornblende.
Hematite—after magnetite.
Epidote—after plagioclase.

Latest:

Cataclasis without production of associated low temperature minerals; bending of micas, albite twins in plagioclase, breaking of quartz.

QUARTZ DIAGRAMS

With the use of the universal stage in a preliminary examination of mineral grain orientation, one hundred quartz axes each were measured in oriented thin sections from the hinges of a No. 1 and a No. 2 fold. In the No. 1 fold (Fig. 60), the distribution of quartz axes is tentatively interpreted as two crossed partial girdles with triclinic symmetry. In the No. 2 fold (Fig. 61), the distribution of quartz axes is tentatively interpreted as three crossed girdles with triclinic symmetry. Figure 62 shows the relation of the quartz-axis diagram to the No. 1 fold, and Figure 63 shows the relation of the quartz-axis diagram to the No. 2 fold.
Fig. 54—LINEATION MAP SHOWING ORIENTATION OF NO. 3 FOLD AXES, ELK CITY REGION, IDAHO.

Bearing & plunge of No. 3 lineation (fold axes)

5 Miles
In order to bring forth a tentative but consistent interpretation of the complex structures present in the Elk City region, it has been necessary to employ a number of assumptions. The approach followed, at first intuitively, has been well described by Weiss and McIntyre (1957, p. 578) who employed it in much more detail than has been done in this study:

... \[\text{minor}\] structures are tentatively separated into distinct generations on the following grounds, without regard to the orogenic significance of the separate generations: (1) structures of similar style and with similar patterns of preferred orientation \(F\) are necessarily with the same directions of preferred orientation \(F\); (2) structures of consistently dissimilar style and with consistently dissimilar patterns of preferred orientation are ascribed to separate generations; and (3) where structures of one style and with one pattern of preferred orientation consistently overprint structures of another style and another pattern of preferred orientation, the former are considered to have formed later than the latter.

The first two assumptions have already been employed in the description of the structures in the Elk City region.

The presence of an axial plane foliation indicates an older, more or less tightly-folded, compositional layering of some sort. Such structure is implied in a figure drawn by Billings (1954, Fig. 284) and seems self-evident, but the presence of minor isoclinal drag folds with axial plane foliation (relating to an assumption to follow) has been overlooked or ignored in many areas of metamorphic rocks, where the foliation has been said to be bedding foliation. If such minor structures do not have the significance generally accorded to minor structures, namely that they reflect the major structures, it should be so stated. Fairbairn (1949, p. 239) describes axial plane foliation in detail:

Axial plane foliation is characterized by (1) foliation parallel to the axial plane of the folded beds, (2) uniform development of the foliation everywhere in beds of the same mineral composition \(F\) no distinction between development on the limbs and in crests and troughs \(F\), (3) uniform development of foliation on open and isoclinal folds, (4) development of new minerals, (5) a lineation parallel to the axial line of the folds \(F\) intersection line of foliation and bedding = plunge of fold \(F\).

The axial plane foliation in the rocks of the Elk City region meets all of these criteria, even the third one, probably because
all the folds that have axial plane foliation have the same intensity of development.

Divergent lineations (non-parallel) reflect different pulses of deformation. Billings (1954, p. 356) says:

"In general, the lineation is systematically related to the major structures, but this is not necessarily the case if the lineation is the result of stresses independent of those that produced the folding." Also, (p. 359), ". . . if the lineation is distinctly younger or older than the folding or thrusting, it may be incongrous to the major structure."

In any outcrop, the tightest folds are oldest and the less intense folds (of different geometry) are younger. This difference may apply only to the Elk City rocks and should be used cautiously, with the principles of Weiss and McIntyre well in mind.

If one lineation, parallel to one set of folds, is folded by another set of folds with its own lineation, then the folded set of lineation (and related folds) is the older (Sander, 1942, cited in Fairbairn, 1949, p. 179).

If the axial planes of a particular set of folds (in this case, the No. 2 folds) are all parallel after a pulse of deformation, then their present non-parallel configuration should mirror the effects of a subsequent pulse of deformation. Billings (1954, p. 34) says: "Over large parts of a folded belt the axial planes of many of the folds dip in the same direction." Carrying this one step further, if the axial planes are not parallel over even a small part of a folded belt, axial plane folding has probably occurred (term defined by Scotford, 1955).

If the drag folds go the "wrong" way in a fold—that is to say, if they have the incorrect direction of transport on one limb with respect to the fold as a whole, and if their axes do not parallel the axis of the major fold—then they are not related to that fold, but are related to different (generally older) folds. Particularly this is so when the drag folds consist of tightly folded foliation present on the limbs of a gentle fold in the foliation: the geometry of the two fold sets is different. One must of course have the caution emphasized by Fairbairn (1949, p. 160) well in mind during the examination of drag folds:

If the S-shapes of drag folds do have the reverse orientation, indicating relative movement . . . in the wrong sense, contemporaneity of origin no longer holds, and local shear folding, operating on an earlier flexure, is responsible for the structure. Most of the discrepancies and so-called "failures" of drag folds to indicate relative movement in accord with known major movement can be ascribed to lack of recognition of the shear folding mechanism.
Fig. 55 Plot of No. 1 fold axes on Schmidt stereonet. Twenty-six axes plotted on lower hemisphere.

Fig. 56 Contoured plot of No. 2 fold axes on Schmidt stereonet. Eighty-seven axes plotted on lower hemisphere.
Billings (1954, p. 78, 81, 83) makes some remarks in connection with drag folds that seem to deserve further emphasis through repetition here:

Ideally, the drag folds are systematically related to the major folds. . . . drag folds plunge in harmony with the major folds, and the axes of the drag folds are parallel to those of the major folds. Incongruous drag folds are those that are not systematically related to the major structure. . . . Incongruous drag folds may be present for several reasons. (1) The minor folds may form later than the major structure under very different stress conditions. (2) The minor folds may be the result of contemporaneous deformation, and thus be distinctly older than the major structure. (3) During a single period of orogeny, partly because of inhomogeneities in the rock and partly because they have been so tightly squeezed, the strata may shear past one another in directions other than that perpendicular to the fold axes. (4) Bain has suggested that under special conditions very plastic rocks may flow toward the center of a syncline, just as in hot weather, tar on a highway flows away from the crown of a road. The resulting folds are the opposite of drag folds.

The incongruous drag folds of the Elk City region do not seem readily explainable by any of the causes suggested by Billings and Fairbairn. To explain incongruous drag folds, perhaps another possible mechanism can now be advanced—the mechanism of multiple folding.

Further, the principle that minor structures reflect the major structure is used. DeSitter (1956, p. 68) says:

We have an enormous mass of facts, from observed microstructures, folds, and faults in rocks, which prove that reduction in size does not influence the shape of a fold at all. Any geologist will know, from his own experiences, exposures which show microstructures which are exact replicas, including many details, of major structures. . . .

Finally, it will be apparent that the author holds strongly with the conception that foliation is essentially a shear structure, that mica grains are oriented parallel to movement surfaces present during crystallization in a metamorphic rock, whatever the reason for the movement surfaces may be. Axial plane shear, renewed slip along an older foliation, and bedding plane slip are among the more common causes for movement surfaces in rocks undergoing metamorphism.
KINEMATIC HISTORY

A certain amount of what would ordinarily be called petrology is included in this section. To some, however, the metasomatic history of the rock, if metasomatic it be, is so much a part of the kinematic history that the author will risk the confusion of combining these elements.

It has doubtless become apparent that the author intends to propose that the Elk City rocks have been subjected to multiple folding and to three episodes of regional metamorphism prior to the emplacement of the Idaho batholith. Lindgren (1904, p. 23) was perhaps the first to propose a single regional metamorphism for these and related rocks, followed by Shenon and Reed (1934a, p. 15) and by Wilson (1937, p. 203).

Examples of multiple folding

Multiple folding is not rare (Billings, 1954, p. 50); a few examples may be cited briefly. Sutton and Watson (1950, p. 241) describe rocks in Scotland that have undergone two periods of folding. White and Billings (1951) describe twice-deformed rocks in New England. Holmes and Reynolds (1954, p. 417) have described double folding in rocks in Scotland in which the two sets of fold axes are at about right angles. Their work (p. 442) shows that the normal stratigraphic methods of unraveling structural history may be inapplicable to multiple-folded rocks. Osterwald (1955, p. 310) describes twice-deformed rocks in the northern Bighorns of Wyoming. King and Rast (1956, p. 185) describe twice-folded rocks in Scotland in which the two sets of folds are at about right angles. Weiss and McIntyre (1957, p. 575) describe the same sort of thing. Their admirable method of analysis probably will set the pattern for all subsequent field investigations into multiple folding. Ramsay (1958, p. 271) describes twice-folded rocks in Scotland in which the fold axes are at about 45°. In reading all these articles, and particularly the last, one is impressed by the similarity of the rocks and structures described to many of the rocks and structures found in the Elk City region. The principal difference between the former areas and the Elk City region is that in the Elk City rocks the successive axes of folding are at about 15° to one another, much closer to being parallel than those cited in the areas of the literature.

No. 1 folds

The tight isoclinal folds (No. 1 folds) of the Elk City region are assumed to be the oldest folds in the rock. Compositional layering, almost certainly sedimentary bedding, has been folded in the formation of these folds (Fig. 5 and 10). Strong axial plane foliation occurs in all such folds, indicating axial plane shear during their formation. $s_1$ (compositional layering) is more or less parallel, in most places, to $s_2$ (axial plane foliation), the most prominent and obvious foliation in the metamorphics. $s_1$ and $s_2$ are clearly not parallel on No. 1 fold hinges
Fig. 57 Plot of No. 3 fold axes on Schmidt stereonet. Twenty-five axes plotted on lower hemisphere.

Fig. 58 Stereogram to show relations of all three lineations in a representative outcrop. This is the Rabbit Creek exposure shown in Fig. 33.
and, at least where seen in outcrop, are several degrees away from parallelism at distances as far as 200 feet from a hinge (Fig. 11). Such folds, seen during reconnaissance, are well exposed on the east face of Buffalo Bump. In rocks low in mica, such axial plane foliation is very difficult or even impossible to see. Further, where subsequent deformation has been strong, as in the crestal portion of No. 2 folds (Fig. 13), the No. 1 folds are not visible.

Crinkly lineation, parallel to the axes of No. 1 folds, almost certainly formed at the same time as the No. 1 folds. Such crinkly lineation has been called No. 1 lineation even where it is present alone, without visible No. 1 folds in the rock. That crinkly lineation has been folded by both sets of intersecting folds supports the assumption that the No. 1 folds are the oldest.

The No. 1 folds were observed with amplitudes from half a millimeter (in thin section) to 200 feet. On the assumption that the small structures mirror the large structures, it is postulated that the oldest major structure in the rock consists of a series of tight isoclinal folds, folds so tight that the limbs are not far from parallel. Although it does not seem possible to decide whether they were overturned to the southwest or to the northeast, these folds must have been recumbent, because the foliation was horizontal or nearly so at the time of the No. 2 folding; hence the foliation was considered by Shenon and Reed (1934b, p. 14) to be bedding foliation.

Axes of the No. 1 folds bear northwest by southeast and, statistically, plunge about equally to the northwest and to the southeast (Fig. 54). As shown by the scatter in this diagram, their bearing and plunge exhibit considerable variation from place to place, which no doubt is to be ascribed to the later foldings.

Many of the biotite gneisses and quartzites are much more feldspathic than seems warranted by their supposed sedimentary origin, unless they were arkosic at the time of their deposition. Plagioclase alone comprises sixty percent or more of some gneisses. Certain quartzites are fifty percent feldspar. Petrographically, it was observed that both plagioclase and microcline in biotite gneiss, quartzite, and augen gneiss include biotite oriented parallel both to $s_2$ and to $s_3$. As described earlier, sodic plagioclase in certain granitic stringers replaces slightly more calcic plagioclase. This replacement is interpreted to mean two generations of plagioclase. The second generation of plagioclase seems clearly to be of No. 2 age. It seems likely then that the first generation of plagioclase is of No. 1 age, although at least in part later than biotite No. 1. Muscovite that formed in the No. 2 deformation replaced microcline in augen gneiss. Microcline in No. 2 granitic stringers encloses other microcline grains that are supposed to be older and therefore of No. 1 age. The summation of these data leads to the hypothesis of alkali metasomatism during the No. 1 folding and metamorphism, in which Beltian(?) sedimentary rocks were converted to feldspathic gneisses and to augen gneiss.
The augen gneisses appear certainly to have formed during the No. 1 period of alkali metasomatism, no doubt at the expense of either biotite gneiss or quartzite, and perhaps of both. Augen, so far as observed, have their long axes aligned parallel to the No. 1 lineation. The augen gneisses contain pytymatic granitic stringers, just as the gneisses and quartzites do. Finally, augen include biotite aligned parallel to $a_2$ and are in turn replaced by muscovite.

One major amphibolite body lies within the map area, northeast of Elk City (Fig. 2). Its structural form may be not nearly so simple as shown on the map, because the contacts are interpolated under heavy forest cover between the outcrops in the stream bottoms. Attitudes on foliation within the body are not parallel to its average strike. Because it parallels roughly the attitudes on foliation in the surrounding rock and parallels the regional trend, it is considered to be a sill. As Shenon and Reed (1934a, p. 13) point out: "The amphibolite sill has undergone the intense structural deformation of the rocks in which they are found..." Thin amphibolite sills are thickened in the crests of No. 1 folds. Thin interlayers (inclusions?) of schist exhibit No. 1 folds, and included granitic stringers (replacement of No. 1 folds?) have the tight isoclinal fold pattern characteristic of the No. 1 folds. Aligned hornblende grains in fold crests plunge parallel to the No. 1 fold axes in the same or in nearby outcrops, indicating that the sill was emplaced prior to the No. 1 deformation. Thus it seems likely that the amphibolite sills were emplaced in the form of gabbro or basalt intrusives prior to the No. 1 metamorphism. Geologists working in less metamorphosed parts of the Belt rocks farther north are unanimous in reaching similar conclusions: the sills were probably emplaced in later Precambrian time, prior to the folding of the Belt rocks (Pardee, 1911, p. 47; Calkins and Jones, 1913, p. 8; Schofield, 1915, p. 68; Umpleby and Jones, 1923, p. 9; Anderson, 1928, p. 7). The homogeneity of the large sill in the Elk City region and its sharp contacts with enclosing rocks seem to argue against its being para-amphibolite.

No. 2 folds

The open isoclinal folds (= tight concentric folds = No. 2 folds) formed next after the tight isoclinal folds. The foliation in the rock (= axial plane foliation with respect to the No. 1 folds) was rather tightly deformed in the development of these folds, which also deform the crinkly lineation related to the No. 1 folds. No. 2 folds bear differently from crinkly lineation. The axial planes of the No. 2 folds exhibit wide variation in strike and dip, but, because all of these folds have similar geometry, they are assumed to be the same generation of folds.

On the assumption that the small structures reflect the major structure, the "pile" of recumbent isoclinal folds has been refolded into large tight concentric folds, which folding may be called axial-plane folding (Scottford, 1955). The foliation planes
Fig. 59 Contoured modified beta-diagram on poles to foliation. 189 poles plotted on lower hemisphere.

Fig. 60 Contoured modified beta-diagram on poles to axial planes of the No. 2 folds. Fifty-two poles plotted on lower hemisphere.
presumably were slip planes, much as bedding planes would have been, in the No. 2 folding.

Axes of the No. 2 folds bear predominantly northwest by southeast much as do the No. 1 folds, although many of them bear northeast by southwest. Northerly and southerly plunges are about equally developed (Fig. 55). It is important to note that the axes form a partial girdle inclined to the northeast. The explanation for this is to be found principally in Figure 59. Statistically, the larger part of the No. 2 axial planes dip to the east; that is, the No. 2 folds are, for the most part, overturned to the southwest. Figure 58 confirms this. The foliation dips predominantly to the northeast, a fact not readily deduced from the cross-sections nor from field work. The No. 2 folds, open isoclinal and overturned to the southwest, are responsible for this preferred direction of dip. The No. 3 folds, with vertical axial planes, reversed the dip of some of the No. 2 axial planes, but not a large proportion of them. Statistically, many of the variably plunging No. 2 fold axes lie in a statistical northeast-dipping No. 2 axial plane that strikes N.10°-20° W. The southwest- overturning of the No. 2 folds accounts for the variation in bearing of the No. 2 fold axes and for the presence of an inclined partial girdle rather than a vertical partial girdle in Fig. 55. A certain smaller amount of the variation is to be attributed to the No. 3 folding, although it does not seem possible to decide just how much.

Formation of granitic stringers

The granitic stringers in the rock appear to have formed at the time of the No. 2 folding. Considerable evidence supports this view. All measured fold-crests on folded granitic stringers coincide with the bearing and plunge of nearby No. 2 folds; indeed, many such folded granitic stringers are drag folds with respect to larger No. 2 folds. The axial planes of folded granitic stringers parallel the axial planes of nearby No. 2 folds. Granitic stringers may parallel foliation (Fig. 14), cut across it at an angle (Fig. 18 and 26), or lie along the axial planes of No. 2 folds (Fig. 27). The term "sill" may be used to describe granitic stringers that lie parallel to the foliation, although strictly speaking, they are axial plane dikes with respect to the No. 1 folds and, as in Figures 4 and 6, not parallel to sedimentary bedding.

Granitic stringers that lie parallel to the foliation or cut across it at various angles may be weakly (Fig. 16) to strongly (Fig. 17), and even intricately (Fig. 22) folded. Axial plane dikes parallel to the axial planes of the No. 2 folds, however, are non-folded or only gently folded, although their mineralogy and textures are the same as in the granitic stringers, and one may be transitional into the other (Fig. 27). Differential movements along the foliation seem necessary to explain the variety of detail in the granitic stringers. Furthermore, some granitic e.t. stringers form boudins whose long axes are parallel to the No. 2 fold axes.
It would seem certain that the granitic stringers were pre-
No. 2 folding if it were not that the granitic stringers are tran-
sitional into axial plane dikes, and that the axial plane dikes
could not have formed except during the No. 2 folding, when axial
plane shear (along $\varepsilon_3$) was operative. These facts make it neces-
sary to postulate that the granitic stringers were formed during
the second folding. From field data alone, one cannot decide
whether their mode of emplacement was by injection or by replace-
ment.

Petrographic data, however, tend to support a replacement
origin for the granitic stringers. The plagioclase in the
stringers is crystalloblastic xenoblastic and corresponds in com-
position and texture to plagioclase in adjacent country rock.
Where the plagioclase in the stringer is An$_{25}$, the plagioclase in
adjacent country rock is An$_{25}$; where the plagioclase in the
stringer is An$_{30}$, the plagioclase in the adjacent country rock is
An$_{30}$. Intrusive magma cannot readily be envisioned to account for
this. Further, the plagioclase-potassium feldspar ratio in the
granitic stringers corresponds closely to the plagioclase-potassium
feldspar ratio in the adjacent country rock. Biotite is concen-
trated along the edges of granitic stringers (within the country
rock); perhaps it is the biotite that was formerly within the
space now occupied by the granitic stringers. Details of prefer-
red orientation of the micas parallel to $\varepsilon_3$ and $\varepsilon_3$ are the same
in the granitic stringers as in the adjacent country rock. More
specifically, axial plane dikes contain biotite oriented parallel
both to $\varepsilon_2$ and to $\varepsilon_3$. An intrusive mechanism does not readily
explain this fact. Further, scattered grains of feldspar in the
granitic stringers include oriented fibrolite microfolds entirely
similar to those included in the feldspars in the country rock, a
phenomenon hard to explain on a magmatic origin.

If it were not for the presence of a few grains of slightly
more sodic plagioclase enclosing slightly more calcic plagioclase
in the granitic stringers, one would be tempted to postulate that
the granitic stringers are simply the result of metamorphic dif-
ferentiation during folding. However, one likely hypothesis for
the origin of the granitic stringers seems to be that of alkali
metasomatism, during the No. 2 folding; metamorphism, operating
along the more active movement zones during flexure folding with
weak shear deformation confined to axial plane zones. The gra-
nitic stringers were folded and even stretched during and just
after their formation.

It is not easy to understand just how the plagioclase in the
two rocks, country rock and granitic stringers, came to have, with
rare exceptions, the same composition. In general, it would seem
that the introduction of soda into the rock should result in the
formation of somewhat more sodic plagioclase—a sort of "dilution"
effect. Indeed, this may be the case for those somewhat more
sodic grains that enclose somewhat more calcic grains. Perhaps
mild metasomatism locally modified the results of a rather wide-
spread metamorphic differentiation. Such differentiation resulted
Fig. 61 Contoured quartz axis diagram from a No. 1 fold (Fig. 10). One hundred axes plotted on lower hemisphere. Contours at three percent intervals per two percent of area.

Fig. 62 Contoured quartz axis diagram from a No. 2 fold (Fig. 11). One hundred axes plotted on lower hemisphere. Contours at three percent intervals per two percent of area.
in a net diffusional transfer of biotite out of the stringers (zones of more active shear) and a compensating diffusional transfer of quartz-feldspathic material from adjacent country rock into the granitic stringers, producing moderately coarser grains. Abundant feldspar may have been present in the rock prior to the No. 2 folding and metamorphism.

The more tightly deformed granitic stringers may be called pytymatic folds, for they bear a strong resemblance to pytymatic folds described in other places by many authors. The origin of pytymatic folds and the granitic material commonly present in them is none too clearly understood. Turner (1930, p. 315) presents four hypotheses on their origin: (a) the veins originate as planar layers of magma injected or segregated in a host rock that later is irregularly deformed upon being rendered mobile by partial anatexis; (b) the folding is caused by plastic deformation of the rock after crystallization of the material filling the veins; (c) pytymatic structures have developed directly by injection of magma along tortuous fissures that have opened up in invaded rocks under the disruptive force of magmatic injection; (d) pytymatic folds may develop through injection of magma into metamorphic rocks undergoing active deformation.

From the preceding discussion it seems virtually certain that the granitic material in the pytymatic folds of the Elk City region was not injected in magmatic form, but rather came into being through either a metasomatic replacement process or a metamorphic differentiation process, or through some combination of the two. Thus none of the hypotheses presented by Turner may be used to explain the origin of the pytymatic folds in the Elk City region.

DeSitter (1956, p. 92), on the other hand, finds that "Many of the pytymatic veins are probably segregation veins which originated during the migmatization or granitization process..." This suggestion is more in accord with the results discussed above; therefore, this work tends to support DeSitter's hypothesis for the origin of pytymatic folds, although it is somewhat different in detail. The major mechanism for the origin of the Elk City pytymatic folds may have been (1) uniform feldspathization of the whole rock in the No. 1 metamorphism, followed by (2) metamorphic or shear differentiation (No. 2 metamorphism) along the most active shears (including locally the S3 axial plane direction). Regional metasomatism was probably absent during the No. 2 metamorphism. Folding and stretching of the feldspathic veins occurred during and after their formation.

Many pytymatic folds have no apparent relation to the structure of the host rock. Axial planes of pytymatic folds may be at considerable variance to the axial planes of folds in the host rock. Some folds may be gentle and some may be tight. The rotation and homogenization of pytymatic fold crests (Figs. 24 and 25) described earlier serves as one possible mechanism to explain such occurrences. The presence of such rotation also serves to
substantiate the presence of differential movements along the foliation during the No. 2 flexure folding.

DeSitter (1956, p. 91) states that "... it is clear that the cause of the peculiarity of every pytymatic structure lies in a difference in physical properties between the vein and host rock material." Many granitic stringers that cut across foliation have the appearance of being shear folded (Fig. 32). Yet, only weak foliation cuts across them, although this may be largely a function of low mica content. Microscopic study reveals that mica grains along the borders of granitic stringers such as the one shown in Figure 26, are oriented, in part, parallel to the fold walls, even on the crests and troughs of the folds. This orientation is taken to indicate that flexure folding has been operative, at least in part, in the formation of these seeming shear folds. Flexure folding, as emphasized before, has been the principal mode of deformation during the No. 2 folding. Thus it would seem that even when the country rock on the flank of a major fold is being deformed, essentially by differential shear parallel to the pre-existing foliation, a small granitic stringer, of different physical properties from the country rock, can deform at least in part by flexure. It should be emphasized that such differential shear caused by flexure folding, consists of slip parallel to pre-existing foliation. This shear movement is analogous to bedding plane slip during flexure folding of sedimentary rocks.

No. 3 folds

The No. 3 folds are assumed to be later than the No. 2 folds, partly because they are more gentle than the No. 2 folds. Considerable evidence tends to support this assumption. Gentle folds in the foliation warp the axial planes of small No. 2 folds (Fig. 40). Gentle folds in the foliation have deformed tight drag folds, presumably of No. 2 age, that do not have the correct direction of transport with respect to the fold in which they are now situated (Fig. 42). Drag fold axes and axial planes are oriented differently from fold axes and axial planes of the large gentle folds (Fig. 39).

Further, in many places, tiny granitic stringers cut the gneiss at seemingly odd angles, not apparently related to other previously described granitic stringers in the rock. These tiny stringers, generally not more than two or three millimeters thick, are planar except for rare gentle folds. The axis of one of these folds, in such a position that its bearing and plunge could be measured, turned out to be parallel to a nearby No. 3 fold axis. On the possibility that the tiny granitic stringers might be relatively weakly activated conjugate shears with respect to the shears along which the No. 2 axial plane granitic dikes have formed, the attitude of the granitic stringer in which the No. 3 fold axis was measured, was plotted on the Wulff stereonet, along with the attitude of a No. 2 axial plane granitic dike in the same outcrop. By Bucher's method (1944, prob. 3), the major axis of the strain ellipsoid was found to plunge eight degrees
Fig. 63 Sketch of a No. 1 fold with an insert quartz axis diagram (Fig. 10).

Attitude of foliation N 06 E 80°E
Axis of fold (b) plunges N-S 32°S

Fig. 64 Sketch of a No. 2 fold with an inset quartz axis diagram (Fig. 11).

Axial plane of fold
N-S 80°E

1 cm

Axial plane foliation

Compositional layering

Folded foliation
along N 57° E (Fig. 65), a reasonable orientation considering the general structure of the area. Thus it seems probable that even the thin, seemingly non-oriented granitic stringers were formed during the No. 2 metamorphic episode as weak shears conjugate to the No. 2 axial plane direction. Then the fact that the axes of rare gentle folds in these granitic stringers parallel the No. 3 fold axes (in individual outcrops), strengthens considerably the supposition that the No. 3 folding followed the No. 2 folding. Similar data from a number of other outcrops yielded comparable results.

The No. 3 fold axes (Fig. 56) exhibit considerable scatter, far more than was expected. At first no reason for this scatter could be conceived. Then, one example of cross-folding vertical to the bearing of a tight No. 2 fold was discovered (Fig. 50). For a time it was thought that certain of these folds might inadvertently have been called No. 3 folds and that their presence was responsible for the scatter. Next, it appeared that the explanation advanced by Weiss and McIntyre (1957, p. 12) was more likely: the fold axes are widely variable in bearing and plunge because the No. 3 folds have been superposed on earlier foliation surfaces of widely divergent attitudes. However, the No. 3 axial planes, though vertical, are not parallel in strike, as they should be by this interpretation. Insufficient evidence is in hand with regard to this problem. Until more information becomes available, it is tentatively suggested that the cross-folds developed, perhaps in the No. 2 folding, at places of local compression caused by reversals in plunge of folds.

On the assumption that the small structures reflect the major structures, it is postulated that the latest set of fold structures in the rock has been formed through a refolding of the earlier axial plane folds, a style of deformation that may be termed double axial plane folding. Figure 64 expresses in a very generalized fashion the author's conception of the fold pattern for the rocks of the Elk City region. The structural cross-sections (Fig. 3) confirm the presence of a deformation structure that has caused the No. 2 axial planes to have widely variable orientations. Involved here is the assumption that the axial planes of a particular set of folds are essentially parallel over a portion of a fold belt as large as that of the present area after a particular deformation.

Summary and discussion

Thus, it is seen that these rocks have been subjected to three periods of folding. This may be termed triple folding or, as above, double axial-plane folding. The rocks were deformed into a pile of tight recumbent isoclinal folds (No. 1 folds), this pile was deformed into open isoclinal folds overturned to the southwest (No. 2 folds), and these folds were refolded (No. 3 folds).

It appears that the foregoing events occurred prior to the intrusion of the Idaho batholith. Intrusive quartz diorite to
granodiorite dikes are non-folded so far as can be seen. The principal post-dike deformation present is that of the microchevron-phylloplane deformation, present in some places. It is not even certain that this deformation was post-dike. The cataclastic structures in the minerals of the quartz diorite dikes may just as well have resulted from Tertiary or other faulting. Further, present evidence is not adequate for an evaluation of the possibility that the quartz diorite to granodiorite dikes may belong to the Tertiary granitic intrusions (Anderson, 1932). They strike northwesterly rather than northeasterly, however. Post-batholith seems to be the most likely assignment for the microchevron-phylloplane deformation, and there it is tentatively assigned until some evidence to the contrary emerges.

Although three successive pulses of folding have been demonstrated, no evidence has been found to determine whether all the pulses of folding occurred in one orogeny, in two, or in three.

Only the barest of preliminary work has been done on the microfabric of the rock. One exploratory, quartz-axis diagram has been prepared from each of two oriented thin sections taken from the crestal portion of a No. 1 and a No. 2 fold. Figure 60, the No. 1 fold, is tentatively interpreted to contain two partial girdles that are not symmetrically oriented with respect to the fold in which they occur (Fig. 62). Figure 61, the No. 2 fold, is tentatively interpreted to contain three girdles that are not symmetrically oriented with respect to the fold in which they occur (Fig. 63). Later cataclasis has had an as yet unstudied effect on the quartz-grain orientation. Both of these rocks have triclinic fabric symmetry, indicative either of non-homogeneous strain or of multiple deformation along non-parallel axes (Billings, 1954, p. 377). Because of the nature of the rock structure, the presence of triclinic symmetry in the microfabric is taken to support the interpretation of multiple deformation.

OROGENIC PERIODS

In an attempt to decide whether the three pulses of folding and the pulse of shear deformation that are postulated for the Elk City rocks are to be attributed to one or to several orogenies, it is helpful, if not necessary, to consult the work that has been done in adjacent areas. The oldest definitely known orogeny in this part of the Rocky Mountains occurred in the later part of the Precambrian (Umplesby, 1917, p. 9; Ross and Forrester, 1958, p. 29). Ross and Forrester state that "With the exception of a few areas where late Precambrian deformation may have been intense, the rocks of the Belt series were thrown into broad, open folds..." Umplesby's description of the rocks of the Mackay region involved in this folding (1917, p. 23) appears to be of considerable significance:

Rocks believed to be of Algonkian age... are uniformly though not intensely metamorphosed. Crumpling
Fig. 65 Highly generalized diagrammatic sketch to illustrate the author's concept of the fold structures in the Elk City region. The axes of the three fold sets are not parallel but about 15° apart in bearing.
is not common, and in most of the quartzitic members the original bedding planes may be clearly traced almost at right angles to the planes of schistosity. The beds are believed from their advanced metamorphism and their lithologic similarity, to be part of the Belt series.

As Umpleby (p. 37) further remarks, regional metamorphism occurred in the Mackay region in the Precambrian.

Over much of central Idaho, the next major deformation took place, according to Ross and Forrester (1958, p. 33) late in the Jurassic period. In areas closer to and west of the Elk City region, some evidence points to an older folding. Wagner (1945) found in the Seven Devils region evidence of a post-Seven Devils volcanics (Permian)-pre-Lucile series (Triassic) period of folding. Cook (1954, p. 4) described in the Seven Devils region a pre-quartz diorite, pale gray-green, sheared, silicified granodiorite that "... appears to grade into the Seven Devils volcanics..."

Livingston (1925, p. 6, 19) found that certain veins, younger than granodiorite, cut the Permian andesites, but do not extend into overlying rhyolites of Triassic age. Thus the sum of the work in the Seven Devils region seems rather clearly to indicate that a period of local(?) folding and emplacement of granodiorite, possibly of replacement origin, occurred prior to the deposition of the Triassic rocks and later than the deposition of the Permian volcanics. The granodiorite is probably the same as that described from the Riggins quadrangle as pre-thrust, pre-quartz diorite. Gilluly (1937, p. 1) proposes two plutonic cycles in the Baker quadrangle in Oregon, southwest of the Elk City region:

Two plutonic cycles are believed to be represented, the earlier probably of post-Carboniferous, possibly Triassic age and the latter probably post-Jurassic. The folding and metamorphism of the pre-Tertiary rocks was essentially complete before the irruption of the biotite-quartz diorite masses.

Hietanen (1952), in describing Belt rocks northwest of the Idaho batholith, states:

The area is structurally complex, situated at the junction of two arcuate segments of Nevadan folding and also on the western border of the Laramide orogenic belt. The major fold axis parallels the trend of the northern arcuate segment of Nevadan folding (N 70°-80° W). The lineation and axis of small folds parallel the trend of the southern arcuate segment (N 50° E). Both sets of folds are locally overturned to the south and are accompanied by low angle thrusts.

Ross (1938, p. 61) mentions in the Wallowa Mountains two periods of folding, one of Permian or early Triassic age and the other of late Mesozoic age. Smith and others (1941, p. 20) are in agreement with the work of Ross.
Thus it appears that in the regions about the Elk City area, three orogenies have occurred after the deposition of the Beltian sedimentary rocks and before the emplacement of the Idaho batholith in the later Jurassic, about 103 million years ago (Ross, 1928, p. 673; Larsen and others, 1954). The oldest of these occurred in the later Precambrian; the next one occurred between the deposition of the Permian volcanics and the deposition of the Triassic rocks; and finally, one occurred in later Jurassic, prior to the emplacement of the batholith. This area appears to have been on or near the west side of the main Laramide orogenic belt (Hietanen, 1952; Anderson, 1948), so that Laramide deformation may have been relatively weak.

TENTATIVE CORRELATION OF KINEMATIC HISTORY, OROGENIC PERIODS, AND SILICATE PARAGENESIS

The kinematic analysis has resulted in the postulation of four separate pulses of deformation in the Elk City rocks. As was mentioned earlier, no evidence from the rock itself is in hand to indicate whether the four sets of structures were produced in one or in several orogenies. All four sets of structures might conceivably have been produced in separate pulses of deformation within one orogeny. However, it seems reasonable to suppose that each of the orogenies found to have been operative in the rocks of neighboring regions, may have been operative in the rocks of the Elk City region. Further, it seems reasonable to suppose that the deformation in each orogeny has left its imprint in the rock in the form of a particular set of structures of a structural habit corresponding to the intensity and direction of the deformation and the relative competence of the rocks at that time.

On the foregoing assumptions, it is tentatively proposed that each of the fold sets in the Elk City rock was produced in one of the orogenies mentioned above. The No. 1 folds are correlated with the late Precambrian orogeny. Tight, recumbent, isoclinal folds, probably with axial plane foliation, were formed. The accompanying metamorphism was probably in the katanzone, inasmuch as some sillimanite was produced, and labradorite formed in the amphibolite. The S\textsubscript{2} foliation is assumed to have been formed primarily at this time, although, as mentioned earlier, it may have been intensified in subsequent No. 2 folding. Biotite No. 1, quartz, garnet, rutile, sillimanite, magnetite No. 1, zircon, apatite, plagioclase No. 1, microcline No. 1, hornblende, labradorite, and sphene are considered to have crystallized during the metamorphism that occurred in conjunction with the deformation.

The No. 2 folds are correlated with the orogeny that occurred after the deposition of the Seven Devils volcanics and before the deposition of the Lucile series. As discussed above, replacement (?) granodiorite formed in the Seven Devils volcanics; inasmuch as replacement granodiorite also formed in the Elk City rocks in the No. 2 folding, this correlation seems to be fairly strong.
Temperature was sufficiently high that muscovite, fibrolite, and biotite formed. The relatively weak $s_3$ foliation formed at this time. Biotite No. 2, muscovite No. 1, plagioclase No. 2, magnetite No. 2, thorite, microcline No. 2, tourmaline, and fibrolite are considered to have crystallized during the mesozonal(?) metamorphism that occurred in conjunction with this deformation. Muscovite, partly parallel to $s_2$, partly parallel to $s_3$, is considered to have formed parallel to both movement directions in the rock during the No. 2 folding; it replaces microcline augen of fairly definite No. 1 age.

The No. 3 folds are tentatively correlated with the main Nevadan orogeny of Jurassic age. This deformation was still rather intense, although metamorphic temperature may have been no higher than mesozene or epidote amphibolite facies, an assumption based on the possibility that non-oriented muscovite, epidote, and allanite may have crystallized at this time. Because this deformation was somewhat less intense than the two preceding ones, no marked parallelism of newly formed minerals was produced.

The batholithic mass some miles to the east seems to have had little or no effect on the rocks of the Elk City area; indeed, large, seemingly non-rotated xenoliths or roof pendants in the batholith a few miles east of Elk City have been so little recrystallized by heat from the batholithic mass that their foliation has not been visibly weakened, either macroscopically or microscopically. This lack of metamorphism incident to batholithic emplacement is in strong contrast, for example, to the effects produced during the emplacement in Montana of the Tobacco Root batholith (Reid, 1957, p. 9), where the foliation in the intruded, highly foliated Archean gneisses was completely destroyed by static recrystallization near the contact and very much weakened a quarter of a mile from the contact. One wonders how high (or how low) the temperature in this part of the Idaho batholith may have been at the time of its formation, or indeed, if it ever passed through a liquid magmatic stage. In this connection, a remark by Mackin and Schmidt (1955) is pertinent: "The batholith is a composite mass, consisting in part of granitic rocks of metamorphic origin and in part of orthomagmatic intrusive rocks emplaced at different times." It is interesting to speculate regarding how much, if any, of the batholith east of Elk City was formed by solid-state processes during the No. 2 deformation with its accompanying formation of granitic stringers in the Elk City rocks.

Anderson and Hammand (1940) describe quartzite, gneiss, and augen gneiss in Paradise Ridge near Moscow, surrounded by an envelope of granodiorite, all enclosed in quartz diorite. The gneiss and augen gneiss are attributed to contact metasomatic alteration of quartzite under stress by emanations from the batholith. I have observed that the augen in the augen gneiss on Paradise Ridge are aligned parallel within the foliation, plunging northwesterly at about 45°. There is some question whether contact metasomatism under stress (in the absence of strain?) can
produce a mineral l ineation. In the light of the present work, it is suggested that the metamorphic rocks in Paradise Ridge may belong to the pre-batholith metamorphic sequence, and that the weakly foliated granodiorite that lies between the metamorphics and the quartz diorite of the main batholith may be a granodiorite produced by solid state processes, much as that in the pytgmatic folds of the Elk City region.

After the No. 3 folding, relatively gentle fracturing occurred, concomitant with dike injection associated with the emplacement of the Idaho batholith. Finally, the microchevron folding-phyllonite deformation is tentatively correlated with the Laramide orogeny. Considerable retrogression occurred at this time; metamorphic temperature was about that of the cooler epizone or lower greenschist facies. At this time the low-temperature minerals formed, including chlorite, sericite, the clay minerals, and hematite. A portion of the cataclastic structure was probably produced at this time, although some undoubtedly must be referred to tertiary and other faulting.

This report is a preliminary attempt to fit kinematics, orogenies, and paragenesis together in a consistent way on not very much evidence. It must be regarded as highly tentative until much more detailed evidence is available either to support it or to change it. It may be remarked here that I have looked briefly at rocks in the vicinity of Orofino and along the Middle Fork of the Clearwater River which have features similar to those of the Elk City rocks. For example, very tight isoclinal fold hinges were seen at a number of places in the Orofino series and in the rocks along the Middle Fork. However, it seems unlikely that the structural history in either of these areas could have been worked out independently, simply because the deformation in the Orofino and Middle Fork rocks has been much more intense and, consequently, much of the evidence has been destroyed. If deformation had been just a little more intense in the Elk City region, much of the evidence would have been destroyed there too. I cannot agree with the conclusions of Johnson (1947) that virtually all of the minerals in the Orofino series, including biotite, andesine, diopside, uralite, hornblende, scapolite, epidote, zoisite, clinzoisite, allanite, quartz, apatite, sphene, zircon, garnet, magnetite, and sericite, were introduced contact metasomatically from the Idaho batholith into quartzites to form the gneisses and amphibolites. The structures, including several kinds of drag folds, seem too complex for such an explanation.
GEOLOGIC HISTORY

If the interpretations presented earlier are in the main correct, some further light has been cast on the geologic history of this part of Idaho. The orogeny that occurred in the later Precambrian was stronger here than has so far been shown in neighboring regions. Large recumbent folds were formed and the rocks were recrystallized under high temperature conditions, perhaps in the presence of alkali metasomatism. The post-Seven Devils volcanic-pre-Lucile series orogeny was also stronger than has been shown in neighboring regions. Rather strong refolding of the earlier, recumbent, isoclinal folds occurred and considerable replacement(?) granodiorite was formed. It is not impossible that parts of the Idaho batholith may have formed at this time, although much of the resulting granodiorite may have been removed upon emplacement of the intrusive quartz diorite and related rocks. The Nevadan orogeny, although relatively strong, did not deform the already competent rocks to any great extent. Folding of this orogeny is expressed largely as folded axial planes of folds of the preceding orogeny.

Following the Nevadan orogeny, the Idaho batholith was emplaced. Still later came the Laramide orogeny, unable to produce more than low temperature deformation features in the already highly competent rocks of the Elk City region. If the vein deposits are overlooked, two periods of high-angle faulting occurred in the middle and late Tertiary, or perhaps faulting went on more or less continuously throughout much of the middle and late Tertiary.
REFERENCES CITED


Fairbairn, H. W., 1935, Notes on mechanics of rock foliation: Jour. Geology, v. 43,


Shenon, P. J., and Reed, J. C., 1934a, Geology and ore deposits of the Elk City, Orogrande, Buffalo Hump, and Tenmile districts, Idaho County, Idaho: U. S. Geol. Survey Circ. 9.


