

Natural Radioactive Disequilibrium of the Uranium Series

GEOLOGICAL SURVEY BULLETIN 1084-A

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By JOHN N. ROSHOLT, Jr.

CONTRIBUTIONS TO GEOCHEMISTRY

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NATURAL RADIOACTIVE DISEQUILIBRIUM OF THE URANIUM SERIES

By JOHN N. ROSHOLT, JR.

ABSTRACT

Many radioactive samples show radioactive disequilibrium because of the numerous geochemical processes affecting ore deposits. As it is difficult to interpret disequilibria by simply comparing radiometric and chemical assay values of uranium, analyses should be made of the abundance of Pa^{231} , Th^{230} , Ra^{226} , Rn^{222} , and Pb^{210} .

Uranium-series disequilibria, as shown by radiochemical studies of samples representing a cross section of most of the significant present-day radioactive deposits in the United States, can be classified according to six basic types. Interpretations of the geochemical history of these types indicate that it may be possible to date uranium deposition within a theoretical range of 2,000 to 200,000 years. Ages ranging between 6,000 and 30,000 years have been calculated for several specific samples.

INTRODUCTION

In the greatly expanded search for uranium in the last 10 years, disequilibrium in radioactive ores has presented a difficult problem to geologists and prospectors. The magnitude and frequency of disequilibria have been generally underestimated, although the importance of disequilibrium in field and laboratory counting measurements has begun to be realized.

Very few complete studies concerning disequilibrium in radioactive deposits have been published. Variations in the protactinium:uranium ratio have been reported by Schumb, Evans, and Hastings (1939) and Wildish (1930). Ratios of Th^{230} to uranium in coral limestone have been reported by Barnes, Lang, and Potratz (1956). A few results of analyses of Ra^{226} and U in mine-dump material have been given by Phair and Levine (1953). T. W. Stern and L. R. Stieff (1959) have reported several analyses of Ra^{226} and U in carnotite ores. Kuroda (1955) has provided a number of ratios of Ra^{223} to Ra^{226} in high-grade uranium minerals. Urry (1948) has reported several analyses of varved-clay samples containing radium. Other reports primarily on radium isotopes have been written by Armbrust

and Kuroda (1956), Koczy (1954), and Chlopin and Vernadsky (1932).

The purposes of this paper are to tabulate and discuss the results of a number of complete analyses of disequilibrium samples, to illustrate a proposed classification of disequilibrium patterns, to study these patterns as clues to the understanding of the geochemical history of the samples and of the deposits, and to point out some of the difficulties when simply comparing radioactivity and chemical analyses of uranium for interpreting equilibrium or disequilibrium in samples.

To make a detailed investigation of the state of radioactive equilibrium in ore-grade geologic samples, several key decay products must be measured and their relative abundances evaluated. Figure 1 shows the parent isotopes and decay or daughter products of the three principal naturally occurring radioactive decay series: the U^{238} , U^{235} , and Th^{232} series. Equilibrium is attained in a radioactive series when all the daughter products decay at the same rate that they are produced from the parent isotope. Thus, at equilibrium each of these daughter products would be present in a constant proportion to its parent isotope. The loss or gain, by geologic processes, of any of certain important isotopes during the more recent part of the existence of a mineral causes disequilibrium in the proportions of the parent isotope to its daughter products. Even though a series is not in complete equilibrium, many of the immediate short-lived daughter products will be in equilibrium with their long-lived parents. Where significant disruption of equilibrium occurs the natural radioisotopes can be separated into the following major isotopes and groups of established equilibrium shown in figure 1: the uranium group, Th^{230} isotope, Ra^{226} isotope, Rn^{222} group, Pb^{210} group, and Pa^{231} group in the uranium series. U^{235} itself will remain in constant abundance with U^{238} (Senftle and others, 1957); thus the U^{235} content is determined from the uranium analyses, which includes the isotopes U^{238} , U^{235} , and U^{234} which are assumed to be present in constant abundance to each other. In addition to these, the Th^{232} group may be present in some rocks and ores and add to the radioactivity.

To describe adequately the long-term state of equilibrium of the uranium series, the abundances of the long-lived isotopes, U, Pa^{231} , Th^{230} , and Ra^{226} should be known. Analysis for Rn^{222} and Pb^{210} , as well as for uranium, is desirable for investigating radioactivity anomalies, for checking the accuracy of uranium and radioactivity analyses, and for investigating emanation properties. With the exception of a few important samples, the results on ores containing significant quantities of Th^{232} are not included in this paper. Radiochemical assays by the author are given in table 2 at the end of the paper.

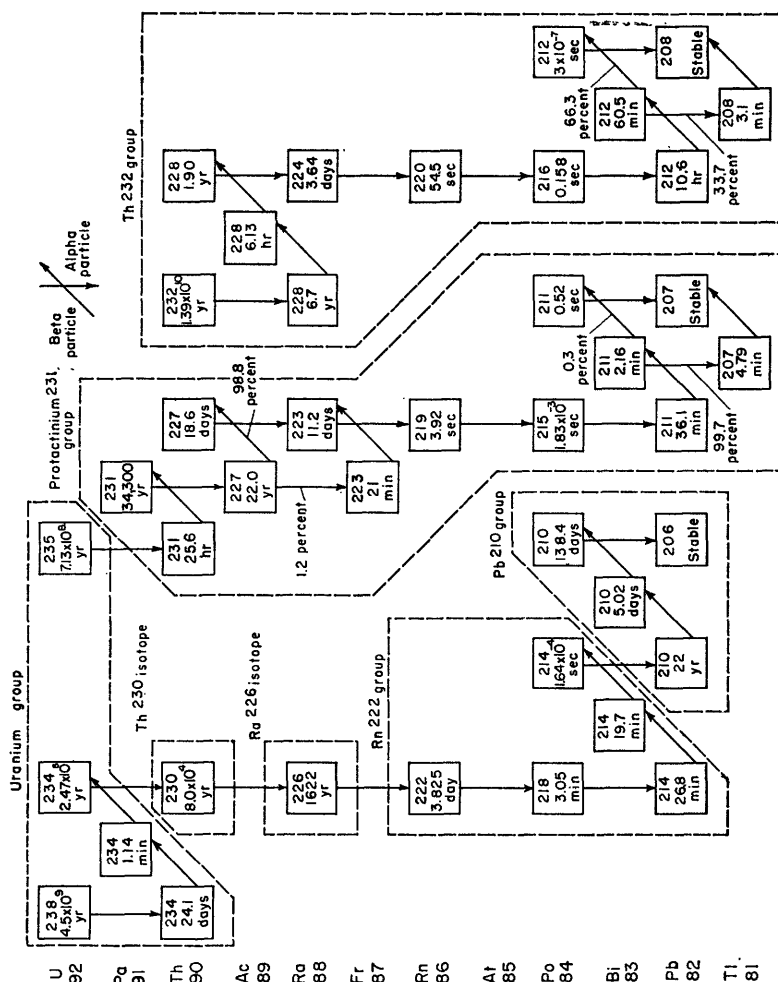


FIGURE 1.—Classification of natural radioisotopes into groups, showing atomic numbers, half-life periods, and modes of decay.

ACKNOWLEDGMENTS

Practically all the later analyses, which include the determination for Pa^{231} , were made by using continuously operating automatic counting systems for parts of the alpha-activity measurements. These systems were designed and maintained by J. R. Dooley, without whose assistance much of this work could not have been completed at this time. This work is part of a program being conducted by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. A preliminary summary of this paper (Rosholt, 1957a) was presented at the Second Nuclear Engineering and Science Conference, Philadelphia, Pa., March 11-14, 1957.

METHOD OF MEASUREMENT AND DEFINITION OF UNITS

All the daughter-product analyses were made by alpha-particle measurements after radiochemical separations of the specific elements were made with the aid of inactive carriers. The abundance of the isotopes Pa^{231} , Th^{230} , Ra^{226} , Rn^{222} , and Pb^{210} was determined. The methods used for these analyses have been described by Rosholt (1954; 1957b).

Equivalent uranium, expressed in percent eU, is the ratio of the radioactivity of the sample to the radioactivity of a uranium-ore standard which is in equilibrium with all of its decay products. Uranium is expressed as U, in percent, and Th^{232} as Th^{232} , in percent. All the decay products are expressed in percent equivalent and thus do not represent the actual amounts of these daughter products. Percent equivalent is defined as the amount, in percent, of primary parent, under the assumption of radioactive equilibrium, required to support the amount of daughter product actually present in the sample. This amount of primary parent may or may not be present in the sample. For the Th^{232} series, the daughter products are calculated as equivalent to Th^{232} and not to U.

Some graphic examples of the definition of percent equivalent are shown in figure 2. The hypothetical sample in equilibrium is one showing 1 percent uranium, 1 percent eU, and 1 percent equivalent of all of the daughter products; that is, 1 percent ePa^{231} , 1 percent eTh^{230} , 1 percent eRa^{226} , and so on. Sample 143 (Texas soil) has 0.65 percent U and 0.96 percent eTh^{230} . This eTh^{230} is present in excess of the uranium content and if equilibrium were to exist between U^{238} and Th^{230} , then 0.96 percent U would be required in the sample.

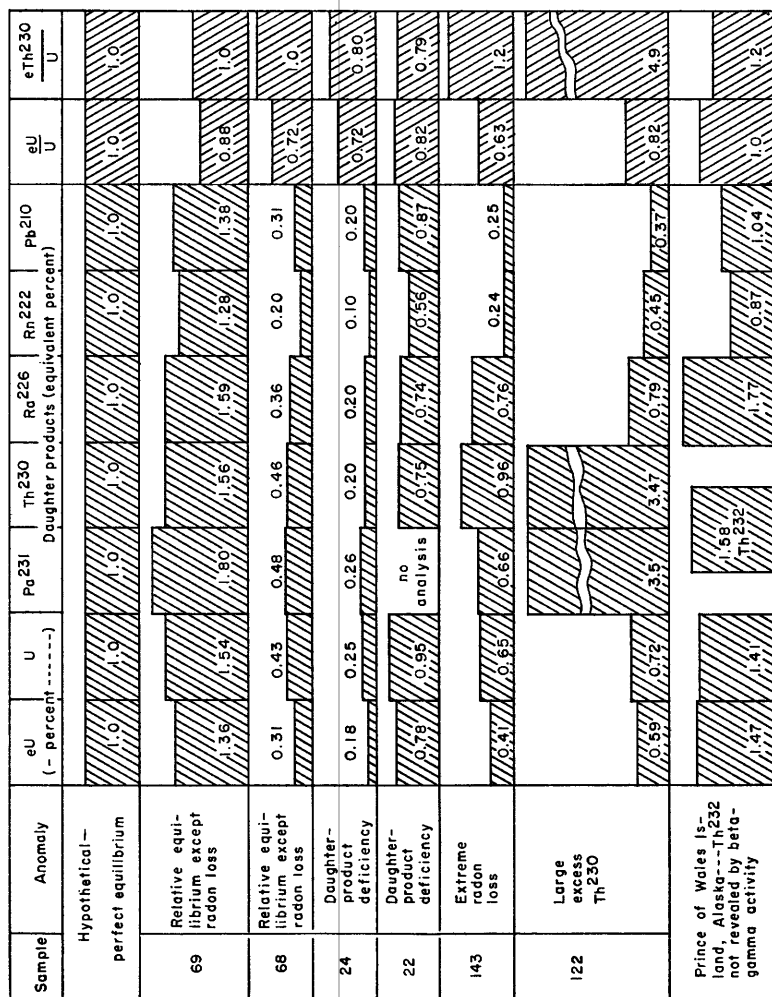


FIGURE 2.—Anomalies in comparison of eU to U illustrating the effect of variations in the abundance of daughter products on beta-gamma (eU) measurements.

Other units which could be used to express this type of result are compared below with the equivalent units. As can be seen, the use of equivalent units simplifies recording and interpreting the data.

Isotope	Percent equivalent	Percent	$\frac{10^{-9} \text{ curies}}{\text{grams of sample}}$
U ²³⁸ plus U ²³⁵	1.0	1.0	3.55
Pa ²³¹	1.0	3.37×10^{-7}	.16
Th ²³⁰	1.0	1.70×10^{-5}	3.39
Ra ²²⁶	1.0	3.39×10^{-7}	3.39
Rn ²²²	1.0	2.15×10^{-12}	3.39
Pb ²¹⁰	1.0	4.28×10^{-9}	3.39

The use of percent equivalent has other advantages besides that of illustrating or permitting direct comparison of uranium and daughter-product abundances in the sample. It also demonstrates that an overall material balance of parent isotopes and daughter products must exist in theoretical equilibrium concentrations, although not necessarily in the concentrations of parent and daughter products found in the samples selected for examination. Stated again, percent equivalent is defined as the amount, in percent, of primary parent, under the assumption of radioactive equilibrium, required to support the amount of daughter product actually present in the sample. This amount of parent does not necessarily have to be present in the disequilibrium sample; actually more or less than that amount of uranium may be present. Thus the deficient amount of uranium or the deficient amount of daughter product, in relation to its immediate parent, must exist elsewhere than in the sample analyzed. To illustrate this principle with sample 143 (fig. 2), 0.96 percent eTh²³⁰ shows that there is a deficiency of 0.96—0.65 or 0.31 percent uranium which must exist somewhere else unaccompanied by Th²³⁰; also, the sample is deficient of 0.76—0.24 or 0.52 percent eRn²²² and 0.76—0.25 or 0.51 percent ePb²¹⁰ which must exist elsewhere, unaccompanied by Ra²²⁶.

If a large enough sample is represented, the parent and all the daughter products will be present in equilibrium. However, this sample may have to be so large that it could not be collected. It also follows that the smaller the sample collected, the greater the probability of increasing the amount of disequilibrium found in the sample. This seldom considered assumption may be important in collecting samples.

COMPARISONS OF EQUIVALENT URANIUM WITH URANIUM

Although it is common practice to compare a sample's actual uranium content determined chemically with its equivalent uranium

(eU), misinterpretations can be made in comparing these two values alone. Radon loss is the most common anomaly and may present some misleading conclusions. Figure 2 shows some examples. Two Colorado Plateau samples (Nos. 68 and 69) in relatively good equilibrium with the exception of some radon loss show eU:U ratios very similar to two other plateau samples (Nos. 22 and 24) which have a deficiency of Th^{230} and Ra^{226} together with a lesser radon loss. Thus the comparison of eU and U will not always indicate whether the sample is deficient in radon products alone or deficient in long-lived daughter products also. Some samples may even be deficient in uranium and still show a low eU:U ratio. Sample 143, of soil from Karnes County, Tex., illustrates this extreme case. The extremely high radon loss completely masks the presence of the long-lived daughters that are actually in amounts in excess of the uranium. The eU:U ratio would indicate major disequilibrium with deficient amounts of daughter products, whereas actually it is the amount of uranium that is deficient.

A routine eU analysis will not indicate the presence of low-energy alpha emitters when beta-emitting daughter products are not present in the sample. Sample 122, a marl from the Nebraska-South Dakota border, illustrates this phenomenon. The large excess of Th^{230} and Pa^{231} is not indicated at all by the eU value because of the much lower eRa²²⁶ and eRn²²² content. Sample 1 (table 2) exhibits a somewhat similar isotope distribution with a large excess of Th^{230} , but a lower excessive content of Pa^{231} . The eU analysis will not reveal the high Pa^{231} content which is evident in many samples, because of the lack of sufficient intensity of beta emission from this group.

In a routine eU analysis the radon loss may completely mask the additional radioactivity created by the presence of Th^{232} and its daughter products, as shown by two samples from Prince of Wales Island, Alaska. Only one is shown in figure 2, for they have very similar analyses; neither is listed in table 2 because they are primarily thorium ores, and complete disequilibrium analyses were not made on them. The eU:U ratio seems to indicate good uranium-series equilibrium, but actually the amount of Th^{232} and the percent equivalent of its daughter products are greater than those in uranium. Equivalent Ra²²⁶ is also in excess of the uranium content.

CLASSIFICATION OF DISEQUILIBRIUM PATTERNS

Study of the isotope-abundance ratios of samples exhibiting significant uranium-series disequilibrium shows that the various types seem to represent certain patterns. With the use of the analyses of the key isotopes $\text{U}^{238} + \text{U}^{235}$, Pa^{231} , Th^{230} , and Ra^{226} it is proposed that practically all disequilibrium samples can be classified according to six

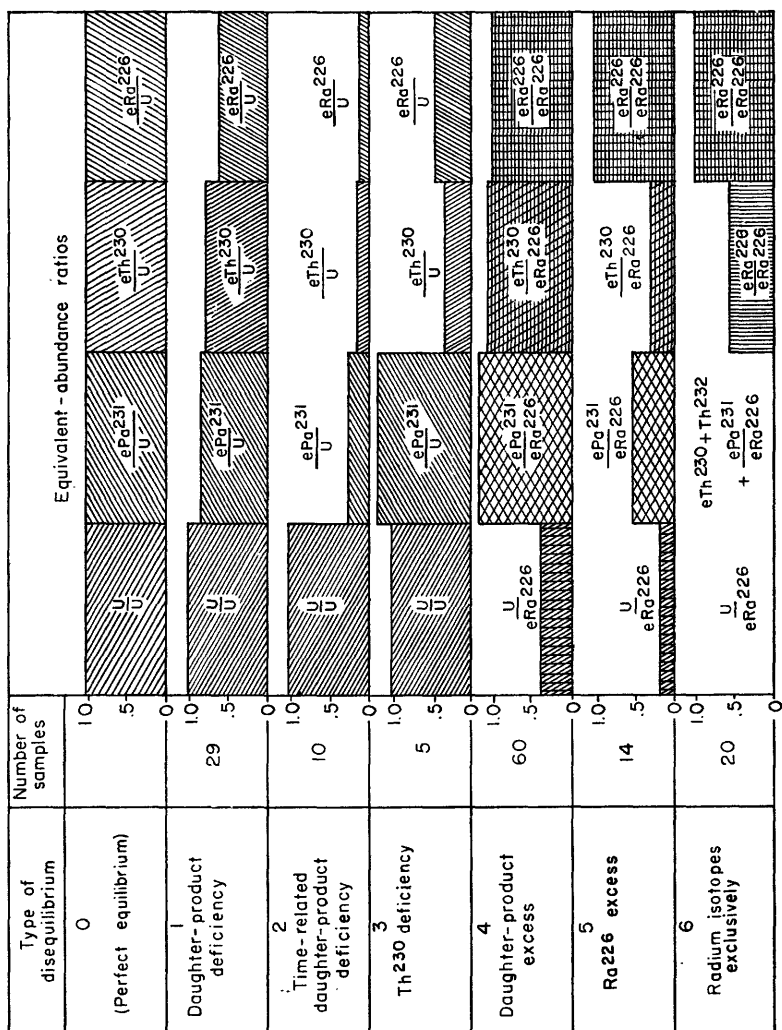


FIGURE 3.—Types of disequilibrium classified by ratios of radioisotopes.

different types that can result from the most recent major process of alteration. The classification is shown in figure 3. The second column shows the number of samples that were analyzed and found to fall in each type; the equivalent-abundance ratios are the average values for the indicated number of samples. The first four rows of equivalent-abundance ratios, (types 0-3) show the comparison of equivalent daughter-product content to uranium content where the U:U ratio is automatically 1. The first row (type 0) represents the hypothetical sample of perfect equilibrium.

The first three types of disequilibrium have values of U in excess of eRa^{226} . Type 1, daughter-product deficiency, is represented by samples in which the generalized relationships are $U > ePa^{231} > eTh^{230} > eRa^{226}$. Type 2, time-related daughter-product deficiency, is a very special kind of type 1 disequilibrium in which each of these daughter abundances must retain a specific relation with each other. This relation must be such that the amount of growth of each isotope from pure uranium, represented by the ratios of ePa^{231} to U, eTh^{230} to U, and eRa^{226} to U, would require the same interval of time. Type 3, Th^{230} deficiency, is represented by samples in which generally $ePa^{231} \leq U < eRa^{226} > eTh^{230}$, the key isotope being the anomalously low Th^{230} .

The last three types of disequilibrium have values of eRa^{226} in excess of U, and as the uranium content is so small, it and all the equivalent daughter-product abundances are compared to eRa^{226} instead of uranium, as in the first three categories. Type 4, daughter-product excess, is represented by a low uranium content. The remaining longer lived daughter products are often present in approximately equilibrium amounts with one another. In some samples, however, the equivalent amounts of the daughter products vary considerably from one to another. Type 5, Ra^{226} excess, as shown in dump material is a special case of type 4, daughter-product excess, where generally $eRa^{226} > ePa^{231} > eTh^{230}$ which is much $> U$, the key isotope being the significantly excessive Ra^{226} . Type 6, the occurrence of radium isotopes exclusively, is a peculiar and not too uncommon type of deposit in certain localities. Here Ra^{228} , a daughter product of Th^{232} , is commonly found with Ra^{226} . The radioactive components are radium isotopes and their immediate decay products, and there is very little or no U, Th^{230} , Pa^{231} , or Th^{232} .

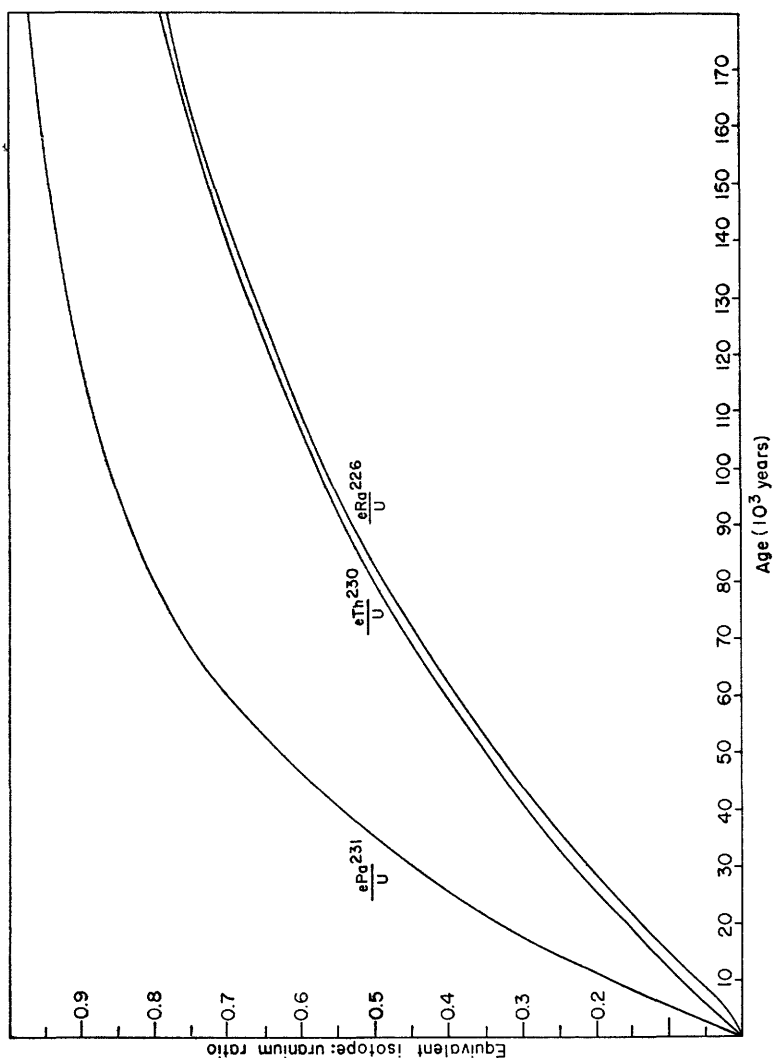
SOME INTERPRETATIONS OF CAUSES OF DISEQUILIBRIUM

The study of the distribution of the radioactive decay products in the types of samples listed is still in its first stage; nevertheless it is

possible to explain, or at least to postulate, some of the causes of disequilibrium.

Two primary processes can be involved in the type 1 ores. Uranium may have migrated to its present location at a time less than that required by its daughter products to reach approximate equilibrium, that is, less than 300,000 years ago. The alternative is that there has been preferentially greater leaching of daughter products than of uranium. The latter explanation is the more probable in carnotite and other types of deposits where uranium fixative agents such as vanadium or phosphate are also present. Samples of this kind (type 1) that do not follow the normal $U > ePa^{231} > eTh^{230} > eRa^{226}$ pattern (with eRa^{226} nearly equal to or only slightly less than eTh^{230}) indicate that some leaching of daughter products has taken place. This kind of deficiency in daughter-product distribution is shown by samples 21, 23, 40, 60, 62, 74, 81, 86, 87, 93, 104, 108, 112, 121, 142, and 144 (table 2). Ra^{226} has been found to be the most common, and, in most samples of this type, the only long-lived daughter product which can be leached. Deficiencies of Rn^{222} and Pb^{210} are not considered major causes of long-lived disequilibrium. When the isotope abundance is similar to that in type 2, considerable weight is thrown to the first explanation (recent deposition of uranium). This distribution is common in many of the pitchblende-type ores such as that at the Happy Jack mine. Samples 20, 22, 24, 35, 45, 47, 52, 57, 60, 61, 62, 73, 86, 87, 104, 107, 118, and 142 may represent this kind of alteration. Some of the samples may represent more recent uranium deposition than is indicated by the abundance of the isotopes (see fig. 4). That is, they may actually be type 2 material that was deposited where some older uranium minerals already existed, or uranium may have subsequently been leached out after the original, relatively recent, uranium deposition. Samples 60, 62, 86, 87, 104, and 142 could result from the combined effect of recent uranium deposition and leaching of Ra^{226} .

Type 2 ores are of special significance because the isotope abundances are such that each isotope indicates nearly the same age for the uranium deposition. The required isotope abundances must match the time intervals when compared to figure 4. For the results of testing of these samples actually to represent the age of the uranium mineral, three conditions must be met: (a) uranium free of all decay products must have been deposited in nearly nonradioactive host rock, (b) there must have been no significant leaching of uranium or long-lived daughter products after deposition, and (c) the rate of deposition must not have been too slow compared to the rate of growth of daughter products. Evaluation of the effect of some of these conditions has been made (Rosholt, 1958). Table 1 shows the


 FIGURE 4.—Age of uranium deposition in years as a function of the ratios of the ratios ePa^{231} to U, eTh^{230} to U, and eRa^{226} to U.

isotope ratios and the possible age of the uranium for all the samples represented by this category. Some anthropological evidence and carbon-14 measurements (Wendorf, Krieger, and Albritton, 1955) for the same stratigraphic location from which sample 141 was obtained support the premise that the age given in table 1 is of the correct order of magnitude. Type 2 disequilibrium is not very common, but increasing knowledge of favorable geochemical and geological environments is now providing a greater probability of locating ores of type 2 disequilibrium. Radiochemical data and field evidence are now being accumulated for a paper devoted primarily to geochemical interpretations based on this kind of disequilibrium.

TABLE 1.—Age determination based on ratio of equivalent isotope to uranium

Sample No. ¹	Isotope ratio			Age (years) on the basis of—		
	$\frac{ePa^{231}}{U}$	$\frac{eTh^{230}}{U}$	$\frac{eRa^{226}}{U}$	Pa ²³¹	Th ²³⁰	Ra ²²⁶
13.....	0.24	0.13	0.13	14,000	16,000	18,000
14.....	.39	.26	.27	25,000	35,000	38,000
38.....	.10	.053	.053	5,000	6,000	9,000
39.....	.088	.022	.021	4,500	2,500	4,500
53.....	.27	.15	.13	16,000	18,000	18,000
54.....	.10	.045	.034	5,000	5,000	6,000
55.....	.45	.18	.16	30,000	23,000	22,000
56.....	.25	.15	.10	14,000	19,000	15,000
58.....	.37	.26	.22	23,000	35,000	31,000
141.....	.33	.18	.10	20,000	23,000	15,000

¹ See table 2 for description of sample.

Type 3 disequilibrium is believed to be the result of rather recent deposition of uranium contaminated with significant amounts of daughter products other than Th²³⁰, and with silica and salts. This type of disequilibrium is often the result of evaporation of solutions containing some of the long-lived isotopes, along with silica and various salts. The low Th²³⁰ content must reflect the relative deficiency of this isotope in the solutions. Sample 67, a hyalite-opal, appears to have this mode of origin. Samples 78, 79, and 80, stratigraphically below three samples (75, 76, and 77) of other classes, are most probably of this mode of origin (R. G. Coleman, oral communication).

Many samples with anomalously high radioactivity are of type 4. In general, disequilibrium of this type, found in samples taken from an oxidized environment, is the result of leaching of uranium. Daughter products may possibly have been added to the host rock, but it is difficult to select samples definitely showing that this occurred. A few samples (4, 36, 37, 42, and 82) have an abnormally low eTh²³⁰ content, which may indicate daughter-product addition when one considers that type 3 samples also have a low eTh²³⁰ content. A few samples (1, 46, 49, 71, and 72) have a low ePa²³¹ content which may have resulted because sufficient time was available for a greater frac-

tion of Pa^{231} than Th^{230} to decay after the uranium was leached. The fact that there is little eRa^{226} in many samples of this type does not appear to be too significant, for radium is easily leached in many different environments.

One very significant anomaly present in many samples of type 4, especially some of the high-grade black uranium minerals, is the high Pa^{231} content and near equilibrium abundances of U, Th^{230} , and Ra^{226} . Samples 41, 59, 61, 65, 66, 68, 69, 89, and 144 show this anomaly. One explanation seems most plausible—uranium and the other decay products are preferentially leached to a greater degree than protactinium. This may be due to the greater ability of protactinium to become hydrolized and reprecipitated immediately from the leaching solutions (Elson, 1954). Additional possible evidence of this high Pa^{231} content in many uranium minerals is furnished by Kuroda (1955). The high ratios of Ra^{223} to Ra^{226} that are characteristic of many of the uranium minerals he analyzed may reflect a high Pa^{231} content.

Most of the samples represented by type 5 disequilibrium occur in pyritic ores or ore dumps and are the result of differential leaching of all components. Sulfates formed in these materials would retain the radium even though it might migrate somewhat, whereas the sulfuric acid formed would leach and remove uranium. Further discussion of this type of disequilibrium is presented by Phair and Levine (1953).

The occurrences of radium isotopes exclusively (type 6 disequilibrium) are commonly associated with oil- and gas-field brines. Radioactive hot-spring deposits also show this type of disequilibrium. These sometimes highly radioactive deposits are the result of coprecipitation of radium with barium sulfate, strontium sulfate, and occasionally iron hydroxide from large volumes of water. It is also believed that the reason for the deposition of radium isotopes, essentially free of other radioactive isotopes, is that the water contained only radium as a significant radioactive component. The radium is believed to come from the pore space of the country rock from which the water is flushed. Materials containing significant amounts of Ra^{228} (without Th^{232}) must be of very recent origin, less than 30 or 35 years old. Samples 28, 127, 129, and 133–140 are of materials with recent additions of radium. Further evidence that many of these materials are of recent origin is the low Pb^{210} content. Sample 128 is a drill cutting from a depth of 2,530 feet and was obtained from rock below a well which was first drilled approximately 25 years ago (A. P. Pierce, oral communication). The well was deepened recently when the sample was collected. The ratio of Pb^{210} to Ra^{226} yields an age of 24 years. Further work describing many of the other aspects of oil-field radioactivity is presented by Gott and Hill (1953).

TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples*

Sample number: Samples collected or submitted by the following: (U. S. Geological Survey unless otherwise indicated): E. R. Landis, 1; R. U. King, 3-5; F. B. Moore, 6-8; B. F. Leonard, 9, 10; Avery Drake, 11, 12; E. W. Grutt, Jr., AEC, 13, 14, 81-83, 87, 89, 91, 93-98, 119; C. T. Pierson, 18, 19; R. A. Laverty, AEC, 20, 21, 99; C. M. Tschanz, 27, 29-32; Helen Cannon, 28; E. D. Lynn, Anaconda Copper Co., 33, 34; S. R. Austin, AEC, 35-42; H. G. Stevens, AEC, 44-46; R. G. Lewis, 67; A. J. Froelich, 70; W. J. Carr, 71, 72; H. E. Nelson, 73, 74; R. G. Coleman, 84-86; D. F. Davidson, 88, 90; W. N. Sharp, 92; W. J. Mapel, 100; P. L. Wells, 101; J. R. Gill, 104, 117, 120; D. E. Peacock, 105, 106; G. E. Ethimon, 107; G. B. Gott, 108, 114-116; E. V. Post, 109; R. S. Jones, 110-113; R. J. Dunham, 121-124; F. W. Stead, 125; A. P. Pierce, 128-130, 132-136; J. W. Hill, 131; R. T. Russell, AEC, 137, 138; H. J. Hyden, 139; D. H. Eargle, 141; F. C. Canney, 142; and P. F. Fix, 143-145. eU (percent): The equivalent uranium (eU) assays were performed by C. G. Angelo, S. P. Furman, and D. L. Schaefer, U. S. Geological Survey. U (percent): The uranium analyses were performed by staff members of the U. S. Geological Survey. Pa₂₄₁ (percent equivalent): Pa₂₄₁ was not determined in the early analyses.

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent		Percent equivalent							
					eU	U	Th ²³²	Pa ²³¹	Th ²³⁰	Ra ²²⁶	Rn ²²²	Pb ²¹⁰	Ra ²²⁸	
COLORADO														
Bent County														
1	225091	LCR-126	Gray sandstone with minor iron staining; from sandstone ridge in valley subject to considerable weathering, sec. 32, T. 27 S., R. 51 W.	4	1.4	0.057	-----	1.9	5.5	3.9	2.6	1.93	-----	
Las Animas County														
2	239443	F 43770	Chip sample of limonite material on earthy ferruginous and manganous substance; Cliff Martin claims near Model, Colo.	6	0.62	0.0002	-----	<0.01	<0.002	1.84	0.87	0.72	<0.01	
Jefferson County														
3	224542	RUK-1-55	6-in. channel across iron-rich quartz-hematite vein in breccia reef at surface. Foot-hills Mining Co., Wright lease near Idle-dale, NE¼, NW¼, sec. 32, T. 4 S., R. 71 W.	4	0.065	0.002	-----	0.13	0.12	0.13	0.10	0.095	-----	
4	218688	RUK-25-54	Quartz vein in amphibolite schist; F. M. D. mine, sec. 25, T. 4 S., R. 71 W.	4	.21	.026	-----	.30	.14	.30	.33	.29	-----	
5	99576	GA-1b	Channel of thrust-fault gouge; Fountain-Benton fault contact, Tucker Gulch, northwest of Golden, sec 21, T. 3 S., R. 70 W.	4	.082	.019	-----	-----	.22	.17	.12	.10	-----	

Boulder County

6	40114	FM 20-11	Dump sample of vein material showing telluride and radioactive material in altered monzonite. X-ray mine.	5	0.014	0.001			0.012	0.035		0.031
7	41162	FM 20-2	Sample of shear-zone quartz vein, 320 ft from portal. Host rock in mine is Tertiary monzonite. Shirley mine, NW $\frac{1}{4}$, sec. 19, T. 1 S., R. 73 W. 14-ft.	5	.072	.007			.071	.12	0.1	.1
8	41170	FM 20-10	One-ft sample of shear-zone quartz vein, 480 ft from portal. Shirley mine.	5	.050	.034			.063	.065	.035	.050
9	87866	BFL 84A	Chip channel of 6-in. vein material in Gold Hill mining area.	5	.064	.017			.044	.12	.088	.080
10	87867	BFL 84	Selected pieces of most radioactive material, same location as No. 9.	5	.40	.076			.27	.61	.59	.64

Gilpin County

11	79647	OT-4	One-fourth-inch pitchblende veinlet in foot-wall at level 6, east, 424 ft from shaft, Old Town mine, Central City district. Mine drains through level 22 of Argo tunnel. A abundant pyrite has produced highly sulfate acid waters.	5	0.33	0.010			0.019	0.67	0.61	0.53
12	79648	OT-5	One-fourth-inch sample of pitchblende veinlet which extends 4 in. along dip length between hanging wall and foot-wall branches at shaft 20 ft above level 7. Old Town mine.	5	.67	.42			.44	.94	.93	.91

Moffat County

13	228859	33020	Medium-grained dark-green to buff sandstone with abundant limonite specks from Browns Park formation at 80- to 82-ft depth of drill hole 5470-3020, Gertrude claims, sec. 17, T. 7 N., R. 94 W.	2	0.12	0.26		0.062	0.035	0.034	0.029	0.033
14	228860	33021	Essentially same type of rock as no. 13, 82- to 84-ft depth, drill hole 5470-3020.	2	.085	.12		.047	.031	.032	.036	.034

TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples—Continued*

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent		Percent equivalent						
					eU	U	Th ²³²	Pg ²³¹	Th ²³⁰	Ra ²²⁶	Rn ²²²	Pb ²¹⁰	Ra ²²³
COLORADO—Continued													
Fremont County													
15	226419	F-32387	Hot-spring sinter; grab sample near spring on A. E. James claim along Salt Creek.	6	0.16	0.0007	---	<0.01	<0.005	1.12	0.07	0.70	<0.01
16	226421	F-32389	Hot-spring sinter; grab sample near spring on A. E. James claim along Salt Creek.	6	.15	.003	---	<.01	<.003	1.69	.06	.86	<.01
17	204985	F-19831	Iron-stained Dakota sandstone from Colexco claims, Garden Park district, north of Canon City.	4	.15	.080	---	---	.15	.16	.14	.13	---
Saguache County													
18	95756	53-P-16A	Pyritic ore; Rawley mine, Bonanza district.	4	0.75	0.59	---	---	0.99	1.09	---	---	---
19	97539	53-P-69A	Lead-silver ore; Bonanza district.	4	.22	.085	---	---	.29	.28	---	---	---
Mesa County													
20	221812	1376	Mill feed, carnotite ore; Climax Uranium Co. mill, Grand Junction.	1	0.33	0.46	---	---	0.40	0.42	0.29	0.38	---
21	221813	1376A	do.	1	.28	.31	---	---	.30	.28	.27	.29	---
Montrose County													
22	226536	LP-1168-2	Drill core 354.8 to 355.8 ft; Long Park	1	0.78	0.95	---	---	0.75	0.74	0.56	0.87	---
23	223173	LP-1361	Drill core 380.8 to 380.9 ft; Long Park	1	.095	.18	---	0.18	.12	.057	.037	.058	---
24	223175	LP-1361	Drill core 389.8 to 390.4 ft; Long Park	1	.18	.25	---	.26	.20	.20	.10	.20	---
25	135848	LP-531-198	Drill core 203.82 to 204.72 ft; Long Park	4	.007	.0034	---	.018	.012	.0085	.008	.009	---
26	135851	LP-530-85	Drill core, carnotite ore, 277.04 to 277.35 ft; Long Park.	0	.21	.26	---	.26	.26	1.009	.16	.26	---

NEW MEXICO
Mora County

27	GX-55-3328	G-360	Uranium ore, Guadalupeita.....	4	0.77	0.42	1.22	1.34	1.08	0.92	0.94	-----
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Sandoval County

28	GX-55-2958	HC-97-55	Calcareous tuffs; radioactive hot springs, 10 miles northwest of San Isidro.	6	0.010	<0.001	-----	-----	0.024	-----	0.015	0.008
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Santa Fe County

29	225164	NM 22	Oxidized dump material; Cobra claim, Cerrillos district.	5	0.093	0.0014	-----	0.036	0.008	0.15	0.14	0.14
30	219708A	NM 23A	Radioactive copper ore from dump; Cobra claim, Cerrillos district.	4	.19	.12	-----	.41	.54	.35	.26	.22
31	219708B	NM 23B	20 percent pyrite in fresh marcasite; Cobra claim, Cerrillos district.	5	.016	.004	-----	.017	.009	.021	-----	.02
32	219708C	NM 23C	Altered marcasite from surface; Cobra claim, Cerrillos district.	5	.013	.002	-----	.015	.003	.020	-----	.02

Valencia County

33	205423	33159	Low-grade uranium-bearing sandstone; Anaconda Copper Co. property, Grants area.	5	0.40	0.003	-----	-----	0.004	1.08	0.60	0.58
34	205424	24983	-----do.-----	4	1.04	.025	-----	-----	1.6	1.95	1.71	1.69

ARIZONA

Coconino County

35	243085	1733R	Blue molybdenum-bearing sandstone; Marcy Mining and Exploration Co.	1	0.82	1.28	-----	0.75	0.66	0.66	0.63	0.53
36	243086	1734AR	Oxidized mineralized log; Black Point Murphy mine.	4	5.7	.20	-----	17.1	8.26	11.2	10.4	10.5
37	243087	1734BR	Red halo around log (sample 36); 2 to 3 ft from log.	4	.039	.021	-----	.11	.059	.072	.045	.084
38	243088	1734CR	Black halo around log (sample 36); 4 to 6 ft from log.	2	.12	.30	-----	.031	.016	.016	.012	.011

TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples—Continued*

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent		Percent equivalent					
					eU	U	Th ²³²	Pu ²⁴¹	Th ²³⁰	Ra ²²⁶	Rn ²²²	Pb ²¹⁰
ARIZONA—Continued												
Coconino County—Continued												
39	243089	1734DR	Pleistocene gravel (same location as sample 36); 2- to 3-in. layer of mineralized gravel overlying scours in Chinle formation; sample is mineralized cement and smaller gravel particles.	2	0.74	1.94	0.17	0.043	0.042	0.036	0.047	---
40	243090	1732R	Ore sample; Jack Daniels No. 3 claim.	1	.39	.59	.41	.61	.55	.40	.37	---
41	243091	1739ZR	Pyritic carbonaceous log, unoxidized; Huskon No. 22 mine.	4	15.6	20.27	24.7	20.2	20.0	11.5	17.5	---
42	243092	1747R	Ore sandstone; Shinarump member of Chinle formation; Kachina No. 1 claim.	4	.54	.52	.58	.62	.73	.63	.64	---
CALIFORNIA												
Plumas County												
43	205449	OJH-1	Massive dark-brown limonitic and manganese earthy material; La Honda mine, Meadow Valley.	6	0.16	<0.001	-----	<0.006	0.43	0.31	0.28	-----
UTAH												
San Juan County (Happy Jack Mine)												
[The following 23 samples are from Happy Jack mine on the southwest rim above White Canyon in the western part of the White Canyon area. The workings extend from the rim 800 feet south through the mine. Station identifications are the same as those shown on the map of the Happy Jack mine by Trites and Chew (1955).]												
OXIDIZED ZONE												
44	79178	HJ-43	Chip sample, lower conglomerate sandstone; stratigraphic section 1; station L, rim outside portal.	4	0.16	0.026	0.42	0.25	0.27	0.21	0.21	-----
45	229189	RTC-41-55	Siltstone; top 0.6-ft channel from west wall; station A, 9 ft south of portal.	1	.12	.24	.14	.10	.082	.058	.034	-----
46	229184	RTC-36-55	Very coarse sandstone, with limonite and hematite; 0.3-ft channel, 5.5 ft above floor. Station A, 15 ft south of portal.	4	3.9	.75	4.05	8.76	6.07	5.47	5.06	-----

47	229188	RTC-40-55	Siltstone and macerated trash; 1.1-ft channel nearest floor at station A.	1	.23	.39	---	.26	.21	.15	.090	.13	---
48	229200	RTC-52-55	Medium-coarse sandstone with thin siltstone seams; 3 ft south of station A.	4	.22	.052	---	.37	.36	.37	.25	.26	---
49	229176	RTC-28-55	Coarse sandstone; impregnated and replaced with abundant sulfides and pitchblende; 0.3-ft channel, 1 ft above floor, station I, 50 ft south of station A.	4	8.5	3.02	---	12.0	15.0	14.7	12.2	12.5	---
50	229177	RTC-29-55	Medium-coarse sandstone; impregnated with limonite and white sulfates; 0.7-ft channel, 0.5 ft above floor at station I.	4	.52	.46	---	1.14	1.08	.82	.51	.70	---
TRANSITION ZONE													
51	229166	RTC-18-55	Coarse sandstone, yellow and green uranium minerals; 1.4-ft channel, 1.5 ft above floor of station AE, 60 ft south of station L, 90 ft west of station I.	4	.33	.36	---	.39	.39	.38	.29	.34	---
52	229167	RTC-19-55	Buff-gray siltstone, jarosite, and yellow uranium minerals along fractures; 1.3-ft channel nearest floor of station AE.	1	.25	.46	---	.24	.22	.16	.11	.16	---
53	229162	RTC-13-55	Carbonaceous siltstone with pitchblende and pyrite along fractures; 1.8-ft channel nearest floor of station AU and Z, 70 ft southeast of station AE.	2	.18	.44	---	.11	.086	.059	.038	.055	---
54	207413	RTC-44-54	Poorly bedded sandstone with thin coal seam; 3.5-ft channel nearest floor of station AV, 45 ft south of station AU.	2	.84	2.16	---	.22	.097	.075	.050	.064	---
SULFIDE ZONE													
55	207408	RTC-35-54	Fine medium crossbedded sandstone with abundant trash seams; 4.1-ft channel, 1 ft above floor at station AQ, 40 ft southwest of station AV.	2	.16	.29	---	.12	.052	.046	.038	.040	---
56	207409	RTC-36-54	Medium-coarse, crossbedded sandstone; abundant sulfides in matrix; 0.8-ft channel, nearest floor of station AQ.	2	.11	.26	---	.066	.039	.027	.014	.022	---
57	207423	RTC-55-54	Coarse sandstone with abundant siltstone seams; yellow sulfides and yellow uranium minerals; 0.5-ft channel, 3 ft above floor southwest of station AS, 270 ft southwest of station AQ.	1	2.4	3.76	---	2.08	1.83	1.66	1.45	1.48	---
58	207424	RTC-56-54	Continuation of above unit; sandstone with abundant yellow sulfides and boron in matrix; 1.3-ft channel, 2.5 ft above floor.	2	.54	1.11	---	.41	.29	.24	.14	.20	---
59	79153	HJ-17	Chip sample, siltstone; from wall of shaft at station M, 80 ft east of station AQ.	4	.12	.12	---	.16	.12	.12	.12	.11	---
60	79155	HJ-19	Chip sample, lower sandstone; near floor at station M.	1	.55	.90	---	.64	.56	.33	.28	.32	---

TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples—Continued*

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent			Percent equivalent					
					eU	U	Th ²³²	Pa ²³¹	Th ²³⁰	Ra ²²⁶	Rn ²²²	Pb ²¹⁰	Ra ²²³

UTAH—Continued													
San Juan County (Happy Jack Mine)—Continued													
SULFIDE ZONE—Continued													
61	79157	HJ-21	Chip sample, altered lower sandstone; near floor at station O, 15 ft south of station M.	1 or 4	12.5	14.61	---	15.3	12.0	11.9	11.0	11.0	---
62	79167	HJ-32	Chip sample, lower siltstone; near floor at station P, 70 ft south of station O.	1	1.2	1.43	---	1.36	1.30	1.14	1.09	1.07	---
63	79175	HJ-40	Chip sample, pitchblende lens; between sandstone beds, north wall at station R, 23 ft west of station F.	4	20.7	19.1	---	25.6	20.9	20.1	19.5	18.2	---
64	207383	RTC-10-54	Thin bedded siltstone; abundant jarosite and limonite along fractures; 12-ft channel, nearest floor of station V, 140 ft south of station R.	3	.19	.35	---	.16	.086	.13	.10	.13	---
65	207387	RTC-14-54	Pitchblende seam at base of gray siltstone bed; grab sample near floor of station BQ, 60 ft south of station R.	4	13.0	16.22	---	17.5	17.1	15.9	14.6	14.7	---
66	207403	RTC-30-54	Silty sandstone, highly impregnated and replaced by yellow sulfides; 0.2-ft channel, 2.7 ft above floor at station 9, 310 ft south of station BQ.	4	15.0	17.26	---	18.4	17.5	16.8	13.6	13.8	---

San Juan County (other than Happy Jack mine)													
67	226707	55-L-10	Hyalite opal in sandstone from near base of Shinarump member of the Chinle formation; 10 ft from ore at Skyline mine, Monument Valley NW ¼, sec. 26, T. 43 S., R. 15 E., Salt Lake meridian.	3	0.12	0.26	---	0.20	0.068	0.10	0.082	0.22	---
68	213745	DF-73-4	Uranium-bearing sandstone from Deer Flat.	4	.31	.43	---	.48	.46	.36	.20	.31	---
69	213765	DF-69-9	Mineralized carbonaceous material from Hidecut mine.	4	1.36	1.54	---	1.80	1.56	1.59	1.28	1.38	---
70	95928	AJF-53-972		4	.44	.060	---	---	.87	.82	---	---	---

Juab County

71	230884	SC-4-55	Tuffaceous sandstone; Goodwill claims, Thomas Range.	4	0.13	0.004	0.28	0.54	0.46	0.20	0.20	-----
72	230888	SC-8-55	-----do-----	4	.034	.006	.072	.088	.088	.058	.069	-----

Piute County

73	86194	F 9013	Vein material; 0.5-ft chip sample from Prosperor mine, 80-ft level, Marysville, Durkee district.	1	0.72	1.14	-----	0.89	0.86	0.44	0.57	-----
74	87179	F 106	Quartz and mineralized monzonite; 3-in. chip sample from Prosperor mine, Marysville, Durkee district.	1	.51	.88	-----	.89	.56	.30	.51	-----

WYOMING

Fremont County (Vibro mine)

[The following six samples are from a channel on the south wall of the open pit, Vibro mine, sec. 20, T. 33 N., R. 90 W., in Wind River formation, Gas Hills area.]

75	233590	233RGC-55-1	Sandstone; oxidized zone; upper channel sample.	4	0.065	0.011	0.18	0.19	0.13	0.083	0.14	-----
76	233591	233RGC-55-2	Sandstone; oxidized zone; next lower sample.	4	.11	.013	.30	.18	.22	.15	.18	-----
77	233592	233RGC-55-3	Sandstone; unoxidized zone; next lower 1.5 ft; high grade.	1	1.3	1.61	1.59	1.56	1.37	.84	1.22	-----
78	233593	233RGC-55-4	Siltstone; unoxidized zone; next lower 2 ft; low grade.	3	.042	.053	.10	.080	.045	.031	.043	-----
79	233594	233RGC-55-5	Mudstone; unoxidized zone; next lower 2 ft; barren.	3	.028	.039	.08	.013	.017	.018	.018	-----
80	233595	233RGC-55-6	Mudstone with conglomerate at base; lowest 2 ft; barren.	3	.038	.074	.044	.007	.011	.013	.011	-----

Fremont County (other than Vibro mine)

81	234601	JR-2-55	Sandstone from Vibro Chemical Co.; sec. 20, T. 33 N., R. 90 W.	1	0.37	0.61	0.59	0.60	0.24	0.16	0.24	-----
82	227773	AE-1309	Open-pit mine; Lucky Mae No. 20 claim, sec. 23, T. 33 N., R. 90 W.	4	4.6	.16	17.8	10.4	13.4	7.05	8.07	-----
83	216654	F-20501	Open-pit mine; Lucky Mae No. 20 claim. Sample contains white clay (radinite, illite, and montmorillonite) with fluorescent hyalite in host rock of arkosic sandstone of the Wind River formation.	4	2.5	.010	8.4	5.85	5.17	4.3	3.91	-----

TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples—Continued*

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent			Percent equivalent					
					eU	U	Th ²³²	P ₂₃₂	Th ²³⁰	R ₂₃₀	Rn ²²²	Pb ²¹⁰	R ₂₃₈

WYOMING—Continued													
Fremont County (other than Vito mine)—Continued													
84	215008	WC-2-5	Carbonaceous sandstone; Crooks Gap area, SE¼ sec. 24, T. 28 N., R. 92 W.	4	.065	.012	---	0.22	0.21	0.16	0.11	0.083	---
85	215009	WC-2-6	Iron-stained sandstone; Crooks Gap area, SE¼ sec. 24, T. 28 N., R. 92 W.	4	.072	.027	---	.30	.23	.21	.12	.078	---
86	215020	WC-5-2	Iron-stained conglomerate; Crooks Gap area, SW¼ sec. 16, T. 28 N., R. 92 W.	1	.068	.13	---	.12	.086	.042	.043	.067	---

Converse County													
87	228607	F 34720	Limonite-stained arkosic sandstone containing yellow uranium minerals in host rock; Wash formation, sec. 24, T. 35 N., R. 72 W.	1	1.8	3.68	---	3.2	2.5	1.7	0.43	0.30	---
88	71552	TW-52-52	White, medium- to coarse-grained sandstone with hard siliceous cement; Fertile River White River formation, Powder River Basin, SW¼, sec. 2, T. 33 N., R. 66 W.	4	.007	.002	---	---	.005	.007	---	.007	---

Johnson County													
89	234600	JR-1-55	Sandstone, Fort Union formation; Kel-Roy claims, sec. 3, T. 42 N., R. 70 W.	4	1.7	2.01	---	2.76	2.02	1.99	1.56	1.83	---
90	75118	TW-115-52	Bleached white coarse-grained sandstone from Fort Union formation; Powder River Basin, near Kaycee.	4	.051	.011	---	---	.063	.084	.075	.075	---

Nebraska County

91	237463	F 35830	Uraniferous brecciated vein material from bottom of a 35-ft deep inclined shaft in Precambrian granite and schist; Potter lease, SW $\frac{1}{4}$ NW $\frac{1}{4}$, sec. 23, T. 31 N., R. 64 W.	0	0.092	0.090	0.09	0.088	0.090	0.094	0.088	-----
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Campbell County

92	211421	WNS-BT-18	Coarse ferruginous woody sandstone from oxidized environment of Wasatch formation, sec. 4, T. 46 N., R. 74 W.	4	0.19	0.074	-----	0.64	0.62	0.29	0.24	-----
93	88309	F 12805	Sample of $\frac{1}{4}$ -in. band of carnotite-type mineral intimately associated with pyrite; overlying a 1-ft thick seam of coal in the Wasatch formation; Triangle claims, sec. 28, T. 41 N., R. 73 W.	1	1.04	1.73	-----	1.79	1.00	.74	.74	-----

Albany County

94	204003	F 17495	Pyritic vein material from fissure in the Precambrian granite of the North Laramie Range; sec. 27, T. 28 N., R. 71 W.	4	0.19	0.098	-----	0.42	0.23	-----	-----	-----
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Crook County

95	90892	F 16695	Sandstone from Homestake Mining Co., northwest of Devils Tower.	1	0.15	0.26	-----	0.093	0.096	0.080	0.032	-----
96	90893	F 16696	do.	4	.24	.009	-----	.45	.46	.43	.47	-----
97	90894	F 16697	do.	4	.23	.015	-----	.51	.57	.47	.31	-----
98	90896	F 16699	do.	4	.61	.11	-----	1.35	1.37	.98	.88	-----

MONTANA

Carbon County

99	238226	1655	Tyuyamunite from breccia zone in top of Madison limestone; Pryor Mining Co., Big Pryor Mountain.	4	-----	45.4	-----	53.5	32.5	25.8	24.7	-----
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TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples—Continued*

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent		Percent equivalent					
					eU	U	Th ²³²	Pg ²³¹	Th ²³⁰	Ra ²²⁶	Rn ²²²	Pb ²¹⁰
MONTANA—Continued												
Daniels County												
100	204067	MBS 174	Black shale.....	4	0.010	0.003	0.003	-----	0.009	0.006	-----	-----
County not known												
101	202149	W-121-A	Flathead quartzite.....	4	0.69	0.029	-----	-----	2.3	2.0	1.0	0.67
CANADA												
NORTH DAKOTA												
McKenzie County												
104	223486	GND-05A	Carbonaceous shale, 0.8 ft; 64 percent ash..	1	1.9	4.2	-----	3.51	3.34	2.61	1.10	0.57
Billings County												
105	240842	F 41812	Dark-brown woody lignite; NW¼ sec. 5, T. 13 N., R. 100 W.	5	1.1	0.13	-----	1.87	0.091	1.90	1.74	1.66
Golden Valley County												
106	240844	F 41815	Carbonaceous sandy clay; NE¼ sec. 7, T. 137 N., R. 106 W.	4	0.36	0.030	-----	1.36	1.34	1.42	0.62	0.42

SOUTH DAKOTA
Fall River County

		F 31494	Grab sample from ore zone in surface workings; carnotite-type mineral in white sandstone host rock in Lakota sandstone; Damisite no. 1 claim, sec. 8, T. 8 S., R. 4 E.	1	0.65	1.13		0.84	0.63	0.62	0.15	0.17
107	228712											
108	222083	S 111-34	Sandstone with carnotite; Gould mine, sec. 12, T. 8 S., R. 3 E.	1	7.9	10.2			9.9	8.33	6.66	6.8
109	206255	BB-56-54	Radioactive barite	6	1100.	(2)			20	2200.	1700.	1700.
110	200023	RSJ-235-53	Ore pod in sandstone; sec. 11, T. 8 S., R. 3 E.	4		.63			.73	.73	.49	.38
111	200022	RSJ-233-53	Reaction zone around ore pod; same location as sample no. 110.	4	.084	.083			.084	.092	.069	.070
112	200024	RSJ-265-53	Clay, at 11 T. 8 S., R. 3 E.	1	.027	.040			.039	.026	.017	.010
113	200025	RSJ-268-53	Conc. between clay and adjacent sandstone; same location as sample no. 112.	5	.016	.007			.007	.029	.028	.020
114	94406A	GG-1A-53	Radioactive sandstone from Fall River sandstone; light fraction; Red Canyon area.	4		.008			.24	.21	.18	.21
115	94406B	GG-1B-53	Heavy fraction of same sandstone as sample no. 114.	4		.056			17.5	17.7	17.1	18.3
116	94406C	GG-1C-53	Opal concentrate from light fraction of same sandstone as sample no. 114.	4		.10			.4	.4		

Harding County

117	235133	SB-5-8	Lignite from Slim Buttes area, 59.1 percent ash.	4	3.5	0.30	---	---	---	---	---	---
118	229487	GSD-580	Lignite, 1-ft sample; Riley Pass, North Cave Hills, 30.7 percent ash.	1	2.3	4.2	---	---	---	---	---	---
119	220658	F 30459	Lignite material from Ludlow member of Fort Union formation; Sentinels and Hand Red no. 1 claim, Slim Buttes area.	4	.15	.002	---	---	---	---	---	---
120	217822	GSD-540	Sandstone; auger-sample hole no. 13, sec. 27, T. 18 N., R. 8 E.	4	.25	.11	---	---	---	---	---	---

Shannon County

121	227654	K1-1au	Isolated remnant of unweathered gray shale enclosed in basal part of weathered yellow shale, Niobrara formation, SE 1/4, sec. 28, T. 36 N., R. 46 W.	1	0.58	1.07	1.1	1.08	0.43	0.11	0.22
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See footnotes at end of table.

KANSAS
Butler County

128	228582	AP 5543	Banded vesicular limestone, Arbuckle group; 2,539- to 2,530-ft depth, Magnolia Anderson no. 7, Augusta Field.	6	0.15	(?)	-----	-----	<0.005	0.21	0.24	0.11	<0.005
129	228583	AP 5545	Dense vesicular limestone, Kansas City group; 2,027- to 2,037-ft depth; South Anderson no. 1, Augusta Field.	6	.14	do	-----	-----	<.005	.15	.15	.052	0.27
130	15539	APP-31	Pipe scale from gas-well pipeline, Simpson formation SW $\frac{1}{4}$ sec. 27, T. 9 S., R. 4 E.	6	1.1	0.001	-----	-----	<.01	2.0	-----	1.7	-----
131	18446	JWH-403	Scale collected from scrap pipe-----	6	8.9	.001	-----	-----	<.01	18.9	18.7	2.5	-----

 OKLAHOMA
Osage County

132	228584	AP-5546	Filter cake from no. 2 tank, Cities Service, Avant Unit.	6	1.3	0.008	-----	-----	<0.01	2.90	3.0	0.030	-----
133	228585	AP-5547	Sulfate scale from water trough, Avant 1-S well.	6	6.5	<.0001	-----	-----	<.1	14.2	14.6	1.30	1.1
134	228589	AP-5551	Ferritoc from waste-water pit, Avant Unit.	6	.033	<.0001	-----	-----	<.005	.062	.058	.004	.014
135	228590	AP-5552	Fresh scale from outlet valve on Avant Unit 1-S well.	6	2.2	(?)	-----	-----	<.01	4.3	4.0	.15	.53
136	228591	AP-5553	Freshly precipitated ferritoc from lime-ferritoc precipitates, Avant Unit.	6	.032	.0004	-----	-----	<.005	.070	.050	.002	.014
137	225192	F 19012	Sand used for road ballast, previously used for oil-field filter sand, sec. 24, T. 24 N., R. 11 E.	6	.47	.013	-----	-----	<.1	.77	.5	.07	.8
138	225193	F 19013	Concretary limonite and BaSO ₄ from salt-water drainage ditch grading from New Boston Pool.	6	2.7	.003	-----	-----	<.2	3.8	3.3	.25	5.8

Creek County

139	231281	H-4S	Brine-soaked filter soil from oil-field operation; NE $\frac{1}{4}$ sec. 9, T. 18 N., R. 7 E.	6	1.1	0.0006	-----	-----	-----	1.79	-----	0.41	1.01
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Tulsa County

140	229127	F 36700	Barium sulfate from Tulsa, Oklahoma----	6	0.78	<0.001	-----	-----	-----	1.1	-----	0.003	1.5
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See footnotes at end of table.

TABLE 2.—*Uranium-series disequilibrium analyses arranged by geographical location of the samples—Continued*

Sample No.	Laboratory No.	Field No.	Description and location	Dis-equilibrium type	Percent		Percent equivalent						
					eU	U	Th ²³²	Pg ²³¹	Th ²³⁰	Ra ²²⁶	Rn ²²²	Pb ²¹⁰	Ra ²²³
TEXAS													
Midland County													
141	229122	ET-110	Fossil from site of anthropological discovery, Folsom culture.	2	0.005	0.013	-----	0.0043	0.0023	0.0013 1.0013	0.001	0.0006	-----
Karnes County													
142	GX-56-45	56-1	Tuffaceous sandstone with secondary uranium minerals; north trench, south Lyssy ore body.	1	1.9	4.35	-----	3.20	2.77	0.49	0.29	0.33	-----
143	GX-55-1258	PFF-55-11	Soil directly over sample 145, Dr. Bozo lease, Marvin Hachenev ranch, northeast base of Tordilla Hill.	4	.41	.65	-----	.66	.96	.76	.24	.25	-----
144	GX-55-1272	PFF-55-23	Black sandstone; Dr. Bozo lease; southwest of nos. 143 and 145.	1 or 4	.29	.57	-----	.71	.55	.47	.11	.10	-----
145	GX-55-1277	PFF-55-30	Selected ore from discovery pit; Dr. Bozo lease.	1	1.4	1.93	-----	1.87	1.58	1.70	.97	.76	-----
Duval County													
146	228087	F-11262	White friable tuff, Continental Oil Co. lease.	4	.062	0.051	-----	1.9	2.5	1.5	0.82	1.0	-----
147	228088	F-11263	One-foot channel in carbonaceous lignitic material; Araisas Exploration lease, north Duval County. Sample is from Dubose member of Jackson formation, overlies medium to fine-grained friable sandstone. Radioactivity occurs in lower 6 in to 1 ft of lignite material where it overlies highly silicified portion of normally friable sandstone.	4	.26	.075	-----	.55	.62	.47	.32	.37	-----

¹ Independent Rasm analysis performed by J. R. Dooley and D. L. Schaefer using the radon-train method.

² Very low.

³ Insufficient sample.

SUMMARY

Radioactive disequilibrium is a fairly complex phenomenon, and it is not an easy task to provide simple and straightforward explanations for the various daughter-product abundances. An approach through multiple hypotheses whose possible acceptance or rejection will be based on further interpretations provided by geological, geochemical, and chemical evidence will undoubtedly be necessary. The initial goal of this study was to investigate the complexity of disequilibrium and the distribution of its types. Unfortunately many of the early samples that were analyzed did not have adequate enough descriptions to permit more detailed interpretations.

Some of the many possible explanations of the causes of disequilibrium have been presented here although some of these may have to be revised when further evidence is available. Even without acceptance of an hypothesis, radioactive-disequilibrium studies provide important clues to the geological and geochemical history of deposits.

REFERENCES

- Armburst, B. F., Jr., and Kuroda, P. K., 1956, On the isotopic constitution of radium (Ra^{224}/Ra^{226} and Ra^{228}/Ra^{226}) in petroleum brines: *Am. Geophys. Union Trans.*, v. 37, no. 2, p. 216-220.
- Barnes, J. W., Lang, E. J., and Potratz, H. A., 1956, Ratio of ionium to uranium in coral limestone: *Science*, v. 124, p. 175-176.
- Chlopin, U. G., and Vernadsky, V. I., 1932, Radium-und mesothoriumbältige natürliche gewässer [Radium and mesothorium content in natural waters]: *Zeitschr. Elektrochemie*, Band 38, nr. 8a, p. 528-530.
- Elson, R. E., 1954, The chemistry of protactinium, in Seaborg, G. T., and Katz, J. J., eds., *The actinide elements* (Natl. Nuclear Energy Ser., Div. IV, v. 14A): New York, McGraw-Hill Book Co., p. 117.
- Gott, G. B., and Hill, J. W., 1953, Radioactivity in some oil fields of southeastern Kansas: *U. S. Geol. Survey Bull.* 988-E, p. 69-122.
- Koczy, F. F., 1954, Geochemical balance in the hydrosphere, in Faul, Henry, ed., *Nuclear geology*: New York, John Wiley and Sons, Inc., p. 120-127.
- Kuroda, P. K., 1955, On the isotopic constitution of radium (Ra^{223}/Ra^{226}) in uranium minerals and recent problems of geochronology: *New York Acad. Sci. Annals*, v. 62, art. 8, p. 177-208.
- Phair, George, and Levine, Harry, 1953, Notes on the differential leaching of uranium, radium, and lead from pitchblende in H_2SO_4 solutions: *Econ. Geology*, v. 48, p. 358-369.
- Rosholt, J. N., Jr., 1954, Quantitative radiochemical method for the determination of major sources of natural radioactivity in ores and minerals: *Anal. Chemistry*, v. 26, p. 1307-1311.
- 1957a, Patterns of disequilibrium in radioactive ores, in Dunning, J. R., and Prentice, B. R., eds., *Advances in nuclear engineering*, v. II, pt. 2: New York, Pergamon Press, p. 300-304.
- 1957b, Quantitative radiochemical methods for the determination of the sources of natural radioactivity: *Anal. Chemistry*, v. 29, p. 1398-1408.

- Rosholt, J. N., Jr., 1958, Radioactive disequilibrium studies as an aid in understanding the natural migration of uranium and its decay products: United Nations Internat. Conf. on the Peaceful Uses of Atomic Energy, 2d, Geneva, 1958, Proc., paper OIC 183, U. N. 772.
- Schumb, W. C., Evans, R. D., and Hastings, J. L., 1939, The radioactive determination of protactinium in siliceous terrestrial and meteoric material: Am. Chem. Soc. Jour., v. 61, p. 3451-3455.
- Senftle, F. E., Stieff, Lorin, Cuttitta, Frank, and Kuroda, P. K., 1957, Comparison of the isotopic abundance of U^{235} and U^{238} and the radium activity ratios in Colorado Plateau uranium ores: *Geochimica et Cosmochimica Acta*, v. 11, no. 3, p. 189-193.
- Stern, T. W., and Stieff, L. R., 1959, Radium-uranium equilibrium and radium-uranium ages of some Colorado Plateau secondary minerals, in Garrels, R. M., and Larsen, E. P., 3d (compilers), *Geochemistry and mineralogy of the Colorado Plateau uranium ores*: U. S. Geol. Survey Prof. Paper 320.
- Trites, A. F., Jr., and Chew, R. T., 1955, Geology of the Happy Jack mine, White Canyon area, San Juan County, Utah: U. S. Geol. Survey Bull. 1009-H, p. 238.
- Urry, W. D., 1948, The radium content of varved clay and a possible age of the Hartford, Connecticut, deposits: Am. Jour. Sci., v. 246, p. 689-700.
- Wendorf, Fred, Krieger, A. D., and Albritton, C. C., 1955, The midland discovery, a report on the Pleistocene human remains from Midland, Texas, with a description of the skull by T. D. Stewart: Austin, Texas, Univ. of Texas Press, 139 p.
- Wildish, J. E., 1930, The origin of protactinium: Am. Chem. Soc. Jour., v. 52, p. 163-177.



