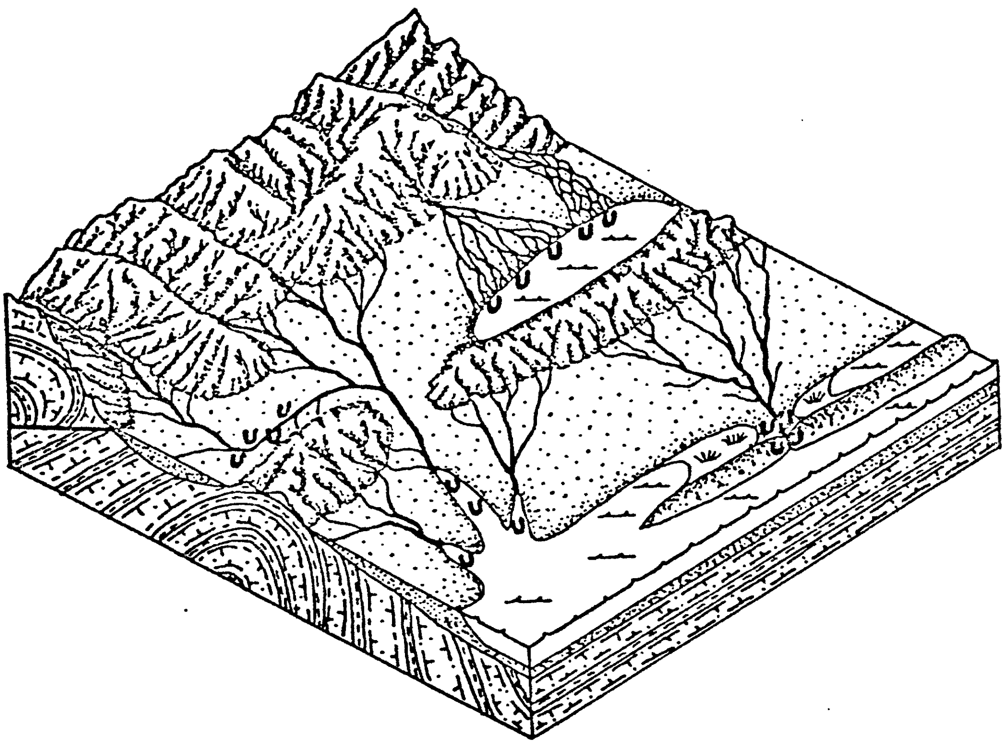
UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# URANIUM IN SEDIMENTARY ROCKS, WITH EMPHASIS ON FACIES CONTROL IN SANDSTONE-TYPE DEPOSITS



By

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This report is preliminary and has not been
edited or reviewed for conformity with U.S.
Geological Survey standards or nomenclature.

## INTRODUCTION

This paper is the text of a talk given at U. S. Geological Survey Branch of Uranium and Thorium Resources in-house seminars during February, 1978. A modified version of the talk was delivered at the Colorado Scientific Society in Golden, Colorado, on March 20, 1978. Slides from the talk are numbered in order of presentation, and selected slides are reproduced to illustrate important points. Names in parentheses indicate people who worked in specific areas and supplied the slides for those areas.

The main purpose of the talk is to demonstrate the importance of facies control of uranium deposits in sedimentary rocks. Non-marine and marginal marine examples from different regions and tectonic settings are discussed. The variety of settings in which uranium is facies controlled suggests that there are inherent features in the depositional environment that set the stage for uranium mineralization. In fluvial-lacustrine settings, as in the Salt Wash member of the Morrison Formation in Utah, and in the Newark Group in Pennsylvania and New Jersey, offshore lacustrine primary grey mudstones are important. The one-to-one relationship between primary grey mudstones and uranium in nearby sandstone beds in both of these areas suggests that the grey mudstones were the source of humic acids that fixed uranium in the nearby sandstones (Peterson, 1977; Turner-Peterson, 1977).

# URANIUM IN SEDIMENTARY ROCKS

Christine Turner-Peterson
and
Fred Peterson

Slide

1. Uranium reserves in the U.S.: 96.8% in sandstone. Other sedimentary hosts include: shale, lignite, limestone, calcrete, and phosphorite. Also PЄ conglomerate.

2. World map showing major sandstone uranium deposits.

3. Source of uranium: granites, acidic tuffs, other.

4. Transportation of $U^{+6}$ in groundwater as uranyl dicarbonate.

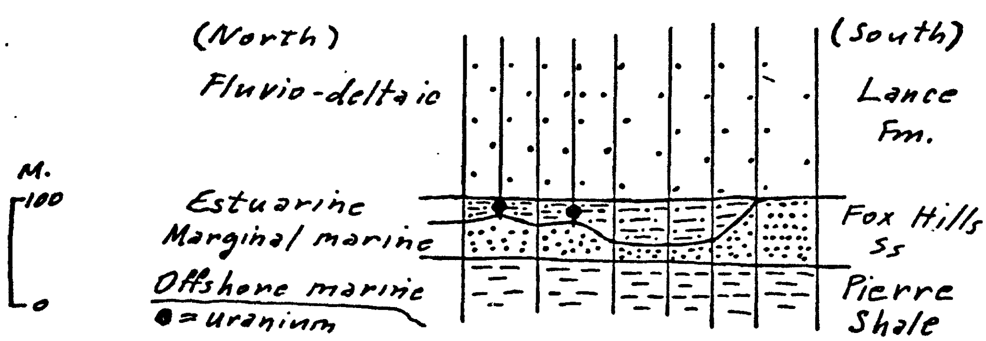
5. Trap for uranium?

6. Conventional ore guides in sandstone: Rocks Devonian & younger (land plants)
   acidic igneous source terrain
   continental rocks/marginal marine
   fluvial channel sandstone
   carbonaceous trash
   SS/Sh 50:50
   pyrite
   alteration

7. Photo of Cretaceous Straight Cliffs Formation, Utah, typical of Cretaceous of the Western Interior. By conventional ore guides listed in slide #6, the fluvial rocks of the Cretaceous of the Western Interior should be favorable for uranium mineralization, but are barren instead. The problem is that the conventional ore guides are associations but not controls. Although it is true that these features are generally associated with uranium, the converse is not true: many rocks that fulfill all of these criteria (K of West. Int.) contain no uranium. Therefore, we need to look for actual controls of uranium mineralization rather than associations. The rest of the talk will emphasize facies control, which is an ore guide, and is one that enables us to eliminate areas that might otherwise appear favorable by conventional criteria.

8. Index map showing location of strat-sections & isopach map, Lance/Fox Hills section, Wyoming, (Harry Dodge and Chuck Spencer).

9. Strat-section of K section near Moorcroft, Wyoming. Uranium is in estuarine rocks of the Upper Fox Hills.

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10. Isopach map of Fox Hills Sandstone: scouring causes thinning of marginal marine sandstones of the Lower Fox Hills SS. The scoured areas are filled in by estuarine deposits of the Upper Fox Hills. The estuary pattern shows up nicely in the isopach map.

11. Same as slide #9. Next sequence of cores taken through the section from offshore marine Pierre Shale, upwards through marginal marine sandstones of the Lower Fox Hills, estuarine deposits of the Upper Fox Hills, and fluvial rocks in the Lance.

12. Photo of core containing bioturbated offshore marine mudstones of the Pierre Shale.

13. Photo of core containing marginal marine sandstones of the Lower Fox Hills SS.

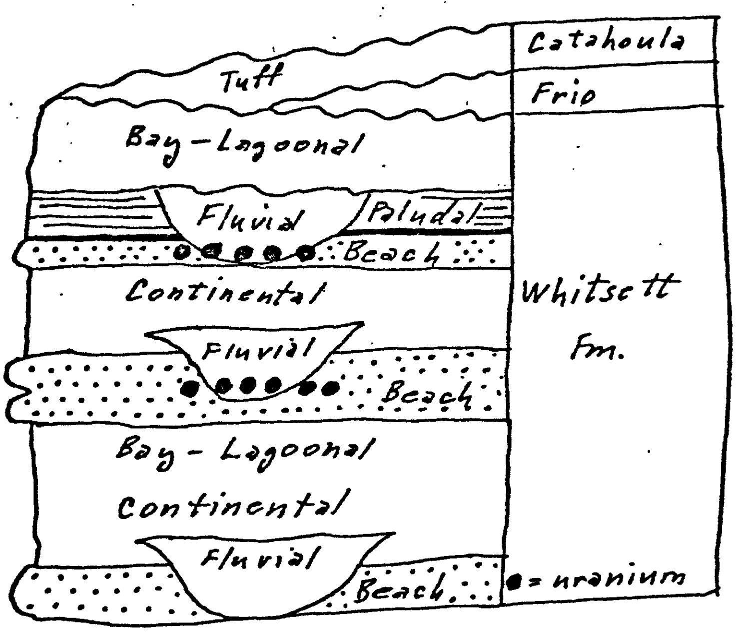
14. Photo of cores containing fine-grained estuarine deposits of the Upper Fox Hills. Dark laminae in the core are rich in carbon; uranium associated with these estuarine deposits.

15. Photo of fluvial sandstones in the Lance Formation.

16. Same as slide #9. The uranium occurs in estuarine deposits in the Upper Fox Hills and therefore is facies controlled.

17. Index map of Tertiary rocks along the south coast of Texas (Ken Dickinson).

18. Schemmatic diagram of Late Eocene units in South Texas. Uranium is associated with distributary channels that cut into beach deposits, and in the barrier beach units as well. Associated sedimentary rocks include paludal and lagoonal units, and some coal.




19. Photo of roll front, Felder Mine, South Texas.

20. Photo of open pit mine in South Texas; lignite at the base, lagoonal deposits in the middle, and the fluvial Catahoula Tuff at the top.

21. Same as slide #18. In summary, uranium in South Texas is in a zone of transition from non-marine to marine rocks.

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22. Wyoming basins and ranges. Important locations for the following discussion include the Powder River Basin, the Wind River Basin, and the uranium districts such as Gas Hills, Crooks Gap, and Shirley Basin. (Dave Seeland) Formations include the Wind River Fm. in the Wind River Basin, and the Wasatch-Fort Union in the Powder River Basin.

23. Map showing moving average crossbedding azimuths for Tertiary units in the Powder River Basin; made from a vector mean map (not shown here).

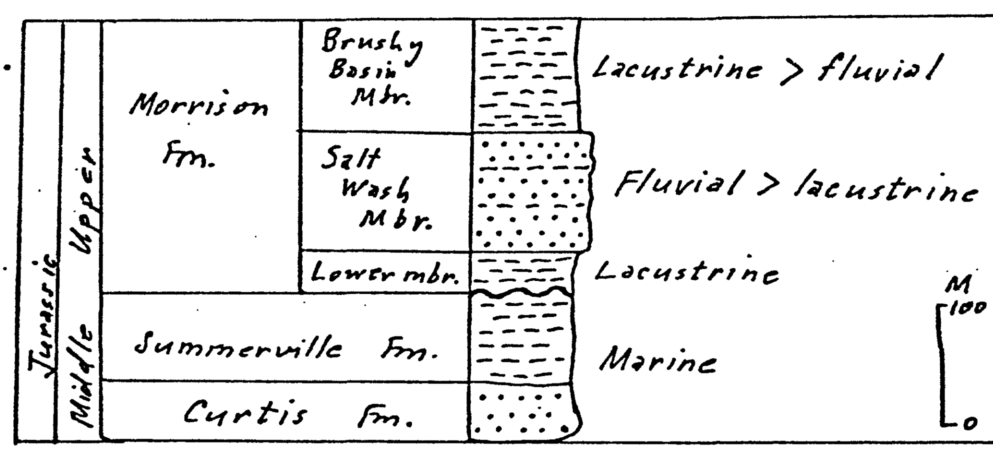
24. Interpretive map of drainage in the Powder River..

25. Contour map of "sand grain regularity" (Area/perimeter$^2$) in Powder River Basin, measured by using the Automatic Image Analyzer. Contours are normal to lines of paleodrainage determined by crossbed measurements. Would therefore be useful in determining paleocurrent directions in the subsurface, where crossbeds cannot not be measured.

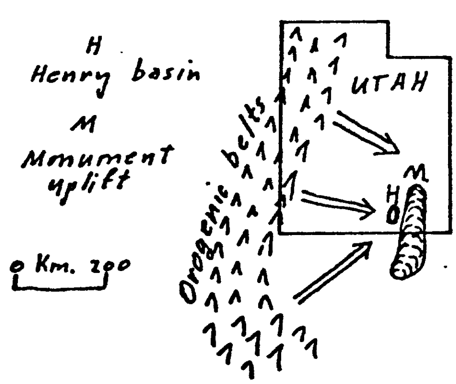
26. Map showing deflection of paleostreams by anticlines that were active at the time of deposition in the Wind River Basin. Illustrates tectonic control of sedimentation. Ponding occurred on the upstream side of the structures and uranium is associated with the areas of ponding associated with stream diversion.

27. Uranium districts in areas surrounding the Granite Mountains. Small anticlines and hogbacks diverted streams. In each district (Gas Hills, Crooks Gap, Shirley Basin) uranium is associated with areas of ponding that are located on the upstream side of structures that were active during sedimentation and caused stream deflection.

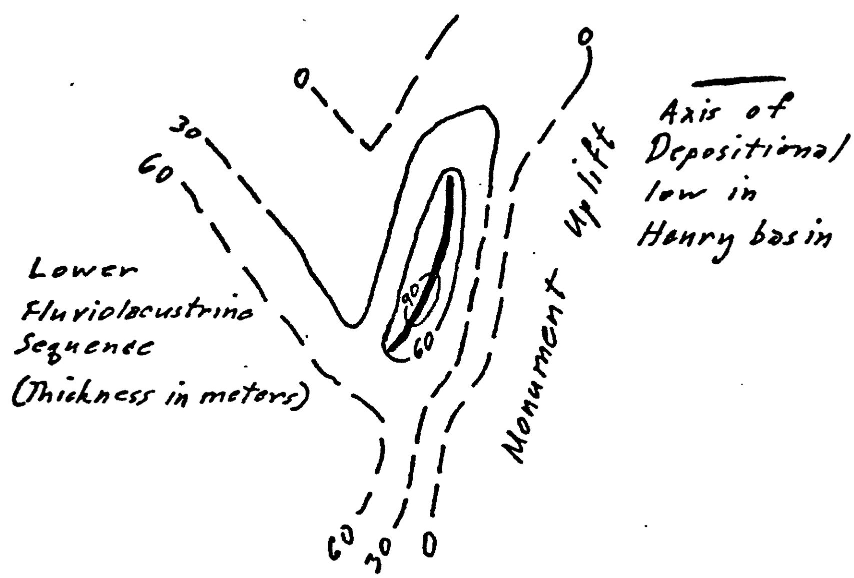
28. Columnar section of Middle & Upper Jurassic rocks in Utah. Salt Wash mbr. of the Morrison Fm. contains several fluvio-lacustrine sequences that contain uranium. (Fred Peterson).



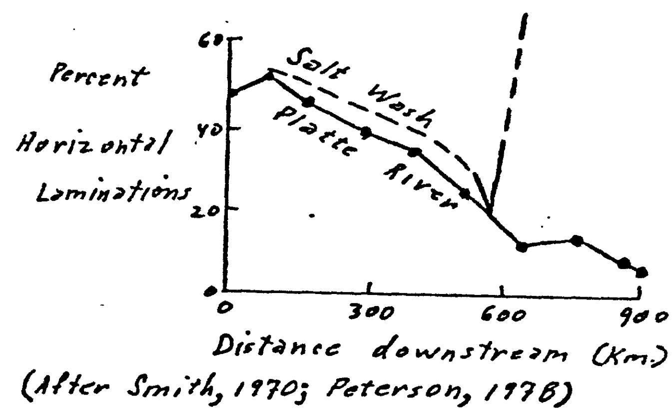

29. Tectonic setting: Monument Upwarp caused ponding of sediments being carried by streams from the west (similar to what Dave Seeland documented in the Tertiary of Wyoming, above). In the structural low on the upstream side of the Upwarp, lacustrine sediments were deposited.



30. Isopach of lower fluviolacustrine sequence showing the depositional low west of (upstream of) the Monument Upwarp.

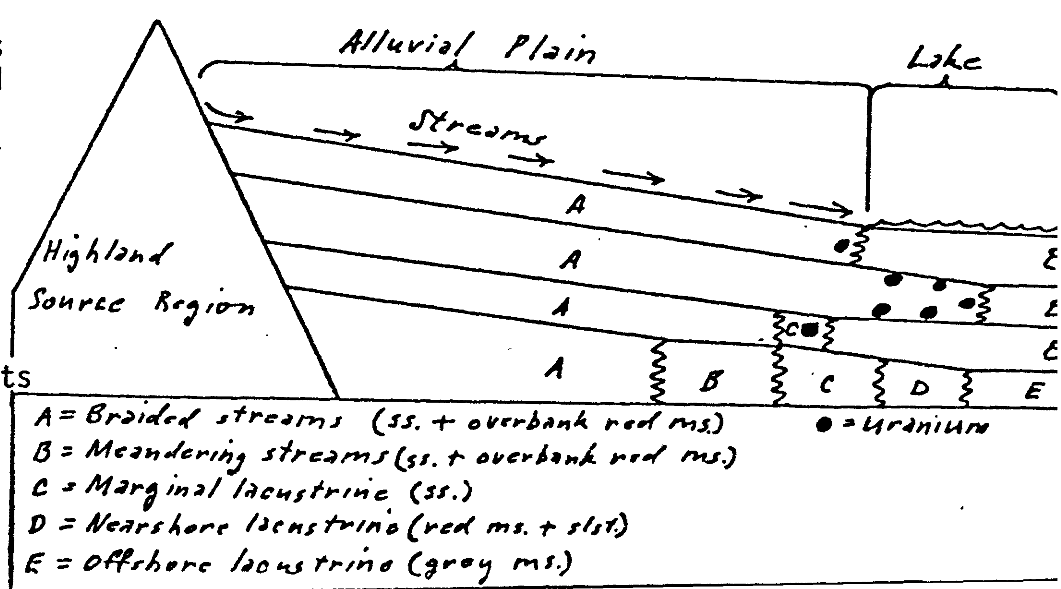



31. Sediments deposited in the depositional low have a greater amount of horizontal bedding in the sandstone units. In fluvial rocks, horizontal bedding reflects high energy & typifies proximal (upstream) sedimentation. % horizontal laminations in the Salt Wash is plotted against distance downstream & is compared with the Platte River. 3 possible explanations include: 1)steepening of gradient-ruled out because of low energy lacustrine mudstones associated with the horizontally-laminated sandstones; 2) one is going upstream- ruled out because it's downslope from west to east; 3) the flat bedding can be attributed to reworking in a lacustrine environment-this explanation makes the most sense.

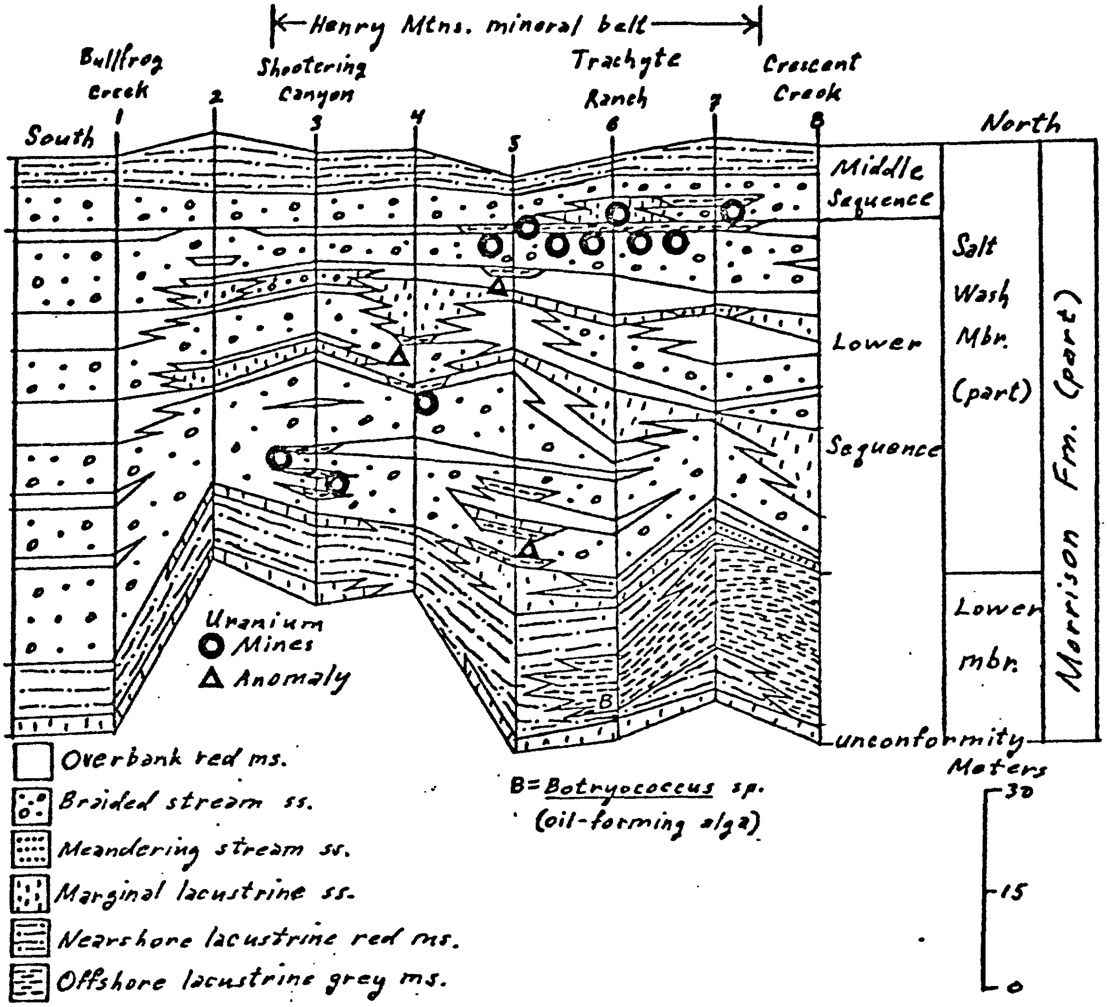



32. Photo of adit in interbedded marginal lacustrine sandstones and offshore lacustrine grey mudstones, Salt Wash mbr. of the Morrison Fm., Henry Mountains, Utah.

33. Facies & U in Salt Wash. A 1:1 correlation between U and grey mudstones. U is in braided stream SS's and marginal lacustrine SS's, but only where they interbed directly with the offshore lacustrine grey ms. Where intervening facies are present (meandering streamSS-- nearshore lacustrine red ms), there is no mineralization. Suggests a key role for the grey offshore lacustrine mudstones.



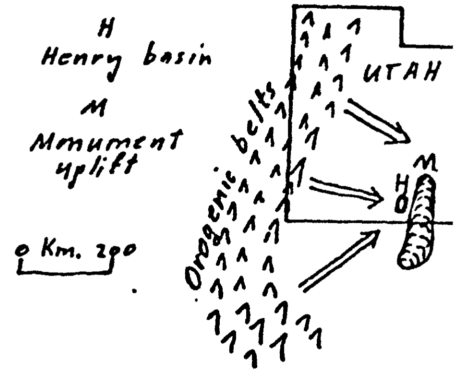
34.




Cross-section of the Henry Mountains Mineral Belt, showing facies control of uranium. Uranium is in the braided stream sandstones, or marginal lacustrine sandstones,where these sandstones are overlain by, underlain by, or lateral to offshore lacustrine grey mudstones. Uranium is not present in meandering stream deposits. The offshore lacustrine grey mudstones associated with uranium deposits yielded a varied suite of spores and pollen, and contain minute (less than .5mm) carbonized wood fragments indicating that the mudstone was originally reduced. These mudstones could have yielded humic acids which are capable of fixing uranium and would account for the 1:1 correlation between the uranium and the offshore lacustrine grey mudstones. Humic acids lost upon compaction of the mudstones fixed uranium in the nearby sandstones (braided stream or marginal lacustrine sandstones). Uranium was delivered by normal ground water.

The thick grey mudstone in the lower member, in the lower right of the diagram above, contains Botryococcus , an oil-forming alga, which would make it more like an oil shale than the humic-acid producing mudstone needed for uranium mineralization. Only grey mudstones that could have produced humic acids are favorable for uranium mineralization. This eliminates both oil-shale type mudstones as well as grey mudstones that are grey because of bleaching of primary red mudstones.

35. Same as slide #29: uranium is facies controlled in the Salt Wash mbr. of the Morrison Fm. in the Henry Mtn. mineral belt. Lacustrine sedimentation occurred because of ponding behind the Monument Upwarp. A similar situation is inferred for the Uravan Mineral Belt, which is east of this area. Ponding in the Uravan area may have occurred on the west (upstream) side of the Uncompaghre Uplift. Fischer (1974) noted that in the eastern part of the Uravan area, the beds become more flat-bedded,"as if they were deposited in standing water".




36. Index map of Triassic-Jurassic basins in the eastern United States, particularly the Newark basin, Pa.-N.J. (Christine Turner-Peterson).

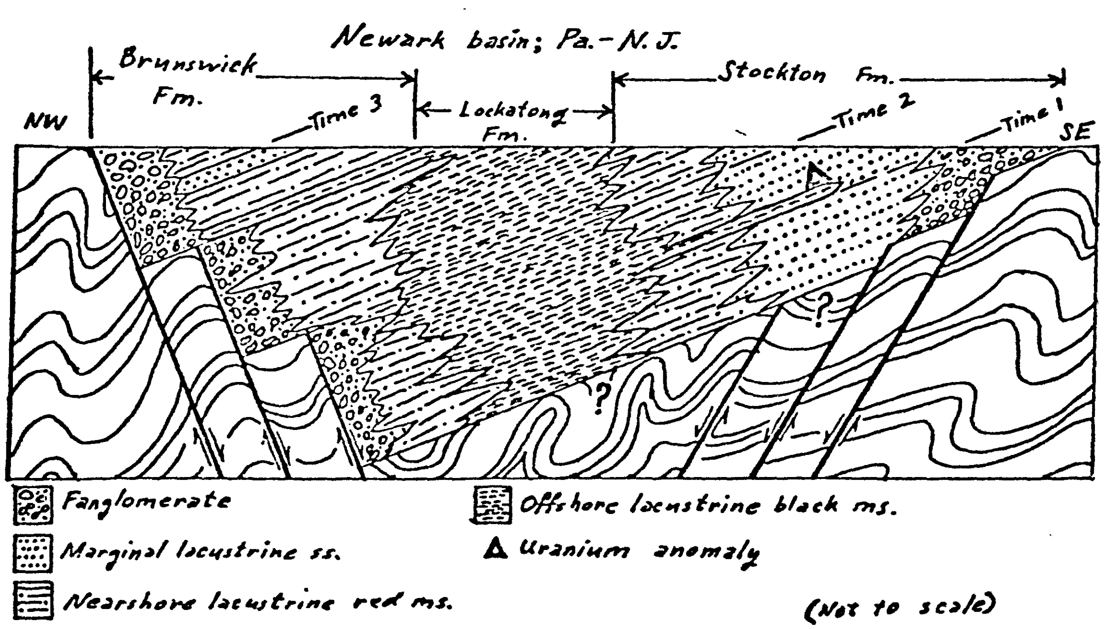
37. Photo of the somewhat less spectacular outcrops in the East.

38. Sedimentologic and structural framework of the Newark basin, showing fans entering the basin from the southeast, delivering sediments to the basin. Lacustrine deposition predominated in the basin, with fluvial deposition being restricted to fans along the basin margin. Typical facies distribution in the basin is, from basin margin to basin center: fanglomerate--marginal lacustrine sandstone--nearshore lacustrine red mudstone--offshore lacustrine black mudstone.

39. Photo of the offshore lacustrine black mudstones of the Lockatong Fm. Humic acids could have been derived from these mudstones because of the high pH associated with the formation of sedimentary analcime within these mudstones. Humic acids are soluble in an alkaline environment. Role of the humic acids and the black mudstones will be discussed later in the talk.

40. Photo of the flat-laminated marginal lacustrine sandstone of the Stockton Fm., Newark basin. Uranium occurs in this facies.

41. Cross-section of the Newark basin. Uranium occurs (as in the Salt Wash in Utah, above) only where marginal lacustrine sandstones interbed directly with offshore lacustrine black mudstones. Where intervening red nearshore lacustrine mudstones occur, no mineralization is present in the sandstones. Another example of facies control and the importance of offshore lacustrine black (or grey) mudstones. It is believed that in the Newark basin, and in the Salt Wash in the Henry Mountains, uranium is associated with the offshore lacustrine mudstones because the mudstones provide the humic acids that are capable of fixing uranium.

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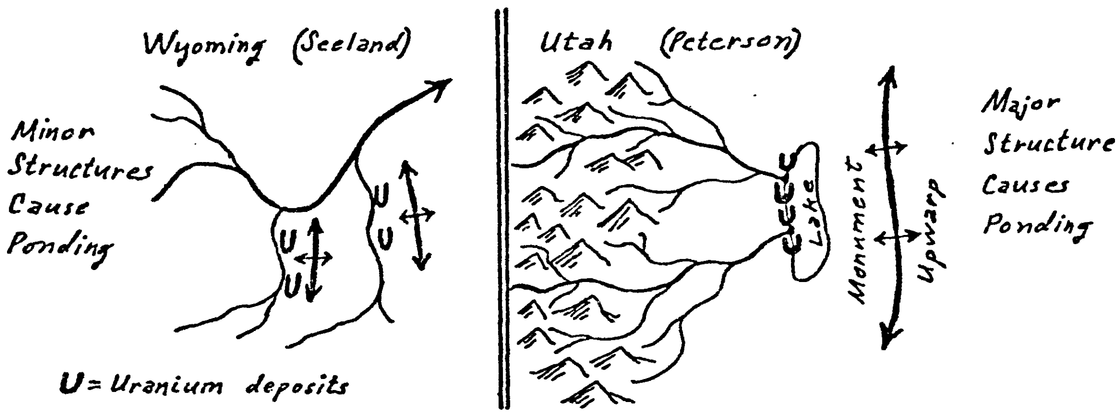
42. Same as slide #36; index map. Connecticut Hartford Basin, Triassic-Jurassic. Next two slides from a thesis by John Perrin- Newgate Mine, Connecticut, in Hartford basin.

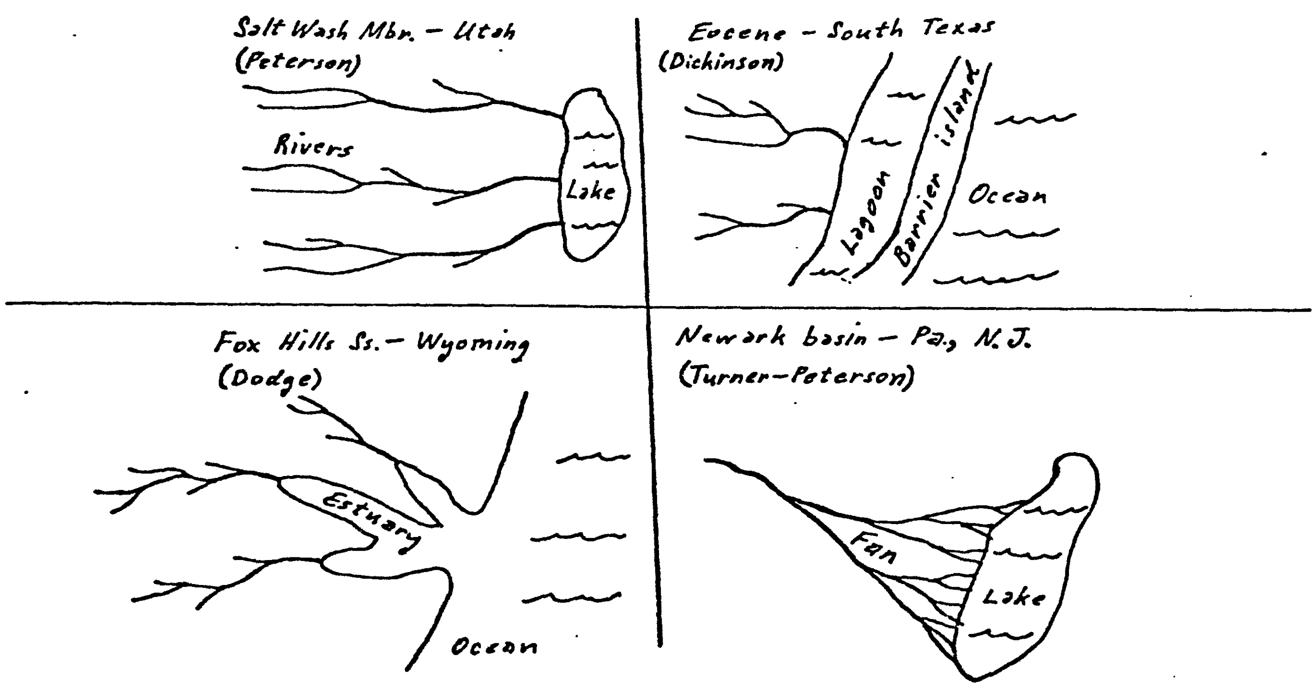
43. Slide showing paleocurrent directions in the Hartford basin in the area west of and in the vicinity of the Newgate Mine, showing west-to-east flowing rivers. In the mine itself, beds contain no crossbedding from which to obtain measurements. Small scours indicate a north-south current direction in the sandstone in the mine, which is normal to paleoslope.

44. Cross-section of the Newgate Mine, showing grey, marginal lacustrine sandstones interbedded with black, offshore lacustrine mudstones. Again, the uranium is associated with offshore lacustrine mudstones.

45. Summary slide showing the importance of tectonics as illustrated earlier in the talk.




46. Schemmatic diagram summarizing the facies control of uranium. Uranium occurs, in these examples, either in marginal marine facies (Cretaceous of Wyoming, Tertiary of South Texas), or in sandstones (either braided stream or marginal lacustrine) associated directly with offshore lacustrine grey mudstones (Jurassic of Utah, Triassic-Jurassic of the East Coast).

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47. TECTONISM

*Controls* →

SEDIMENTATION

*Controls* →

URANIUM DISTRIBUTION

48. <u>Conventional Ore Guides</u>

SS/Sh ratio

fluvial rocks

carbonaceous trash

The shortcomings of several of the most commonly used ore guides (see list from slide #6) will be illustrated by example in the next sequence of slides.

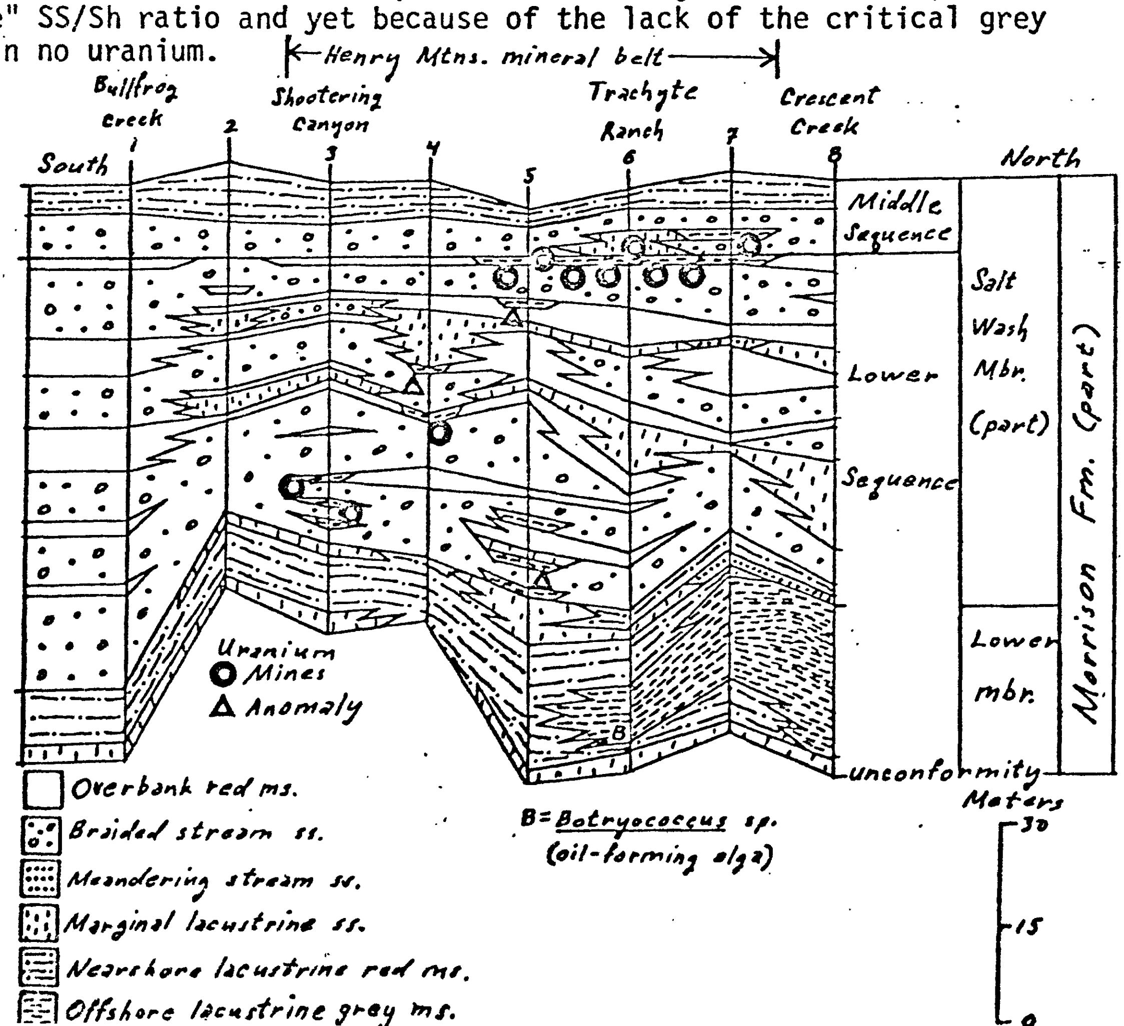
49. <u>Ore Guide</u>

SS/Sh ratio

<u>Problem with ore guide</u>

Averages too much section; does not distinquish type of shale, which is critical.

50. Same as slide # 34, cross-section of the Henry Mountains Mineral Belt. Because uranium occurs only in association with a specific kind of mudstone, namely grey offshore lacustrine mudstones, the sandstone/shale ratio would be misleading here. The grey mudstones are thin in places (less than .5 m) and would be masked by the effect of the red mudstones which are far more abundant and have nothing to do with the mineralization. SS/Sh ratios, for instance, determined for the first section on the left of this slide (south of Bullfrog Creek section) would have a "favorable" SS/Sh ratio and yet because of the lack of the critical grey mudstones, contain no uranium.



51. ORE GUIDE — PROBLEM WITH ORE GUIDE

| ORE GUIDE | PROBLEM WITH ORE GUIDE | |
|---|---|---|
| Fluvial rocks (channel SS) | Salt Wash: | 95% fluvial<br>5% lacustrine-U assoc. with offshore lacustrine mudstones(grey) |
| | Lance, Fox Hills: | fluvial- no mineralization<br>estuarine-U |
| | Newark: | lacustrine-U |

52. ORE GUIDE — PROBLEM WITH ORE GUIDE

| ORE GUIDE | PROBLEM WITH ORE GUIDE |
|---|---|
| Carbonaceous trash | Cretaceous of Western Interior; non-marine part is fluvial with carb. trash-NO U. U in estuarine deposits.<br>South Texas (Felder Mine)-U, no carb. trash present.<br>Newark basin-U, but no carb. trash, "clean SS" |

53. NEW ORE GUIDES

TECTONIC HISTORY

FACIES DISTRIBUTION

54. TECTONIC HISTORY

Structures that:

1. Run athwart paleodrainage systems

AND

2. were active during sedimentation and caused ponding

55. FACIES DISTRIBUTION

"Base Level Facies"

1. estuaries
2. beaches
3. lakes
4. local ponding in major drainage systems

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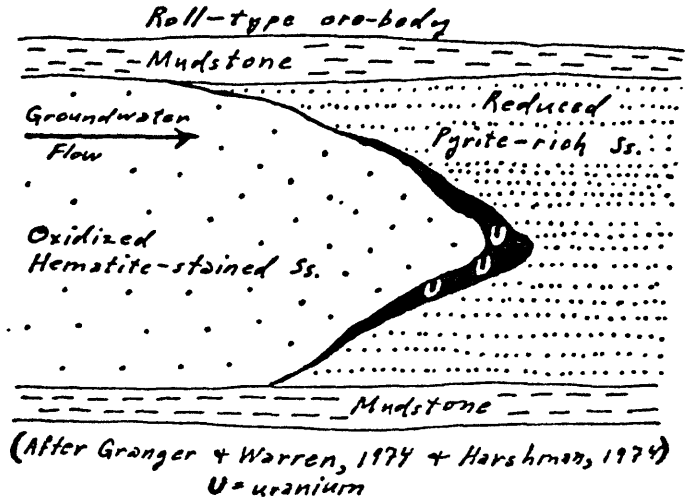
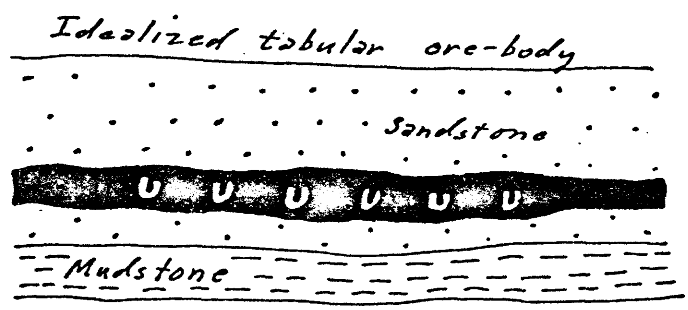
56. Idealized roll-front uranium deposit; uranium is carried from left to right in the diagram in oxidizing groundwater and precipitated at a redox interface. Inorganic precipitation of uranium.




57. Idealized tabular uranium deposit; ore body is associated with organic carbon (humate) and is concordant with bedding. Ore is located totally within reduced rocks.




58. REDOX ORGANIC PRECIPITATION

GREY ZONE
--------------???????????---------------

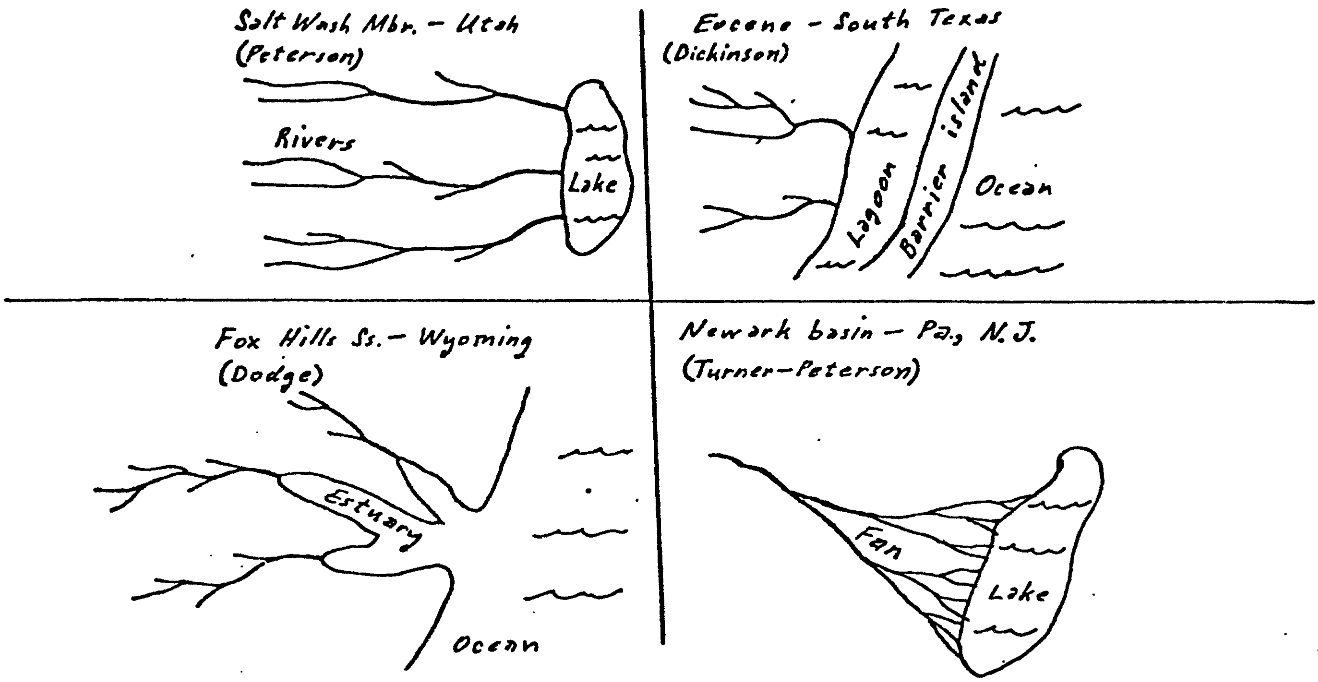
ROLL TABULAR

Next sequence of slides will illustrate the grey zone of uranium geochemistry.

59. Plateau-type uranium deposit from Grants Mineral Belt, showing "rolls" within an otherwise tabular ore body.

60. Slide showing redistribution in Ambrosia Lake tabular bodies. Pre-fault ore is concordant with bedding, and post-fault ore is redistributed along fractures. (Elmer Santos).

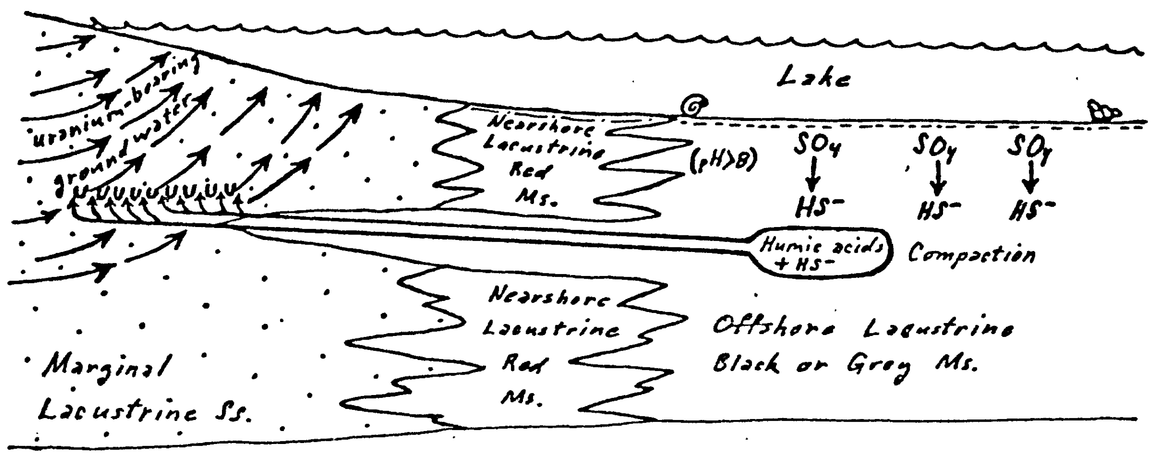
61. Same as slide #58. The "how" of uranium mineralization remains a subject of considerable debate, but the facies concept can contribute to the location of uranium, however it precipitated.

62. 


Same as slide # 46. The facies control of uranium mineralization as demonstrated earlier in the talk ought to offer certain constraints on models that are generated to explain the uranium mineralization. If the facies control is fortuitous, which seems unlikely, the facies would have no bearing on the mineralization mechanism. But perhaps facies control tells us that there is something inherent in the deposition of the sediments that sets the stage for mineralization. Pore fluids and ground water flow patterns can be inferred from reconstruction of paleogeography and this may have some bearing on the uranium mineralization.

63. Slide showing ground water flow patterns near lakes; greatest seepage into the lake occurs in the nearshore zone. Uranium-bearing groundwater would thus be delivered into the marginal lacustrine sands in the lake by ground water.

64. Slide showing loss of pore water during early burial in clayey sediments; pore water forced out during the first stage of dehydration is that which is physically expelled before the onset of inter-layer chemical changes.




**65.** Model explaining uranium mineralization in the Salt Wash member of the Morrison Fm., Utah (Peterson, 1977), and the Stockton Fm. of the Newark basin, Pa.-N.J. (Turner-Peterson, 1977).

During early burial diagenesis occurred near the sediment/water interface; pH in the pore fluids in the offshore lacustrine muds was high (8) as evidenced by the presence of carbonate units and sedimentary analcime (the latter only noted in the offshore mudstones of the Newark basin). Humic acids, resulting from the degradation of plant material entering the lake, are soluble in pH's greater than 7, and thus would have been contained in the pore waters in the offshore muds. Sulfate reduction also occurred in the euxinic mudstones and bisulfide ($HS^-$) would have been the stable sulfide species because of the high pH.

Compaction-induced lateral movement of the pore fluids from the offshore lacustrine muds into the nearby sands would result in the introduction of humic-rich and bisulfide-rich fluids into the zone of normal ground water associated with braided stream sandstones and marginal lacustrine sandstones near the lake margins. The lower pH in the zone into which the fluids were expelled would favor the formation of organo-clay complexes (pH 7-7.5), which would explain the association of uranium with clay films surrounding sand grains and with clay clasts. The bisulfide would join with the iron leached from the clay clasts by the strongly leaching humic acids and form pyrite. Uranium would be delivered to this zone by the groundwater that passes upward into the lake, and the uranium would be fixed by the humic acids. This model explains the association of uranium, pyrite, and humic-acids, but more importantly it is one example of how facies can be used to place constraints on a geochemical model of uranium mineralization.

**66.** Photo of Mahogany Bed, Green River Fm., Utah. Oil Shale. If lacustrine model explains uranium mineralization, why is there no uranium associated with the Green River? As mentioned earlier, only certain kinds of offshore lacustrine mudstones are favorable. Those in the lacustrine Green River are mostly oil-shale, not the type to produce humic acids. Lake basins may be "fingerprinted" for favorability by analysis of the offshore lacustrine grey mudstones.

67. Coastline hydrology: shows that the coastline forms a hydrologic boundary between the flow of groundwater down the paleoslope towards the ocean, and the flow of pore fluids expelled from offshore marine muds into the marginal marine zones. Suggests that similarities may exist between what happens at a lake margin and at the non-marine to marine transition zone.

68. Same as slide #47

TECTONISM
↘ controls
SEDIMENTATION
↘ controls
URANIUM DISTRIBUTION

69. BASINS AS DYNAMIC ENTITIES IN URANIUM MINERALIZATION

"Sedimentary basins are viewed as combinations of gases, liquids, and semi-solids distributed through a solid matrix." (Burst). This statement has implications in the approach to uranium geology. Conventional wisdom has "mineralizing fluids" being introduced into "host rocks", without regard for the environment of deposition that may have governed the geochemistry. The model proposed here is an attempt to work within the constraints developed during facies analysis: only normal ground water and pore fluids are required by the model. As Langford (1977) elaborated, "All epigenetic theories assume, in the last analysis, that some unknown but benevolent force guides the uranium into selected strata..."

70. Map showing location of major shale deposits of the world; Alum Shale- Sweden, Chattanooga Shale, U.S. Uranium probably fixed near sediment/water interface.

71. Major calcrete deposits of the world. Yeelerrie, Australia; carnotite precipitated by evaporative concentration.

72. Slide of calcrete in Yeelerrie.

73. Map showing major phosphorite uranium deposits in the world; Phosphoria, Idaho and Bone Valley, Florida. Uranium replaces calcium in apatite structure-similar atomic radius

74. Uranium in lignites below unconformity, with ash beds above. N. & S. Dakota, Montana.

75. Graph showing increased humic acid content in weathered lignites-may explain the mineralization of lignites below unconformity.

76. Todilto Limestone-tyuyamunite in fetid lacustrine black limestone. New Mexico.

78. Photo of Rifle Mine; Uranium and vanadium in eolian Entrada SS.

77. Diagram showing uranium in lacustrine Todilto and underlying eolian Entrada SS. Bleached zone below the Todilto extends below the mineralized zone.

79. Distribution of uranium and vanadium with respect the the deposition edge of the Todilto Limestone. Suggests that mineralization may be associated with Todilto.

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(some with brief annotation)

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