# ROCK ALTERATION CRITERIA IN THE SEARCH FOR URANIUM

By PAUL F. KERR, Columbia University

## CONTENTS

## ILLUSTRATIONS

## ABSTRACT

Rock alteration may serve as a guide in the search for uranium. Although the criteria are more obvious in igneous and metamorphic rocks, they are also observed in places in sediments. An outstanding example of rock alteration associated with uranium mineralization occurs at Marysvale, Utah, where solutions primarily responsible for the deposition of pitchblende seem to have reacted with the wall rock to form a halo of clay, chlorite, sericite, and quartz. At some uranium-bearing ore zones in northwestern Canada and in the Sunshine mine, Idaho, red hematitic coloration is associated with the ore. Alteration associated with uranium deposition in the Colorado Plateau sediments has recently been recognized. However, its extent and significance is only partly established. In several isolated sites at Temple Mountain, Utah, solutions have penetrated sediments, dissolved underlying limestone and appear to have caused the collapse of the overlying sandy strata. This has been accompanied by local deformation, bleaching, upward chemical transfer and, in places, uranium deposition.

Evidence is increasing that study of rock alteration may be of value in prospecting for uranium, and that is should be used with the generally recognized geological and geophysical methods.

## INTRODUCTION

Alteration features associated with uranium mineralization have received somewhat less attention than the phenomenon merits because: radioactivity counters and scintillation devices often furnish a direct indication of ore bodies; thick sedimentary sections in which alteration criteria often are not recognized; very localized effects such as the red stain that accompanies some pitchblende veins.

Alteration effects associated with uranium mineralization in igneous or metamorphic rocks appear to be more readily detected than those in sediments. The argillic halos that accompany veins in quartz monzonite at Marysvale, Utah, are easily recognized features. On the other hand, alteration effects in the Colorado Plateau sediments may receive little attention. This paper outlines the types of alteration which are found with uranium mineralization excepting those in pegmatite occurrences since the latter have not proved to be of economic significance.

This investigation is based on data from the literature as well as recent detailed studies of uranium deposition at Marysvale, Utah; a current investigation of Temple Mountain on the San Rafael Swell, Utah; reconnaissance in the western United States and Canada; and previous studies of hydrothermal alteration associated with copper mineralization at Santa Rita, N. Mex., and Silver Bell, Ariz.

Few of the alteration criteria associated with uranium deposits differ appreciably from those of copper, zinc, tungsten, and other metals. However, their applicability to uranium is selective. The term alteration is applied here to the development of clay mineral halos, chloritization, alunitization, fluoritization, carbonatization, silicification and ferrugination. It is noteworthy that the criteria of contact metamorphism in general have not been applicable to the United States uranium deposits.

### TYPES OF ALTERATION

Significant alteration effects in certain uranium and metal deposits are believed to be indicative of hydrothermal activity. Much applicable information is found in the studies of Lovering (1949) at Tintic, Utah; Sales and Meyer (1948) at Butte, Mont.; Peterson, Gilbert, and Quick (1946) at Castle Dome, Ariz.; Stringham (1953) at Bingham, Utah; Williams (1952) at Park City, Utah; and Leroy (1945) at Santa Rita, N. Mex.

Hydrothermal solutions traversing faults, fractures, or shear zones generally react with the wall rock so that a sequence of alteration develops. Although these vary with the character of the rock, chlorite and montmorillonite are two of the earliest minerals to form at the expense of the wall rock; they tend to be prevalent around the margins of altered areas. Somewhat later, and in a more centralized position, kaolinite, some montmorillonite and often illite (hydrous mica) occur. At the core of the altered area dickite may be associated with kaolinite, or kaolinite with illite. Often sericite and silicification are found at the center. Although no two districts in which alteration of this type has been described are identical, most exhibit a progressive sequence of various degrees of wall rock replacement. Maps of these altered areas frequently reveal important trends in metallic mineralization which may favor certain of the alteration stages. Such maps have been made of the copper deposits at Santa Rita, N. Mex. (Kerr and others, 1950) and Silver Bell, Ariz. (Kerr, 1951). More recently a similar study (fig. 185) has been made of the uranium-bearing area at Marysvale, Utah (Kerr and others, 1956).

Types of hydrothermal alteration, believed to be related to the general process of uranium emplacement, particularly in the western United States include ferrugination, fluorization, chloritization and argillization, alunitization, and dolomitization.

### FERRUGINATION

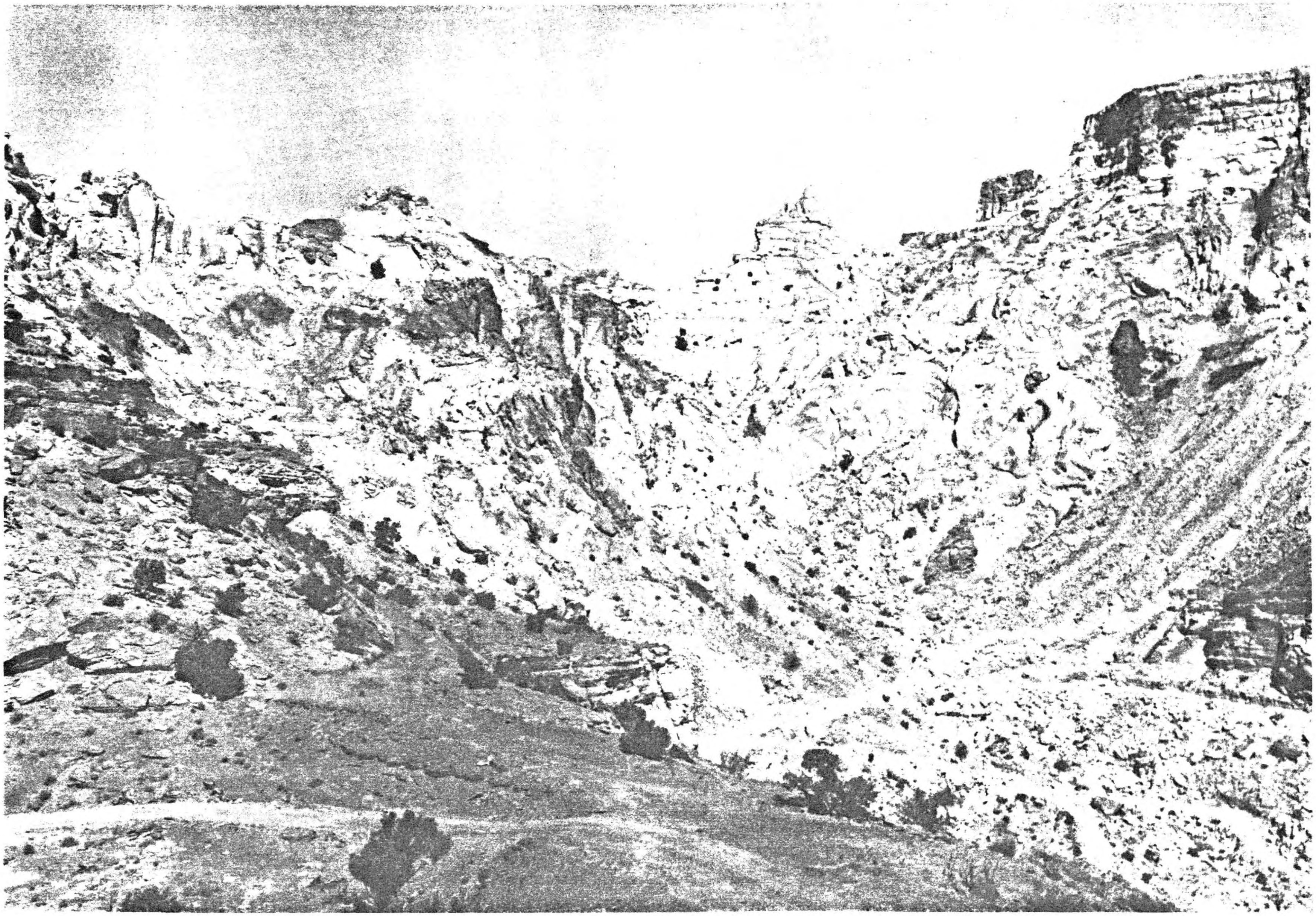
Iron is one of the most common elements associated with uranium. In fact, the identification of pitchblende may be hindered by the intimate mixture of fine-grained pyrite. In the replacement of wood structure in logs and of other plant remains in the Shinarump conglomerate at White Canyon, Utah (Miller 1953), cells of wood structure may be filled either with pyrite, chalcopyrite or bornite, and cell walls may be replaced by pitchblende. $H_2S$ derived from decayed vegetation is thought to have fixed the iron in the sulfide form.

Hematitic alteration produces shades of red which are found with certain veins in the Canadian Shield, and in the Sunshine mine, Idaho (Kerr and Robinson, 1953) where color intensity varies directly with the amount of pitchblende. It is thought that during hypogene vein formation, given sufficient temperature, the ferrous ion may change the uranyl ion to the uranous ion and thus cause the precipitation of pitchblende. At the same time the resultant ferric iron forms hematite which is essentially colloidal and acts as a pigment for the accompanying colloidal silica. Dawson (1951) has called attention to the hematitic alteration of wall rock with pitchblende-bearing veins in the Goldfields region, Saskatchewan, Canada. A somewhat similar coloration is found at depth in some of the Marysvale veins.

Masses of siderite are found near the uranium ores of Temple Mountain, Utah (pl. 12). Field and analytical data seem to indicate that the upward-moving thermal solutions removed iron from the underlying ferruginous sediments and redeposited it as siderite in veins and replacement masses at a higher level. Although the uranium occurs in asphaltite, it may be closely associated with pyrite. A nodule (Kerr and Lapham, 1954) of this material is illustrated in Figure 186.

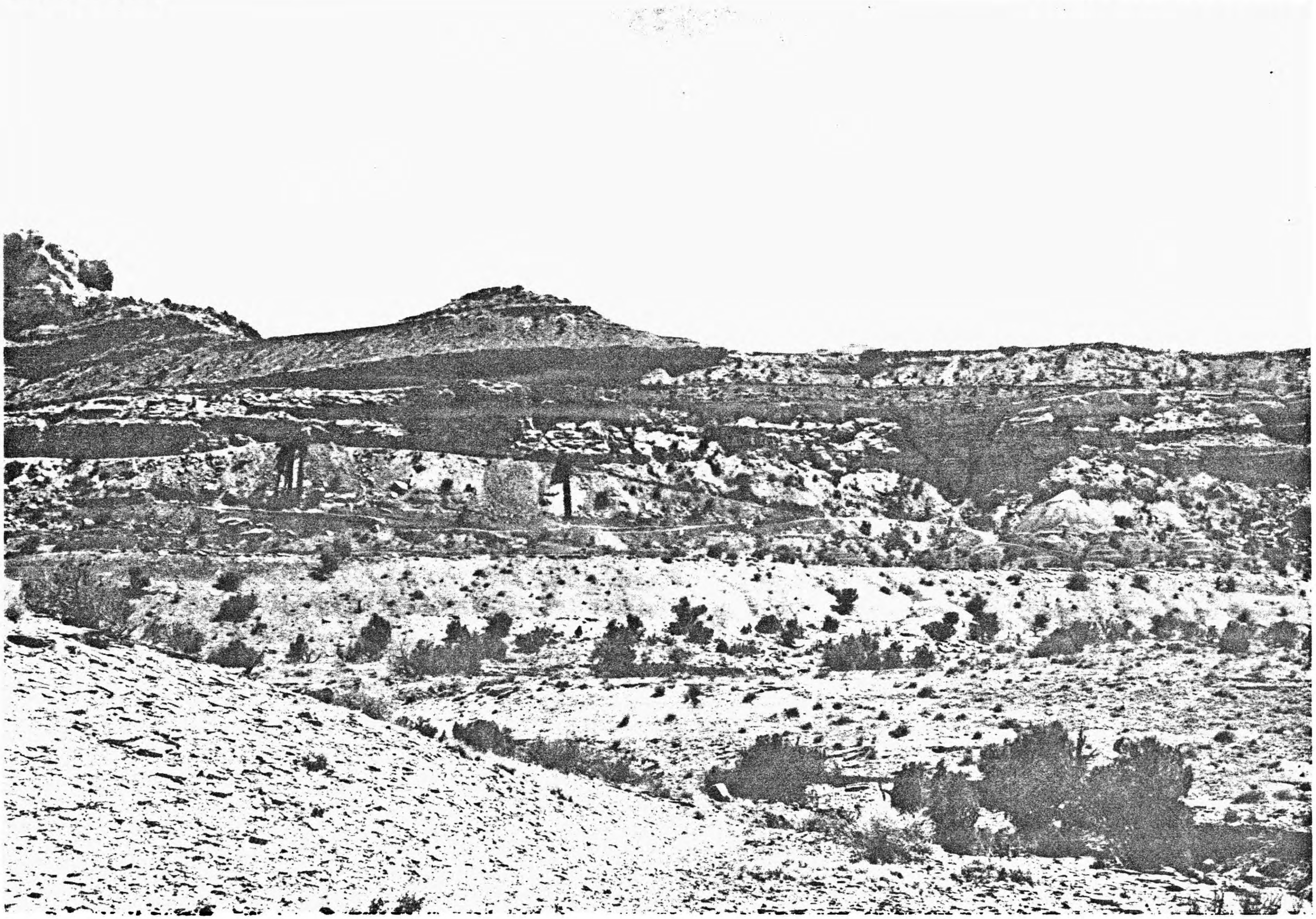
### FLUORITIZATION

Because the oxides $UO_2$, $ThO_2$, $CeO_2$ and $CaF_2$ all have a face-centered cubic "fluorite" lattice with a unit cell close to 5.50Å, it is not astonishing that they prefer the same geochemical environment. According to Phair and Shimamoto (1952) who describe euhedral uranothorite inclusions in fluorite, it seems probable that the association of uranium, thorium, and rare earth minerals may prove extensive in fluorite-rich hydrothermal deposits. Kerr and Dahl (1953) note microscopic particles, presumably pitchblende, in highly radioactive fluorite at Grants, N. Mex. Brown, Emery, and Meyer (1954) note an interesting radioactivity anomaly which is associated with fluorite at Hicks' Dome, Ill. Bray (1942) reports pitchblende in fluorite which is associated with pyrite, galena and sphalerite at Jamestown, Colo., and Lovering (1954) describes radioactive fluorite in veins and pipelike bodies east of Beatty, Nev. Black or extremely dark-



AREAS OF FERRUGINATION (DARK) BORDERING A COLLAPSE FEATURE AT TEMPLE MOUNTAIN, UTAH

AN ARGILLIC AND ALUNITIC AREA FORMED BY ALTERATION OF A VOLCANIC AGGLOMERATE AT BIG ROCK CANDY MOUNTAIN NEAR MARYSVALE, UTAH



A KAOLINIZED ZONE BELOW THE ORE-BEARING MOSS BACK SANDSTONE (100 FEET THICK), VANADIUM KING MINE WORKINGS EAST OF TEMPLE MOUNTAIN, UTAH

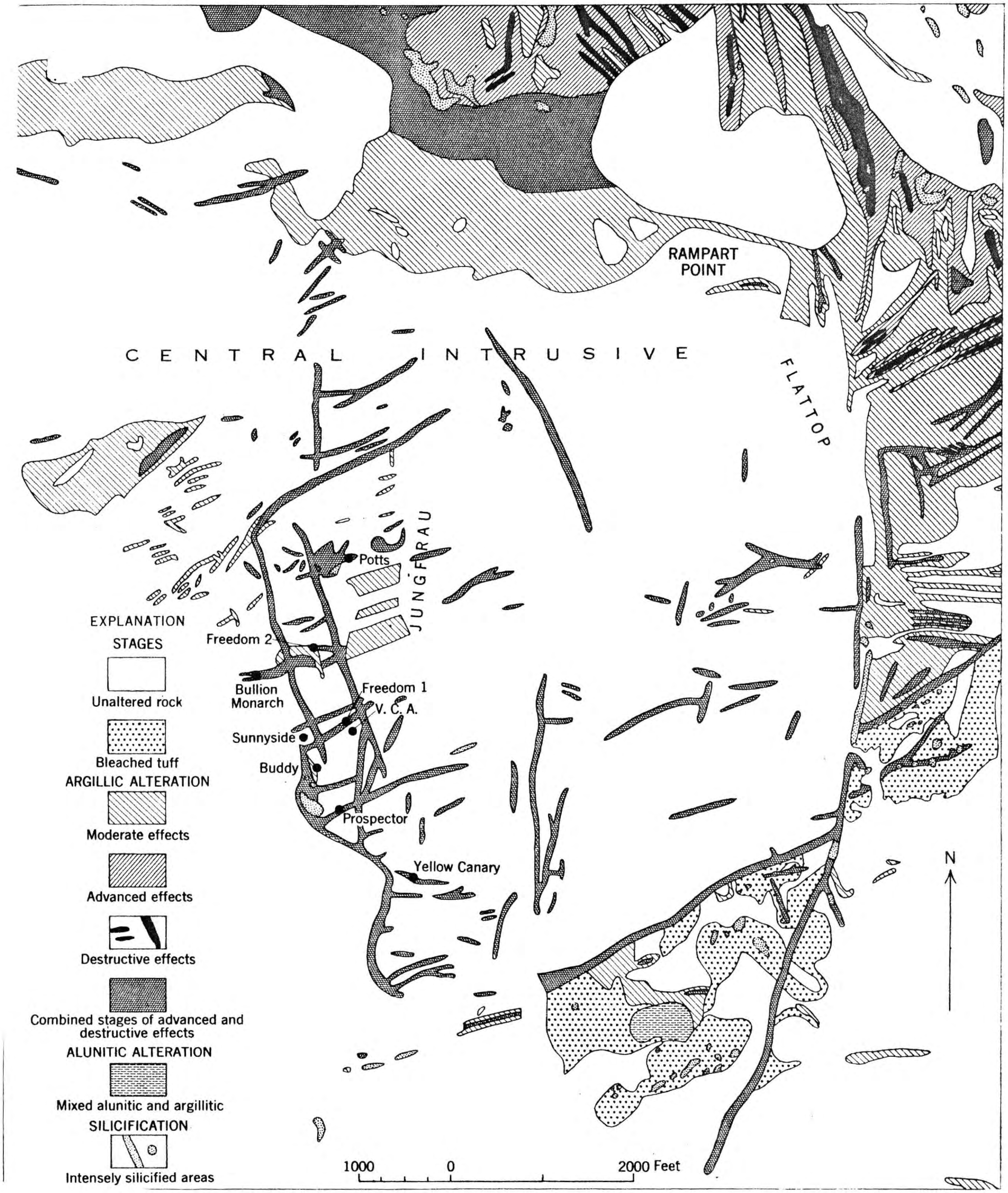


FIGURE 185.—Map showing alteration zones or channels in part of the Marysvale district, Utah.

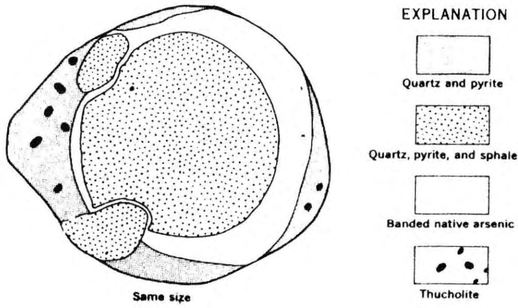


FIGURE 186.—Sketch showing a section of a pyrite-native arsenic nodule from Temple Mountain, Utah (after Kerr and Lapham, 1954).

purple fluorite is commonly associated with radioactivity at Marysvale. In fact, in western areas the widespread occurrence of such fluorite is frequently considered significant in the search for uranium.

### CHLORITIZATION AND ARGILLIZATION

Argillic alteration associated with uranium mineralization is illustrated at Marysvale, Utah (Kerr and others, 1956) where an airborne radiometric survey of the mining area shows radioactivity anomalies that correspond to areas of alteration. The area in which the effects (pl. 13) are most noticeable is about 7 miles square, and it is clearly outlined by white or iron stained clay. The clay-filled channels (figure 185) which constitute the veins at Marysvale have a wide range in clay and uranium content. They provided the conduits along which uranium-bearing solutions migrated upward, as shown by a radiometric comparison of the wall-rock and vein. The principal uranium mineral of the veins is pitchblende (fig. 187) although secondary uranium minerals are found near the surface, and the rare uranium molybdenum mineral umohoite (Brophy and Kerr, 1953), occurs in one of the mines.

The association of argillic alteration and pitchblende is most common at Marysvale in quartz monzonite. Preceding alteration the feldspar grains are lustrous and the ferro-magnesian minerals, if present, are generally unchloritized. As alteration begins a chloritic zone develops in which plagioclase tends to become dull and biotite to be chloritized. This occurs not only at Marysvale but at places in the Boulder batholith in Montana (Sales and Meyer, 1948), in southwestern New Mexico near Silver City (Kerr and others, 1950) and along the Colorado Front Range. Rocks in which ferromagnesian minerals are scarce may yield a montmorillonite rather than a chloritic zone.

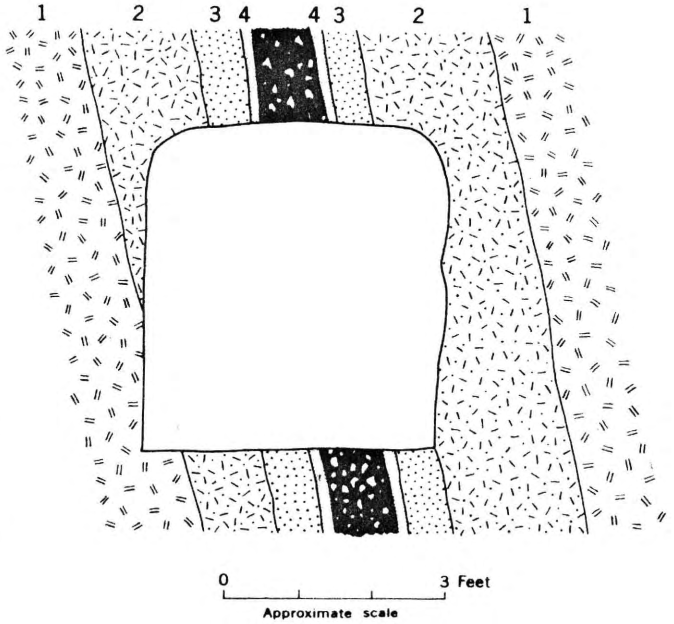


FIGURE 187.—Pitchblende vein at Marysvale, Utah, showing (1) unaltered quartz monzonite, (2) chlorite-bearing zone, (3) montmorillonite-illite zone, and (4) kaolinite-illite (or hydrous mica) zone which borders the fluorite-quartz-uraninite breccia zone (black).

The two most conspicuous clay minerals of the dominantly argillic stage at Marysvale are montmorillonite and kaolinite. As alteration becomes more intense, rock texture is destroyed, and illite develops. In places this stage is accompanied by the introduction of fluorite. Toward the close of the argillic stage, or perhaps later, the main precipitation of pitchblende and pyrite is believed to occur.

Patches of altered rock similar to those at Marysvale are found within a radius of 20 miles. It seems, therefore, that the alteration is widespread, and comparatively recent as determinations of the Marysvale pitchblende by J. L. Kulp (oral communication 1955) indicate an age of about 10 million years. Altered patches, perhaps an extension of the Marysvale pattern, have been observed in volcanic rocks near the margin of the Colorado Plateau. A center of hydrothermal activity concealed beneath the sediments of the Plateau could have provided a source for the accumulation of uranium in sediments.

Recent studies along the San Rafael Swell (Kerr and others, 1956) and elsewhere contribute criteria which may provide an approach to the problem of alteration and uranium in sediments. Weeks (1952, written communication) reports gray shale at the Scenic No. 4 claim in the White Canyon area, Utah, which i completely kaolinized. Green clay zones, although widely distributed in the Moss Back sandstone of th San Rafael Swell, have not as yet been found to b related to ore deposition. However, around the inward-facing escarpment faults, which are accompanie by bleaching and in places by uranium mineralization cut the Moss Back and other members of the Chinl formation. These bleached rocks (pl. 14) are yellowish brown (in contrast to the adjoining red o dark brown strata) and appear to extend up along fault lines, with an appearance of enlargement in the stone below the Shinarump.

Laboratory study of this bleached material indicates the presence of kaolinite and illite. Although further investigation is necessary, the form and mineralization of the bleached zones suggests upward-migrating solutions. Since significant uranium mineralization occurs in association with such a zone at Temple Mountain, this criterion seems worthy of consideration.

## ALUNITIZATION

Alunite occurs commonly near uranium deposits, although the relationship and significance of such association remain largely undetermined. At Marysvale extensive areas of alunite (fig. 188) have formed by hydrothermal alteration of tuffs and pyroxene andesites. The major hydrothermal alunitization seems to precede uranium mineralization, but there is some alunite which is an end-stage product.

Alunite and kaolinite have been found in veinlets in conglomerate of the Moss Back member at Temple Mountain where they occur around the margin of the ore-bearing area, and seem to resemble caliche in outcrop. Alunite is reported in several of the other Plateau uranium deposits. Gruner and Gardiner (1952) report it in the Moenkopi of the Capitol Reef area, Utah; at Deer Flats north of White Canyon, and southeast of Fruita, Utah. Weeks (written communication, 1952) finds alunite at the Skyline claim, Monument Valley, Ariz., where it fills joint cracks in altered arkosic sandstone.

## DOLOMITIZATION

Dolomitization appears to have attracted less attention than it warrants in the study of uranium deposition in sediments. Dolomitization of the Wingate sandstone occurs at several places on Temple Mountain, where it forms distinctive brown patches. This remarkable change from a rather pure eolian sandstone

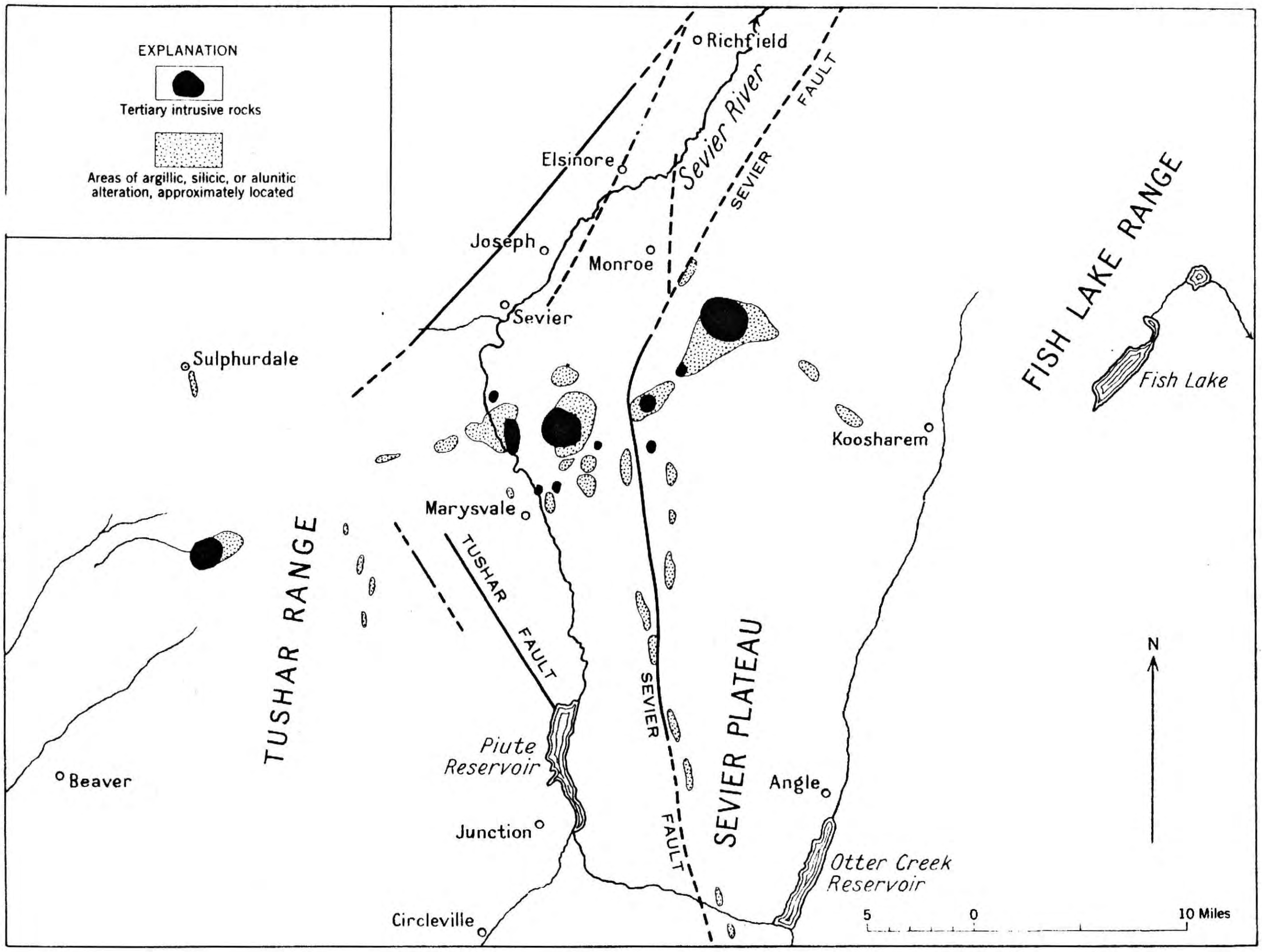


FIGURE 188.—An early reconnaissance map in the vicinity of Marysvale, Utah, showing the general distribution of clay zones, silicification, and alunite bodies.

to a massive dolomite is gradual, but it occurs in three recognizable stages.

The first stage of dolomitization is "nodular impregnation" in which nodular dolomite surrounds suspended unaltered sand. These nodules have an average diameter of about one-half inch, and occur in patches from a few to hundreds of feet across. They tend to follow the Wingate sandstone, but may extend across the beds or occur in irregular masses which penetrate the underlying sandstone of the Chinle formation. The second stage is "interstitial impregnation" in which dolomite replaces quartz grains within the nodules as well as in the areas between the nodules. In thin section a radial strain which is relict of the nodular form may be present. The third stage is "massive replacement" in which the nodular development is completely obliterated and sand grains of the Wingate are completely replaced.

The relation between dolomitization and uranium deposition is indirect. The dolomite at Temple Mountain occurs near areas of solution stoping which are referred to as "collapse features" (Kerr and others, 1955). These have been interpreted as breccia pipes, but it seems likely that they result rather from solution and collapse. Thermal solutions that penetrated carbonate and arenaceous sediments have produced cavities into which great blocks of overlying strata have fallen. The collapsed zones seem to be funnel shaped in cross section and to originate along faults. Their surface exposure is circular or elliptical, with a maximum diameter of 1,000 feet. Although uranium is sparse in these areas, it occurs nearby in greater concentration. The uranium-bearing asphaltite is found in veinlike masses that cut the dolomite. The emplacement of uranium seems, therefore, to be later than dolomitization.

It seems reasonable that the sequence of solutions that removed calcium and magnesium from the underlying strata and deposited them in the Wingate sandstone as dolomite also could have introduced the uranium. Scattered uranium occurrences throughout a vertical length of 1,500 feet of exploratory drilling seem to support this theory. It is likely, therefore, that the dolomitic areas at Temple Mountain are indicative of solution action on sediments. In turn, this suggests that (on the San Rafael Swell at least) dolomitization may indicate nearby uranium emplacement.

## SILICIFICATION

The relation of silicification to uranium mineralization is worthy of consideration. Often there is no immediate application to uranium discovery, as illustrated by the silicified logs in the uranium deposits of the San Rafael Swell. Large masses of conglomerate of the Moss Back are silicified, but thus far they have failed to yield uranium. Nevertheless, bodies of silicified rock in the vicinity of uranium deposits merit investigation. One surface mass of silicified rock at Marysvale overlies an extension of the Bullion Monarch vein system, a system that has been highly productive of uranium. In this area, cherty quartz stringers are associated with high-grade pitchblende ore, and the fluorescence of chalcedonic nodules may be due to contamination by uranium. The role of silicification probably varies with the type of deposit, the generations of mineralization, and the associated rock types.

## CONCLUSION

The criteria of rock alteration that are useful in the search for uranium bear a striking resemblance to those for other metals. However, conditions may vary with the locality, and render recognition much more difficult. This is true of the Colorado Plateau sediments in comparison with areas of igneous or metamorphic rocks. Argillic alteration and dolomitization are believed to represent earlier stages in the ore-forming process in the sediments at Temple Mountain. Significant alteration features in hydrothermal uranium deposits appear to include: ferrugination, as shown by widely distributed pyrite and hematitic coloration; fluoritization, as shown by the association of fluorite and pitchblende; chloritization and argillization, as shown by wall rock alteration which follows or accompanies uranium emplacement; alunitization, depending upon depositional environment; and dolomitization, as shown by its proximity to uranium deposition.

## REFERENCES CITED

Bray, J. M., 1942, Minor chemical elements in fluorites from Jamestown, Colo.: Am. Mineralogist, v. 27, p. 769–775.

Brophy, G. P., and Kerr, P. F., 1953, Hydrous uranium molybdate in Marysvale ore; *in* Annual report for June 30, 1952 to April 1, 1953: U. S. Atomic Energy Comm. RME-3046, p. 26–44, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Brown, J. S., Emery, J. A., and Meyer, P. A., Jr., 1954, Explosion pipe in test well on Hicks Dome, Hardin County, Ill.: Econ. Geology, v. 49, p. 891–902.

Dawson, K. R., 1951, A petrographic description of the wall-rocks and alteration products associated with pitchblende-bearing veins in the Goldfields region, Saskatchewan: Canada Geol. Survey Paper, no. 51–24, 58 p.

Gruner, J. W., and Gardiner, Lynn, 1952, Mineral associations in the uranium deposits of the Colorado Plateau and adjacent regions with special emphasis on those in the Shinarump formation, Part III, Annual report, July 1, 1951 to June 30, 1952: U. S. Atomic Energy Comm. RMO-566, 40 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Kerr, P. F., 1951, Alteration features at Silver Bell, Ariz.: Geol. Soc. America Bull., v. 62, p. 451–480.

Kerr, P. F., Kulp, J. L., Patterson, Claire, and Wright, R. J., 1950, Hydrothermal alteration at Santa Rita, N. Mex., Geol. Soc. America Bull. 61, no. 4, p. 275–347.

Kerr, P. F., Brophy, G. P., Dahl, H. M., Green, Jack, and Woolard, L. E., 1956, Alteration and uranium mineralization, Marysvale, Utah: Geol. Soc. America Bull. (in press).

Kerr, P. F., and Dahl, H. M., 1953, Uranium-fluorite association in the Todilto limestone, Grants, N. Mex.: U. S. Atomic Energy Comm. RME–3051, 6 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Kerr, P. F., Kelley, D. R., Keys, W. S., Bodine, M. W., Jr., 1955, Annual report for June 30, 1954 to April 1, 1955, Part III. Collapse features, Temple Mountain uranium area, Utah: U. S. Atomic Energy Comm. RME–3110 (Pt. 3), 138 p., issued by U. S. Atomic Energy Comm Tech. Inf. Service, Oak Ridge, Tenn.

Kerr, P. F., and Lapham, D. M., 1954, Report on a nodule from Temple Mountain, *in* Annual report for June 30, 1953 to April 1, 1954, Part I: U. S. Atomic Energy Comm. RME–3096, p. 7–15, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Kerr, P. F., and Robinson, R. F., 1953, Uranium mineralization in the Sunshine Mine, Idaho: Min. Eng., v. 5, p. 495–511.

Leroy, P. G., 1954, Correlation of copper mineralization with hydrothermal alteration in the Santa Rita porphyry copper deposit, New Mexico: Geol. Soc. America Bull., v. 65, p. 739–768.

Lovering, T. S., 1949, Rock alteration as a guide to ore—East Tintic district, Utah: Econ. Geology, Monograph 1, 65 p.

——— 1954, Radioactive deposits of Nevada: U. S. Geol. Survey Bull. 1009–C, p. 63–106.

Miller, L. J., 1953, Uranium ore controls of the Happy Jack deposit, White Canyon, San Juan County, Utah: U. S. Atomic Energy Comm., RME–33, 34 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Peterson, N. P., Gilbert, C. M., and Quick, G. L., 1946, Hydrothermal alteration in the Castle Dome copper deposit, Ariz.: Econ. Geology, v. 41, p. 820–840.

Phair, G., and Shimamoto, K. O., 1952, Hydrothermal uranothorite in fluorite breccias from the Blue Jay mine, Jamestown, Boulder County, Colo.: Am. Mineralogist, v. 37, p. 659–666.

Sales, R. H., and Meyer, Charles, 1948, Wall rock alteration, Butte, Mont.: Am. Inst. Min. Metall. Eng. Trans., v. 178, p. 9–35.

Stringham, B., 1953, Granitization and hydrothermal alteration at Bingham, Utah: Geol. Soc. America Bull., v. 64, p. 945–991.