Natural Radioactivity in the Geologic Environment

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Most Abundant Radioactive Elements

- Potassium, isotope 40 (^{40}K)
- Uranium, isotopes 238 & 235 (^{238}U & ^{235}U)
- Thorium, isotope 232 (^{232}Th)

Uranium 238 Decay Products

$^{238}\text{U} \;\; \alpha > \;\; ^{234}\text{Th} \;\; \beta > \;\; ^{234}\text{Pa} \;\; \beta > \;\; ^{234}\text{U} \;\; \alpha > \;\; ^{230}\text{Th} \;\; \alpha > \;\; ^{226}\text{Ra}$

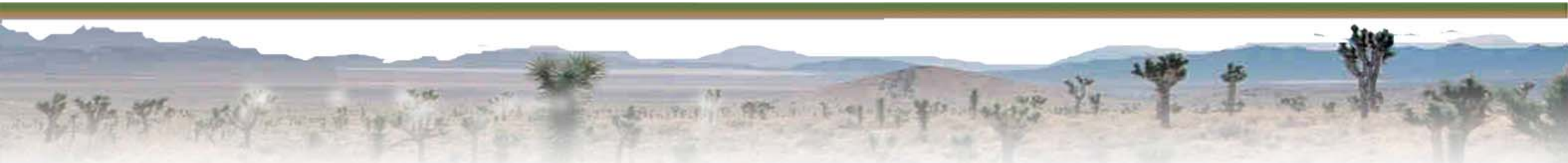
$^{226}\text{Ra} \;\; \alpha > \;\; ^{222}\text{Rn} \;\; \alpha > \;\; ^{218}\text{Po} \;\; \alpha > \;\; ^{214}\text{Pb} \;\; \beta > \;\; ^{214}\text{Bi}$

$^{214}\text{Bi} \;\; \beta > \;\; ^{214}\text{Po} \;\; \alpha > \;\; ^{210}\text{Pb} \;\; \beta > \;\; ^{210}\text{Bi} \;\; \beta > \;\; ^{210}\text{Po} \;\; \alpha > \;\; ^{206}\text{Pb}$

Not shown: 14 gamma emissions from ^{226}Ra, ^{214}Pb, & ^{214}Bi

Lookin' for a home…

- *Potassium*, *uranium* and *thorium* form large positive ions (cations). These "fat cats" require minerals with large crystal structure openings to fit into.
- Such minerals are most common in certain types of rocks "evolved" through processes in the Earth's crust. These rocks may have evolved by either the "distillation" of molten magma or "sifting" by 'sedimentation.



Granite

- The rock which commonly contains the highest radioactive element content is *granite*. Granite evolves by the concentration of light weight minerals from magmas generated deep within the crust. These “lightweights” are generally light in color and contain high concentrations of elements which do not fit into dense mineral structures.

Radioactivity in Granite

- ^{40}K is most commonly concentrated in *feldspars* (K-spar family) & *micas*, while uranium and thorium are incorporated in such accessory minerals as *zircon* & *sphene*.
- Radioactive minerals often leave tell-tale “baked” zones or “halos” in surrounding non-radioactive minerals.

Granite Rocks

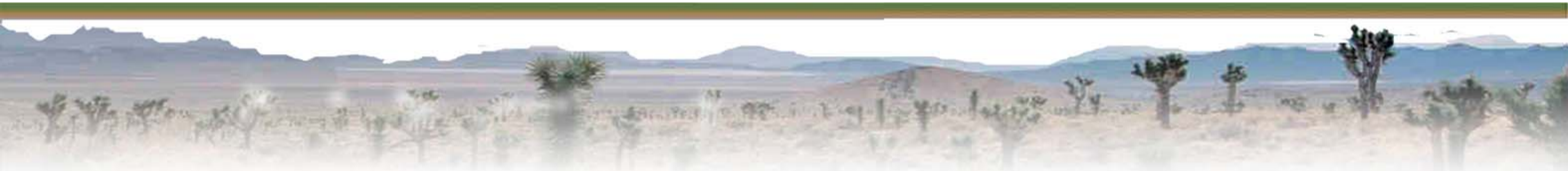
- Granite forms from the slow cooling of magma deep beneath the Earth's surface. If the magma erupts onto the surface, it forms either *rhyolite* lava flows or deposits of *ash fall* or *flow tuffs*. Erupted granitic rocks are very fine-grained, and often contain the radioactive elements distributed within very fine volcanic glass particles. Granite, rhyolite, and tuff all have similar radioactive element contents.

Pegmatite

- One type of granitic rock in which radioactive minerals are particularly common is the very coarse-grained variety known as *pegmatite*.
- Pegmatite usually contains rare earth element minerals as *monazite*, which host U & Th. In pegmatite, U & Th also sometimes form their own minerals, such as *uraninite* (UO_2) & *thorianite* ($ThSiO_4$).

Shale

- *Shale* is a sedimentary rock which evolves through the weathering of rocks by chemical decomposition & water transport, deposition, & compaction of mud. Most of the minerals in shale are *clay minerals*, which have large openings in their crystal structures. K, U, & Th fit well into clays & their cousins, the *zeolites*. K is also present in very small particles of mica & feldspar.



Sandstone and Conglomerate

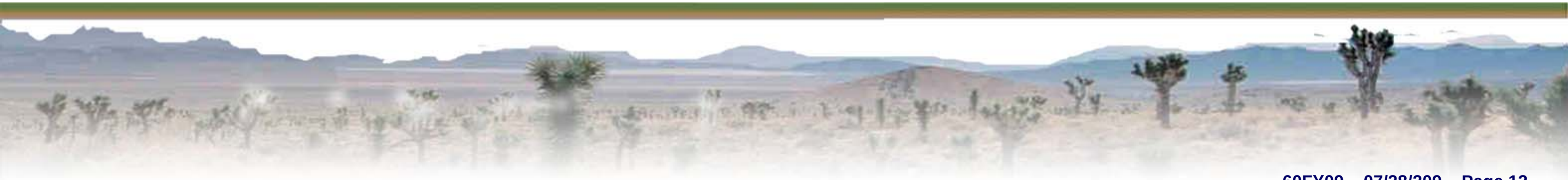
- *Sandstone* & *conglomerate* are sedimentary products of weathering, erosion, deposition & cementation, similar to shale. Unlike shale, they seldom have a high content of radioactive minerals when deposited. However, they are much more porous and permeable & often host U & Th minerals deposited by groundwater. Many major uranium mines are in sandstone and/or conglomerate.

Phosphorite and Coal

- *Bedded phosphate* or *phosphorite* deposits form when phosphorus from seawater is incorporated in the shells of tiny marine organisms as the calcium phosphate mineral *apatite*, and deposited as a biochemical sediment. Apatite hosts both U & Th in its structure. Likewise, the hydrocarbon compounds in coal may also host these elements. In some instances, both phosphate & coal contain enough uranium to be considered low-grade uranium ore deposits.

Metamorphic Rocks

- Metamorphic rocks are formed by the effects of great heat & pressure on pre-existing igneous (magmatic) or sedimentary rocks. Metamorphic rocks formed from rocks which already contain a high content of radioactive elements tend to retain that content.



Some Typical K, U, Th-Bearing Minerals

Mineral	Nominal Composition	Abundances[a] K	U	Th
Adularia	$KAlSi_3O_8$	14.0		
Allanite	$(Ca,Ce,Y,Th)_2(Al,Fe,Mg)_3Si_3O_{12}(OH)$		*	***
Alunite	$KAl_3(SO_4)_2(OH)_6$	9.4	–	–
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$	–	*	*
Apophyllite	$KCa_4(Si_8O_{20})(OH,F)\cdot 8H_2O$	4.1	–	–
Autunite	$Ca(UO_2)_2(PO_4)_2\cdot 10\text{-}12H_2O$	–	48-50	–
Baddeleyite	ZrO_2	–	**	**
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	8-9	–	–
Carnallite	$KMgCl_3\cdot 6H_2O$	14.1	–	–
Carnotite	$K_2(UO_2)_2(VO_4)_2\cdot 3H_2O$	7.2	53	–
Glauconite	$K(Fe,Mg,Al)_2(Si_4O_{10})(OH)_2$	4.6-6.2	–	–
Hornblende	$NaCa_2(Mg,Fe,Al,)_5(Si,Al)_8O_{22}(OH)_2$	***	–	–
Jarosite	$KFe_3(SO_4)_2(OH)_6$	7.8	–	–
Lepidolite	$KLi_2Al(Si_4O_{10})(OH)_2$	7.1-8.3	–	–
Leucite	$KAlSi_2O_6$	17.9	–	–
Microcline	$KAlSi_3O_8$	14.0	–	–
Monazite	$(Ce,La,Y,Th,)PO_4$	–	**	2-20
Muscovite	$K(Al)_2(AlSi_3O_{10})(OH)_2$	9.8	–	–
Nepheline	$(Na,K)AlSiO_4$	3-10	–	–
Orthoclase	$KAlSi_3O_8$	14.0	–	–
Phlogopite	$KMg_3(AlSi_3O_{10})(OH)_2$	9.4	–	–
Pitchblende	Massive UO_2	–	88	–
Polyhalite	$K_2Ca_2Mg(SO_4)_4\cdot 2H_2O$	13.0	–	–
Sanidine	$KAlSi_3O_8$	14.0	–	–
Sphene (Titanite)	$CaTiSiO_5$	–	*	*
Sylvite	KCl	52.4	–	–
Thorianite	ThO_2	–	–	88
Thorite	$ThSiO_4$	–	***	72
Torbernite	$Cu(UO_2)_2(PO_4)_2\cdot 8\text{-}12\ H_2O$	–	32-36	–
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2\cdot 5\text{-}8.5\ H_2O$	–	45-48	–
Uraninite	UO_2	–	88	–
Xenotime	YPO_4	–	***	**
Zircon	$ZrSiO_4$	–	**	**

Relative Original Occurrence of Radioactive Elements in Rocks

Common	**Occasional**	**Rare**
Granite	Andesite	Basalt
Shale	Conglomerate	Limestone
Bedded Phosphate	Sandstone	Bedded Gypsum/Salt
Coal	Slate>Gneiss	Quartzite
	Metaconglomerate	Marble

Radioactive Elements in Soils

- Radioactive minerals may occur either as residual or secondary deposits in soils.
- Residual deposits form because of the heavy weight of minerals bearing U & Th. Like gold, they tend to concentrate with coarse gravel in streams, and in black sands on beaches.

Radioactive Elements in Soils
(continued)

- Secondary deposits form due to the leaching of uranium from minerals during chemical weathering. Uranium is mobile in groundwater, but is readily precipitated by humic acids in soils. It may be found in carbonized plant or animal remains, and may also fill openings in porous soils.

U and Th Ore Deposits

- With the exception of some rare pegmatites, most ore deposits of U & Th are formed by weathering (leaching), transport, & deposition of these elements by groundwater. These deposits may occur as veins, pods, or blanket-like zones in a variety of host rocks, many of which originally contained little or no radioactive element content.