GJBX-5(78)

PRELIMINARY STUDY OF URANIUM FAVORABILITY OF THE BOULDER BATHOLITH, MONTANA

BENDIX FIELD ENGINEERING CORPORATION
Grand Junction Operations
Grand Junction, Colorado 81501

January 1978

MASTER

ISSUED BY THE U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE
UNDER CONTRACT NO. E(05-1)-1664

DISCLAIMER

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SUMMARY

The Boulder batholith of southwestern Montana is a composite Late Cretaceous intrusive mass, mostly composed of quartz monzonite and granodiorite. This study was not restricted to the plutonic rocks; it also includes younger rocks that overlie the batholith, and older rocks that it intrudes.

The Boulder batholith area has good overall potential for economic uranium deposits, because its geology is similar to that of areas that contain economic deposits elsewhere in the world, and because at least 35 uranium occurrences of several different types are present.

Potential is greatest for the occurrence of small uranium deposits in chalcedony veins and base-metal sulfide veins. Three areas may be favorable for large, low-grade deposits consisting of a number of closely spaced chalcedony veins and enriched wall rock; the Mooney claims, the Boulder area, and the Clancy area. In addition, there is a good possiblity of by-product uranium production from phosphatic black shales in the project area. The potential for uranium deposits in breccia masses that cut pre-batholith rocks, in manganese-quartz veins near Butte, and in a shear zone that cuts Tertiary rhyolite near Helena cannot be determined on the basis of available information. Low-grade, disseminated, primary uranium concentrations similar to porphyry deposits proposed by Armstrong (1974) may exist in the Boulder batholith, but the primary uranium content of most batholith rocks is low.

The geologic environment adjacent to the Boulder batholith is similar in places to that at the Midnite mine in Washington. Some igneous rocks in the project area contain more than 10 ppm U_3O_8, and some metasedimentary rocks near the batholith contain reductants such as sulfides and carbonaceous material.

INTRODUCTION

PURPOSE

The project was undertaken by the Bendix Field Engineering Corporation (BFEC) for the Grand Junction Office of the U.S. Energy Research and Development Administration (ERDA).

LOCATION

The Boulder batholith is exposed over about 1,500 sq mi in southwestern Montana. The project area (Fig. 1) covers approximately 3,000 sq mi, and is largely defined by the limits of the batholith, but younger overlying rocks and older host rocks are also included.

PREVIOUS WORK

The U.S. Geological Survey has published 11 geologic maps that cover 60 percent of the project area. Most of the remaining 40 percent is covered by open-file or unreleased geologic maps, and by maps included in two unpublished doctoral dissertations. References to these are listed on Plate 1. About 5 percent of the area is not covered by detailed geologic mapping.

Publications specifically dealing with uranium in the batholith include those by Roberts and Gude (1953a, 1953b), who described the geology of uranium deposits in the Clancy and Free Enterprise areas, and by Tilling and Gottfried (1969), who reported on throium, uranium, and potassium contents of igneous rocks.

Between 1950 and 1959, many short publications that dealt with uranium deposits in the Boulder batholith were released by the U.S. Atomic Energy Commission, including two reports on drilling projects (Jarrard and Mead, 1955; Moen, 1959). Of particular interest is a detailed mineralogical study of selected uranium veins in the batholith (Wright and others, 1957).

PROCEDURES

The project involved review of literature on the area, field investigations, laboratory analyses, and petrographic studies. Field work included examination of outcrops, mines, and prospects, and collection of 122 samples for laboratory analysis and petrographic study. Two areas in the Boulder batholith that contain many uranium occurrences, north of Boulder (Pl. 1) and surrounding Clancy (Pl. 2), were studied and sampled in detail to determine if distinctive geologic features, which are not characteristic of the batholith as a whole, are present in these areas.

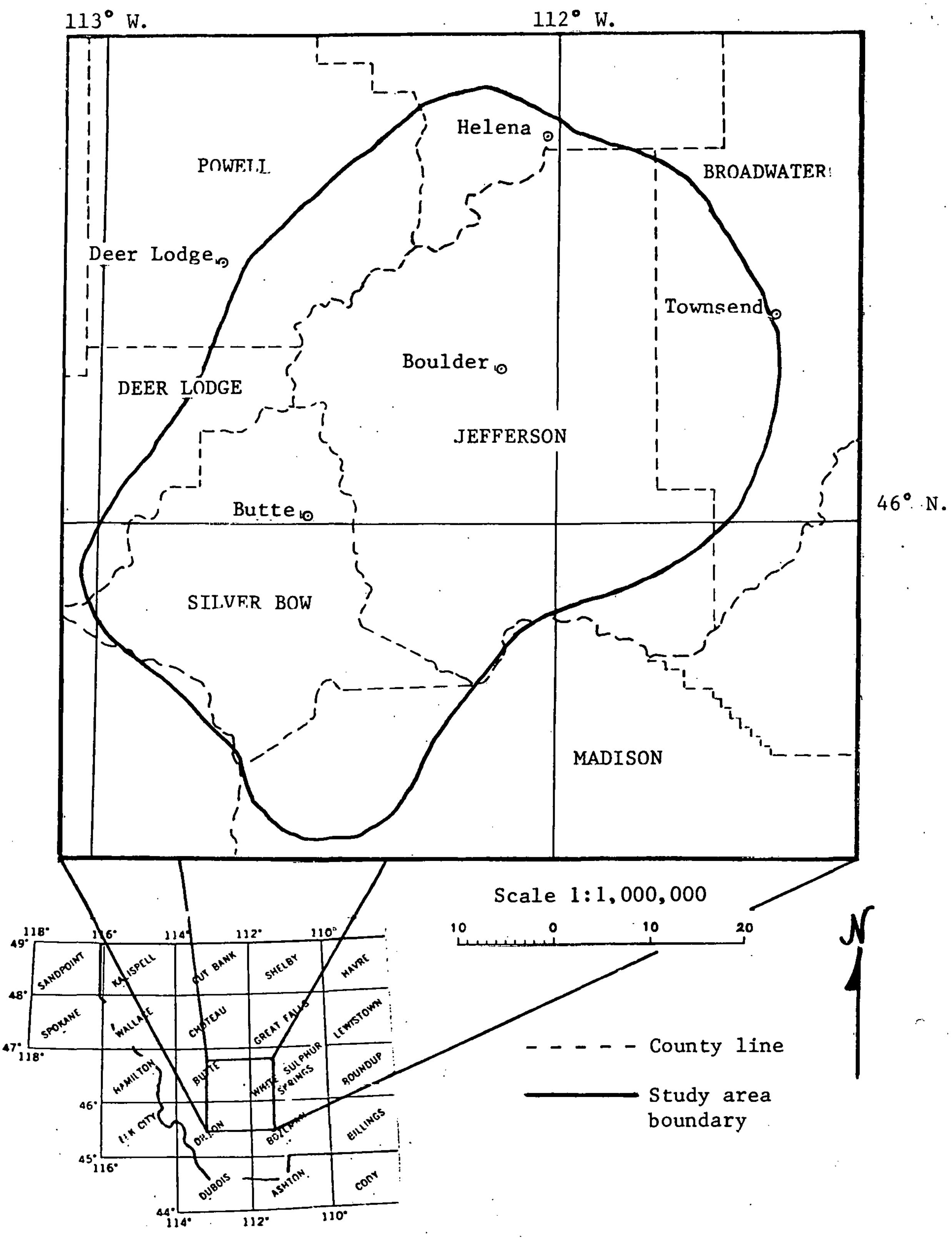

Figure 1. Location map.

All samples were analyzed for equivalent uranium, equivalent thorium, and equivalent potassium, using gamma-spectrometric methods; and U_3O_8 contents of 61 samples were obtained by fluorometry (App. A). Petrographic analyses of 65 samples were performed to determine mineralogy and modal composition; partial modes of 40 samples were determined by stereomicroscopic examination of stained slabs (Tables 1, 2, 3). Uranium minerals in selected radioactive samples were identified by x-ray diffraction techniques.

ACKNOWLEDGMENTS

Robert I. Tilling of the U.S. Geological Survey, Reston, Virginia, provided information on locations of samples for which uranium, thorium, and potassium contents have been published (Tilling and Gottfried, 1969). Harry W. Smedes of the U.S. Geological Survey provided information on areas for which published or open-file geologic maps were not available.

REGIONAL GEOLOGY

ROCK UNITS

The Boulder batholith is a composite intrusion of Late Cretaceous age. It includes rocks which range in composition from gabbro to alaskite; however, at least 90 percent of the exposed rocks are quartz monzonite or granodiorite (Pl. 1).

The batholith was emplaced in sedimentary and metamorphic rocks of Precambrian to Late Cretaceous age. The Elkhorn Mountains volcanics, which include andesite, quartz latite, and rhyolite, are considered to be extrusive equivalents of the batholith, on the basis of composition and radiometric age (Robinson and others, 1968). Where contact relations have been observed, these volcanics are cut by rocks of the batholith.

Post-batholith rocks include Tertiary sedimentary rocks, which are mostly restricted to peripheral basins, and at least two volcanic units. The quartz latite Lowland Creek volcanics of early Eocene age (Smedes and Thomas, 1965) unconformably overlie the batholith on the west, and subvolcanic rocks of similar composition and age intrude the batholith. Rhyolite flows and intrusions (referred to as post-Lowland Creek rhyolite on Pl. 1), which are restricted to the northern third of the batholith, have been assigned ages that range from Oligocene to Pliocene (Becraft and others, 1963; Ruppel, 1963).

TABLE 1. URANIUM AND THORIUM CONTENTS OF CHALCEDONY VEIN SAMPLES.

Sample number	Rock type	Fluorometric U_3O_8 (ppm)	Gamma-spectrometric data eU (ppm)	eTh (ppm)	eU/eTh	Uranium minerals	Plate location
03	Buff to brown silica breccia	390	339.6	7.0	48.5	meta-autunite	2
62	Buff to brown silica vein	39	37.3	8.9	4.2		2
64	Buff to brown silica breccia	220	168.7	18.2	9.3	fluorescent opal	2
67	Buff to red-brown silica breccia	--	197.2	6.4	30.8		2
70	White to buff silica vein	--	61.4	14.9	4.1	fluorescent opal	3
96	Ochre-colored silica vein	--	38.0	2.0	19.0		3
97	Black to ochre silica-barite breccia	540	232.3	34.2	6.8		3
99	Reddish-brown silica vein	--	28.9	27.4	1.1		3
508	Gray silica vein	99	76.6	5.0	15.3	fluorescent opal	3

TABLE 2. URANIUM AND THORIUM CONTENTS OF SAMPLES OF ALTERED WALL ROCK ASSOCIATED WITH CHALCEDONY VEINS.

Sample number	Rock type	Fluorometric U_3O_8 (ppm)	Gamma-spectrometric data eU (ppm)	Gamma-spectrometric data eTh (ppm)	Gamma-spectrometric data eU/eTh	Uranium minerals	Plate location
02	Silicified quartz monzonite	12	13.8	19.1	0.7		2
25	Argillized quartz monzonite	800	592.6	21.9	27.1	meta-autunite, meta-uranocircite	2
48	Argillized quartz monzonite	7	4.8	30.8	0.2		2
69	Argillized quartz monzonite	28	18.2	21.4	0.9		3
72	Chloritized quartz monzonite with pyrite	--	5.0	18.6	0.3		3
73	Silicified quartz monzonite	3910	--	--	--	coffinite	3
74	Silicified quartz monzonite	--	492.2	19.1	25.8	meta-autunite	3
95	Silicified alaskite	8	7.2	30.5	0.2		3
98	Weakly altered alaskite	--	25.1	38.2	0.7		3
511	Argillized quartz monzonite	--	4.9	21.5	0.2		2
530	Argillized quartz monzonite	6	3.6	16.7	0.2		1

TABLE 3. URANIUM AND THORIUM CONTENTS OF IGNEOUS ROCKS IN THE BOULDER BATHOLITH PROJECT AREA.

	Rock Type	Number of Samples		Modal Mineralogy: Potash Feldspar	Plagioclase	Quartz	Horn-blende	Biotite	Opaques	Alteration Minerals	Gamma Spectroscopic data: eU ppm	eTh ppm	eU/eTh	Fluorometric U_3O_8 ppm
POST-BATHOLITH	Post-Lowland Creek rhyolites	3	ave. range	Too fine-grained for petrographic modal determinations, mostly potash feldspar and quartz or cristoballite, with subordinate plagioclase and minor biotite, some samples contain glass.							11.0 7.9-13.0	42.7 33.4-58.1	0.27 0.22-0.36	17 12-25
POST-BATHOLITH	Lowland Creek volcanics	4	ave. range	28 10-54	28 0-46	33 0-60	trace 0-2	8 trace-20	3 trace-10	trace	4.3 1.5-10.0	11.0 4.3-17.7	0.38 0.21-0.56	4 4-5
BATHOLITH AND RELATED ROCKS	Alaskite	25	ave. range	36 15-54	21 0-45	42 25-60	----	trace 0-1	trace 0-1	trace	4.5 2.1-8.3	38.0 12.8-50.2	0.12 0.05-0.23	6 4-9
BATHOLITH AND RELATED ROCKS	Silicic granitic rocks	2	ave. range	16	32	43	2	5	2	?	7.0 6.1-7.8	25.8 20.8-30.8	0.29 0.20-0.38	16 10-22
BATHOLITH AND RELATED ROCKS	Leucocratic granitic rocks	6	ave. range	38 25-53	26 17-36	29 24-38	----	6 trace-9	trace 0-2	?	10.5 2.6-30.7	28.1 15.6-42.2	0.35 0.10-0.86	18 4-43
BATHOLITH AND RELATED ROCKS	Quartz monzonite	25	ave. range	30 20-44	33 22-40	22 10-35	6 0-12	5 0-8	1 trace-5	3 1-14	4.8 3.0-8.7	20.5 14.2-33.1	0.23 0.17-0.43	6 4-14
BATHOLITH AND RELATED ROCKS	Granodiorite	4	ave. range	20 15-25	41 32-55	16 10-20	9 5-11	8 5-14	4 1-11	4 3-5	3.0 2.0-3-6	16.5 15.4-17.5	0.18 0.13-0.23	
BATHOLITH AND RELATED ROCKS	Elkhorn volcanics	2	ave. range	10 0-20	40 35-44	42 40-45	2 1-4	2 1-3	1	trace	2.2 2.1-2.4	10.4 9.8-11.1	0.22 0.21-0.22	

STRUCTURE

Klepper and others (1971a, p. 1578) described the batholith as a "steep-sided pluton... intruded transgressively from below under a cover a few kilometers thick, and occupying a large fraction of the total thickness of the crust." However, according to Hamilton and Myers (1974, p. 365) the batholith is "a thin and shallow mass that spread over a floor of premagmatic rocks and that was covered for the most part only by its own volcanic ejecta."

A thorough review of structural features within and surrounding the batholith is beyond the scope of this report, but a few general characteristics can be cited. Prebatholith strata form a large tectonic basin, with batholithic rocks confined mostly to its center. Peripheral premagmatic rocks are younger toward the batholith, except in the Elkhorn area (about 10 mi east of Boulder, see Pl. 1). The contact between the batholith and the overlying Elkhorn Mountains volcanics dips gently except along the eastern side of the batholith. Robinson and others (1968) implied that the eastern contact is fault controlled.

Faults, shear zones, dikes, and veins within the batholith generally follow three structural trends: N. 30° E. parallel to the long axis of the batholith, N. 60° E., and N. 85° E.

URANIUM OCCURRENCES

There are 35 uranium occurrences in the project area. Most are in the northern half of the Boulder batholith. In the early 1950s, several deposits were developed, but only small amounts of ore were shipped.

Several types of uranium occurrences have been identified during this study, including one type not previously reported in the area.

CHALCEDONY VEINS IN BATHOLITH ROCKS

Approximately one third of the uranium occurrences are in single veins or in zones of discontinuous veins of chalcedony, which have been referred to in the literature as "siliceous reefs" (Wright and others, 1957). Most of the uranium produced from the Boulder batholith came from chalcedony veins: 700 tons of ore containing 0.5 percent U_3O_8 was taken from the W. Wilson mine near Clancy (Jarrard, 1957, p. 29), and 150 tons of ore with an average grade of 0.2 percent U_3O_8 was produced from the Free Enterprise mine near Boulder (Roberts and Gude, 1953b, p. 147).

Chalcedony veins containing uranium deposits are mostly restricted to three parts of the batholith: the Boulder area, the Clancy area, and the Mooney claims (Pl. 1). All three areas are characterized by swarms of nearly vertical veins with individual strikes between N. 60° E. and due east. Pervasive argillic alteration, chiefly affecting plagioclase and mafic minerals, accompanies the veins. Outcrops consist mostly of vein material and silicified wall rock, which forms envelopes up to 2 ft thick adjacent to the veins. Sericitic and chloritic wall-rock alteration has been noted by Wright and others (1957), but these alteration types are subordinate to argillic alteration in terms of volume and intensity. Alaskite is generally only slightly altered and may crop out near veins. Outcrops of unaltered quartz monzonite or granodiorite are restricted to areas that do not contain many veins.

Uraniferous chalcedony veins are characteristically dark gray, brown, or reddish-brown; whereas barren veins are generally white, gray, or buff. Many uranium concentrations are in breccia veins which contain chalcedony and alaskite clasts in dark-gray or brown siliceous cement.

Vein mineralogy consists of microcrystalline silica with opal, white mica, limonite or hematite, minor pyrite, and local barite. Uraninite and pitchblende, in association with base-metal sulfides, are the only primary uranium minerals reported in the veins, but coffinite is present in silicified wall rock at the W. Wilson mine (sample 73, Pl. 3). Many veins contain secondary uranium minerals.

The chalcedony veins are undoubtedly post batholith, but temporal relations between the chalcedony veins and Tertiary volcanic rocks are unclear. Becraft (1956, p. 273) stated that all uranium occurrences are "pre-dacite" (that is, older than the Lowland Creek volcanics), but Becraft and others (1963, p. 59) cited examples of chalcedony veins which cut dacite dikes. Wright and others (1957, p. 202) placed the age of primary uranium mineralization of the W. Wilson mine at about 45 m.y., on the basis of two radiometric dates on uraninite.

Background radioactivity near uranium-bearing veins is slightly higher than in adjacent areas. In the vicinity of the W. Wilson mine in the Clancy area, radioactivity is several times normal background. Uranium and thorium contents for chalcedony vein samples and for altered quartz monzonite and alaskite adjacent to veins, are reported in Tables 1 and 2. Note that the chalcedony veins, and altered rocks associated with them, have high U/Th ratios in comparison with igneous rocks in the project area (Table 3).

Because of the abundance of known uranium concentrations, potential for uranium is good in the chalcedony veins, which are similar to productive French vein deposits (Rich and others, 1975, p. 306). However, it is not likely that large single-vein deposits will be discovered because the veins are generally less than 5 ft thick and uranium tenor is spotty along single veins or vein zones, although locally the grade exceeds 1 percent U_3O_8 (Roberts and Gude, 1953a, p. 82 and 1953b, p. 147). Samples 3 and 64 (Table 1 and Pl. 2) were collected from the same vein, but 90 ft apart, and both are from radioactive sites extending no more than 2 ft along the vein. Furthermore, uranium ore bodies in chalcedony veins may not have much vertical extent. In the Free Enterprise mine, economic uranium was not found at depths in excess of 80 ft (Thurlow and Reyner, 1950, p. 11), but drill data in the vicinity of the W. Wilson mine indicate that ore grade uranium is present at a depth of about 200 ft (Moen, 1959, p. 39). Our review of data collected on the W. Wilson vein by Wright and others (1957, p. 24 and Pl. 2) and by Roberts and Gude (1953a, Pl. 19) indicates that 10,000 to 20,000 tons of ore carrying 0.2 percent U_3O_8 may have been present before high-grade ore was removed.

The potential for larger, low-grade deposits, consisting of two or more closely spaced veins and uranium-enriched wall rock, could not be determined. In some areas near the Free Enterprise mine, as many as four subparallel chalcedony veins are present over a distance of 100 ft. Samples 25 and 74 (Table 2) indicate that wall rock may be considerably enriched; however, both samples were taken from mine dumps, and their spatial relationship to veins is unknown.

CHALCEDONY VEIN IN ELKHORN MOUNTAINS VOLCANICS

The Redrock occurrence, about 9 mi west of Boulder, is the only uranium deposit known in the Elkhorn Mountains volcanics. It consists of a reddish-gray to brown uraniferous chalcedony vein up to 4 ft thick. This vein is similar to chalcedony veins in the batholith rocks, except that is has vugs of drusy quartz. Irregular chalcedony veinlets are present and the wall rock is silicified and argillized adjacent to the vein.

Radioactivity of the vein exceeds 10 times background, and a sample containing 0.11 percent U_3O_8 was collected by Peterson and Hetland (1953). Locally the vein contains traces of sulfide and meta-autunite.

The host rock is a mass of breccia, approximately 500 ft by 3,000 ft, which has been referred to as a breccia pipe (Ruppel, 1963, p. 73). Matrix material is generally lacking, and the breccia is mainly cemented by chalcedonic silica.

This type of occurrence is not promising, although uranium is associated with volcanic breccia pipes in the southwestern United States (for example, uranium accumulations are common in breccia-filled diatremes on the Navajo and Hopi Reservations; Shoemaker, 1956). Very little uranium has been produced from breccia pipes of proven volcanic origin.

BASE-METAL SULFIDE VEINS

Numerous quartz veins containing lead, zinc, and (or) copper sulfides, with associated precious metals, occur in and adjacent to the Boulder batholith. The productive veins in the Butte area are the best known. Uranium concentrations have been reported in at least 15 quartz vein deposits, chiefly in the northern half of the batholith, and a small amount of uranium ore was shipped from a sulfide-quartz vein in Lone Eagle mine (Pl. 1).

The base-metal sulfide veins are distinguished from chalcedony veins by the presence of coarse-grained quartz gangue and considerable amounts of fine- to coarse-grained base-metal sulfides. They generally occur as isolated veins or vein zones (except at Butte) and trend from N. 70° E. to S. 60° E. In the northern part of the batholith, wall-rock alteration includes sericitic, argillic, and chloritic zones proceeding outward from the veins (Becraft and others, 1963, p. 42). Similar alteration has been described in the Butte area by Guilbert and Zeihen (1964).

Becraft (1956, p. 366) considered base-metal sulfide veins in the northern part of the Boulder batholith to be older than the chalcedony veins. According to Miller (1973, Fig. F-2), the age of sulfide mineralization at Butte ranges from 56 to 63 m.y., based on K-Ar dating. Wright and others (1957, p. 203) gave a maximum age of 40 m.y. (determined radiometrically) for pitchblende at the Lone Eagle mine where primary uranium mineralization is closely associated with late-stage microcrystalline quartz. This has led to speculation that uranium mineralization in the base-metal sulfide veins occurred synchronously with deposition in the chalcedony veins. However, a sample of sulfide-rich, coarsely crystalline, quartz vein material, without visible chalcedony or secondary uranium minerals, was collected by the authors from the Josephine mine dump; it assayed 0.30 percent U_3O_8 (sample 7, Pl. 1).

Potential for uranium deposits is good in the base-metal sulfide veins of the Boulder batholith because of the number of occurrences and because of similar mineralogic associations elsewhere in the world. Wright and others (1957, p. 206) considered that major uranium ore bodies are more likely to be associated with base-metal sulfide veins than with chalcedony veins because the base-metal sulfide veins are larger and more persistent. The Comet and Gray Eagle mines (Pls. 1 and 2) are in a vein zone that produced about 500,000 tons of base and precious metal ore and yielded samples containing as much as 0.52 percent U_3O_8 (Becraft and others, 1963, p. 84). The main vein is 20 to 70 ft thick, 2,000 ft long, and has been mined to a depth of 960 ft. However, anomalous radioactivity was encountered in only two of nine drill holes in the Comet-Gray Eagle vein zone, and no significant uranium concentrations were found (Jarrard and Mead, 1955, p. 9).

MANGANESE-QUARTZ VEINS

Uranium is concentrated in a swarm of east-trending veins about 1 mi west of Butte. These veins are characterized by the association of coarsely crystalline quartz with manganese oxide and pyrite. Locally, rhodochrosite and sphalerite are present. Individual veins range from 3 to 20 ft thick and are generally several hundred feet apart. The country rock is alaskite that has been altered to clay and (or) white mica adjacent to the veins.

Manganese-bearing veins were considered by Guilbert and Zeihen (1964, p. 7) to be part of the outermost zone of mineralization in the Butte district. Because of its mobility, uranium in fluids which produced base and precious metal mineralization at Butte may have been driven outward into a peripheral zone.

Radioactivity up to four times background was encountered along the veins. Uranium content of three samples collected from the veins ranges from 33 ppm to 443 ppm (samples 537, 539, and 546, Pl. 1).

The potential for economic uranium deposits in manganese-bearing veins cannot be assessed on the basis of available information, but the veins are of interest because manganese minerals are present in several productive uranium deposits elsewhere in the world.

DEPOSITS IN PALEOZOIC ROCKS

Phosphoria Formation

Uranium is concentrated in a 50-ft-thick phosphatic black shale in the Permian Phosphoria Formation on Humbug Mountain, about 12 mi northeast of Melrose (sample 532, Pl. 1). The uranium is most abundant in layers which contain grains of a fluorescent green mineral (probably autunite or meta-autunite). A sample containing 64.8 ppm eU was collected from this locality (sample 532, Pl. 1). Swanson (1970, p. 756) estimated an average of 0.005 percent uranium for phosphate-rich rock near Melrose. Potential is good for production of by-product uranium from phosphatic rock in the area.

Three Forks Formation

Carbonaceous black shales in the Devonian Three Forks Formation, approximately 6 mi southwest of Helena, contain anomalous amounts of uranium associated with abundant limonite and a few chalcedony veinlets. The shale contains finely divided pyrite and graphite. A sample from this locality contains 31 ppm U_3O_8 (sample 517, Pl. 1).

East of Melrose are several uranium occurrences in chalcedonic breccia cutting Paleozoic black shale and limestone. Radioactivity of these deposits is generally up to four times background. At one place it is nearly 10 times background and the rock contains 0.036 percent U_3O_8 (sample 533, Pl. 1). According to Trites and Tooker (1953), the uranium-bearing rock fills fractures along faults and forms lenticular replacement bodies in Mississippian and Cambrian rocks, but our observations and recent detailed geological mapping (Smedes, personal commun., 1976) indicate that the occurrences are mostly restricted to the Three Forks Formation.

The potential for uranium deposits associated with chalcedony in the Three Forks Formation is undetermined at this time. By analogy to the chalcedony veins, the potential for large deposits is poor, but geologic conditions suggest that the deposits occupy tectonic breccia bodies or solution collapse features, which may increase in size with depth. Examples of such deposits include the Orphan mine in Arizona (Gornitz and Kerr, 1970) and the Thornburg mine in Colorado (Malan and Ranspot, 1959).

URANIUM IN TERTIARY RHYOLITE

About 6 mi southeast of Helena a small amount of rock in a shear zone cutting Tertiary rhyolite contains 220 ppm eU (sample 515, Pl. 1). Except for limonite and clay, no minerals other than those found in the host rhyolite were found in the uranium-rich rock, although thin veins of white opal are nearby. A sample of the host rock, taken 50 ft from the fault (sample 516, Pl. 1) contains 25 ppm U_3O_8 and 13 ppm eU. This type of uranium occurrence has not been previously reported in the project area, and potential for larger bodies of uraniferous rock cannot be demonstrated. However, significant uranium concentrations have been found in veins and fault zones in volcanic rocks in the Marysvale district, Utah (Gilbert, 1957), the Lakeview district, Oregon (Cohenour, 1960), and the McDermitt caldera, Nevada (Rytuba, 1976).

FAVORABILITY FOR NEW TYPES OF URANIUM DEPOSITS

Because of the large number of uranium occurrences and favorable geology, there is potential for types of uranium deposits that have not yet been discovered in the Boulder batholith area. In addition to possible uranium deposits in Tertiary sandstones peripheral to the batholith (Wopat and others, 1977), undiscovered deposits may include contact deposits in Precambrian to Mesozoic strata surrounding the batholith, and "porphyry" deposits as postulated by Armstrong (1974).

MIDNITE MINE TYPE DEPOSITS

The uranium deposit at the Midnite mine in northeastern Washington is in sulfide-rich Precambrian metasedimentary rocks adjacent to cretaceous granitic rocks that contain an average of 12 ppm U. Nash and Lehrman (1975) presented evidence that the unoxidized uranium ore is of supergene origin.

Nash (1975, p. 3) suggested that a geologic environment favorable for Midnite mine type deposits includes source rocks with more than about 10 ppm uranium or 30 ppm thorium, and metasedimentary host rocks with sedimentary or fracture permeability and 1 percent or more sulfides. Nash suggested that carbon compounds or ferromagnesian minerals may suffice as reductants, if sulfides are absent.

At many places bordering the Boulder batholith, conditions similar to those at the Midnite mine may exist. Shales and siltstones of Precambrian and Cambrian age near the southern end of the batholith contain abundant disseminated sulfides, and rocks of similar age and lithology border the batholith or its satellitic plutons in several other places (Pl. 1). In addition, carbonaceous black shales of Paleozoic and Mesozoic age, such as those in the Three Forks Formation, are adjacent to batholith rocks.

Except for a sample of leucocratic granitic rock reported to contain 30.7 ppm Th (Tilling and Gottfried, 1969, sample 1753), adequate plutonic source rocks have not been found adjacent to prebatholith rocks. However, 26 samples of unaltered plutonic rocks from internal portions of the batholith contain adequate amounts of uranium or thorium (as defined by Nash, 1975). The post-Lowland Creek volcanic rocks are also a possible source for Midnite mine type deposits. Rhyolite adjacent to favorable host rocks near Helena contains 25 ppm U_3O_8 (sample 516, Pl. 1).

PORPHYRY URANIUM DEPOSITS

The Boulder batholith may contain large, low-grade accumulations of disseminated primary uranium similar to the "porphyry" deposits proposed by Armstrong (1974). Siliceous and leucocratic granites and quartz monzonites, along with alaskites that generally include some pegmatitic material, are present in many parts of the Boulder batholith (Pls. 1, 2 and 3), but the uranium content of surface samples is generally low (Table 3). Sample 84, which contains 43 ppm U_3O_8, is an exception. It is from a body of leucocratic granite about 4,000 ft long and 1,000 ft wide east of Clancy (Pl. 3).

Potential for uranium deposits similar to the Rössing deposit in southwest Africa is considered to be poor in the Boulder batholith. The Rössing deposit has been cited by some authors as a "porphyry" uranium deposit, but is now acknowledged to be of anatectic origin (Armstrong, personal commun., 1977). Although prebatholith rocks are metamorphosed adjacent to the batholith, migmatitic rocks have not been described by authors who have studied contact areas. High-grade uraniferous pegmatites similar to those which characterize the Rössing deposit have not been found in the Boulder batholith area.

URANIUM SOURCE ROCKS

Seventy-seven samples of igneous rock were analyzed for uranium and thorium as a first step in delineating favorable uranium source rocks for supergene deposits in or adjacent to the batholith. Mean and range values for modal mineralogy, uranium and thorium content, and uranium-thorium ratios are reported in Table 3. Analytical and location data for each sample collected are reported in Appendices A and B. Sample locations are plotted on Plates 1, 2, and 3.

Tilling and Gottfried (1969) presented thorium, uranium, and potassium analyses for 150 samples of igneous rock from the Boulder batholith region, but did not give sample locations. Fifty-four sample locations, obtained from these authors, are reported in Appendix C (also see Pls. 1, 2, and 3).

In general, the results of the present study agree with those of Tilling and Gottfried. For instance, both studies indicate that silicic batholith rocks and post-Lowland Creek rhyolites have relatively high uranium and thorium contents. However, mean uranium contents and uranium-thorium ratios of alaskite samples collected for this study are lower than those reported by Tilling and Gottfried (1969), and the mean uranium content of leucocratic granites and of quartz monzonites is higher.

The low uranium content of the alaskites is surprising, considering their mineralogy and high thorium content. It may be the result of primary igneous processes, such as release of uranium-enriched fluids during the last stages of crystallization, or the result of removal of uranium from the rocks subsequent to crystallization, including removal by surface weathering processes. Uranium occurrences are associated with large masses of alaskite in the Clancy and Boulder areas (Pls. 2 and 3) and west of Butte in the area that contains the manganese-quartz veins (Pl. 1). However, large amounts of alaskite are absent near other occurrences, such as the Mooney claims (Pl. 1).

The post-Lowland Creek rhyolite is considered to be a favorable uranium source rock because samples taken during this study average 17 ppm U_3O_8 and 43 ppm eTh. Uranium and thorium contents of rhyolite in the project area presented in Tilling and Gottfried (1969) are similarly high (samples 52C-1 and 52C-20, App. C), but six samples of post-Lowland Creek rhyolite and quartz latite taken northwest of the project area contain only average amounts of uranium and thorium (App. C and Pl. 1).

Exposures of post-Lowland Creek volcanic rock are confined to the northern part of the project area where most of the uranium occurrences are. This spatial association suggests that some of the uranium mineralization was derived from processes related to post-Lowland Creek volcanism.

Five samples of Oligocene tuffaceous sedimentary rocks from the Helena and Townsend basins east of the batholith contain an average of 17 ppm eU and 43 ppm eTh (Wopat, personal commun., 1977). The exact correlation of mean uranium and thorium contents between these rocks and the post-Lowland Creek volcanic rocks indicates that they were produced during the same period of volcanism. A uranium-rich pyroclastic blanket must have once covered a larger area than that containing rhyolite exposures at this time, and many of the uranium occurrences in the Boulder batholith area may be related to Oligocene rhyolite volcanism.

CONCLUSIONS

The Boulder batholith project area is judged to be favorable for uranium resources because of the following reasons:

1. Uranium occurrences are numerous.
2. Several types of uranium occurrences are present.
3. The geologic setting is favorable for types of deposits known elsewhere, but not yet discovered in the Boulder batholith area.

Potential exists for uranium deposits in chalcedony veins and base-metal sulfide veins, but it is unlikely that large single-vein deposits will be discovered. Three areas in the batholith, the Mooney claims, the Boulder area, and the Clancy area, may be favorable for large, low-grade deposits consisting of a number of closely spaced chalcedony veins and intervening wall rock enriched in uranium.

The potential of other types of uranium occurrences has not been determined. Uranium occurrences associated with breccia masses near Melrose are of interest because of the common association of uranium with tectonic breccias and solution-collapse breccias. Too little is presently known about the uranium in manganese-quartz veins near Butte and in Tertiary rhyolite near Helena to allow meaningful speculation about favorability for deposits in these geologic environments.

The Boulder batholith area has potential for contact deposits similar to the Midnite mine in Washington. Igneous rocks in the project area contain anomalous amounts of uranium and thorium, and possible metasedimentary host rocks border the batholith.

Large, low-grade "porphyry" uranium deposits might be present in the batholith because bodies of favorable types of plutonic rock are abundant; however, the uranium content of most samples of these rock types is low.

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APPENDIX A.

URANIUM AND THORIUM CONTENT OF SAMPLES FROM THE BOULDER BATHOLITH PROJECT AREA

APPENDIX A. URANIUM AND THORIUM CONTENT OF SAMPLES FROM THE BOULDER BATHOLITH PROJECT AREA

Sample number	Fluorometric U_3O_8 ppm	Gamma-spectrometric data* eU (ppm)	eTh (ppm)	eU/eTh	Rock type	Plate location
01	6	4.3	37.2	0.12	Alaskite	2
02	12	13.8	19.1	0.72	Silicified quartz monzonite	2
03	390	339.6	7.0	48.5	Silica breccia vein	2
04		82.5	24.7	3.3	Altered quartz monzonite	2
05		48.2	31.5	1.5	Altered alaskite	2
06		180.6	22.8	7.9	Altered alaskite	2
07	2947	2504.3	121.6	20.5	Quartz vein with sulfides	1
25	800	592.6	21.9	27.1	Argillized quartz monzonite	2
36		10.0	17.7	0.56	Lowland Creek quartz latite	2
37		3.3	14.7	0.22	Quartz monzonite	2
38		2.8	28.1	0.10	Altered Lowland Creek volcanic	2
39	6	4.5	36.5	0.12	Alaskite	2
40	16	12.7	11.9	1.1	Sericitized quartz monzonite	2
41		2.2	12.8	0.17	Alaskite	2
42	6	6.0	21.8	0.28	Quartz monzonite	2
43	5	3.3	15.7	0.21	Lowland Creek rhyolite	2
44		2.9	17.5	0.17	Granodiorite	2
45	8	4.2	14.9	0.28	Quartz monzonite	2
46	5	3.7	40.1	0.09	Alaskite	2
47		2.3	36.6	0.06	Alaskite	2
48	7	4.8	30.8	0.16	Argillized quartz monzonite	2
49		2.4	46.4	0.05	Alaskite	2
50		2.1	9.8	0.21	Elkhorn Mountains andesite	2
51		3.4	20.2	0.17	Quartz monzonite	2
52		6.7	23.3	0.29	Quartz monzonite	2
53		5.9	24.5	0.24	Quartz monzonite	2
54		4.3	21.2	0.20	Quartz monzonite	2
55		2.4	11.1	0.22	Elkhorn Mountains dacite	2
56		4.0	20.3	0.20	Quartz monzonite	2
57		4.0	36.9	0.11	Alaskite	2
58		3.4	17.2	0.20	Granodiorite	2
59		6.6	50.2	0.13	Alaskite	2
60	5	4.7	25.7	0.18	Quartz monzonite	2
61		3.0	15.8	0.19	Quartz monzonite	2
62	39	37.3	8.9	4.2	Silica vein	2
63		4.5	40.6	0.11	Alaskite	2
64	220	168.7	18.2	9.3	Silica breccia vein	2
65	6	6.3	14.8	0.43	Quartz monzonite	2
66	5	3.5	37.8	0.09	Silicified alaskite	2
67	180	197.2	6.4	30.8	Silica breccia vein	2
68	9	5.9	41.7	0.14	Alaskite	2
69	28	18.2	21.4	0.85	Argillized quartz monzonite	3
70		61.4	14.9	4.1	Silica vein	3
71	5	3.6	18.0	0.20	Quartz monzonite	3
72		5.0	18.6	0.27	Chloritized quartz monzonite	3
73	3910	3955.0	40.0	98.8	Silicified quartz monzonite	3
74		492.2	19.1	25.8	Silicified quartz monzonite	3
75		3.8	38.6	0.10	Alaskite	3
76	6	4.4	20.9	0.21	Quartz monzonite	3
77	22	22.9	40.2	0.57	Altered granite	3
78	14	8.7	28.6	0.30	Quartz monzonite	3
79	12	7.9	36.7	0.22	Post Lowland Creek rhyolite	3
80		7.0	27.1	0.26	Quartz monzonite	3
81		6.1	34.6	0.18	Alaskite	3
82	6	4.6	18.5	0.25	Quartz monzonite	3
83		4.5	21.3	0.21	Quartz monzonite	3
84	43	30.7	35.7	0.86	Leucocratic plutonic rock	3
85		1.5	4.3	0.35	Lowland Creek andesite	3
86		5.5	35.1	0.16	Alaskite	3
87		5.6	33.1	0.17	Quartz monzonite	3
88		3.3	37.2	0.09	Altered alaskite	3

*Gamma-spectrometric data are reported as received from the laboratory. Only the first two digits of each datum are valid.

Sample number	Fluorometric U_3O_8 ppm	Gamma-spectrometric data* eU (ppm)	eTh (ppm)	eU/eTh	Rock type	Plate location
89		5.5	41.7	0.13	Altered alaskite	3
90		8.3	35.7	0.23	Alaskite	3
91		7.1	22.4	0.32	Altered quartz monzonite	3
92		4.8	41.7	0.12	Alaskite	3
93		11.3	37.2	0.30	Altered alaskite	3
94		4.9	37.4	0.13	Altered alaskite	3
95	8	7.2	30.5	0.20	Altered alaskite	3
96		38.0	2.0	19.0	Silica vein	3
97	540	232.3	34.2	6.8	Silica-barite breccia vein	3
98		25.1	38.2	0.66	Altered alaskite	3
99		28.9	27.4	1.1	Silica vein	3
100		6.4	18.4	0.35	Quartz monzonite	3
501		4.6	16.7	0.28	Quartz monzonite	3
502		2.5	15.3	0.16	Silicified quartz monzonite	3
503	6	4.4	17.4	0.26	Quartz monzonite porphyry	1
504	6	4.0	39.6	0.10	Alaskite	3
505	7	4.9	44.5	0.11	Silicified alaskite	3
506	6	5.0	43.5	0.11	Alaskite	3
507		8.7	17.8	0.49	Silicified alaskite	3
508	99	76.6	5.0	15.3	Silica vein	3
509	45	37.8	14.6	2.6	Altered quartz monzonite	2
510		4.1	16.9	0.24	Quartz monzonite	2
511		4.9	21.5	0.23	Argillized quartz monzonite	2
512		2.0	15.4	0.13	Granodiorite or quartz monzonite	1
513	6	4.3	23.1	0.19	Quartz monzonite	1
514	5	2.8	33.2	0.08	Altered alaskite	1
515		221.7	53.8	4.1	Limonitized rhyolite	1
516	25	13.0	58.1	0.22	Post Lowland Creek rhyolite	1
517	31	27.4	7.0	3.9	Three Forks Formation black shale	1
518		3.6	12.5	0.29	Three Forks Formation siltstone	1
519		2.6	19.9	0.13	Leucocratic plutonic rock	1
520		17.6	6.9	2.6	Three Forks Formation siltstone	1
521		3.6	15.8	0.23	Granodiorite	1
522	7	5.8	42.2	0.14	Leucocratic plutonic rock	1
523	22	7.8	20.8	0.38	Silicic plutonic rock	1
524	10	6.1	30.8	0.20	Silicic plutonic rock	1
525	25	19.9	31.3	0.64	Leucocratic plutonic rock	1
526	6	3.2	32.5	0.10	Leucocratic plutonic rock	1
527		5.9	19.7	0.30	Leucocratic plutonic rock	1
528		6.6	48.8	0.14	Alaskite	1
529	8	6.6	40.5	0.16	Alaskite	1
530	6	3.6	16.7	0.22	Argillized quartz monzonite	1
531	4	2.1	31.9	0.07	Alaskite	1
532		64.8	1.1	58.9	Phosphoria Formation	1
533	360	289.7	1.6	181.1	Silica breccia	1
534		4.9	13.4	0.37	Precambrian siltstone	1
535	5	3.5	12.1	0.29	Precambrian siltstone	1
536	4	4.6	15.6	0.29	Leucocratic plutonic rock	1
537	34	36.9	2.7	13.7	Manganese-quartz vein	1
538	4	2.5	32.6	0.08	Alaskite	1
539	184	206.1	5.0	41.2	Manganese-quartz vein	1
540	4	2.5	6.1	0.41	Lowland Creek quartz latite	1
541		3.6	17.3	0.21	Quartz monzonite	1
542	48	56.5	38.6	1.5	Altered quartz monzonite	1
543	4	3.4	19.1	0.18	Quartz monzonite	1
544	5	3.7	34.6	0.11	Alaskite	1
545		4.9	47.4	0.10	Altered alaskite	1
546	443	219.4	13.9	15.8	Brecciated manganese-quartz vein	1
547		5.0	23.7	0.21	Quartz monzonite	1
548	15	12.0	33.4	0.36	Post Lowland Creek rhyolite	1
549	5	3.1	14.2	0.22	Quartz monzonite	1

APPENDIX B.

LOCATION OF SAMPLES LISTED IN APPENDIX A

APPENDIX B. LOCATION OF SAMPLES LISTED IN APPENDIX A

Sample Number	1/64	1/16	1/4	Sec.	T.	R.
01	SW	SE	SW	7	6N	4W
02	SW	SE	NE	19	6N	4W
03	NE	NE	SE	18	6N	4W
04	SE	NW	SE	19	6N	4W
05	SE	NW	SE	19	6N	4W
06	SE	NW	SE	19	6N	4W
07	SW	SE	NE	26	8N	6W
25	SE	NW	SE	19	6N	4W
36	SW	NW	SE	12	6N	5W
37	SE	SE	NW	12	6N	5W
38	SW	SW	NW	12	6N	5W
39	SW	SE	NW	12	6N	5W
40	NW	NE	NW	12	6N	5W
41	SW	NW	NW	7	6N	4W
42	SW	SW	NW	7	6N	4W
43	SE	NW	SW	7	6N	4W
44	SW	SE	SW	7	6N	4W
45	NE	NE	SW	18	6N	4W
46	NW	SE	SW	18	6N	4W
47	SE	SE	SW	18	6N	4W
48	SE	SE	NW	19	6N	4W
49	NE	SE	NW	19	6N	4W
50	SW	NE	SW	35	7N	5W
51	NW	NW	SW	35	7N	5W
52	SW	NW	NW	2	6N	5W
53	NW	SE	NE	27	7N	5W
54	SW	NW	SE	34	7N	5W
55	NW	NW	NE	3	6N	5W
56	SW	SW	SW	27	7N	5W
57	NE	NE	NE	33	7N	5W
58	SE	SE	NE	33	7N	5W
59	NE	SE	NW	2	6N	5W
60	NE	NE	SW	2	6N	5W
61	NW	NW	NW	1	6N	5W
62	SW	SE	NE	19	6N	4W
63	NE	SW	SW	17	6N	4W
64	NE	NE	SE	18	6N	4W
65	NE	NE	SE	18	6N	4W
66	SE	NW	SE	17	6N	4W
67	SE	NW	SE	17	6N	4W
68	NW	SE	SE	19	6N	5W
69	SE	SE	NW	17	8N	3W
70	SE	SE	NW	17	8N	3W
71	NW	NE	SE	17	8N	3W
72	SE	NE	SE	17	8N	3W
73	SE	NE	SE	17	8N	3W
74	NE	NE	SE	17	8N	3W
75	SW	NW	NW	16	8N	3W
76	NW	SW	SE	9	8N	3W
77	NW	NW	NW	32	8N	2W
78	NW	NW	NW	32	8N	2W
79	NW	NW	SW	29	8N	2W
80	NW	SE	SW	30	8N	2W
81	SW	SW	SW	24	8N	2W
82	SE	SE	NW	20	8N	2W
83	NE	SW	NW	20	8N	2W
84	NW	SW	NE	24	8N	3W
85	NW	SE	SW	24	8N	3W
86	NE	NE	SW	15	8N	3W
87	SE	NE	SE	15	8N	3W
88	NW	SW	NW	15	8N	3W

Sample Number	1/64	1/16	1/4	Sec.	T.	R.
89	SE	NE	NW	30	8N	3W
90	NE	NW	NE	16	8N	3W
91	NE	NW	NE	16	8N	3W
92	NE	NW	NE	16	8N	3W
93	NE	NW	NE	16	8N	3W
94	NE	NW	NE	16	8N	3W
95	NE	NW	NE	16	8N	3W
96	NE	NW	NE	16	8N	3W
97	NE	NW	NE	16	8N	3W
98	NE	NW	NE	16	8N	3W
99	NE	NW	NE	16	8N	3W
100	SW	SE	SW	16	8N	3W
501	SE	NW	NE	8	8N	3W
502	SE	SE	NW	8	8N	3W
503	SW	SW	NW	23	8N	4W
504	NW	NW	SE	7	8N	3W
505	SW	NW	NE	24	8N	4W
506	SE	SW	SE	13	8N	4W
507	SW	NE	SW	24	8N	4W
508	SE	NE	SW	35	8N	4W
509	NW	NE	NW	12	6N	5W
510	NW	SE	NW	19	6N	4W
511	SW	SE	NE	19	6N	4W
512	SE	NE	NW	29	9N	5W
513	NW	SE	SW	33	9N	5W
514	NE	SE	NW	12	9N	SW
515	NE	SE	SW	14	9N	3W
516	NE	SE	SW	14	9N	3W
517	SE	SE	SW	14	9N	3W
518	SE	SE	SW	14	9N	3W
519	SE	SE	SW	14	9N	3W
520	SE	SE	SW	14	9N	3W
521	NW	NE	NW	26	9N	3W
522	NE	NE	SW	23	9N	3W
523	NE	NW	SE	13	2N	7W
524	NE	NE	NW	19	2N	6W
525	NW	NE	SE	1	2N	6W
526	NW	NE	SE	1	2N	6W
527	NW	SE	SW	16	3N	5W
528	NW	SE	SW	16	3N	5W
529	NW	SE	NE	20	3N	5W
530	NE	NE	NE	6	2N	9W
531	NW	NW	NE	28	3N	9W
532	SE	SE	NE	32	1N	8W
533	SW	NE	SW	18	2S	8W
534	NW	NW	NE	26	1S	9W
535	SE	NW	SE	23	1S	9W
536	NE	NE	NE	23	1S	9W
537	SE	SW	NE	16	3N	8W
538	NW	SW	NE	16	3N	8W
539	NW	NW	NW	15	3N	8W
540	NW	SE	SW	10	3N	8W
541	SE	NW	NE	22	3N	8W
542	NE	NW	NW	22	3N	8W
543	NE	SE	SE	13	3N	9W
544	NW	NE	NE	22	3N	8W
545	NW	NE	SE	15	3N	8W
546	NW	NW	NE	23	3N	8W
547	SW	NW	NW	19	6N	5W
548	SE	SE	NW	26	8N	6W
549	SE	NW	NE	26	8N	6W

APPENDIX C.

URANIUM AND THORIUM CONTENT REPORTED IN TILLING AND GOTTFRIED (1969) FOR IGNEOUS ROCKS FROM THE BOULDER BATHOLITH AREA, AND SAMPLE LOCATIONS

APPENDIX C. URANIUM AND THORIUM CONTENT REPORTED IN TILLING AND GOTTFRIED (1969) FOR IGNEOUS ROCKS FROM THE BOULDER BATHOLITH AREA, AND SAMPLE LOCATIONS.

Sample Number	Uranium (ppm)	Thorium (ppm)	U/Th	Rock Type	LOCATION 1/64	1/16	1/4	Sec.	T.	R.
1753	8.0	30.7	0.26	Leucocratic plutonic rock	NE	NE	SE	5	1N	8W
S1419	1.7	5.6	0.30	Mafic (syenogabbro)	NW	NE	NE	21	9N	2W
63K350	2.3	5.9	0.39	Mafic (syenogabbro)	NE	SE	NW	9	2N	5W
4T349	1.7	9.3	0.18	Granodiorite	SE	NE	SE	17	9N	3W
2T1093	1.7	8.0	0.21	Granodiorite	NW	NW	SW	14	1N	6W
2T1065	1.2	8.1	0.15	Granodiorite	SW	SE	NE	32	2N	5W
5T60	3.9	8.8	0.44	Granodiorite	SE	SW	NW	21	1N	8W
6K445	20.0	42.0	0.48	Alaskite	NW	SE	NE	19	3N	5W
62K00	9.0	39.6	0.23	Alaskite	NW	SW	NW	3	4N	7W
1K241	8.3	20.1	0.41	Silicic plutonic rock	SW	NE	SW	13	2N	7W
3T273	4.6	18.0	0.26	Quartz monzonite	SE	NW	NE	8	9N	3W
6K306	3.3	11.8	0.28	Quartz monzonite	NE	NE	SW	13	2N	7W
W21	2.1	12.8	0.16	Leucocratic plutonic rock	SW	SW	SE	12	1N	7W
2T275	3.7	24.2	0.15	Leucocratic plutonic rock	NW	SE	SE	5	1S	6W
2T797	5.0	17.3	0.29	Leucocratic plutonic rock	SE	NE	NW	11	2S	7W
4T505	4.4	17.1	0.26	Post-Lowland Creek rhyolite	NE	SE	SW	14	9N	8W
52C-1	11.6	44.0	0.26	Post-Lowland Creek rhyolite	NE	SE	SW	14	9N	3W
52C-8	4.4	26.0	0.17	Alaskite	SW	NW	NW	1	6N	3W
52C-10	2.9	13.0	0.22	Quartz monzonite	NE	SE	SW	23	9N	3W
52C-13	3.2	15.5	0.21	Quartz monzonite	NW	SE	NE	34	9N	3W
52C-15	4.9	34.0	0.14	Alaskite	NE	SW	NE	9	9N	3W
52C-20b	8.5	34.2	0.25	Post-Lowland Creek rhyolite	SW	NE	NE	29	8N	3W
52C-20c	18.0	42.0	0.43	Post-Lowland Creek rhyolite	SW	NE	NE	29	8N	3W
52C-37	1.6	10.4	0.15	Leucocratic plutonic rock	NW	SE	SW	35	7N	4W
52C-45	2.6	14.9	0.17	Silicic plutonic rock	NW	NE	NE	31	6N	4W
52C-52	7.1	19.0	0.37	Quartz monzonite	SW	NW	NW	19	6N	5W
52C-60	5.1	18.8	0.27	Quartz monzonite	NE	NW	NW	15	5N	6W
52C-65	2.4	15.2	0.16	Quartz monzonite	SW	NW	SW	12	6N	7W
52C-79	2.6	10.4	0.25	Post-Lowland Creek qtz. latite	NW	SW	SE	33	10N	7W
52C-80	2.6	18.8	0.14	Post-Lowland Creek rhyolite	NE	SE	NE	27	10W	8W
52C-81	2.4	8.8	0.27	Post-Lowland Creek qtz. latite	SE	NW	NW	29	10N	8W
52C-83a	2.2	3.2	0.69	Post-Lowland Creek qtz. latite	NW	NE	SW	30	10N	8W
52C-83b	2.1	9.6	0.22	Post-Lowland Creek qtz. latite	NW	NE	SW	30	10N	8W
52C-113	12.1	18.3	0.66	Silicic plutonic rock	SE	SW	NW	23	8N	4W
52C-114	1.6	17.9	0.09	Quartz monzonite	NE	SW	NW	20	8N	5W
52C-116	2.3	11.1	0.21	Granodiorite	NE	SW	SW	36	10N	6W
53C-135	6.2	31.3	0.20	Post-Lowland Creek rhyolite	SW	NW	SW	33	10N	7W
53C-140	5.7	16.9	0.34	Granodiorite	NE	NE	NW	29	9N	5W
53C-149	4.5	16.9	0.27	Quartz monzonite	NW	NW	NW	27	2N	7W
53C-150	3.6	15.6	0.23	Quartz monzonite	SW	NE	NE	3	1N	7W
53C-154	2.3	12.7	0.18	Leucocratic plutonic rock	SE	NE	SE	11	1N	7W
53C-163	1.2	5.4	0.22	Granodiorite	SW	NW	SE	16	1N	6W
53C-166	1.2	6.6	0.18	Granodiorite	NE	NW	SW	15	1N	6W
53C-168	1.6	6.6	0.24	Granodiorite	NE	NE	SW	14	1N	6W
53C-191	3.3	9.2	0.36	Granodiorite	NW	NE	SW	21	1N	8W
53C-202	5.2	15.6	0.33	Quartz monzonite	NE	NE	NE	15	6N	5W
53C-203	4.3	23.0	0.19	Silicic plutonic rock	SW	SW	SE	34	7N	5W
53C-204	2.0	8.1	0.25	Leucocratic plutonic rock	SW	NE	NE	21	8N	4W
53C-205	5.1	16.2	0.31	Quartz monzonite	SE	SE	NE	33	7N	5W
53C-206	3.4	19.0	0.18	Silicic plutonic rock	NE	NW	SE	33	7N	5W
53C-207	2.4	7.6	0.32	Leucocratic plutonic rock	NE	NW	NE	14	8N	5W
53C-209	3.8	16.2	0.23	Quartz monzonite	NW	NW	NW	4	8N	5W
54C-248	3.2	7.9	0.41	Quartz monzonite	NW	SE	SE	18	1N	7W
54C-249	7.5	40.0	0.19	Alaskite	NE	NE	NW	11	8N	4W

PLATE 1

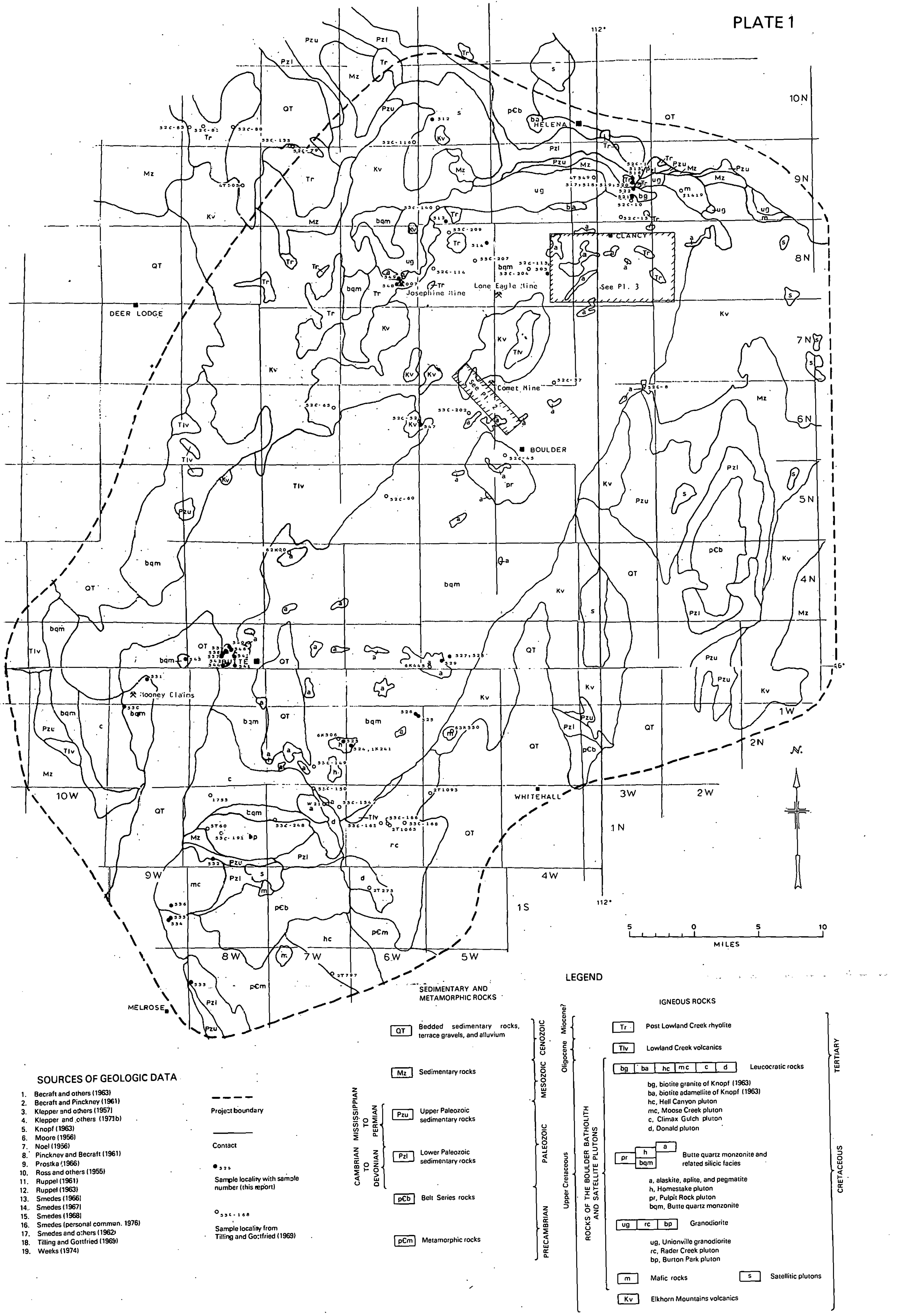
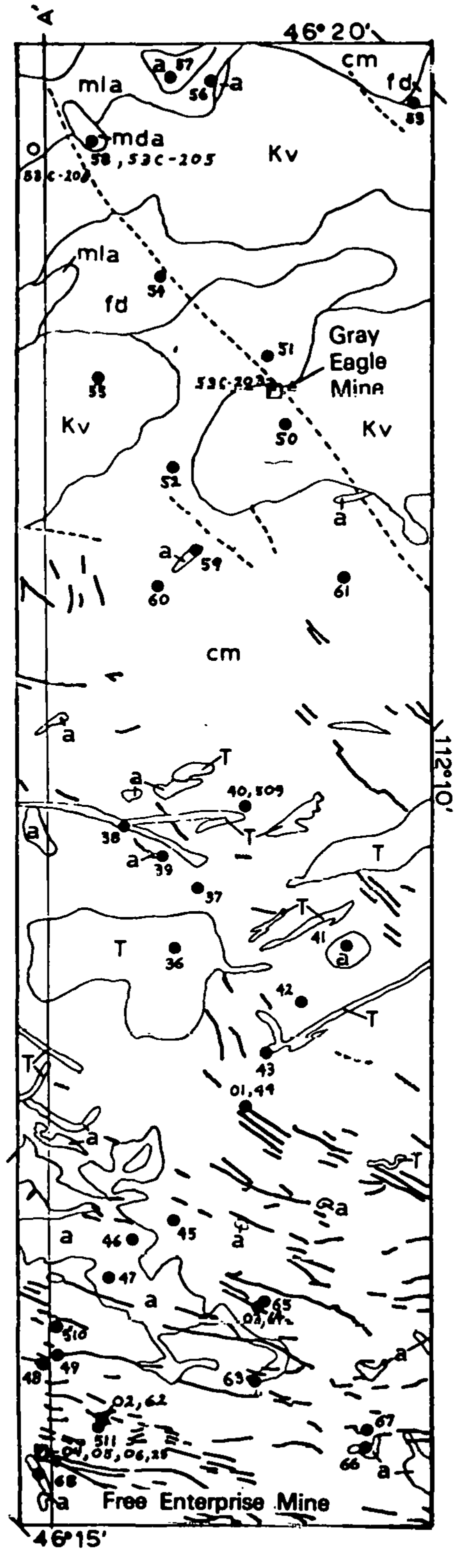


PLATE 1. GENERALIZED GEOLOGIC MAP OF THE BOULDER BATHOLITH

PLATE 2



adapted from Becraft and others, 1963

LEGEND

	T	Tertiary igneous rocks (Lowland Creek volcanics and equivalents)	TERTIARY
BOULDER BATHOLITH	a	Alaskite, aplite, and pegmatite	CRETACEOUS
		Butte quartz monzonite	
	cm	Undivided coarse- and medium-grained quartz monzonite and granodiorite	
	mla	Medium-grained quartz monzonite	
	fd	Fine-grained quartz monzonite	
	mda	Medium-grained granodiorite	
	Kv	Elkhorn Mountains volcanics	

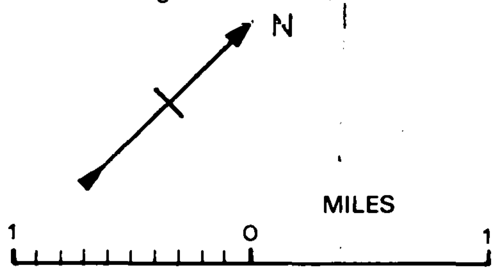
—— Contact

- - - - Quartz vein

—— Chalcedony vein

● 45 Sample locality with sample number (this report)

○ 53C-20 Sample locality from Tilling and Gottfried (1969)



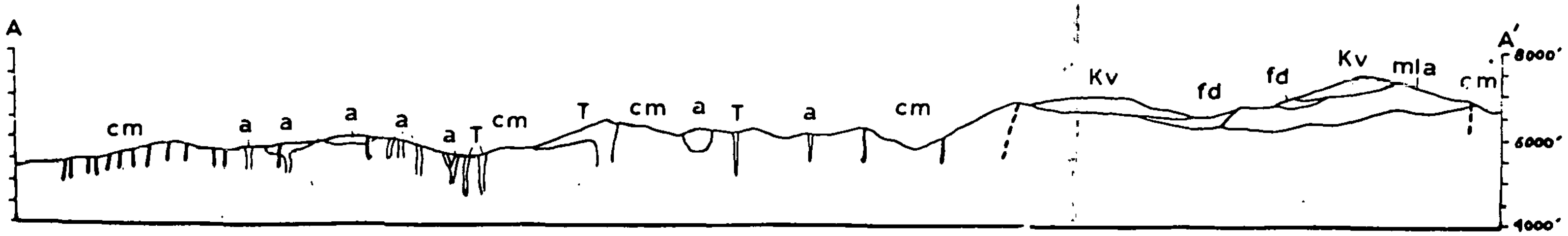
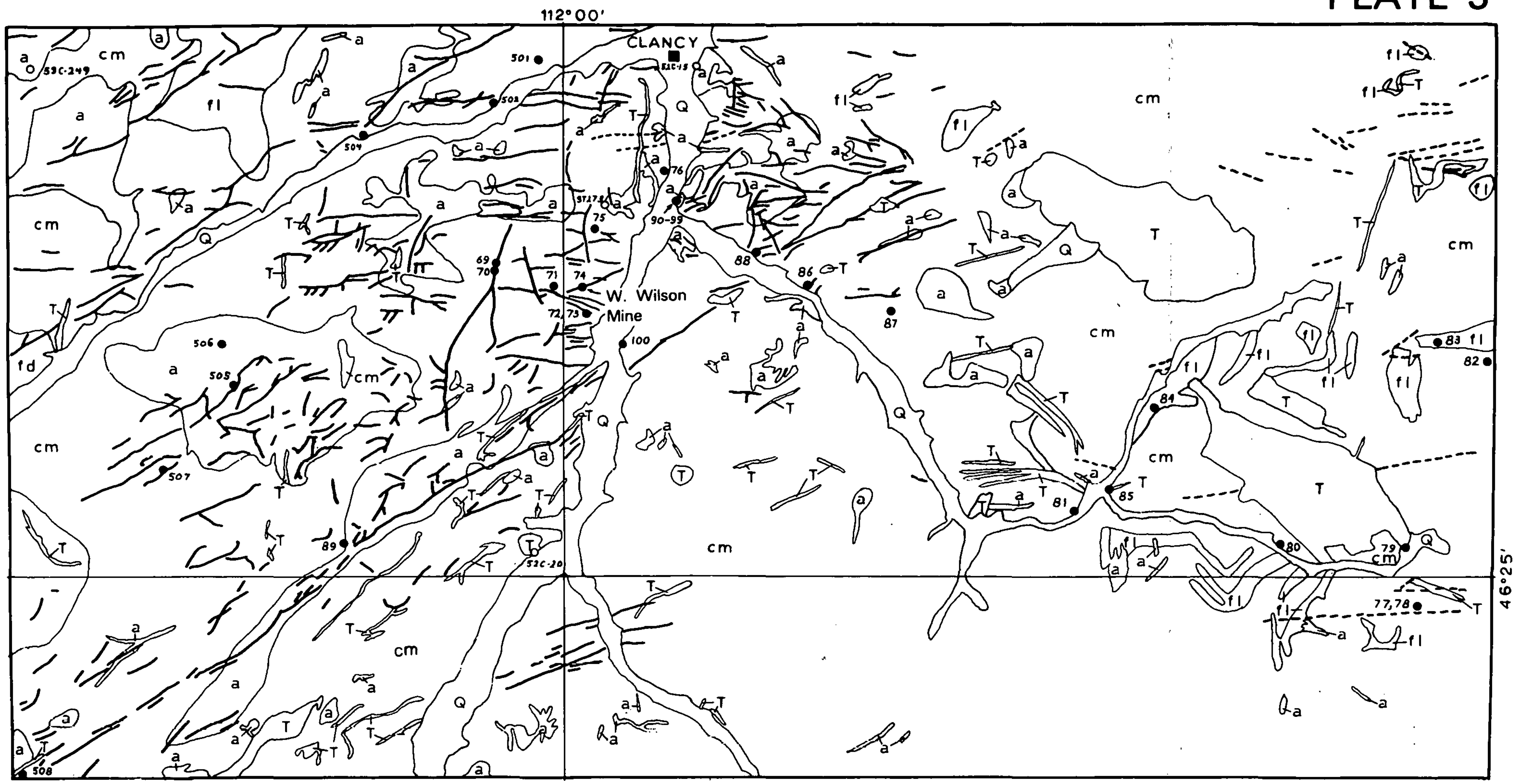


PLATE 2. GEOLOGIC MAP OF FREE ENTERPRISE MINE AREA



adapted from Becraft and others, 1963, and Smedes, 1966

LEGEND

ROCKS OF THE BOULDER BATHOLITH

UPPER CRETACEOUS

a	Alaskite, aplite, and pegmatite
fl	Fine-grained, light-colored quartz monzonite and granodiorite, locally contains large amounts of aplite
fd	Dark-gray, porphyritic quartz monzonite with fine-grained ground mass
cm	Medium- to coarse-grained quartz monzonite and granodiorite

Q	Quaternary deposits
T	Tertiary igneous rocks

——— Contact

- - - - Quartz vein

▬▬▬ Chalcedony vein

•10 Sample locality with sample number (this report)

○ 63K350 Sample locality from Tilling and Gottfried (1969)

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PLATE 3. GEOLOGIC MAP OF CLANCY AREA