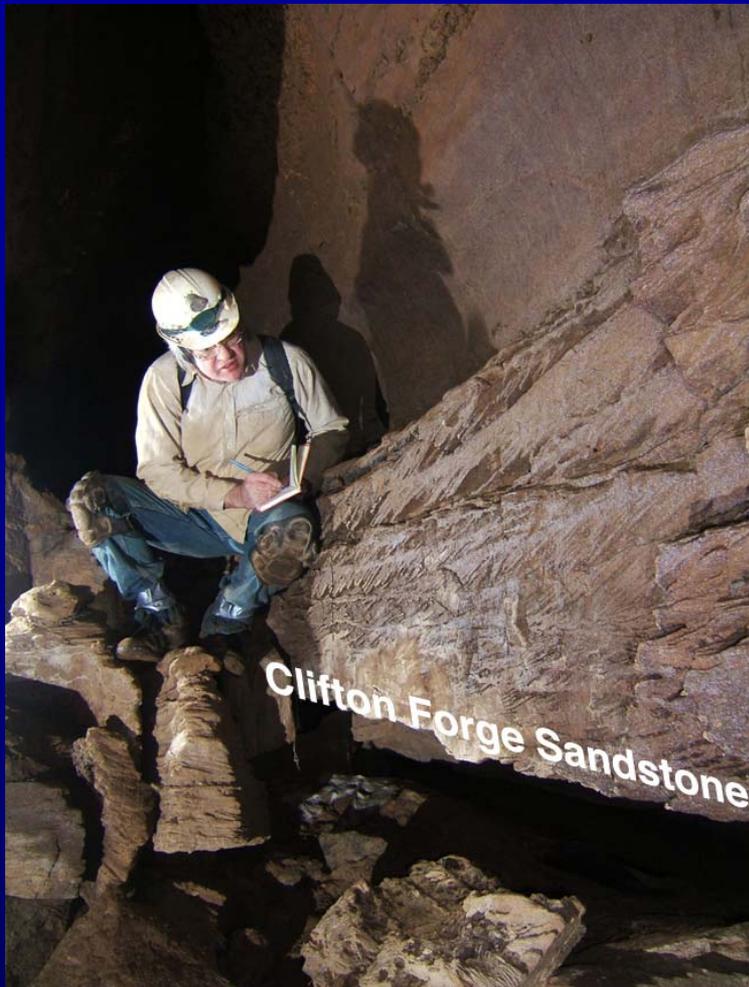


New Stratigraphic Findings in the
Silurian-Devonian of Highland County,
Virginia,

and

Their Importance to Geologic Mapping
in the Williamsville 7½ Quadrangle
(Virginia) Carried Out Under the
EDMAP Program of the U.S. Geological
Survey



Seldon M. Walker¹, John T. Haynes¹, Philip C. Lucas², Rick Lambert³, Steven J. Whitmeyer¹

¹Dept. of Geology and Environmental Science, James Madison University, Harrisonburg VA

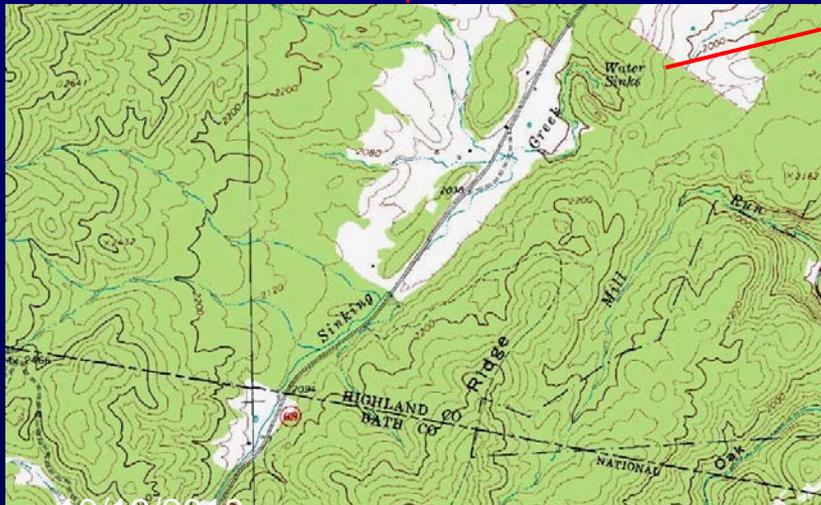
²Virginia Speleological Survey, Burnsville, VA

³Virginia Speleological Survey, Monterey, VA

10/13/2010

Location of our EDMAP study area

In the Valley and Ridge
of western Virginia



10/13/2010



The Water Sinks in February 2010, showing entrances to the Old Water Sinks Cave, above the entrance to the Water Sinks Subway Cave

Working to open the lid (frozen shut) to the Water Sinks Subway Cave, Feb. 16th



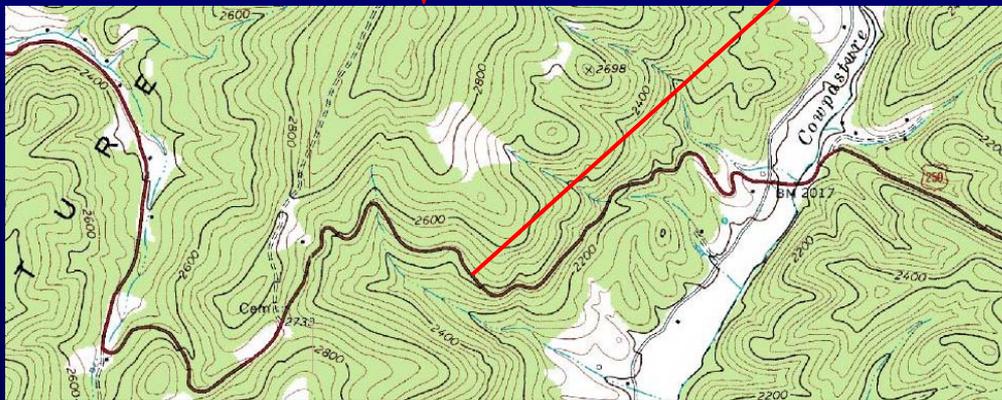
Outcrops in adjacent quadrangles have proven to be important as well

In the Valley and Ridge of western Virginia



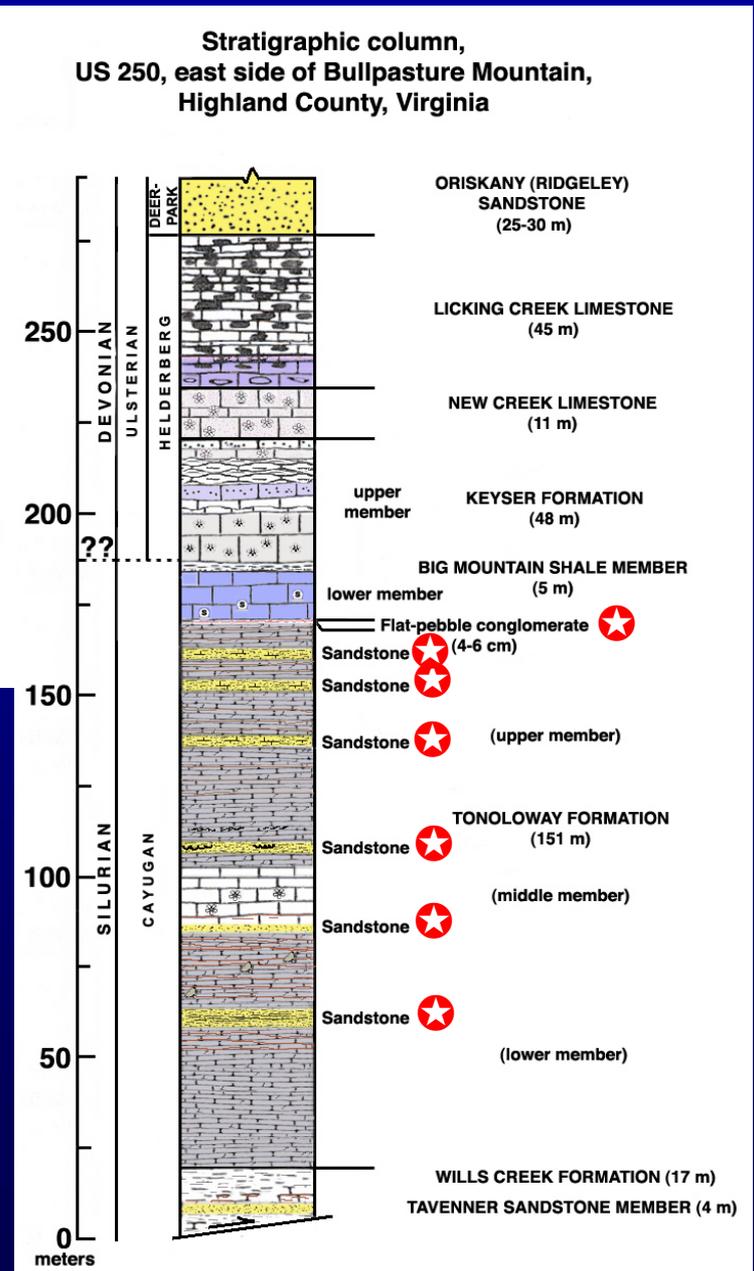
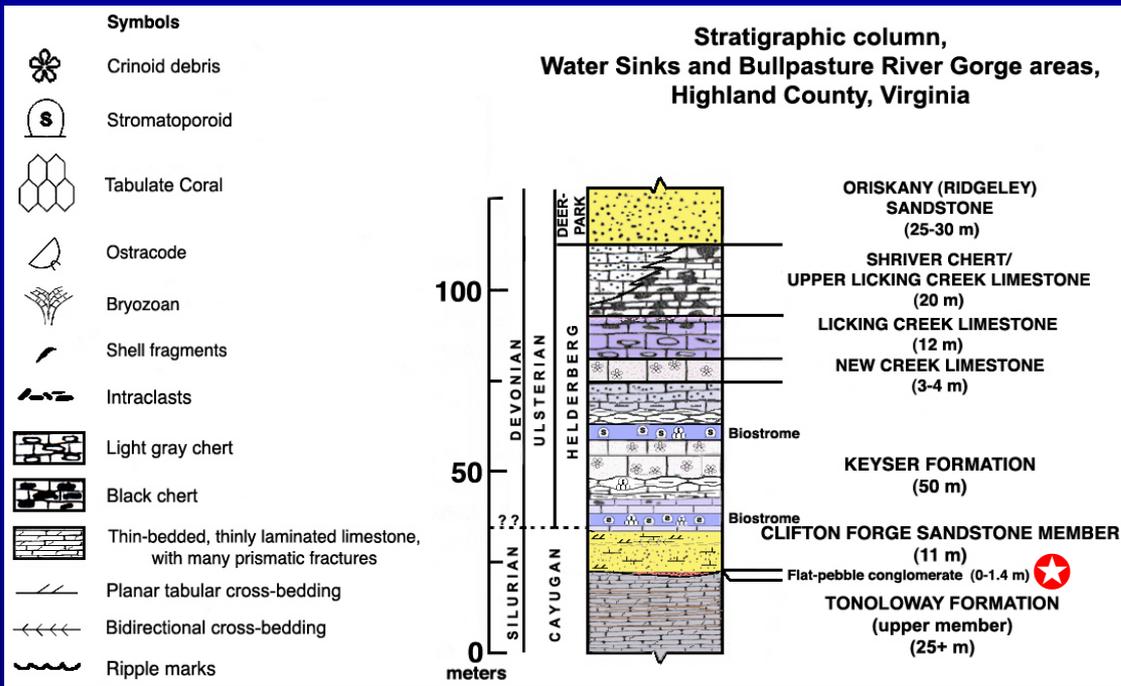
Contact of the Tonoloway and Keyser as placed by Woodward (1941, 1943) and by us

Part of the long exposure of Silurian and Devonian strata along US 250 on the east flank of Bullpasture Mountain



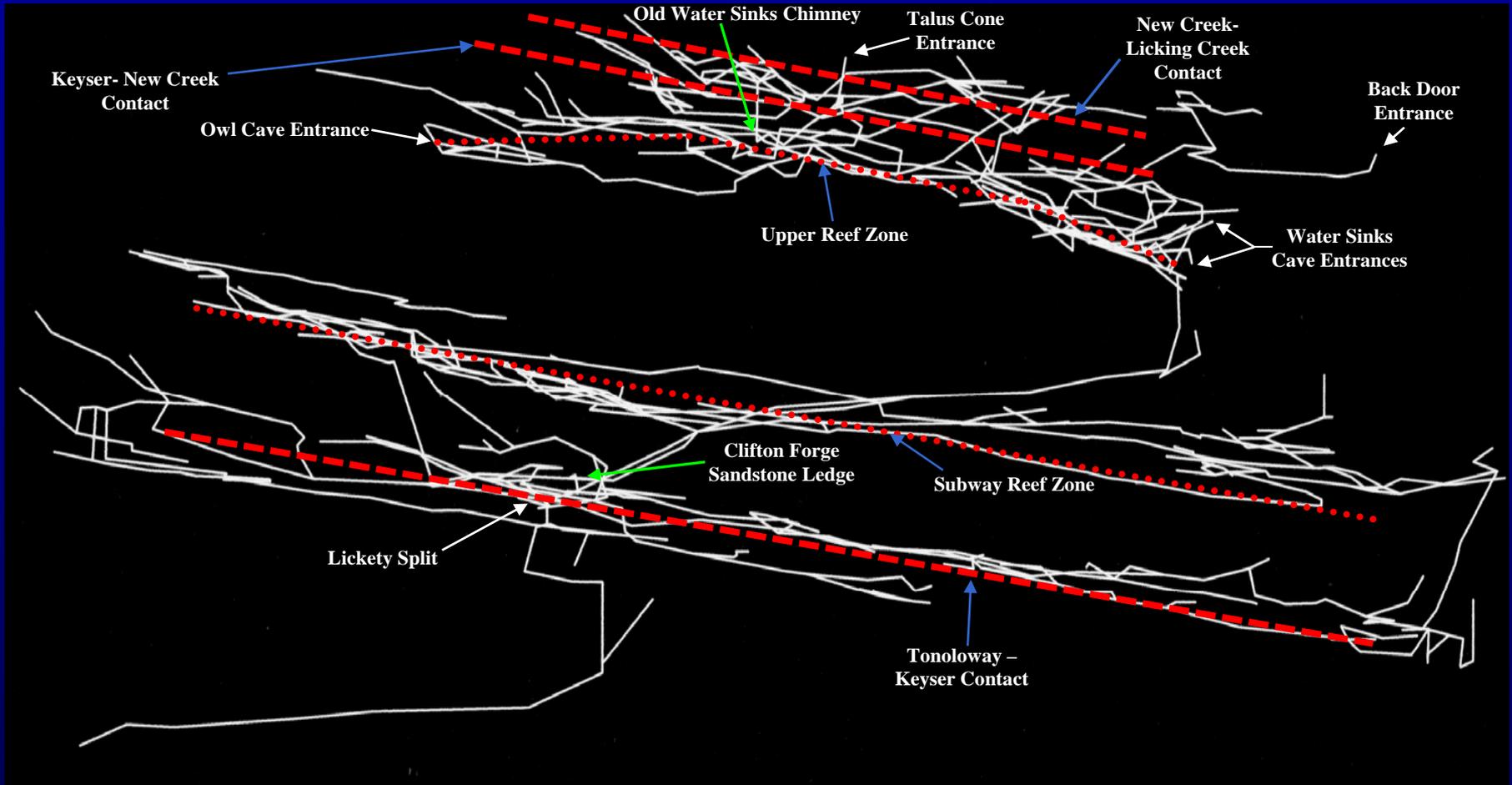
Flat pebble conglomerate at the Tonoloway - Keyser contact

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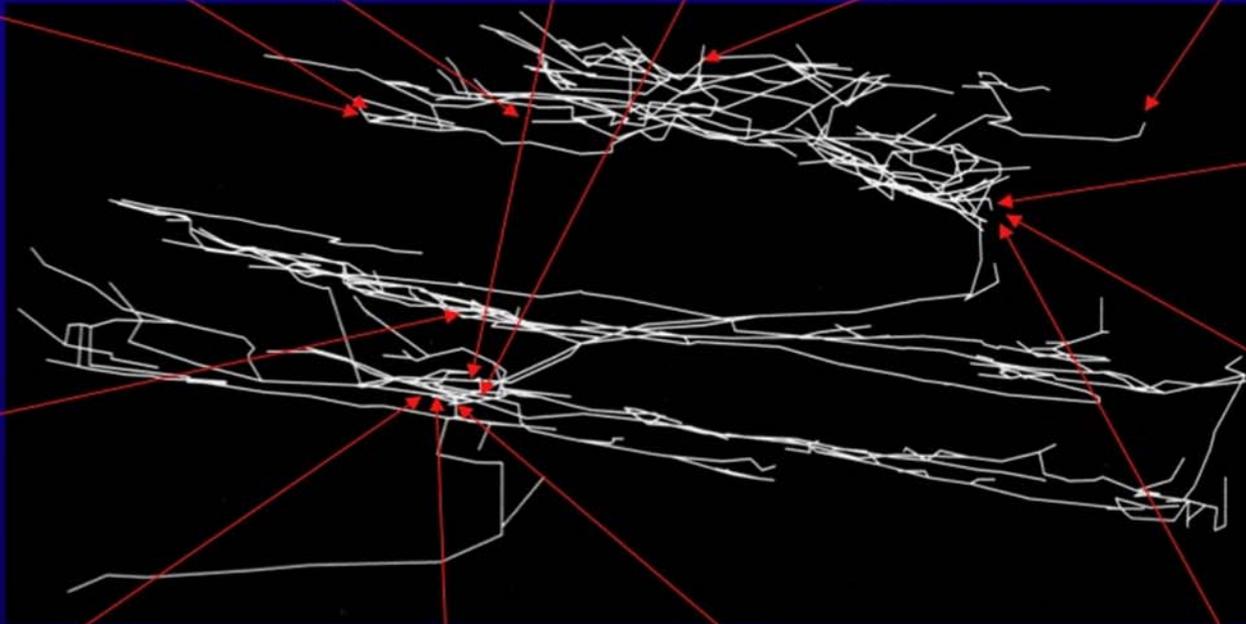
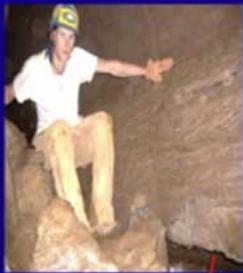


From study of surface and subterranean exposures, our mapping has added significantly more detail to the stratigraphic column of the Tonoloway and Keyser Formations in the Williamsville quadrangle

Key geologic locations in the Water Sinks



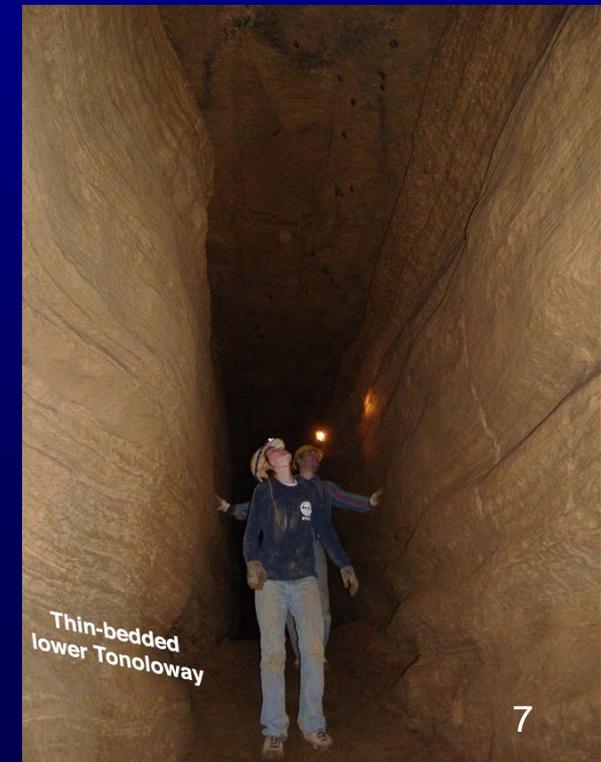
View is N36E



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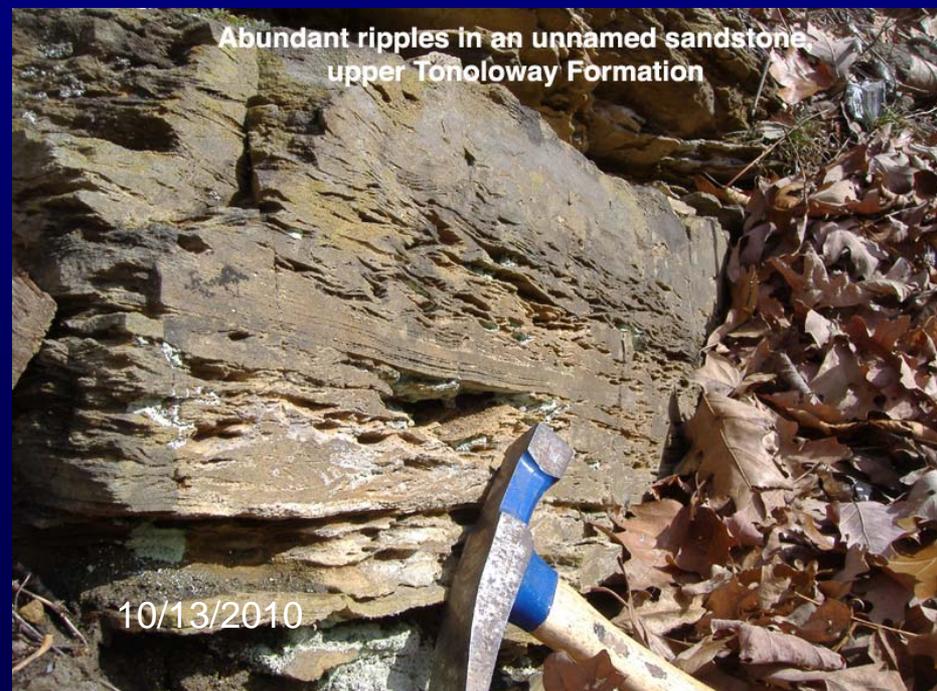
What is the Tonoloway? the Keyser?

The process of identifying, defining, and differentiating these two units began with a comprehensive literature review, to learn which lithologic criteria had been used to differentiate these units stratigraphically in prior regional studies, especially Swartz (1929), Butts (1940), Woodward (1941, 1943), Lesure (1957), Edmundson (1958), Bick (1960), Deike (1960), Dorobek and Read (1986), and Rader and Johnson (1993)



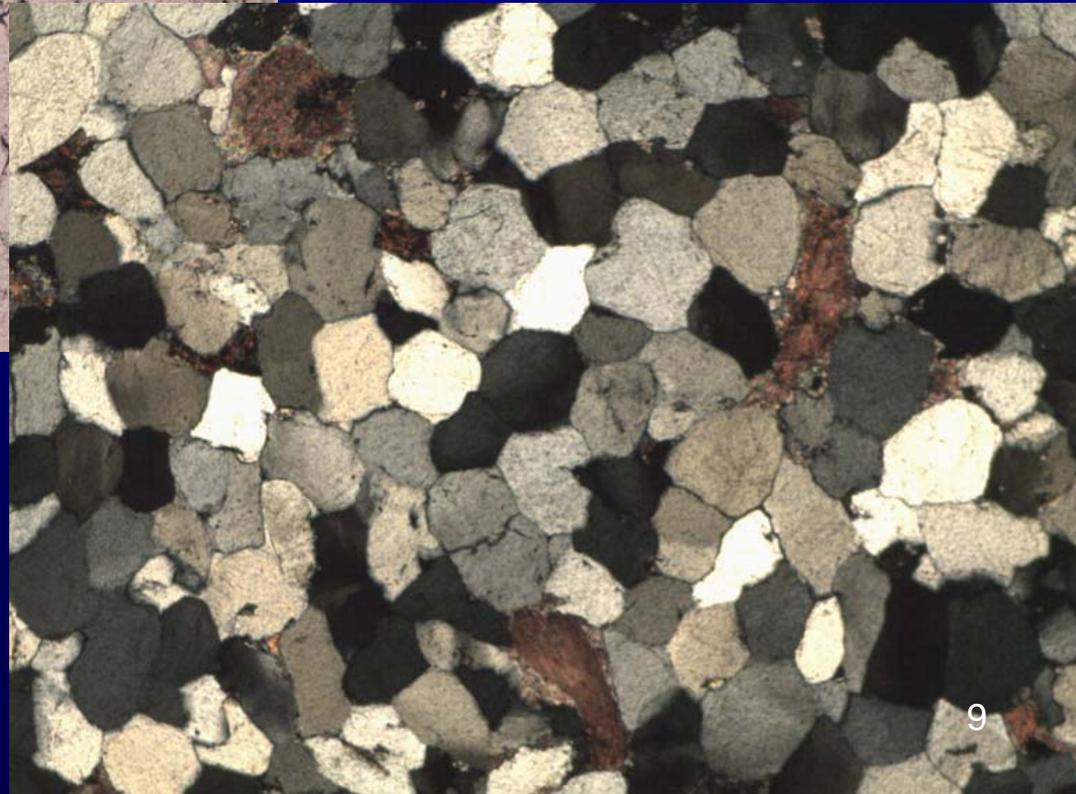
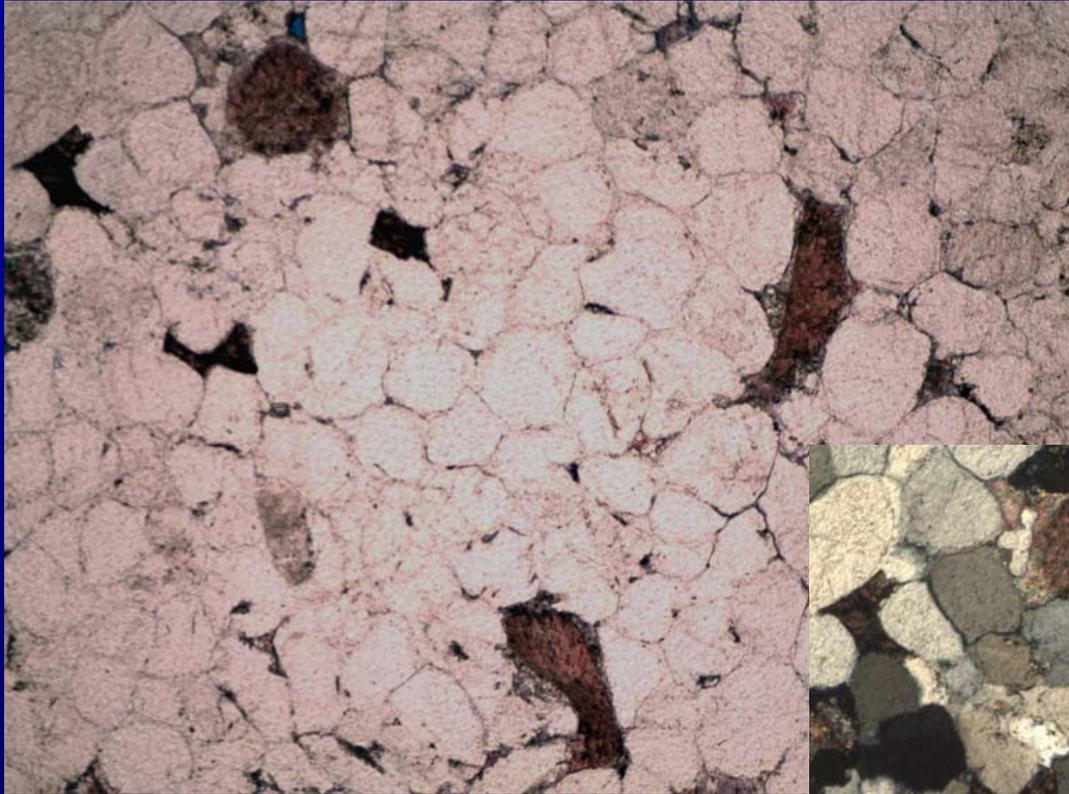
What is the Tonoloway? the Keyser?

We have studied many exposures in the area including Bullpasture Mountain and gorge (top), US 250 (bottom), Lower Gap, Water Sinks area, and Breathing and Butler Caves, in order to see for ourselves what criteria have been, could be, and should be, used to identify, define, and differentiate these stratigraphic units



What is the Tonoloway? the Keyser?

With thin sections, we have begun a comprehensive petrographic study of the units in these formations that are of particular importance stratigraphically and hydrogeologically



Photomicrographs of quartz arenite from the sandstone in the Tonoloway that makes the ceiling of Breathing Cave, showing quartz overgrowths and syntaxial overgrowths on echinoderm grains. PPL (top) and XPL (right), 10X

What is the Tonoloway Formation?

From prior studies, filtered and refined by our observations, the Tonoloway in this area is the stratigraphic unit above the Wills Creek Formation and below the Keyser Formation, and which is comprised of:

1. Upper and lower members (60 to 70 m thick each) that consist predominantly of thin-bedded, thinly laminated medium gray to black lime mudstones, and numerous rectilinear fractures that are essentially perpendicular to bedding



Thin limestones of the uppermost Tonoloway Formation in the Water Sink Subway Cave (above) and along US 250 (right) with the characteristic fractures

10/13/2010

What is the Tonoloway Formation?

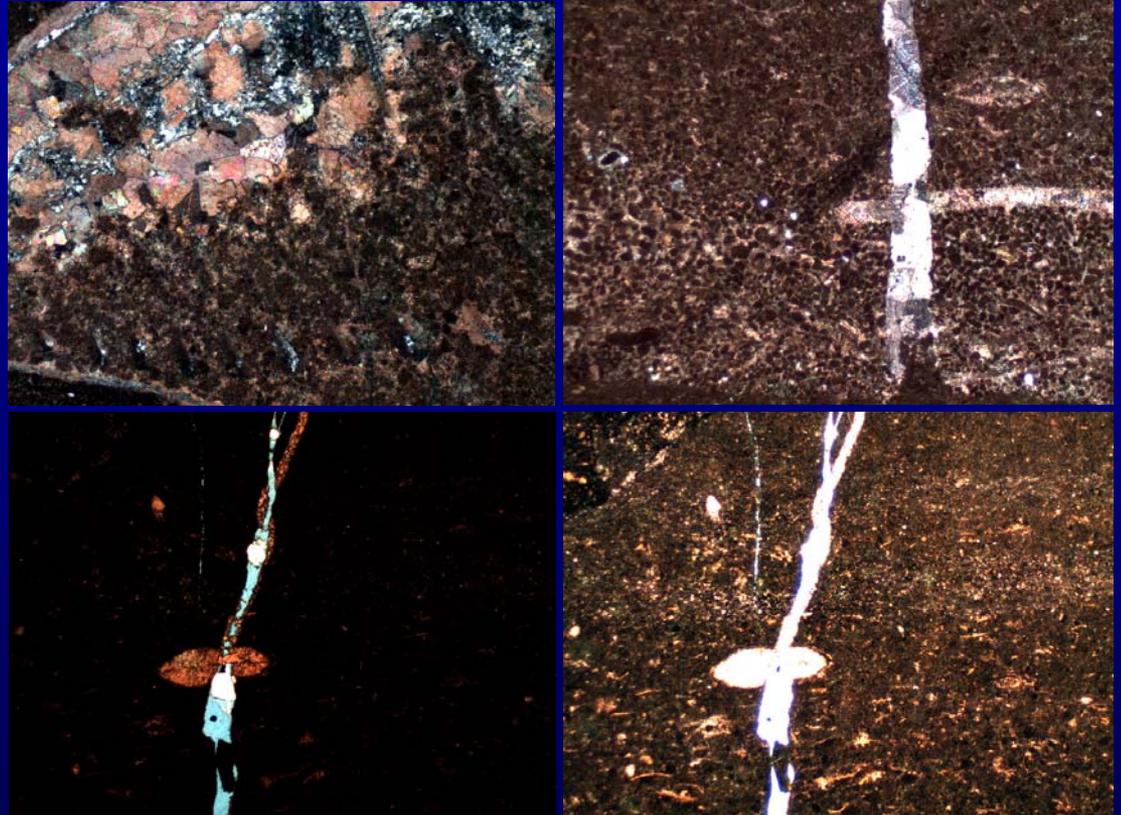
2. The peloidal grainstones to lime mudstones of the upper and lower Tonoloway are characterized by **repetitive and ubiquitous tan to pink to red argillaceous partings (up to 2 cm thick) that are wavy to anastomosing in some beds, but bedding parallel in most others**



Pink to red partings in the lower Tonoloway Formation along US 250 (right) and in the wall of the Grand Canyons stream passage in Breathing Cave (left). These partings are slightly more siliciclastic than the black limestone, and ostracodes are common to abundant in a few horizons, but the overall fossil diversity and abundance of the limestones in this interval is very low

What is the Tonoloway Formation?

3. A few ostracode-rich grainstone to wackestone beds are present in the lower member.



Hand sample of breakdown from the Grand Canyons stream gravels in Breathing Cave (left), with the prominent alternation of reddish argillaceous laminae and black lime mudstone, including one with many ostracodes, whole and fragmental. The photomicrographs show a large whole ostracode (upper left, XPL, 10X) filled with peloids, sparry calcite, and chert, and smaller ostracodes including one cut by a fracture (upper right, XPL, 10X; lower left and right, PPL, 10X). Note the numerous ostracode fragments as well (lower right)

What is the Tonoloway Formation?

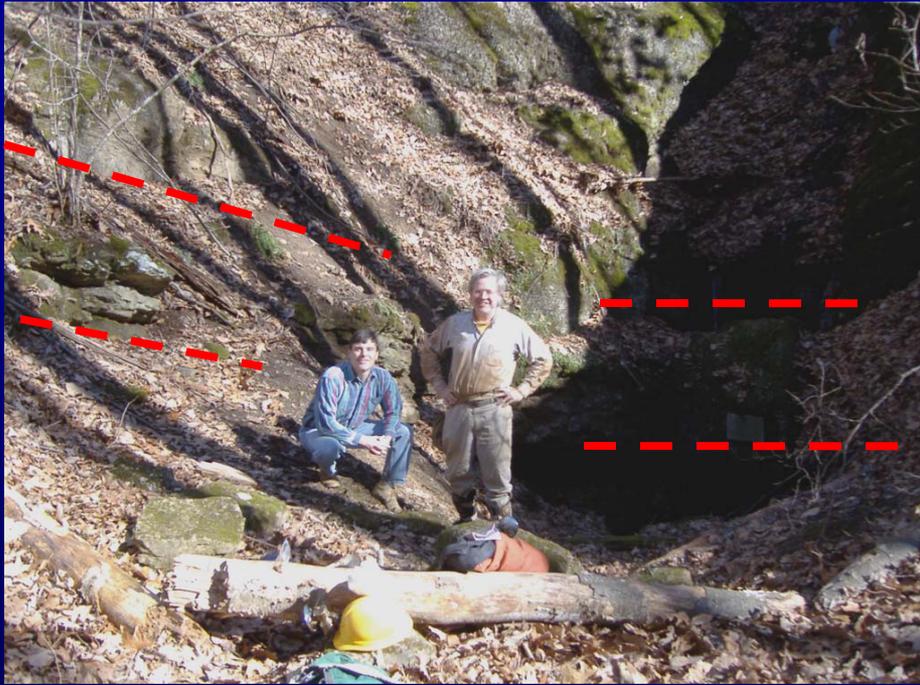
4. A middle member (~20 m thick) of thick-bedded, massive bioclastic grainstones and packstones with a more diverse and abundant faunal content than the upper and lower members



The middle member of the Tonoloway Formation along US 250. View at left shows the contact between the lower member (left of line) and the middle member, and the picture at right shows several large crinoid fragments in the thick-bedded limestone, which weather very differently than the thin-bedded limestones of the lower and upper members of the Tonoloway.

What *is* the Tonoloway Formation?

5. In the upper and lower members, but not in the middle member, several (6-8 or more) sheet sandstones that are calcareous and/or calcarenaceous quartz arenites (<1 to ~4 m thick).



Entrance to Breathing Cave (left) with the sandstone layer that makes the ceiling of the cave's passages; above this sandstone are crinoidal grainstones and packstones of the middle member of the Tonoloway. The same sandstone, with appreciable vuggy porosity, exposed along US 250.

In the intervening distance, this sandstone also forms the ceiling of caves along the east side of Bullpasture Mountain, including Bullpasture Mountainside Cave.

What *is* the Tonoloway Formation?

5. In the upper and lower members, but not in the middle member, several (6-8 or more) sheet sandstones that are calcareous and/or calcarenaceous quartz arenites (<1 to ~4 m thick).



Sandstones in the lower Tonoloway that are associated with Butler Cave: the Nicholson entrance to Butler Cave (right) with the sandstone layer that makes the ceiling of the cave's highest passages, and the hillside above the SOFA entrance to Butler Cave (left) with the sandstone layer beneath which many of the cave's passages have developed. Associated thin-bedded, thinly laminated, fractured limestones with pink to red partings throughout are typical of the lower Tonoloway.

What *is* the Tonoloway Formation?

6. Some flat-pebble conglomerate beds are present in the lower and upper members of the Tonoloway.

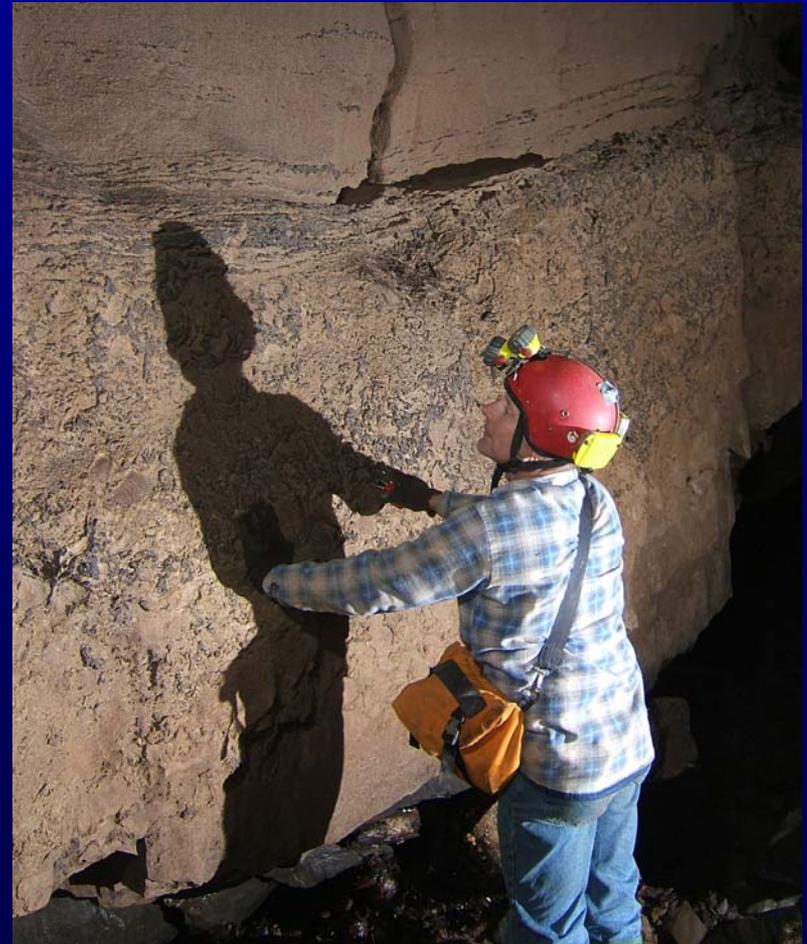


Flat-pebble conglomerates, with prominent micritic intraclasts, in the upper member of the Tonoloway along US 250. The bed at right occurs immediately beneath the lowest massive bioclastic grainstone of the lower Keyser Formation.

What *is* the Keyser Formation?

From prior studies, filtered and refined by our observations, the Keyser in this area is the stratigraphic unit above the Tonoloway Formation and below the New Creek Limestone, and which is comprised of:

1. Upper (20 to 25 m thick) and lower (0 to 14 m thick) members, with prominent thick-bedded to massive reefal framestone horizons of stromatoporoids and corals



Stromatoporoid framestones in the upper Keyser just above the Clifton Forge Sandstone in the Bullpasture River Gorge (left) and 10/13/2010 on the Water Sinks Subway Cave (right)

What *is* the Keyser Formation?

2. Thick-bedded to massive, gray to blue-gray crinoidal grainstones to wackestones, some with cross-bedding, some with quartzose zones, and some with pink grains, and nodular-bedded intervals that appear cherty but are not.



Cross-bedded crinoidal grainstone in the lower member of the Keyser along US 250 (left), and cross-bedded quartzose lime mudstone in the upper member of the Keyser at the waterfall in the Water Sinks.

What *is* the Keyser Formation?

3. A middle member (5-15 m thick) that is a calcareous greenish gray mudrock with minor sandstone to the north (Big Mountain Shale Member) and a cross-bedded sandstone of calcareous and calcarenaceous quartz arenites to the south (Clifton Forge Sandstone Member);



Facies of the middle member of the Keyser Formation: the Big Mountain Shale along US 250 (left), with a thin sandstone at its base, just above the lower contact line, and the upper part of the Clifton Forge Sandstone in the Water Sinks along the western edge of Chestnut Ridge (right), with a thin greenish shale just below the lower contact line.

These two exposures are about 19 km apart, and the facies change occurs in the intervening distance, along Bullpasture Mountain.

What *is* the Keyser Formation?

4. Where the Clifton Forge Sandstone is present, it directly overlies the Tonoloway Formation, and the lower Keyser is either missing by erosion and/or it has changed facies into the lowest beds of the Clifton Forge Sandstone. The Clifton Forge is continuous vertically with just a thin medial shale, and in the Water Sinks Subway Cave it is about 5 m thicker than the Big Mountain Shale is at the US 250 exposure.

The contact between the resistant ledges of the Clifton Forge Sandstone (left of line) and thin-bedded limestones and fine-grained sandstones of the upper Tonoloway Formation (right of line) on the north side of the Bullpasture Gorge just east of Marshalls Cave.



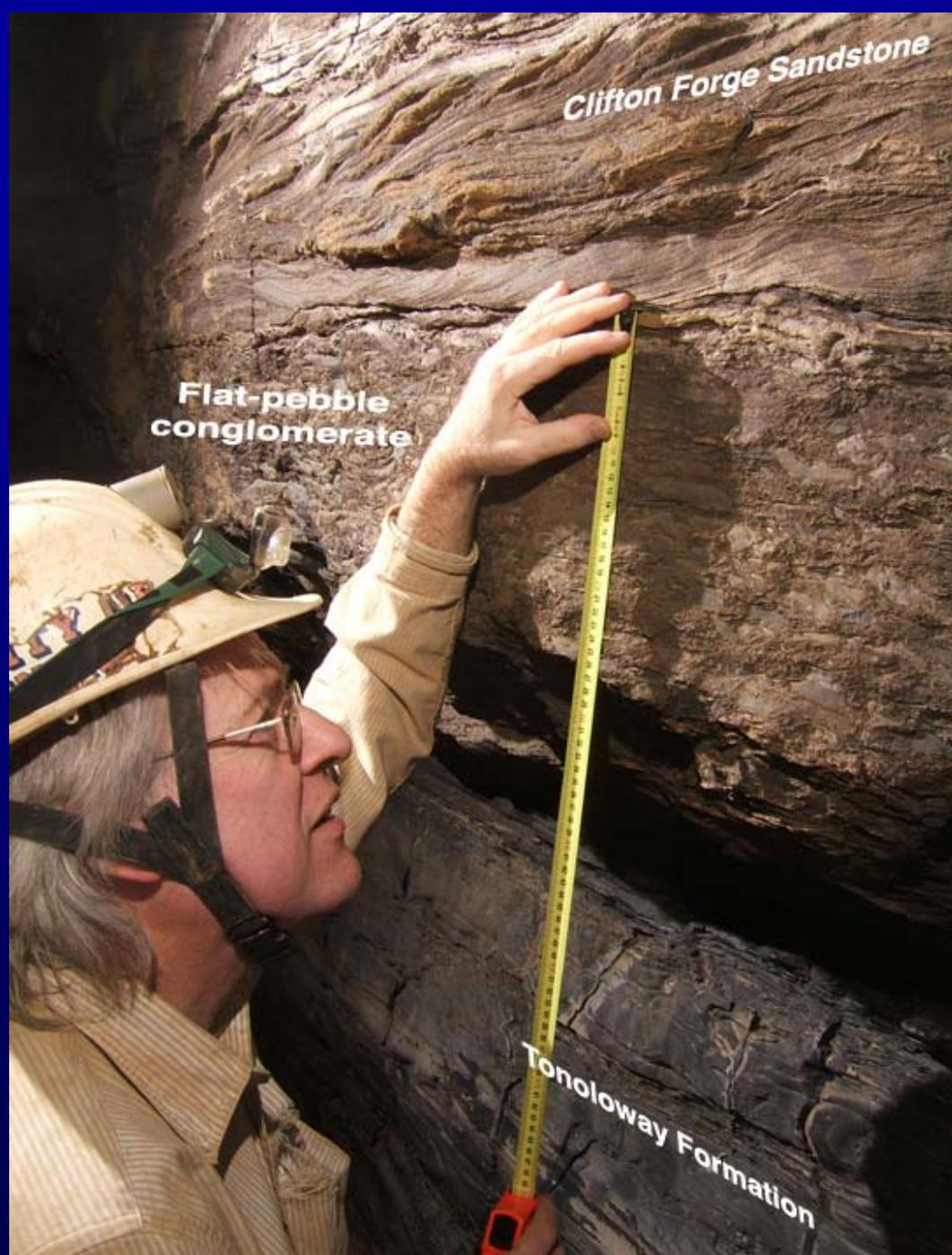
What is the nature of the stratigraphic contact between the Tonoloway and Keyser Formations?

From our observations, along with some by Woodward (1941, 1943):

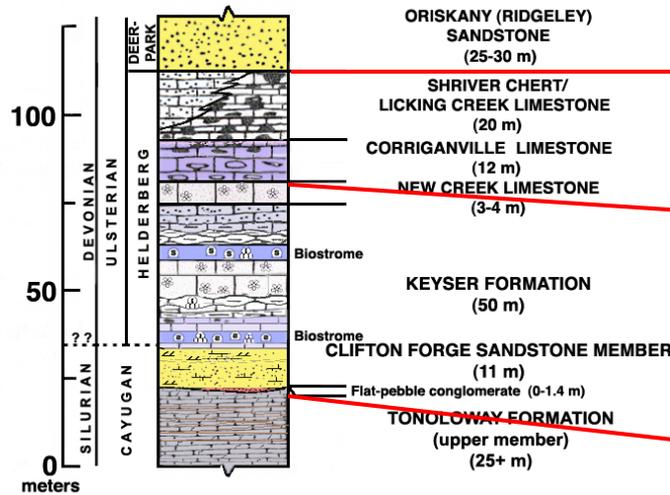
1. The stratigraphic contact in this area between the dark gray, distinctly fractured, and thin bedded and thinly laminated lime mudstones of the upper member of the Tonoloway and (a) the cross-bedded crinoidal grainstones and stromatoporoid framestones of the lower member of the Keyser (US 250 section) or (b) the cross-bedded calcareous and calcarenaceous quartz arenites of the Clifton Forge Sandstone (Water Sinks Subway, Sink of Sinking Creek, and Bullpasture Gorge sections), is variable, and is either
 - A. an erosional unconformity over lateral distances of about 5 m (Sink of Sinking Creek) to over 30 m (Bullpasture Gorge, just east of Marshalls Cave), but with no appreciable relief on the surface of the unconformity
 - B. a flat-pebble conglomerate that varies in thickness from 0 to 1.3 m over a lateral distance of about 50 m (in the Water Sinks Subway Cave),
 - C. a flat-pebble conglomerate that is about 6 cm thick (US 250 section)



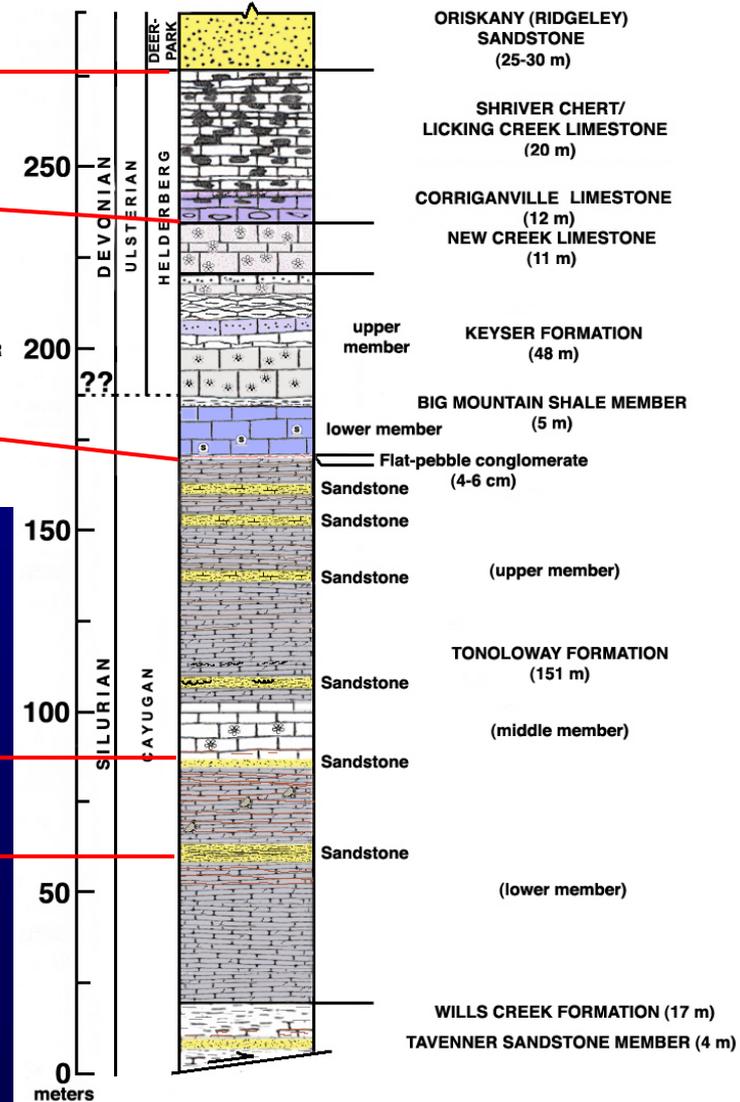
The flat-pebble conglomerate at the Tonoloway – Keyser contact in the Water Sinks Subway Cave marks an abrupt change in lithology and depositional environment, just as it does in the section along US 250



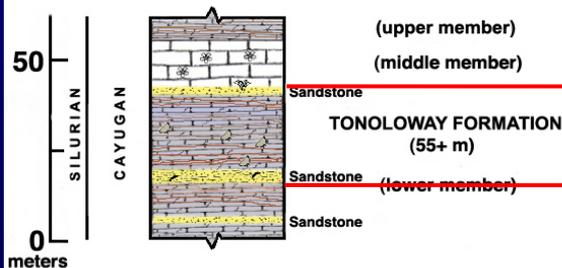
Stratigraphic column,
Water Sinks and Bullpasture River Gorge areas,
Highland County, Virginia



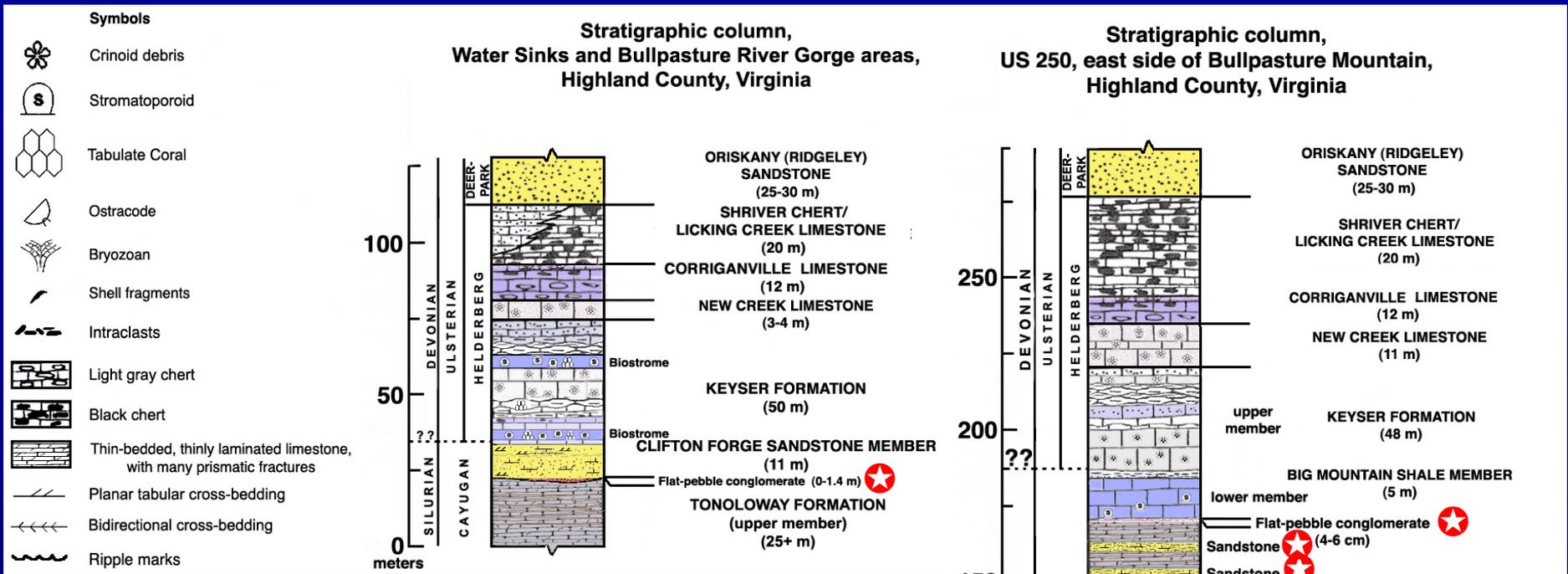
Stratigraphic column,
US 250, east side of Bullpasture Mountain,
Highland County, Virginia



Stratigraphic column,
Breathing Cave and Butler Cave area,
Bath County, Virginia



Stratigraphic correlations



From study of surface and subterranean exposures, our mapping has added significantly more detail to the stratigraphic column of the Tonoloway and Keyser Formations in the Williamsville quadrangle