ed for selected energy levels and crystal thicknesses. These illustrate the greater efficiency of this detector at low energy levels. This is further emphasised by the plot of crystal thickness against energy level for various efficiencies. These results indicate that a thickness of 100 mm (4 inches) has an efficiency of 80% for the 1.76 MeV peak while a thickness of 50 mm (2inches) has only a 50% efficiency. Corresponding efficiencies for 0.5 MeV re 95% and 80%.

Combining crystal efficiency with the stpectra for uranium and thorium which are normally taken with large crystal volumes illustrates the need for very large crystals for the 1.76 and 2.62 MeV uranium and thorium channels.

Airborne surveying is briefly discussed and reference made to sources of detailed information. Ground total count work is discussed and relative merits of integral and differential spectrometry illustrated. For maximum sensitivity with small crystals work should be limited to total count. Spectrometry requires a minimum of 50 mm crystal thickness and larger sizes are an advantage. Field assaying is outlined and the calibration of scintillometers and spectrometers discussed. Borehole logging with total count and spectrometric ratemeters is described with particular reference to crystal thicknesses and volumes. Continuous logging and static readings are compard with illustrations and statistics compared. Restrictions on logging speds are illustrated. Mention is made of radiometric standization pits at Australian Mineral Laboratories and extension to inhole assaying discussed.

HELIUM ISOTOPES IN ENERGY EXPLORATION

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1. Introduction

Sources of energy are becoming a more important component of the minerals industry, both for national use and for export income. There are few opportunities to integrate concepts of metal mining into the energy environment. However, we believe that the implications that can be drawn from observation of the natural variation of helium isotope abundances can be useful in the exploration for oil and gas reservoirs for concealed uranium deposits.

2. Concept

Tracing the dispersion of highly mobile "pathfinder" elements is a well-developed concept in mineral exploration especially applicable to the search for base metal deposits. Radon is commonly used to infer the presence of uranium mineralization; its association is clearly recognized as ^{238}U is its only progenitor. Similarly helium is a suitable indicative element because one of its isotopes, ^{4}He, is generated by the α-decay or uranium and its α-emitting daughters.

In oil and gas exploration, a comparable strategy calls for the identification of an associative element which is functionally relatable to hydrocarbon trap mechanisms and which undergoes a spatial dispersion capable of detection at the surface. In recent years, helium has been proposed as a suitable element.

It will be shown in the following discussion, that helium isotope determination is capable of yielding much more valuable information than measurements of total (elemental) helium.

3. Discussion

An isotopic approach to exploration is suggested on the basis that (i) helium has two naturally occurring stable isotopes whose ratio is known to vary over at least 5 orders of magnitude and (ii) known reactions are sufficient to explain these natural isotopic abundance variations.

Three major contributions to the helium inventory are readily identifiable.

(i) A primordial component included during planetary formation.

(ii) A ^{4}He radiogenic component due to natural α-decay integrated over the life of the earth.

(iii) A ^{3}He radiogenic component from the β-decay of tritium originating in atmospheric and geologic sources.

The ^{4}He radiogenic component is princiaplly due to uranium and thorium decay.

The relevant reactions are

$$^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He$$
$$^{235}U \rightarrow {}^{207}Pb + 7\,{}^{4}He$$
$$^{232}Pb \rightarrow {}^{206}Pb + 6\,{}^{4}He$$

For a crustal average of 4 ppm U and 12 ppm Th, the present crustal generating capacity of ^{4}He is 8.2×10^{-13} $cm^3/g/y$. Assuming the age of the crust is 4.5×10^{9} y and that no appreciable amount of U or Th has been added or removed, the production of ^{4}He at the time of formation of the crust was 31×10^{-13} $cm^3/g/y$. Using an average annual production rate of $\sim 20 \times 10^{-13}$ $cm^3/g/y$ over the period 4.5×10^{9} y, one calculates that a gram of average crustal material should contain 9×10^{-3} cm^3 of ^{4}He. In fact, the observed figure is 10-30% of this amount, the remainder having been lost from lattice locations, by diffusion into pore space or fissures and ultimately by degassing into the atmosphere.

In the case of ^{3}He, the parent source is principally the reaction

$$^{3}H \xrightarrow{T_{1/2} = 12.35\ y} {}^{3}He + \beta$$

Tritium is generated in the crust by the reactions

$$^{6}Li \xrightarrow{n} {}^{3}H + {}^{4}He$$

and

$$^{7}Li \xrightarrow{\alpha} {}^{3}H + 2\,{}^{4}He$$

and in the atmosphere by

$$^{14}N \xrightarrow{n} {}^{3}H + {}^{12}C$$

Isotopic abundance ratios are conveniently compared by normalization to R, the constant atmospheric ratio of $^3He/^4He$, which is determined to be 1.4×10^{-6}. Although not measured, primordial helium is estimated to have an isotopic ratio in the range of 10-100R. The ratio in uraniferous rocks may be as low as 10^{-4} R; in lithium-bearing rocks, 10-15R. In crustal rocks $^3He/^4He$ ratios are 10-50 times lower than the atmospheric value. The constant generation of ^4He in crustal rocks and the ^3He production from geologic and atmospheric sources, results in a continual leakage of new helium into the atmosphere. Stratospheric losses offset these inputs so that atmospheric helium has a substantially constant isotopic composition at a fixed concentration.

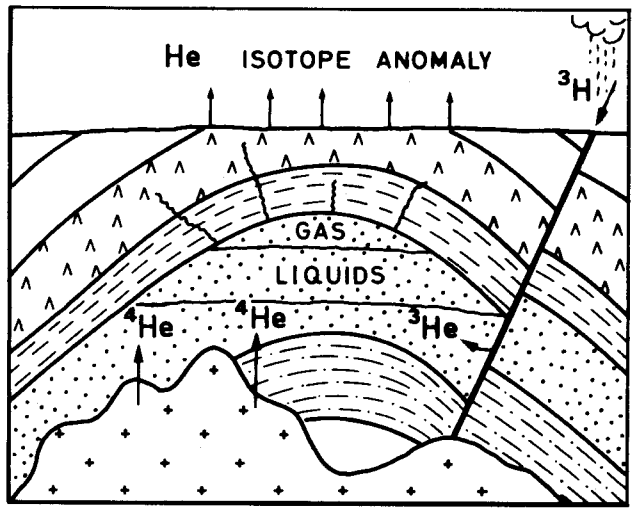

FIGURE 1

Oil/gas reservoir showing local sources of ^4He and ^3He which characterize the helium isotopic composition of trapped gas. Slow leakage produces a characteristic anomaly at the surface.

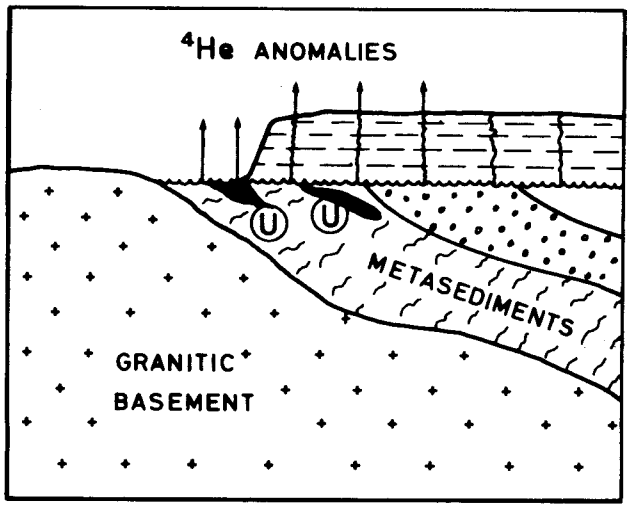

FIGURE 2

Uranium mineralization is shown generating ^4He below an unconformity. Helium leakage to the surface via joints, fractures and faults produces surface isotopic anomalies with very low $^3He/^4He$ ratios.

4. Oil/Gas Exploration

The specific association of helium with hydrocarbons is based on empirical observation and deductive speculation. Published analytical data from world-wide sources show that in 90% of oil and gas reservoirs examined, helium is present in the gas component at levels ranging from 100 ppm (volumetric) to greater than 10%. The apparent absence of He in 10% of wells analysed, is probably due to inadequate technique sensitivity in the measurements. Subsurface helium concentration and containment is considered to parallel mechanisms needed for hydrocarbon accumulates — porous transport strata leading to a structural trap restricting further migration of gaseous and liquid phases. The solubility of helium in both aqueous fluids and hydrocarbon liquids increases with pressure and temperature, so that the associative model of helium with hydrocarbon reservoirs is compelling.

Within the oil/gas structure, the gaseous component of the trapped helium locates with other natural gases above the liquid phases. The high mobility of helium suggests a ready escape mechanism by slow diffusion through overlying cap rock and subsequent dissolution in pore fluids allowing transport to the surface. Thus a surface helium anomaly either on-shore or submarine, could be indicative of a subsurface gas trap.

It is reasonable to surmise that the isotopic composition of helium in the gas of any particular gas/oil reservoir is a combination of both local sources and migration from lateral zones from hydrocarbon source rocks (Fig. 1.). In this event, one might expect, on volume considerations, that the lateral source component will be significant, and being in equilibrium with tritiated ground waters, well-gas will be significantly enriched in ^3He compared with ^4He rich average crustal values. Not all productive structures can be expected to bear a unique $^3He/^4He$ ratio. Rather, each trap should have helium which is a summation of local and sub-adjacent U/Th derived ^4He, a ^3He component dependent on age and recharge of local aquifers and a component labelled with helium production mechanisms pertinent to the hydrocarbon source rock. Thus each oil/gas trap will have a single unique $^3He/^4He$ ratio which will differentiate it from other local reservoirs.

5. Uranium Exploration

The current state of uranium exploration in Australia has defined two major provinces:

(i) the East Alligator River area in the Pine Creek Geosyncline and
(ii) the Stuart Shelf in South Australia.

In the East Alligator River area major deposits have been found in metamorphosed lower Proterozoic sediments overlain by Carpentaria platform sediments. While remaining surface radiometric anomalies are not fully evaluated, there is a growing need for an exploration tool capable of indicating deeply buried deposits. In particular, a means of detecting mineralization beneath the Kombolgie sandstone will become increasingly important. Similarly the completely covered Stuart Shelf area is an appropriate region for subsurface exploration by highly dispersive correlative elements.

Applications of helium dispersion in the vicinity of uranium

mineralization are well known. However, the technique suffers from diurnal and seasonal variations of helium concentration in ambient atmosphere. Thus, on site helium "sniffing" has met with mixed success as an exploration tool. Helium *isotopic* measurements, however, are invariant with respect to ephemeral variations in absolute helium concentration and thus are likely to preserve detectable anomalies. In particular, as uranium derived helium will be solely ^4He, surface atmospheric and ground water isotopic helium anomalies will be characterized by very low $^3He/^4He$ ratios (Fig. 2).

6. Conclusion

Total helium monitoring in field situations has enjoyed mixed success in the search for uranium mineralization in Australia, due to diurnal and climatic variations. Helium isotopic analysis will provide exploration-relevant information regardless of the absolute ambient concentration. Although no helium isotope measurements have ever been carried out in this country, future application of this technique may have an important impact on exploration for oil/gas reservoirs and for uranium mineralization.