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GEOLOGICAL SURVEY

Uranium and thorium in the middle Precambrian Estes Conglomerate, Nemo District, Lawrence County, South Dakota--A preliminary report

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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ABSTRACT

The Estes Conglomerate, which is exposed in the Nemo District on the northeastern flank of the Black Hills, South Dakota, is inferred to be of early middle Precambrian age (early Precambrian X or Paleoaphebian) and to be resting on late early Precambrian (late Precambrian W) granitic continental crust. The Estes contains beds of quartzite and quartz-pebble conglomerate (oligomictic conglomerate) with matrices of micaceous quartzite that locally contain 5 to 25 percent dispersed pyrite. Highly oxidized outcrop samples of the oligomictic conglomerate have anomalously high contents of both uranium (10 to 40 ppm) and thorium (20 to 800 ppm). High thorium values in the oligomictic conglomerate favor a placer mechanism for the concentration of radioactive minerals and appear to eliminate the possibility of epigenetic processes, such as reduction of uranium by pyrite. The presence of abundant old prospect pits and of several abandoned mines suggests that these conglomerates may also contain some gold. Early prospectors may have been attracted by the gossan produced by oxidation of pyrite. Uranium in the Estes Conglomerate may be of similar origin to the economically very important uranium deposits in the Matinenda Formation of the Elliot Lake District, Ontario. Because uranium is rapidly dissolved in acidic, oxygenated ground water, such as is present where pyrite is weathering, most of the uranium originally present in the analyzed samples has probably been leached out. Conglomerate located below the zone of weathering and oxidation has good potential for economic uranium deposits.

INTRODUCTION

Estimates suggest that approximately 30 percent of the World's reasonably assured uranium reserves (excluding the U.S.S.R., China, and Eastern Europe) occur in Precambrian conglomerates (Nininger, 1974). Currently, uraniferous Precambrian conglomerate is being mined in the Elliot Lake District of Ontario and in the Witwatersrand District of South Africa, and potentially exploitable uraniferous conglomerates have been reported from northern Canada, Brazil, and Australia (Robertson, 1974). Although no economic deposits of uranium have been found in the Precambrian conglomerates in the United States, the potential for finding such deposits appears to be sufficiently high to warrant an aggressive search. This report describes preliminary results based on investigation of surface exposures of newly discovered radioactive conglomerates near Nemo, South Dakota.

EXPLORATION MODEL

Beds of radioactive conglomerate were discovered during reconnaissance of the Estes Conglomerate near Nemo, South Dakota, in the spring of 1976. The exploration model that led to their discovery is based primarily on hypotheses discussed by Roscoe (1973) and Robertson (1974), which are summarized below. Known deposits of uraniferous Precambrian conglomerate occur in upper Precambrian W or in lower Precambrian X (Paleoaphebian in the Canadian terminology) strata where uranium-bearing minerals occur along with pyrite, gold, and other heavy minerals in the matrices of sedimentologically mature quartz-pebble conglomerates (oligomictic conglomerate). These deposits are inferred to be ancient placers. Such placers are further inferred to have formed necessarily before the earth's atmosphere became sufficiently rich in oxygen to cause oxidation of pyrite or dissolution of uraninite (or other uranium-thorium oxide minerals) during the weathering process that freed these minerals from igneous rocks. This change in the earth's atmosphere (Cloud, 1968) from nonoxidizing to oxidizing (with respect to ferrous iron and quadrivalent uranium), which Roscoe (1973) dubbed the "oxyatmoversion," occurred approximately 1900 to 2100 m.y. ago and immediately preceded the deposition of Lake Superior-type iron-formation (Proterozoic iron-formation). Placer uranium deposits may occur in conglomerate that formed prior to this so-called oxyatmoversion, but they are much less likely to occur in younger conglomerate. In addition to the requirement for a primitive, nonoxidizing atmosphere, several other factors appear to limit the distribution and preservation of uranium deposits of the Elliot Lake-Witwatersrand type. These include the development of continental crust that contains granitic rocks and pegmatite, and is of sufficient thickness to rise above sea level and of sufficient lateral extent to give rise to river systems that drained large areas of rock containing disseminated uraninite and other uranium-bearing minerals. These rivers were capable of the high degree of winnowing or sorting necessary to produce economic concentrations of the very minor trace minerals of uranium. The tectonic stability that was necessary to enable such large areas of continental crust to develop and to permit the deposits formed to persist to the present time may not have developed simultaneously over the entire Earth. The Dominion Reef with its uraniferous oligomictic conglomerate was deposited in southern Africa approximately 2800 m.y. ago (Anhaeusser, 1973), whereas the earliest known oligomictic conglomerates that are associated with extensive epicontinental rocks in North America (for example, the Matinenda Formation at the base of the Huronian Supergroup) were deposited between approximately 2160 and 2500 m.y. ago (Van Schmus, 1976).

If these working hypotheses are to be accepted as the basis for an exploration model, conditions necessary for the development and preservation of uranium deposits of the Elliot Lake-Witwatersrand type apparently existed for only a relatively short time in the area now comprised by the United States. The Archean style of tectonics, characterized by the gneiss belt-granite-greenstone belt association, gave place to a Proterozoic style of tectonics, characterized by epicontinental sedimentary rocks, along the southern edge of the Canadian shield approximately 2500 m.y. ago (Goldich and others, 1966; Van Schmus, 1976) and at approximately the same time in the Rocky Mountain region (Reed and Zartman, 1973; Hills and others, 1968). The worldwide deposition of hematite-jasper facies iron-formation of the Lake Superior type, hypothesized to mark the advent of an oxidizing atmosphere (Cloud, 1968), occurred between approximately 1900 and 2100 m.y. ago. Accordingly, this exploration model leads to the conclusion that epicontinental or ensialic sedimentary or metasedimentary rocks deposited between 1900 and 2500 m.y. ago are favorable sites to explore for placer uraninite deposits. In the United States, rocks fitting or possibly fitting these criteria are found in a series of synclinoria exposed in the northern peninsula of Michigan; central Minnesota; the Black Hills of South Dakota; the Hartville uplift, possibly the central Laramie Mountains, the northern Medicine Bow Mountains, and the northern Sierra Madre of Wyoming; possibly along the northeastern flank of the Uinta Mountains in Utah; and possibly along the Salmon River arch in Idaho. Other Precambrian rocks in the United States do not appear to be as favorable using this particular exploration model. It should, however, be kept in mind that the genetic hypotheses or attempted generalizations on which this exploration model is based stem from empirical relations derived from a small number of case studies (essentially only the Elliot Lake District and the Witwatersrand) and therefore must be considered tenuous. When and if other members of the class or set to which the Elliot Lake and Witwatersrand deposits belong are found, some of the empirical relations used to formulate the exploration model may prove to be nonessential, and the exploration model may need to be modified or abandoned.

PREVIOUS WORK

An article presenting a general summary of the Precambrian geology of the Black Hills, including the Nemo District, can be found in "Mineral and Water Resources of South Dakota" (Redden and Norton, 1975). The first report dealing specifically with the Precambrian geology of the Nemo District was published by Runner (1934), and, more recently, Bayley (1970 and 1972a) has remapped the area in his study of taconite in the district. Harrer (1966) also reviewed some aspects of the Precambrian geology of the Nemo District in his discussion of iron resources of South Dakota. Zartman, Norton, and Stern (1964) and Zartman and Stern (1967) obtained U/Pb ages of approximately 2500 m.y. on zircon from the Little Elk Granite a few miles north of Nemo, and Bayley (1972a) contended that metasedimentary rocks in the Nemo District rest unconformably above the Little Elk Granite. Numerous K/Ar and Rb/Sr mineral dates in the approximate range from 1600 to 1700 m.y. have been obtained from pegmatite and granite that intrude metamorphosed sedimentary rocks in other parts of the Black Hills, and an Rb/Sr whole-rock isochron of 1740 m.y. has been reported on the Harney Peak Granite (Riley, 1970), which intrudes metamorphosed sedimentary rocks in the southern Black Hills. These age determinations suggest a minimum age of at least 1750 m.y. for the major sedimentary succession in the Black Hills. Bayley (1970, 1972a) agreed with Runner's (1934) conclusion that the Estes Conglomerate and the underlying Nemo Group (Estes System and Nemo System of Runner, 1934) are unconformably overlain by metasedimentary rocks of Runner's Lead System, although Bayley (1972a) placed the unconformity beneath the Roberts Draw Limestone (marble) whereas Runner considered part of Bayley's Roberts Draw Limestone to be in his Estes System. The Roberts Draw Limestone and overlying metasedimentary formations may correlate approximately with strata intruded by Harney Peak Granite (Bayley, 1972b; Redden and Norton, 1975), and therefore the Estes Conglomerate appears to be older than 1740 m.y. Redden and Norton (1975) indicate that a great thickness of Precambrian strata overlies the Estes Conglomerate (possibly as much as 60,000 feet or 18,400 m), which suggests that the Estes Conglomerate may be considerably older than 1740 m.y. The probable early middle Precambrian age of the Estes Conglomerate and its epicontinental situation thus suggest that it might be an appropriate host for Elliot Lake-Witwatersrand-type placer uranium, and it was examined in the spring of 1976.

The present report on radioactivity in the Estes Conglomerate gives preliminary results of a field investigation, supplemented by a small number of uranium and thorium analyses. Petrographic studies and additional analytical studies are in progress and will be reported at a later time.

LOCATION, ACCESSIBILITY, AND MINING HISTORY

The Nemo District, located in figure 1, is approximately 14 miles (23 km) northwest of Rapid City, South Dakota, in the Black Hills National Forest. The radioactive facies of the Estes Conglomerate crops out in Lawrence County, but probably extends into Meade and Pennington Counties in the subsurface. The areas of interest are primarily in the Nemo and Piedmont 7-1/2 minute quadrangles, but extend into the Deadman Mountain and Tilford quadrangles in the subsurface (U.S. Geological Survey 1/24,000 topographic map series). The area of interest is also covered by U.S. Geological Survey Miscellaneous Geologic Investigations Map I-712 (Bayley, 1972a).

The Nemo District has been prospected extensively for both iron and gold. The Benchmark Iron-formation (Bayley, 1972a), a banded taconite, crops out discontinuously for approximately 23 km in the district (Harrer, 1966, p. 10), and by means of a magnetic survey (Bayley, 1972a) and by drilling it can be traced for several more kilometers in the subsurface. Harrer (1966, p. 11) estimated that in

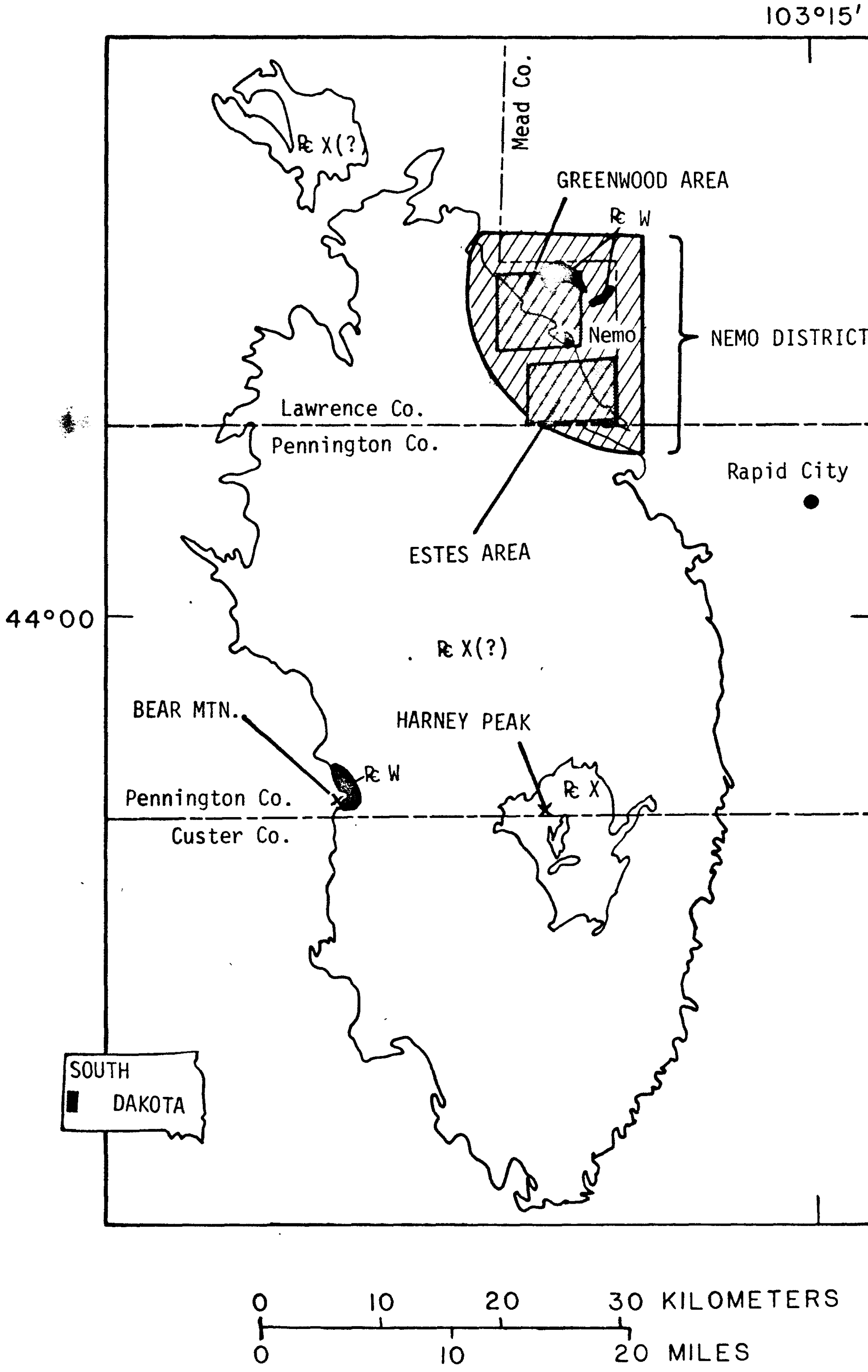


Figure 1.--Precambrian rocks in core of the Black Hills uplift showing location of Nemo district and Estes and Greenwood areas.

excess of 0.5 billion tons of taconite containing 29 percent iron may exist in the Nemo District. Iron-formation is presently being mined, for use in cement, from a pit approximately 1.5 km southeast of Nemo (NE 1/4 sec. 34, T. 3 N., R. 5 E.). In addition to the Benchmark Iron-formation, a taconite-pebble conglomerate occurs within the Estes Conglomerate and is of possible economic value. Both the Benchmark Iron-formation and the taconite facies of the Estes Conglomerate have been heavily prospected, and shallow pits dot the surface over these rocks.

Gold mining has been attempted on a small scale in the district during the past (U.S. Bureau of Mines, 1954), but there are presently no active mines and the amount of gold recovered is not known. The two largest mines known to the author (the Lucky Strike Company mines near the community of Greenwood, sec. 18, T. 3 N., R. 5 E; figure 5) are in Estes Conglomerate, and the ore zone appears to have been in pyrite-bearing, radioactive, oligomictic conglomerate.

Other areas underlain by Estes Conglomerate are dotted with mostly shallow prospect pits. These appear to be most abundant in, but not limited to, areas underlain by the better sorted, radioactive facies of conglomerate. Whether these pits were dug in search of gold or of taconite is not known. It is possible that the red and brown limonitic outcrops produced by oxidation of pyrite gave hope of finding taconite deposits, but most probably they were viewed as gossan. In any case, most pits appear to be quite old.

GENERAL GEOLOGY

Black Hills

The core of the Black Hills uplift exposes a very thick, structurally complex sequence of middle Precambrian metasedimentary rocks. Although the present configuration of the Black Hills uplift is that of a gentle anticline, as Bailey (1970) pointed out, the middle Precambrian structure, of which the metasedimentary rocks are a part, is probably a complex synclinorium. The extent and configuration of this synclinorium is not known, but Lidiak (1971) presented geophysical evidence for a northward-trending structure separating the Precambrian-W Wyoming Province from rocks of similar age in Minnesota and trending northward into North Dakota in the subsurface. Lower Precambrian rocks crop out in the cores of two structural domes in the Black Hills (fig. 1)--one, the subject of this report, in the Nemo District, and the other, the Bear Mountain dome (Redden, 1968; Ratté and Zartman, 1970, on the western edge of the Black Hills. In both domes, Precambrian W basement gneisses are overlain, with apparent unconformity, by middle Precambrian quartzite and conglomerate. Thus, in the Black Hills, the middle Precambrian synclinorium appears to be ensialic.

Nemo District

The Nemo District is isolated from the rest of the Black Hills by a system of faults that makes correlations difficult and uncertain. The general structure of the Nemo area as it appears on Bayley's (1972a) map is that of a complex dome or half dome with several culminations. The eastern side of the dome is covered by the Cambrian Deadwood Formation and overlying Paleozoic formations, and the Little Elk Granite, presumably the oldest rock exposed, crops out only in Little Elk Canyon, where it occurs as an inlier surrounded by Deadwood Formation.

The structure within the exposed part of the dome is typified by steeply plunging isoclinal folds. Complex folding, faulting, limited exposure, and, if Bayley is correct, three unconformities make the structure difficult to interpret, and a more detailed study of the stratigraphy and structure would be required to understand the distribution of rocks within the area. Section 2, T. 2 N., R. 5 E., which contains the largest known mass of radioactive conglomerate, was remapped in detail to determine whether the radioactivity could be related to recognizable structural or stratigraphic features. The information acquired was used to modify Bayley's (1972a) map and is given in figures 2, 3, and 4. Beds of conglomerate dip steeply (generally 70° to 90°) and are isoclinally folded. However, it was not possible to determine whether there are several zones of radioactive beds or only one zone that is repeated by folding. Nevertheless, these data should prove useful in locating drill holes to intersect the radioactive beds at depths of up to several hundred feet (100 to 200 m).

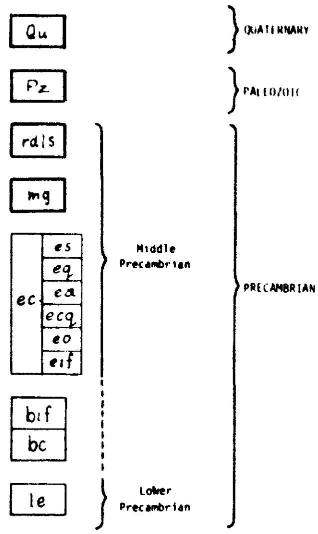
The Nemo dome lies within the biotite zone (Redden and Norton, 1975), the lowest grade metamorphic zone in the Black Hills. On the basis of preliminary hand-specimen petrography, the Estes Conglomerate may be of even lower grade, as only chlorite and white mica have been recognized as metamorphic indicator minerals.

Stratigraphy

The first careful study of stratigraphy of Precambrian rocks in the Nemo District was that of Runner (1934). As mentioned above, Bayley (1972a) has revised Runner's stratigraphy. Unfortunately, Bayley died in 1974, before publishing detailed descriptions of his newly defined stratigraphic units. Runner's descriptions, therefore, remain the most detailed available, although Bayley's (1972a) map is far more detailed than Runner's. This report makes use of Bayley's rather than Runner's stratigraphy, although the author has some reservations, particularly regarding the stratigraphic and structural position of parts of the Roberts Draw Limestone. Only the lower part of the stratigraphic column is relevant to the present report and only that part will be discussed. The distribution of mapped formations and of informal subdivisions of Estes Conglomerate is shown on figures 2 and 5.

EXPLANATION FOR FIGURES 2 THROUGH 5

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qu Undifferentiated surficial deposits and residuum

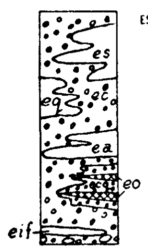
Pz Sedimentary rocks

Unconformity

rdls ROBERTS DRAW LIMESTONE

Unconformity

mg METAGABBRO



ESTES CONGLOMERATE

- ec — Polymictic conglomerate generally with a chloritic matrix and an open framework. Also undifferentiated Estes Conglomerate
- es — Chloritic schist or phyllite with scattered pebbles
- eq — Chloritic or micaceous quartzite with scattered pebbles and conglomeratic layers
- ea — Coarse to fine-grained black or gray arkose with layers of black shale
- ecq — Micaceous quartzite with pebbly layers, slightly radioactive.
- eo — Quartz and quartzite pebble conglomerate ("oligomictic") with pyritiferous, micaceous quartzite matrix. Generally radioactive
- eif — Conglomerate consisting predominantly of taconite pebbles.

Unconformity

NEMO GROUP

bif BENCHMARK IRON-FORMATION

bc BOXELDER CREEK QUARTZITE

Unconformity

le LITTLE ELK GRANITE

Contact - Dashed where approximately located

Indefinite contact of Qu

Fault

Strike and dip of bedding

85 Inclined

Vertical

Strike and dip of cleavage

75 Inclined

Vertical

Abandoned mine

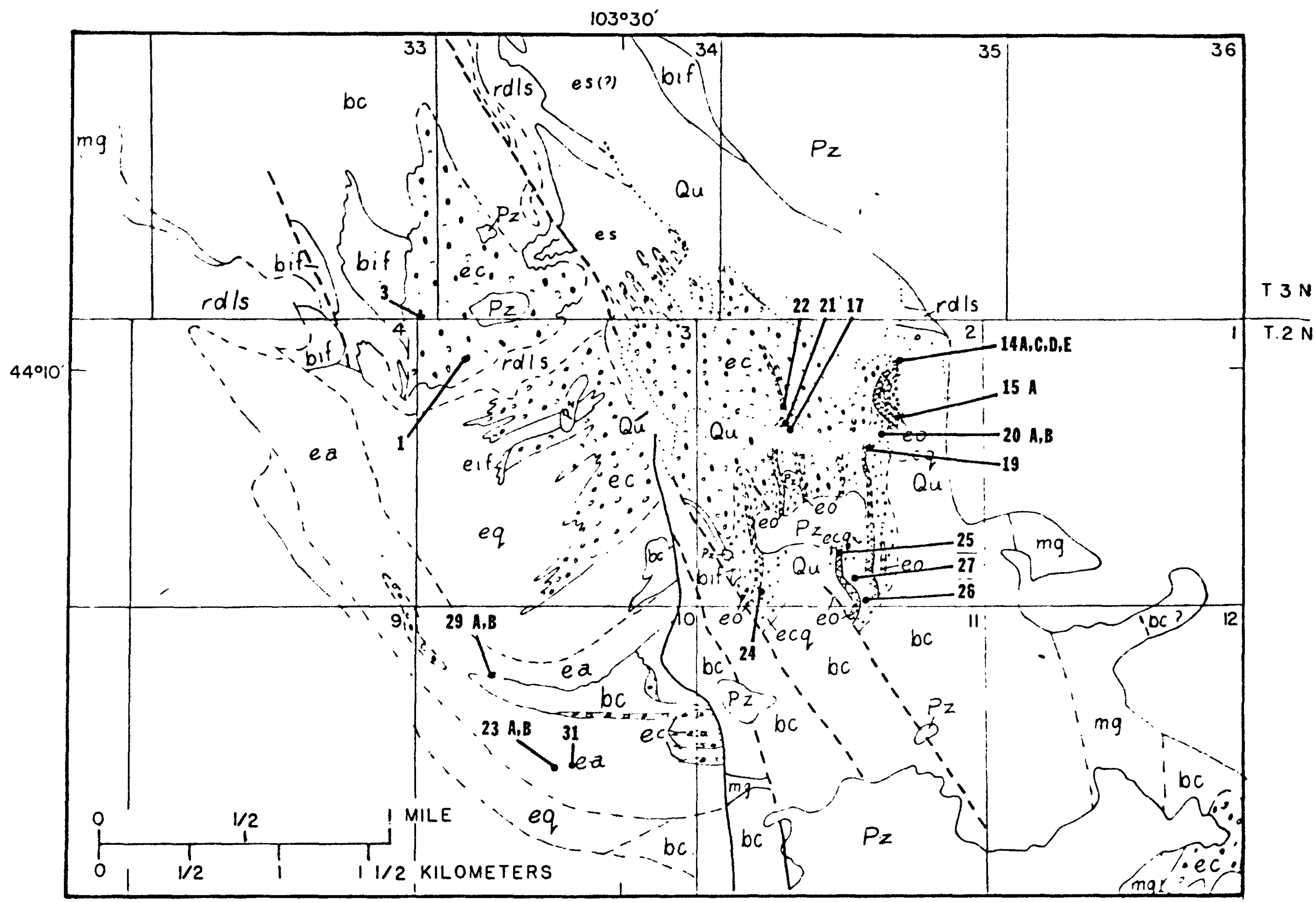


Figure 2.--Geology of the Estes area showing sample localities. (Geology from Bayley, 1972a, except for modifications in sec. 2).

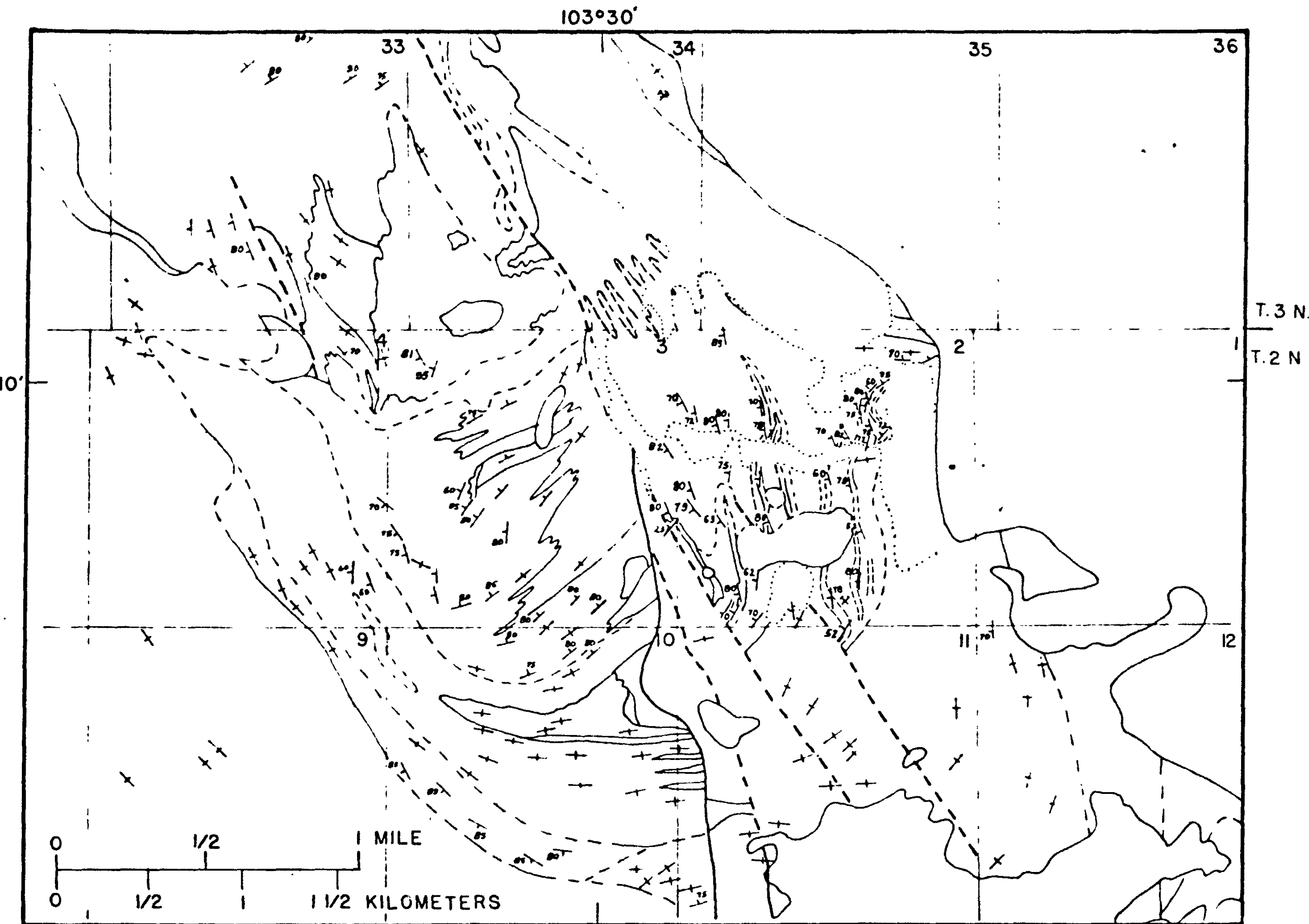


Figure 3.--Orientation of bedding in the Estes area. Geologic contacts from figure 2.

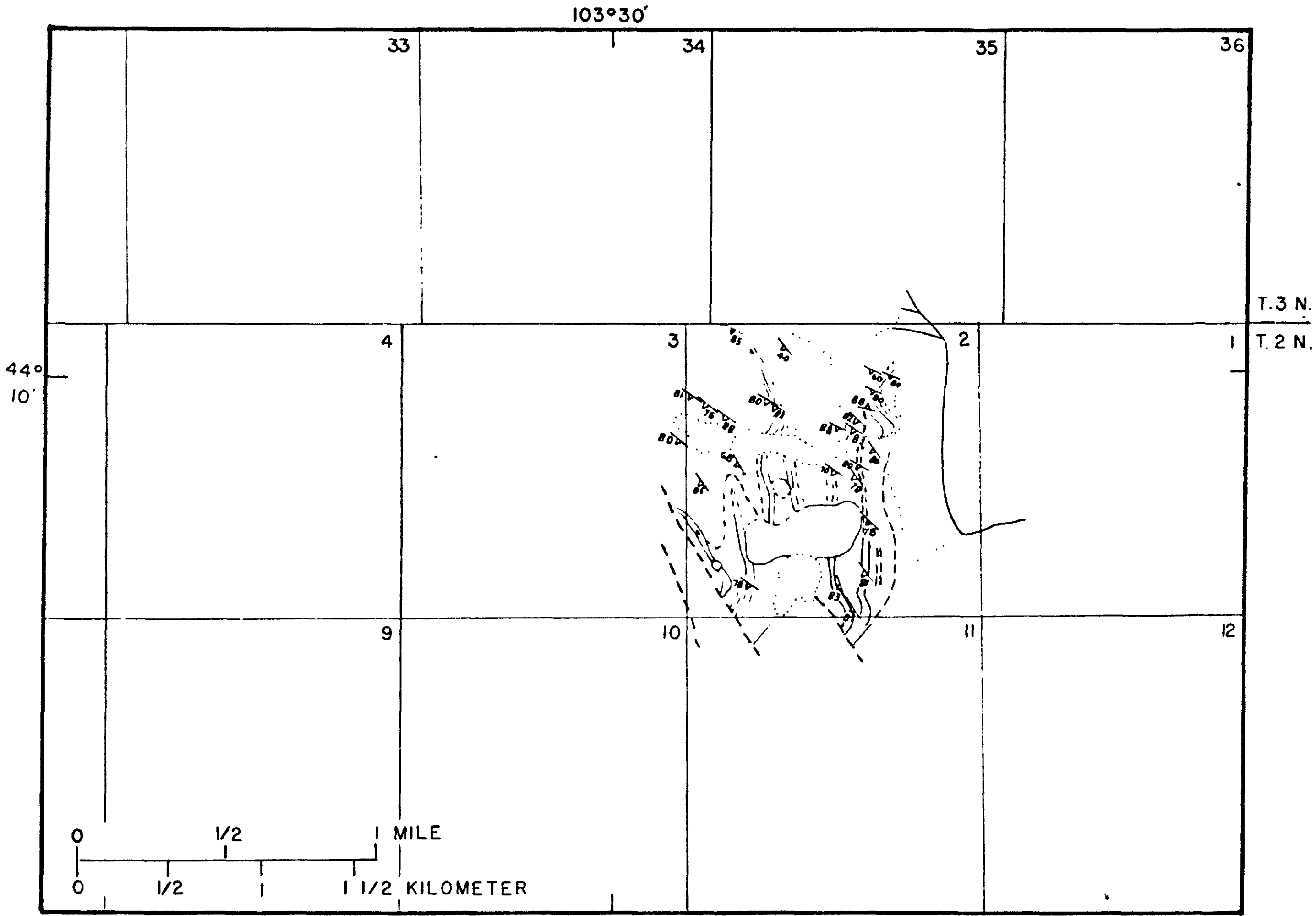


Figure 4.--Orientation of cleavage in the Estes area, sec. 2.

Little Elk Granite

The Little Elk Granite (fig. 5) is a medium-grained biotite granite gneiss. Runner (1934) reported a modal composition of microcline plus albitic plagioclase, 60 percent; quartz, 25 percent; biotite plus muscovite, 15 percent; with minor apatite, tourmaline, zircon, and pyrite. Runner also reported small tourmaline-bearing, aplite dikes intruding the Little Elk Granite and a few small quartz veins containing 10 percent tourmaline and minor apatite, muscovite, rutile, and pyrite. Taylor (1935) reported pyrrhotite as well as pyrite, and he also mentioned magnetite. The presence of pyrite as an accessory mineral both in the granite gneiss and in the quartz veins is noteworthy.

The contact relationship between Little Elk Granite and metasedimentary rocks is of special importance, because the Little Elk Granite is the only rock that has been dated in the district. Runner (1934) described the Little Elk Granite as "clearly intrusive into the pre-Cambrian sediments . . .," whereas Bayley (1972a) infered an unconformity between the Little Elk Granite and his Boxelder Creek Quartzite, the oldest metasedimentary formation; Zartman and Stern (1967) concluded that the relationship is inconclusive, but they favor an unconformable relationship. The problem is that the Little Elk Granite is in contact with the Deadwood Formation along all except approximately 2 km (mainly sec. 4, T. 3 N., R. 5 E.) of its contact, and exposures along that short segment of contact are very poor. The contact between granite gneiss and metasedimentary rock could not be found in the present study, and none of the dikes, which Runner (1934) reported as being numerous in the border zone, were noted. However, a rather schistose zone with gneiss layers, interpreted here as a zone of sheared Little Elk Granite, crops out near the contact, and this zone may have been interpreted by Runner as metasedimentary rock intruded by granite dikes.

The lack of dikes and the low grade of metamorphism in Estes Conglomerate within approximately 100 m of the inferred contact with Little Elk Granite support but do not prove Bailey's interpretation of the relationship between Little Elk Granite and Estes Conglomerate. However, I am not convinced that quartzite and taconite that crop out locally near the inferred contact necessarily belong to the Nemo Group or that they necessarily form continuous layers paralleling the contact with Little Elk Granite as shown by Bayley (1972a). Therefore, it appears likely, although it has not been proven, that the Estes Conglomerate lies unconformably over the Little Elk Granite. However, the relationship between Little Elk Granite and the Nemo Group is indeterminate; not only is the contact relationship uncertain between quartzite and taconite near the contact, but these rocks may belong to the Estes Conglomerate rather than to the Nemo Group.

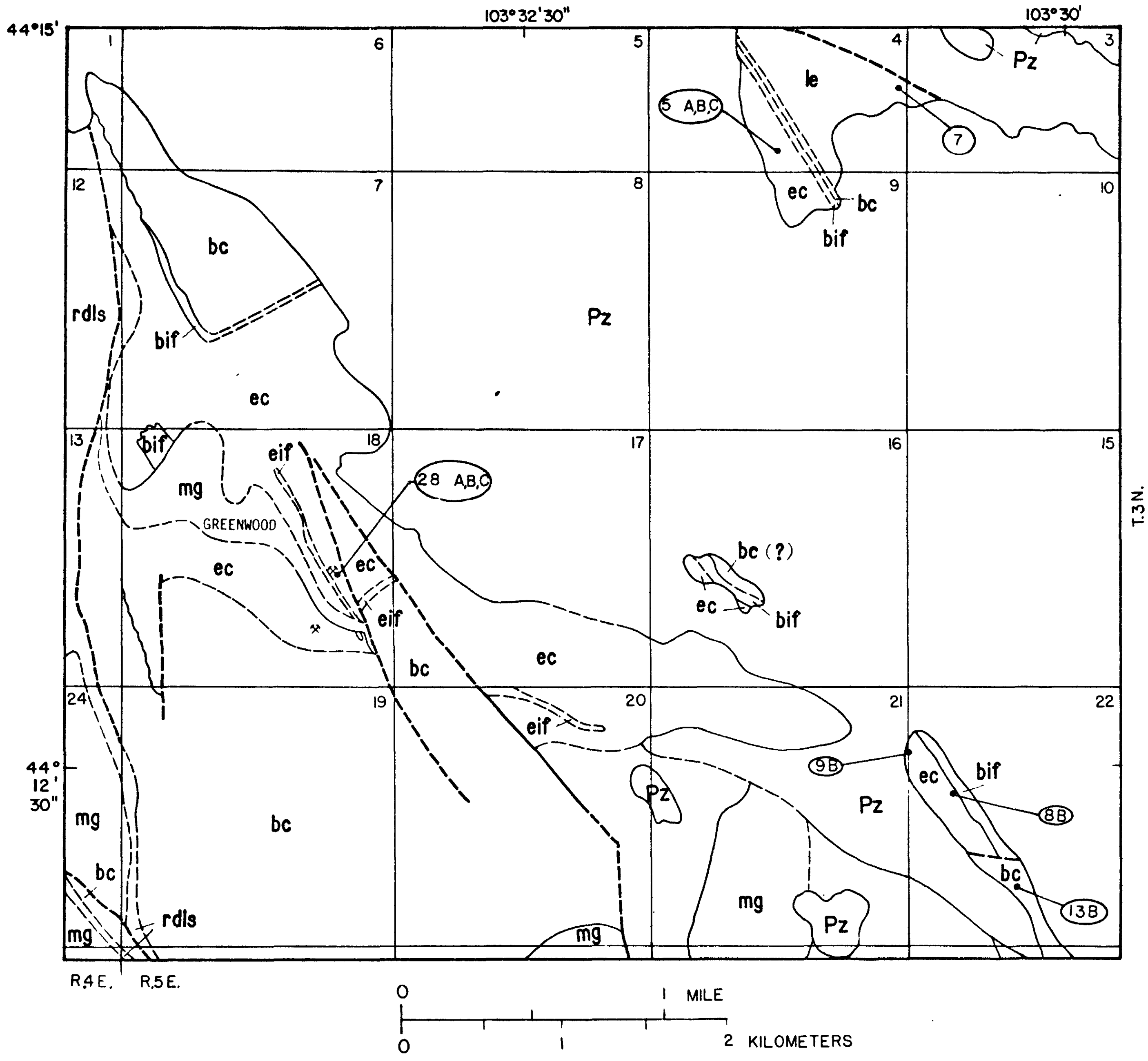


Figure 5.--Geology of the Greenwood area showing sample localities. (Geology from Bayley, 1972a.)

Boxelder Creek Quartzite

The Boxelder Creek Quartzite, the lowest metasedimentary formation recognized by Bayley (1972a), consists predominantly of an off-white to light-buff-colored, crossbedded, very hard orthoquartzite, containing layers of quartz-mica schist. No disseminated pyrite was found, but magnetite has been noted by Runner (1934) on both flat beds and cross beds. Small pebbles containing magnetite and hematite(?), which may have been pebbles of iron-formation, were observed in conglomeratic layers in sec. 33, T. 3 N., R. 5 E. Bayley (1970) estimated a thickness in excess of several thousand feet ($\sim$1000 m) for the Boxelder Creek Quartzite. No areas of anomalous radioactivity have been detected in the Boxelder Creek Quartzite.

Benchmark Iron-Formation

The Benchmark Iron-formation consists of a banded quartz-taconite rock apparently deposited conformably above the Boxelder Creek Quartzite. Runner (1934) stated that locally it grades along strike into quartzite. Taconite layers consist of micaceous, metallic-gray specular hematite (locally with euhedral magnetite or martite), and quartz-rich layers consist of fine, sugary, white quartz. Both Runner and Bayley inferred that the Nemo Group was folded before deposition of the Estes Conglomerate, and the intermittent distribution of Benchmark Iron-formation along the contact with Estes Conglomerate is in accord with this inference. However, it is noteworthy that the Benchmark Iron-formation is everywhere in contact with the Estes Conglomerate. Apparently it was not deeply or complexly infolded with the Boxelder Creek Quartzite before deposition of Estes Conglomerate.

Estes Conglomerate

Bayley (1970) described the Estes Conglomerate as ". . . primarily a boulder conglomerate formation, which changes laterally by interfingering, to three distinctly different facies: quartzite and quartz-mica schist, meta-arkose, and pebbly chlorite schist. . . each facies is basal to its own area--which probably indicates that the pre-Estes topography had considerable relief." All facies are pebbly or contain pebbly layers. The distributions of these facies, as mapped by Bayley (1972a), are shown in figure 2, with a modification based on the present study shown only in section 2. This modification consists of subdividing the conglomeratic facies on the bases of degree of sorting in conglomeratic layers and of chloritic versus quartzitic matrix.

The arkosic facies, consisting of black arkose and black metapelite exposed in sections 3, 4, 9, and 10, is the least deformed and least recrystallized portion of the Estes Conglomerate. Cleavage development is poor to nonexistent, and clasts of feldspar and opalescent blue to smoky quartz are subrounded to angular and show little of the stretching common to pebbles in other facies of the conglomerate. Small pebbles and granules of quartz and feldspar, possibly derived from the Little Elk Granite, constitute the bulk of the arkosic material, but pebbles in the layers of coarser conglomerate within the arkosic facies are chiefly of quartzite. The black or dark-gray color in both arkose and metapelite appears to result from finely divided graphite. Some layers of metapelite particularly are graphite rich. Feldspar was not observed in other facies of the Estes Conglomerate, although Bayley (1970) speculated that it was present originally but has been eliminated by pervasive shearing and recrystallization.

Where the conglomeratic facies lies directly on the Nemo Group, the lower part of the formation appears to consist predominantly of poorly sorted, polymictic boulder conglomerate having a chlorite-rich matrix. Boulders of quartzite (presumably Boxelder Creek Quartzite) 0.5-1.5 m in length are common, and pebbles and boulders of taconite and phyllite are abundant. Taconite pebbles are sufficiently abundant in some places, particularly where the Estes Conglomerate is in contact with Benchmark Iron-formation, to constitute a potential iron resource (Bayley, 1970; Harrer, 1966).

Where the Estes Conglomerate has been studied most carefully, in sections 2, 3, and 34 (fig. 2), the conglomeratic facies grades laterally into and interfingers with micaceous quartzite (eq in section 3) and chloritic pebbly phyllite (es in sections 2 and 34). In both intergradational situations, the conglomerate is poorly sorted, and pebbles and cobbles, predominantly of quartzite, taconite, and schist, are scattered through the finer grained matrix (open framework).

In an irregular band (fig. 2) trending approximately northeastward from the southern edge of south-central section 2 to central and northeastern section 2, the conglomerate is better sorted and consists of quartz and quartzite pebbles in a matrix of pyrite-bearing micaceous quartzite (referred to hereafter as the oligomictic conglomerate). Beds of oligomictic conglomerate are interlayered with pebbly micaceous quartzite. Taconite and schist pebbles are uncommon in the oligomictic conglomerate, and pebbles of quartz and quartzite appear to form a framework of pebbles resting one against the other, with quartzite filling in between the pebbles. Commonly, the smaller pebbles and granules of quartz are the same opalescent blue grains that were described in the arkose.

The matrix of oligomictic conglomerate is predominantly quartz and white mica, with some chlorite locally and possibly some chrome mica. It contains 5 to 25 percent pyrite. No feldspar has been observed; but, as noted by Bayley (1970), feldspar may have been converted to micas during metamorphism. Euhedral to subhedral pyrite is disseminated through the matrix of oligomictic conglomerate, rather than in veins. However, because the matrix is recrystallized, it has not been possible to determine whether pyrite was originally detrital.

Pyrite was not observed in the Boxelder Creek Quartzite, but it is finely disseminated through several pebbles of quartzite in the oligomictic facies of the Estes Conglomerate. These quartzite pebbles are believed to have been derived from the Boxelder Creek Quartzite. Except for the arkose, the Estes Conglomerate appears to be severely deformed, with a thoroughly recrystallized matrix. A very pronounced cleavage is developed (fig. 4), which locally makes recognition of bedding difficult, particularly where cleavage approximately parallels bedding. Pebbles are stretched into triaxial ellipsoids or rod-shapes, commonly with ratios of longest to shortest axes being between 3 and 5. Long axes plunge very steeply and appear to parallel the intersections of cleavage and bedding.

Oligomictic conglomerate is everywhere deeply weathered and stained various shades of red and brown, probably as the result of oxidation of pyrite. Except in highway cuts (NE 1/4 sec. 2, fig. 2) and in mine dumps (east center sec. 18, fig. 5), pyrite is generally oxidized to limonite. Its former presence must be inferred from abundant limonite-filled holes, many of which are approximately cube-shaped, and from comparison with the few relatively unoxidized rocks from highway cuts and old mines. However, even the freshest rocks obtained from highway cuts and mines are partially oxidized, stained brown or red, and contain pores and vugs where soluble minerals have leached out.

Oligomictic conglomerate has been most carefully studied in the Estes area (fig. 2, sec. 2, T. 2 N., R. 5 E.); however, it has also been observed in the Greenwood area (fig. 5, secs. 4, 7, 16, 17, and 18, T. 3 N., R. 5 E.), where it has not been carefully mapped. A layer of rather coarse, pyritiferous oligomictic conglomerate appears to have been the ore bed at the abandoned Lucky Strike Company gold mine near Greenwood (sec. 18, T. 3 N., R. 5 E.).

At present,the stratigraphic position of oligomictic conglomerate within the Estes Conglomerate cannot be interpreted unambiguously. According to Runner's (1934) interpretation of the structure and stratigraphy, the oligomictic beds occur in the middle to the top of the formation and grade downward into coarser and less sorted facies. Bayley (1970, 1972a), however, correlated a layer of marble that crosses the Estes Conglomerate (fig. 2, secs. 3, 4, 34, and 35) with his younger Roberts Draw Limestone, and he correlates quartzite (secs. 2, 11, and 12), which Runner included in the upper part of his Estes System, with the Boxelder Creek Quartzite. Bayley's correlations require a more complex structure and stratigraphy in the Estes Conglomerate and suggest that the oligomictic conglomerate in section 2 lies near the base of the formation rather than higher in the formation. The present study has not focused on these problems and cannot resolve the differences between Runner and Bayley.

RADIOACTIVITY IN THE ESTES CONGLOMERATE

Anomalous radioactivity in the Estes Conglomerate was first detected by use of a scintillometer while examining conglomerate near its contact with Little Elk Granite in sec. 4, T. 3 N., R. 5 E. (see fig. 5). After its detection, the part of the area underlain by Estes Conglomerate was mapped and a more detailed waist-level total-gamma survey was made using a conventional scintillometer (figs. 6 and 7). Values contoured in figures 6 and 7 are raw scintillometer readings in counts per second, taken at waist level with a Mount Sopris Model SC-132*. No attempt was made to compensate for topographic effects and for differences in amount of outcrop, or to convert counts per second for the particular instrument to milliroentgens or equivalent uranium. Background levels over open-framework, poorly sorted, chloritic conglomerates, quartzites, and other normal rocks in the area range from approximately 40 cps to 100 cps. Background over the arkose is generally in the range from 100 to 135 cps, and for the oligòmictic conglomerate it ranges from 100 to 600 cps.

*Use of this brand name is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

As may be seen by comparing figures 2 and 6, the gamma anomaly is pronounced over and faithfully follows beds or zones of the oligomictic conglomerate. Radioactive beds range in thickness from a few cm to approximately 2 m. Not all beds of well-sorted conglomerate were found to be anomalously radioactive; however, all anomalously radioactive beds in section 2 appear to be very well sorted, pebble-framework, pyritiferous oligomictic conglomerate. Using the scintillometer, these radioactive beds or zones could be traced very well along strike, even where they do not crop out, so long as they are covered by only thin residual soil. Where alluvium or thick soil exists, as for example in the NW 1/4 sec. 2, it was not possible to determine whether the radioactive beds persist or pinch out (or possibly are folded back).

As in section 2, not all oligomictic conglomerate in sections 4, 7, 16, 17, 18, 20, and 21 (T. 3 N., R. 5 E.) are anomalously radioactive, but all radioactive conglomerates appear to be oligomictic. However, these sections have not been studied in much detail. The principal exception to this generalization may be observed in a highway cut immediately north of Nemo in west-central section 22. Here a somewhat chloritic and limonitic pebbly phyllite is anomalously radioactive (see also samples BH-76-13a and BH-76-13b in Table 1).

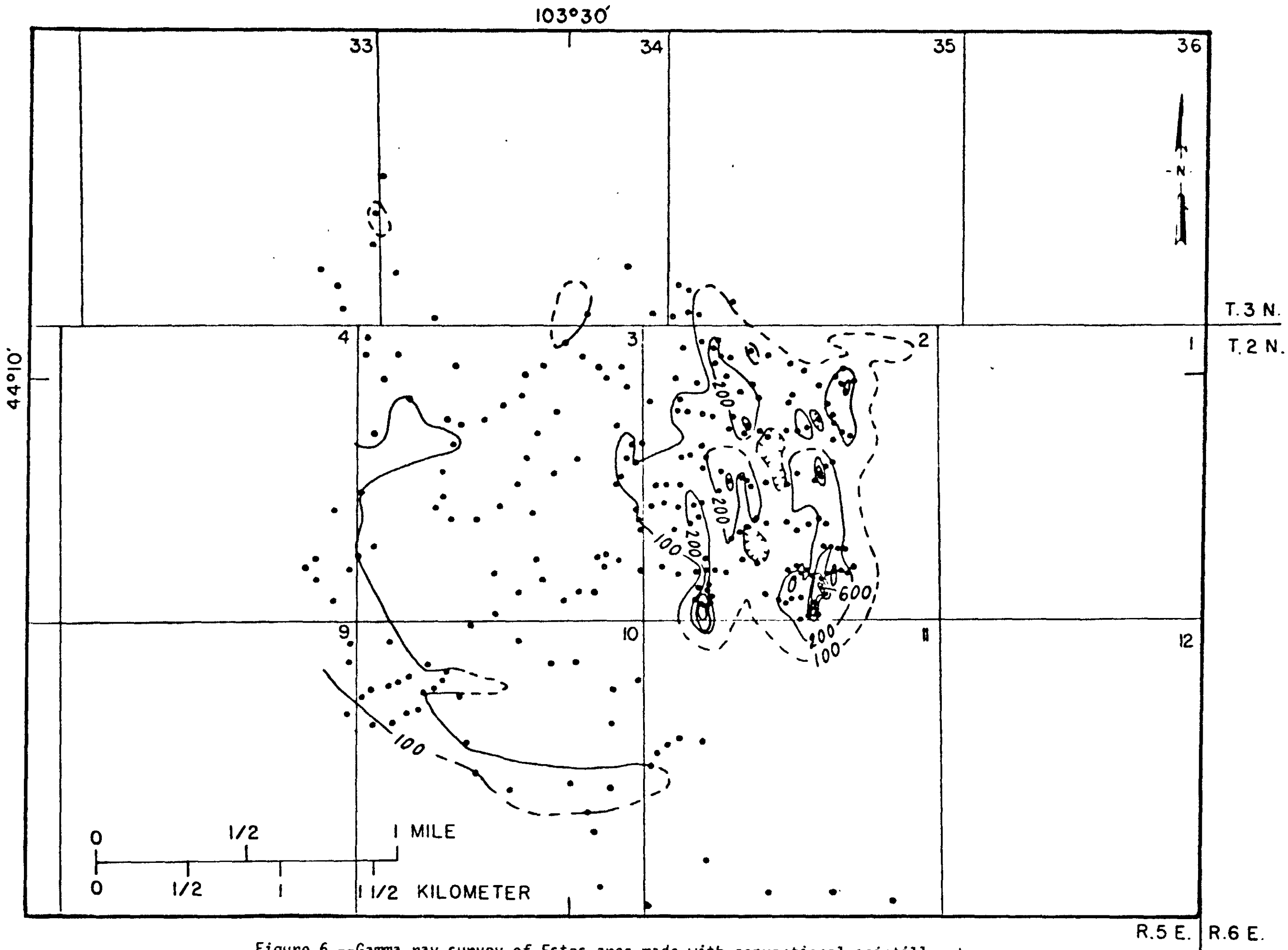


Figure 6.--Gamma-ray survey of Estes area made with conventional scintillometer held at waist level. Units are counts per second and contour interval is 100 cps. Dots represent localities where data was recorded. Contours are dashed where data is insufficient for precise location.

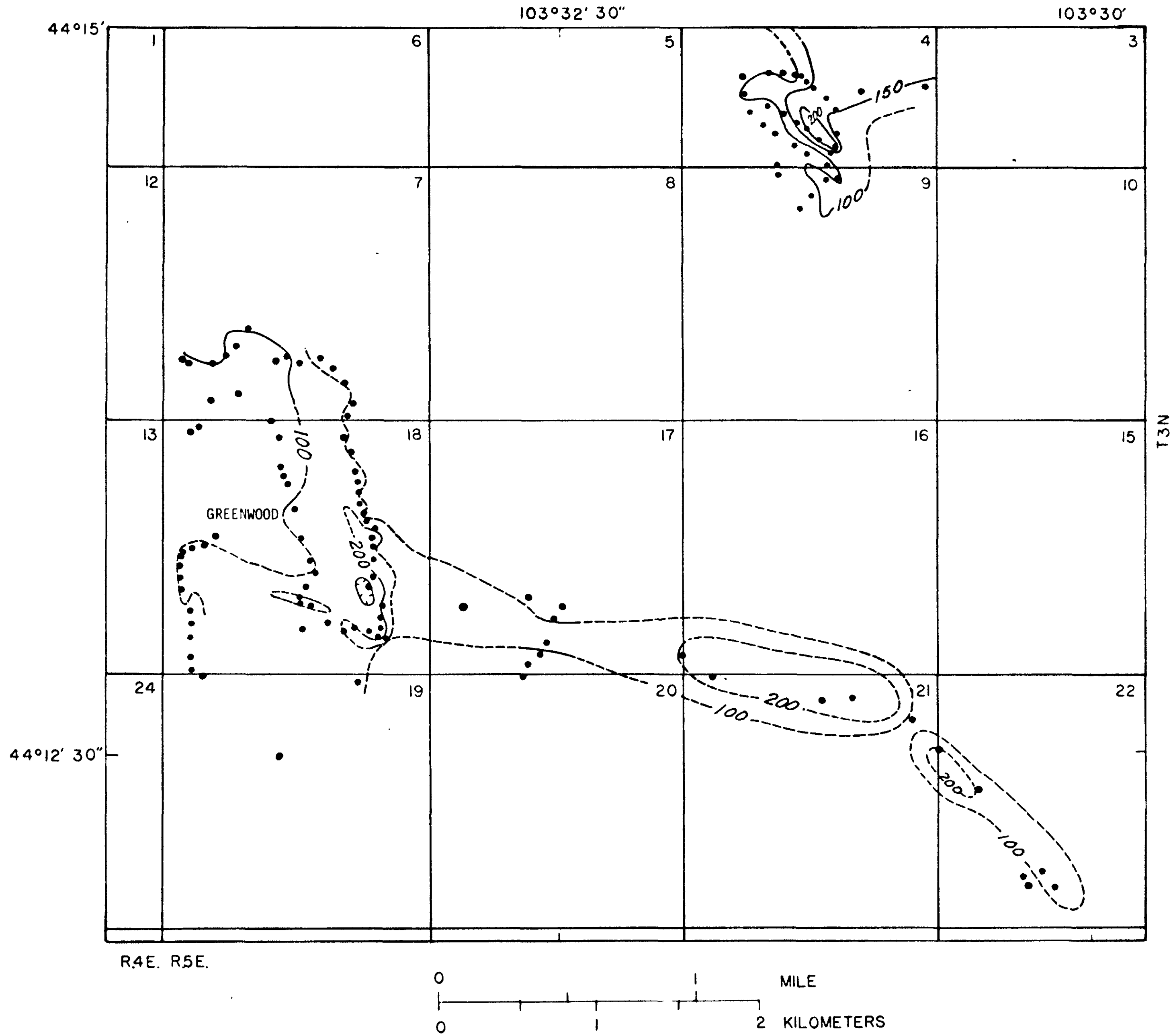


Figure 7.--Reconnaissance waist-level gamma-ray survey of Greenwood area. Contours are dashed where data is insufficient for precise location. High values coincide with unmapped oligomictic beds and zones.

Table 1 shows analyses for uranium and thorium by delayed neutron and gamma spectrometric methods from 32 samples of Estes Conglomerate and one sample of Little Elk Granite. Locations from which the samples were collected are plotted on figures 2 and 5. All samples of the oligomictic conglomerate are at least moderately anomalous in both uranium and thorium concentrations. On the basis of delayed neutron analyses, uranium in the Estes Conglomerate ranges from approximately 1 ppm to 40 ppm and thorium from approximately 3 ppm to over 800 ppm.

Differences in apparent uranium content between the two methods of analysis provide some insight into the importance of rock weathering in determining the uranium content of samples collected from oxidized outcrops of the Estes Conglomerate. The delayed neutron method directly measures uranium (^{235}U) and thorium (^{232}Th) present in the sample, whereas the gamma spectrometric method measures gamma rays emitted by daughter isotopes that are produced by the decay of parent uranium and thorium isotopes. Uranium and thorium contents are then calculated assuming that the parent and daughter isotopes have not moved independently through the rocks. If that assumption is correct, gamma spectrometric analyses should agree with delayed neutron analyses.

Results listed in Table 1 indicate that this assumption is justifiable with regard to thorium. Only sample BH-76-15a gives any indication of possible disequilibrium in its thorium decay series. Thorium is a relatively insoluble and immobile element in the weathering environment, and its daughter products have geologically trivial half lives that ordinarily allow insufficient time for daughter elements to move through rock. By contrast, uranium analyses by the two methods are highly discordant, indicating that uranium and/or its daughter products have moved significantly during relatively recent geological history (on the order of 10^3 to 10^5 years).

Uranium is highly soluble and mobile in oxidizing environments, and it is to be expected that acid ground water produced by oxidation of pyrite in the oligomictic conglomerates would efficiently dissolve and remove uranium. Therefore, on the basis of these analyses of oxidized rocks, I speculate that oligomictic conglomerate from below the oxidized zone may be considerably richer in uranium than the analyzed samples.

Table 1.--Uranium and thorium content of Estes Conglomerate and Little Elk Granite

[All samples are moderately to strongly oxidized. Delayed neutron analyses by H. T. Millard, Jr., A. J. Bartell, and C. Shields, and gamma spectrometric analyses by C. E. Bunker and C. A. Bush. n.a. = not analyzed.]

Sample no.	Map symbol	Uranium (ppm)		Thorium (ppm)	
		Delayed neutron	Gamma spect.	Delayed neutron	Gamma spect.
BH-76-1------	ec	1.4	n.a.	3.9	n.a.
BH-76-3------	ec	0.9	n.a.	3.4	n.a
BH-76-5a-----	ecq[1]	16	11	176	161
BH-76-5b-----	ecq[1]	41	32	164	174
BH-76-5c-----	eo	14	11	111	98
BH-76-7------	le	n.a.	2.7	n.a.	29
BH-76-8b-----	eo	5.8	3.6	125	125
BH-76-9b-----	eo	10	7.8	139	130
BH-76-13a----	ec[1]	11	n.a.	700	n.a.
BH-76-13b----	ec[1]	22	8	814	816
BH-76-14a----	eo	36	76	188	180
BH-76-14c----	eo	14	13	82	81
BH-76-14d----	eo[2]	122	n.a.	971	n.a.
BH-76-14e----	eo	5.9	n.a.	41	n.a.
BH-76-15a----	eo	10	23	21	[3]38
BH-76-17-----	eo	10	n.a.	108	n.a.
BH-76-19-----	eo	21	n.a.	173	n.a.
BH-76-20a----	eo	23	n.a.	82	n.a.
BH-76-20b----	ecq	4.3	n.a.	14	n.a.
BH-76-21-----	ec	2.1	n.a.	8.4	n.a.
BH-76-22-----	eo	17	n.a.	99	n.a.
BH-76-23a----	ea	3.3	n.a.	9.9	n.a.
BH-76-23b----	ea	2.8	n.a.	11	n.a.
BH-76-24-----	eo	11	n.a.	48	n.a.
BH-76-25-----	eo	18	n.a.	112	n.a.

Table 1.--Continued

Sample no.	Map symbol	Uranium (ppm)		Thorium (ppm)	
		Delayed neutron	Gamma spect.	Delayed neutron	Gamma spect.
BH-76-26------	eo	11	n.a.	110	n.a.
BH-76-27------	eo	16	n.a.	182	n.a.
BH-76-28a-----	eo[4]	6.4	n.a.	24	n.a.
BH-76-28b-----	eo[4]	8.7	n.a.	41	n.a.
BH-76-28c-----	eo[4]	7.1	n.a.	12	n.a.
BH-76-29a-----	ea[5]	4.0	n.a.	15	n.a.
BH-76-29b-----	ea	2.4	n.a.	11	n.a.
BH-76-31------	ea	2.2	n.a.	7.9	n.a.

[1]Mapped as Boxelder Creek Quartzite by Bayley (1972a).

[2]Limonitic crack filling in oligomictic conglomerate.

[3]Thorium series appears to be out of equilibrium.

[4]From ore zone of Lucky Strike Company mine.

[5]Black "shale" layer arkosic facies.

CONCLUSIONS

The presence of uranium and disseminated pyrite in the matrix of oligomictic beds suggests that the Estes Conglomerate and the underlying Benchmark Iron-formation and Boxelder Creek Quartzite may have been deposited before the Earth's atmosphere became oxidizing (Roscoe's, 1973, oxyatmoversion) approximately 1900 to 2100 m.y. ago. Carbon that occurs in the black-arkose facies of the Estes Conglomerate in the form of graphite is also suggestive of a nonoxidizing atmosphere.

By analogy with deposits in the Elliot Lake District of Ontario and in the Witwatersrand of South Africa, I speculate that pyrite, uranium and thorium minerals, and gold (unconfirmed by analyses) may have been deposited as detrital minerals in ancient placer deposits in the oligomictic layers of Estes Conglomerate. This speculative hypothesis is difficult to test because metamorphism appears to have caused recrystallization of pyrite and neither uranium-thorium minerals nor gold has been observed. However, the distribution of pyrite and of uranium and thorium appears faithfully to follow sedimentary beds and zones in the best-sorted oligomictic conglomerate, as would be expected under the placer hypothesis. Further, pyrite has been reported as an important accessory mineral in underlying Little Elk Granite, which is presumed to be the source of much detritus in the Estes Conglomerate. No evidence suggestive of a hydrothermal or other origin has been recognized.

Although a placer origin is tentatively proposed for pyrite, uranium, and thorium, and possibly for gold, in the conglomerate, other possibilities cannot be eliminated at present. Uranium in ground water may possibly have been reduced and precipitated by the pyrite in the conglomerate during the present weathering cycle or during a former one (for instance, the cycle that preceded deposition of the Deadwood Formation). From this alternative, epigenetic hypothesis, one would infer that uranium should be concentrated at the interface between the oxidized surface zone and a deeper unoxidized zone and that the deeper zone should be barren. This hypothesis can be tested conclusively only by drilling. However, the presence of anomalous amounts of thorium in the conglomerates suggests that the alternative hypothesis is not the correct one. Thorium is not expected to follow uranium in low temperature, near-surface processes.

The mineralogy of radioactive conglomerate has not yet been studied; and, although a strong argument can be made that radioactive minerals were concentrated by a placer process, it has not been established whether uranium occurs in soluble oxide minerals or in less soluble resistate minerals such as thorite, allanite, or monazite. If high uranium and thorium values are primarily in placer concentrations of these minerals, values in oxidized outcrops may differ little from values in unoxidized rocks below the weathering zone. However, if pyrite in Estes Conglomerate is detrital, it can be argued that conditions allowing deposition of detrital uraninite also probably existed. The abundance of pyrite in oligomictic beds of Estes Conglomerate, in contrast to its relative scarcity in rocks in which syngenetic pyrite is to be expected (such as the carbon-rich black arkose and black shale or the finer grained, chloritic facies of Estes Conglomerate), is favorable to the hypothesis that pyrite is a detrital heavy mineral. Whatever the present mineralogy of oxidized oligomictic conglomerate may be, it will surely not include labile uranium minerals such as uraninite. The presence or absence of uraninite in unoxidized conglomerate can only be proven by core drilling.

The Estes Conglomerate, its subsurface extensions under Paleozoic rocks to the east, and perhaps other clastic metasedimentary rocks in the Black Hills appear to be favorable for uranium deposits of the Elliot Lake type. Radioactive oligomictic conglomerates have been recognized in the rather small area of exposure of the Estes Conglomerate (approximately 18 km^2) in the Nemo district, where they appear to become more abundant in the eastern and northeastern exposures. This is perhaps the result of their having a higher admixture of detritus derived from the Little Elk Granite rather than from the Nemo Group. Structure inferred from Bayley's (1972a) magnetic survey of the iron-formation suggests that several additional square km of Estes Conglomerate are buried at a shallow depth under Paleozoic cover.

In the Nemo district, the black arkose and the Boxelder Creek Quartzite have been inadequately explored. The black arkose stands out as a very slight anomaly (fig. 6) in the waist-level gamma survey. However, no anomalies comparable to those in the oligomictic conglomerate were detected. The Boxelder Creek Quartzite must also be sufficiently old and sufficiently well sorted to have potential for placer uranium, although no anomalous radioactivity and no pyrite were discovered. Quartzite in sections 11 and 12 especially deserves attention because it may be all or in part a well-sorted facies of the Estes Conglomerate.

In addition to their potential as a source for uranium, the oligomictic beds of Estes Conglomerate may have potential for gold. This potential deserves evaluation by modern methods, using the placer hypothesis as a guide to distribution of values. If both gold and radioactive minerals are detrital heavy minerals in the Estes Conglomerate, perhaps surface radioactivity can be used as a guide in prospecting for gold.

Precambrian W granite and schist, exposed in the core of the Bear Mountain dome in Pennington and Custer Counties, are overlain unconformably by conglomerates, quartzite, and schist of the Vanderlehr Formation in the Berne quadrangle (Redden, 1968) and by equivalent strata in the Medicine Mountain quadrangle (J. C. Ratté, oral commun., 1976). A reconnaissance survey of these rocks revealed no anomalous radioactivity, and neither oligomictic conglomerate nor disseminated pyrite was found. However, well-sorted orthoquartzite is present and more thorough study is perhaps warranted.

Conglomeratic rocks similar to those in the Bear Mountain dome appear as large inclusions in the Harney Peak Granite according to Redden and Norton (1975). These rocks, as well as other quartzite and conglomerate in the Black Hills (Redden and Norton, 1975), are not known to have been explored for uranium.

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