UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EVALUATION OF PROTEROZOIC QUARTZITE AND CONGLOMERATE IN CENTRAL IDAHO FOR QUARTZ-PEBBLE CONGLOMERATE URANIUM DEPOSITS

By

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This report is preliminary and has not been edited
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INTRODUCTION

Geologic setting of uraniferous quartz-pebble conglomerate

Large, medium- to low-grade deposits of uranium in Precambrian quartz-pebble conglomerate constitute a very significant portion of the world's known uranium resources. In these deposits, uranium occurs as rounded grains of uraninite and brannerite along with rounded clasts of pyrite, monazite, zircon, and native gold. The deposits generally are considered to have formed as placer concentrations of heavy minerals (Roscoe, 1973; Pretorius, 1975), although detrital pyrite and uraninite are uncommon in modern placers. According to Roscoe (1973), placer concentrations of uraninite and pyrite formed during a period of time early in the Earth's history, when free oxygen was not abundant, and when, therefore, pyrite and uraninite did not oxidize during weathering. After approximately 2300 m.y. ago, the Earth's atmosphere became more oxidizing, and placer concentrations of pyrite and uraninite ceased to form except under unusual circumstances, such as possibly during glaciation. Thus, economic placer concentrations of uranium appear to be restricted to rocks deposited very early in the Earth's history and to be absent from rocks formed less than approximately 2300 m.y. ago.

Uranium-bearing quartz-pebble conglomerate occurs in fluvial fan (fan-delta) deposits formed at the margins of late Archean or early Proterozoic lakes or epicontinental seas. Perhaps the best known of the uranium-bearing conglomerates are those of the Witwatersrand basin in South Africa. There, mines in quartz-pebble conglomerate, which have yielded approximately 55 percent of the gold mined throughout human history, produce uranium and potentially can produce thorium as byproducts or coproducts of the gold mining operations. Witwatersrand conglomerates were deposited along the margins of a late Archean to early Proterozoic epicontinental sea or large lake (Pretorius, 1974).

In North America, economically important deposits are found in the Elliott Lake district, Ontario, where fluvial-deltaic to littoral marine basal strata of the Huronian Supergroup rest unconformably on Archean igneous and metamorphic rocks near the southern margin of known Archean rocks. Several other occurrences of uraniferous quartz-pebble conglomerate (apparently all subeconomic at the present time) are known in Canada and in the United States, and all are in upper Archean or lower Proterozoic marginal marine deltaic strata deposited unconformably upon Archean granites and gneisses near the margins of Archean shields (Hills, 1980). For North America, the margins of Archean shields (Archean cratons) appear to be the most favorable areas in which to explore for uranium-bearing quartz-pebble conglomerate.

The southern margin of the Archean craton crosses North America from southern Ontario, through the Great Lakes area, through South Dakota, and through southern Wyoming. Along most of its length in the United States, this margin is buried beneath Phanerozoic sedimentary rocks. However, the margin is exposed in several Laramide uplifts, where it crosses the Rocky Mountain region, and in four of these uplifts, uraniferous quartz-pebble conglomerates have been discovered (Black Hills of South Dakota, Laramie Mountains, Medicine Bow Mountains, and Sierra Madre of Wyoming) (Hills, 1980).

The margin of the old Archean craton apparently continues westward into Utah, but it has not been located precisely there (Houston and Karlstrom, 1980; Hills, 1980). Archean rocks have been recognized in the Uinta Mountains, in the Wasatch Mountains, and in the Raft River and Albion Ranges. The margin of the Archean shield has been inferred to be a few tens of kilometers to the south and west of these Laramide uplifts and to continue northward through Idaho or western Montana, where it must pass west of the Ruby Range and Tobacco Root Mountains (Houston and Karlstrom, 1980; Hills, 1980). Along all of its length west of the Sierra Madre, its position is drawn so as to enclose all known Archean rocks. However, the actual position of the margin is not known, and it may be significantly to the south and west of the lines drawn by Hills (1980) and Houston and Karlstrom (1980). In addition, the present western edge of the Archean may not correspond with the late Archean or early Proterozoic western edge. Geologically more recent tectonic events may have reduced the original extent of the Archean.

Purpose of investigation

Despite the uncertainties regarding position and tectonic significance of the margin of the Archean shield in Utah, Idaho, and Montana, the area around this margin is the last unevaluated area in the United States that appears to have potential for uraniferous quartz-pebble conglomerate. Within the area, no rocks known to be of appropriate age have been identified, but several areas contain quartzites and conglomerate that are possibly of appropriate age.

The investigations reported here were undertaken to evaluate two areas in central Idaho (fig. 1), in which quartzites or conglomerates were known that might possibly be of sufficient age and of an appropriate tectonic environment to be favorable for uraniferous quartz-pebble conglomerate. This work was done in cooperation with the Department of Energy as part of its National Uranium Resource Evaluation, World-Class uranium deposits project.

Methods and scope

The project described in this report is a field reconnaissance of the quartzites near Lowell and Salmon, Idaho, supported by some geochemical

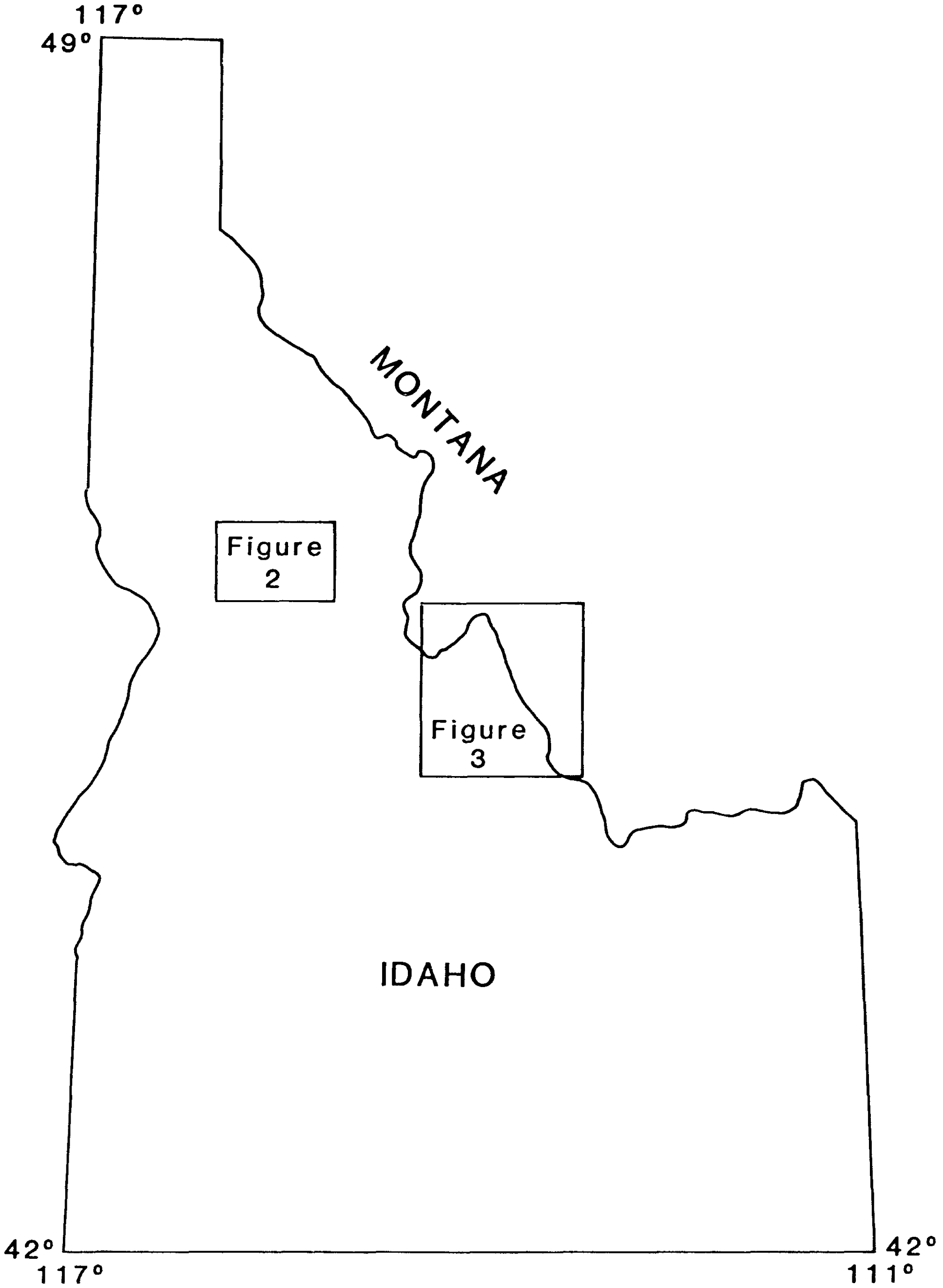

Figure 1.--Location of the Lowell-Elk City (figure 2) and Salmon-Cobalt (figure 3) areas.

data. In identifying the most appropriate areas for study and sampling, it made use of published geologic maps and of consultation with several U.S. Geological Survey geologists working in the area. However, much of the area is incompletely mapped and access is generally poor. Much of the area, especially around Lowell, is in wilderness, or RARE II status and is accessible only by pack trails or helicopter. This study was therefore limited mainly to quartzites accessible by road or jeep trail, but one day of helicopter support allowed visits to outcrops of conglomeratic quartzite on Blacktail Ridge in the Selway-Bitteroot Wilderness (Fenn Mountain and Big Rock Mountain quadrangles). Despite the limited access, I believe that a representative suite of the known quartzites was examined and sampled, and my generalizations are probably valid for these. However, an area of several thousand square miles in the 1^ox2^o Elk City quadrangle is inaccessible by road and is incompletely mapped. My generalizations cannot be extended to this area.

Samples of quartzite and conglomerate collected for this study were submitted to the U.S. Geological Survey laboratories, where they were analyzed according to the specifications prescribed for rock samples in the NURE 1^ox2^o quadrangle evaluation program. Uranium and thorium were analyzed by the delayed neutron method (table 1), and other elements were analyzed by an emission spectrograph with digital direct reader (Appendix).

Scintillometer measurements reported in this study were made with a Geometrix model GR101A.*

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*Use of brand or manufacturer's names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 1.--Uranium and thorium content of quartzites and conglomerates [Delayed neutron analyses by H. T. Millard, Jr., B. Vaughn, S. Lasater and B. Keaton]

Sample Number	Th ppm	U ppm	Th/U	Comments
LOWELL-ELK CITY AREA				
79-I-1	4.3	0.6	7.2	Quartzite near Elk City
79-I-2	29.0	4.0	7.3	Conglomerate of Lizard Lakes area
79-I-3	2.9	0.4	7.2	Conglomerate of Lizard Lakes area
79-I-4	4.5	0.6	7.5	Quartzite of Lizard Lakes area
79-I-5	9.0	1.9	4.7	Quartzite of Prichard Formation
79-I-6	5.2	0.5	10.4	Quartzite of Ravalli Group
79-I-7	3.1	0.4	7.8	Quartzite of Revett Formation
SALMON-COBALT AREA				
79-I-8	18.8	1.9	9.9	Dark, fine grained quartzite
79-I-9	15.5	3.1	5.0	Dark, fine grained quartzite
79-I-10	11.4	2.3	5.0	Dark, fine grained quartzite
79-I-11	15.8	2.8	5.6	Light, fine grained quartzite, magnetite on crossbeds
79-I-12	16.2	4.0	4.1	White, phyllitic fine grained quartzite, sheared
79-I-13	<11.	3.3	<3.3	Dark, micaceous fine grained quartzite
79-I-14	1730.	6.1	284.	Quartzite with veins containing thorite
79-I-15	8.8	1.6	5.5	Dark, fine grained quartzite
79-I-16A	420.	2.7	156.	Dark quartzite with thorite veins
79-I-16B	2260.	18.7	121.	Dark quartzite with thorite veins
79-I-16C	1030.	5.5	187.	Dark quartzite with thorite veins
79-I-17	16.1	4.2	3.8	Dark, fine grained quartzite with biotite
79-I-18	7.8	2.2	3.6	Dark, fine grained quartzite with biotite
79-I-19	8.9	1.9	4.7	Very dark, fine grained quartzite
79-I-20	9.9	2.4	4.1	Dark, fine grained quartzite streaked with dark minerals
79-I-21	13.2	4.1	3.2	Dark, very fine grained, slaty siltstone
79-I-22	<0.9	0.4	<2.3	Slaty siltstone with massive sulfides
79-I-23	17.0	3.8	4.5	Mud-pebble conglomerate; siltstone
79-I-24	13.8	1.0	14.	Light colored siltstone
79-I-25	<1.5	0.6	<2.5	White, fine grained quartzite, limonite in pores
79-I-26	2.4	1.0	2.4	White, fine grained quartzite, cross beds
79-I-27	10.3	2.8	3.7	Dark, very fine grained quartzite
79-I-28	15.3	3.0	5.1	Dark siltstone
79-I-29	22.4	3.6	6.2	Dark, very fine grained quartzite, some limonite

CRITERIA USED IN ASSESSING FAVORABILITY

Based on the genetic model for uranium-bearing quartz-pebble conglomerates developed by Roscoe (1973), D. S. Robertson (1974), and others, uraniferous quartz-pebble conglomerates and the geologic environments in which they are found have certain observable or determinable characteristics, which Mathews and others (1979) called recognition criteria. The recognition criteria looked for in the present study are summarized in table 2 and discussed below.

Uranium oxide minerals were resistates before the Earth's atmosphere became strongly oxidizing, an event inferred to have taken place approximately 2300 m.y. ago. After this event, which Roscoe (1973) terms the "oxyatmoversion", formation of significant placer deposits of uranium oxide minerals became improbable, and therefore, conglomerates determined to be younger than early Proterozoic may be considered as unfavorable.

Furthermore, among the rocks known to occur in Archean or early Proterozoic terrains, only certain alkali-rich and peraluminous granites and their associated pegmatites bear appreciable uraninite. Therefore, only depositional environments on or adjoining continental crust, where such granites might exist, and where fluvial systems existed that were adequate to concentrate and transport the uraninite, are favorable. Ensimatic depositional environments, such as island arcs or other eugeosynclinal environments may be considered as unlikely to host uraniferous quartz-pebble conglomerates, and therefore as unfavorable.

In adddition to these characteristics of the tectonic environment, uraniferous conglomerates share certain petrographic and geochemical attributes that can be used as criteria of favorability. A high-energy medium of trans-

Table 2.--Criteria useful in recognizing conglomerates and sandstones that are possible hosts of Precambrian quartz-pebble-type (placer-type) uranium deposits

Favorable Attributes	Unfavorable Attributes
I. Age	
A. >2300 m.y. old (Archean or early Proterozoic).	A. <2300 m.y. old.
II. Tectonic Setting	
A. Epicontinental basin or coastal plain on or adjoining Archean craton.	A. Ensimatic basin or eugeosyncline not adjoining Archean continental crust.
B. Adjoining Archean contains uraniferous granitic rocks.	B. Adjoining Archean contains no uraniferous granitic rocks.
III. Depositional Environment	
A. Fluvial fan (fan delta) or marine/lacustrine shore facies. Wet environment with continuous vigorous washing of sediment.	A. Low energy marine or lacustrine environments such as offshore or deep-water deposits. Alluvial or glacial environment. Arid environment with episodic deposition.
B. Adjoining highlands with mantle of saprolite (probably humid with deep chemical weathering).	B. Adjoining lowlands or arid highlands without saprolite mantle.
IV. Petrographic Characteristics	
A. Oligomictic conglomerates (almost exclusively quartz, jasper, chert pebbles). Pebbles are very well rounded and very uniform in size. They form a framework that trapped finer matrix sand.	A. Polymictic conglomerate (pebbles of several rock types, some of which are not composed of resistate minerals). Pebbles are angular and poorly sorted. They are scattered through a matrix of finer sediments.
B. Pyrite is the chief iron mineral in placer concentrations between pebbles and in streaks on topset and foreset beds. If unrecrystallized, it occurs as rounded sand grains or small pebbles (buckshot pyrite). In oxidized rocks, the former presence of pyrite can be inferred from limonite pseudomorphs and limonite-stained molds, pores or vugs.	B. Magnetite is the chief iron mineral in placer concentrations. Pyrite is absent or occurs as disseminated grains in fine-grained sedimentary rocks.
C. Small, rounded (muffin-shaped) uraninite grains may occur in unoxidized specimens, but these are difficult to observe.	C. All uranium can be accounted for as a component of resistate minerals such as zircon and monazite.
D. Conglomerates and associated sandstones are a characteristic yellowish-green (pistachio) color.	D. Conglomerates and associated sandstones are red or brown or occur with red clastic rocks (redbeds). Caution: oxidation of pyrite can produce red and brown colors on outcrops and to a depth of many meters below the topographic surface. This secondary color can be misleading.
V. Geochemical Characteristics	
A. Th/U <2 in unoxidized specimens.	A. Th/U >5 in unoxidized specimens.
B. Oxidized specimens with placer concentrations of heavy minerals have high Th contents and evidence for the former presence of pyrite.	B. Specimens with placer concentrations of heavy minerals have high Th contents but show no evidence for the former presence of pyrite.
C. $^{208}Pb/^{206}Pb$ ratios in oxidized specimens indicate a low Th/U existed before weathering.	$^{208}Pb/^{206}Pb$ ratios indicate a high Th/U ratio existed before weathering.

portation and a high-energy depositional environment are necessary to winnow or wash out light minerals and form placers. The Witwatersrand and Elliot Lake, Ontario, conglomerates are notable for their high degree of sedimentological maturity. These conglomerates, called oligomictic conglomerates, consist of highly rounded, exceptionally well sorted pebbles, almost exclusively composed of quartz, chert, or jasper. Poorly sorted, polymictic conglomerates, associated with sedimentary rocks formed in low-energy environments, are not favorable for placer uraninite deposits.

Furthermore, because uraniferous quartz-pebble conglomerates were formed under an oxygen-impoverished atmosphere, the conglomerates and associated sandstones are distinguished from younger conglomerates and sandstones by several special characteristics. According to Roscoe (1973), placer deposits that formed before the oxyatmoversion are characterized by abundant pyrite (yellow-sand placers), whereas placer deposits that formed later are characterized by abundant magnetite (black-sand placers). Magnetite, although present in the source rocks for both old and young placers, is conspicuous by its absence from yellow-sand placers. Apparently magnetite is sulfidized to pyrite in the yellow-sand placers, and the presence of abundant magnetite in placer concentrations suggests that the placers formed after the oxyatmoversion.

Pyrite occurs in sedimentary rocks of all ages that have formed under anoxic conditions. Its presence is significant only in determining favorability for uraniferous conglomerate where it occurs in placer concentrations, which in strata deposited after the oxyatmoversion generally were well aerated and contain little or no pyrite. Quartzite and feldspathic sandstone associated with yellow-sand-bearing conglomerates are characteristically yellowish green (pistachio) to greenish gray as a result of ferrous iron stain coating the quartz and feldspar and in the clay minerals. Thus, the presence of pyrite as the chief iron mineral in placer concentrations and a yellowish-green or greenish-gray color in conglomerates and associated sandstones are favorable characteristics, but abundant magnetite in placers and red or brown coloration are unfavorable characteristics. (Oxidation of pyrite commonly produces red and brown coloration in outcrop and even to depths of several meters. Therefore this criterion must be used with caution.)

In the Huronian Supergroup, in the Elliot Lake district, Roscoe (1973) and J. A. Robertson (1976) have shown that conglomerates and quartzites deposited after approximately 2300 m.y. ago have Th/U >>1 (the Lorrain Formation has Th/U >10 according to J. A. Robertson, 1976), whereas those deposited earlier have Th/U <1 to 2, indicating the presence of uranium oxide minerals in the earlier sandstones and conglomerates even where significant placer concentrations do not occur. This geochemical criterion is a useful indicator of favorability in recently glaciated areas or where drill holes are available, but may be misleading where outcrops are oxidized and leached. High Th/U may result from removal of uranium by oxidizing ground waters. In such places, anomalous concentrations of thorium combined with evidence for the former presence of pyrite (limonite pseudomorphs or limonite-stained molds, pores, or vugs) in sandstone or conglomerate are favorable signs.

Hills and Delevaux (1977) used lead isotope systematics as a recognition criterion for highly oxidized and leached uraniferous conglomerates in the Black Hills, South Dakota. Based on the ratio of radiogenic ^{208}Pb to radiogenic ^{206}Pb an estimate was made of the Th/U ratio that existed in the conglomerates before weathering. Using this ratio and the present thorium content, they estimated the pre-weathering uranium content of weathered conglomerates. Lead isotope data necessary for this recognition criterion were not available in the present study.

In many areas where conglomerates occur it will not be possible to determine with certainty whether the favorable or the unfavorable recognition criteria, listed in table 2, apply. Subequent geologic history may have obscured the evidence, or appropriate information may not be available. This is the case for some criteria in both of the areas reported on here. Despite this, the partial information available permits somewhat subjective judgments to be made. In order that the reader may know how I evaluated each of the criteria in table 2, for each of the two areas examined, I have assigned numerical values to the recognition criteria as shown in table 3.

Table 3.--Method of assigning numerical values to recognition criteria

Presence of Favorable Attribute			Presence of Unfavorable Attribute	
Certain	Probable	Uncertain	Probable	Certain
+2	+1	0	-1	-2

Tables showing the numerical evaluations are included in the sections on assessments of the two study areas.

GEOLOGIC SETTING OF THE LOWELL-ELK CITY AREA

The Lowell-Elk City area is within the Clearwater orogenic zone, a belt of metamorphic rocks of largely unknown extent. The Clearwater orogenic zone contains gneisses and schists that have yielded $^{207}Pb/^{206}Pb$ ages in the range 1600 to 1800 m.y. (Reid and others 1970; Reid and others 1973) and which are intruded by rocks that range in age from at least 1450 m.y. (Armstrong, 1975) to the very young Cenozoic volcanic and shallow intrusive rocks related to vulcanism on the Snake River Plain. Most prominent among the intrusive rocks is the middle to Upper Cretaceous Idaho batholith, which bisects the Clearwater orogenic zone between Elk City and Salmon. In fact, the areal extent of the Idaho batholith is greater than the exposed and recognized remnants of Proterozoic rocks in the Clearwater orogenic zone, and previous to the work of Reid and others (1970), workers in the area considered metamorphism to be approximately coeval with emplacement of the batholith. Granitic rocks which intrude the Yellowjacket Formation in the vicinity of Shoup, and which Armstrong (1975) dated at approximately 1450 m.y. old, were previously considered to be related to the Idaho batholith. Thus, it was only in the decade of the 1970's that it became clear that early Proterozoic Y and Proterozoic X age rocks underlie central Idaho (Long and others 1960, previously reported 1400 m.y. old lead in the Coeur d'Alene district of northern Idaho).

QUARTZITE AND CONGLOMERATE OF THE LOWELL-ELK CITY AREA

General

Quartzite layers and locally metaconglomerate, ranging in thickness from less than one meter to many meters, occur within the metamorphic terrane near

Lowell and at other scattered localities in the Clearwater and Nezperce National Forests. The maximum age of these rocks is still uncertain, but they must be at least 1600 m.y. old, as inferred from the previously mentioned dates obtained from zircon by Reid and others (1973). Greenwood and Morrison (1973) assigned these quartzites and associated metasedimentary rocks to the Belt Supergroup, but Armstrong (1975) argued in favor of splitting them out from the Belt and considering them to belong to a pre-Belt basement complex. Harrison (1972) had previously concluded that age data from better known areas bracketed the time of Belt sedimentation between 1450 and 850 m.y. However, the published radiometric dates from the lower Belt in the less metamorphosed areas all use methods that are susceptable to thermal resetting, and therefore are not as reliable as could be wished for. Nevertheless, unmetamorphosed Belt strata in western Montana rest unconformably on basement rocks that were metamorphosed 1600 m.y. ago and dates from Belt rocks or from igneous rocks that intrude Belt rocks elsewhere do not suggest an age greater than approximately 1450 m.y. Whether or not metamorphic rocks of the Clearwater orogenic zone are called part of the Belt Supergroup, they apparently are significantly older than Belt rocks of Montana, and they may have been deposited under an entirely different tectonic regime.

Greenwood and Morrison (1973) and Reid and others (1973) subdivided the metasedimentary rocks of the area into three major units, which they correlated with the Wallace Formation, the Ravalli Group, and the Prichard Formation, units assigned to the Belt Supergroup where they have been mapped elsewhere in northern Idaho. Each of these units contains quartzite and because of my lack of familiarity with the stratigraphy and lack of a geologic base map, I was at times uncertain about which units were being examined and sampled. Nevertheless, at least some quartzite in each of the three units was examined and scintillometer traverses were made across the units where they crop out between Syringa and Deadman Creek along the Middle Fork of the Clearwater and along the Lochsa Rivers, near Lowell, Idaho (fig 2). Reid and others (1973) described the rocks along the Lochsa and the Middle Fork of the Clearwater Rivers in this area in detail, and only a brief summary will be given here.

Prichard Formation

Strata correlated with the Prichard Formation crop out in a 5.5 km wide belt which strikes approximately northwest and which crosses the Middle Fork of the Clearwater at a high angle (Reid and others 1973, their fig. 1). These strata consist of biotite-muscovite-quartz-feldspar schist, quartz-feldspar gneiss, quartzite, and very minor bands of calc-silicate rock. Much of the quartzite is clean and white with only minor biotite but it appears to range in composition to quartz-feldspar gneiss. A few layers of the quartzite weather to a rusty yellow-brown, which suggests that pyrite may have been present in the fresh rock. Sample 79-I-5 is from one of these rusty-weathering layers. No pebbles were visible in any of the quartzite in this area, and no original sedimentary structures other than gross bedding could be recognized. Scintillometer readings over this formation ranged from 40 cps over pure quartzite to 150 cps over biotite schist. Rusty-weathering quartzites gave readings of approximately 50 cps.

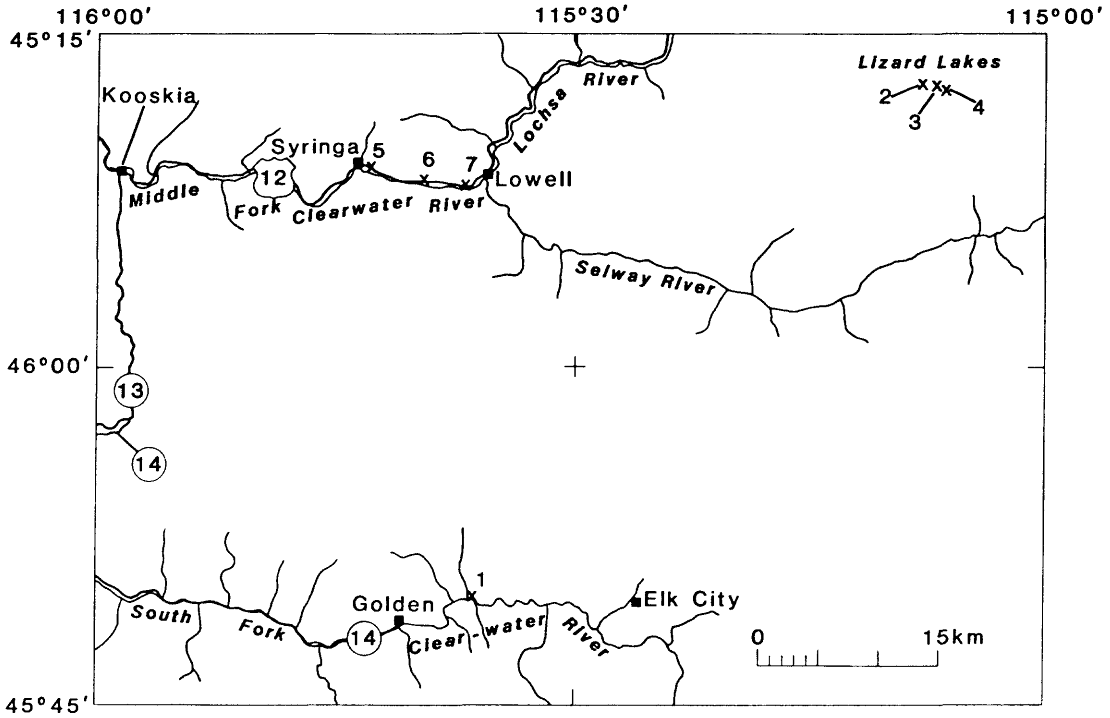

Figure 2.--Sample localities in the Lowell-Elk City area.

Ravalli Group

Strata assigned to the Ravalli Group crop out in a belt that is approximately 6.5 km wide, immediately east of the Prichard Formation. The Ravalli Group consists of several distinctive lithologies where it is found along the Lochsa and Clearwater Rivers, but only one formation, the Revett Formation, was mapped as a distinct unit by Reid and others (1973). All units, however, are predominantly pelitic and quartzitic. Biotite and muscovite schists are interlayered with garnetiferous amphibolites and with epidote and hornblende bearing quartzite. Garnets are common in the schists of the Ravalli Group, and according to Reid and others (1973), constitute 50 percent or more of some approximately one-meter thick layers.

The Revett Formation consists of approximately 600 meters of heterogeneous quartzite in layers that range from a few centimeters to several meters thick and that range from sugary white to glassy gray-green. Quartzite is interbedded with thin layers of schist.

No pebbles or other primary sedimentary features except for gross bedding were visible in any of the quartzite of the Ravalli Group. However, pyrite, a characteristic mineral in uraniferous quartz-pebble conglomerates, was observed in fresh quartzite from deep roadcuts in the Revett. This pyrite formed tissue-thin coatings on fine fractures in the quartzite, and also occurred as disseminated crystals; it was surely not of detrital origin, but conceviably it could have been mobilized from detrital pyrite during metamorphism. Sample 79-I-7 is pyrite-bearing quartzite from the Revett.

Scintillometer readings over the Ravalli Group ranged from 50 to 150 cps, and as was the case with the Prichard Formation, the lowest readings came from quartzite and the highest from mica schist. No anamalous radioactivity was found in the quartzite.

St. Regis Formation and Wallace Formation

Schist assigned to the St. Regis Formation and (or) Wallace Formation crops out in a belt approximately 6.5 km wide north and east of Lowell, Idaho. This schist, which is devoid of quartzite, is succeeded on the northeast by a 5 to 6 km-wide belt of schists and gneisses containing abundant diopside gneisses and minor feldspathic quartzite. Nothing resembling metaconglomerate was observed and no radiation anomalies were detected.

Metaconglomerate of the Lizard Lakes area

Immediately south of the Lizard Lakes in the Fenn Mountain, Idaho, 7 1/2' quadrangle and stretching eastward into the Big Rock Mountain, Idaho, 7 1/2' quadrangle, between two glaciated valleys, lies a forested arete called Blacktail Ridge. Approximately 1.5 km of the crest of the arete is underlain by generally clean and well-sorted quartzite and conglomerate. The quartzite is characteristically pure and snowy white with few grains of any mineral other than quartz, but some layers are micaceous with several percent feldspar and a few layers weather to a rusty yellow brown. A pale green mica, possibly fuchsite, is a common, though never abundant, accessory mineral in the purer layers. Metaconglomerate, like the quartzite is generally snowy white quartz or quartzite with the same accessory mineral suite found in the quartzite. Pebbles are highly flattened and elongate, and appear to consist of quartzite, although some may have been fragments of quartz that were granulated during metamorphism.

No significant heavy mineral concentrates and no pyrite were found in either the metaconglomerate or in the quartzite. However, scattered small pores, some limonite stained, suggest the former presence of a very minor amount of pyrite (sample 79-I-2), as does the yellow-brown rusty weathering stain on some layers (sample 79-I-3). One minor occurrence of quartzite streaked with dark minerals (principally biotite, garnet and magnetite, but some limonite-stained pores) was observed on Frisco Peak (sample 79-I-4). Possibly these dark mineral streaks represent recrystallized placer concentrations of heavy minerals, but no anomalous radiation was detected.

Metaconglomerate of the Elk City area

Quartzites, associated with lithologies like those found along the Middle Fork of the Clearwater, crop out in the vicinity of Golden and Elk City, Idaho (Reid, 1959; Greenwood and Morrison, 1973). These quartzites were reconnoitered briefly and found to be generally indistinguishable from the ones found along the Middle Fork of the Clearwater. No significant heavy mineral concentrations were found, no conglomerates were recognized (though the high degree of metamorphism and shearing may have made pebbles unrecognizable), no evidence for more than traces of pyrite was collected, and no anomalous radioactivity was detected. Radiation levels ranged from approximately 50 to 70 cps over quartzite and 100 to 150 cps over schist. Sample 79-I-1 was collected from quartzite containing streaks of dark minerals (mainly biotite) and where the scintillometer read 70 cps.

Assessment

Quartzites and conglomerate of the Lowell-Elk City area possibly are sufficiently old to contain placer uranium deposits, but no evidence of uranium mineralization has been found. Furthermore, although the tectonic relationship of the Clearwater orogenic belt to the Archean craton is poorly understood, no evidence has been recognized for an Archean basement under the Clearwater belt. Sedimentary rocks of the Clearwater belt may have been deposited over ensimatic crust, and they may bear a relationship to the Archean of western Montana that is analogous to the relationship between 1700-1800 m.y. old gneisses of the Front Range in Colorado and the Archean of southern Wyoming. If this speculation is correct, quartzites and conglomerate of the Lowell-Elk City area are too young and were deposited in the wrong tectonic environment to contain uraniferous quartz-pebble conglomerates.

Aside from a few small, inconsequential streaks of dark minerals, which may have formed by recrystallization of detrital heavy minerals, no evidence of significant placer concentrations was seen in the field. Trivial amounts of pyrite were observed in one outcrop, and equally trivial amounts were inferred from the presence of limonite-stained pores in other outcrops, but we observed no evidence for the presence of the anomalously large amounts of pyrite that characterize the known uraniferous quartz-pebble conglomerates and their associated quartzites. Metamorphism and deformation have obliterated primary textures and colors in all quartzites and conglomerates examined in this area except for the conglomerate on Blacktail Ridge, where some textures are preserved. This conglomerate is well sorted but exhibits no other recognition criteria.

No significantly anomalous radioactivity was observed and no significantly anomalous concentrations of uranium and thorium were found among our analyzed samples. Indeed, concentrations of uranium and thorium in these quartzites are strikingly low for quartzites and conglomerates that one would expect to contain concentrations of heavy resistate minerals such as zircon and possibly monazite. Sample 79-I-2, a slightly rusty-weathering, schistose conglomerate, which contains 29 ppm Th and 4 ppm U, is the only sample to show any enrichment of uranium and thorium, and it is well within the normal range for conglomerate.

In conclusion, I found no evidence to suggest that uraniferous quartz-pebble conglomerates of the Elliot Lake or Witwatersrand type exist in the Lowell-Elk City area. Numerical evaluations of the recognition criteria from table 2 are listed in table 4.

GENERAL GEOLOGIC SETTING OF THE SALMON-COBALT AREA

In the Salmon National Forest, near the towns of Salmon, Shoup, and Cobalt, Idaho (fig. 3), a thick sequence of fine-grained quartzites of low metamorphic rank is found in fault contact with most other Precambrian rocks. The names Yellowjacket Formation, Hoodoo Quartzite, Lemhi Group, and Swauger Formation have been applied to various parts of this sequence (Ross, 1934, 1947; Ruppell, 1973, 1975, has raised the Lemhi to Group status). In the vicinity of Shoup, Idaho, these rocks are intruded by gneissic granite, from which Armstrong (1975) obtained Rb-Sr dates of approximately 1450 m.y. Therefore, it was considered possible that these quartzites might be old enough to contain placer uranium deposits, if appropriate high-energy-facies deposits could be located.

Precambrian quartzites of the Salmon-Cobalt area are generally monotonous in texture, color, and mineralogy. These rocks consist mostly of fine to very fine grained quartz sand and silt, interlayered with siltstone and silty shale. Pure-white quartzites occur locally, but greenish-gray colors predominate with the finer grained rocks being characteristically dark greenish gray. No graphite has been identified, and although some carbon probably is

Table 4.--Numerical evaluation of recognition criteria for Precambrian quartz-pebble-type uranium deposits in the Lowell-Elk City area

Recognition Criteria		Numerical Evaluations	Comments
I.	A	-1	Probably approximately 1700 m.y. old
II.	A	-1	Probably eugeosynclinal
	B	0	No information
III.	A	0	Metamorphism destroyed most evidence
	B	0	No information
IV.	A	+1	Conglomerate of Blacktail Ridge may be oligomictic
	B	-1	Heavy mineral streaks contain magnetite
	C	-1	Analytical data suggests U is in resistate minerals
	D	0	Primary color altered by metamorphism
V.	A	-1	Only one specimen unoxidized
	B	0	No information
	C	0	No information

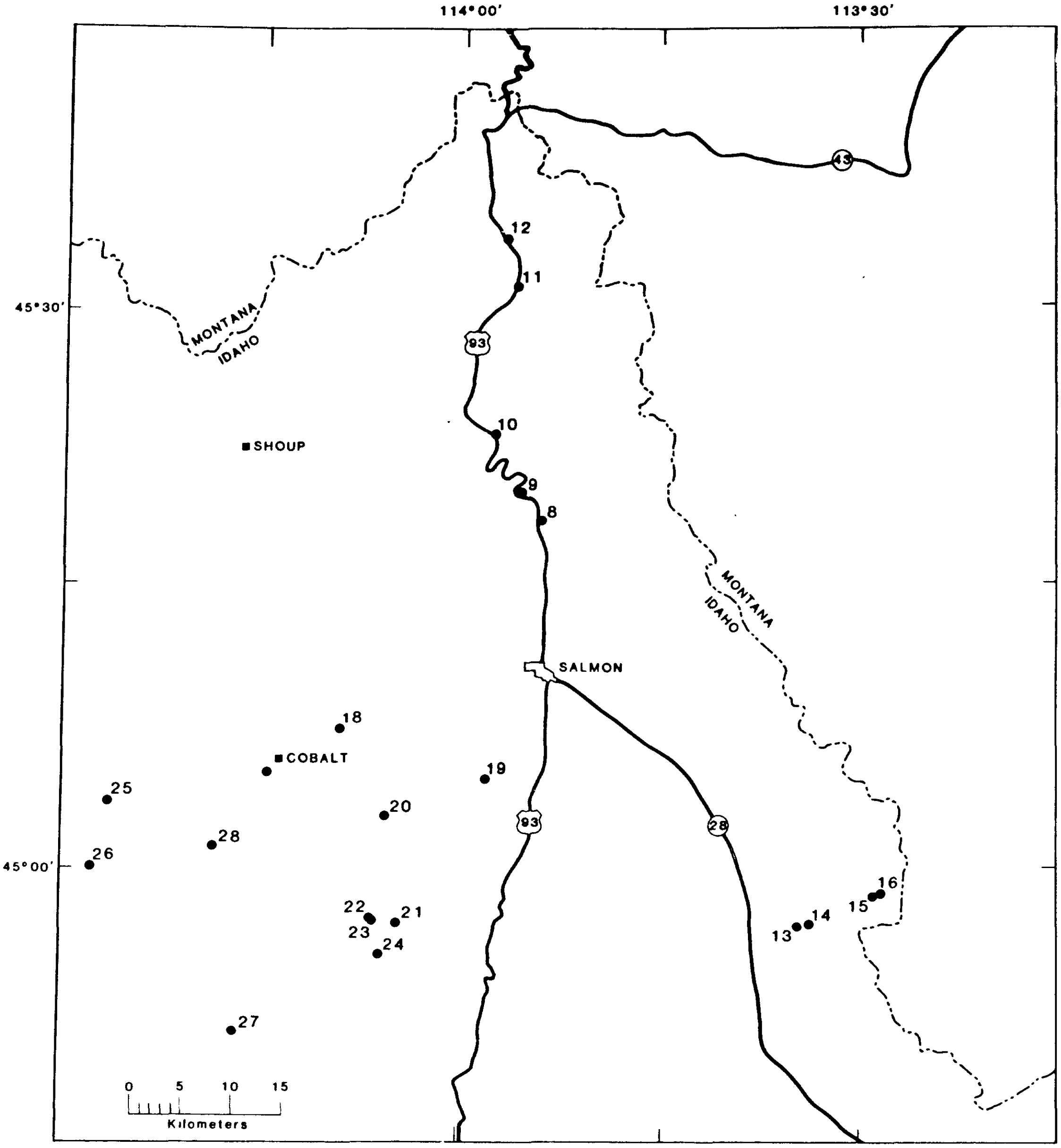

Figure 3.--Sample localities in the Salmon-Cobalt area.

present, chlorite appears to be the main pigment. In addition to quartz and chlorite, most quartzites appear to contain minor amounts of feldspar and limonite-stained pores (limonite possibly replacing pyrite, although no disseminated pyrite was observed). Locally, minor amounts of magnetite were observed forming heavy mineral streaks that mark bedding or crossbedding.

Sedimentary structures other than bedding, although nowhere prominent, are generally present. Tabular crossbeds are present locally in the cleaner, better sorted light-colored quartzites, and load casts are common in the finer, less well sorted strata. All structures observed indicated that bedding is right-side-up, but no attempt was made to study these structures systematically throughout the area. Mud pebbles 2 to 5 cm in longest diameter were observed in a few localities, but otherwise no clasts larger than sand-size were observed.

Scintillometer readings on the quartzites range from 40 to 50 cps on the pure white varieties (such as sample 79-I-25) to 125 cps on dark, fine-grained micaceous varieties (79-I-17). More typically scintillometer readings were in the range 80 to 100 cps. However, in the vicinity of Lemhi Pass, quartzite is cut by innumerable small veins or carbonatite dikes containing thorite (Staatz, 1979), and there, scintillometer readings of 250 to 1000 cps are common (samples 79-I-14, 79-I-16A through 79-I-16C).

Assessment

Because the Precambrian quartzites of the Salmon-Cobalt area are in fault contact with all Precambrian rocks except apparently the 1400 m.y. old granitic complex dated by Armstrong (1975), their relative age and tectonic relationship with other Precambrian rocks are not known with certainty. However, they appear to be less highly metamorphosed and deformed than rocks of the

Clearwater orogenic belt immediately to the north, and unless they were transported a considerable distance before juxtaposition with rocks of the Clearwater belt (which may be the case; see Ruppel, 1975), they are probably younger than 1600 to 1700 m.y., and therefore, too young to contain uraniferous quartz-pebble conglomerates. Although the former presence of pyrite is inferred from the presence of disseminated pores filled by limonite, pyrite appears never to have been abundant, and no evidence suggesting concentration of pyrite as a heavy, placer mineral was found. Indeed, iron oxide minerals (magnetite) rather than pyrite, found marking the slip face of crossbeds, supports the inference that these quartzites were deposited after the so-called oxyatmoversion (Roscoe, 1973).

The abundance of fine-grained sandstones and mudstones, and the former presence of considerable clay, indicated by the abundant chlorite in most layers of the quartzite, suggest that the formation was deposited in a consistently low energy environment, such as Howard and Reineck (1981) describe for the transition zone between nearshore and offshore marine facies. Their transition facies is deposited below normal wave base but above storm wave base. The uncommon clean white quartzite with crossbeds and heavy mineral streaks may represent deposits of the more distal nearshore facies, whereas the mudstone beds may represent deposits of the proximal offshore facies. (Bioturbation, an important characteristic of the offshore facies of modern sediments, is not present in the Yellowjacket, which has a minimum age of 1400-1500 m.y.) It also appears possible that the quartzites could have been deposited in a transitional facies of a large lake. In any case, the consistently low energy depositional environment was not suitable for the formation of significant placer concentrations.

Although somewhat higher than for rocks in the Lowell-Elk City area, uranium and thorium concentrations and scintillometer readings for the quartzites of the Salmon River-Cobalt area are quite normal and characteristic of unmineralized quartzite. Except for thorite-bearing veins in quartzite in the vicinity of Lemhi Pass, no radiation or geochemical anomalies were found.

In conclusion, no evidence was found to support the hypothesis that the Precambrian quartzites of the Salmon-Cobalt area are favorable for uraniferous quartz-pebble conglomerate. Numerical evaluations of the recognition criteria from table 2 are listed in table 5.

SUMMARY OF CONCLUSIONS

Although no upper limit has been established for the age of the quartzites of either the Lowell-Elk City area or the Salmon-Cobalt area, circumstantial evidence suggests that quartzites of both localities were deposited after the supposed oxyatmoversion of approximately 2300 m.y. ago. Characteristics common to the known uraniferous quartz-pebble conglomerates, such as abundant detrital pyrite in placer concentrations, few or no iron oxides, radioactive heavy mineral concentrations (abundant thorium even in weathered rocks from which uranium has been leached), and well-sorted oligomictic conglomerates, were generally absent. Although well-sorted quartz-pebble or quartzite-pebble conglomerate was found at one locality in the Lowell-Elk City area, no evidence of significant placer formation was found there. Additionally, no significant radiation or uranium-thorium geochemical anomalies were found that could be attributed to sedimentary processes. Therefore, neither area appears to be geologically favorable for deposits of uraniferous quartz-pebble conglomerate of the Elliot Lake-Witwatersrand type.

Table 5.--Numerical evaluation of recognition criteria for Precambrian quartz-pebble-type uranium deposits in the Salmon-Cobalt area

Recognition Criteria		Numerical Evaluations	Comments
I.	A	-1	Probably between 1450 and 1700 m.y. old
II.	A	+1	Extent and uniformity suggest esialic setting
	B	0	No information
III.	A	-2	Low energy marine or lacustrine environment
	B	0	No information
IV.	A	0	No conglomerates
	B	-2	Magnetite on foreset beds
	C	-1	Analytical data suggest U is in resistate minerals
	D	+1	Quartzites are greenish gray
V.	A	-1	Many specimens appear unoxidized
	B	0	No Th-rich placer concentrations
	C	0	No information

ACKNOWLEDGMENTS

This project benifited from advice and discussions in the field with William R. Greenwood and Edward T. Ruppel, U.S. Geological Survey. It was financed partly by U.S. Department of Energy.

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APPENDIX

Table of rock sample analyses by emission spectrograph with digital direct reader

[H indicates interference]

[Project Leader: P. J. Lamothe; Analyst: T. Fries]

LAB NO. FIELD NO.	D-221190 79-I-1	D-221191 79-I-2	D-221192 79-I-3	D-221193 79-I-4	D-221194 79-I-5	D-221195 79-I-6	D-221196 76-I-7
FE %-S	<0.050	1.9	<0.050	1.0	0.72	0.25	0.27
MG %-S	<0.10	0.35	<0.10	0.11	1.1	0.20	<0.10
CA %-S	0.070	0.060	0.050	0.080	2.2	0.66	0.050
TI %-S	0.050	0.53	0.050	0.10	0.19	0.090	0.10
MN PPM-S	<200.	430.	<200.	620.	280.	<200.	<200.
AG PPM-S	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
AS PPM-S	<200.	<200.	<200.	<200.	<200.	<200.	<200.
AU PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.
B PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.
BA PPM-S	810.	1000.	220.	110.	230.	1400.	73.
BE PPM-S	1.5	1.3	1.3	1.3	1.9	1.6	1.3
BI PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10
CD PPM-S	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
CO PPM-S	2.6	5.4	3.6	4.2	4.0	5.5	6.5
CR PPM-S	13.	190.	18.	20.	46.	18.	19.
CU PPM-S	3.5	14.	7.0	16.	14.	4.8	8.2
LA PPM-S	<20.	80.	<20.	<20.	25.	<20.	<20.
MO PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.
NB PPM-S	<25.	<25.	<25.	<25.	<25.	<25.	<25.
NI PPM-S	4.6	17.	7.0	9.6	9.4	11.	9.7
PB PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.
SB PPM-S	<100.	<100.	<100.	<100.	<100.	<100.	<100.
SC PPM-S	<10.	16.	<10.	<10.	<10	<10.	<10.
SN PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.
SR PPM-S	59.	88.	14.	<10	180.	220.	<10.
TE PPM-S	<50.	<50.	<50.	<50.	<50.	<50	<50.
V PPM-S	23.	220.	36.	24.	78.	50.	35.
W PPM-S	<100.	<100.	<100.	<100.	<100.	<100	<100.
Y PPM-S	10.	18.	<10.	<10.	21.	10.	<10.
ZN PPM-S	<50.	<50.	<50.	<50.	<50.	<50.	<50.
ZR PPM-S	69.	88.	250.	62.	280.	180.	530
SI %-S	>40.	26.	>40.	>40	>40	>40	>40.
AL %-S	1.7	12.	1.2	1.2	4.4	3.1	0.36
NA %-S	0.41	0.30	<0.15	<0.15	1.1	1.0	<0.15
K %-S	1.6	>5.0	0.53	0.61	0.70	0.98	0.12
P %-S	0.040	0.070	0.030	0.030	0.070	0.040	0.030
CE PPM-S	<100.	170.	<100.	<100.	<100.	<100.	<100.
GA PPM-S	<10.	32.	<10.	<10.	<10.	<10	<10.
LI PPM-S	<50.	<50.	54	<50.	<50.	<50.	<50.
RE PPM-S	<50.	<50.	<50.	<50.	<50.	<50.	<50.
TL PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.
HG PPM-S	<500.	<500.	<500.	<500.	<500.	<500.	<500.
SE PPM-S	<200.	<200.	<200.	<200.	<200.	<200.	<200.

LAB NO.		D-221197	D-221198	D-221199	D-221200	D-221201	D-221202	D-221203	D-221204
FIELD NO.		79-I-8	79-I-9	79-I-10	79-I-11	79-I-12	79-I-13	79-I-14	79-I-15
FE	%-S	3.6	3.1	2.5	2.0	3.4	4.0	3.9	1.2
MG	%-S	0.47	0.69	0.53	0.40	0.75	1.2	0.13	0.23
CA	%-S	0.080	0.21	0.27	0.32	0.61	0.17	4.1	1.4
TI	%-S	0.28	0.24	0.23	0.38	0.42	0.24	0.10	0.20
MN	PPM-S	250.	300.	260.	<200.	690.	250.	>5000	560
AG	PPM-S	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
AS	PPM-S	<200.	<200.	<200.	<200.	<200.	<200.	<200.	<200.
AU	PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.
B	PPM-S	<10.	<10.	32.	120.	51.	60.	<10.	<10.
BA	PPM-S	750.	620.	520.	400.	1000.	400.	180.	680.
BE	PPM-S	2.1	2.3	2.2	2.1	2.6	2.5	4.2	2.4
BI	PPM-S	<10.	<10.	<10.	<10	<10.	<10.	<10.	<10.
CD	PPM-S	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
CO	PPM-S	7.7	9.1	6.7	5.1	7.0	8.8	11.	5.0
CR	PPM-S	38.	35.	35.	51.	59.	31.	21.	34.
CU	PPM-S	5.4	5.7	5.3	6.9	6.8	23.	12.	4.8
LA	PPM-S	93.	38.	53.	43.	51.	25.	55.	36.
MO	PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10	<10.
NB	PPM-S	<25.	<25.	<25.	<25.	<25.	<25.	<25.	<25.
NI	PPM-S	16.	20	16.	9.8	16.	18.	14.	9.2
PB	PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10
SB	PPM-S	<100.	<100.	<100.	<100.	<100.	<100.	<100.	<100.
SC	PPM-S	<10.	<10.	<10	<10.	17	<10.	<10.	<10.
SN	PPM-S	<10.	<10.	<10	<10.	<10.	20.	<10	<10.
SR	PPM-S	59.	170.	91.	32.	46.	31.	220.	39.
TE	PPM-S	<50.	<50.	<50.	<50.	<50.	<50.	<50.	<50.
V	PPM-S	73.	71.	67.	68.	98.	57.	63.	64.
W	PPM-S	<100.	<100.	<100	<100.	<100.	<100.	<100.	<100.
Y	PPM-S	32.	28.	28.	23.	36.	30.	190.	21.
ZN	PPM-S	<50.	<50.	<50.	<50.	<50.	<50.	<50.	<50.
ZR	PPM-S	320.	170.	160	290	300.	310.	<20.	190.
SI	%-S	38.	36.	38.	>40.	34.	38.	>40.	39.
AL	%-S	6.1	6.7	6.2	5.0	7.5	5.5	0.67	6.4
NA	%-S	1.6	2.7	2.1	0.46	1.1	1.2	<0.15	2.7
K	%-S	3.0	2.0	1.9	2.9	4.0	2.7	0.34	2.0
P	%-S	0.040	0.050	0.070	0.060	0.070	0.050	0.12	0.050
CE	PPM-S	180.	<100.	<100.	<100	<100.	<100.	<100.	<100.
GA	PPM-S	15.	15.	12.	12.	19.	14.	<10	11.
LI	PPM-S	<50.	<50.	<50.	<50.	<50	<50	<50.	<50.
RE	PPM-S	<50.	<50.	<50.	<50	<50	<50.	<50	<50.
TL	PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10	<10.
HG	PPM-S	<500.	<500.	<500.	<500.	<500.	<500.	<500	<500
SE	PPM-S	<200.	<200.	<200.	<200.	<200	<200.	<200	<200.

LAB NO.		D-221205	D-221223	D-221224	D-221206	D-221207	D-221208	D-221209	D-221210
FIELD NO.		79-I-16A	79-I-16B	79-I-16C	79-I-17	79-I-18	79-I-19	79-I-20	79-I-21
FE	%-S	9.3	>20.	6.2	4.8	2.4	3.2	1.5	4.4
MG	%-S	1.4	<0.10	<0.10	0.70	0.19	0.41	0.28	1.0
CA	%-S	3.1	0.26	2.6	0.16	0.10	0.13	0.17	0.16
TI	%-S	0.47	0.66	0.64	0.31	0.23	0.22	0.15	0.22
MN	PPM-S	2300.	620.	240.	270.	230.	370	210.	340.
AG	PPM-S	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
AS	PPM-S	<200.	<200.	<200.	<200.	<200.	<200.	<200.	<200.
AU	PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.
B	PPM-S	<10.	H	<10.	500.	180.	<10	21.	<10.
BA	PPM-S	>5000.	760.	1400.	2500.	2300.	810.	570.	590.
BE	PPM-S	2.5	2.6	1.5	1.6	1.4	2.3	2.2	1.8
BI	PPM-S	<10.	H	<10.	<10.	<10.	<10.	<10.	<10.
CD	PPM-S	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
CO	PPM-S	14.	16.	6.1	13.	6.8	8.2	5.6	15.
CR	PPM-S	59.	58.	100.	44.	26.	39.	21.	25.
CU	PPM-S	16.	12.	8.0	18.	16.	6.4	7.0	45.
LA	PPM-S	130.	<20.	<20.	<20.	<20.	35.	50.	30.
MO	PPM-S	<10.	H	<10.	<10.	<10.	<10.	<10.	<10.
NB	PPM-S	84.	H	57.	<25.	<25.	<25.	<25.	<25.
NI	PPM-S	19.	21.	9.6	13.	12.	13.	10.	16.
PB	PPM-S	44.	38.	10	<10.	<10.	<10.	<10.	<10
SB	PPM-S	<100.	<100.	<100.	<100.	<100.	<100.	<100.	<100
SC	PPM-S	73.	34.	<10.	10.	<10.	<10.	<10.	<10.
SN	PPM-S	34.	H	<10.	<10.	<10.	<10.	<10.	<10.
SR	PPM-S	630	51.	210.	170.	89.	22.	46.	62
TE	PPM-S	<50.	<50.	<50.	<50.	<50.	<50.	<50.	<50.
V	PPM-S	140.	780.	190.	83.	57.	76.	59.	58.
W	PPM-S	<100.	H	<100.	<100.	<100.	<100.	<100.	<100.
Y	PPM-S	78.	66.	93.	18.	35.	22.	26.	23.
ZN	PPM-S	200.	<50.	<50.	<50.	<50.	<50.	<50.	100.
ZR	PPM-S	390.	130.	410.	210.	230.	77.	160.	290.
SI	%-S	30.	<10.	28.	37.	>40.	36.	>40.	35.
AL	%-S	6.3	2.9	9.3	8.2	4.4	5.6	4.9	6.4
NA	%-S	1.9	<0.15	5.3	0.77	<0.15	<0.15	1.4	2.2
K	%-S	>5.0	4.1	>5.0	>5.0	4.1	3.4	2.8	1.9
P	%-S	0.060	0.040	>0.45	0.060	0.040	0.040	0.050	0.040
CE	PPM-S	1000.	H	<100.	<100.	<100.	<100.	<100	<100.
GA	PPM-S	26.	29.	21.	26.	10.	13.	<10.	19.
LI	PPM-S	490.	<50.	<50.	<50.	<50.	<50.	<50.	<50.
RE	PPM-S	<50.	<50.	<50.	<50.	<50.	<50.	<50	<50.
TL	PPM-S	<10.	<10.	<10.	<10	<10.	<10	<10	<10
HG	PPM-S	<500.	<500	<500	<500.	<500.	<500.	<500	<500
SE	PPM-S	<200.	<200.	<200.	<200.	<200	<200.	<200	<200

LAB NO.	D-221211	D-221212	D-221213	D-221214	D-221215	D-221216	D-221217	D-221218
FIELD NO.	79-I-22	79-I-23	79-I-24	79-I-25	79-I-26	79-I-27	79-I-28	79-I-29
FE %-S	>20.	3.7	2.4	<0.050	<0.050	3.1	3.3	3.7
MG %-S	0.43	0.63	0.81	<0.10	0.12	1.1	0.74	0.87
CA %-S	0.080	0.28	0.22	0.050	0.10	0.32	0.88	0.48
TI %-S	0.080	0.27	0.26	0.030	0.050	0.31	0.26	0.29
MN PPM-S	660.	1600	290.	<200.	<200.	210.	550	420.
AG PPM-S	H	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
AS PPM-S	3000.	<200.	<200.	<200.	<200	<200.	<200.	<200.
AU PPM-S	<10.	<10.	<10.	<10.	<10.	<10.	<10.	<10.
B PPM-S	H	<10.	5000.	140.	<10.	60.	27.	30.
BA PPM-S	340.	1300.	510.	470.	800.	680.	680.	170.
BE PPM-S	2.4	3.4	2.3	1.3	1.6	3.2	3.2	3.5
BI PPM-S	H	<10.	<10.	<10.	<10.	<10.	<10.	<10.
CD PPM-S	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
CO PPM-S	10000.	15.	9.3	4.7	4.4	6.1	6.1	18.
CR PPM-S	15.	34.	37.	10.	13.	64.	35.	36.
CU PPM-S	10000.	82.	9.8	4.7	4.0	4.7	14.	42.
LA PPM-S	<20	37.	<20.	<20.	25.	36.	59.	90.
MO PPM-S	H	<10.	<10.	<10.	<10.	<10.	<10.	<10.
NB PPM-S	<25	<25.	<25.	<25.	<25.	<25.	<25.	<25.
NI PPM-S	450.	18.	16.	5.2	6.2	25.	20.	22.
PB PPM-S	21.	33.	<10.	<10.	<10.	<10.	<10.	<10.
SB PPM-S	<100.	<100.	<100.	<100.	<100.	<100.	<100.	<100.
SC PPM-S	12.	10.	16.	<10.	<10.	16.	11.	<10.
SN PPM-S	H	<10.	20.	<10.	<10.	<10.	<10.	<10.
SR PPM-S	41	42.	71.	14.	55.	56.	75.	86.
TE PPM-S	<50	<50.	<50.	<50.	<50.	<50.	<50.	<50.
V PPM-S	56.	77.	83.	24.	36.	100.	67.	77.
W PPM-S	H	<100.	<100.	<100.	<100.	<100.	<100.	<100.
Y PPM-S	23.	44.	67.	<10.	16.	37.	39	69.
ZN PPM-S	<50.	91.	<50.	<50.	<50.	<50.	<50	<50.
ZR PPM-S	65.	280.	170.	110.	31.	270	200	350.
SI %-S	<10.	34.	37	>40.	>40.	33.	34.	38.
AL %-S	2.1	7.1	7.0	1.1	3.1	7.3	7.6	6.1
NA %-S	0.40	1.3	0.47	<0.15	1.2	1.6	1.8	2.4
K %-S	1.1	4.9	2.8	0.88	2.2	4.0	3.1	1.6
P %-S	0.020	0.060	0.060	0.030	0.040	0.060	0.050	0.060
CE PPM-S	H	<100.	<100.	<100.	<100.	<100.	120.	150.
GA PPM-S	28.	22.	27.	<10.	<10.	26.	19.	16.
LI PPM-S	<50.	<50	<50.	<50.	<50.	<50.	<50	<50
RE PPM-S	<50.	<50	<50.	<50.	<50.	<50.	<50.	<50.
TL PPM-S	<10.	<10.	<10	<10.	<10.	<10.	<10.	<10.
HG PPM-S	<500.	<500.	<500.	<500.	<500.	<500.	<500.	<500.
SE PPM-S	<200.	<200	<200.	<200.	<200.	<200.	<200.	<200.