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NATURAL RADIATION

Stanley S. Johnson

Natural radiation has always been an integral part of our environment. It is as much a part of our every day environment as the light and heat of the sun's rays. This cosmic radiation is part of the "background radiation" and although filtered through the atmosphere from outerspace, immerse us in a constant flux of radiation. Low-level radiation emanating from soil or rock is also not new or something that man created. It is produced by the radioactive elements and their isotopes that are part of the minerals and rocks that comprise the Earth's crust. Soils produced from the weathering of these rocks and minerals, the food we eat, the water we drink, and the air we breathe contain radioactive elements. The natural background radiation to which Man is exposed per year is estimated to be about 110 millirems. Sources of this radiation are from cosmic rays (35 mrem), air (5 mrem), building materials (34 mrem), food (25 mrem), and the ground (11 mrem) (General Electric). General Electric estimates that the average natural radiation background for Virginia is 125 mrem. Natural background sources account for 67.6 percent of the average individual exposure and medical radiation, fall out, occupational exposure, releases from the nuclear industry, and miscellaneous sources account for the remaining percentage.

Excluding radiation from nuclides produced by nuclear detonations (Table 1) and cosmic radiation, radioactivity in the natural environment is due mainly to the presence of various natural occurring elements and their isotopes. Most of the rocks and minerals that make up the Earth's crust and the surficial materials derived from them contain these natural radioactive elements, but those that are the most important contain uranium, thorium, potassium and their daughter isotopes. Almost all rocks and minerals exhibit a low level of natural radioactivity that can be attributed to one or some combination of these elements (Table 2). The minerals and rocks containing these elements are generally very widespread. The amount of these elements that are present commonly is measured in parts-per-million (ppm). Because the natural background radiation generally is low, it is regarded as an insignificant health problem. However, this is only generally true. In recent years one of the isotopes in the uranium-232 decay series, radon-222 (gas; daughter isotope of radium-226), has attracted a considerable amount of attention because of its tendency to concentrate in enclosed spaces, such as in houses and other buildings (Table 3).

As a general rule, radon is dissipated and diluted by the gasses in the atmosphere. Because radon is a gas, it is able to migrate from its natural sources through pores, fractures, and other openings to the Earth's surface. This migration is extremely variable because of the various aspects of local geology and other natural conditions. For example, depending upon local atmospheric pressure gradients, soil moisture, or groundwater movement, the gas may migrate along subsurface fractures in a preferred direction.

The amount of radon present in near-surface rocks and their overlying soils and groundwater is not uniformly distributed. Uniformity is not attained because of the nonuniform distribution of uranium and its radioactive decay products in the Earth. Some areas may be generally free of radioactive elements, whereas other areas may contain high concentrations of uranium, potassium, and thorium-bearing minerals.

This article is written to convey answers to many questions the writer has been asked over the past few years. The questions asked were generally related to radon, but the answers and discussions always got back to the "parent" of radon and thus to the rocks, minerals, and geology of the area in question. Other articles on aspects of radon and radioactivity published in *Virginia Minerals* are by Lasch (1988), Johnson (1979), and Johnson, Gathright, and Henika (1979).

Table 1. Some of the more prominent thermonuclear fission products (Hansen, 1975).

Element	Isotope	Gamma-ray Radiation energy (MeV)	Half-life
Strontium	Sr-89	———	50.5 days
Strontium	Sr-90	———	27.7 years
Yttrium	Y-90	1.75	64.2 hours
Yttrium	Y-91	1.19	57.5 days
Zirconium	Zr-95	0.73	65 days
Niobium	Nb-95	0.76	35 days
Ruthenium	Ru-103	0.56	40 days
Ruthenium	Ru-106	———	1 year
Rhodium	Rh-106	1.56, 1.23, 1.07, 0.80, 0.74	1.3 min.
Iodide	I-131	0.37	8.08 days
Cesium	Cs-137	0.66	26.6 years
Barium	Ba-140	0.51	2.8 days
Lanthanum	La-140	1.6, 2.3	40 hours
Cerium	Ce-144	0.13, 0.08	285 days

Note: There are more than 100 radionuclides produced in a thermonuclear explosion by fission and neutron reactions.

Table 2. Average radioelement content of rocks (Hansen, 1975).

	K^{40}ppm	Th ppm	U ppm	U/Th	Th/K^{40}	U/K^{40}
Basaltic Rocks						
average	0.8	4.0	1.0	.25	5.0	1.2
range	0.2-2.0	0.5-10.0	0.2-4.0	——	——	——
Granitic Rocks						
average	3.0	12.0	3.0	.25	4.0	1.0
range	2.0-6.0	1.0-25.0	1.0-7.0	——	——	——
Shales						
average	2.7	12.0	3.7	.31	4.5	1.4
range	1.6-4.2	8.0-18.0	1.5-5.5	——	——	——
Sandstones						
average	1.0	1.7	0.5	.29	1.5	.46
range	0.7-3.8	0.7-2.0	0.2-0.6	——	——	——
Carbonates						
average	0.3	1.7	2.2	1.3	5.6	7.3
range	0.0-2.0	0.1-7.0	0.1-9.0	——	——	——

URANIUM-THE ELEMENT

Uranium was first isolated in 1841 by Peligot. It was first recognized by Martin Klaproth as an unknown element in pitchblende and he attempted to isolate the metal (element) in 1789 (Hammond, 1989). This new element was named for the plant Uranus (Greek goddess of astronomy). Pitchblende was used as a pigment over 2000 years ago to give a rich yellow color to glass. Glass of this type has been found in mosaics of the ancient Roman Empire.

The element uranium is a heavy, dense, silvery-white metal that is slightly softer than steel and is malleable and ductile. Pure uranium has a specific gravity of approximately 18.9, thus making it almost as heavy as gold (19.3). Uranium metal is a strong reducing agent; it is dissolved by acids, but is unaffected by alkalis. Uranium is the last member in the series of naturally occurring elements shown on the Periodic Table.

Uranium is radioactive and has 16 radioactive isotopes. Naturally occurring uranium contains (by weight) 99.2830 percent ^{238}U, 0.7110 percent ^{235}U, and 0.0054 percent ^{234}U (Hammond, 1989). The only naturally occurring fissionable nuclide is ^{235}U. Uranium-238 is of major importance because it yields plutonium (^{239}Pu), a fissionable material. The half lives of ^{235}U and ^{238}U are 7.13 x 10^8 and 4.51 x 10^9 years, respectively. Natural uranium is only mildly radioactive because of the slow radioactive decay rates (Woodmansee, 1975).

USES

Enriched uranium is used for nuclear programs that include weapons, propulsion systems, and research and development. The predominant use of uranium (UO_2) is as nuclear fuel for power reactors. The fuel for reactors is processed into several "types" depending on the reactor specifications.

Small quantities of depleted uranium (in fissionable ^{235}U), which is mildly radioactive, are used in nonenergy applications because of the unique properties of the element. Uranium is adaptable for such uses because the metal is extremely dense, pyrophoric, alloys readily with other metals, forms stable compounds, and is easily fabricated. Depleted uranium metal is used in inertial guidance devices, ordnance applications, gyro compasses, control surfaces and counterweights in aircraft and space vehicles, ballast applications, missile re-entry vehicles, shielding material for several purposes, shipping containers for radioisotopes and spent nuclear fuel, and research. Other uses are in the ceramic and glass industry and in steel and nonferrous metallurgy.

THORIUM-THE ELEMENT

The element thorium was discovered in 1828 in the mineral thorite by Jons Berzelius. The element is named for Thor (Scandinavian god of war). Thorium is a silvery-white, soft and very ductile metallic element. Pure thorium has a specific gravity of 11.72. It is mildly radioactive and has 10 isotopes. Thorium (^{232}Th) occurs naturally and goes through 10 decay steps before becoming stable as a lead isotope (^{208}Pb). Thorium disintegrates (alpha emitter) with the production of thoron gas (radon-220) and represents a radiation hazard (Hammond, 1989).

USES

The thorium compounds (mainly thorium oxide) are mainly used for refractories, incandescent lamp mantles, ceramics, welding electrodes, and aerospace alloys. In the aerospace industries, thorium is alloyed with magnesium, where the resultant alloy metal has high strength and excellent creep resistance (Hedrick and Templeton, 1990). The incandescent lamp mantles used in typical oil and gas lanterns are coated with thorium nitrate. The thorium nitrate coated mantle, when burned, converts to an oxide and gives an intense white light when heated with oil or gas. Other nonenergy thorium uses are in welding electrodes, electron tubes, high refractive glass, and as catalysts.

In energy production, thorium-232 is converted to uranium-233. In the United States, one commercial electric generating plant used thorium as its fuel. This thorium-fueled nuclear reactor is located at Fort St. Vrain, Colorado (Hedrick and Templeton, 1990). This commercial reactor discontinued operation in August of 1989 and was undergoing decommissioning in 1990 (Hedrick, 1991).

POTASSIUM-THE ELEMENT

The radioactive element that most individuals are not aware is potassium-40, a daughter isotope of potassium. The element potassium was discovered in 1807 by Humphrey Davy. It was the first metal to be isolated by electrolysis. Potassium is never formed in a free state in nature. The element is the seventh most abundant in the Earth's crust; about 2.4 percent by weight (Hammond, 1989). Potassium metal is silvery in color, soft, and easily cut with a knife. The metal oxidizes rapidly in air and must be preserved in a mineral oil. Ordinary potassium is composed of three isotopes, one of which is ^{40}K (0.0118%), a radioactive isotope that has a half life of 1.28 x 10^9 years. The radioactivity from potassium-40 presents no appreciable hazard (Hammond, 1989).

USES

Potassium is required for life; we must continuously replace it in our bodies. Potassium is obtained from the food we eat, mainly vegetables. Vegetables and other plant life take the potassium from the soil through their root systems. Thus the major use for potassium is for fertilizer. Potassium is one of three of the most important fertilizers, the other two are nitrogen and phosphorus.

URANIUM, THORIUM, AND POTASSIUM IN THE NATURAL ENVIRONMENT

URANIUM

The estimates of abundance of elements in the Earth's crust are based on their abundance in igneous rocks. The average content of uranium in the Earth's crust is approximately 2 to 4 ppm; for thorium, 7 to 13 ppm. The geochemical differences between uranium and thorium cause segregation during magmatic differentiation at the time of crystallization. As a general rule, most of the thorium crystallizes as discrete disseminations in the original rock at the time of formation. Most of the uranium however, moves from the rock in hydrothermal solutions. Uranium is also easily oxidized and taken into solution after primary crystallization. This is not the same for thorium. Because of this factor, uranium can be carried over long distances and redeposited in other rocks, in many cases, at higher concentration than the original occurrence.

As previously mentioned, almost all rocks and minerals exhibit a low level of natural radioactivity due to the presence of various radioactive isotopes (Table 3). At least 20 naturally occurring elements are radioactive. Uranium does not occur naturally as an element but is chemically combined with other elements to form various minerals. Uranium is highly soluble and widely distributed in the crust of the earth.

Uranium is an important element in 155 minerals and is measurable in over 500 other minerals (Woodmansee, 1975). Some of the more important uranium minerals are pitchblende, uraninite, carnotite, autunite, davidite, torbernite, and coffinite. Uraninite is the most common uranium mineral; the mineral pitchblende is the massive form of uraninite. It is found throughout the world in sedimentary deposits, granitic rocks, pegmatites, and primary vein deposits. Coffinite, a uranium silicate, occurs in unoxidized sedimentary rocks. Carnotite, a hydrated potassium uranium vanadate, is an important secondary uranium-vanadium mineral. The oxidation of primary uranium minerals gives rise to a considerable number of secondary, brightly colored minerals. These secondary, oxidized uranium minerals occur as varieties of hydrated oxides, sulfates, phosphates, vanadates, silicates, and carbonates. Uranium-bearing minerals are found in all of the major rock groups - igneous, metamorphic, and sedimentary.

Most of the uranium and thorium (and their isotopes) are found in accessory minerals such as zircon, monazite, sphene, apatite, and others that are not as common. These accessory minerals contribute to the radioactivity of the rock and its weathered product. Accessory minerals such as, pyrochlore, allanite, xenotime, uraninite, and thorite, are highly radioactive, but generally they are not evenly distributed and concentrations are rare. Generally potassium, uranium, and thorium content decreases in igneous rocks as they become less felsic in composition. Ultramafic rocks such as dunite have the lowest content of radioactive minerals and display the lowest radioactivity levels of all igneous rocks.

Metamorphic rocks may display the same degree of radioactivity as their parent rocks, except where radionuclides have been introduced or removed during metamorphism. Gneisses and schists have moderate- to high-radioactivity. This variability in radioactivity is due to the degree of concentration of potassium-bearing and other radioactive accessory minerals present in the rock.

In sedimentary rocks such as sandstone, limestone, dolomite, and non-carbonaceous shale, most of the radionuclides are in the detrital particles. With the exception of black, carbonaceous shale and arkosic sandstone, sedimentary rocks are low in radioactivity. Uranium enrichment in black shale results from the affinity of organic matter for uranium. High potassium concentration (from sylvite and carnallite) are found in saline deposits in sedimentary units. Table 4 indicates the relative radioactivity of selected rocks.

In the igneous rocks, uranium-bearing mineral occurrences are more likely to be found in rocks that are low in iron and magnesium and high in sodium and potassium (felsic/acidic). These include rocks such as granites (intrusive) and rhyalitic volcanic flows and tuffaceous ash (extrusive). Uranium occurs in granites and similar rock types as "films" on fractures and around common rock forming minerals, as discrete uranium minerals, and as impurities in other accessory minerals such as zircon, apatite, monazite, and sphene. These accessory minerals generally resist oxidation and chemical weathering and, thus by physical weathering and fluvial processes, are concentrated into heavy mineral placer deposits (high energy stream and beach environments).

The uranium "films" and less resistant discrete uranium minerals (such as uraninite) oxidize quickly on oxygenated surfaces and in groundwater. The soluble uranium "moves" in solution with the groundwater until the uranium is precipitated or absorbed when the oxygenated water passes through permeable sedimentary rocks, such as sandstone. The uranium is precipitated when the water encounters a reducing environment that might be caused by the presence of carbonaceous material, sulfide bearing minerals, or hydrogen sulfide. It is by these processes that the major uranium occurrences (and deposits) are formed in sedimentary rocks.

The solution of uranium into oxygenated waters also allows for the dissolved uranium to be carried into streams, rivers, and oceans. The large area of low grade uranium resource in the Devonian-age black shales (Chattanooga Shale-southeastern United States) is due to precipitation from sea water. The uranium-bearing sea water is also the source of the uranium in phosphorite deposits.

Uranium ores in the United States occur mainly in conglomeratic, sedimentary strata that consist of fluvial, lacustrine, and marginal-marine sandstones. The host rocks are generally feldspathic, arkosic, or quartzose sandstone. The sandstones are generally medium- to coarse-grained and poorly sorted. The degree of sorting is important because it is a factor that controls permeability. The sandstone also contains pyrite (sulfide mineral) and organic matter, thus "setting-up" a reducing environment.

In addition to the uranium-bearing mineral occurrences (and deposits) in igneous rocks and in sedimentary rock types (such as sandstone and shale), some uranium occurrences (and deposits) occur in "veins". A "vein" generally includes occurrences where fractures are the major control for localization of the uranium minerals. In a broad sense, the fracture

Table 3. Natural radioactive decay series of uranium-238, thorium-232, and potassium.

Element	Isotope (mass no. and symbol)	Approximate Half-Life
Uranium-238 Series		
Uranium	$_{92}U^{238}$	$4.51x10^9$ years
Thorium	$_{90}Th^{234}$	24.1 days
Protactinium	$_{91}Pa^{234}$	6.8 hours
Uranium	$_{92}U^{234}$	$2.47x10^5$ years
Thorium	$_{90}Th^{230}$	$8x10^4$ years
Radium	$_{88}Ra^{226}$	1600 years
Radon	$_{86}Rn^{222}$	3.8 days
Polonium	$_{84}Po^{218}$	3.1 min.
Lead	$_{82}Pb^{214}$	26.8 min.
Bismuth	$_{83}Bi^{214}$	19.7 min.
Polonium	$_{84}Po^{214}$	$1.64x10^{-4}$ sec.
Lead	$_{84}Pb^{210}$	21 years
Bismuth	$_{83}Bi^{210}$	5.0 days
Polonium	$_{84}Po^{210}$	138.4 days
Lead	$_{82}Pb^{206}$	Stable
Thorium-232 Series		
Thorium	$_{90}Th^{232}$	$1.41x10^{10}$ years
Radium	$_{88}Ra^{228}$	6.7 years
Actinium	$_{89}Ac^{228}$	6.1 hours
Thorium	$_{90}Th^{228}$	1.9 years
Radium	$_{88}Ra^{224}$	3.6 days
Radon	$_{86}Rn^{220}$	55 sec.
Polonium	$_{84}Po^{216}$	0.15 sec.
Lead	$_{82}Pb^{212}$	10.6 hours
Bismuth	$_{83}Bi^{212}$	60.6 min.
Thallium	$_{81}Tl^{208}$	3.1 min.
Lead	$_{82}Pb^{208}$	Stable
Potassium-40 Series		
Potassium	$_{19}K^{40}$	$1.28x10^9$ years
Argon	$_{18}Ar^{40}$	Stable

also means veins in fault-controlled and intrusive contact occurrences. As a general rule, the vein-type occurrence is present in areas (or regions) where tectonic and igneous activity has taken place. A pegmatite occurrence is in the vein-type category.

THORIUM

Thorium is another important element that is present in several minerals and contributes to the general background radioactivity. The minerals in which thorium mainly occurs originate in igneous rocks, as disseminated and discrete minerals. Thorium is also found in minerals that constitute part of the heavy mineral fraction in beach sands (mainly monazite). Thorium is not as soluble as uranium and is thus

Table 4. Relative radioactivity of selected rocks.

Rock Type	High	Moderate	Low
Igneous			
granite	X		
syenite	X		
pegmatite	X		
rhyolite	X		
diorite		X	
gabbro			X
basalt			X
diabase			X
ultramafic			X
Metamorphic			
gneiss (general)	<——	——>	
schist (general)	<——	——>	
marble			X
slate			X
quartzite			X
Sedimentary			
sandstone	<——	——	——>
shale	<——	——	——>
carbonate (pure)			X
siltstone	<——	——	——>
Sediments			
clay	<——	——	——>
black sands	X		

not as mobile in the "chemical" environment, but does move by mechanical processes as discrete resistant mineral grains. Thorium is about three times more abundant than uranium (Hammond, 1989).

Thorium is usually associated with uranium and the rare-earth elements (Hedrick and Templeton, 1990). It also occurs in similar rocks as uranium such as granite, pegmatite, and gneiss. The more important minerals that contain thorium are monazite, thorite, thorianite, uranothorite, and thorogummite. Most thorium compounds are obtained as a byproduct of processed monazite for rare-earth elements. Hedrick and Templeton (1990) report that in the United States, thorium-bearing monazite is recovered as a byproduct from mining of zirconium and titanium minerals in Florida and from gold and industrial sand mining activities in North Carolina. None of the monazite was processed in the United States.

Deposits of thorium-bearing minerals in the United States occur in beach and stream placers, veins, and carbonatites. Large reserves are estimated to occur. In addition to the United States' deposits, large resources are known to occur in Australia, Brazil, Canada, India, Greenland, and South Africa. It is noted by Hedrick and Templeton (1990) that satisfactory alternative materials are not available for most of the major nonenergy uses of thorium.

POTASSIUM (POTASH)

The most abundant rock-forming minerals that contain radioactive isotopes are the potassium feldspars (orthoclase and microcline) and muscovite mica. The primary unstable isotope in these rocks is potassium-40. The count-per-second rate of background radioactivity from potassium-40 (for example, from feldspars and micas) generally predominate over the count rates from either uranium or thorium in almost all rocks except the carbonates (limestone and dolomite).

Among the acidic igneous rocks, granitic and pegmatitic types generally contain large amounts of potassium feldspar and mica and some accessory radioactive minerals. Thus relatively high levels of radioactivity are normally measured over them. Mafic rocks such as basalt normally lack potassium-, uranium-, and thorium-bearing minerals and exhibit low radioactivity. Igneous rocks that are without mica and feldspar usually have very low concentrations of potassium.

The term "potash" is a generic term for many of the potassium-bearing minerals, ores, and finished products. The term comes from the potassium carbonate that remains after the leaching of wood ashes. Potassium (potash, K_2O) production in the United States centered in southwestern New Mexico with produciton from five companies and six underground mines (Searls, 1990). In Utah, production was from a solution mining operation as a byproduct from halite mining and from subsurface and surface brines using solar evaporation techniques (Searls, 1990). Production was also reported from California. According to Searls (1990), 95 percent of the potash was used in the fertilizer industry. Deposits of potash are extensive and there are no substitutes for potassium as an essential plant nutrient.

Mica production in the United States is mainly centered in North Carolina with about 61 percent of the production; the rest of the production comes from Connecticut, Georgia, New Mexico, Pennsylvania, South Carolina, and South Dakota (Davis, 1990). The bulk of the mica was ground and used in joint cement, paint, roofing, oil well drilling, and rubber products (Davis, 1990).

SUMMARY

Natural radioactivity is part of our environment. It comes from soils, rocks, and the atmosphere. The natural radioactivity background will depend on the geologic conditions present in the area. Radioactive minerals can be found in all of the chief classes of rocks - igneous, sedimentary and metamorphic. Virginians are estimated to receive about 125 millirems per year from natural background sources (67.6 percent).

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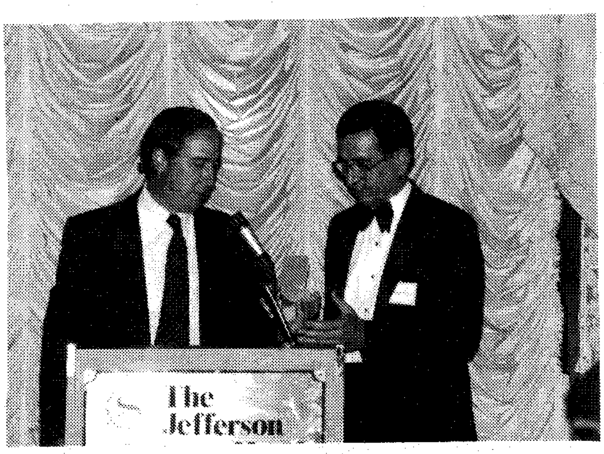
THOMAS JEFFERSON MEDAL AWARDED TO ROBERT C. MILICI

Bob Milici received the Thomas Jefferson Medal for Outstanding Contributions to Natural Science from the Virginia Museum of Natural History on January 16, 1991, in Richmond. Bob's brief acceptance speech touched upon some of the current needs and opportunities for natural science.

> Thank you. I am greatly honored to receive the Thomas Jefferson award for outstanding contributions to natural science in Virginia. The study of natural science is, like the play of children, a self rewarding activity. And Virginia is a magnificant playground - with provinces ranging from the coastal regions on the east through the Piedmont and lofty mountains of the Blue Ridge, the rugged terrain of the western Valley and Ridge, to the southwestern Plateau, from whence comes our great resources of coal and natural gas.
>
> It is evident, however, that there will be an increasingly *vital* need for our science during this last decade of the

20th century and on into the 21st century. Ever-growing populations will change the face of Virginia from predominantly rural and agricultural to urban and suburban, especially in the northern and eastern parts of the state. More and more people will not only require greater amounts of resources for their support but will apply increasingly adverse pressures upon the natural environment that surrounds and nurtures us. For this reason, it is most important that a broad base of knowledge be made available to all of our citizens so that we might choose collectively the narrow path - between exploitation and economic development on one hand and conservation and preservation on the other - that will provide the highest quality of life for us all, not only in Virginia, but indeed in the nation and in the world.

It is important to stress that we can achieve this goal only through education and a public awareness of the competing needs both to protect and exploit the natural environment. This is especially true for our children and grandchildren, who will be dealing with these complex problems in the near future when populations will be greater and available natural resources may be less than they are today.



L.W. Ward presenting the Thomas Jefferson Medal to Robert C. Milici.

MINERAL UPDATE

ERYTHRITE

Lance E. Kearns
James Madison University

The relatively rare mineral erythrite (hydrated cobalt arsenate) has been identified from the Luck Stone (New Goose Creek) Quarry in Loudoun County, Virginia. The specimens were discovered in a hydrothermal vein on the north wall of the quarry by Mr. Robert Duncan and submitted for identification by Mr. Mark Duncan of Richardsville, Virginia. Identification was made by X-ray diffraction analysis and chemical (EDAX) analysis. The EDS spectrum indicates a relatively pure erythrite with no observed Ni (annabergite) or Zn (koettigite) substitution.

The erythrite occurs as numerous, tiny (less than 1 mm), pink spheres composed of radiating crystals (Figure 1). It is associated with a white fibrous amphibolite, milky quartz, chlorite, and chalcopyrite. The origin of the erythrite is most likely due to the oxidation of cobaltite contained within the Triassic diabase which is mined at the Goose Creek Quarry.

Erythrite has not previously been reported from Loudoun County. The only other reported occurrences in Virginia are from the Old Dominion soapstone quarry (Mitchell and Bland, 1964) and the Alberene soapstone quarry (Giannini and Penick, 1983), both located in Albemarle County.

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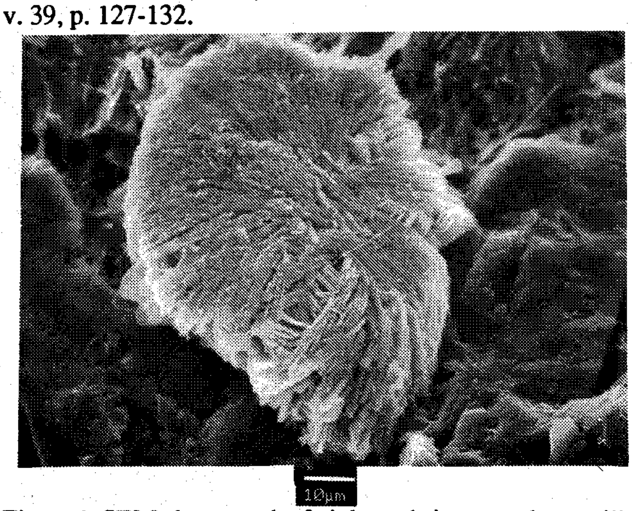

Figure 1. SEM photograph of pink erythrite crystals on milky quartz and white fibrous amphibolite from Luck Stone Quarry (New Goose Creek Quarry), Loudoun County, Virginia.

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NEW PUBLICATION RELEASED

Publication 103: Heavy-mineral studies — Virginia Inner Continental Shelf, edited by C.R. Berquist, Jr., 1990.
Price $2.50.

Publication 105: Physiographic diagram of Virginia, by Edgar Bingham with geologic cross section by Jack Lee Mason, scale - 1:750,000, 1991.
Price $3.00.

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