CHAPTER 6

URANIUM FAVORABILITY OF CORDILLERAN METAMORPHIC CORE COMPLEXES: A SUMMARY

By

Stephen J. Reynolds

INTRODUCTION

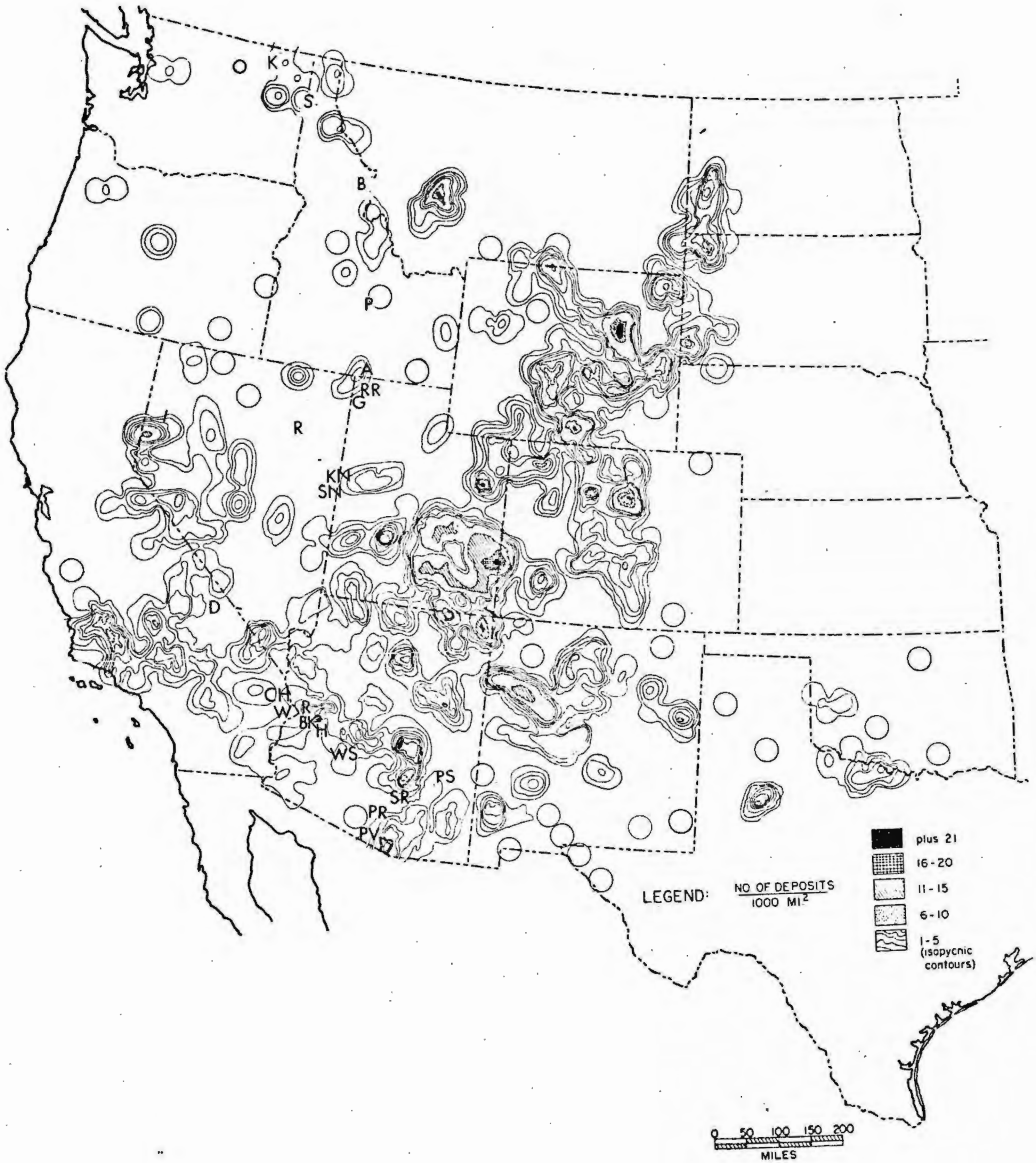
Cordilleran metamorphic core complexes have been recently recognized as unique centers of plutonism, metamorphism, and deformation. The uranium favorability of the complexes has not been previously described in the literature. The favorability of the complexes for various types of uranium occurrences is discussed in Chapter 4. Geochemical parameters indicative of uranium favorability are presented in Chapter 5. The specific uranium favorability of each complex is outlined in Appendix D. The present Chapter briefly summarizes the more detailed conclusions contained within Chapters 4 and 5 and Appendix D, and recommends future studies that will further clarify the uranium favorability of Cordilleran metamorphic core complexes.

URANIUM FAVORABILITY

Regional Considerations

As recognized by many geologists, the most favorable areas for the discovery of uranium deposits are generally situated in uranium provinces that contain numerous known occurrences or are underlain by rocks which exhibit high background abundances of uranium. Cordilleran metamorphic core complexes are distributed over such a large and geologically diverse area that regional considerations, such as those utilized in defining uranium provinces, provide a useful first-order indication of favorability of the complexes. Studies on the regional variations in radioelement content of plutonic rocks of the western United States

Figure 6-1. Density of uranium occurrences per unit area for the western United States. Diagram is modified from Gabelman (1976). Letters indicate the approximate positions of the following metamorphic core complexes: O - Okanogan, K - Kettle, S - Selkirk, B - Bitterroot, P - Pioneer, A - Albion, RR - Raft River, G - Grouse Creek, R - Ruby, KN - Kern, SN - Snake, CH - Chemehuevi, W - Whipple, R - Rawhide, BK - Buckskin, H - Harcuvar-Harquahala, WS - White Tank-South Mountains, PC - Picacho, SR - Santa Catalina-Rincon-Tortolita, PS - Pinaleno-Santa Teresa, PR - Papago Indian Reservation area (Sierra Blanca, Comobabi, and Coyote complexes), and PV - Pozo Verde. The letter D indicates the location of the Death Valley region.


K
S
B
P
A
RR
G
R
KN
SN
D
CH
WSR
BK
H
WS
PS
SR
PR
PV
LEGEND: NO OF DEPOSITS / 1000 MI.²
plus 21
16-20
11-15
6-10
1-5 (isopycnic contours)
0 50 100 150 200
MILES

(Larsen and Gottfreid, 1961; Marjaniemi and Robbins, 1972; Swanberg and Blackwell, 1973; Munroe and others, 1975; Castor and others, 1977) are extremely pertinent since plutons in the crystalline cores of the complexes might be expected to conform with established regional patterns. Results of these studies and sampling during this project indicate that compared with the rest of the core complex belt, the Kettle, Selkirk, Albion-Raft River, and Ruby complexes are located in areas that have plutons with relatively high radioelement contents. Data on the uranium abundances of Precambrian basement of the western U.S. (Malan and Sterling, 1969) can be similarly used as an indication of regional favorability.

Uranium provinces are characterized by a high concentration of uranium occurrences as indicated on Figure 6-1 for the Colorado Plateau, Wyoming basins, and the Colorado Front Range. This figure also documents that the Kettle, Selkirk, Albion-Raft River, western Arizona, and Santa Catalina complexes are located in areas of relatively abundant uranium occurrences as compared with the remainder of the core complex belt. In order to further evaluate the distribution of uranium occurrences both within and adjacent to the core complexes, we have compiled and plotted on million-scale maps the locations of all uranium occurrences (See Appendix C and accompanying maps). These maps provide a visual comparison of the density of uranium occurrences between individual complexes and between core complexes and their surrounding areas. In general, the core complexes have approximately the same density of uranium occurrences as the rest of the Cordillera. Exceptions are the Kettle and Selkirk complexes which have an exceptionally large number of occurrences both within and adjacent to their crystalline cores. Some areas such as the Albion, Rawhide and Santa Catalina complexes have an intermediate number of occurrences, while others including the South Mountains, White Tank, Picacho, and Comobabi complexes of Arizona contain few or none. This variation in the number of occurrences per complex is probably the best over-all favorability index. Figure 6-2 is derived from the aforementioned maps and emphasizes the density of uranium occurrences per one degree quadrilateral for the core complex belt. As revealed before, certain areas of the belt such as northeastern Washington are characterized by a profusion of occurrences. These areas are clearly the most favorable for possessing significant uranium deposits and reserves.

Occurrence of Uranium in Cordilleran Metamorphic Core Complexes

As discussed in Chapter 4, numerous processes were operative during the prolonged geologic evolution of Cordilleran metamorphic core complexes. These processes could have conceivably produced a wide variety of uranium occurrences. However, the core complexes are most favorable for those types of occurrences which

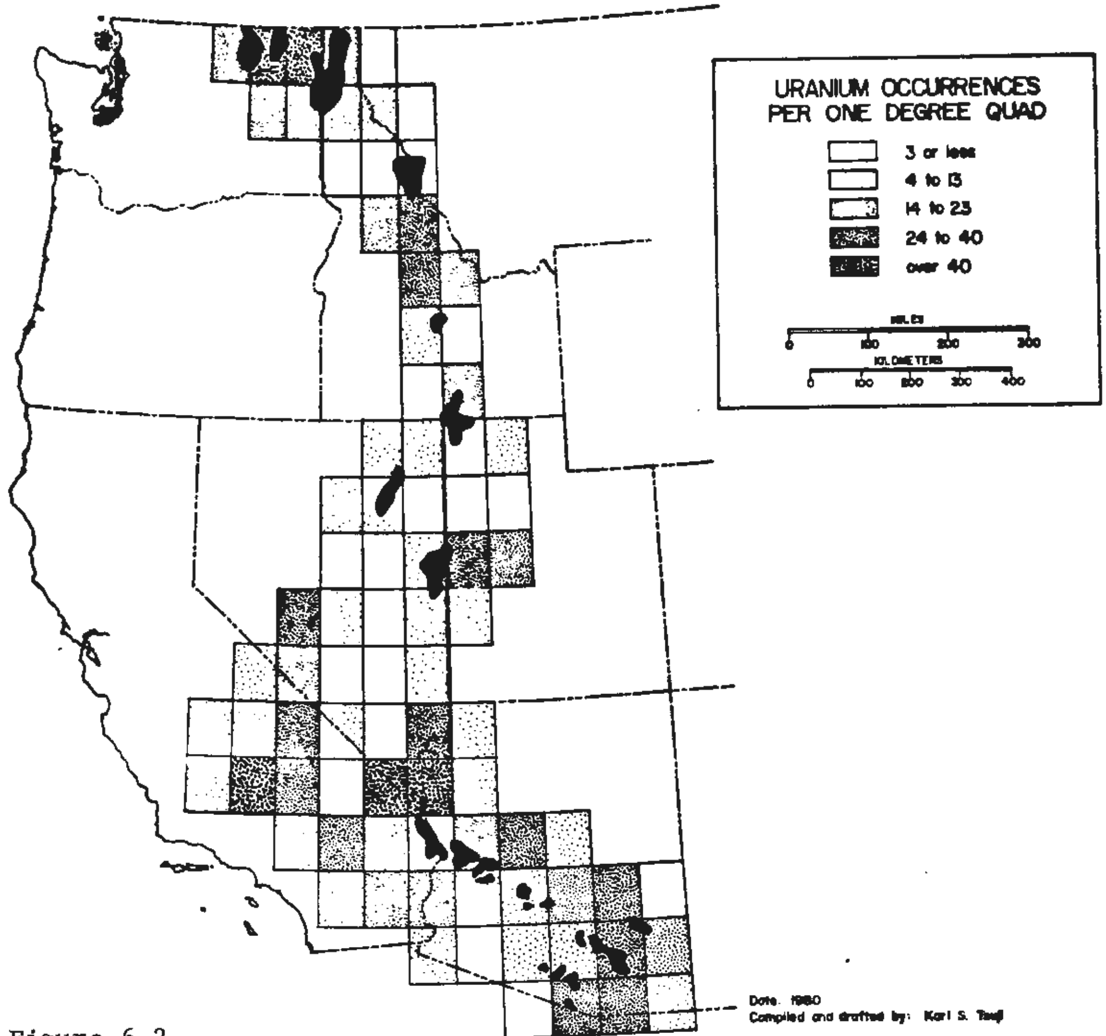


Figure 6-2.

DENSITY OF URANIUM OCCURRENCES PER ONE DEGREE QUAD IN THE METAMORPHIC CORE COMPLEX BELT

1) are actually known to be present in the complexes; or 2) are not documented in the complexes, but can be reasonably postulated to exist based on the concepts outlined in Chapter 4. Listed below are ten uranium occurrences from the core complex belt that are significant either because of past production or because they are illustrative of a potentially important type of deposit.

1) Kettle Pegmatites: These granitic pegmatites are interlayered with amphibolite-grade metamorphic rocks and are characterized by high uranium contents. Some of the pegmatites may owe their origin to in-situ anatexis of uraniferous sedimentary rocks, whereas others are clearly cross-cutting and have been introduced from depth. Biotitic metamorphic rocks adjacent to the pegmatites are locally mineralized, possibly by contact metasomatism.

2) Graeber Lease, Kettle complex: High-grade uranium mineralization occurs in biotitic metamorphics that exhibit a mylonitic fabric. The deposit is located on the northeastern flank of the complex and may have been formed by a combination of metamorphic and mylonitic processes.

3) Mount Spokane, Selkirk complex: Spectacular meta-autunite coats fractures in weathered, but otherwise unaltered muscovite-bearing alaskite and pegmatite. Mineralization was strongly controlled by several types of structures and was probably deposited by ground waters which had leached uranium from the granitic rocks.

4) Tiger Formation, adjacent to Selkirk complex: Uranium mineralization is associated with carbonaceous material in Tertiary sedimentary rocks. The sedimentary rocks are in the upper plate of the Newport fault (dislocation surface) but are topographically lower than some uraniferous granites of the lower plate. The source of the uranium might be the plutons or syn-sedimentation volcanism.

5) Core of the Albion complex: Uranium is present in association with pegmatites of the Tertiary Almo muscovite granite and as veins in older Precambrian basement rocks. The ultimate origin of the uranium is uncertain for both types of occurrences.

6) Goose Creek area, west of the Albion complex: Mineralization occurs in late Tertiary carbonaceous sediments. Anomalously uraniferous tuffs are reported by Mapel and Hail (1969) who suggest that the ash is the source of the uranium. Nevertheless, similar favorable lithologies such as lignites and carbonaceous shales might be present down the hydraulic gradient from uraniferous rocks exposed in the core of the Albion Range.

7) Ruby granite and marshes: This project has documented the existance of a uraniferous biotite granite phase of what has been collectively mapped as Jurassic granite (Howard and others, 1979). Any uranium leached from the granite could be trapped in adjacent sediment-filled basins which locally contain modern day playas and marshes.

8) Rawhide dislocation surface: Several uranium occurrences in this western Arizona complex are locallized along the dislocation surface between lower-plate mylonitic gneisses and upper-plate Paleozoic, Mesozoic, and middle Cenozoic sedimentary and volcanic rocks. Uranium is accompanied by a distinct copper and iron mineralization which has a known regional association with the dislocation surface. The mineralization must be middle or late Tertiary and may have been deposited concurrent with movement on the dislocation surface.

9) Anderson Mine - Artillery Mountains - Black Butte area, west-central Arizona: These three occurrence areas have much in common although separated by significant distances. Uranium mineralization is present in lacustrine units of middle Tertiary age that lie up-section (northeast) of exposures of the dislocation surface. Uranium mineralization may be largely the result of alteration of volcanic ash, but the present orientation of bedding in all three areas (a pronounced southwest dip) is probably a function of tilting that accompanied movement on the dislocation surface.

10) Blue Rock Mine area, eastern Santa Catalina complex: Uranium is present in fractures and along faults that separate a variety of sedimentary, metamorphic and plutonic rocks. It is uncertain whether the fault system is a dislocation surface similar to those exposed on the western margin of the complex or Laramide low-angle faults with large amounts of displacement. Uranium mineralization may owe its origin to groundwater leaching of adjacent granitic or overlying uraniferous sedimentary rocks. Alternatively, it may have been formed by hydrothermal fluids which permeated the fault system during or after its movement.

The ten areas described above are exemplary of the various types of uranium occurrences present within and adjacent to metamorphic core complexes and are depicted in an idealized cross-section of a metamorphic core complex in Figure 6-3. The types of occurrences represented by these examples will probably be the most common in the complexes. It follows that Cordilleran metamorphic core complexes will be most favorable for additional deposits that are similar to those outlined above.

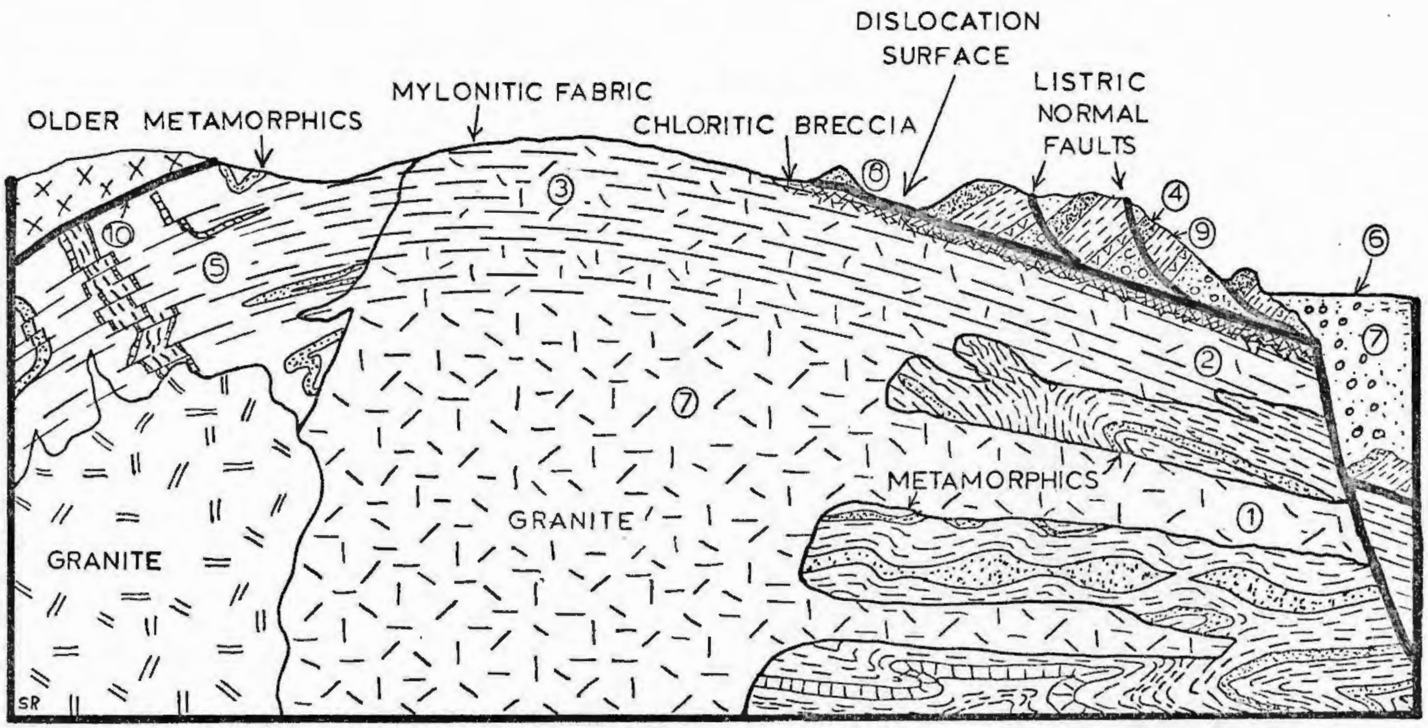


Figure 6-3. Schematic cross-section of a typical metamorphic core complex showing the geologic setting of important uranium occurrences. Circled numbers indicate the positions of the following uranium deposits discussed in this chapter: 1) Kettle Pegmatites; 2) Graeber Lease, Kettle complex; 3) Mount Spokane, Selkirk complex; 4) Tiger Formation, adjacent to Selkirk complex; 5) Core of the Albion complex; 6) Goose Creek area, west of the Albion complex; 7) Ruby granite and marshes; 8) Rawhide dislocation surface; 9) Anderson Mine - Artillery Mountains - Black Butte area, west-central Arizona; and 10) Blue Rock mine area, eastern Santa Catalina complex.

Conclusions

The uranium favorability of metamorphic core complexes is as varied as their geologic settings and tectonic histories. A majority of the complexes are very unfavorable for uranium deposits On the opposite extreme of the favorability spectrum are complexes such as the Kettle Mountains which are as favorable for uranium deposits as any crystalline areas of the western U.S. All the complexes are grouped below according to their relative uranium favorability.

High favorability - Kettle, Selkirk, Albion

Moderate to low favorability - Okanogan, Bitterroot, Raft River, Ruby, Rawhide, Buckskin, Santa Catalina-Rincon, Pinaleno-Santa Teresa

Very low favorability - Pioneer, Grouse Creek, Snake, Kern, Death Valley, Homer, Dead, Sacramento, Chemehuevi, Whipple, Harcuvar, Harquahala, White Tank, South Mountains, Picacho, Tortolita, Sierra Blanca, Comobabi, Coyote, Alvarez, Kupk, Pozo Verde.

Each complex will have different favorability for the various types of uranium occurrences discussed in Chapter 4 and earlier in this section. Therefore, the geology of each complex must be evaluated on an individual basis to predict the types of uranium occurrences most likely to be present. Cordilleran metamorphic core complexes , as a group, are probably most favorable for pegmatitic, hydrothermal, metamorphic, authigenic, allogenic, and peripheral lacustrine occurrences. The dislocation zone on the flanks of the core complexes is conceivably an important permeable channel or depositional site for ascending or descending uraniferous fluids. The uranium potential of such zones may not have been properly evaluated by traditional exploration in the complexes. Uranium mineralization in such zones might be largely concentrated below the water table, out of view of surface observation.

CRITERIA FOR EVALUATION OF FAVORABILITY

As might be expected, the criteria for evaluation of uranium favorability vary from complex to complex. Numerous criteria are dispersed throughout the text of this chapter as well as chapters 4 and 5. The most favorable complexes will be those that are situated within uraniferous provinces and contain abundant occurrences or a record of significant past production. Delineation of regional zones of uraniferous plutons or mineral deposits might help reveal favorable areas.

Within each complex, favorability criteria are governed by the geology of that specific complex. The presence of highly uraniferous plutonic rocks suggests potential for a variety of plutonic uranium deposits and provides a uranium source for subsequent redistribution by metamorphic, mylonitic, hydrothermal, and near-surface processes. High uranium content will commonly be matched by high potassium and thorium enabling the detection of such uraniferous granites by standard ground or airborne radiometric techniques. As discussed more fully in Chapters 4 and 5, the chemistry of igneous rocks is a very powerful indicator of uranium favorability. High alkalinity of the magma series is as important as a thorough degree of differentiation. Igneous rocks with high K_2O and $K_2O + Na_2O$, in conjunction with low CaO, MgO and FeO contents, are those most likely to be uraniferous. Uranium-rich igneous rocks may also have high abundances of trace elements such as fluorine, lithium, beryllium, tin, tungsten and molybdenum. Models for the behavior of uranium and these elements in igneous environments provide other important favorability criteria (see Pilcher, 1978; Mathews, 1978b; Files, 1978).

Metamorphic rocks are most favorable for uranium deposits if they exhibit high background uranium contents and radioactivity. Schist, gneiss, and migmatite that are rich in biotite, muscovite, garnet, and sulfides are the typical host-rocks of metamorphic uranium deposits. Structures within metamorphic and plutonic rocks will commonly be accompanied by chlorite, hematite and mineralization such as copper, iron, and gold.

Favorability criteria for sedimentary uranium deposits will not be reviewed here, but are outlined in numerous Bendix open-file reports such as Marjaniemi and Robbins (1975), Wopat and others (1977) and Mickle and Mathews (1978). Metamorphic core complexes may be favorable for peripheral sedimentary uranium deposits if their plutonic and metamorphic rocks contain abundant leachable uranium. Zones of brecciated and permeable rocks that flank the complexes would be efficient channels for distributing uranium leached from the complexes into adjacent receptive sedimentary lithologies.

RECOMMENDATIONS FOR FUTURE STUDY

There is much information that, if available, would provide insight into additional aspects of the uranium favorability of Cordilleran metamorphic core complexes. More extensive sampling of the plutonic and metamorphic rocks of each complex will provide more data on background uranium abundances, thereby more specifically verifying the favorability of complexes not sampled during this project.

There is clearly much to be learned regarding uranium deposits produced by metamorphic and mylonitic processes. Detailed geochemical sampling programs in conjunction with petrologic study would better document the behavior of uranium during progressive metamorphism and mylonitization. Such sampling must be done in rocks that exhibit high background uranium contents, such as those present in the Kettle complex. The Kettle complex would also be ideal for examining the effect on uranium and other elements by processes that accompany formation of the dislocation surface. Understanding the origin of copper, iron, gold, and uranium mineralization associated with the dislocation surfaces, such as that in western Arizona, is critical in evaluating the general favorability of all core complexes.

The flanks of the complexes should be evaluated for subsurface uranium deposits either in the dislocation zone or in nearby upper-plate sedimentary units. This could be accomplished only by drilling adjacent to uraniferous core rocks such as those present in the Kettle, Selkirk, and Albion complexes.

Finally, the relationship, if any, between classic mantled gneiss domes and Cordilleran metamorphic core complexes must be examined in more detail. Some mantled gneiss domes including those near Rossing and the Rum Jungle regions are very favorable for uranium deposits. A large number of mantled gneiss domes are located in uranium provinces or areas otherwise characterized by abundant uranium and large-ion-lithophile element mineralization. Several uraniferous gneiss domes should be inspected to document their similarities and differences with Cordilleran metamorphic core complexes. Such a comparison might reveal why gneiss domes are generally favorable for uranium while metamorphic core complexes, as a tectonic species, are not.