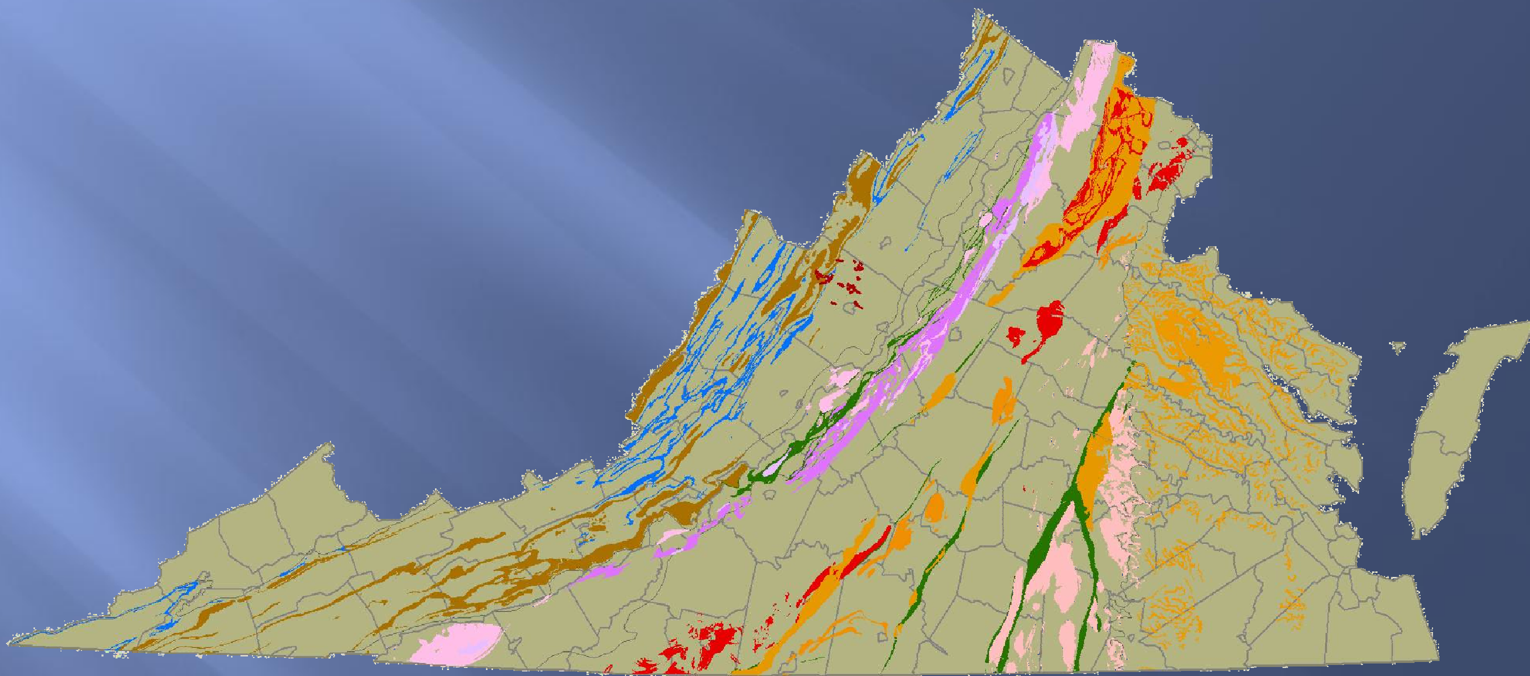
Geology of Uranium in Virginia



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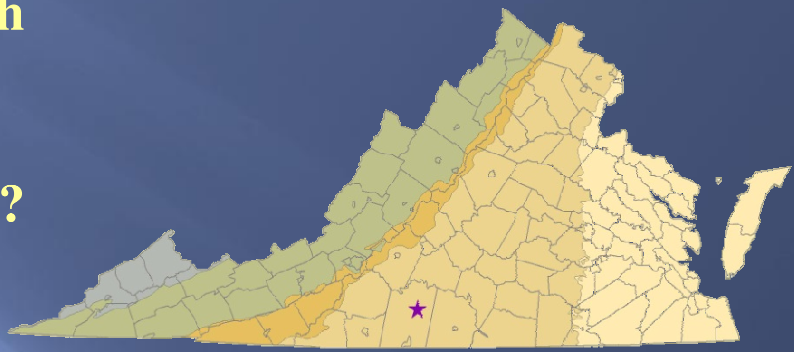
Renewed interest in uranium at Coles Hill raises many questions and concerns

What are the risks to public health and the environment?



A significant energy fuel resource?

Would mining bring positive economic impacts?

Where else in Virginia does uranium occur? Other deposits?

What is the natural variability in geologic materials?

Are there risks associated with natural U concentrations?

Styles of mineralization, exploration guides for economic deposits?

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VA DGMR is gathering data to help provide answers to these questions and concerns

1) U geochemistry and natural "background" concentrations in rocks

2) U and Th occurrences in Virginia

3) Comparable datasets (NURE)

4) Styles of economic mineralization

5) Regulatory challenges of U mining

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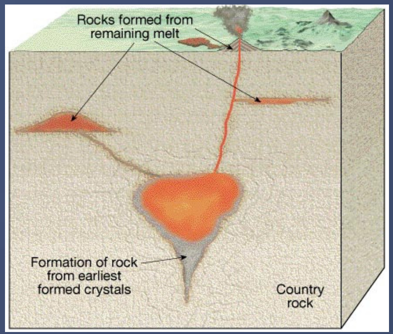
$^{238}U_{92}$

Naturally radioactive, dense, metallic element, large ionic size (U^{+4} = 1.05 A), lithophile, derived from mantle.

Under high temperature igneous processes (partial melting, fractional crystallization of magma), U tends to concentrate in late-magmatic K- and Si-rich differentiates.



Geochemically mobile under oxidizing conditions as uranyl ion $(U^{+6}O_2)^{2+}$.

Relatively immobile as U^{+4} under reducing conditions.

Sources: Faure (1986); Gabelman (1977); Rose, et al (1979); Rogers and Adams (1969)

The important uranium isotopes

Isotope	Natural Abundance (%)	Half-life (yrs)	Decay Energy (MeV/atom)	Stable Daughter
^{238}U	99.28	4.5 billion	47.5	^{206}Pb
^{235}U	0.71	710 million	45.2	^{207}Pb
^{234}U	0.006	244,500	*	intermediate

Sources: Faure (1986); Rogers and Adams (1969)

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World-Wide Average U and Th Content in Igneous, Metamorphic, and Sedimentary Rocks

Rock Type	U (ppm)	Th (ppm)	Th/U
Ultramafic	0.01	0.05	3.6
Basalt	0.4	1.6	4.0
Gabbro	0.8	3.8	4.7
Granite	4.8	21.5	4.5
Nepheline syenite	14	48	3.4
Granulite	1.6	7.2	4.5
Granitic gneiss	3.5	12.9	3.7
Sandstone	1.4	5.5	3.9
Shale (gray-green)	3.2	11.7	3.7
Carbonate	2.2	1.2	0.5
Shale (black carbonaceous)	8.0	1.7	0.2
Marine phosphorite	76		<1
Crustal rocks (avg)	2.5	10	4
Sea water	0.003	10^{-5}	0.0002

Sources: Rogers and Adams (1969); Gabelman, 1977; Rose, et al (1979); Woodmansee (1975)

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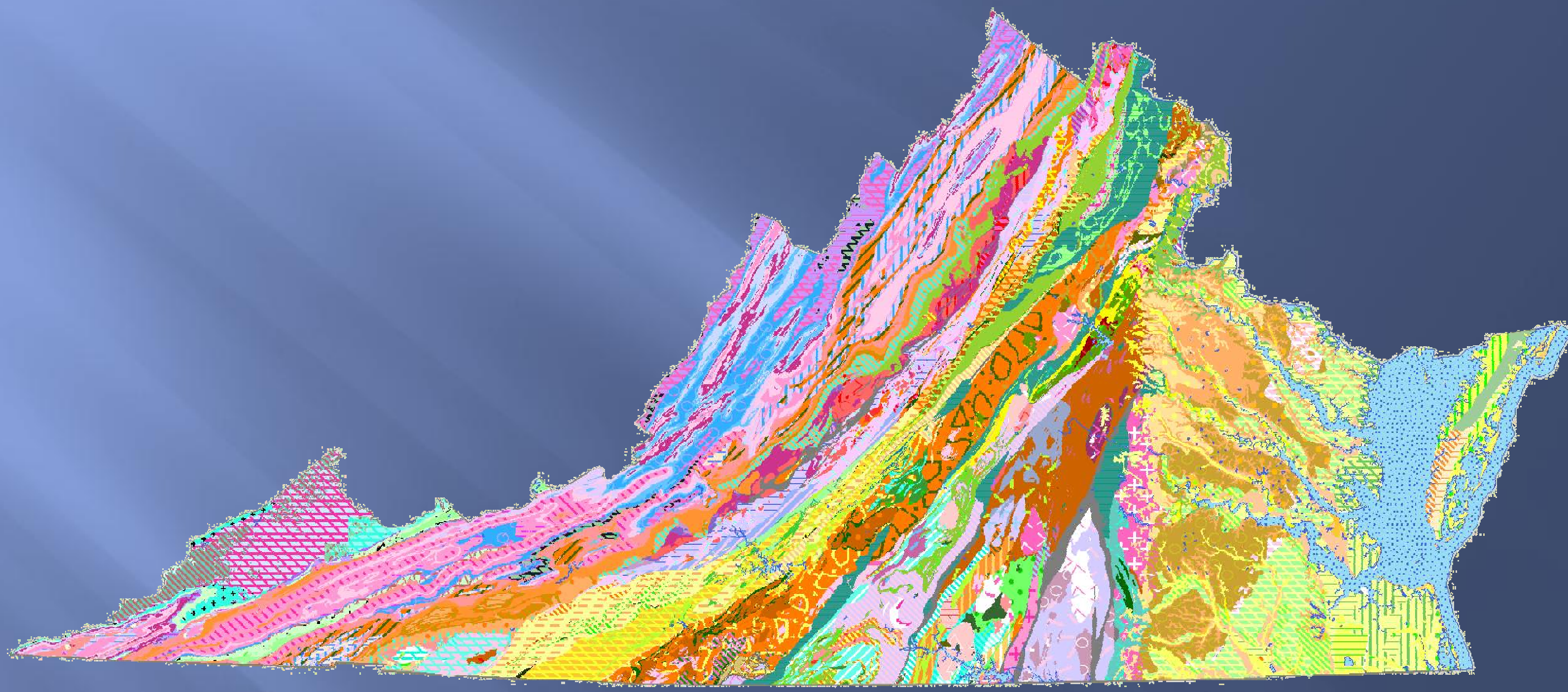
Geologic Map of Virginia



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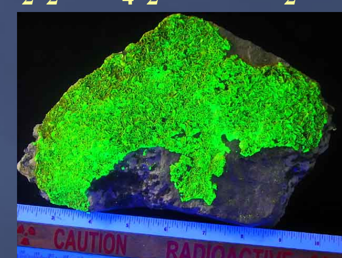
Identifying U-bearing rocks

Positive radiometric U signal (detection of Bi^{214} radioactive decay)

Identification of U-enriched minerals

Autunite $Ca(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$ (48% U)



Geochemical assays

U-enriched (95 ppm U) mylonite, Pittsylvania Co

Bedrock in Virginia
Naturally-Elevated Uranium Content

1) Middle - Late Proterozoic alkali-rich plutonic rocks
2) Devonian-Mississippian black shales and sandstones
3) Late Paleozoic pegmatites and late magmatic stage granitic rocks
4) Triassic-Jurassic sandstones/shales, contact metamorphic aureoles
5) Late Jurassic-Early Cretaceous alkalic intrusives
6) Marine phosphorites
7) Mylonite / shear / cataclasite zones

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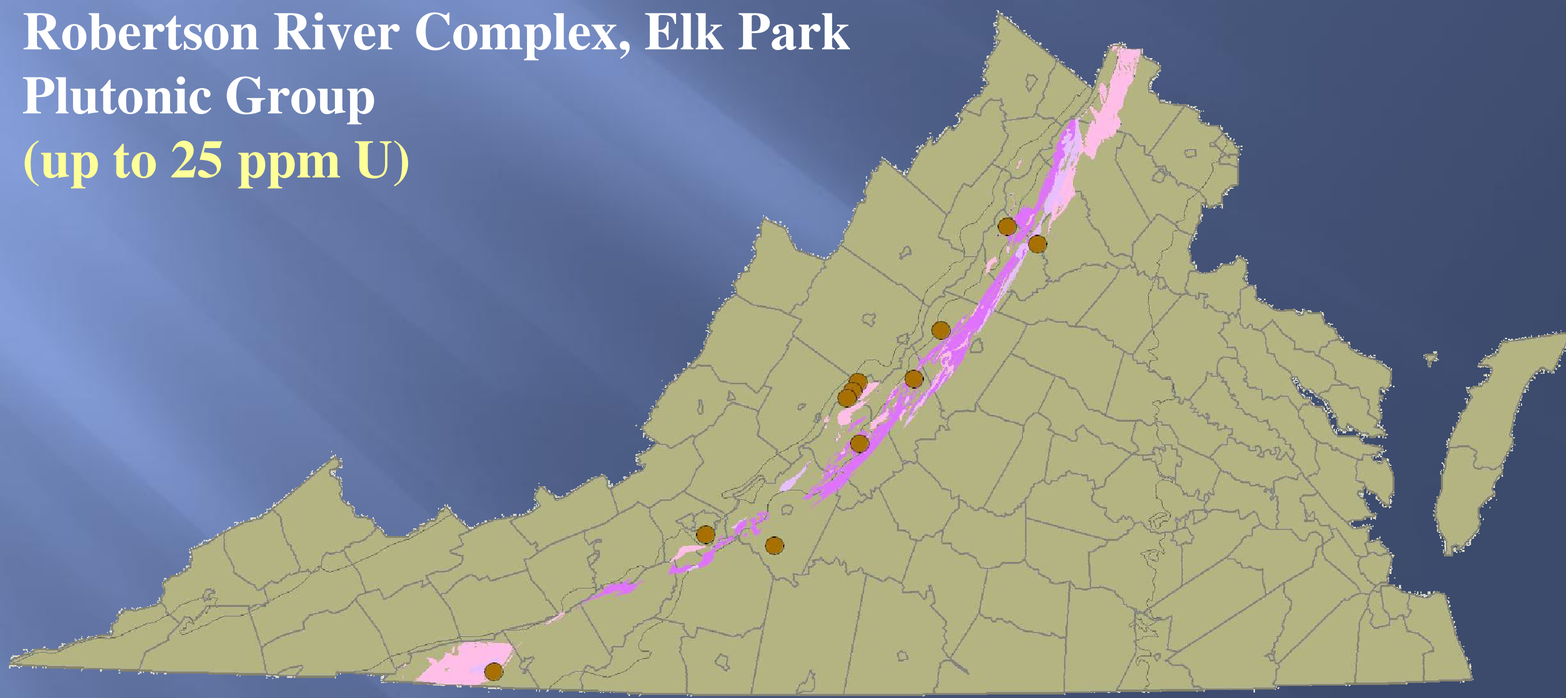
1. Proterozoic alkali-rich plutonic rocks

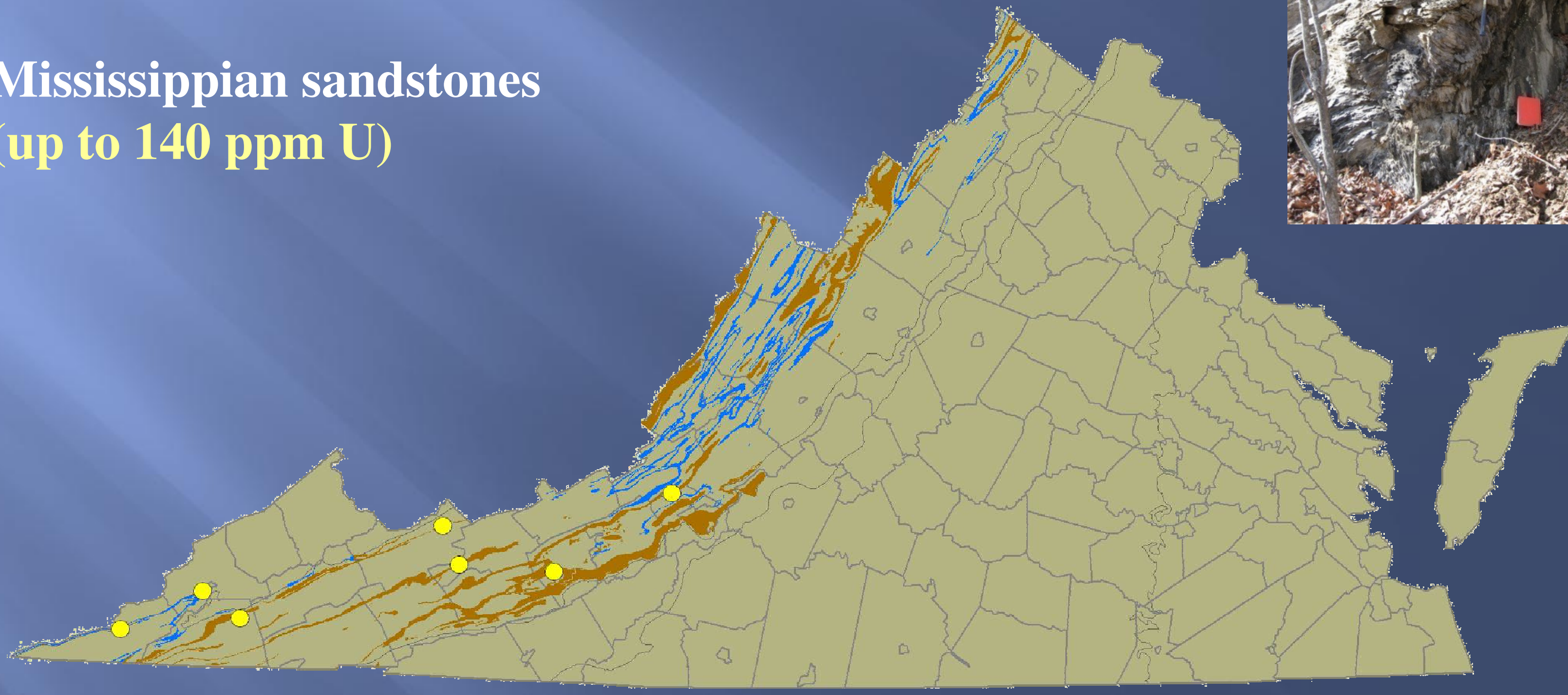
Middle - Late Proterozoic Plutons
Crozet, Old Rag, Marshall Granites, Robertson River Complex, Elk Park Plutonic Group
(up to 25 ppm U)



2. Devonian – Mississippian sedimentary rocks

Devonian – Mississippian black shales
(~70 ppm U)

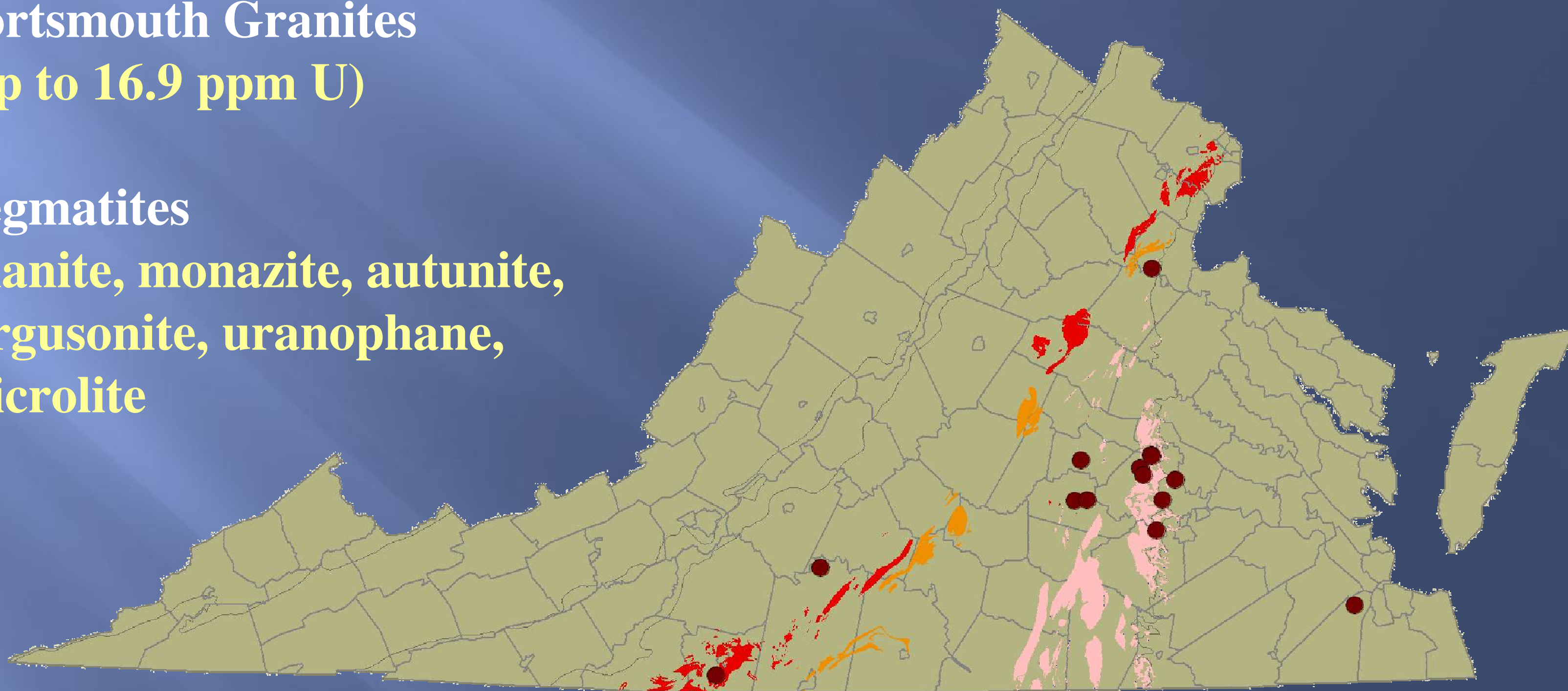
Mississippian sandstones
(up to 140 ppm U)



3. Paleozoic pegmatites and late-magmatic stage plutonic rocks

Paleozoic Plutons
Petersburg, Falls Run, Red Oak, Portsmouth Granites
(up to 16.9 ppm U)

Pegmatites
allanite, monazite, autunite, fergusonite, uranophane, microlite



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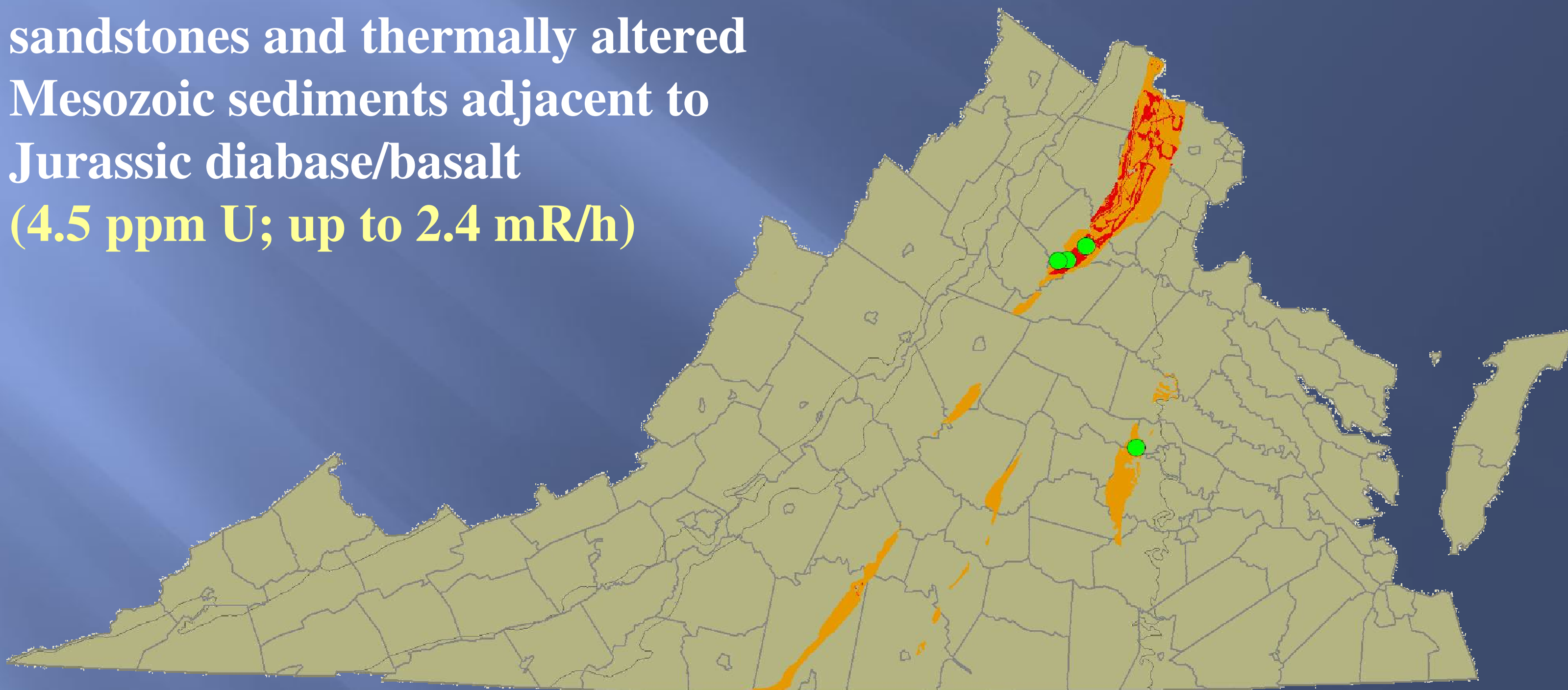
4. Triassic - Jurassic black shales and contact metamorphic zones

Carbonaceous black shales, sandstones and thermally altered Mesozoic sediments adjacent to Jurassic diabase/basalt
(4.5 ppm U; up to 2.4 mR/h)



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5. Mesozoic alkalic intrusive rocks

Nepheline syenite dikes in Augusta Co
(up to 22 ppm U)

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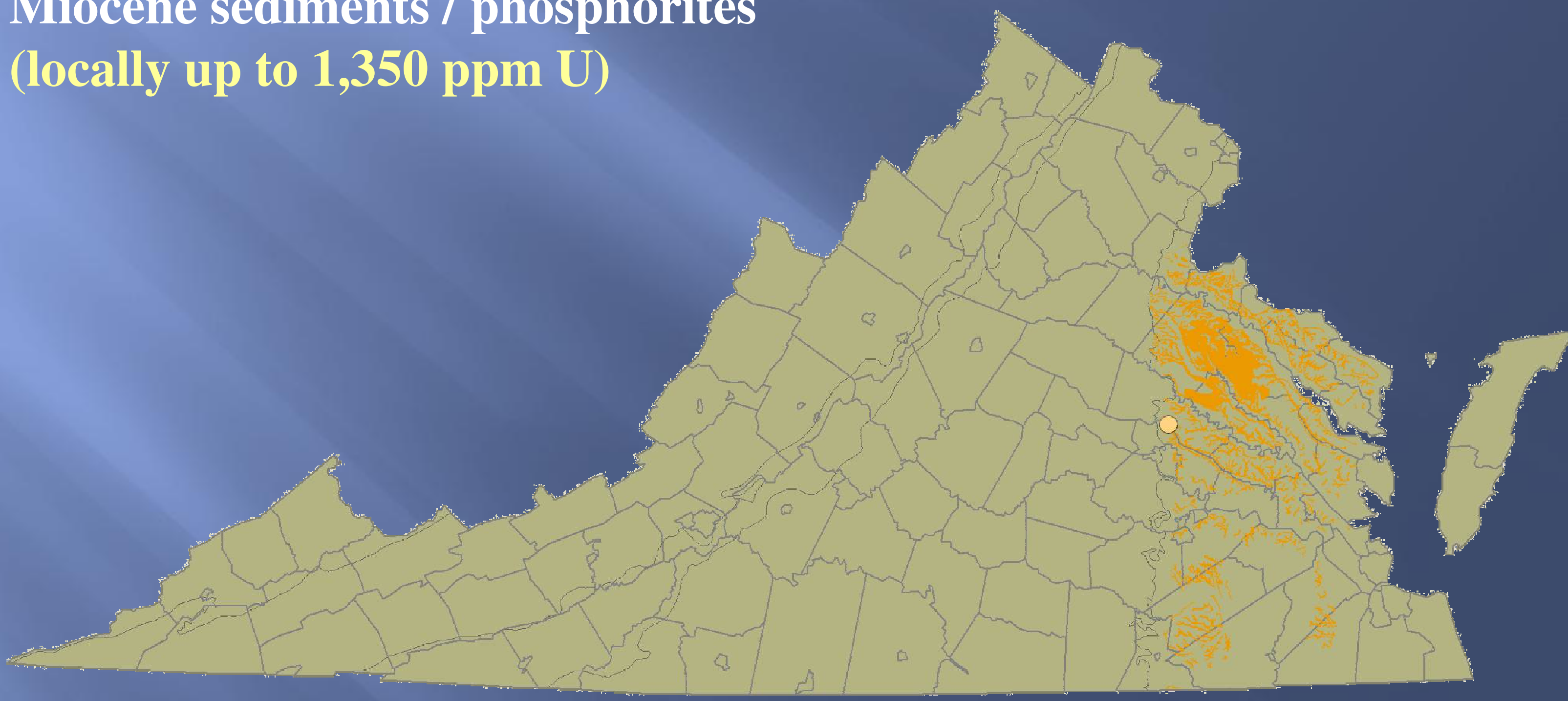
6. Tertiary marine phosphates

Miocene sediments / phosphorites
(locally up to 1,350 ppm U)



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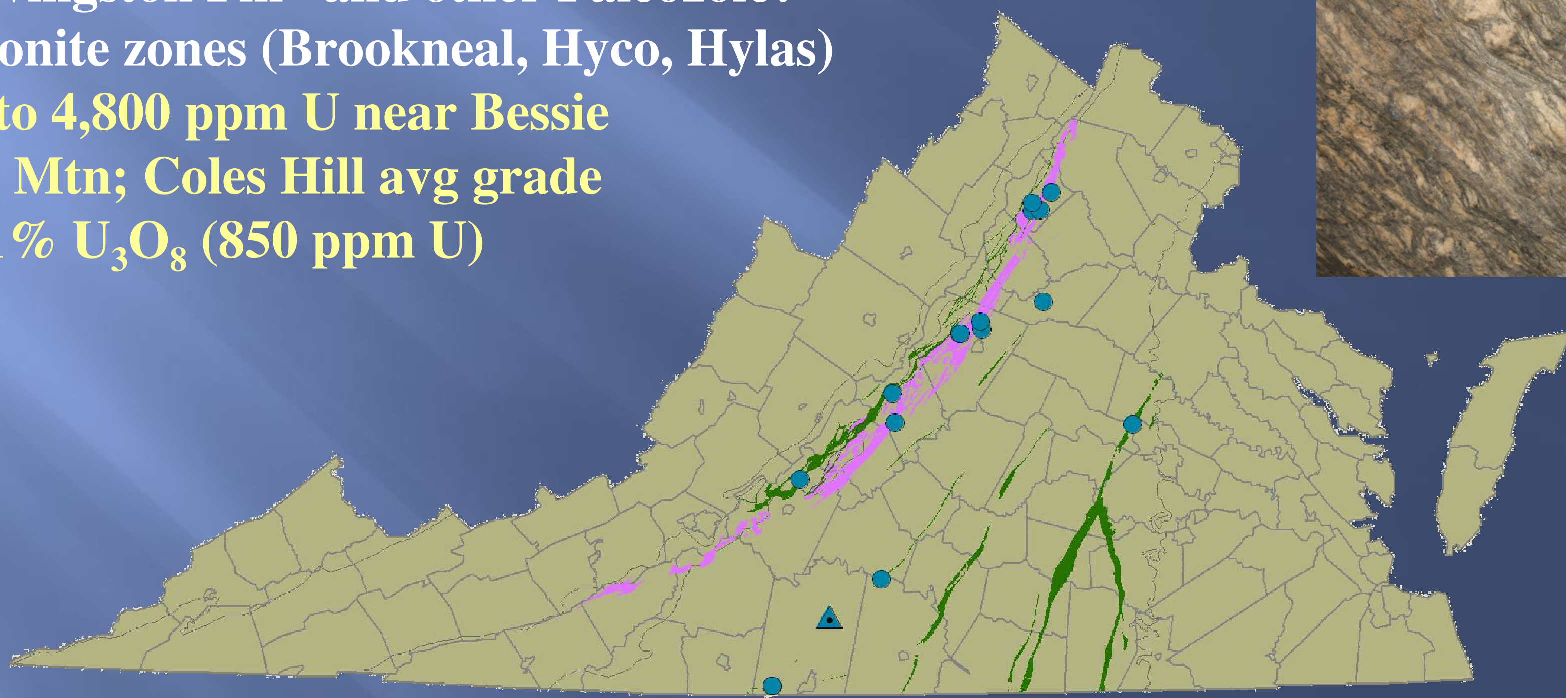
7. U- enriched mylonite, shears, and cataclasite

Shear-hosted veins in Proterozoic "Lovingston Fm" and other Paleozoic? mylonite zones (Brookneal, Hyco, Hylas)

Up to 4,800 ppm U near Bessie Bell Mtn; Coles Hill avg grade ~0.1% U_3O_8 (850 ppm U)



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7. U- enriched mylonite, shears, and cataclasite

Mylonitic Leatherwood granite,
Pittsylvania Co

Ore grade U enrichment,
Coles Hill, Pittsylvania Co

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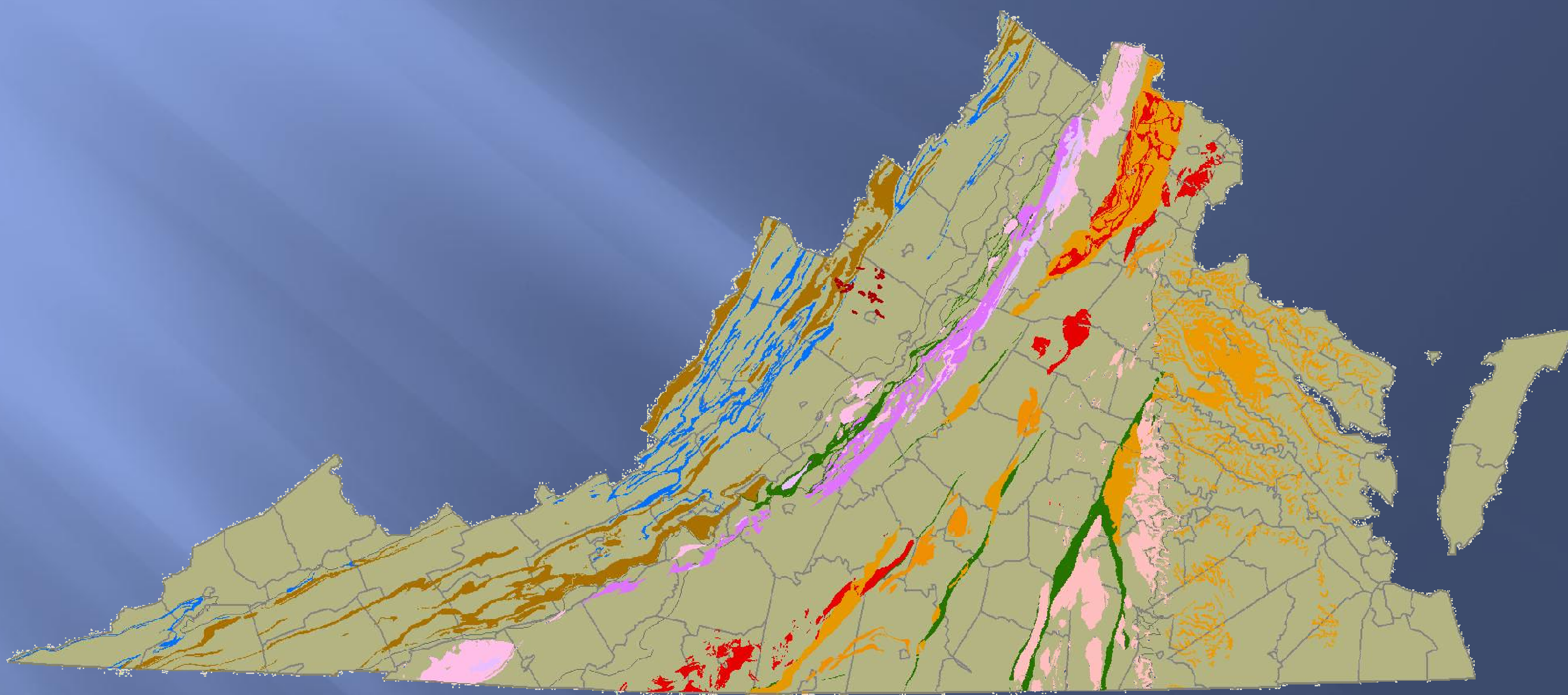
Bedrock in Virginia
Naturally-Elevated Uranium Content



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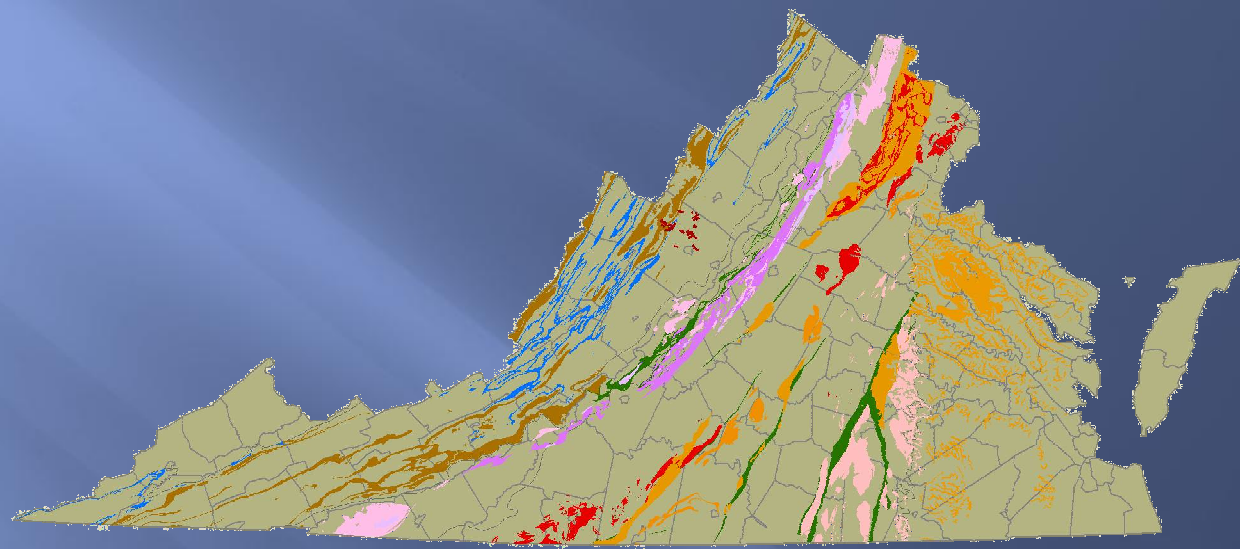
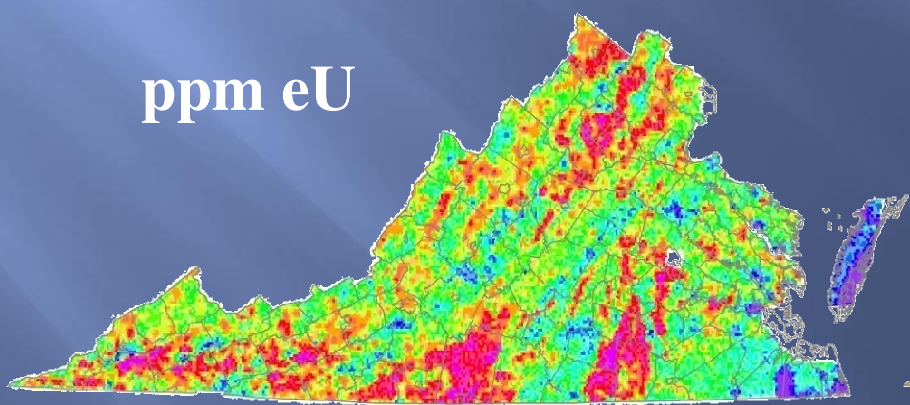
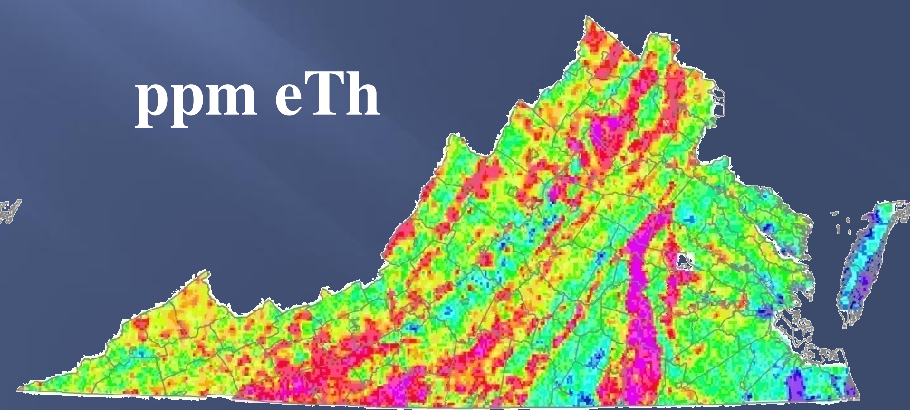
Bedrock distribution with naturally-elevated uranium compares well with NURE aeroradiometric data…



ppm eU

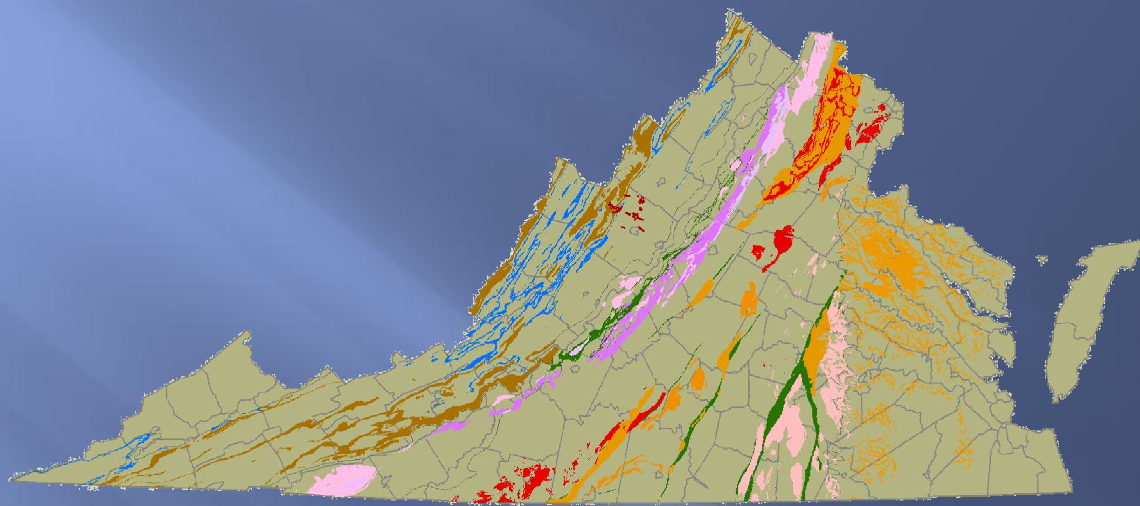


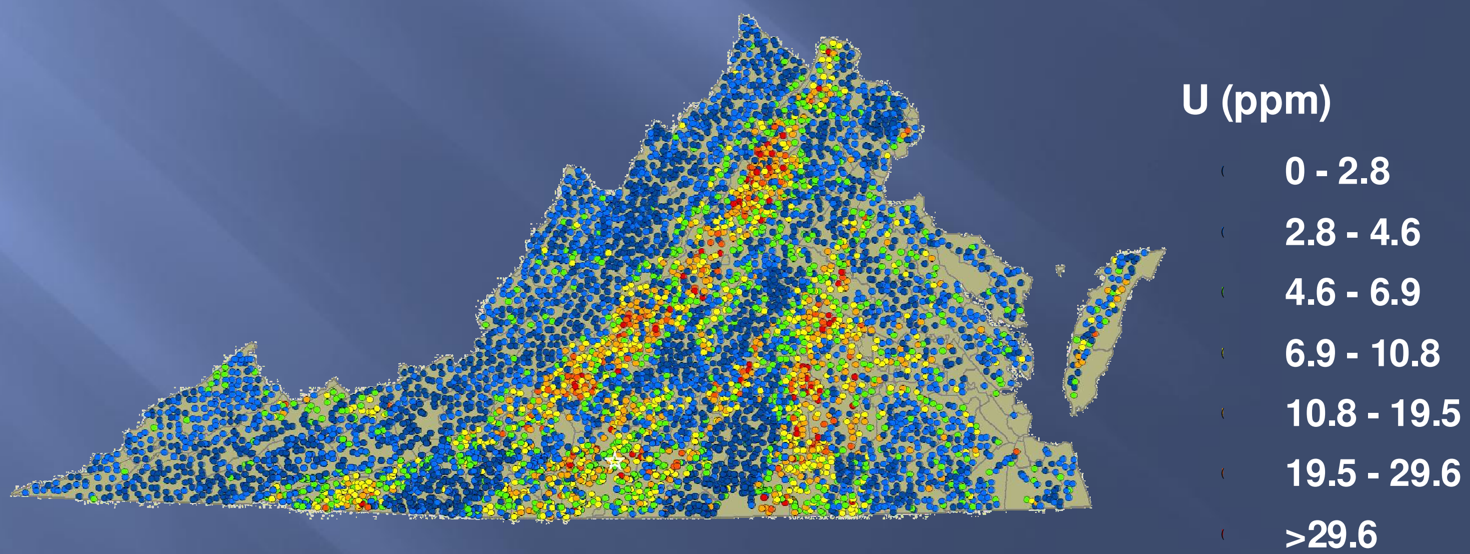
ppm eTh



Source: Kucks (2005) USGS OFR 2005-1413

…and NURE stream sediment geochemistry





Source: Modified from Grossman (1998) USGS OFR 98-622

Key Observations

To date, ~60 occurrences have been identified in published and unpublished reports, and on-going field investigations.

The occurrences highlight 7 geologic terranes that may have naturally-elevated background concentrations of U compared to world-wide averages for comparable rock types.

These bedrock units represent possible sources of U, having important implications for public health (e.g. radon), and locating economic deposits.

With the exception of Coles Hill, none of the occurrences identified to date are presently considered economic deposits due to low grade and/or limited extent.

New geologic models of U-mineralization have yet to be fully applied in VA, and the existence of other economic deposits remains uncertain.

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Styles of Uranium Mineralization

Deposit Type	Example	Typical (ppm U)
Unconformity-related	McArthur River,CAN	8,500 – 200,000
Sandstone-hosted	Smith Ranch, USA	400 – 4,000
Hematite breccia complex	Olympic Dam, AUST	300 – 500
Qtz pebble conglomerate	Witwatersrand, RSA	130 – 1,100
Vein (granite-related)	Shinkolobwe, DRC	250 – 8,500
Igneous rock-related	Rossing, NAM	60 – 300
Volcanic/caldera related	Streltsovsk caldera, RUS	400 – 40,000
Metasomatite	Espinharas, BRAZ	1,000 – 25,000
Surficial	Yeelirrie, AUST	<1,500
Collapse breccia pipe	Arizona Strip, USA	2,500 – 8,500
Marine phosphorite	Melovoe, KAZ	60 - 300
Metamorphic (contact)	Mary Kathleen, AUST	<850
Coal and lignite-related	Koldjat, KAZ	<50
Black shale hosted	Alum shale, SWED	50 - 400

Sources: IAEA (2009); British Geological Survey (2007); Rogers and others (1978)

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Regulatory challenges if uranium mining is allowed in Virginia

Mining of uranium presents unique challenges

Potential exposure to elevated radionuclides

Radon hazards (underground mine workers, mine ventilation outlets, emissions from waste rock and stockpiles)

Uranium chemical toxicity

Radionuclide transport in mine waters (e.g. radium)

Managing mine waste rock and ore stockpiles

Potential for release of airborne particulates

Long-term environmental monitoring

Bond release criteria, surety and long-term liability

A new statutory framework for uranium would be necessary

§45.1-283 of the Code of Virginia prohibits the acceptance of permit applications until a program for permitting uranium mining is established by statute.

Existing mineral mining statutes and regulations do not address the unique characteristics of uranium.

Uranium mining would require a comprehensive regulatory program that incorporates specific technical standards, best management practices, and key public input and transparency throughout the life cycle of mining.

Uranium Studies

- The Uranium Working Group (UWG) reviewed studies and past reports including:
- Common themes and recommendations were considered in the UWG Report

- National Academies
- Chmura
- Research Triangle Institute
- Virginia Beach
- Fairfax Water
- 1984 UTF
- Others

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Recent Studies - Common Themes

- Mine plans should be evaluated as part of a complete life cycle analysis.
- Permitting and licensing of the mine and mill should be coordinated, to the extent possible.
- Health and environmental concerns should be evaluated holistically.
- Opportunities for meaningful public involvement in the regulatory process should be provided.

Sources: NAS (2011)

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Recent Studies - Common Themes

- There should be transparency throughout the permitting, mining and reclamation phases.
- An environmental impact analysis prior to the commencement of mining activities is an internationally accepted best management practice.
- Engineering design standards must consider the possibility of extreme weather and climate events.

Sources: NAS (2011), Chmura (2011)

Recent Studies - Common Themes

- A comprehensive and effective community-engaged environmental monitoring program is necessary to assure compliance and foster transparency.
- Virginia's positive water balance conditions and implications for runoff from mine waste, tailings, ore stockpiles must be considered.
- Future impacts of mine dewatering on groundwater resources must be considered.

Sources: Chmura (2011), RTI (2011)

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Recent Studies - Common Themes

- Groundwater resources should be protected in accordance with Virginia's anti-degradation policy for groundwater.

- Thorough site characterization supplemented by predictive modeling would be necessary to evaluate the potential risks of environmental impacts.

- Waste rock and ore stockpiles must be managed effectively to prevent the release of radiological and non-radiological contaminants.

Sources: UTF (1984), RTI (2011), IAEA (2002)

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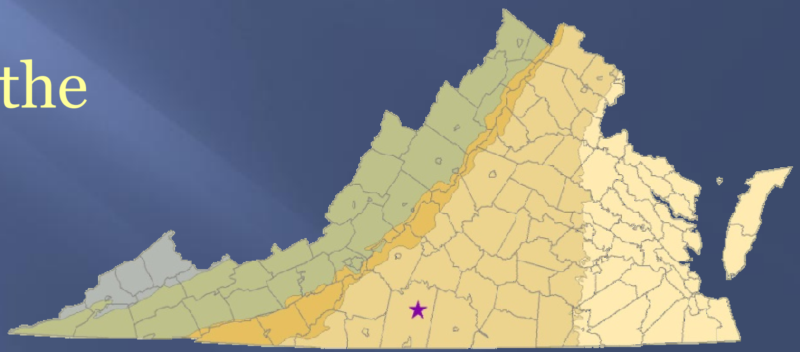
Conceptual Regulatory Framework for Uranium Mining

Framework for Statewide application considering all likely mining methods (surface, underground, in-situ recovery), with or without an associated mill.

The Coles Hill site is presently the only known uranium deposit of commercial interest.



A site-specific analysis ensures that all conditions that may be unique to this site are included in the statewide framework.

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Conceptual Regulatory Framework for Uranium Mining

Environmental Impact Analysis
Mine Permitting
Engineering Designs and Best Management Practices
Management of Mine Waste
Environmental Monitoring of Mine Sites
Compliance and Enforcement
Mine Site Reclamation
Long Term Monitoring
Financial Assurances

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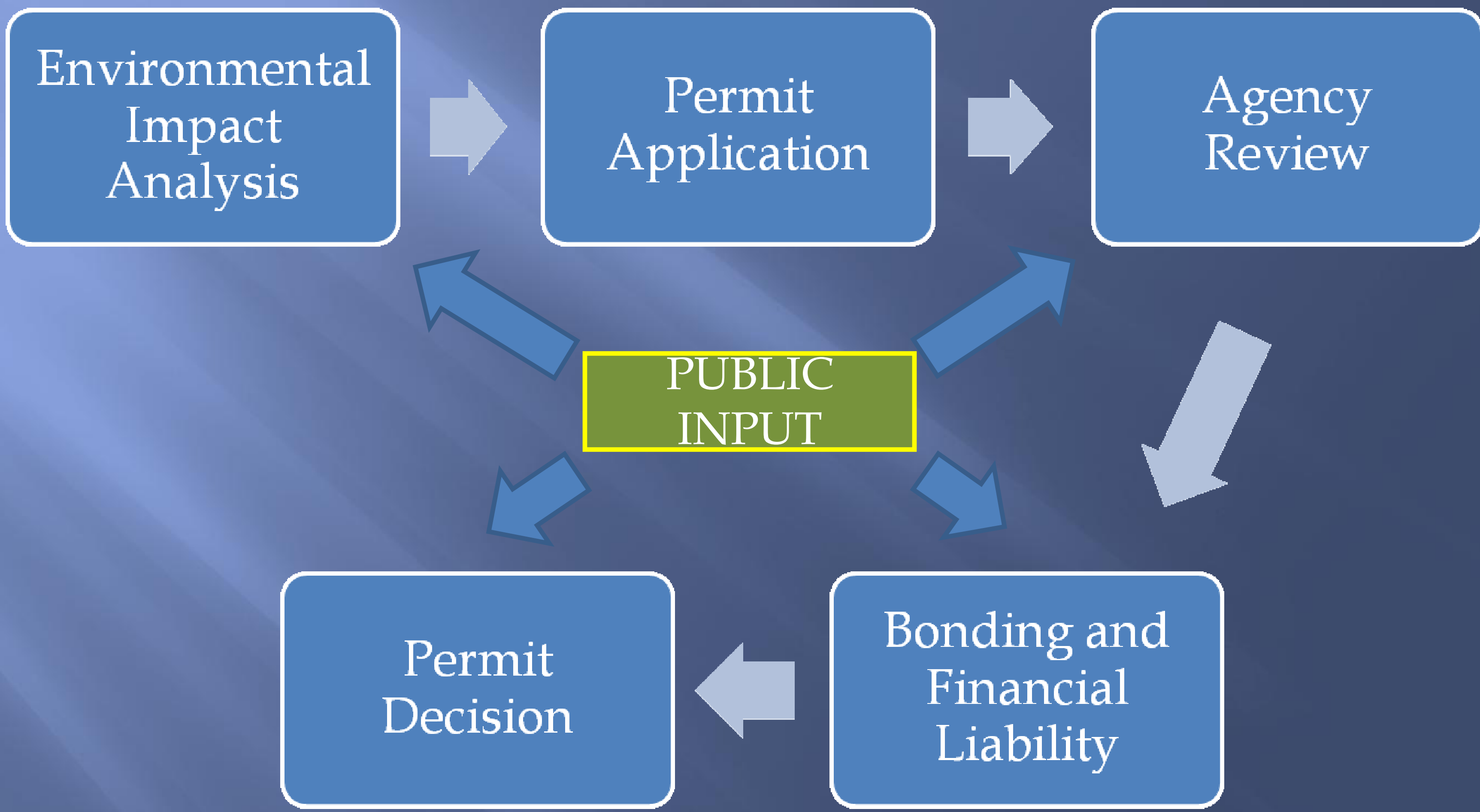
Permitting Process



Questions?

For more information:

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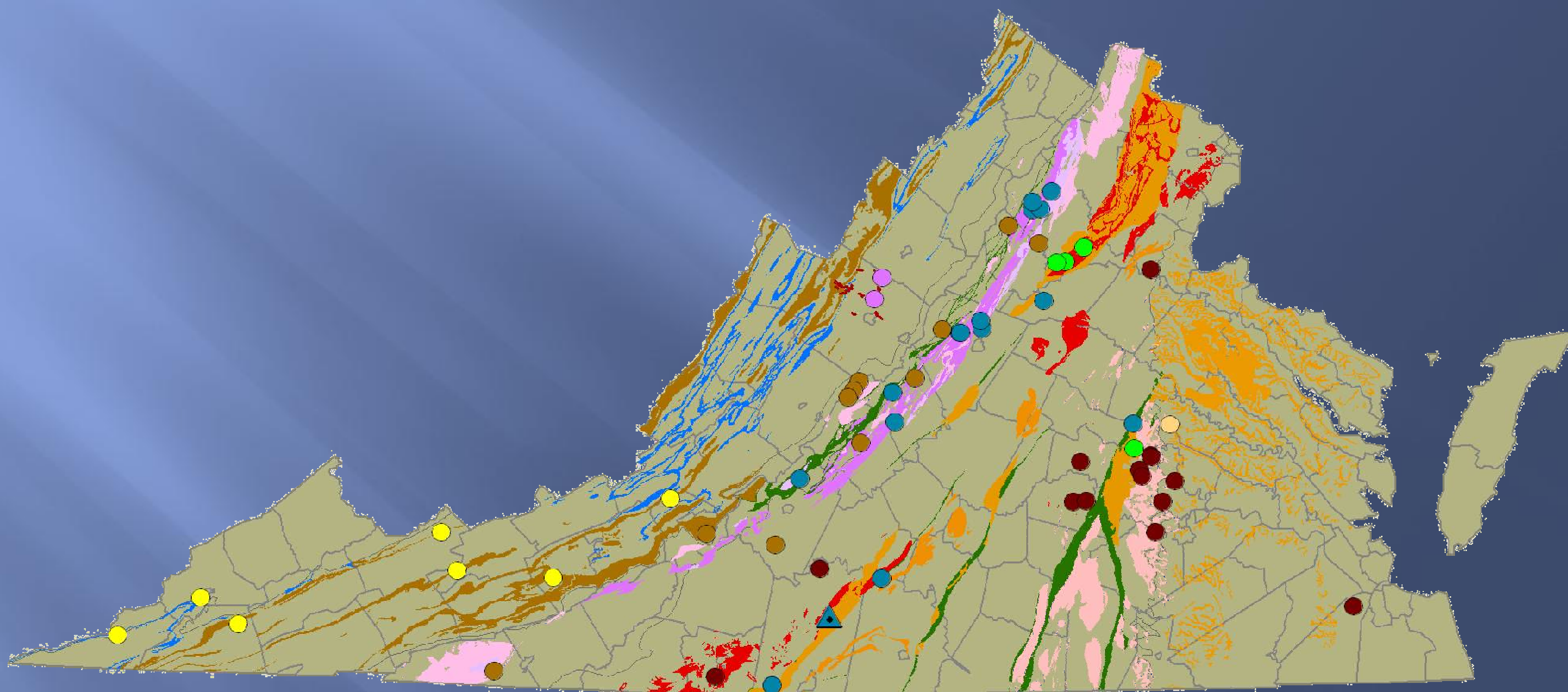
Bedrock in Virginia
with Uranium Occurrences



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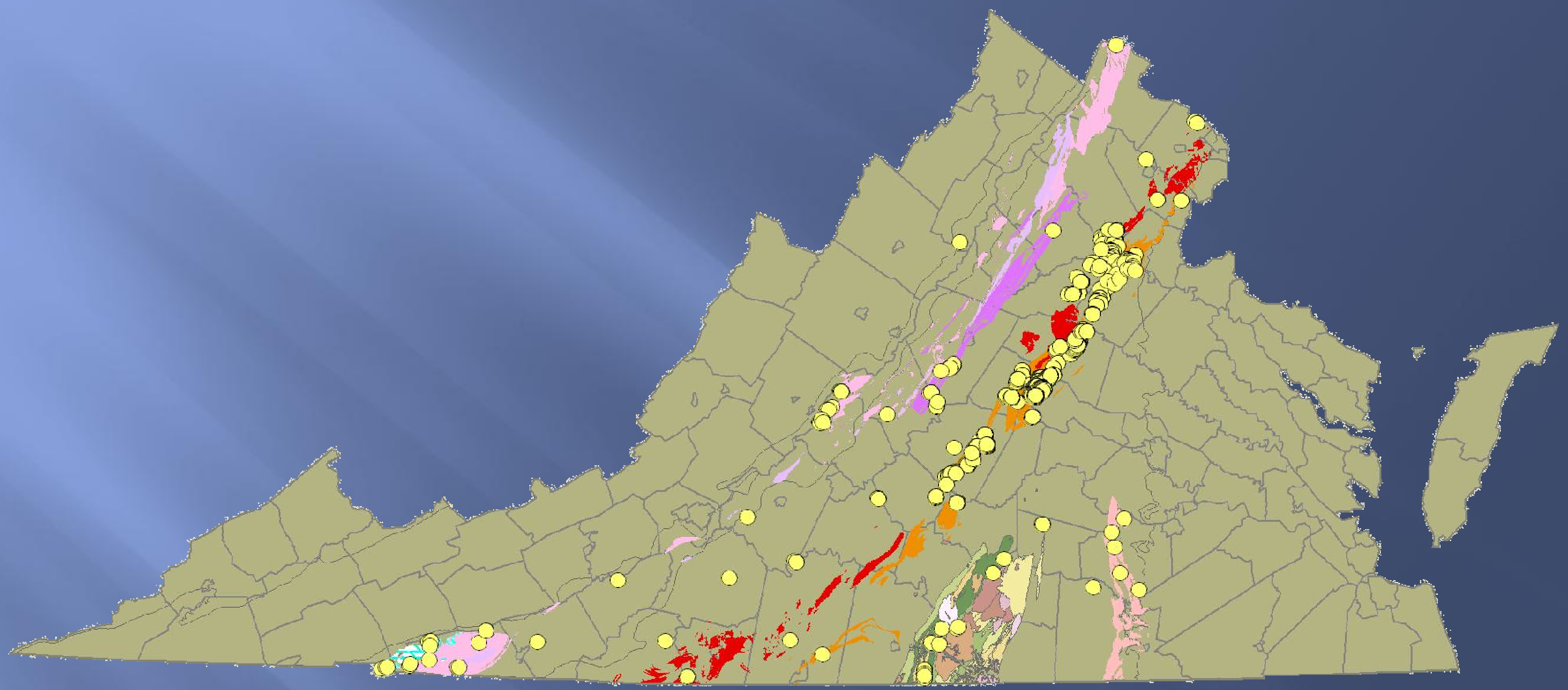
Gold Occurrences in Virginia



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