Tectonic Events at the Intersection Between the Hope Fault and the Purcell Trench, Northern Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 719

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By JACK E. HARRISON, M. DEAN KLEINKOPF, *and* JOHN D. OBRADOVICH

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The right-lateral Hope Fault was active intermittently from Precambrian to Eocene whereas the Purcell Trench is a Late Cretaceous graben

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By JACK E. HARRISON, M. DEAN KLEINKOPF, and JOHN D. OBRADOVICH

ABSTRACT

The intersection between the Purcell Trench, a topographic depression extending from Coeur d'Alene Lake northward for about 280 miles, and the Hope fault, a major west-northwest-trending right-lateral fault at least 100 miles long, is in the Idaho panhandle. The zone of intercept in the Purcell Trench is largely hidden by glacial debris.

Recent geologic mapping of all bedrock exposures in and near the trench has been used with gravity and aeromagnetic data and potassium-argon age determinations to interpret the tectonic events in the area. The Purcell Trench appears to be a structural feature in the United States that extends for a few miles into Canada where it joins a series of valleys without obvious structural control. The structural part of the trench includes a graben that contains the Upper(?) Cretaceous Sandpoint Conglomerate. The part of the trench in the United States is near the east edge of the Kootenay arc mobile belt, which is a zone of intense deformation and magmatism that began at least as early as the late Precambrian. The present trench is a young feature formed at the time of intrusion of the Kaniksu batholith, about 100 m.y. (million years) ago.

The first break along the Hope fault probobly formed in Belt time. The Hope fault now has an apparent right-lateral offset of 16 miles, of which 3-4 miles are early Tertiary. Subsidiary faults fan out to the northwest from the main Hope fault at its junction with the Purcell Trench. This fault system offsets the Purcell Trench and graben, as well as the Selkirk Mountains that form the west wall of the trench. Some faults in this system contain granodiorite and dacite porphyries that are about 50 m.y. old.

Major intrusive rocks in the area are quartz monzonite and granodiorite, both of the Kaniksu batholith. These rocks are about 100 m.y. old.

The sequence of tectonic and intrusive events in the area in the Precambrian was open folding on north-trending axes, faulting on the Hope fault, intrusion of Purcell sills at least 870 m.y. ago, and block faulting. In the Late Cretaceous the events were intrusion of quartz monzonite of the Kaniksu batholith about 100 m.y. ago accompanied by thrusting from west to east; migmatization and metamorphism of Prichard Formation and Purcell sills to form schists, gneisses, and amphibolite; and cross folding on tight upright to overturned major east-trending and minor north-trending axes. Still later, perhaps 95 m.y. ago, granodiorite of the Kaniksu batholith was emplaced, the trench faults were formed, and the Sandpoint Conglomerate was dumped into the Purcell graben that was forming east of the rising Selkirk Mountains. Tectonism accompanying the final pulse of intrusion culminated in right-lateral movement on the Hope fault, during which the north block moved east. This movement resulted in dilation in and near the trench where granodiorite and dacite porphyries later filled faults. Both the Purcell graben and the Selkirk Mountains were offset 3-4 miles at that time.

INTRODUCTION

Two major structural features, the Hope fault and the Purcell Trench, intersect in northern Idaho (fig. 1). Although the features have been known for about 60 years, the exact nature of each and the relation between them have not been fully understood, largely because the trench is filled by glacial debris that covers all but a few outcrops. Additional complications have been the uncertainty in the age of higher grade metamorphic rocks thought to be confined to the west wall of the trench and the consequent uncertainty in the kind and amount of trench faulting necessary to bring these rocks adjacent to low-grade metamorphic rocks on the east wall.

In 1903 Daly (1912) originally identified the topographic trench during his survey along the 49th parallel. He (1906, p. 597) named it the Purcell Trench. By "trench" Daly (1906, p. 596) meant "a long, narrow, intermontane depression occupied by two or more streams (whether expanded into lakes or not) alternately draining the depression in opposite directions." He described the Purcell Trench as extending from Bonners Ferry northward about 200 miles into Canada, through the valleys of Kootenay Lake and the Duncan River to the mouth of the Beaver. He (1912, p. 600) also noted that "the constructional profiles [of the Rocky Mountain and Purcell Trenches] may have been those of grabens * * *." Daly's geologic map (1912, sheet 6) shows pre-Belt rocks faulted against Belt rocks at the Purcell Trench.

Calkins (1909) justified extension of the Purcell Trench south from Bonners Ferry about 80 miles "at least to the southern end of Lake Coeur d'Alene." He also identified and named the Hope fault, which he

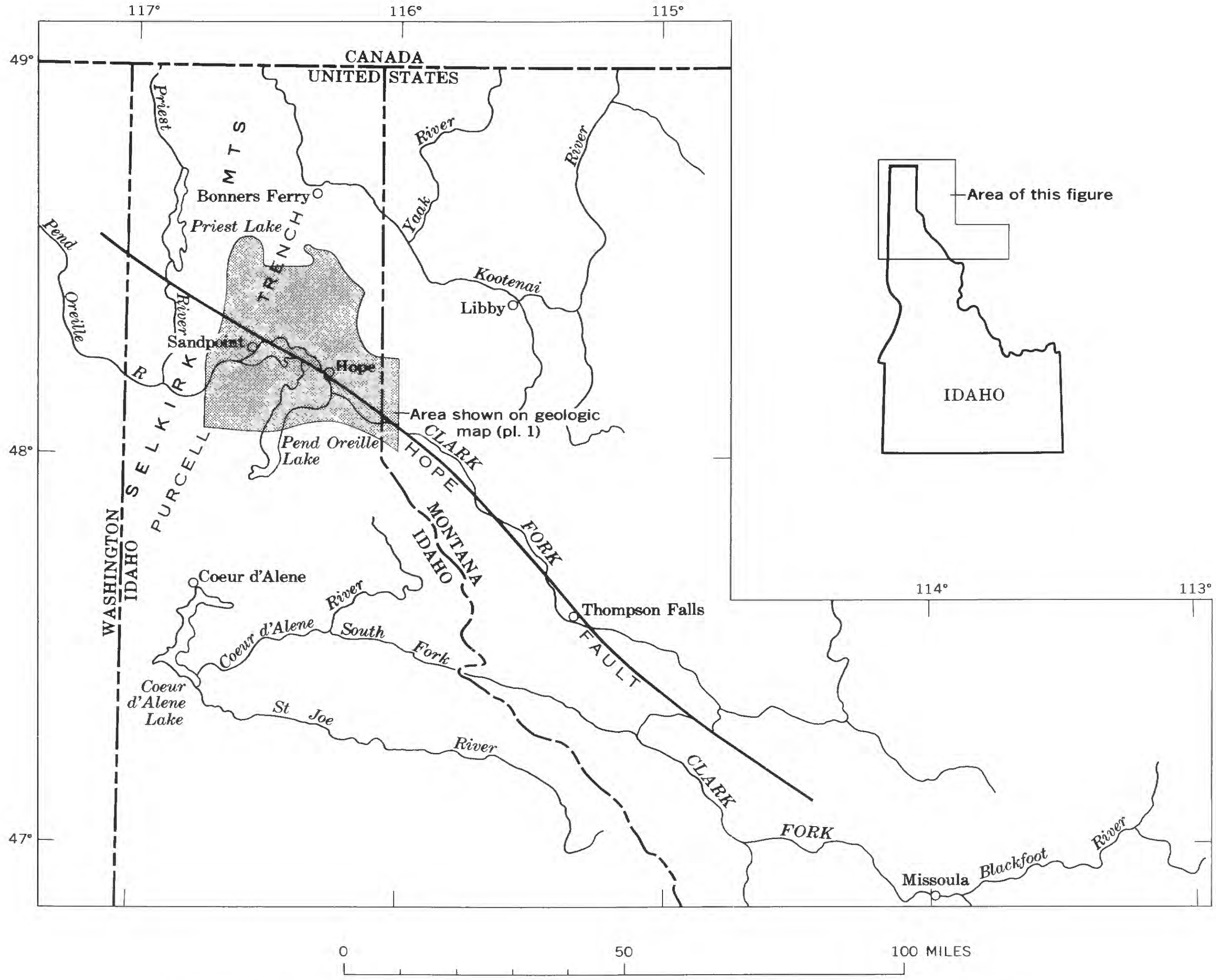


FIGURE 1.—Location of study area with reference to the Purcell Trench and the Hope fault.

recognized as a major fault occupying the Clark Fork valley for about 40 miles of its length southeast from Hope, Idaho, and reported that some evidence of faulting was found in the Purcell Trench. His geologic map shows metamorphic rocks of questioned older Precambrian age which are separated from Belt rocks by Coeur d'Alene Lake at the south end of the Purcell Trench.

Schofield (1915, p. 168) argued that the trench owes its present form to modification of a preexisting valley; Rice (1941, p. 4, map 603A) concurred and showed no fault in the north-northwest-trending valley occupied by Kootenay Lake, although he did show several north- to northeast-trending faults in and near the Purcell Trench at the international boundary. Fyles (1964, 1967) studied part of the Kootenay Lake and Duncan Lake areas in detail. He mapped several faults parallel to and near the valleys that contain the lakes, but he showed no master structure in the valleys. He (1964, p. 9, 10) used the term "Purcell Trench" in only a topographic sense.

Kirkham and Ellis (1926, pl. 3, p. 32, 33) identified what they called the Kootenai fault in the Purcell Trench. On their geologic cross section the fault is shown as high angle; the text suggests downthrow to the east but also points out that the fault may be an east-dipping thrust. They believed that rocks on both sides of the trench belong to the Prichard Formation, in contrast to the hypothesis of Daly who believed that the schistose rocks on the west were pre-Belt.

Anderson (1930, pl. 14) made the first geologic map that showed the intersection between the Hope fault and the Purcell Trench. His reconnaissance led him (p. 44) to suggest that a main high-angle trench fault with downthrow on the east connected with the Kootenai fault as mapped to the north by Kirkham and Ellis and, after adjustment for right-lateral offset on the Hope fault, with the Pend Oreille fault mapped by Sampson (1928, pl. 2) as extending up the long north-trending part of Pend Oreille Lake. The question of the presence of older or younger Precambrian rocks on the west wall of the Purcell Trench did not arise because Anderson mapped the Selkirk Mountains, which form the west wall, as granodiorite of Jurassic(?) age. Anderson (1930, p. 19-22) did, however, identify, describe, and name the Sandpoint Conglomerate. This formation is unique to the Purcell Trench, and its origin is critical to the reconstruction of tectonic events.

Among the more recent mentions of the Hope fault and the Purcell Trench are Pardee's (1950, p. 399) inclusion of the Hope fault as one of the late Cenozoic block faults in western Montana, Griggs' (1964) confirmation of Calkins (1909) observations about the Purcell Trench near Coeur d'Alene Lake, and Savage's (1967) listing of the existing concepts of origin of the Purcell Trench and the Sandpoint Conglomerate. Nevin (1966), working only on the west side of the trench near Bonners Ferry, felt that evidence for a pre-Belt age of the higher metamorphic grade rock was compelling and that a fault-controlled trench was possible but not essential to explain the structure of the area.

Wheeler's (1966) summary of tectonics in the Western Cordillera of British Columbia does not even mention the Purcell Trench, and yet a companion paper by Yates, Becraft, Campbell, and Pearson (1966) on tectonics of the same Western Cordilleran province in the United States recognizes it as a significant though somewhat enigmatic structural feature that forms the east boundary of the Kootenay arc mobile belt, a broad zone in eastern Washington and southeastern British Columbia in which intrusion, extrusion, and deformation have been intense.

Recent detailed geologic mapping (Harrison and Schmidt, 1971) of the Elmira quadrangle disclosed a series of geologic relations bearing on the tectonic history of the Hope fault and the Purcell Trench. The narrowest part of the topographic trench is at Elmira, Idaho, where the walls are only $1\frac{1}{2}$ miles apart; this affords the nearest approach to continuous outcrop anywhere in the United States part of the trench. All the east side and much of the trench is included in the Elmira quadrangle. All other outcrops in the trench south of Elmira and west of the Elmira quadrangle were mapped in detail, and several reconnaissance traverses were extended from the trench for a few miles back into the Selkirk Mountains on the west side. M. D. Kleinkopf prepared a gravity map of the trench to accompany the geologic map of this report. An aeromagnetic map of part of the area was placed in open file in 1962 (Meuschke and others, 1962), and another map adjoining on the east was published in 1969 (U.S. Geological Survey, 1969). Radiometric dating of some rocks in and near the trench by J. D. Obradovich has further clarified the actual age of certain geologic events. This report uses these new geologic, geophysical, and isotopic age data to help unravel the complex tectonic history at the intersection of the Hope fault and the Purcell Trench.

We are particularly grateful for stimulating discussions of regional tectonics with our colleagues, S. Warren Hobbs, A. B. Griggs, S. H. B. Clark, and F. K. Miller. D. T. Bishop, Idaho Bureau of Mines and Geology, who is currently preparing a geologic map of Boundary County, gave helpful criticism and provided some unpublished data on faults in his map area. D. L. Peterson provided unpublished gravity data on the Purcell Trench between Pend Oreille and Coeur d'Alene Lakes.

GENERAL GEOLOGY

ROCK TYPES

Most rock types in the area have been described extensively in other reports. For most rocks discussed in this report, only brief descriptions will be given. The interested reader is referred to Anderson (1930) for the petrography of the Sandpoint Conglomerate and of the intrusive rocks in general, to Gillson (1927) for the petrography of the grandiorite, to Sampson (1928) for descriptions of the Cambrian sedimentary rocks, to Harrison and Jobin (1963) for descriptions of the Belt rocks, and to Savage (1967) for descriptions of the surficial deposits.

Belt Supergroup

Belt rocks of the area are a drab, fine-grained, monotonous sequence at least 42,000 feet thick of argillite, siltite, quartzite, and minor amounts of carbonate rocks. About half of the sequence is the

Prichard Formation, which is the Belt unit exposed most extensively in and near the Purcell Trench (pl. 1). Effects of both regional and contact metamorphism are evident in Belt rocks. In general, rocks above the middle of the Wallace Formation are in the chlorite-sericite zone of the greenschist facies; below mid-Wallace, rocks of appropriate composition contain increasing amounts of biotite with depth in the stratigraphic section. All Burke and Prichard rocks are well into the biotite zone. Contact metamorphism varies considerably depending upon the type of intrusive rock and the degree of deformation accompanying the intrusion. The true effects of the contact metamorphism may be masked by the pervasive regional metamorphism, which is probably related to a metamorphic event about 700-800 m.y. ago (Reid and Greenwood, 1968, p. 77; Wheeler, 1966, p. 28). Contact metamorphism by Purcell sills prior to the main regional metamorphism is now shown by the formation of hornfels within a few feet of each side of the sill. Contact zones formed after the main regional metamorphism are as much as 2,000 feet wide around Cretaceous granodiorite bodies. At places andalusite has formed in the contact zone. More commonly, the rocks are slightly schistose or gneissic because of formation of biotite and muscovite in crystals larger than usual in the regional biotite zone. Some rocks in the contact zone exhibit abnormal magnetism due to formation of magnetite and pyrrhotite. Forceful intrusion which shoulders aside the wallrocks has formed recumbent folds whose axes are subhorizontal and about parallel to the outline of the intruding granodiorite; but little pegmatite, migmatite, or brecciation occurs in the contact zone. The granodiorite commonly is seriate porphyritic at the contact. A second type of contact metamorphism is shown by the Prichard Formation in the northwestern part of the mapped area (pl. 1). In that area the rocks are migmatized through a lit-par-lit injection of alaskite, at places are prograded into the garnet zone and perhaps even into the first phases of the sillimanite zone, and are highly deformed by at least two fold systems.

The Belt Supergroup ranges in age from about 900 m.y. to more than 1,300 m.y. (Obradovich and Peterman, 1968). Lithostratigraphic equivalents of the Belt formations in the mapped area were deposited during two main episodes about 1,100 and 1,300 m.y. ago according to Obradovich and Peterman. The oldest age was determined by rubidium-strontium whole-rock dating of sedimentary rocks near the east edge of the Belt terrane and of metamorphic biotite in the Prichard Formation near Alberton, Mont. Obviously, the Prichard Formation is older, but its maximum age is limited by the general 1,800-m.y. age of the Precambrian crystalline terrane in nearby parts of western Montana.

The significance of the increasing metamorphic grade of the Prichard Formation from east to west at the north end of the mapped area needs to be emphasized. Exposed in that area is a transition from typical biotitic but bedded rocks of the Prichard Formation into high-grade schists and gneisses identical with those called pre-Belt in many earlier studies partly because they were high-grade metamorphic rocks and partly because the transition had never been observed owing to the glacially covered gap represented by the Purcell Trench. A similar kind of transition zone on the western flank of the Selkirk Mountains south of Priest Lake has been described by Barnes (1965). Thus, the Selkirk Mountains, cored by granodiorite and quartz monzonite, have Prichard Formation on their outer flanks that decreases in metamorphic grade away from the mountain core. The Purcell Trench has apparently interrupted what was a continuous transition zone on the eastern flank of the mountains.

Purcell Sills

Sills of Precambrian gabbro to quartz diorite are abundant in the lower part of the Prichard Formation (pl. 1). Precambrian sills of similar composition have been called Moyie sills, Purcell sills, and the Wishards sill by various authors. The commonly accepted name for them in the area of the report is Purcell sills, but no time or genetic connotation between Purcell sills and Purcell lava is implied.

The sills range in thickness from a few feet to 3,000 feet. Originally the sills consisted of hornblende, calcic plagioclase, and, in minor amounts, quartz, pyroxene, and common accessory minerals. Some of the sills are differentiated. Many sills that are near faults or that were deformed by folding have been altered considerably and now contain abundant biotite, calcite, and epidote. The sills vary in thickness along their strike, but they are persistent and form good structural markers in folded or highly faulted areas (pl. 1).

In the most highly deformed and metamorphosed areas and in migmatite, the sills are transformed to amphibolite. The transition zone at the north end of the mapped area shows, from east to west, competent sills that have dragged zones of Prichard biotitic argillite on both sides, then sills bounded by schistose and gneissic Prichard rocks and containing small zones of sheared rock (amphibolite) where minor north-trending fold axes cut the sill, and finally, at and west of the Purcell Trench, highly deformed amphibolite interlayered with schist, gneiss, and migmatite.

Again the significance of these sills and of their metamorphism needs to be emphasized. The abundance of the sills throughout a several-thousand-foot-thick section of Prichard Formation and their obvious transformation to amphibolite during progressive metamorphism virtually obviate all previous objections to identifying the high-grade metamorphic rocks north of the Hope fault and west of the trench with lower grade rocks on the east.

Some further observations about the sills are pertinent to this study. One sill south of the Hope fault (pl. 1) is repeated several times by faults but maintains a constant stratigraphic position. No sill in that stratigraphic position, or higher, occurs on the north side of the Hope fault north of the town of Clark Fork. The thickest sill north of the Hope fault (from which samples 48 and 49 were collected) persists as a thick sill for several miles northward but pinches down rapidly as it cuts southward across the Hope fault scarp and nears the fault. Both these unusual occurrences suggest that the ancestral Hope fault may have been in existence at the time the Purcell sills were emplaced.

Lakeview Limestone

One small area of Lakeview Limestone is shown on the geologic map (pl. 1) on the east side of Pend Oreille Lake and south of the community of Granite. The Lakeview is of Cambrian age. As it is of little consequence in this study, it will not be described or discussed further.

Migmatite

Migmatite is exposed extensively in the northwestern part of the mapped area (pl. 1). The rock unit consists of schists and gneisses derived from the Prichard Formation, metagabbro and amphibolite derived from the Purcell sills, and one or both of the related intrusive rocks—alaskite and cataclastic quartz monzonite. Proportions of each rock type range from about 10 percent to about 90 percent in a given outcrop. The unit grades in general from a high content of leucocratic igneous rock near contacts with quartz monzonite to a low content near contacts with schistose and gneissic Prichard Formation. Contacts themselves are gradational over hundreds of feet and their designations are necessarily arbitrary.

Migmatite is generally highly deformed, but major folds can be traced from migmatite continuously into rocks of the Prichard Formation. Migmatite west of Elmira contains moderately abundant layers of amphibolite, but the combination of intense folding and limited outcrop precludes mapping of individual amphibolite layers at the scale of the map.

Quartz Monzonite

The quartz monzonite is a distinctive but somewhat variable rock consisting of orthoclase, oligoclase-andesine, quartz, muscovite, and biotite. The quartz monzonite is clearly intruded by granodiorite. Contacts at many places are sharp, and the granodiorite does not show the cataclasis of the older quartz monzonite.

Several varieties of quartz monzonite, some of which show cataclastic effects, have been mapped and described in detail by Clark (1967), who distinguished a quartz monzonite gneiss unit from several varieties in a main mass. The main mass of quartz monzonite is exposed on the hills west of the town of Cocolalla (this report, pl. 1). Clark (1967) suggested that the quartz monzonite gneiss unit at the north end of her mapped area might be a more metamorphosed variety of the quartz monzonite near Cocolalla. Barnes (1965, p. 44-45) also identified cataclastic quartz monzonite in his mapping on the west flank of the Selkirk Mountains.

Granodiorite

Several bodies of granodiorite are so similar in texture and mineralogy that they can be described together. Most of the granodiorite is a mottled black, white, and pink seriate porphyritic rock consisting principally of potassium feldspar, oligoclase-andesine, quartz, and biotite, and, in minor amounts, hornblende locally. The larger phenocrysts commonly are orthoclase and are about half an inch long. Phenocrysts as large as 5 inches long occur in a few places, and at other places medium-grained equigranular granodiorite forms a part of the exposures. Foliation in most rocks is shown by planar arrangement of tabular feldspars and, in the finer grained varieties, by planes of biotite crystals. Foliation is parallel to contacts with the enclosing rocks. Very minor amounts of pegmatite are associated with the granodiorite.

Most contacts between granodiorite and other rocks are sharp, and seriate porphyritic granodiorite occurs at places adjacent to the contact. At a few places, narrow broken zones of older rocks are mixed with granodiorite to form a few feet of migmatic rock that is entirely different from the migmatite mapped as a unit on plate 1. Some zones of contact metamorphism extend outwards from the granodiorite for about 2,000 feet. In these zones the rocks are metamorphosed to hornfels and further recrystallized into highly biotitic rocks that have a schistose or gneissic texture near the granodiorite. Where rocks, such as the Prichard Formation, are in the biotite zone of regional metamorphism throughout the area and are in contact with granodiorite, the effects of both regional and contact metamorphism are so similar that an outer boundary for the contact zone is impossible to map.

Clark (1967, p. 10-12) described a mafic border zone, and A. B. Griggs (oral commun., 1970) reported more melanocratic margins of bodies at the south end of Pend Oreille Lake. One sample of mafic rock (sample 7, pl. 1) was collected at the border of the Gold Creek granodiorite body for potassium-argon age determination to check whether the mafic rock belonged to the Purcell sills or to a mafic border zone of the granodiorite. As will be discussed later, the isotopic data indicate the mafic rock to be a Purcell sill that is somewhat altered near the granodiorite.

The various major bodies of granodiorite in the mapped area will be called (1) the Granite Point body for the mass in the south-central part of the mapped area, (2) the Lightning Creek body for the plug north of Clark Fork, (3) the Gold Creek body for the large mass east of the Purcell Trench, and (4) the Selkirk Mountains mass for the large body coring those mountains.

The various quartz monzonites and the granodiorite are the chief components of the Selkirk Mountains part of the Kaniksu batholith of northern Idaho and eastern Washington. A greater variety of plutons that form the batholithic complex in eastern Washington has been studied by F. K. Miller and L. D. Clark (written commun., 1971).

Diabase-Diorite

Dikes of diabase-diorite and lamprophyre are common in the mapped area. They are particularly abundant in the central part of the mapped area (pl. 1) where they cut the granodiorite and Prichard Formation. Only two small bodies of diabase-diorite east-southeast from Sandpoint are large enough to be shown at the scale of plate 1. The dikes follow joints and faults. Some dikes south of the Hope fault occupy the southern part of a fault whose northern part contains a granodiorite or dacite porphyry dike.

Sandpoint Conglomerate

Plate 1 shows the location of all exposures of the Sandpoint Conglomerate, which was first identified and named by Anderson (1930, p. 19-22). The conglomerate is composed of subangular to slightly rounded boulders, cobbles, and pebbles of Purcell sills and slightly biotitic rocks of the Prichard Formation (fig. 2). The clasts are firmly cemented in a silty, clayey, and calcareous chloritic matrix. Crude bedding and crossbedding can be distinguished at most places where exposures are reasonably good. Everywhere the beds strike north and dip east (pl. 1). Measured dips range from 14° to 46°; most are about 25°.

The conglomerate is faulted and fractured, and most observed contacts with older rocks are along faults. It is in depositional contact in only two places—against a low hill underlain by a Purcell sill and against a low hill underlain by regionally metamorphosed Prichard rocks. One fault within the conglomerate contains a thin dacite porphyry dike.

Original thickness of the deposit cannot be determined because the top is everywhere eroded. In the fault block southeast of Elmira, the conglomerate is in depositional contact with a Purcell sill at an elevation of 2,200 feet and is almost continuously exposed on strike to the north where it caps a hill at 2,988 feet, indicating a minimum thickness of about 800 feet.

On the basis of reconnaissance geology, Anderson (1930, p. 19-22) originally reported that the conglomerate contained calcareous clasts from either the Cambrian Lakeview Limestone or the Precambrian Wallace Formation and was intruded by granodiorite. From these observations he dated the conglomerate as Paleozoic(?). Each outcrop area of the Sandpoint Conglomerate was examined carefully during recent geologic mapping, and at no place was the conglomerate found in any except fault contact with granodiorite. No clasts of carbonate rocks could be found in the conglomerate in outcrop, hand specimen, or thin section, even though the rock reacts visibly to acid owing to the calcareous cement in the matrix. Thus all the evidence used by Anderson to date the rock as post-Cambrian Paleozoic(?) must be discarded. The conglomerate can be dated relative to tectonic history of the area, and we will present our interpretation in a later part of this report.

Granodiorite and Dacite Porphyries

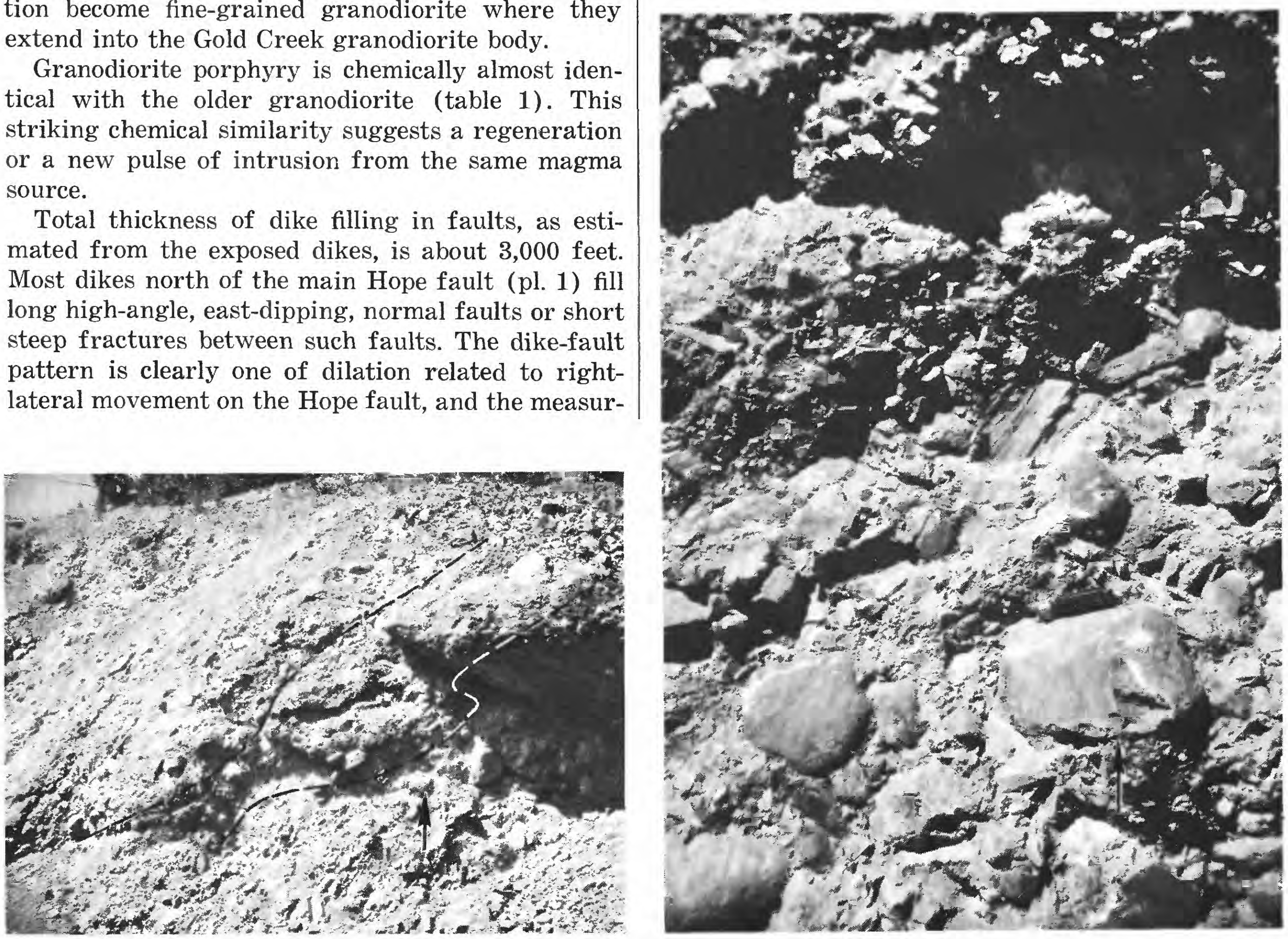
Granodiorite and dacite porphyry dikes were found to cut all other bedrocks in the mapped area except quartz monzonite with which they were not found in contact. Dikes range in thickness from a few inches to several hundred feet; many of the large dikes are compound as shown by multiple chill margins within a dike. The dikes invariably fill faults, many of which occur between branches of the Hope fault or fan out from that fault (pl. 1). Only a few dikes occur south of the main Hope fault.

Small dikes and margins of large dikes are invariably dacite or dacite porphyry; they have small feldspar and quartz phenocrysts set in a granophyric or glassy groundmass. Large dikes are more crystalline. Most large dikes have at least a 50-percent granophyric groundmass that encloses potassium feldspar phenocrysts, which commonly have a plagioclase rim, and smaller phenocrysts of plagioclase, quartz, hornblende, and, in places, biotite. Some dikes that are porphyry in Prichard Formation become fine-grained granodiorite where they extend into the Gold Creek granodiorite body.

Granodiorite porphyry is chemically almost identical with the older granodiorite (table 1). This striking chemical similarity suggests a regeneration or a new pulse of intrusion from the same magma source.

Total thickness of dike filling in faults, as estimated from the exposed dikes, is about 3,000 feet. Most dikes north of the main Hope fault (pl. 1) fill long high-angle, east-dipping, normal faults or short steep fractures between such faults. The dike-fault pattern is clearly one of dilation related to right-lateral movement on the Hope fault, and the measurable dike filling merely sets a minimum for the amount of dilation accompanying intrusion of the porphyries.

The pattern of dikes north of the Hope fault is critical in determining actual direction of movement on the Hope fault during the dilation that accompanied dike intrusion. Many dikes fill gash fractures, for they expand northward and thin down or taper out southward. This is possible mechanically only if the north side actually moved east, because if the south side moved west, the widest part of the tension (gash) fractures would necessarily occur where the dikes join the Hope fault and its branches (fig. 3). Possible support for eastward movement of the



A B

FIGURE 2.—Sandpoint Conglomerate. *A*, Exposure in a quarry about 1 mile east of Colburn. Dashed lines show approximate contacts of a crude bed containing somewhat smaller clasts. Irregularity of lower contact due in part to irregularity of quarry face. Arrow points to clast also shown in *B*. Geologic pick at lower left of crude bed gives scale. *B*, Closeup view of angular to subrounded cobbles and pebbles from Purcell sills (generally more rounded) and Prichard Formation. Contact between coarser and finer beds extends from left to right across center of photograph. Arrow points to clast also shown in *A*. Jackknife on clast gives scale.

TABLE 1.—*Chemical analyses of granodiorite and granodiorite porphyry*

[Analysts: C. L. Parker, D. F. Powers, and R. T. Okamura]

	1	2	3	4
SiO_2	66.89	66.40	67.17	63.74
Al_2O_3	15.86	15.20	15.73	15.79
Fe_2O_3	1.51	1.12	.98	1.50
FeO	2.16	3.24	1.84	2.16
MgO	1.28	1.97	1.44	2.23
CaO	4.07	3.58	2.59	2.90
Na_2O	3.09	2.64	4.13	4.08
K_2O	3.75	3.10	3.91	4.09
H_2O+	.52	1.24	1.03	1.41
H_2O-	.02	.10	.19	.37
TiO_2	.51	.63	.38	.56
P_2O_5	.21	.28	.19	.35
MnO	.11	.09	.05	.07
CO_2	.01	.00	.16	.47
Cl	.02	.01	.00	.01
F	.06	.08	.07	.10
Subtotal	100.07	99.68	99.86	99.83
Less O	.03	.03	.03	.04
Total	100.04	99.65	99.83	99.79

1. Seriate porphyritic granodiorite, Granite Point body.
2. Seriate porphyritic granodiorite, Lightning Creek body.
3. Granodiorite porphyry having a granophyric groundmass, east side of Bottle Bay.
4. Granodiorite porphyry having a granophyric groundmass, west side of valley at mouth of Pack River.

north block is found about 20 miles southeast of the mapped area on the north side of the Hope fault, where a unique area several miles wide of overturned Belt rocks indicates a crustal shortening perhaps comparable to the amount of crustal lengthening represented by dilation in the Purcell Trench.

Surficial Deposits

The surficial deposits contain a wide variety of glacial debris and more recent unconsolidated deposits. None of these shows evidence of displacement along post-Pleistocene faults. Most mountain streams are still attempting to clear glacial debris from their valleys. A relatively thin fill (hundreds rather than thousands of feet) that covers the lowlands is shown by the exhumed low hills of a preglacial topography now represented on the geologic map by the scattered bedrock outcrops in the Purcell Trench and Clark Fork valley.

STRUCTURE

Extensive faulting dominates the structural pattern of the mapped area (pl. 1). An intricate shattered-glass pattern of block-mosaic faults that is related primarily to intrusion of granodiorite (King and others, 1970) extends for about 20 miles to the south. Several varieties of folds occur in the mapped area, but they are so highly faulted that their continuity is not readily apparent.

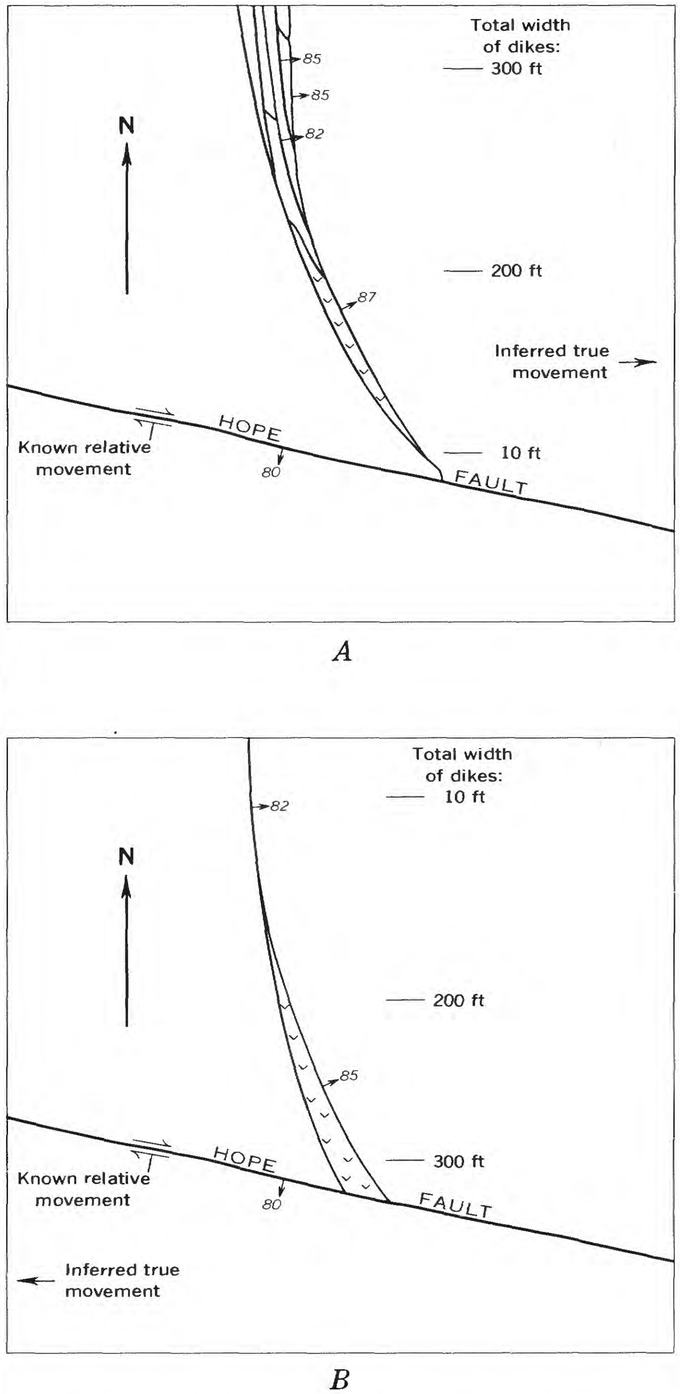


FIGURE 3.—Possible stresses needed to form tensional openings north of the Hope fault. A, Inferred true movement toward east. B, Inferred true movement toward west.

Folds

The largest fold is a broad ill-defined north-northeast-trending syncline in the Belt Supergroup, whose axis south of the Hope fault is near the southeast corner of the mapped area (pl. 1). North of the Hope fault, this axis apparently is offset about 8 miles to the east, which is about half of the total apparent right-lateral movement on the Hope fault. Most of the rocks east of the Purcell Trench and south of the Gold Creek granodiorite body are on the west flank of this broad open syncline. This simple pattern is modified not only by extensive faulting but also by local drag folds associated with the faults, by local folds between some of the faults, and by deformation that includes recumbent folds in zones around granodiorite intrusive bodies.

Open north-trending broad folds characterize most of the Belt terrane north of lat 47°. In Canada, the broad tectonic province is called the Purcell anticlinorium, and the mild orogeny involving gentle folding, some plutonism, and local regional metamorphism has been named the East Kootenay orogenic event by White (1959) and has been dated by Leech (1962) as being about 800 m.y. old. An older folding and metamorphism about 1,200 m.y. ago seems reasonably well documented for parts of Belt terrane near lat 47° (Reid and Greenwood, 1968, p. 76, 77), and even older folding and metamorphism farther south has been suggested (Reid and others, 1970). Within our study area, the extensive Cretaceous and Tertiary intrusions have reset the potassium-argon clocks of metamorphic micas in Belt rocks (table 2), so that the age of metamorphism and older folding cannot be dated by isotopic methods. The gentle open folding persists without apparent interruption (angular unconformity) from top to bottom of the Belt rocks in the mapped area, and thus in style and geologically reasonable age it seems likely to be related to the formation of the Purcell anticlinorium about 800 m.y. ago.

A different style of folding is represented in the Prichard Formation and the migmatite in the northern part of the mapped area (pl. 1). In that area east-northeast-trending upright to overturned folds which have a wavelength of about 3 miles are cross folded (the cross folds having a wavelength of a few hundred feet) on multiple axes that trend north-northeast approximately parallel to the strike of thrust faults in the same area. The east trend of the crestal planes of the large folds results from drag of the east limb of an older north-trending plunging anticline in the upper plate of a low-angle thrust plane that had a direction of transport to the east-southeast. Essential to this concept is a tear fault that trends east to form the southern boundary of the thrust. Field evidence for a tear fault is only permissive because the granodiorite has either followed along or obliterated any preintrusion faults in the critical area (pl. 1). A small amount of transport has left the dragged fold upright and cutoff along the tear fault, and more transport has caused overturning and twisting of the axial plane. Further transport would have generated overturned to isoclinal folds with northeast-trending axes (fig. 4). Crestal zones of the smaller cross folds are characterized by recumbent, almost ptygmatic, minor folds

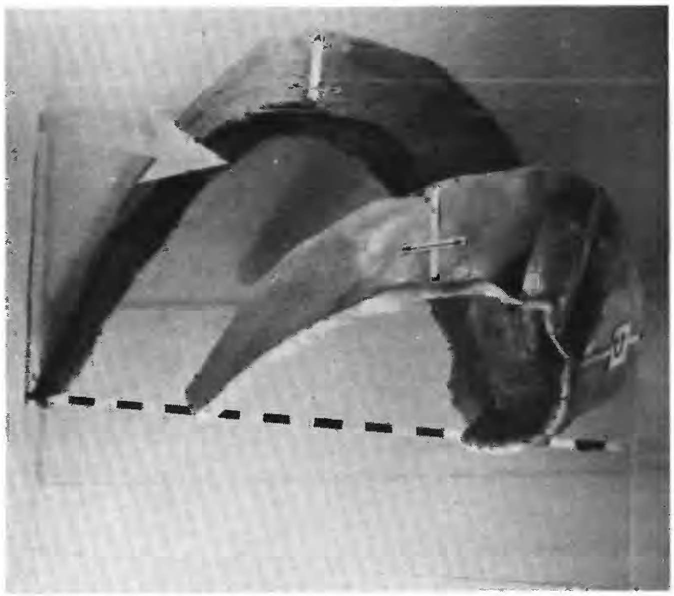


FIGURE 4.—Clay model, illustrating top view of folds formed in upper plate of thrust that cuts open fold almost at 90° to its axial plane. Glass plate represents thrust plane; large arrow shows direction of transport of upper plate. Dashed line shows inferred vertical tear fault. Upright (left), overturned (right), and terrace (center) folds in upper plate shown by standard symbols.

in the migmatite where the older fold has gentle dips. Cross folds in more steeply dipping parts of older folds tend to be of terrace or chevron type, and their central parts are rotated and sheared. Overturning of the older large fold and generation of north-northeast-trending cross folds whose axes are subparallel to the strike of the thrust are both compatible with low-angle thrusting from west to east. The mapped area does not contain junctions of the old north-trending open-fold system with the younger east- to northeast-trending cross-folded system, but it seems clear that the old open system is part of a regional pattern upon which the cross-folded system was superposed during thrusting. D. T. Bishop (written commun., 1970) has also concluded independently from geologic mapping in

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Boundary County that the east-trending folds are thrust over older open north-trending folds.

Scraps of folds trending north or north-northwest were mapped (pl. 1) in Prichard Formation and Purcell sills of low metamorphic grade in the Purcell Trench. Some of these appear to reflect drag structures between branches of the Hope fault system, but the disconnected outcrops do not allow conclusive statements on whether the folds represent a system different from the broad open-fold system which they resemble in style of folding.

Faults

Faults of the area can be conveniently discussed under four systems: Hope fault, block faults, thrust faults, and trench faults. The Hope fault (or fault zone) is a major structural element that extends for about 80 miles southeast of Hope, Idaho, and probably many miles to the northwest. Apparent horizontal movement along the fault is right lateral for 16 miles, and apparent vertical movement is about 22,000 feet down on the south (Harrison and Jobin, 1963, p. K28-K29). The main Hope fault traverses the entire mapped area (pl. 1), and branches fan out to the northwest from the town of Hope across the Purcell Trench into the Selkirk Mountains. Many faults filled by porphyries are obviously part of this system, and they clearly cut through and offset most bedrocks including the Sandpoint Conglomerate. One of the main branching faults loops around some of the bedrock outcrops in the trench and extends up Pack River. This fan-shaped system of faults had displaced the eastern front of the Selkirk Mountains about 3-4 miles right laterally within the mapped area. A fault, similar in trend to the main Hope fault, in the northeastern part of the area also shows an apparent right-lateral displacement of about 2 miles where it offsets the contact between granodiorite and Belt rocks. Obviously, some movement on this system is of porphyry intrusion age. Evidence previously cited concerning the distribution and behavior of Purcell sills suggests that the main branch of the Hope was in existence in Precambrian time and that Precambrian folds are offset more than the eastern front of the Selkirk Mountains. This difference in amount of offset demonstrates that part of the movement on the Hope fault followed Precambrian folding but preceded intrusion of Tertiary porphyries.

Block faults characterize much of the terrane south of the Gold Creek granodiorite body and east of the Purcell Trench (pl. 1). An extensive discussion of the origin of the block faults south of the Hope fault is presented by King, Harrison, and Griggs (1970). They demonstrate that some of the faults are Precambrian in age. Those old faults helped control intrusion of granodiorite during tectonic upwelling. Subsequent collapse into the granodiorite helped create the present block-fault mosaic. Faults of the mosaic are unusual in that many intersect without apparent offset, suggesting that blocks moved only up and down. The blocks show a general pattern of stepping down from east to west and from north to south.

A general stepping down of faults from east to west north of the Hope fault is similar to the pattern south of the fault. A somewhat more dense pattern near the intrusive granodiorite, plus clear evidence of postgranodiorite faulting, suggests that the block faults north of the Hope fault are similar in origin to those south of the fault.

Thrust faults form an important part of tectonic framework in the northern part of the mapped area (pl. 1). These faults strike north-northeast and dip moderately to gently west. Although many small thrusts are exposed in outcrop, the major ones can be seen in very few places. Where observed, they show zones of extensive slickensides, some gouge, and many small faults over tens of feet of outcrop. This fractured gouge zone weathers easily and, like many of the high-angle fault zones, forms a weak zone that now is represented by valleys or notches filled by surficial deposits. Postthrust steep faulting and intrusion cut off the thrusts, and this destruction of parts of the thrusts and the limited exposure of the thrusts make reconstruction of their original extent difficult. Most probably the various mapped segments represent three imbricate faults. The existence of such thrusts, particularly as much as 10 miles east of the Purcell Trench, is a new discovery in the area.

Most of the trench faults are difficult to define because of their sparse outcrops. Two sets of high-angle faults not related to other fault systems seem to be present (pl. 1). One set, well documented in several places, trends north parallel to the trench. This set is evident on the west wall where outcrops in the Selkirk Mountains adjacent to the fault are crushed and slickensided. We will refer to this major fault as the "frontal fault." In places it brings high-grade metamorphic rocks and quartz monzonite on the west against low-grade Prichard Formation, Purcell sills, and Sandpoint Conglomerate on the east. Three faults parallel the frontal fault on the east wall of the trench in the north-central part of the mapped area (pl. 1). The two most eastern of these appear to be cut off by the granodiorite, although they could extend through the granodiorite in covered areas. The westernmost brings Sandpoint Conglomerate into juxtaposition with the Prichard Formation, Purcell sills, and granodiorite. A fault is required father south in the trench to separate rocks with northwest-trending dikes at the lake from rocks with north-trending dikes farther northwest in the trench (pl. 1). As will be discussed later, the gravity map shows a north-trending ridge beneath the western part of the trench; the ridge is indicated also by the line of scattered bedrock outcrops. This partly buried topographic ridge is reasonably interpreted as fault controlled, which leads us to extend with some confidence the east trench fault (or faults) beneath the trench in the approximate position shown. This extension then defines a graben that is clearly exposed in the northern part of the mapped area and that can be extended with reasonable confidence to the main branch of the Hope fault.

A second possible fault set of the trench system is not nearly so well defined. It seems to trend east-northeast to nearly east and to be downdropped on the south. Southeast of Elmira, one such fault brings Sandpoint Conglomerate on the south side against higher grade Prichard Formation and migmatite on the north. Another east-trending fault is required a few miles farther south to separate highly deformed migmatite from a normal low-grade Purcell sill. A third fault of similar trend is required at the north end of the Sunnyside outcrop area (pl. 1) to separate granodiorite, with steep north-trending foliation but without porphyry dikes, from a large Purcell sill which contains porphyry dikes that trend north into the granodiorite. If these faults are part of a set, many others could be buried beneath the cover of surficial deposits in the trench.

The constructional profile in the Purcell trench is that of a graben which contains cross faults. Except for the graben structure, the trench faults resemble the block faults in habit, and our distinction between the two types is probably more for convenience than for distinguishing genetic differences.

ISOTOPIC AGE DATA

Potassium-argon analyses on samples from a region which is so highly deformed and which contains multiple intrusions are commonly subject to a large degree of interpretation because of possible argon loss from the minerals, particularly the micas. Argon loss from both hornblende and biotite in some of the Precambrian rocks of the area is evidenced by the young ages reported. When the isotopic data are considered together with the geologic evidence in the mapped area, a consistent pattern emerges to lead credence to interpretation.

Analytical techniques that were employed have been outlined in detail elsewhere (Kistler and others, 1965; Evernden and Curtis, 1965).

ROCKS IN AND NEAR THE PURCELL TRENCH

Analytical data on rocks in and near the Purcell Trench are given in table 2. Granodiorite porphyry, which is the youngest intrusive rock in the area, gives consistent age data on hornblende and biotite (table 2, samples 1 and 2). We feel confident that the intrusive event that produced the porphyry happened about 50 m.y. ago in the early Tertiary. Because the porphyries fill dilation fractures associated with right-lateral movement on the Hope fault (pl. 1), that movement which offsets the Purcell Trench and the Selkirk Mountains must also be early Tertiary in age.

TABLE 2.—*Isotopic data on some rocks in and near the Purcell Trench*

Sample No. on pl. 1	Rock type	Estimated geologic age	Mineral	K_2O (percent)	Radiogenic Ar^{40} [1] (moles/g $\times 10^{-10}$)	Radiogenic Ar^{40} (percent)	Age (m.y.)
1	Granodiorite porphyry	Tertiary	Biotite	7.94	6.02	85.2	50.7 ± 3.0
			Hornblende	.864	.660	76.3	51.0 ± 1.5
2	do	do	do	.758	.569	70.4	50.2 ± 1.5
3	Seriate porphyritic granodiorite	Cretaceous	Biotite	8.13	8.96	93.5	73.2 ± 2.0
4	Fine-grained granodiorite	do	do	9.16	7.78	91.5	56.7 ± 1.6
5	Seriate porphyritic granodiorite	do	Hornblende	.510	.516	64.4	95.2 ± 3.8
			Muscovite	8.59	6.24	89.2	77.5 ± 2.2
			Biotite	7.26	7.40	91.7	76.1 ± 2.1
6	Gabbro (Purcell sill)	Precambrian	Hornblende	.802	13.10	98.5	870 ± 25
7	Quartz diorite (Purcell sill)	do	do	1.24	10.01	97.8	480 ± 15
8	Biotitic argillite, Prichard Formation	do	Biotite	8.30	8.53	77.9	68.4 ± 2.7
9	do	do	do	5.14	7.19	88.9	92.3 ± 3.5

[1] Decay constants for K^{40}:
$\lambda_{\beta} = 4.72 \times 10^{-10} yr^{-1}$, and
$\lambda_{\epsilon} = 0.584 \times 10^{-10} yr^{-1}$.
Atomic abundance:
$K^{40}/K = 1.19 \times 10^{-4}$.

Samples of two different varieties of granodiorite (table 2; samples 3, 4) give biotite ages of about 73 and 57 m.y. The seriate porphyritic granodiorite (table 2, sample 3) contains green biotite and is typical of most granodiorite in the area. Sample 5 (table 2) is also of the typical seriate porphyritic granodiorite, but it is a sparse variety that contains muscovite and hornblende as well as biotite. The hornblende in sample 5 gives an age of about 95 m.y., whereas the muscovite and biotite give ages of about 77 m.y. This discordance is typical of that within the Kaniksu batholithic complex currently under investigation by Engels in Stevens and Spokane Counties, Wash. (Yates and Engels, 1968; J. C. Engels, written commun., 1971). Engels attributes the various discrepancies among mineral pairs primarily to argon loss as a function of mineral type and of distance from various intrusions of the well-documented and widespread event 50 m.y. ago. As a consequence, she prefers to define one major event about 100 m.y. ago and another about 50 m.y. ago. Mineral ages between these two are assigned, with good cause for many of the minerals, to the 100-m.y.-old event. Gabrielse and Reesor (1964) encountered similar problems in studying potassium-argon ages of plutonic rocks in southern British Columbia 100 miles north of our study area. They also concluded that two major events about 100 m.y. ago and 60 m.y. ago seem to be indicated. Until the true time span for the complex and multiple intrusive process of the Kaniksu batholith is determined, perhaps the generalization of "about 100 m.y." is necessary. Certainly potassium-argon ages between 50 and 100 m.y. ago in the Kaniksu batholith area must be suspect until the age and sphere of influence of every 50-m.y.-old intrusive rock is determined, and this determination does not seem likely to be made in the near future.

On geologic grounds the Cretaceous granodiorite represents an intrusion at a shallower depth and into a cooler environment than the older event involving thrusting, migmatization, and high-grade metamorphism accompanying intrusion of the quartz monzonite. On the other hand, the granodiorite event occurred at greater depth and in warmer surroundings than the 50-m.y.-old event that resulted in near-surface fracture filling by porphyry dikes. Clearly, the granodiorite is the youngest member of the batholithic intrusive complex at the eastern edge of the Kootenay arc, but how much time is truly represented from start to finish of the batholithic emplacement cannot be determined from our limited data. We tentatively place the end at about 95 m.y. ago based on the age of the hornblende from the granodiorite.

Hornblendes from two samples of Purcell sills (table 2; samples 6, 7) give ages of about 870 and 480 m.y. The quartz diorite (sample 7) was analyzed to determine whether the mafic rock, not quite typical of Purcell sills but adjacent to the Gold Creek granodiorite body (pl. 1), was a mafic border similar to that described by Clark (1967, p. 10-12) west of Cocolalla or whether it was an altered Purcell sill. It seems clear that the quartz diorite is an altered sill whose hornblende has lost considerable argon. The gabbro (sample 6) was collected from one of the freshest appearing more magnetic sills of the area. The age of 870 m.y. is about the same as the ages determined on similar sills farther east in Belt terrane (Obradovich and Peterman, 1968, p. 740; J. D. Obradovich, unpub. data). R. E. Zartman (oral commun., 1970) has studied isotopes of lead from veins in Purcell sills north and east of our study area. He found that some sills contain leads of Precambrian age and that the model age for those leads indicates that they are older than the 870 m.y. suggested by our one potassium-argon age. We cannot dismiss the possibility that the extensive reheating near the Purcell Trench during Cretaceous and Tertiary time has also affected our "fresh" hornblende sample; therefore, we conclude that the indicated age of the Purcell sills of 870 m.y. must be considered a minimum age for sills of this area.

Biotite from bedded Prichard argillite (table 2; samples 8, 9) was analyzed in the hope of discovering that heating from the various younger intrusive rocks had not been so extensive as to affect biotite formed during regional (probably Precambrian) metamorphism. The apparent ages of 68 and 92 m.y. indicate extensive argon loss from the biotite and suggest widespread heating in and near the Purcell Trench during intrusion of both the large masses of granodiorite and the smaller masses of porphyries.

REGIONAL CORRELATIONS

Data on ages of the multiple Precambrian events of the general region are still few and are thus insufficient to allow comprehensive historical reconstructions. Information on Cretaceous and Tertiary events is much more abundant, and the historical pattern is beginning to emerge.

Yates and Engels (1968, p. D246) identified two distinct igneous events in northern Stevens County, Wash., which is about 100 miles northwest of our study area. They dated the two-mica gneissic quartz monzonite of the Kaniksu batholith and a satellite granodiorite pluton to the west of the batholith as being about 100 m.y. old. J. C. Engels (written commun., 1971) reports that several varieties of granodiorite and quartz monzonite plutonic bodies in the Chewelah-Loon Lake area about 60 miles west of the Purcell Trench are about 100 m.y. old and that one is about 200 m.y. old. Quartz monzonite of the Kaniksu batholith collected near Arden, Wash., about 60 miles northwest of our study area, has also been dated by lead-alpha methods as being about 94 m.y. old (Larsen and others, 1958, p. 56). Intrusive monzonitic rocks of the Coeur d'Alene district about 40 miles southeast of our study area also give lead-alpha ages of about 120 m.y. (Larsen and others, 1958, p. 54). This widespread 100-m.y.-old event is probably represented in our study area by the quartz monzonite phase of the Kaniksu batholithic complex. We have not attempted to date the quartz monzonites of the mapped area because everywhere they are subjacent to the younger granodiorite. Heating during intrusion of the granodiorite surely has affected the Ar^{40}/K^{40} ratio of the minerals in the quartz monzonite.

A younger series of volcanics and granitic intrusive rocks forms another clear-cut event identified by Yates and Engels (1968). This intrusive-extrusive episode occurred about 50 m.y. ago and corresponds in time to the intrusion of granitic rocks in the Chewelah-Loon Lake area (J. C. Engels, written commun., 1971) and of porphyries in the Purcell Trench. A moot point may be whether the old and dominant crustal break, the Hope fault system, may be reflected somehow in structural features that have controlled intrusion and extrusion as far into the Kootenay arc mobile belt as Stevens County, Wash. At least the trend of the Hope fault system can be projected on strike into that area.

The regional pattern of events can be analyzed from a vertical or a horizontal section. The vertical picture seems reasonably clear at the eastern edge of the Kootenay arc along the Purcell Trench. The intrusive sequence—quartz monzonite with thrusting and high-grade metamorphism, granodiorite with local folding and narrow contact zones, then porphyry with chilled dikes and dike margins filling faults—presents a geologic picture of intrusions succeedingly nearer the surface accompanying new tectonic pulses of different style at the edge of a restless zone. The 95-m.y. age of our typical granodiorite may be low owing to argon loss from hornblende as a result of heating that accompanied intrusion of the 50-m.y.-old porphyries. The batholithic granodiorite event, however, in its geologic expression is significantly different from the quartz monzonite batholithic event about 100 m.y. ago and the chemistry is remarkably similar to the chemistry of the younger intrusives of 50-m.y. age (table 1). We suggest that the granodiorite is about 95 m.y. old, though perhaps it may be as old at 100 m.y.

The horizontal pattern for the region also seems evident. Starting in the middle of the block-fault terrane (fig. 7) and progressing westward we find (1) scattered Cretaceous plutons protruding through low-grade Belt rocks that have relatively simple structure, (2) a gradual increase in size and abundance of Cretaceous plutons, an increase in metamorphic grade of Belt rocks, and at the eastern edge of the Purcell Trench the first abundant Tertiary hypabyssal dikes, and (3) in the Kootenay arc mobile belt abundant Cretaceous and Tertiary plutons, complexly folded high-grade metamorphic rocks, and Tertiary volcanic rocks. The crustal hot area obviously was more intense in the west and persisted for a long time. This multiple intrusive process involving reheating of an area that may have remained warm between intrusive pulses complicates the potassium-argon age interpretations. The composite Kaniksu batholith may represent a long series of magmatic events similar to those documented for the Sierra Nevada batholith (Evernden and Kistler, 1970) in the Upper Cretaceous.

GEOPHYSICAL DATA

Gravity and aeromagnetic surveys provide further information about the structural framework and distribution of lithologies at the intersection between the Hope fault and the Purcell Trench.

The gravity survey was done by the U.S. Geological Survey. It was tied to the North American gravity-control network, station WA 100, located at the Coeur d'Alene, Idaho, airport (Behrendt and Woollard, 1961, p. 70). Data were obtained for 250 stations along roads and jeep trails (pl. 1). These data were corrected for drift, latitude, elevation, and terrain effects. Terrain corrections were computed by means of templates devised by Hammer (1939) for zones B through H, and by means of electronic computer analysis of digitized topographic maps out to a distance of 167 km from each station. The data were reduced to complete Bouguer values using an assumed rock density of 2.67 g/cm^3 (grams per cubic centimeter). Vertical and horizontal positions for the gravity stations were determined from benchmark and photogrammetric control shown on 7½- and 15-minute topographic maps. Vertical positions for about 10 percent of the stations were determined from altimeter surveying.

The aeromagnetic surveys were done by the U.S. Geological Survey and Lockwood, Kessler, and Bartlett, Inc. (pl. 1). Aeromagnetic data of these surveys have been previously released through an open-file map (Meuschke and others, 1962) and a geophysical map (U.S. Geological Survey, 1969). The data were recorded from a fluxgate magnetometer towed by fixed-wing aircraft at barometric elevations of 5,000, 6,000, and 7,000 feet above sea level (pl. 1). Flight paths were north-south with a spacing of half a mile in the northwestern part of the area, east-west with a spacing of half a mile in the southern third of the area, and east-west at a spacing of 1 mile for the remainder of the area. The flight path locations were recorded by a gyrostabilized 35-millimeter continuous-strip camera. The magnetic values are relative to arbitrary datums and are contoured at intervals of 10 and 20 gammas (pl. 1).

PHYSICAL PROPERTIES

Density and magnetic susceptibility measurements were made for the major rock types in the study area (table 3; figs. 5, 6).

Determinations of saturated bulk densities (fig. 5) show that the average densities for the gabbroic rocks of Purcell sills and the lamprophyre-diabase dike rocks are significantly greater than the other major rock types. The gabbroic rocks averaged 2.92 g/cm^3 and are of sufficient mass to produce well-defined gravity maximum anomalies (pl. 1). The lamprophyres and diabases are relatively dense (table 3); four samples averaged 2.84 g/cm^3. They are, however, of insufficient volume anywhere in the mapped area to produce anomalies measurable by the wide gravity station spacing.

Thirty-five of the magnetic values are from the magnetic studies by King, Harrison, and Griggs (1970) in the Packsaddle Mountain quadrangle immediately to the south. Magnetic properties for 80 samples expressed in terms of magnetization and magnetic susceptibility show that the lamprophyre and diabase rocks and the granodiorite are significantly more magnetic than the felsic varieties or the gabbroic rocks of the Purcell sills (fig. 6). The low values for the gabbro, averaging about 0.0002 emu/cm^3 (electromagnetic units per cubic centimeter) susceptibility, are rather surprising, although Dobrin (1960, p. 269) does show a wide range of values for gabbro, 0.0000681-0.002370, expressed in centimeter-gram-second units. King, Harrison, and Griggs noted that the sills showed a neg-

TABLE 3.—*Physical properties of rocks in and near the Purcell Trench*

[Data obtained from hand specimens and cores; two sets of numbers shown where two cores from the same sample were measured]
k, magnetic susceptibility in electromagnetic units per cubic centimeter.
J, remanent magnetization in electromagnetic units per cubic centimeter.
Q, Koenigsberger ratio ($J/0.58k$).
N.d., no data.

Sample No. on pl. 1	$k \times 10^{-3}$	$J \times 10^{-4}$	Q	Density (g/cm^3)	Remarks
			Granodiorite and dacite porphyry		
1	0.27	------	------	2.66	
2	.66	------	------	2.54	
3	1.00	------	------	2.70	
4	.60	------	------	3.01	
5	.47	------	------	2.56	
6	153.75	------	------	2.67	
7	1.00	------	------	2.67	
8	1.78	------	------	2.63	
9	.79	0.81	0.18	2.63	
10	1.32	1.27	.17	2.59	
			Granodiorite and related rocks		
11	1.47	3.54	0.42	2.66	Granite Point body.
	1.21	6.20	.89	2.63	Do.
12	.89	.30	.06	2.61	Do.
	1.18	.32	.05	2.61	Do.
13	.07	.11	.27	------	Do.
	1.19	9.71	1.40	------	Gold Creek body.
14	1.35	9.20	1.17	------	Do.
	.26	1.11	.74	------	Do.
15	.23	.03	.02	2.66	Do.
16	.28	.30	.19	2.64	Do.
17	.70	------	------	2.71	Do.
18	.39	------	------	2.70	Do.
19	.05	------	------	------	Do.
20	.02	------	------	2.67	Do.
21	1.76	------	------	2.67	Do.
22	1.35	------	------	2.65	Do.
23	.36	[1].34	.16	2.58	Sunnyside dike.
	.78	[1].52	.12	2.60	Do.
24	.04	.05	.22	------	Lightning Creek body.
	.05	.09	.31	------	Do.
25	.55	.30	.09	------	Do.
	.61	.10	.03	------	Do.
26	.35	.14	.07	------	Do.
27	.07	.14	.35	2.81	Sill.
28	.06	.05	.13	2.73	Dike.
29	.07	.08	.20	------	Granophyric sill.
30	N.d.[2]	------	------	2.65	Pegmatite dike.
			Lamprophyre and diabase		
31	0.13	------	------	2.89	Lamprophyre dike in deformed area.
32	2.43	0.40	0.03	2.68	Lamprophyre dike.
33	1.01	2.59	.44	2.77	Do.
34	4.46	8.61	.33	3.03	Diabase dike.
			Alaskite and migmatite		
35	0.10	------	------	2.71	
36	.02	------	------	2.61	
37	.03	------	------	2.65	
38	N.d.[2]	------	------	2.74	
39	.02	------	------	2.69	
			Quartz monzonite gneiss		
40	0.02	------	------	2.67	
41	.04	------	------	2.61	
42	.02	------	------	2.60	
43	.02	------	------	2.63	
			Gabbroic rocks of the Purcell sills		
44	0.08	0.11	0.23	2.77	
45	.07	.09	.21	2.97	
46	.11	.04	.06	------	
	.11	.06	.09	------	
47	.69	.02	.04	------	
	.10	.36	.62	------	
48	.07	.01	.03	------	
	.07	.02	.05	------	
49	.11	.06	.09	------	
50	.09	.63	1.2	------	
51	.04	------	------	2.99	
52	.18	9.23	8.84	2.89	
	.17	9.15	9.30	------	
53	.04	------	------	2.94	
54	.03	------	------	2.75	

See footnotes at end of table.

TABLE 3.—*Physical properties of rocks in and near the Purcell Trench*—Continued

Sample No. on pl. 1	$k \times 10^{-3}$	$J \times 10^{-4}$	Q	Density (g/cm^3)	Remarks
Gabbroic rocks of the Purcell sills—Continued					
55	.07	23.1	56.9	------	
	.07	25.0	61.6	------	
56	.07	------	------	2.92	
57	1.18	------	------	2.89	Light-colored differentiate.
58	.68	------	------	3.18	
59	.13	------	------	2.98	
60	.08	------	------	2.94	
61	.81	------	------	2.85	
Schist, gneiss, granofels, and skarn of the Prichard Formation					
62	0.16	------	------	2.74	Gneissic argillitic siltite.
63	.08	------	------	2.70	Quartzitic granofels.
64	.15	------	------	2.75	Mica schist.
65	.26	------	------	2.99	Garnet-quartz skarn.
66	.11	------	------	2.67	Quartz granofels.
67	.05	------	------	2.75	Biotite-quartz-plagioclase gneiss.
68	.12	------	------	2.80	Schistose argillite.
69	N.d.[2]	------	------	2.68	Quartzitic granofels.
70	.02	------	------	2.71	Mica schist.
71	.02	------	------	2.70	Biotite-quartz-plagioclase gneiss.
72	N.d.[2]	------	------	2.66	Mica schist.
73	.05	------	------	2.67	Gneissic argillitic siltite.
74	.14	------	------	2.68	Schistose argillite.
75	.09	------	------	2.65	Do.
Highly biotitic but bedded rocks of the Prichard Formation					
76	0.06	------	------	2.74	Pyrrhotitic argillite.
77	.05	------	------	2.73	Silty argillite.
78	.30	------	------	2.72	Laminated pyrrhotitic argillite and siltite.
79	.14	------	------	2.77	Do.
80	.08	------	------	2.73	Do.
Low-grade metamorphic rocks of the Belt Supergroup					
81	------	------	------	2.71	Libby Formation—silty argillite.
82	------	------	------	2.72	Libby Formation—argillitic siltite.
83	------	------	------	2.68	Do.
84	------	------	------	2.76	Striped Peak Formation—silty argillite.
85	------	------	------	2.77	Striped Peak Formation—dolomitic siltite.
86	------	------	------	2.73	Striped Peak Formation—quartzite.
87	------	------	------	2.76	Wallace Formation—argillite.
88	------	------	------	2.73	Wallace Formation—silty argillite.
89	------	------	------	2.72	Do.
90	------	------	------	2.77	Do.
91	------	------	------	2.76	Wallace Formation—silty dolomite.
92	------	------	------	2.76	Wallace Formation—dolomitic siltite.
93	------	------	------	2.79	Wallace Formation—argillitic siltite.
94	------	------	------	2.75	Do.
95	------	------	------	2.72	Do.
96	------	------	------	2.68	Do.
97	------	------	------	2.70	Wallace Formation—siltite.
98	------	------	------	2.61	Wallace Formation—quartzite.
99	------	------	------	2.76	St. Regis Formation—silty argillite.
100	------	------	------	2.67	St. Regis Formation—argillitic siltite.
101	------	------	------	2.72	Revett Formation—argillitic siltite.
102	------	------	------	2.66	Revett Formation—quartzite.

[1] Core showed unstable remanent magnetism.
[2] Magnetic susceptibility not detectable by method used.

ligible susceptibility and attributed the lack to alteration which may have destroyed the initial magnetism. Any significant remanent magnetism (fig. 6) is assumed to be parallel to the earth's field. King, Harrison, and Griggs found the remanent magnetism to be rather uniformly low with a Koenigsberger ratio, Q, of 0.2 or less. The few exceptions were attributed to lightning strikes.

GRAVITY INTERPRETATIONS

The gravity field of the study area shows a variety of trends and local closures that are superimposed on a regional gradient which dips eastward at about 0.5 mgal (milligal) per mile. The regional is defined by a 60-mgal gradient, which extends for about 120 miles from the Kootenay arc mobile belt on the west across the study area and into the block-fault terrane of western Montana (fig. 7).

Gravity gradient zones correlate with many of the known faults and provide a basis for projecting other faults across areas covered by alluvium. The north-northeast-trending faults of the Purcell Trench produce gradient zones—one gradient zone of 5-10 mgal is well defined along the west wall. In most places the zone is well out in front of the steep topography of the mountain front. The Hope fault, which is nearly normal to the trench, produces many parallel and subparallel gravity trends along its trace. However, it causes little distortion where it crosses the strong north-trending gradient zone of the Purcell Trench.

The northwest-trending strike-slip faults produce intermittent but readily detectable distortions in the predominantly northwest strike of the gravity contours. The northern of the two faults that merge up Pack River near the mouth of Caribou Creek is well defined by a northwest-trending gravity gradient zone, although wide-spaced gravity control precludes detecting the fault where it crosses the north-northeast gradient zone at the mountain front. The causes of the subtle northeastern trends that are shown by the gravity data may be in part due to the configuration of the bedrock surface beneath the surficial deposits. The topographic effects on the gravity data appear to be minor and are not believed to affect the interpretations presented here. The strong topographic control of present valleys by known faults, however, indicates that buried topography in the Purcell Trench is also fault controlled.

Many of the discrete gravity anomalies north of the Hope fault are, by correlation with outcrops and by projection in the subsurface, attributed to the high-density gabbroic rocks (2.92 g/cm^3) of the Purcell sills and the low-density granodiorite (2.67 g/cm^3) relative to the surrounding Belt rocks (2.72 g/cm^3). Less dense surficial deposits may contribute to some of the low-amplitude minimum gravity ano-

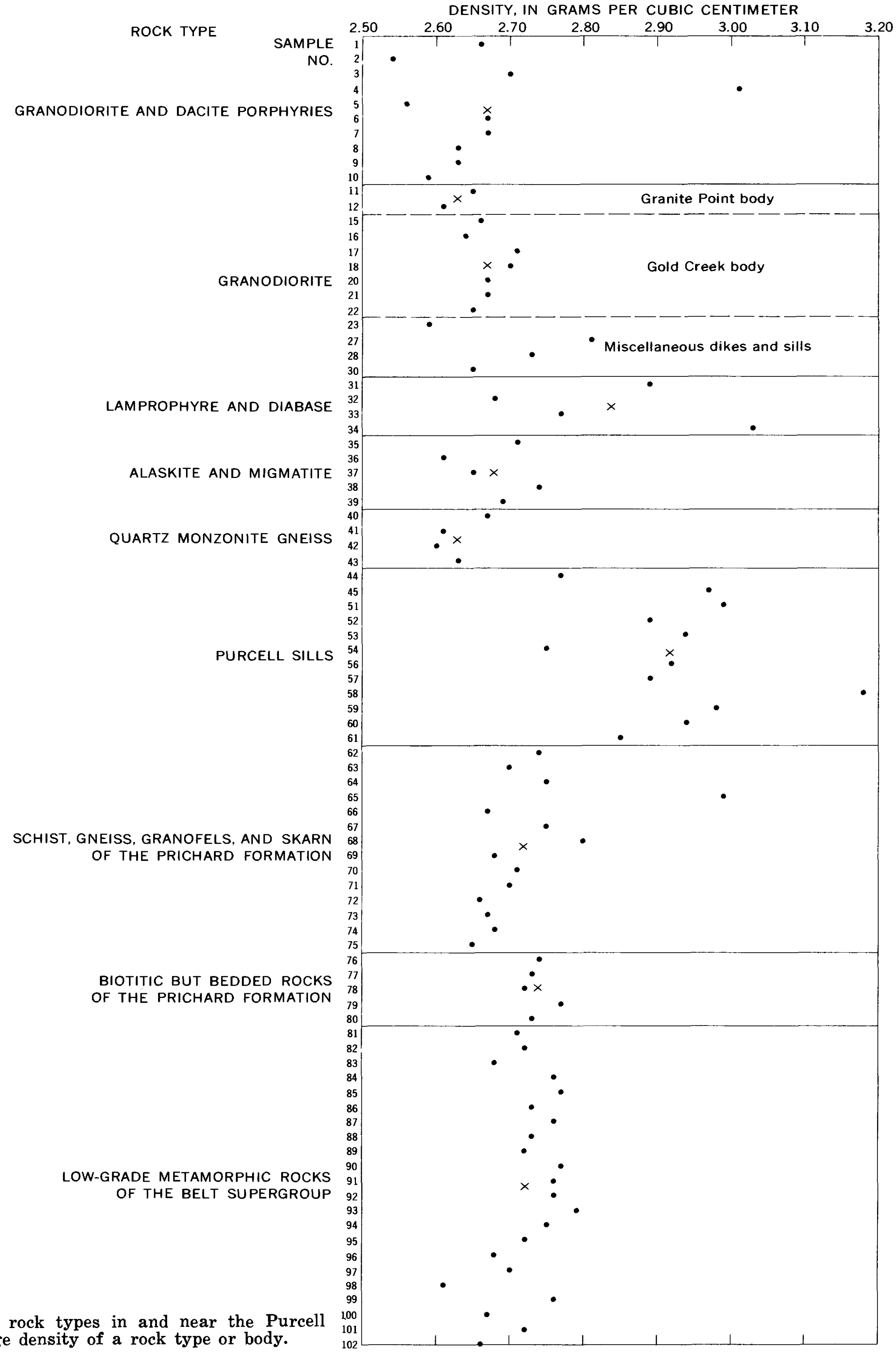

FIGURE 5.—Density of rock types in and near the Purcell Trench. ×, average density of a rock type or body.

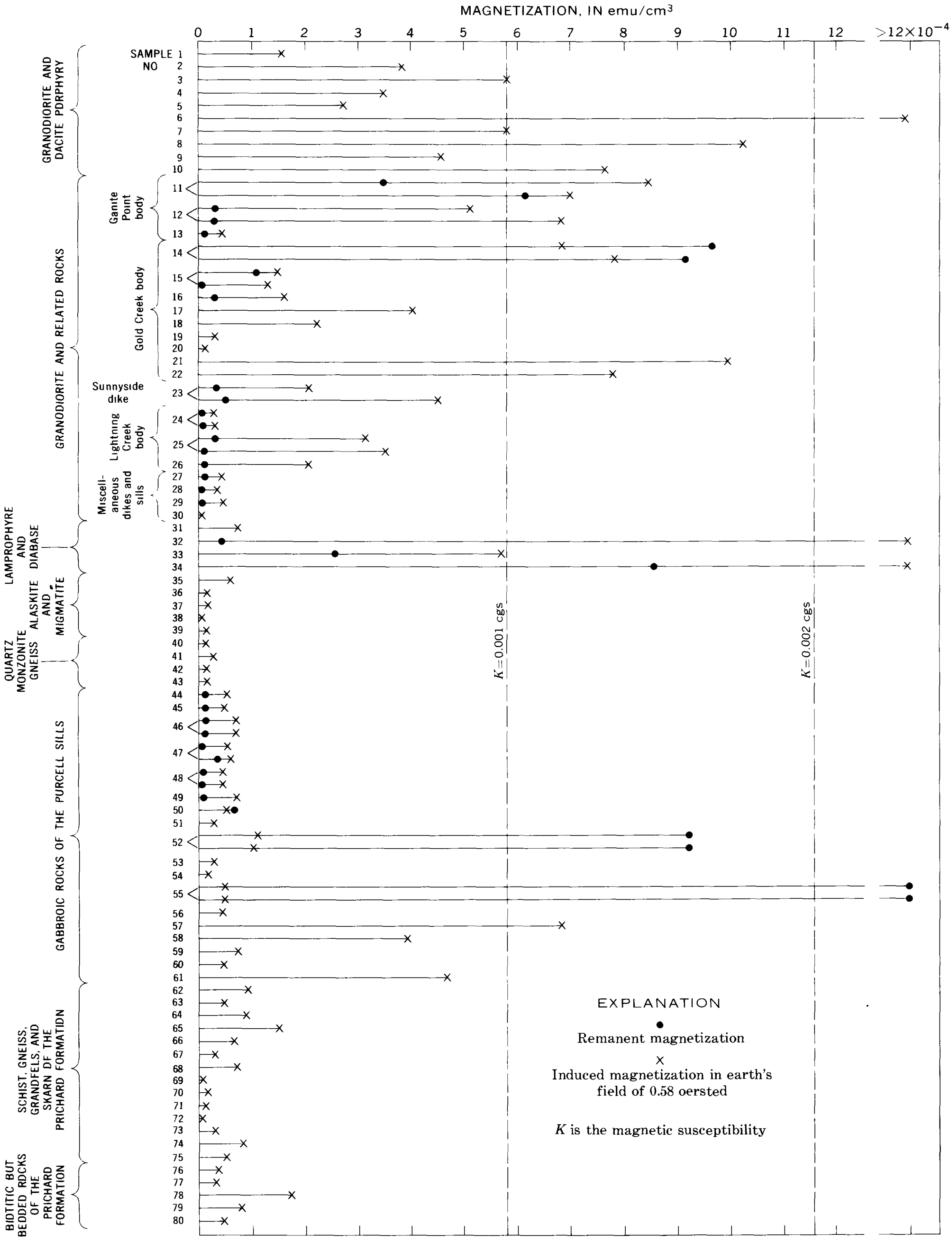

FIGURE 6.—Magnetization of rocks in and near the Purcell Trench. Sample numbers refer to those given in table 3 and shown on plate 1.

malies. The loose correlation of some of the gravity anomalies with the outcrops can be attributed partly to the lack of gravity control and to the unknown configuration of the Purcell sills and granodiorite in the subsurface.

Gravity Anomalies

The anomalies are identified by alphabetical letters on plate 1 and are keyed to the discussions to follow. Anomalies A through H are attributed mainly to gabbroic rocks of the Purcell sills; anomalies I through P, to granodiorite rocks.

A. The southwest-trending minimum nosing probably reflects cumulative effects of the sills.

B. The maximum closure correlates with the sills.

C. The maximum anomaly reflects sills that are partly buried by Sandpoint Conglomerate.

D. The maximum closure may be due to a greater subsurface extent of the sill outcrop.

E. The north-northeast-trending maximum anomaly correlates with a complex of sills. The maximum trend extends from the closure E north to D, which suggests a fault-controlled block within the trench.

F. The northeast-trending maximum anomaly may be due to a sill in the subsurface southwest of the faulted outcrop. The sill may extend in an arcuate pattern in the subsurface to connect with the sill outcrop at anomaly E.

G. The maximum closure reflects mainly sill outcrop.

H. The maximum anomaly correlates with sill outcrop.

I. The southwest-trending gravity minimum anomaly may represent a granodiorite mass in the subsurface of considerably greater extent than the small outcrop. A thick section of surficial deposits could account for part of the anomaly.

J. The minimum closure may reflect a granodiorite or quartz monzonite body that did not penetrate the thrust plate of Belt rocks. Several hundred feet of preserved sediments could account for the minimum anomaly.

K. The minimum closure may be caused by low density, possibly highly fractured buried granodiorite near the fault intersections. The small outcrop of granodiorite along the Pack River suggests that the surficial deposits are not thick.

L. The minimum anomaly may be due to buried granodiorite. Low-density sediments preserved along the fault would contribute to the anomaly.

M. The minimum closure at M may be caused by the faulting along the west side of the granodiorite and gabbroic sill complex.

N. The minimum anomaly may be caused by a north-trending fault-controlled valley of sediments, between masses of high-density Purcell sill.

O. The minimum anomaly may be due to low-density fractured granodiorite along the fault zone.

P. The extensive minimum anomaly appears to center over the main mass of the granodiorite batholith.

Q. The minimum anomaly within the Purcell Trench may be caused by a fault-controlled valley which is cut into Sandpoint Conglomerate and which is filled by glacial debris and alluvium.

R. The source of the minimum anomaly on the batholith is unknown. Grus at least 30 feet thick is known in the areas and may contribute, along with a thick glacial cover, to the gravity low.

S. The cause of the maximum anomaly is not known.

T. The minimum anomaly may be due to a low-density fracture zone that has been developed along the Hope fault zone.

U. The source of the large maximum anomaly appears to be composite. The steep gradient along the northwest side probably is due to the low-density lake fill. The southeastward elongation may be due to a concentration of sills.

V. The minimum nosing may be an expression of a southeast-trending second-order fault branching from the Hope fault.

W. The gravity maximum trend probably represents the large highly faulted sill.

MAGNETIC INTERPRETATIONS

The aeromagnetic map (pl. 1) is shown on a bedrock geologic map that was constructed from interpretation of the geologic and gravity maps of plate 1 as modified slightly by the aeromagnetic data. The aeromagnetic map shows a complex of anomalies superimposed on the regional magnetic field which dips to the southwest in this region at a rate of about 6 gammas per mile (pl. 1).

Magnetic gradient zones and anomaly trends correlate with most of the major structural features of the area. The gradient zones, often in conjunction with gravity trends, were useful in interpreting the fault patterns beneath surficial deposits. The magnetic data along and to the south of the Hope fault were studied by King, Harrison, and Griggs (1970). They noted that the fault defines a zone of demarcation between low magnetic gradients on the south and variable but high magnetic anomalies on the northeast (pl. 1). In addition, they concluded that positive magnetic anomalies reflect both exposed and buried granodiorite cupolas and stocks south of the Hope fault and that major faults were expressed by linear negative anomalies. However, north of the Hope fault, in the area of this report, the magnetic field is distorted by porphyry dikes, certain Purcell sills, and exposed and buried granodiorite. The highly magnetic lamprophyres (fig. 6) apparently are not concentrated enough to produce detectable anomalies, but notable magnetic anomalies do correlate with the porphyry dike swarms and with limited areas of unaltered Purcell gabbro. A major negative trough that trends north along the west edge of the area of the data correlates with the segment of the Purcell Trench. Some of the northeastward-trending "grain" in the magnetics can be correlated with trends of the Purcell sills. Most of the northwestward-trending faults that cross the Purcell Trench are confirmed by the magnetic data. The northernmost fault up Pack River, which was also mentioned in the gravity discussion, is a good example.

The Purcell sills range in composition from quartz diorite to gabbro. The quartz dioritic rocks (such as table 3; samples 53, 54) are altered varieties that commonly contain only 1 percent or less of magnetite and abundant biotite, quartz, and, at some places, sphene, calcite, and epidote. The unaltered gabbro (such as table 3; samples 57, 58) contains as much as 9 percent magnetite and is virtually a hornblende-plagioclase gabbro. The variation in magnetic susceptibility (table 3) correlates well with rock type, degree of alteration, and magnetite content. Isotopic dating of the hornblende also correlates with the same features in that the quartz diorite of low magnetic susceptibility (table 3; samples 53, 54) gives an anomalously low age of 480 m.y. (table 2, sample 7), whereas the freshest gabbro of high magnetic susceptibility (table 3; samples 57, 58) gives an older minimum age of 870 m.y. (table 2, sample 6).

Although the terrain is steep, particularly on the east, no topographic effects were detected that would detract from the interpretation.

Magnetic Anomalies

The local magnetic closures and nosings are identified on plate 1 by letters. Magnetic anomalies have been given the same letter as the gravity anomalies (pl. 1). Additional anomalies with no gravity counterpart are included (letters X, Y, Z, and AA on pl. 1).

B. The positive magnetic anomaly may be caused by buried granodiorite bounded by the graben fault. The outcropping sills in this area probably are not a factor contributing to the anomaly because laboratory measurements show their susceptibility to be negligible (fig. 6).

J. See discussion of W below.

M. The positive magnetic anomaly suggests the presence of more extensive granodiorite and porphyry dikes extending beneath the lake from the outcrop on shore.

R. The cause of the arcuate northeast-trending negative magnetic anomaly is unknown. As for the coincident gravity anomaly, the grus along with a thick glacial cover may contribute to the negative anomaly.

W. The large magnetic positive anomaly apparently is caused by the complex of granodiorite and porphyry dikes. The elongation of the anomaly to the north-northwest and south-southeast correlates with the trend of the dike swarm. It is postulated that the dikes extend northwestward beneath and beyond the Sandpoint Conglomerate and the upper plate of the thrust to the magnetic positive anomaly J which may represent a greater concentration of near-surface dikes beneath the thrust. Anomaly J lies across the railroad tracks, but flightpath photography shows no evidence of a train or other cultural magnetic disturbances present during the overflights.

X. The positive anomalies correlate with outcropping granodiorite; one body of granodiorite is shown on plate 1, and two others are shown on early reconnaissance maps of Anderson (1930, pl. 14) in the area beyond the area of geologic data presented in this report.

Y. Several low-amplitude positive magnetic anomalies over the batholith suggest local magnetite enrichment in exposed and near-surface granodiorite rocks.

Z. The negative anomalies probably represent deformed Purcell sills of low susceptibility.

AA. The magnetic positive anomalies of 80-100 gammas in amplitude apparently represent Purcell sills of higher than average magnetite content for this region, which have escaped the excessive deformation and alteration that may have destroyed much of the magnetite in many of the other sills.

SEQUENCE OF TECTONIC EVENTS

A very long and complicated history of folding, faulting, and intrusion is represented in the mapped area. Within the area, conclusive data on the sequence of several Precambrian events are few, but data on most Cretaceous and Tertiary events seem well documented. We interpret the geologic, geophysical, and isotopic data as indicating the following events:

1. Precambrian time: Axial plane faulting of metamorphosed Belt rocks gently folded on north-trending axes, perhaps accompanied by intrusion of Purcell sills sometime prior to 870 m.y. ago. This faulting included first movement on the ancestral Hope fault. Block faulting at some time before deposition of Cambrian sedimentary rocks.
2. Late Cretaceous time:
   (a) Intrusion of the quartz monzonite of the Kaniksu batholith about 100 m.y. ago. Eastward thrusting, accompanied by refolding, migmatization, and final stages of high-grade metamorphism of Prichard Formation and Purcell sills. East-trending upright to overturned folds formed and crossfolded during thrusting.
   (b) Emplacement of the granodiorite of the Kaniksu batholith about 95 m.y. ago. The granodiorite intruded through the older thrust plates. It was accompanied by some shouldering aside and consequent local folding where it intruded rocks of the Prichard Formation. Metamorphism in contact zones was largely thermal and occurred in the biotite zone of the greenschist facies.

   The intrusion at depth was accompanied by tectonic swelling over a large area of the United States part of the Kootenay arc at least from the Magee fault zone (King and others, 1970) southeast of Pend Oreille Lake to the Canadian border. Sandpoint Conglomerate formed at the surface as a local torrentially deposited fanglomerate dumped off the east side of the rising Selkirk Mountains into the then-forming Purcell graben. Location of conglomerate probably was controlled by frontal fault north of the Hope fault.

   (c) Collapse of the graben as the granodiorite cooled.
3. Early Tertiary time: Renewed tension across the Purcell Trench accompanied first by further relative depression of the graben and uplift of the Selkirk Mountains. A total throw on the frontal fault of at least 6,000 feet down on the east is required to allow for derivation of the low-grade metamorphic rocks of the Sandpoint Conglomerate from Prichard rocks once roofing the intrusives of the Selkirk Mountains. This event was followed closely about 50 m.y. ago by southeast movement of the block north of the Hope fault, which resulted in fan faults from the main fault and tension fractures filled by porphyries. Both the Selkirk Mountains and the Purcell graben were offset several miles right laterally. Dilation appears to have been limited to the area east of the frontal fault and was generally confined to rocks below the thrusts. Slight eastward tilting of the graben is suggested by the average dip of 25° in the Sandpoint Conglomerate, because an initial dip of more than about 15° seems unlikely for a large water-laid fanglomerate unless it represents foreset beds in a deltaic deposit.

The complexity of the intersection between the Purcell Trench and the Hope fault is more clearly understood if viewed in context of the regional framework. The Purcell Trench marks the general eastern border of a highly active tectonic zone. The active zone is old and recurrent, for it represents a positive area that probably occurred during late Belt time (Harrison and Campbell, 1963, fig. 4) and certainly during Windermere time (latest Precambrian) when volcanics and conglomerates were deposited on Belt rocks across the western slope of the Selkirk Mountains northward into Canada. The area of northeastern Washington is also sieved by Cretaceous batholiths and covered in part by Tertiary volcanic rocks. The area thus seems to represent an old crustal hot zone of considerable size that was persistently active at least through the Tertiary.

Thrusting to the east at the edge of the Kootenay arc is not surprising, and its extent may be much greater than indicated by the few faults identified to date. D. T. Bishop (written commun., 1970) identified the Strawberry Mountain thrust (the easternmost thrust on pl. 1) in Boundary County. Clark (1967, pl. 1) mapped large overturned to recumbent folds just west of the Purcell Trench along the Pend Oreille River (fig. 1). Although she does not interpret these structural features as being related to thrusting, her data permit such an interpretation. Rice (1941) showed younger Belt rocks thrust over Prichard (his Aldridge) Formation a few miles west of the Purcell Trench at the international boundary.

REGIONAL IMPLICATIONS

The principal tectonic provinces that involve Belt rocks are shown in figure 7. The simplest of these structurally is the block-fault terrane in which generally broad open north-trending folds have been block faulted during Cenozoic time (Pardee, 1950) to form basin-and-range structure and topography. Three major downfaulted areas occur within this terrane—the Purcell Trench, which forms the western boundary; the Libby Trough, which includes a series of dropped blocks of Cambrian rocks but which is not as pronounced topographically as other trenches; and the Rocky Mountain Trench, which is a graben (Mudge, 1970). On the east is the Montana thrust belt, a wide zone of imbricate and complicated thrusts of Cretaceous age (Mudge, 1970). On the west is the Kootenay arc mobile belt, a complex zone of intense deformation, faulting, intrusion, and extrusion. Superposed on the block-fault terrane and the mobile belt are the Lewis and Clark line (or the Osburn fault zone) and the Hope fault (or fault zone).

Northward in British Columbia, the central simpler tectonic province is called the Purcell anticlinorium. It is considered to be bounded on the east by the Rocky Mountain Trench and on the west by the Kootenay arc (Wheeler, 1966, fig. 2-1). A few miles into Canada the apex of the anticlinorium becomes distorted and complicated by extensive thrusting, folding, and high-grade metamorphism of Paleozoic and younger ages.

The Purcell Trench appears to be partly a graben and partly a topographic accident. South of Kootenay Lake in British Columbia, Rice (1941, map 603A) showed faults in and near the Purcell Trench

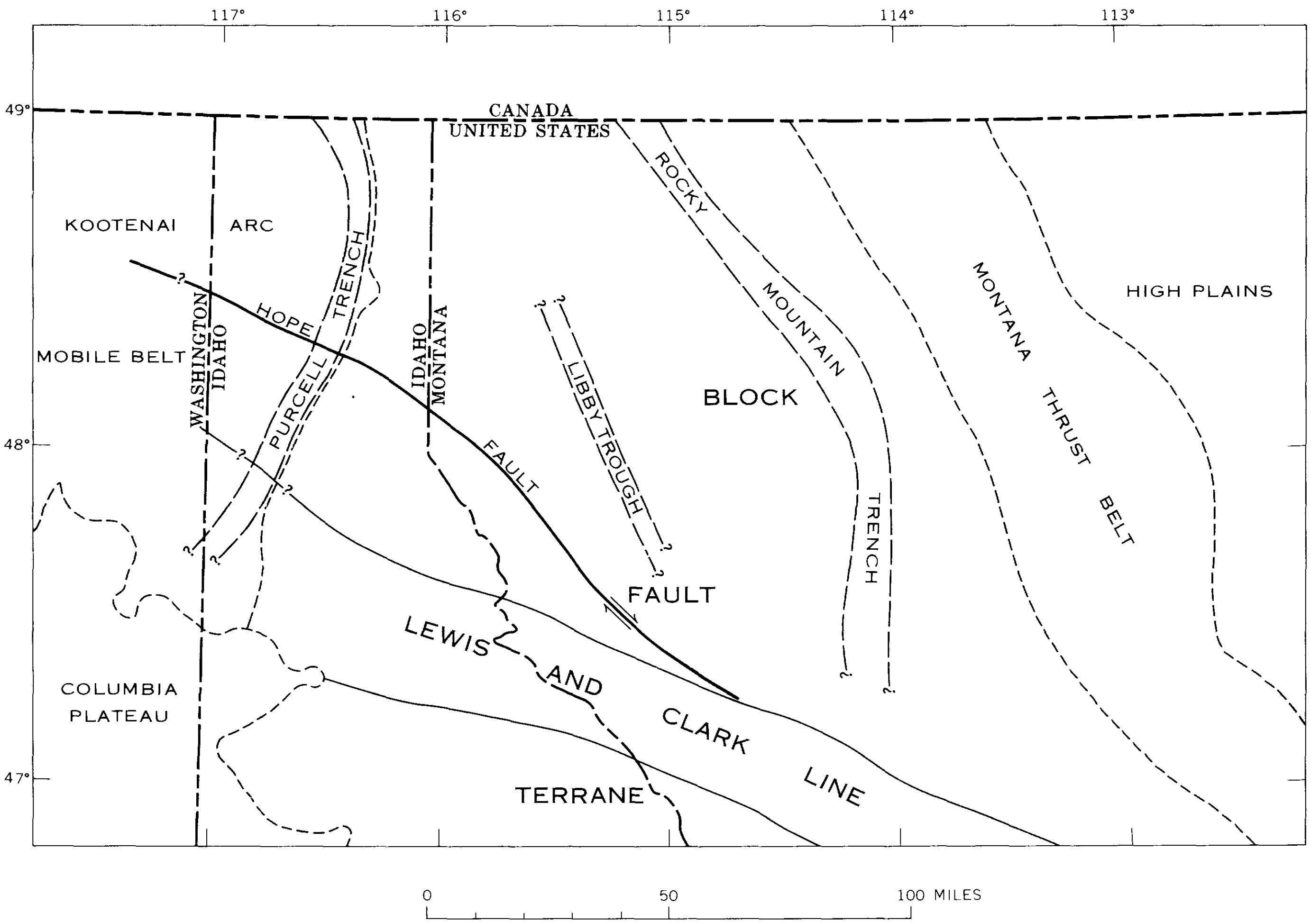

FIGURE 7.—Principal geologic and tectonic provinces, eastern Washington, northern Idaho, and northwestern Montana.

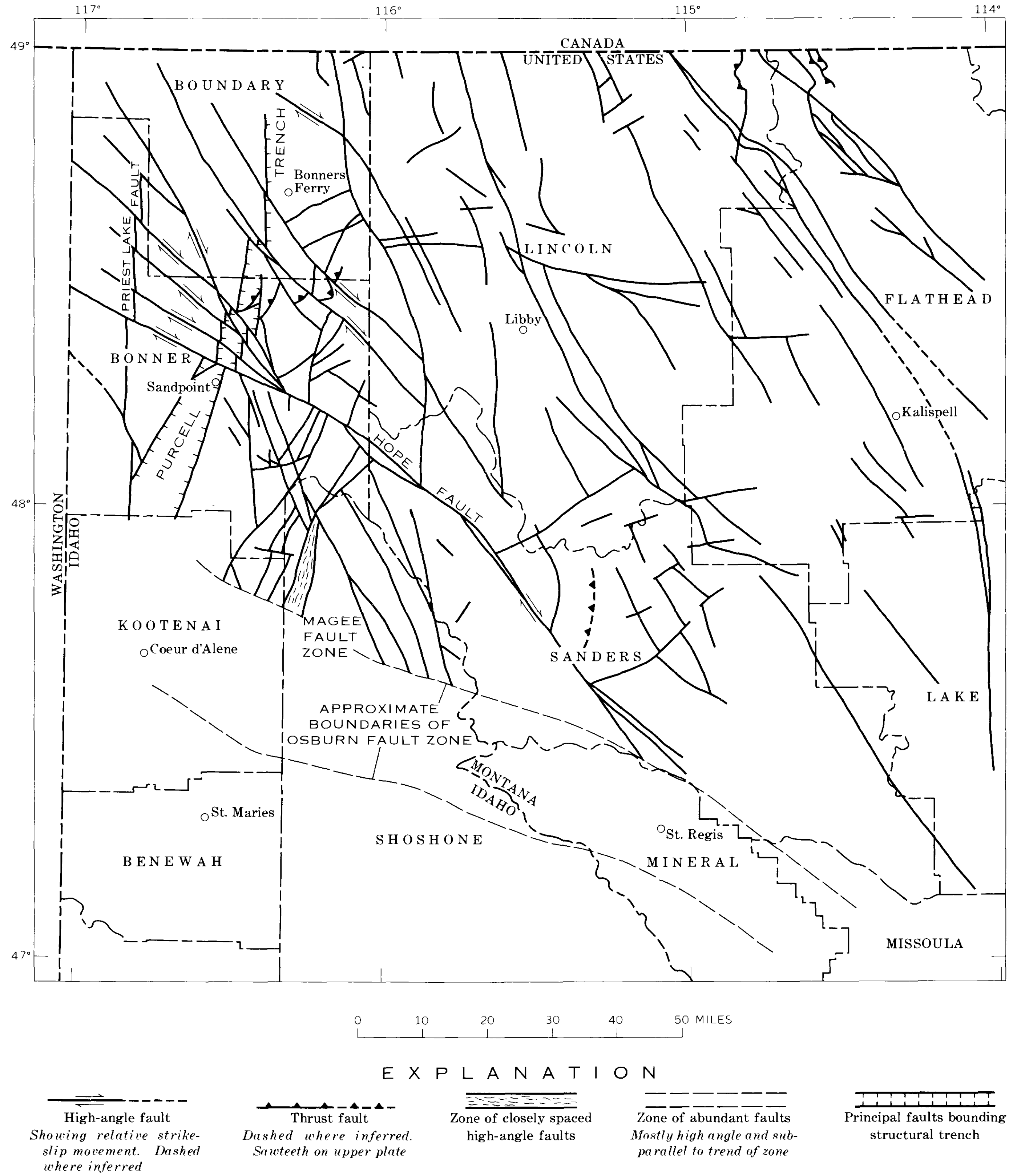

FIGURE 8.—Major faults in northern Idaho and northwestern Montana. Modified from Bayley and Muehlberger (1968).

that cross the topographic trench at a low angle to the northeast. These faults are on strike with trench faults to the south in northern Idaho (fig. 8). Some trench faults just north of the Hope fault form a graben that contains Sandpoint Conglomerate, as well as older Belt rocks and Purcell sills.

South of the Hope fault, existence of a graben is more speculative. Clark (1967, p. 128) emphasized the relatively low grade of metamorphism of rocks in the "Fish Creek unit" southwest of Cocolalla (pl. 1). She correlated these rocks with the Prichard Formation, and we agree. The anomalously low grade compared with that of metamorphic rocks a few miles to the west may be due to tectonic lowering in the graben.

Farther south, the trench is broader and less well defined where it joins a broad flat area north of Coeur d'Alene known as Rathdrum Prairie. In this area a major north-trending high-angle fault mapped by Savage (1967, fig. 2A) along Priest Lake and extending several tens of miles to the south probably connects with a north-south fault indicated by a pronounced north-ternding gravity trough (D. L. Peterson, written commun., 1969) found in Rathdrum Prairie. The junction of these major faults (fig. 8) may help explain the location of such a broad valley.

The Purcell Trench in the United States does approximate the eastern edge of the Kootenay arc mobile belt. Faulting at the edge of the mobile belt has resulted in a structural trench, partly a graben, whose continuity is certainly topographic but not necessarily that of a single structural feature. Northward into Canada the topographic continuity is obvious, but no single feature controls the trench which may be there because of glacial widening of valleys superposed on the present bedrock or because of control by joints rather than by faults.

The pronounced pattern of northwest-trending high-angle faults of northern Idaho and northwestern Montana (fig. 8) is not cut off at the Purcell Trench as previously supposed. Many of these faults were active during the Cenozoic (Pardee, 1950), but many also appear to be as old as Precambrian and others are Cretaceous in age. Early Tertiary movement on the Hope fault system is clearly that of northeast blocks moving toward the southeast, which is the reverse of what is required by current theories of the effects of continental drift on this particular continental plate (Hamilton and Myers, 1966, p. 535). Local reactivation of the persistent mobile belt may control the absolute direction of thrusting and dilation in this small part of the crust, which may be anomalous in terms of continental tectonics.

The extent of the Hope fault system to the northwest is not known. It seems clear, however, that this old structural element is a big one in the crustal framework of the northwestern United States.

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