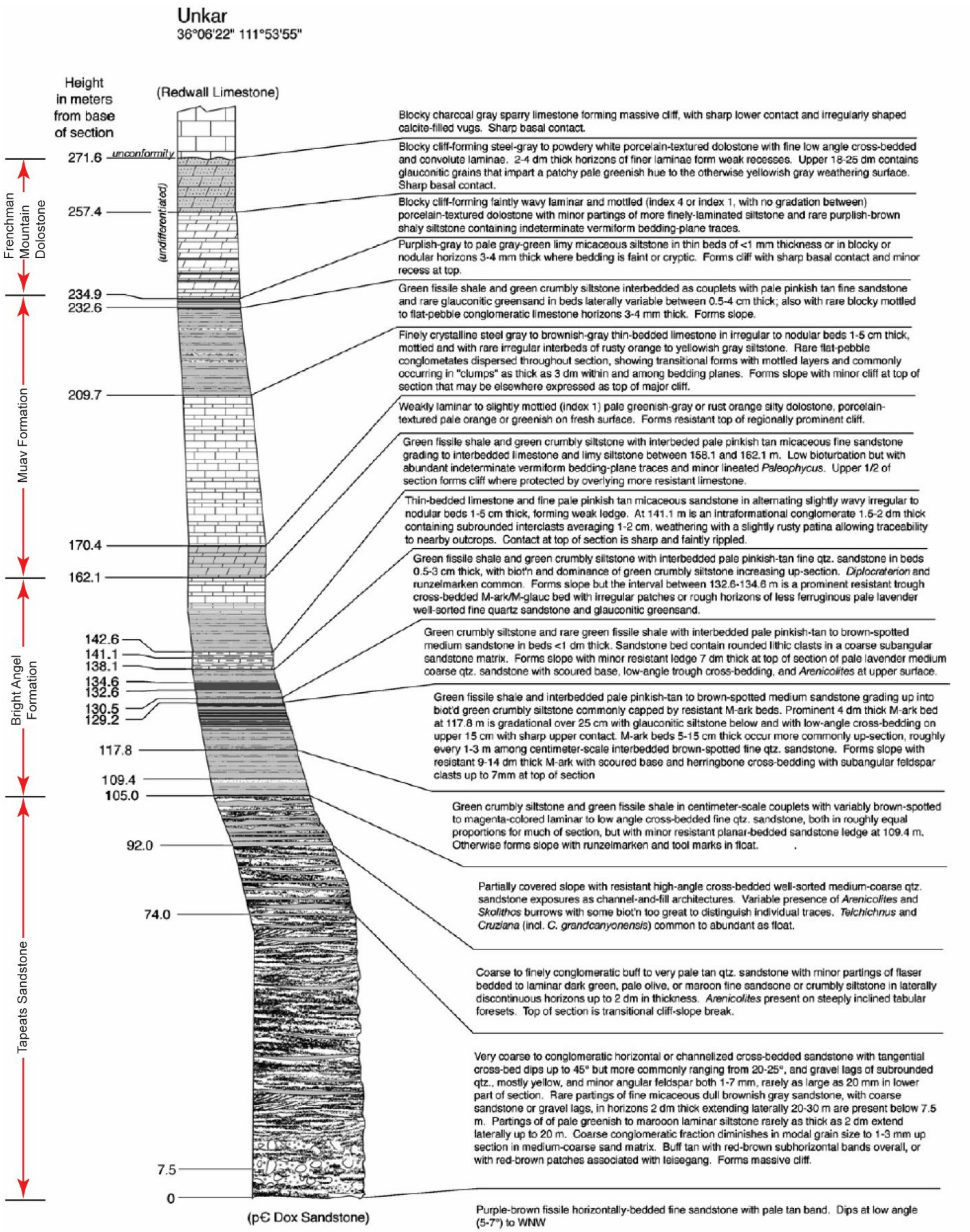
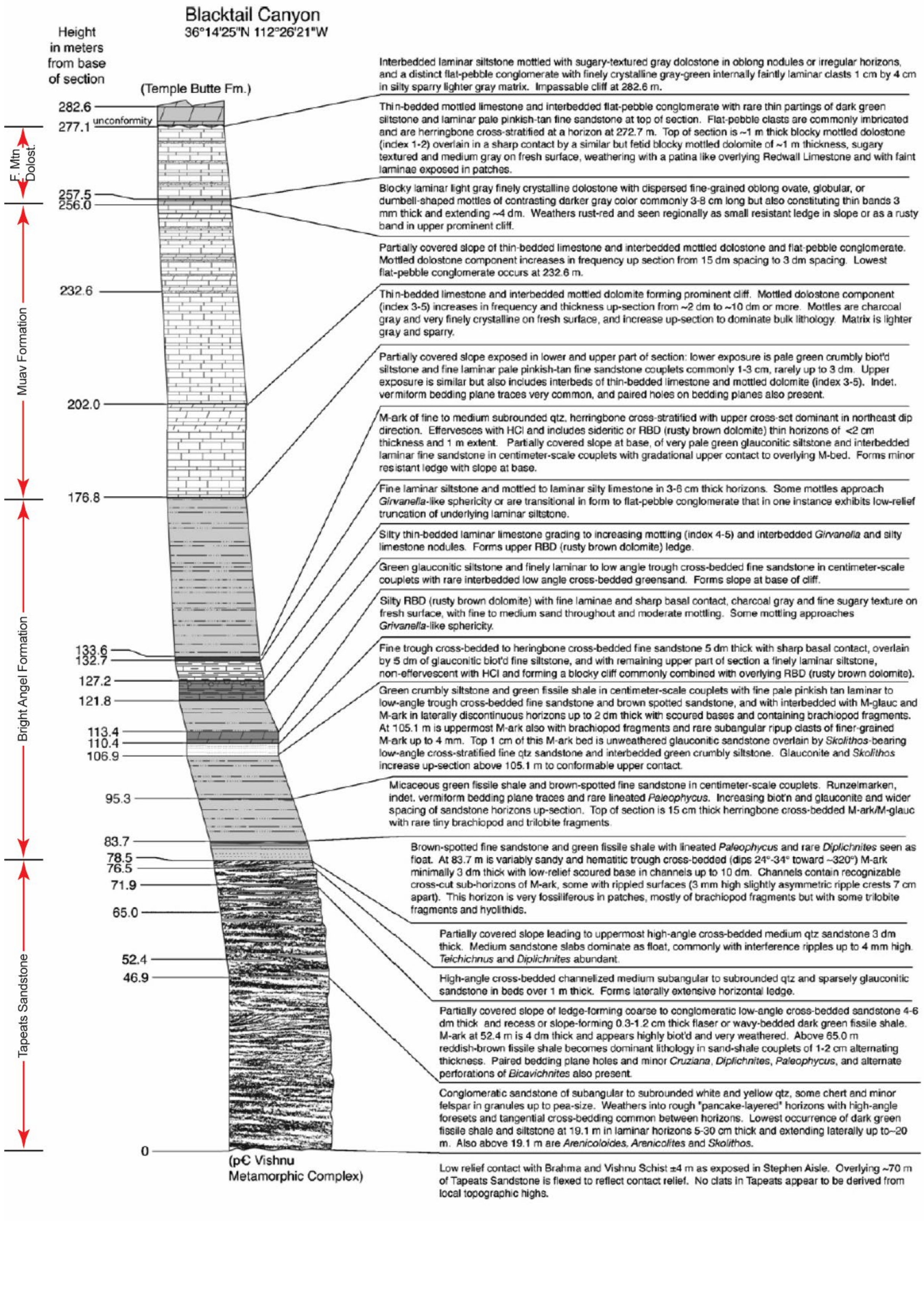
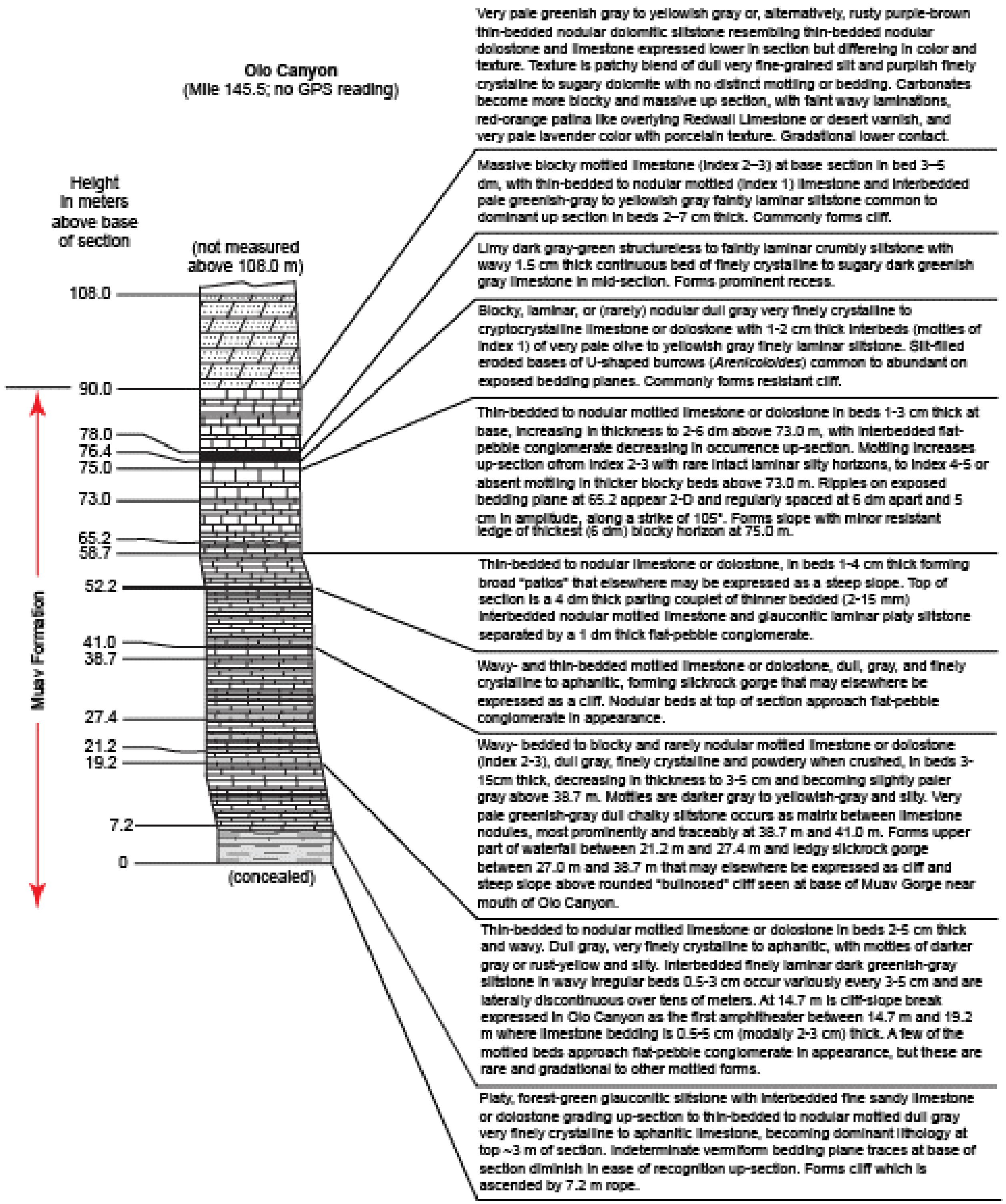
Appendix A– Graphic Stratigraphic Log of Unkar Creek Area (River Mile 73) as Measured by Rose (2006)



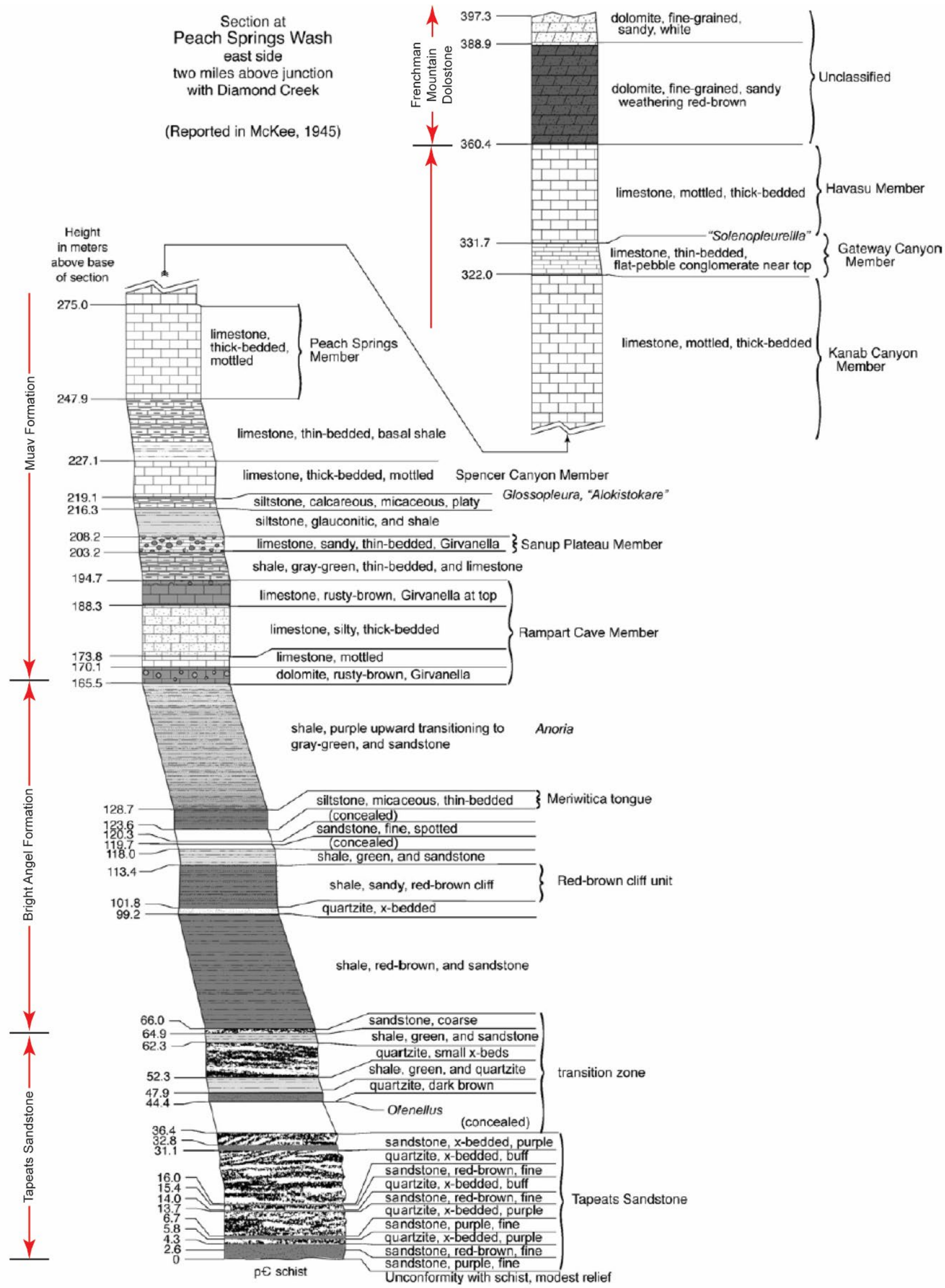
Appendix B – Graphic Stratigraphic Log of Blacktail Canyon Area (River Mile 120.5) as Measured by Rose (2006)



Appendix C – Graphic Stratigraphic Log of Olo Canyon Area (River Mile 146) as Measured by Rose (2006)



Appendix D – Graphic Stratigraphic Log of Diamond Creek Area (River Mile 226) as Measured by Rose (2006)



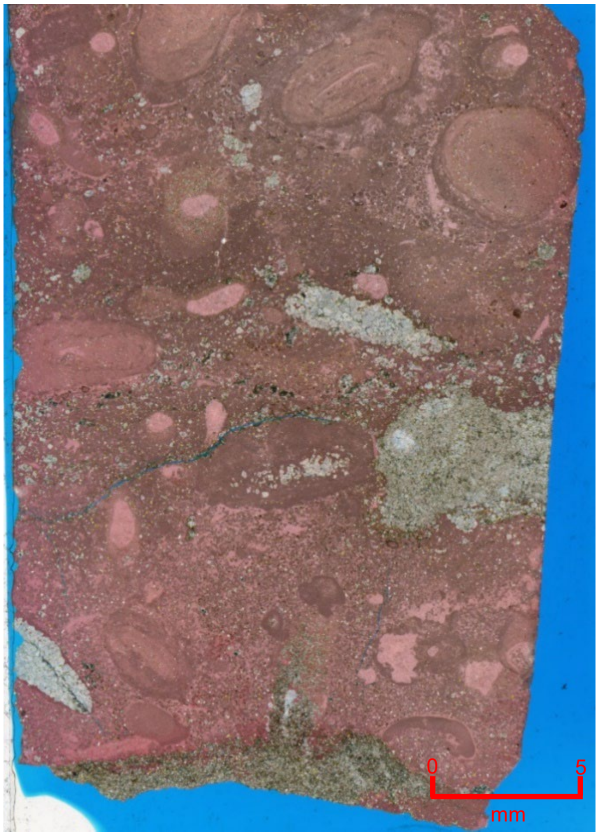
Appendix E – Locations and Petrographic Descriptions of Muav Formation Samples

The thin sections of the rock samples for this study were all mounted on standard 1.5 inch (~38 mm) long by 1.0 inch (~25 mm) wide glass microscope slides. Before the slices were cut from the rock samples using a diamond saw, the rock samples were impregnated under confining pressure with epoxy resin that contained a blue dye. This ensured that grains did not get dislocated or the rock fabrics get distorted during the sawing of the slices. However, this process left the thin sections with a blue dye staining as the surrounding background and in any holes or pores within the rock fabrics. Before cover slips were added, the thin sections were stained so as to make the K-feldspar and calcite in the rock fabrics more easily distinguished. Thus, the K-feldspar grains have a distinctive yellow color and the calcite is pinkish in plane polarized light.

The high resolution digital images of the whole thin sections (reproduced below) were obtained using a digital scanner that had been programmed accordingly. When the rock samples were collected in the field the right sides up (tops) were carefully marked, so that the thin sections were cut perpendicular to the bedding and stratigraphic upwards was marked on the thin sections. Consequently, all the images of the whole thin sections below are oriented with stratigraphic upwards always being to the top of the pages. Thus, most of the whole thin sections are reproduced lengthwise vertically, while some are oriented lengthwise horizontally, so that always stratigraphic upwards is at the top of each image (as annotated with an arrow). Carefully following this procedure allowed for observation of sedimentation features such as bedding planes, cross-laminations and laminae, as well as the sorting and grading of grain sizes. Furthermore, because the images were cropped to remove extraneous details (such a labels) and then sized equally when placed with their respective petrographic descriptions below, a scale bar has been annotated to each image.

Regional Samples

<u>MLS-01</u> N 36° 23.543’ W 112° 37.581’ (N 36.392° W 112.626°)
RM 143.5 – river left ledges just above Kanab Rapid.
Massive, bedded limestone of the Kanab Canyon Member.
At normal scale, this rock in the thin section is a mud-supported limestone in which there are a variety of grains and grain sizes in sufficient quantity for the rock to be classified as a wackstone, a mud-supported limestone with >10% clastic grains. While the quartz and K-feldspar grains and muscovite flakes within this rock are not very visible at this scale they constitute about 4% of the rock, while mostly rounded



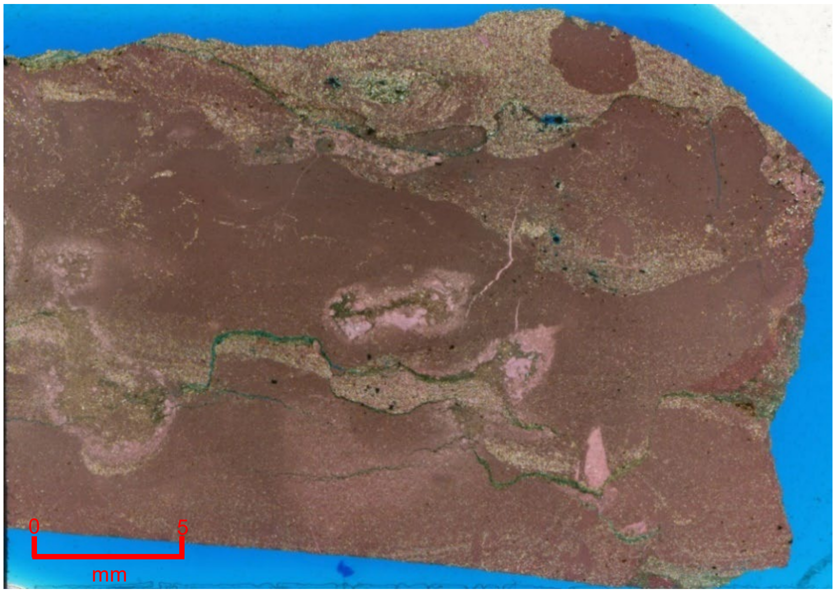
clasts composed of calcite or dolomite easily constitute >6% of it, all set in a micrite "groundmass". Calcite constitutes 65% of the rock and dolomite ~31%. The carbonate clasts vary in size up to ~4 mm, many of which appear to be composed of micrite (calcite mud) and most of them are rounded. Many of the smaller micrite clasts are elongated and would appear to be biogenic, largely shell fragments derived from bivalves and brachiopods, or micrite surrounding a nuclear shell fragment. The biogenic clasts are generally rounded, suggestive of transport before deposition. Partial dolomitization of the micrite appears to have occurred in three ways – dolomite totally replacing some of the biogenic clasts, scattered dolomite replacing the micrite between the clasts, and massive dolomite replacement of an area of the micrite between the clasts.

Under the microscope, the rock consists of a densely packed mosaic of very tiny (mud-sized) particles (0.01-0.03 mm, $\phi = +6.72 - +5.01$) of calcite (micrite) variably iron-oxides-stained in various patterns (often circular or oval), with subordinate scattered tiny to very small (0.02-0.06 mm, $\phi = +5.71 - +4.05$), and some small (0.07-0.12 mm, $\phi = +3.77 - +3.06$), small-medium (0.14-0.24 mm, $\phi = +2.84 - +2.06$), medium-large (0.26-0.32 mm, $\phi = +1.95 - +1.65$) and large (0.39-0.56 mm, $\phi = +1.36 - +0.83$), dolomite sub-angular grains, fragments and rhombs (some "skeletal" with internal growth zones marked by iron oxides), and scattered occasional tiny to small (0.01-0.20 mm, $\phi = +6.72 - +2.33$, fine silt to fine sand size) sub-angular to rounded quartz grains and fragments, even fewer tiny to very small (0.01-0.10 mm, $\phi = +6.72 - +3.32$) sub-angular to sub-rounded K-feldspar grains, and rare very small-small (0.03-0.19 mm long, $\phi = +5.01 - +2.40$) edge-on muscovite flakes within the calcite mosaic. Some scattered specks and tiny patches of iron oxides, and most dolomite grains and rhombs are outlined by iron oxides, with iron oxide also delineating internal growth zones within rhombs. In places the dolomite grains, fragments and rhombs are clumped together with tiny patches of the calcite matrix between them, often small and very small ones clumped together separately, but all outlined by iron oxides and dusted with light iron oxides streaks. Adjacent to and surrounding several such very large clumps (1-5 mm across) of very small and small dolomite grains and rhombs are small and long, thin edge-on muscovite flakes at various angles wedged between tiny-very small dolomite grains and rhombs within the calcite matrix with subsidiary tiny quartz grains and fragments and even fewer tiny K-feldspar grains and fragments aligned with them and amongst them closely scattered within the calcite matrix like a "halo". Numerous very small edge-on muscovite flakes and a few tiny subangular K-feldspar grains and fragments are wedged at various angles between the mass of very small and small dolomite grains and rhombs jammed tightly together in the interior of the very large clumps. Within the calcite matrix are medium and large blotchy and linear patches of very small-small (0.04-0.23 mm, ϕ = +4.64 – 2.13) calcite crystals with no iron oxides staining evident, all likely due to recrystallization. Some curved, linear, V-shaped and flattened ovoid zones within the calcite matrix, sometimes enclosing iron-oxides-stained dense calcite matrix, that are free of iron oxides staining and consist of very tiny to very small, recrystallized calcite crystals give the impression of being edge-on slices through brachiopod, bivalve or some other fossil shells. There are also circular and ovoid shaped patches of iron-oxides-stained dense calcite matrix surrounded by non-iron-oxides-stained, tiny-very small, recrystallized calcite crystals. In one huge circular area are numerous large (0.39-0.56 mm, ϕ = +1.36 - +0.83) (and smaller near the curved edge) dolomite rhombs packed tightly together set in the calcite matrix with nearby scattered tiny and small dolomite rhombs with internal growth zones marked by iron oxides (sometimes known as skeletal rhombs), and a few very tiny quartz grains and rare very tiny K-feldspar grains wedged between the rhombs. In several instances very small angular K-feldspar grains and tabular laths, and tiny quartz fragments are included in medium dolomite rhombs. Sometimes the larger dolomite rhombs appear to have the calcite matrix encroaching on their edges, while others have the pinkish calcite stain, suggesting some partial calcite replacement of some dolomite grains and rhombs. Even some of the quartz grains appear to have their edges coated with calcite, further suggestive of some partial calcite replacement. In places some of the dolomite rhombs, particularly the larger rhombs are broken with offset fragments still together. In another place there is a large, rounded clump of tightly interlocking small to small-medium dolomite rhombs dusted with, and cleavages marked by, iron oxides, and with a touch of pink staining in spots perhaps indicative of some partial calcite substitution, surrounded by the calcite matrix with a few tiny quartz and K-feldspar fragments, and more dolomite rhombs, nearby. And some clumps of dolomite rhombs appear to have been somewhat broken apart with, or due to, some calcite substitution or replacement. In yet another area there is a very large circular zone within the dense iron-oxides-stained calcite matrix in which there are curvilinear and irregular features of the same dense iron-oxides-stained calcite matrix but in between there is recrystallized calcite as tiny non-iron-oxides-stained crystals, as well as several very small, medium and large iron-oxides-stained dolomite rhombs. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is occasional blue dye staining between and encroaching on some grains, sometimes covering grains and thus distorting their colors.

MLS-02   N 36° 19.383'   W 112° 43.301'   (N 36.322°   W 112.722°)

RM 153.6 – river right just above Sinyella Rapid

Massive, bedded limestone of the Gateway Canyon Member. Maybe styolites in Muav Formation nearby.

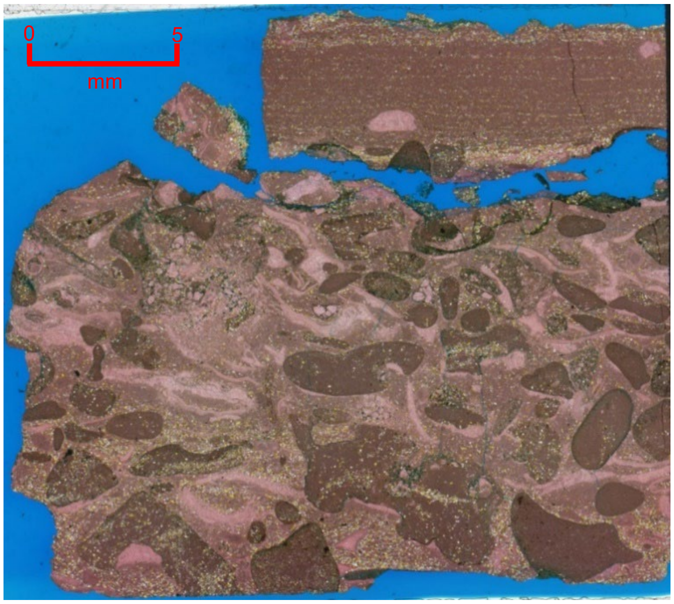


At normal scale, this rock in the thin section is also a mud-supported limestone in which there are a variety of grains and grain sizes in sufficient quantity for the rock to be classified as a wackstone. While the quartz and feldspar grains and muscovite flakes within this rock are not very visible at this scale, they constitute about >25% of the rock, while much of the rock consists of calcite (~69%) predominantly as micrite "groundmass" but also as micrite in elongated and subrounded biogenic clasts, probably bivalve and brachiopod shell fragments. Elongated irregular patches within the rock, recognizable due to their different lighter color, appear to consist of coarser-grained quartz, feldspar and muscovite with fewer calcite grains and thus may be a primary depositional feature. Dolomite constitutes ~2% of the rock and may be secondary alteration of calcite, though some thin calcite veins are visible in fractures suggesting some later calcite mobilization. Other fractures appear to be lined by iron oxides and illite.

Under the microscope, scattered tiny to very small (0.02-0.18 mm, ϕ = +5.71 - +2.48) sub-angular to sub-rounded K-feldspar and quartz grains and angular fragments, and occasional tiny-very small to long (0.04-0.42 mm, ϕ = +4.64 - +1.25), thin edge-on muscovite flakes (at various angles but often parallel to the bedding, sometimes broken, and sometimes with split and/or frayed ends) are set in an ultra-fine-grained (0.03-0.12 mm, ϕ = +5.01 - +3.06, mud-fine silt particle size) calcite matrix with speckled iron oxides dusting and small blotches and streaks of iron oxides, some of the streaks potentially being altered edge-on muscovite flakes. Some quartz and K-feldspar grain edges are fuzzy due to the encroachment of pink staining on them which may be due to calcite alteration or iron oxides linings. In some sections of the rock fabric the density (or numbers) of tiny to very small K-feldspar and quartz grains and angular fragments, with rare plagioclase grains (evident from the multiple twinning under crossed polars), is much higher than in other sections, and with the occasional thin edge-on muscovite flakes and very small iron oxides blotches make up more than 60% of the rock. Where the calcite matrix is less iron-oxides-stained some scattered or clumped together tiny calcite crystals are evident and elsewhere there are large such patches, some irregularly-shaped, or thick linear areas where the calcite matrix has recrystallized to form small-medium (0.20-0.30 mm, ϕ = +2.33 -+1.75) bladed tabular calcite crystals at various angles grouped together or medium and large (0.38-0.70 mm, ϕ = +1.39 -+0.52) interlocking platy and sub-euhedral calcite crystals with different extinction angles grouped together, sometimes in unusual patterns enclosing iron-oxides-stained blotches. It is possible that a few scattered tiny and very small carbonate rhombs may be dolomite, with or without iron oxides staining. Elsewhere very small or small recrystallized non-iron-oxides-stained calcite crystals are either thinly scattered or regularly spaced densely through the ultra-fine-grained iron-oxides-stained calcite matrix, with the scattered small iron oxides blotches still present, and sometimes patches of the cleaner recrystallized calcite grains merge with the surrounding iron-oxides-stained dense calcite matrix. The general iron oxides staining sometimes encroaches on the K-feldspar and quartz grains, but in some instances may be accompanying possible illite alteration of the edges of the K-feldspar grains and perhaps also of the edge-on muscovite flakes. In a fracture zone parallel to the bedding the calcite matrix has been recrystallized into long linear patches that like the edge-on muscovite flakes parallel the fracture zone and the bedding, while the illite alteration of K-feldspar grains seems more pronounced and there appear to be some tiny iron-oxides-stained dolomite rhombs. In some places very small, small and small-medium (0.06-0.24 mm, ϕ = +4.05 - +2.06) “skeletal” dolomite rhombs (iron oxides coating the cores with “clean” outer growth zones) are randomly disturbed in the calcite matrix, perhaps appearing to be the result of growth from altering the calcite in which they are solidly wedged in continuum with the calcite matrix of very small-small crystals, evidenced in some instances by what appears to the dense iron-oxides-stained calcite matrix in the cores of the dolomite rhombs. Very scattered, very small and small grains which have a blotchy appearance due to light iron oxides staining probably accompanying illite alteration may possibly be plagioclase. Some large areas where the iron oxides staining of the calcite matrix and the scattered K-feldspar and quartz grains included in it is very intense, though some grains and the thin edge-on muscovite flakes are still visible. Several distinctive sharp-edged, thick linear, long and very long curvilinear, and “worm-like”, non-iron-oxides-stained zones of recrystallized(?) calcite matrix shaped like the cross-sections of various different fossil shells (bivalves and brachiopods) sit firmly wedged in the dense iron-oxides-stained calcite matrix. Sometimes these possible cross-sections of fossils shells seem to be broken fragments. Two relatively thick, what appear to be, “clean” calcite veins cross-cut the rock fabric almost perpendicular to the bedding. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is occasional blue dye staining between and encroaching on some grains, sometimes covering grains and thus distorting their colors, as well as along hairline fractures and fracture zones.

MLS-03 N 36° 11.633’ W 113° 05.433’ (N 36.194° 113.091°)

RM 180.2 – river left below Son of Lava Rapid, 1 foot (0.3 m) below the tuff bed sampled for the RATE zircon fission-track ages study (Snelling 2005b). Top of the Peach Springs Member of the Muav Formation.



At normal scale, this rock in the thin section almost looks like a carbonate breccia, but closer scrutiny indicates that it is also a micrite (calcite mud) supported limestone that can best be classified as a wackstone because of its content of quartz, K-feldspar and muscovite grains of ~25%, with remainder of being calcite (~71%) and dolomite (~3%). The upper part of the sample (left) shows the original depositional laminated bedding. So, the irregular patches in the remainder of the sample are suggestive of lighter-colored calcite recrystallized (most likely post-deposition) from the darker-colored micrite that constitutes the laminated limestone in the upper part of the sample. Many of the pink curvilinear fragments appear to be fossil shells fragments of bivalves and brachiopods, though other such biogenic clasts are rounded. The scattered dolomite likely replaces calcite grains, and some pink streaks would appear to be calcite veinlets, suggesting calcite remobilization also.

Under the microscope, scattered tiny to very small (0.02-0.15 mm, ϕ = +5.71 - +2.75) sub-angular to sub-rounded and sub-euhedral K-feldspar grains (sometimes exhibiting cross-hatched twinning under crossed polars) and tiny to very small-small (0.02-0.22 mm, ϕ = +5.71 - +2.19) sub-angular to sub-rounded quartz grains and angular fragments (some quite elongated and long), with many scattered very small to very long (0.04-0.76 mm, ϕ = +4.64 - +0.40), thin edge-on muscovite flakes (at various angles but often parallel to the bedding, and are sometimes bent) and numerous evenly scattered very small blotches of iron oxides, set in an ultra to fine-grained (0.02-0.12 mm, ϕ = +5.71 - +3.06, mud-coarse silt-very fine sand particle size) densely packed calcite matrix which is variably stained with iron oxides, sometimes lightly but otherwise heavily dusted. Long, thin streaks of iron oxides appear to be due to alteration of some edge-on muscovite flakes. There are long and very long (up to 3 mm), sharply-defined, thick linear and curvilinear areas where the micro-crystalline calcite matrix is clean of iron oxides staining that would appear to represent the cross-sections through various different fossil shells (bivalves and brachiopods) and sit firmly wedged in the otherwise variously iron-oxides-stained calcite matrix. One occurrence of an ovoid area of tiny spots of clean micro-crystalline calcite matrix is also suggestive of representing the cross-section through some micro-fossil. Some of the calcite matrix appears to be recrystallized as tiny "clean" (non-iron-oxides-stained) calcite crystals, often scattered evenly through the calcite matrix. The edges of some K-feldspar grains appear to be altered, probably to illite. Some areas of the calcite matrix have been recrystallized to clean (non-iron-oxides-stained) interlocking small to medium (0.14-0.35 mm, ϕ = +2.84 - +1.50) and large (0.47-0.65 mm, ϕ = +1.09 - +0.58) calcite crystals at different extinction angles, while other areas of the matrix are also recrystallized to calcite crystals, but they are small-medium and variably lightly stained with iron oxides, sometimes with a stark sharp linear boundary with the adjoining densely iron-oxides-stained ultra to fine-grained calcite matrix, and sometimes grading gradually into the regular calcite matrix or the smaller-grained recrystallized calcite matrix. One area consists of a very large platy calcite crystal with very few K-feldspar and quartz grains embedded in it, but with remnants of the regular ultra-fine-grained calcite matrix (with more K-feldspar and quartz grains set in it) from which it recrystallized. Several sharply defined areas of the densely iron-oxides-stained ultra to fine-grained calcite matrix are ovoid in shape, surrounded by relatively "clean" recrystallized matrix. Some areas of the densely iron-oxides-stained ultra to fine-grained calcite matrix contain a much higher density (number) of tiny-very small K-feldspar and quartz grains and angular fragments so they make up at least 60% of the rock fabric, but many of those grains have fuzzy edges due to illite alteration or the calcite matric encroaching on them. Some small thin edge-on muscovite flakes transverse between the densely iron- oxides-stained ultra-fine-grained calcite matrix and the areas recrystallized clean (non-iron-oxides-stained) interlocking small to medium-large calcite crystals, and are included in the latter, indicating the muscovite was not altered or impacted by the calcite recrystallization process. Several medium and large recrystallized calcite crystals appear to be sub-angular to sub-rounded clasts that are surrounded by a matrix consisting of small and very small calcite crystals (some of which also look like clasts) with K-feldspar and quartz grains included and variable iron oxides staining and small blotches or surrounded by the densely iron-oxides-stained ultra to fine-grained calcite matrix. A few areas of recrystallized calcite matrix contain scattered and clumped tiny and very small (0.02-0.06 mm, ϕ = +5.71 - +4.05) dolomite rhombs, highlighted by blue dye staining from impregnation of the sample. Some of these tiny and very small (blue-dye-stained) dolomite rhombs are clumped with tiny and very small, recrystallized calcite grains around the inside perimeter within the circular cross-section of a fossil shell, consisting of "clean" micro-crystalline calcite. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is occasional blue dye staining between and encroaching on some grains, sometimes covering grains and thus distorting their colors, as well as along hairline fractures and fracture zones.

Matkatamiba Fold (River Mile 148.8) Samples

N 36° 23.553’   W 112° 37.558’   (N 36.393°   W 112.626°)

RM 148.8 – river right, near the base of the vertical cliff rising above the long, steep slope up from the river-bank.

MFML-01   N 36° 23.553’   W 112° 37.558’   (N 36.392°   W 112.626°)

Top of the Gateway Canyon Member of the Muav Formation, upstream away from the hinge zones of the fold.

At normal scale, this rock in the thin section looks somewhat like are fine-grained carbonate siltstone rather than a limestone, because its lighter color highlights its content dominated by quartz and K-feldspar grains (~26 % each) accompanied by muscovite flakes (likely ~5%), the remainder being calcite (~22%) and dolomite (~20%). As a limestone in outcrop and hand specimen this would be thus classified as a wackestone, a mud-supported limestone with >10% clastic grains. There is a clear indication of the original bedding in the sample, so the fairly equi-granular rock fabric is clearly due to the original deposition. Since calcite exhibits a pinkish stain, the calcite grains appear to be scattered through the rock likely as cement, though there is a concentration of them in a patch (upper right in the thin section). The lighter color of the rock would suggest the subordinate dolomite is also scattered through the rock fabric and thus is likely replacing the calcite cement. The greenish tinge in scattered grains, streaks and fractures likely represents post-depositional illite alteration, probably of K-feldspar as glauconite.

Under the microscope, scattered and sometimes interlocking tiny to very small (0.03-0.14 mm, ϕ = +5.01 - +2.84) and small (0.17-0.27 mm, ϕ = +2.57 - +1.90), angular and sub-angular to sub-rounded quartz grains and fragments (often irregularly shaped, sometimes even elongated, with fuzzy and/or jagged edges) and tiny to very small (0.03-0.15 mm ϕ = +5.01 - +2.75), sub-euhedral, angular and sub-angular to sub-rounded K-feldspar grains (some exhibiting striping under crossed polars), former laths and fragments, with numerous tiny to small in length (0.04-0.21 mm, ϕ = +4.64 - +2.25), thin edge-on muscovite flakes at various angles including some parallel to the bedding (sometimes thicker with frayed ends or are bent) wedged between other grains, are set in a dolomite matrix of tiny to very small (0.03-0.09 mm, ϕ = +5.01 - +3.47) densely-packed grains that are stained with iron oxides, which is minor in some areas but is a major part of the rock fabric in other areas, and occasionally in those areas where the dolomite matrix is major it has been recrystallized into very small to large (0.11-0.76 mm, ϕ = +3.19 - +0.40) irregularly-shaped and raggedly-shaped or sub-euhedral to sub-angular crystalline patches (or sometimes micro-crystalline patches that have included other mosaic grains in them) or crystals that still cement some of the mosaic, or has been recrystallized into tiny, very small and small (0.03-0.23 mm, ϕ = +5.01 - +2.13) rhombs outlined by iron oxides. Additionally, there are occasional scattered tiny and very small (0.04-0.12 mm, ϕ = +4.64 - +3.06), sub-angular calcite grains that appear to be detrital and/or cement/matrix and dominate in some areas instead of the dolomite cement, and occasionally there are small to medium (0.14-0.48 mm, ϕ = +2.84 - +1.06), elongated and thick micro-crystalline calcite grains that are at various angles and appear to be cross-sections through fossil shells (bivalves and brachiopods). In some cases, what is likely recrystallized calcite matrix occurs as long and thick, ragged-edged, or round irregular-edged (framboid-like with possible sieve-like texture), micro-crystalline masses that are also iron-oxides-stained, particularly around their edges and sometimes weave their way between other mosaic grains. Some of the K-feldspar grains are stained green, possibly indicating some illite alteration to glauconite (0.04-0.22 mm,

ϕ = +4.64 - +2.19), while several tiny-very small (0.04 mm, ϕ = +4.64) rounded heavily iron-oxides-stained grains with high relief and high birefringence are likely zircon. Occasional very small irregular heavy iron oxides blotches are scattered within the rock fabric between and encroaching on various mosaic grains. Sometimes the dolomite matrix and/or the recrystallized dolomite rhombs encroach on the edges of other mosaic grains. Where the quartz and K-feldspar grains are interlocking, including quartz grains with other quartz grains and K-feldspar grains with other K-feldspar grains, the edges often meet at triple points. In some places the calcite grains between the other mosaic grains are more numerous and become the dominant though still minor matrix/cement. Some quartz grains have internal "ghost" outlines of faint iron oxides suggesting some overgrowths in optical continuity have cemented adjoining quartz and K-feldspar grains, which do occur in clumps, which means some silica cementing has occurred along with, likely prior to, the carbonate cementing. Sometimes the large (0.47-0.76 mm, ϕ = +1.09 - +0.40) crystals probably produced by recrystallization of the dolomite matrix have portions on their fringes or their centers (cores) that are calcite (as evidenced by the pink stain), which possibly suggests that the dolomite may have replaced the calcite or the calcite has replaced the dolomite, possibly the former. In several places the dolomite matrix of tiny densely-packed grains occur in thick bands between the other mosaic grains that are heavily stained with iron oxides, but within the bands are numerous tiny to small (0.04-0.21 mm long, ϕ = +4.64 - +2.25), thin edge-on muscovite flakes parallel to them. In other places the long and thick micro-crystalline grains that appear to be cross-sections through fossil shells consist of iron-oxide-stained microcrystalline dolomite which must have replaced the original microcrystalline calcite. Finally, one area of the rock fabric is dominated by carbonate, with a few scattered quartz, and K-feldspar grains (some greenish from illite alteration) and rare edge-on muscovite flakes embedded in a dominant mass of recrystallized calcite (generally micro-crystalline) cement, with several large dolomite rhombs, some incompletely grown with the appearance of having grown to replace the massive area of calcite cement (one with an apparent microcrystalline calcite core), as some of the scattered quartz and K-feldspar grains are also embedded in the rhombs. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is occasional blue dye staining between and encroaching on some grains, sometimes covering grains and thus distorting their colors, as well as along hairline fractures.

MFML-02 N 36° 20.557' W 112° 40.701' (N 36.343° W 112.678°)
Top of the Gateway Canyon Member of the Muav Formation 47.5 m (156 feet) along the bed west/downstream of sample MFML-01.
At normal scale, this rock in the thin section again looks somewhat like are fine-grained carbonate siltstone rather than a limestone, which is to be expected because it is from the same stratigraphic interval,

47.5 m laterally from the previous sample. Its lighter color highlights its content dominated by quartz (~28%) and K-feldspar (~25 %) grains accompanied by muscovite flakes (likely <1%), the remainder being calcite (~20%) and dolomite (~27%). As a limestone in outcrop and hand specimen this would be thus classified as a wackestone. The original bedding is clearly evident in the sample as parallel laminations, so the fairly equi-granular rock fabric is clearly due to the original deposition. Since the calcite exhibits a dark pinkish stain, the calcite grains appear to be scattered through the rock likely as cement, though there are concentrations of them in streaks that appear to follow the laminations. The lighter color of the rock would suggest the more dominant dolomite is also scattered through the rock fabric and thus is likely replacing the calcite cement. The greenish tinge in scattered grains and streaks likely represents post-depositional illite alteration, probably of K-feldspar as glauconite.

Under the microscope, scattered and sometimes interlocking tiny to very small (0.03-0.14 mm, ϕ = +5.01 - +2.84), angular and sub-angular to sub-rounded quartz grains and fragments (often irregularly-shaped or even elongated), and tiny to very small (0.03-0.15 mm, ϕ = +5.01 - +2.75), angular and sub-angular to sub-rounded K-feldspar grains, with occasional tiny to small (0.04-0.20 mm long, ϕ = +4.64 - +2.33), thin or sometimes thick, edge-on muscovite flakes at various angles (but often parallel to the bedding, sometimes degraded and sometimes with frayed ends and/or are bent) wedged between the other grains, are set in a dolomite matrix of very small (0.09-0.12 mm, ϕ = +3.47 - +3.06) densely-packed grains, or sometimes scattered very small rhombs, or sometimes patches consisting of several grains or rhombs, that in each case are stained with iron oxides, but also with occasional minimally iron-oxides-stained small (0.15-0.20 mm, ϕ = +2.75 - +2.33), medium (0.26-0.36 mm, ϕ = +1.95 - +1.46) and large (0.44-0.63 mm, ϕ = +1.15 - +0.67) recrystallized dolomite sub-euhedral to irregular patches that have mosaic quartz and K-feldspar grains embedded in them, and then also some iron-oxides-stained very small to small-medium (0.04-0.20 mm, ϕ = +4.64 - +2.33), irregular sub-round calcite grains, some of which look like framboids and have their perimeters surrounded by dolomite suggesting dolomite replacement of calcite. Indeed, some of the dolomite patches also have pink-stained calcite cores. In some places, medium to large clumps of the very small densely-packed dolomite matrix grains have cores areas with the pink stain indicative of calcite, so this is also evidence that dolomite has replaced calcite. Iron oxides not only stain the dolomite matrix heavily, but also occurs as tiny, small and medium blotches between grains and covering other grains. Where the quartz and K-feldspar grains are clumped together and interlocking, sometimes in bands across the rock fabric, the grains have irregular shapes, so their edges often meet at triple points. This indicates that the original quartz grains have been overgrown in optical continuity, sometimes with "ghost" outlines but often without leaving any, thus cementing the adjoining quartz and K-feldspar grains, which means some silica cementing occurred along with, and likely prior to, the carbonate cementing. Some areas are dominated by the mosaic of quartz and K-feldspar grains with scattered, similar-sized calcite (pink-stained) and dolomite (iron-oxides-stained though with some retained pink staining) between them, whereas adjoining areas are dominated by densely-packed very small dolomite grains and occasional rhombs (all iron-oxides-stained though with some retained pink staining indicative of some calcite content) with only a few scattered tiny to very small quartz and K-feldspar grains, though both areas contain occasional tiny to small, thin edge-on muscovite flakes parallel to the bedding. Other areas of both scattered and clumped quartz and K-feldspar grains are dominantly cemented by tiny to very small calcite grains and irregularly interstitial small patches, or larger patches of adjoining grains, that are heavily iron-oxides-stained, though some dolomite grains are also present (heavily iron-oxides-stained too). Several huge patches or bands of recrystallized dolomite consist of large, minimally iron-oxides-stained, sub-euhedral "platy" crystals adjoining one another and generally meeting at triple points with minimal inclusion of other mosaic grains which peripherally abut and impinge on the bands/patches – quartz, K-feldspar and heavily iron-oxides-stained calcite grains. In another area the rock fabric is dominated by carbonate grains/crystals as cement – small and medium recrystallized minimally iron-oxides-stained dolomite crystals, small "rosettes" consisting of pink-stained calcite cores surrounded by overgrown "clean" dolomite, and very small iron-oxides-stained, pink-stained calcite grains, with only scattered very small quartz and K-feldspar grains. Occasional heavily but uniformly spread dark brown iron-oxides-stained large irregularly shaped dolomite patches between medium "clean" dolomite patches and crystals, and surrounding quartz, K-feldspar and calcite grains. Calcite replaces or coats several small or long, thick, bent or broken edge-on muscovite flakes with frayed ends, and also in the same areas is scattered as interstitial cement in grains and elongated irregular patches weaving between other mosaic grains. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is occasional blue dye staining between and encroaching on some grains, sometimes covering grains and thus distorting their colors, as well as along hairline fractures.

MFML-03   N 36° 20.408’   W 112° 40.497’   (N 36.340°   W 112.675°)

Top of the Gateway Canyon Member of the Muav Formation 13.5 m (44 feet) along the bed west/downstream of sample MFML-02.

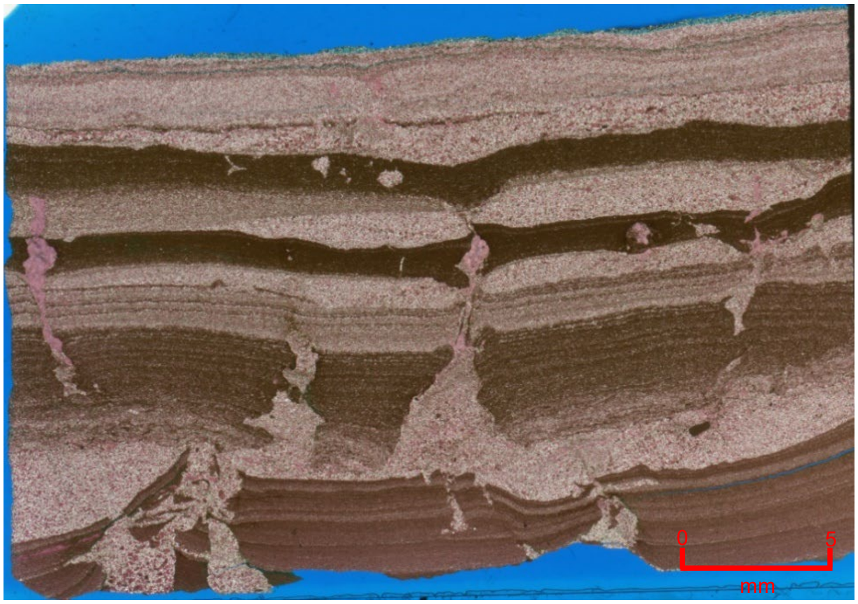
At normal scale, this rock in the thin section again looks somewhat like are fine-grained carbonate siltstone rather than a limestone, which is to be expected because it is from the same stratigraphic interval, 13.5 m laterally from the previous sample. Its lighter color highlights its content dominated by quartz (~39%) and K-feldspar (~26 %) grains accompanied by muscovite flakes (likely <1%), the remainder being calcite (~31%) and dolomite (~3%). As a limestone in outcrop and hand specimen this would be thus classified as a wackestone, a mud-supported limestone with >10% clastic grains. The original bedding is very clearly evident in this sample as parallel laminations, some closely-spaced, while there is also a hint of some cross-laminations, so the fairly equi-granular rock fabric is clearly due to the original deposition. Since the calcite exhibits a dark pinkish stain, the calcite grains appear to be scattered through the rock likely as cement, though there may be concentrations of them following the laminations. The lighter color of the rock reflects the high quartz grain content but would also suggest the very subordinate dolomite is also scattered through the rock fabric and thus is likely replacing some of the calcite cement. The minor greenish tinge in scattered grains and streaks likely represents post-depositional illite alteration, probably of K-feldspar as glauconite.

Under the microscope, an interlocking mosaic dominated by tiny to very small (0.02-0.12 mm, ϕ = +5.71 - +3.06), angular and sub-angular to sub-rounded quartz grains and fragments, and subordinate tiny to very small (0.02-0.11 mm, ϕ = +5.71 - +3.19), angular and sub-angular to subrounded K-feldspar grains and laths (occasionally exhibiting cross-hatched twinning under crossed polars), with many tiny to small-medium in length (0.03-0.33 mm, ϕ = +5.01 - +1.60), thin or thicker, edge-on muscovite flakes at various angles (but often parallel to the bedding, sometimes several stacked on top of one another, and sometimes bent or broken, and/or with frayed ends) wedged between the other grains, and numerous scattered tiny to very small (0.03-0.13 mm, ϕ = +5.01 - +2.95) interstitial calcite grains and occasional rhombs, pink-stained and often iron oxides stained (sometimes heavily), usually isolated between other mosaic grains but sometimes connected to one another in small to very large patches (the latter with tiny quartz grains embedded in them), all acting as cement. Where the quartz and K-feldspar grains are usually interlocking, and sometimes clumped together, the grains have irregular shapes, so their edges often meet at triple points. This indicates that the original quartz grains have been overgrown in optical continuity without leaving any "ghost" outlines, thus cementing the adjoining quartz and K-feldspar grains, which means some silica cementing occurred along with, and likely prior to, the carbonate cementing. Occasional scattered very small (0.04-0.12 mm, ϕ = +4.64 - +3.06), sub-angular to rounded, often irregularly-shaped, "clean" or lightly to heavily iron-oxides-stained dolomite grains and rhombs (some large enough to show "skeletal" zoning of growth zones), and sometimes in clumps, are wedged between the other mosaic grains adding to the carbonate cement, sometimes with pink stains within them indicating possible partial replacement of original calcite. Otherwise, some calcite grains have tiny spots of dolomite replacement around some of their edges, while sometimes the calcite and particularly dolomite cement appears to encroach on mosaic grains such as quartz. Occasional scattered very tiny-tiny irregularly-shaped iron oxide blotches are between mosaic grains but sometimes encroach on them. Rare greenish-stained, tiny to very small (0.03-0.06 mm, ϕ = +5.01 - +4.05), subrounded K-feldspar(?) grains and fragments may be partially altered to illite or glauconite. A large irregularly-shaped patch of recrystallized calcite engulfs several mosaic quartz and K-feldspar grains as well as including some "clean" dolomite grains, so perhaps this recrystallization happened after dolomitization of some of the calcite. The rock fabric has a general lamination/layering parallel to the bedding marked by lineations with lined up edge-on muscovite flakes, quartz grains and other mosaic grains, and the interstitial calcite and dolomite cement. There also appears to be some subtle variations in the sizes of the mosaic grains, particularly quartz, with some bands/areas/laminae having generally slightly larger grains, dominantly very small quartz and K-feldspar grains and "cleaner" calcite and dolomite cement grains, whereas other bands/areas/laminae are dominated by tiny mosaic grains and iron-stained carbonate cement grains. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is abundant blue dye staining between and encroaching on many grains, sometimes covering grains and thus distorting their colors, as well as along hairline fractures.

<u>MFML-04</u> N 36° 20.462' W 112° 40.655' (N 36.341° W 112.678°)

Top of the Gateway Canyon Member of the Muav Formation 7.5 m (24 feet) along the bed west/downstream of sample MFML-03. Area of most intense folding.

At normal scale, this rock in the thin section is different to the previous samples at the same stratigraphic interval, even though this sample is only 7.5 m away from neighboring sample MFML-03. While there are laminae of the same fine-grained carbonate siltstone, there are alternating laminae of micrite (calcite mud). And within these laminae are even finer thin laminae, sometimes also alternating between

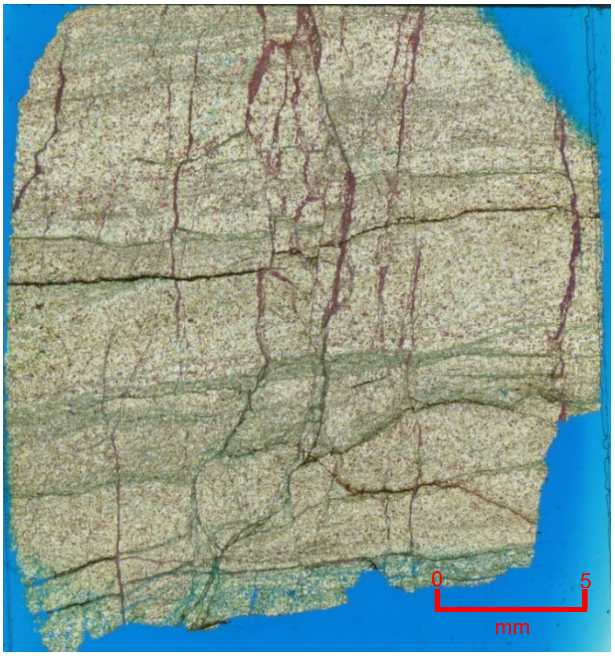


carbonate siltstone and micrite. It is also immediately apparent that very soon after deposition these laminae were disturbed, as some of the fine-grained silt has moved through breaks in the micrite laminae, intruding like diapirs and veins, or injectites. The dark pinkish color through the rock is indicative of its dominant calcite content (~51%) with subordinate dolomite (~17%), the calcite grains not just being concentrated in the micrite laminae but are also scattered through the finer-grained siltstone laminae, which also contain quartz (~12%) and K-feldspar (~15%) grains and muscovite (>2%) flakes. Even so, as a limestone in outcrop and hand specimen due to its dominant carbonate content, this rock essentially would still be thus classified as a wackestone due to its many quartz and K-feldspar grains. An in it the primary depositional alternating laminae have been preserved, along with the immediate post-depositional disturbance of some of the laminae.

Under the microscope, subordinate tiny (0.02-0.06 mm, ϕ = +5.71 - +4.05) K-feldspar and quartz grains with irregular edges and shapes in an interlocking mosaic with dominant tiny (0.03-0.06 mm, ϕ = +5.01 - +4.05) calcite grains as the cement, variably stained by iron oxides, which also occurs as scattered specks between and mostly on grains. Occasional scattered tiny (0.03-0.06 mm long, ϕ = +5.01 - +4.05) thin edge-on muscovite flakes are generally parallel the bedding. Laminae are evident in the rock fabric, the main difference between some adjoining laminae appearing to be the intensity of the iron oxides staining, because otherwise the make-up of the rock, including the scattered edge-on muscovite flakes, seems to be essentially the same, although there often also appears to be some graded bedding, with slightly coarser grains in the less iron-oxides-stained laminae compared with the slightly finer-grained mosaic in the more intensely iron-oxides-stained laminae. In stark contrast, elsewhere some laminae consist of a much coarser-grained mosaic of about equally dominant very small to small (0.07-0.14 mm, ϕ = +3.77 - +2.84) sub-angular K-feldspar and quartz grains, and occasional very small to small (0.07-0.19 mm long, ϕ = +3.77 - +2.40) thin edge-on muscovite flakes at various angles, with about equally dominant very small to small (0.07-0.14 mm, ϕ = +3.77 - +2.84) interstitial calcite, and some tiny to very small (0.02-0.07 mm, ϕ = +5.71 - + 3.77) dolomite, grains as cement and variably iron-oxide-stained with scattered iron oxides specks, although adjoining areas have dominantly interstitial carbonate cement (including some large patches of it) or dominantly other mosaic grains. In adjacent areas the coarser-grained mosaic rock material appears to have been "injected" between segments of the finer-grained mosaic laminae on either side of them (both containing tiny edge-on muscovite flakes), which would thus have had to occur while the rock was still soft and the carbonate cement not fully hardened. In the coarser-grained mosaic the tiny to very small K-feldspar grains and laths and quartz grains and fragments are sub-angular to sub-rounded, and with the occasional tiny to very small thin edge-on muscovite flakes at various angles and occasional tiny iron oxides specks and blotches "float" in the dominant interstitial pink-stained calcite cement, though some dolomite grains and rhombs (both "clean" and iron-oxides-stained) are also part of the mosaic and may partially replace some tiny to very small (0.02-0.06 mm, ϕ = +5.71 - + 4.05) K-feldspar grains, which rarely may instead be partially altered to (greenish stained) illite or glauconite. Variably wide bands of recrystallized calcite, consisting of very small to small crystals (0.07-0.14 mm, ϕ = +3.77 - +2.84), with very tiny quartz grains embedded in them sit parallel to and between the variably iron-oxides-stained laminae, except where a mushroom-shaped "lobe" has "upwelled" into the adjoining heavily iron-oxides-stained band/area. In one area the banded laminae of the rock fabric have been disrupted at a steep angle, with the bands (which still include tiny thin edge-on muscovite flakes parallel to the laminae) delineated by the variable intensity of iron oxides staining and the different grains sizes of the mosaic and cement grains (very tiny versus very small), the latter including small, recrystallized grains in some bands. Often within the bands/laminae the iron oxides staining, and the iron oxides specks and coated grains help define the lineations parallel to the laminae boundaries. In another apparently disrupted zone perpendicular to the bedding there is a large vein-like area of recrystallized small to medium (0.16-0.23 mm, ϕ = +2.66 -+2.13) calcite crystals with different extinction angles and some tiny quartz grains embedded in them changing laterally into the regular mosaic grains and interstitial calcite cement, all between iron-oxide-stained "fractures" on either side. Similarly, there are two adjacent huge circular areas of recrystallized small to medium crystals with different extinction angles with irregular edges that merge with the surrounding regular mosaic grains and very small interstitial calcite and dolomite cement grains. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains, occasionally covering grains and thus distorting their colors, as well as associated with hairline fractures.

MFML-05 N 36° 20.470’ W 112° 40.630’ (N 36.341° W 112.677°)

Top of the Gateway Canyon Member of the Muav Formation 4 m (13 feet) along the bed west/downstream of sample MFML-04. Area of most intense folding.



At normal scale, this rock in the thin section is similar to the first three samples (MFML-01 through MFML-03) laterally nearby at the same stratigraphic interval, but different from the neighboring sample MFML-04 only 4 m away. It looks somewhat like are fine-grained carbonate siltstone rather than a limestone. Its lighter color highlights its content dominated by quartz (~35%) and K-feldspar (~17%) grains and muscovite (<0.5%) flakes, but calcite (~44%) grains still dominate with subordinate dolomite (~4%). As a limestone in outcrop and hand specimen this would be thus classified as a wackestone. The original bedding is very clearly evident in this sample as parallel laminations and bands, a few closely-spaced, while there is also a hint of some cross-laminations, so the fairly equi-granular rock fabric is clearly due to the original deposition. Since the calcite exhibits a dark pinkish stain, the calcite grains appear to be scattered through the rock likely as cement, though there may be concentrations of them following the laminations. Dark pinkish calcite also fills thin post-depositional fractures as veinlets cross-cutting the laminations and bands. The lighter overall color of the rock reflects the high quartz grain content but would also suggest the very subordinate dolomite is also scattered through the rock fabric and thus is likely replacing some of the calcite cement. The minor greenish tinge in scattered grains and streaks likely represents post-depositional illite alteration, probably of K-feldspar as glauconite.

Under the microscope, a tightly-fitting, interlocking mosaic of predominant tiny to very small (0.03-0.17 mm, $\phi = +5.01 - +2.57$), angular and sub-angular to sub-rounded (some irregularly-shaped) quartz grains and subordinate tiny to very small (0.03-0.15 mm, $\phi = +5.01 - +2.75$), often irregularly-shaped, sub-angular to sub-rounded K-feldspar grains and laths with occasional very small (0.04-0.17 mm, $\phi = +4.64 - +2.57$), and rare small (0.20-0.22 mm, $\phi = +2.33 - +2.19$), thin edge-on muscovite flakes at various angles but generally parallel to the bedding, scattered tiny to very small (0.03-0.18 mm, $\phi = +5.01 - +2.48$), and occasionally small (0.21-0.29 mm, $\phi = +2.25 - +1.80$), irregularly-shaped grains in patches and stringers of interstitial calcite cement (some variably iron-oxides-stained or sometimes recrystallized), the amount of which varies through the rock, and occasional very tiny-tiny iron oxides specks. Often many of the quartz grains are tightly clumped together with faint edges so the clumps look like single large grains, and the junctions of their edges, and with the edges of adjacent K-feldspar grains, often meet at triple points. With no pores this is indicative of quartz overgrowths to bind the grains together, even if there are no "ghost" outlines of the original detrital grains. Similarly, some K-feldspar grains can be clumped together with edges meeting at triple points, and with quartz grains and calcite cement too, some of the latter being partially sub-euhedral. In some areas the mosaic quartz and K-feldspar grains are much smaller (tiny) and are accompanied by likely dolomite alteration compared to general mosaic of very small grains. in adjoining areas. Occasional very small (0.04-0.14 mm, ϕ = +4.64 - +2.84), sub-euhedral and sub-angular to sub-rounded dolomite grains are wedged within the mosaic between quartz and K-feldspar grains, possibly replacing the interstitial calcite cement and sometimes possibly mosaic K-feldspar grains. Some very small (0.04-0.11 mm, ϕ = +4.23 - + 3.19) K-feldspar grains may be partially altered to greenish-stained illite or glauconite. Thin parallel stringers and veins of calcite, sometimes accompanied by elongated blotches and stringers of iron oxides, cross-cut the rock fabric approximately perpendicular to the bedding and appear to fill fracture zones, sometimes close together or even anastomosing, in which the adjacent quartz and K-feldspar grains are tiny and angular. Sometimes within these calcite veins and/or accompanying them within the same vein or as a separate veinlet are what appear to be very small sub-euhedral grains of dolomite that may either be replacing calcite or mosaic K-feldspar grains, so could indicate minor dolomitization as a late effect. Sometimes this dolomite alteration accompanying a calcite vein network also spreads into the adjoining mosaic (which may also be smaller-grained zones parallel to the bedding than the adjoining regular mosaic, potentially due to being crushed) to alter the mosaic grains and particularly replace the calcite cement. In one instance one of these thin veins of calcite cross-cuts the rock fabric at a lower oblique angle to the bedding with the calcite generally iron-oxides-stained at the vein edges which were at a fairly consistent width apart. In all these instances there does not appear to have been any fracturing, crushing or dislocation of mosaic grains during the introduction of the veins along the fracture planes and zones. In some other parts of the rock fabric though the interlocking mosaic of quartz and K-feldspar grains appears to be fractured at an oblique angle across the field of view by a network zone of fractures so that the mosaic grains are tinier and angular, and some are elongated fragments, being aligned parallel to the fracturing, with many tiny thin edge-on muscovite similarly aligned. Thin stringers of iron oxide and thicker veins of iron oxides (or possibly iron-oxides-coated calcite) cross-cut the mosaic parallel to the bedding (following other possible fractures or bedding planes?) and also cross-cut calcite veins or veinlets perpendicular to the bedding. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains, occasionally covering grains and thus distorting their colors, as well as associated with hairline fractures, some of which were likely induced during sample impregnation.

MFML-06 N 36° 20.368' W 112° 40.643' (N 36.339° W 112.677°)

Folded limestone bed at the top of the Gateway Canyon Member of the Muav Formation. Sample taken from the bend in the top of the monocline, about 3 m (10 feet) below the contact, about 6 m (19.5 feet) west/downstream from sample MFML-05.

At normal scale, this rock in the thin section is different again from the preceding samples from the same stratigraphic interval even though it has some similarities, yet this sample is laterally only about 6 m from the neighboring sample. It consists of quartz (~7%) and K-feldspar (~9%) grains and muscovite (<1%) flakes embedded in a dominant, pink-stained calcite (~75%) matrix with some subordinate dolomite (~8%). Because the silicate grains are so prevalent and large enough to be visible this rock is a silty carbonate, even though in outcrop it appears to be a limestone. It is best classified as a wackestone. It has suffered from soft-sediment deformation because the original layers have been disturbed after their deposition, as evidenced by the "blobs" and "swirls" made up similarly to the regular layering in the rock. While the silicate grains appear to "float" in the calcite matrix, there are more dense accumulations. Several large curvilinear solid calcite features appear to be cross-sections of fossilized bivalve shells. Other areas in the rock show "swirling" layers and disconnected "blobs" that are greenish, likely due to post-depositional illite alteration of K-feldspar grains to glauconite, plus possible iron oxides staining.

Under the microscope, variably scattered tiny to very small (0.03-0.17 mm, $\phi = +5.01 - +2.57$) and small (0.19-0.26 mm, $\phi = +2.40 - +1.95$), angular and sub-angular to subrounded and rounded K-feldspar clasts and former laths and quartz clasts and fragments (some with cracks and some with ragged or obscured edges) set in a predominant tiny-grained (0.03-0.05 mm, $\phi = +5.01 - +4.23$) calcite matrix or sometimes very small to small (0.07-23 mm, $\phi = +3.77 - +2.13$) interstitial calcite grains (recrystallized?), all variably stained by iron oxides (sometimes heavily stained), with occasional very small (0.04-0.18 mm, $\phi = +4.64 - +2.48$) and small (0.19-0.33 mm, $\phi = +2.40 - +1.60$) in length, thin edge-on muscovite flakes at various angles (even when several are in proximity to one another), and some scattered tiny to very small iron oxides blotches and what appear to be iron-oxides-replaced edge-on muscovite flakes. Some K-feldspar grains and laths exhibit multiple twinning under crossed polars, sometimes even suggesting those grains may be plagioclase. Some thin edge-on muscovite flakes are bent around quartz and K-feldspar grains or simply within the calcite matrix, and/or are broken, sometimes have frayed and/or split ends, and sometimes several are stacked on top of one another. Also present are thin/narrow and some thicker edge-on cross-sections of fossil shells (bivalves and brachiopods) of various sizes and shapes (usually linear but also curvilinear) composed of relatively iron-oxides-free micro-crystalline calcite, though occasionally some are outlined by iron oxide or are quite iron-oxides-stained. Occasional tiny to very small (0.02-0.15 mm, ϕ = +5.71 - +2.75) dolomite rhombs are also set in the calcite matrix and are variably iron-oxides-stained. In some areas of the rock fabric the calcite matrix has been heavily altered to, and replaced by, heavily iron-oxides-stained, tiny to very small (0.02-0.15 mm, ϕ = +5.71 - +2.75) and even small (0.18-0.31 mm, ϕ = +2.48 - +1.70) dolomite sub-euhedral grains and rhombs (the larger rhombs with the characteristic internal skeletal growth zones) that are both scattered and clumped. Some of the dolomite may also be replacing K-feldspar grains. Sometimes patches of the calcite matrix of various shapes from thin and thick linear to irregular ovoids have been recrystallized to relatively iron oxide free microcrystalline calcite, large patches consisting of very small (0.15-0.23 mm, ϕ = +2.75 - +2.13) to small-medium (0.30-0.62 mm, ϕ = +1.75 - +0.69), recrystallized platy calcite crystals and rhombs at different extinction angles (sometimes with quartz and K-feldspar grains still embedded in them), and even to scattered very small recrystallized calcite rhombs. The iron oxides staining of the dominant tiny/fine-grained calcite matrix (micrite) varies, and some swaths are lined either side of them with heavy iron oxides staining as border stringers (sometimes appearing to follow either fractures or bedding planes accompanied by thin edge-on muscovite flakes paralleling them) demarcating the boundaries from the adjoining matrix which is recrystallized to very small-small calcite crystals. In some areas the long thin edge-on muscovite flakes are at the same oblique angle with the elongated quartz and K-feldspar grains aligned parallel at the same angle within the calcite matrix. A few very small (0.04-0.09 mm, ϕ = +4.23 - + 3.47) K-feldspar grains may be partially altered to greenish-stained illite or glauconite. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains, occasionally covering grains and thus distorting their colors, as well as associated with hairline fractures, some of which were likely induced during sample impregnation.

MFTB-01 N 36° 23.553' W 112° 37.558' (N 36.392° W 112.626°)

Bottom of the Havasu Member of the Muav Formation. sample taken from just above the boundary opposite sample MFML-01 from the top of the Gateway Member.

At normal scale, this rock in the thin section is dominated by pink-stained calcite (~71%), but there is subordinate dolomite (~17%) that appears to occur in unstained lighter-colored patches. In outcrop this is a limestone, but the presence of scattered fine quartz (~5%) and K-feldspar (~6%) grains with occasional muscovite (<0.5%) flakes classifies this rock as a wackestone, a mud-supported limestone with >10% clastic grains. There is a hint of fine laminations that may be at an angle to the bedding, but there has clearly been some disturbance of the rock fabric after deposition, as evidenced the lighter, pink-stained calcite veins filling cross-fractures and the wavy and irregular laminations that thicken and thin through disrupted laminations and that are marked by a greenish tinge, likely due to post-depositional illite alteration of K-feldspar grains and sometimes accompanying iron oxides staining. The lighter dolomite patches and streaks appear to be associated with these disrupted laminations and the illite alteration, and with cross-cutting iron oxides in thin fractures. Under the microscope, scattered tiny to very small (0.02-0.12 mm, ϕ = +5.71 - +3.06), angular to sub-rounded K-feldspar and quartz grains (some with ragged or obscured edges), occasional tiny to very small (0.03-0.17 mm, ϕ = +5.01 - +2.57), thin edge-on muscovite flakes, and many tiny to very small (0.02-0.09 mm, ϕ = +5.71 - +3.47), often heavily iron-oxides-stained dolomite rhombs, set in a dominant, very-fine-grained (0.01-0.04 mm, ϕ = +6.72 - +4.64) calcite matrix (micrite) which is variably iron-oxides-stained with iron oxides outlining many tiny calcite grains and rhombs, and with scattered iron oxides speckles, tiny blotches and thin long streaks (which may be replacing edge-on muscovite flakes). In several areas the few tiny quartz and K-feldspar grains, tiny dolomite rhombs and tiny thin edge-on muscovite flakes (and iron oxides streaks probably replacing them) are aligned in "streaks" within the calcite matrix at oblique angles to the bedding. Sometimes medium and large-huge sized patches (some elongated) of the calcite matrix have been recrystallized to very small to small (0.05-0.18 mm, ϕ = +4.23 - +2.40) and medium (0.36 mm, ϕ = +1.46) platy calcite crystals at different extinction angles. The larger dolomite rhombs (which are very small to small, 0.12-0.14 mm, $\phi = +3.06 - +2.84$ and 0.24 mm, $\phi = +2.06$) have internal growth zones with heavily iron-oxides-stained cores and "clean" outer rims giving the rhombs a typical skeletal structure. Some very small thin edge-on muscovite flakes may be stacked on top of one another, and some are bent around the scattered grains and rhombs set in the matrix or wedged tightly between where grains and rhombs are clumped. Throughout the rock fabric some of the K-feldspar grains may be partially or fully altered to or replaced by dolomite. There are also large-huge patches and bands of larger, more densely-scattered or sometimes clumped, very small, angular to sub-rounded quartz and K-feldspar grains (with ragged or obscured edges, and where clumped sometimes meet at triple points), and similar-sized iron oxides blotches, with fine-grained calcite matrix and sometimes some tiny and very small dolomite rhombs between them. In some areas of the fine-grained calcite matrix, fine-grained dolomite grains and rhombs have replaced the calcite grains in patches, and there are also many tiny dolomite rhombs scattered throughout the nearby calcite matrix. There are also medium, large-huge and huge patches and wide bands of the matrix where it has been moderately to largely replaced by tiny to very small, lightly or heavily iron-oxides-stained dolomite grains and rhombs (sometimes densely packed together) with a few to many recrystallized tiny to very small calcite matrix grains and rhombs (and a few tiny to very small quartz and K-feldspar grains and tiny thin edge-on muscovite flakes) scattered between them. Alternately the dolomite replacement of the calcite matrix consists of small, only lightly iron-oxides-stained dolomite rhombs and grains, clumped and intergrown together. What appears to be a fracture cross-cutting the rock fabric roughly perpendicular to the bedding is filled with several adjoining elongated, medium-sized "clean" dolomite crystals and elongated heavy iron oxides patches and streaks. Elsewhere along another possible fracture at an oblique angle almost perpendicular to the bedding the calcite matrix has been recrystallized to adjoining, very small, almost non-iron-oxides-stained calcite crystals (similar to those scattered through the matrix). And in another place a similar apparent fracture is marked by strings of tiny heavily iron-oxides-stained dolomite rhombs and elongated iron oxides blotches and stringers. Elsewhere a thick double small-medium-sized crystal width calcite vein cross-cuts the regular fine-grained calcite matrix at an angle almost perpendicular to the bedding. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains (particularly dolomite rhombs), occasionally covering grains and thus distorting their colors, as well as associated with hairline fractures, some of which were likely induced during sample impregnation.

MFTB-02 N 36° 20.557' W 112° 40.701' (N 36.343° W 112.678°)

Bottom of the Havasu Member of the Muav Formation 47.5 m (156 feet) along the bed west/downstream of sample MFTB-01.

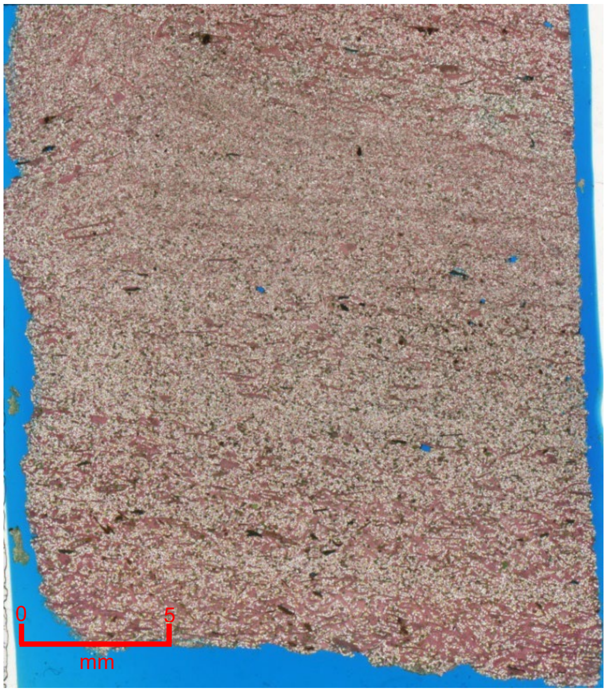
At normal scale, this rock in the thin section looks totally different to the neighboring sample at the same stratigraphic level only 47.5 m away laterally. While in outcrop it is a limestone, in thin section it appears to be a carbonate siltstone, due to abundance in it of quartz (~56%) and K-feldspar (~18%) grains with scattered muscovite (~4%) flakes. Yet abundant scattered, pink-stained calcite mud or micrite (~18%) with minor subordinate dolomite (~4%) is still very evident. Rather than being classified as a wackestone, with mud-supported silicate grains, this is a more like a packstone because of instead being grain-supported. Fine laminations are evident, often being marked by either calcite and/or silicate grains. The rock fabric looks fairly uniform and undisturbed. Quite a few small curvilinear calcite patches scattered through the rock are at various low angles but still sub-parallel to the laminations and bedding and are likely the cross-sections of fossilized shells (bivalves and brachiopods). There are also a few scattered grains with a greenish tinge that are likely due to illite alteration of K-feldspar grains to glauconite.

Under the microscope, scattered but very dominant tiny to very small (0.04-0.12 mm, ϕ = +4.64 - +3.06) and small (0.13-0.20 mm, ϕ = +2.95 - +2.33), very angular-angular and sub-angular to sub-rounded quartz grains and elongated fragments, subordinate tiny to very small (0.04-0.12 mm, ϕ = +4.64 - +3.06) and small (0.13-0.23 mm, ϕ = +2.95 - +2.13), angular and sub-angular to sub-rounded K-feldspar grains, and former laths, occasional very small to small (0.05-0.18 mm, ϕ = +4.23 - +2.48), small (0.20-0.26 mm, ϕ = +2.33 - +1.95), medium (0.30-0.42 mm, ϕ = +1.75 - +1.25) and large/long (0.82 mm, ϕ = +0.29) (and one very long, 1.18 mm, ϕ = -0.23), thin edge-on muscovite flakes at various angles but generally parallel to the bedding, and scattered iron oxides specks and very tiny to small blotches, are all set in a subordinate matrix of calcite consisting of very small (0.05-0.11 mm, ϕ = +4.23 - +3.19), small (0.13-0.17 mm, ϕ = +3.06 - +2.57) and small-medium (0.20-0.47 mm, ϕ = +2.33 - +1.09) crystals (many of which are due to recrystallization, particularly the larger crystals, and thus are set at different extinction angles) which are variably iron-oxides-stained, including along cleavage planes. The density of the scattering of the quartz and K-feldspar grains varies through the rock fabric from a generally wide spacing to places where many grains touch one another and there are occasional small clumps of grains where those grain edges often meet at triple points. Sometimes the edges of the quartz and K-feldspar grains are ragged, being obscured by the calcite matrix encroaching on them. A few of the K-feldspar grains exhibit multiple twinning under crossed polars that could suggests they may instead be plagioclase. Often the edge-on muscovite flakes have one end frayed, some flakes are bent, and sometimes two are stacked on top of one another. The scattered minor, tiny to very small (0.02-0.09 mm, ϕ = +5.71 - +3.47) and very small to small (0.12-0.20 mm, ϕ = +3.06 - +2.33) dolomite grains sometimes appear to be partially replacing some K-feldspar grains and even some edge-on muscovite flakes, while other very small (0.06-0.12 mm, ϕ = +4.05 - +3.06) K-feldspar grains and a few muscovite flakes may have been replaced by illite or glauconite (evident from greenish stain). Within the calcite matrix there are occasional curvilinear and sometimes bent (some completely bent over) cross-sections of fossil shells (bivalves, brachiopods) of varying lengths and thicknesses (one is quite a large rectangular shape), even two possible shell fragments and one medium-large ovoid fossil shell cross-section, that consist of micro-crystalline calcite outlined or sometimes speckled or coated by iron oxide staining. One large elongated ovoid area within the calcite matrix is heavily speckled and outlined by iron oxides staining and contains very few quartz and K-feldspar clasts in stark contrast to their dominating presence in the adjoining calcite matrix, but still contains many very small recrystallized platy calcite crystals. Sometimes large-huge patches of the calcite matrix have been recrystallized into one or several larger calcite crystals (as evident from the distinctive single "rhomboidal" cleavage and each being at different extinction angles) that fully or only peripherally include quartz and K-feldspar grains and fragments (including some illite-altered K-feldspar grains). A tiny high relief, high birefringent, iron-oxides-stained tabular crystal may be zircon. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains (particularly dolomite rhombs), occasionally covering grains and thus distorting their colors.

<u>MFTB-03</u> N 36° 20.408' W 112° 40.497' (N 36.340° W 112.675°)

Bottom of the Havasu Member of the Muav Formation 13.5 m (44 feet) along the bed west/downstream of sample MFTB-02.

At normal scale, this rock in the thin section is almost identical to the neighboring sample MFTB-02 from the same stratigraphic interval only 13.5 m away laterally. While in outcrop this rock is again a limestone, in thin section it looks more like a carbonate siltstone because of its high content of quartz (~20%) and K-feldspar (~16%) grains with scattered muscovite (~1%) flakes set in a pink-stained calcite (~61%) matrix with subordinate dolomite (~2%) and siderite (<1%). Even with a lower abundance of silicate grains this



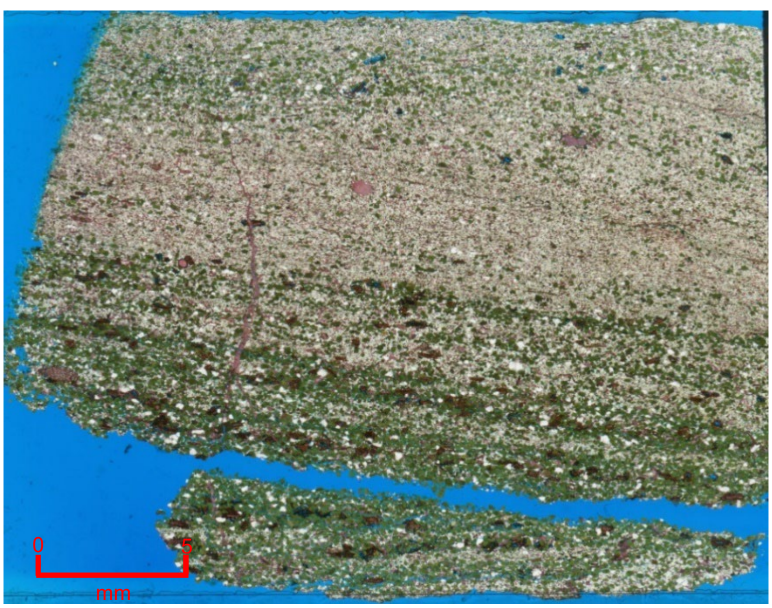
rock would probably still be classified as a grain-supported packstone instead of a mud-supported wackestone as there are no contiguous bands or laminae of only micrite (calcite mud). Fine laminations are very evident, often being marked by either calcite and/or silicate grains. The rock fabric looks fairly uniform and undisturbed, except in one section (top left) where the laminations seem to build into a "wave" or ripple in cross-section. Numerous small curvilinear calcite patches scattered through the rock are at various low angles but still sub-parallel to the laminations and bedding and are likely the cross-sections of fossilized shells (bivalves and brachiopods). There are also a few scattered grains with a greenish tinge that are likely due to illite alteration of K-feldspar grains to glauconite.

Under the microscope, scattered tiny to very small (0.03-0.18 mm, ϕ = +5.01 - +2.48), irregularly-shaped angular to sub-rounded and rounded quartz grains and elongated angular fragments and slivers, subordinate tiny to very small (0.03-0.20 mm, ϕ = +5.01 - +2.33), irregularly-shaped angular to sub-rounded K-feldspar grains and former laths, numerous very small to small (0.04-0.21 mm, ϕ = +4.64), small-medium (0.23-0.30 mm, ϕ = +2.13 - +1.75) or long (0.45-0.47, ϕ = +1.15- +1.09) and very long (1.23 mm, ϕ = -0.30), thin (or sometimes thick) edge-on muscovite flakes at various angles but generally parallel to the bedding, and occasional tiny to very small scattered iron oxides blotches, are all set in a predominant pervasive recrystallized calcite matrix consisting of micrite and very small (0.06-0.12 mm, ϕ = +4.05 - +3.06) and small (0.15-0.20 mm, ϕ = +2.75 - +2.33) to larger (0.27-0.42 mm, ϕ = +1.90 - +1.25) platy calcite crystals at different extinction angles (and sometimes with characteristic cleavage evident), which are lightly iron oxides speckled and stained (or sometimes heavily stained or with iron oxides streaks). The density of the scattering of the quartz and K-feldspar grains varies through the rock fabric from a usual wide spacing to places where there are occasional small clumps of grains, some of whose grain edges meet at triple points. Sometimes the edges of the quartz and K-feldspar grains are ragged, being obscured by the calcite matrix encroaching on them. A few of the K-feldspar grains exhibit multiple twinning under crossed polars that could suggests they may instead be plagioclase. Often the edge-on muscovite flakes have one end frayed, some flakes are bent, some are wedged between quartz and K-feldspar grains, and sometimes two are stacked on top of one another. Dolomite (0.05-0.09 mm, ϕ =

+4.23 - +3.47) and/or calcite (both with characteristic carbonate cleavage) appears to be partially replacing some K-feldspar grains, while other K-feldspar grains (0.04-0.12 mm, ϕ = +4.64 - +3.06) and a few muscovite flakes (0.18-0.21 mm, ϕ = +2.48 - +2.25) may have been replaced by illite (glauconite, evident from greenish stain), or some edge-on muscovite flakes have been replaced by iron oxides (± illite). It would also appear that occasionally a few K-feldspar grains have been replaced by siderite (0.09 mm, ϕ = +3.47) (rather than dolomite or calcite). Within the calcite matrix there are occasional linear and curvilinear cross-sections of fossil shells of varying lengths and thicknesses, and even a possible shell fragment, that consist of micro-crystalline or perhaps even recrystallized calcite outlined or often speckled, dotted or heavily coated by iron oxides staining. Two unusual possible elongated and rounded clasts, or possible elongated (ovoid or squashed) fossil cross-sections that has been infilled), which consist of iron oxides outlined recrystallized calcite matrix with tiny to very small, sub-angular to sub-rounded quartz, K-feldspar, illite- and/or siderite-replaced K-feldspar grains and very small thin edge-on muscovite flakes crammed together, surrounded by even thicknesses of recrystallized calcite matrix clear of any other embedded grains forming "borders" that are either the fossil shell cross-sections or coatings around the rounded clasts. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains (particularly dolomite rhombs), occasionally covering grains and thus distorting their colors.

<u>MFTB-04</u> N 36° 20.462' W 112° 40.655' (N 36.341° W 112.678°)

Bottom of the Havasu Member of the Muav Formation 7.5 m (24 feet) along the bed west/downstream of sample MFTB-03. Area of most intense folding, syncline in the sample.



At normal scale, this rock in the thin section appears to be somewhat different to neighboring sample MFTB-03 from the same stratigraphic level only 7.5 m away laterally. Yet even though it has a similar abundance of quartz (~23%) and K-feldspar (~19%) grains with occasional muscovite (<1%) flakes the rock fabric is dominated by glauconite (~6%) grains that give it an overall greenish tinge. Even though pink-stained calcite (~50%) is the matrix with subordinate dolomite (<3%) it seems concentrated into laminae that are not dominated by glauconite grains. Even though this is a limestone in outcrop it appears more like a carbonate siltstone and would be classified as a grain-supported packstone rather than a mud-supported wackestone because the coarser-grained silicate minerals dominate the rock's texture. Laminations are very evident, both parallel to the bedding and at a low angle suggestive of cross-laminations. Some scattered larger curvilinear and rounded calcite patches would be cross-sections of fossilized shells (probably bivalves and brachiopods). A long thin calcite vein filing a fracture cross-cuts the cross-laminations. Some larger darker grains may be iron-oxides-stained dolomite rhombs.

Under the microscope, the rock fabric consists of two different dominant grain combinations. One combination is a tightly-fitting interlocking mosaic dominated by scattered very small to small (0.06-0.18 mm, ϕ = +4.05 - +2.48) and small-medium (0.20-0.45 mm, ϕ = +2.33 - +1.15), rounded and often elongated, greenish grains of glauconite (illite) finely speckled and streaked with iron oxides staining (some with embayed edges), interspersed between with subordinate tiny to very small (0.02-0.15 mm, ϕ = +5.71 - +2.75), small-medium (0.20-0.38 mm, ϕ = +2.33 - +1.39) and medium (0.42-0.50 mm, ϕ = +1.25 - +1.00), angular to sub-rounded quartz grains, and fewer tiny to very small (0.02-0.13 mm, ϕ = +5.71 - +2.95) and small (0.15-0.29 mm, ϕ = +2.75 - +1.80), angular to sub-rounded K-feldspar grains (a few exhibit cross-hatched twinning under crossed polars), with occasional very small (0.05-0.10 mm, ϕ = +4.23 - +3.32), small (0.12-0.17 mm, ϕ = +3.06 - +2.57) or longer (0.21-0.28 mm, ϕ = +2.25 - +1.85), thin or thick, edge-on muscovite flakes (at various angles but often parallel to the bedding) wedged between glauconite, quartz and K-feldspar grains, all set in a crystallized interstitial calcite matrix (micrite) of tiny to very small (0.04-0.13 mm, ϕ = +4.64 - +2.95) and small (0.15-0.30 mm, ϕ = +2.75 - +1.75) grains dispersed as infilling between the various grains, though in places appearing to replace or coat some K-feldspar mosaic grains, either wholly, partially or along internal cracks. Several very large, elongated and flattened pores (or they could be dissolution holes as they are much larger than any of the mosaic grains) are lined thickly with calcite heavily stained by iron oxides, with crystals grown inwards to infill the remaining spaces. Some of the greenish glauconite grains have broken off ends suggesting they are detrital clasts, while others are cracked and others have internal inclusions of tiny quartz and/or K-feldspar grains (or one with an iron oxides grain), some of which are larger fragments and internally peripheral to the glauconite grains, and two also have an internal ribbed scaffolding structure (due to later dissolution? one has calcite infilling between the ribbed scaffolding), which suggests the glauconite (illite) grew around those grains as pellets, although most of the glauconite grains have no hint of any internal structure reflecting the sequential growth zones that would thus be expected. While nearly all quartz grains show no evidence of any "ghost" outlines of the original detrital grains, the edges of the quartz, K-feldspar and many of the glauconite grains, and often the interstitial calcite cement, meet at triple points, particularly where the quartz and K-feldspar grains are clustered, which suggests the possibility of some quartz cementation prior to or concomitant with the carbonate cementing. Many mosaic quartz grains are cracked into sub-grains, while other quartz grains are irregularly-shaped to infill "spaces" within the mosaic. Often the edge-on muscovite flakes have one end frayed, some flakes are bent around mosaic grains such as glauconite, wedged between them and quartz grains, and sometimes two are stacked on top of one another. The calcite cement grains are variably stained by iron oxides and sometimes have been recrystallized to form large and even huge (0.42-0.77 mm, $\phi = +1.25 - +0.38$) platy crystals (with characteristic cleavage evident), or sometimes have formed large patches of recrystallized calcite, that in either instance engulf some of the mosaic quartz and K-feldspar grains and are often partially outlined by iron oxides. Some glauconite grains are grossly elongated, yet still rounded with the quartz and K-feldspar mosaic grains tightly packed around them so they likely had to be primary deposited grains. Other glauconite grains are partially altered and/or replaced by calcite stained with iron oxides especially heavily along internal cleavage cracks, giving the grains a variable brownish tinge. Some of the K-feldspar grains are replaced by carbonate, probably dolomite (because the pink stain delineating calcite is not on them). Some tiny to very small (0.03-0.09 mm, $\phi = +5.01 - +3.47$), small (0.14-0.30 mm, $\phi = +2.84 - +1.75$) and larger-sized (0.58 mm, $\phi = +0.78$ and 1.33 mm, $\phi = -0.40$) dolomite rhombs, and a partial dolomite rhomb, lightly iron-oxides-stained with characteristic cleavages or even coated heavily by iron oxides, sit within the mosaic touching nearby rounded glauconite grains with interstitial calcite cement/matrix between them. There are also indications that some dolomite is in places partly replacing the calcite matrix. Also, occasionally present are thin or thick, variably elongated rectangular grains, sometimes bent, or elongated curvilinear patches, that consist of iron-oxides-stained calcite (giving these grains a brownish tinge) or are calcite outlined by iron oxide, or are illite replacing calcite, that possibly represent the cross-sections through fossil shells (bivalves and brachiopods), which are sometimes broken into segments. In some areas the small-medium-sized rounded glauconite grains dwarf the tiny quartz and K-feldspar grains with tiny edge-on muscovite flakes, very small interstitial calcite cement patches and clumps of very tiny, heavily iron-oxides-stained dolomite rhombs that form the mosaic between them. In other places the glauconite grains are clumped together, often with few or no tiny mosaic grains between them, or in several instances are clumped with the larger than usual small and small-medium subangular-subrounded quartz grains with tiny mosaic grains tightly fitted against their embayed edges on their sides not touching glauconite grains. Tiny to very small iron oxides blotches are occasionally scattered through the mosaic. Several very large ovoid patches consist of a mosaic of scattered very tiny quartz and K-feldspar grains with tiny edge-on muscovite flakes overwhelmingly dominated by the calcite matrix between them made up of variably iron-oxides-stained tiny to very small grains, all quartz, K-feldspar and calcite grain boundaries being irregular and blurred. A very short calcite “vein” cuts from a calcite-infilled pore across and offsets an elongated rounded glauconite grain and ends in a medium interstitial calcite grain between tiny mosaic quartz and K-feldspar grains. In the second dominant grain combination in the rock fabric there are much fewer of the same rounded glauconite grains, so the same mosaic of quartz and K-feldspar grains dominates, often in clusters, with the same interstitial calcite cement, occasional edge-on muscovite flakes, and the same other features such as larger calcite cement patches variably iron oxides stained, and long curvilinear iron-oxides-outlined calcite cross-sections of fossil shells. Two larger rounded and ovoid patches of calcite matrix, one is spattered heavily with iron oxides and both consisting of recrystallized calcite, are outlined by heavy iron oxides staining and also appear to be almost like “pellets” or rounded clasts. Two thick veins consisting of small calcite crystals of various shapes at different extinction angles cross-cut the rock fabric almost perpendicular to the bedding, meandering around glauconite grains but cutting through quartz and K-feldspar grains and separating their pieces. Sometimes the edges of the quartz and K-feldspar grains are ragged, being obscured by the calcite matrix encroaching on them. Where the edge-on muscovite flakes are parallel to the bedding the mosaic quartz and K-feldspar grains and the interstitial calcite cement also appear elongated parallel to the bedding, likely being a depositional feature. In several places several close-spaced parallel hairline fractures cross-cut the rock fabric almost parallel to the bedding but with little disruption of the rock fabric except for the fracture lines being sporadically marked by alteration (illite ± calcite) or iron oxides. Elsewhere a low angle, iron-oxides-filled hairline fracture appears to be lined by calcite matrix. A small-medium-sized sub-rounded quartz grain is fractured but not displaced, with recrystallization healing through the fracture zone which parallels at the same angle a nearby edge-on muscovite flake and the fractures elsewhere through the rock fabric mentioned above. Some edge-on muscovite flakes lie along and within a fracture, probably facilitating the location of the fracture that is at the same low angle to the bedding as are other fractures, and which separates a paralleling zone of a higher proportion of calcite matrix with a reduced number of mosaic grains from the regular mosaic with scattered interstitial calcite matrix, all with paralleling edge-on muscovite flakes. There are no remaining pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains (particularly dolomite rhombs), occasionally covering grains and thus distorting their colors, as well as associated with hairline fractures, some of which were likely induced during sample impregnation.

<u>MFTB-05</u> N 36° 20.470' W 112° 40.630' (N 36.341° W 112.677°)

Bottom of the Havasu Member of the Muav Formation 4 m (13 feet) along the bed west/downstream of sample MFTB-04. Area of most intense folding.

At normal scale, this rock in the thin section appears totally different from the neighboring sample MFTB-04 from the same stratigraphic level only 4 m away laterally. It is definitely a limestone in outcrop and in thin section, being dominated by pink-stained calcite (~93%) as micrite (mud). There are very few quartz (3%) and K-feldspar (~4%) grains scattered unevenly though the calcite matrix and muscovite flakes are not evident. With <10% silicate grains in it this rock would be classified as a carbonate mudstone (totally calcite mud-supported). The rock texture is uniformly massive with little variation apart from scattered elongated blotches (perhaps visible due to iron oxides staining) that appear that appear to crisscross the rock fabric interspersed with lighter calcite curvilinear and rounded patches that may be cross-sections of fossilized shells (bivalves and brachiopods). A thick and long dark streak (the color perhaps again due to iron oxides staining cuts obliquely across the rock and then flattens into anastomosing stringers. There appear to be some scattered glauconite grains due to illite alteration of some K-feldspar grains.

Under the microscope, sparsely scattered tiny to very small (0.02-0.16 mm, ϕ = +5.71 - +2.66) K-feldspar grains (often with diffuse edges), and subordinate tiny to very small (0.01-0.15 mm, ϕ = +6.72 - +2.75), and small (0.23 mm, ϕ = +2.13) irregularly-shaped, angular and sub-angular to sub-rounded quartz grains and angular fragments (often with diffuse edges), set in a pervasive dominating massive recrystallized calcite matrix consisting of tiny to very small (0.02-0.07mm, ϕ = +5.71 - +3.77), very small (0.10-0.14 mm, ϕ = +3.32 - +2.84), and small-medium (0.16-0.30 mm, ϕ = +2.66 - +1.75) calcite crystals, which is variably iron oxides stained, sometimes have cleavages lined by iron oxides, sometimes are spotted and heavily stained with tiny iron oxides specks, and which are at different extinction angles. Within the calcite matrix are numerous elongated, thin and thick, linear, curvilinear and ovoid shapes outlined and sometimes stained or speckled or "ribbed" by iron oxides that are possible cross-sections and fragments of fossil shells (bivalves and brachiopods), sometimes with apparent internal divisions reminiscent of internal chambers, and are often quite distinctive, even sometimes with quartz and K-feldspar grains and edge-on muscovite flakes within them, as well as "lenses" with iron-oxide-stained edges that contain more tiny K-feldspar grains. Sometimes there is incomplete pink staining of the calcite matrix so very small to small and small calcite rhombs are evident. Occasional very small (0.03-0.11 mm, ϕ = +5.01 - +3.19), small (0.14-0.20 mm, ϕ = +2.84 - +2.33) or long (0.33-0.47 mm, ϕ = +1.60 - +1.09), thin edge-on muscovite flakes at various angles sit within the calcite matrix, and sometimes are bent against adjoining clumps of K-feldspar, glauconite and quartz grains with alteration and iron oxides staining, and even one end frayed. Some very small to small and small-medium rounded greenish grains (possibly glauconite/illite replacing K-feldspar), speckled with iron oxides staining and sometimes iron-oxides-lined internal cracks, are occasionally scattered among the other grains in the calcite matrix. In some places the K-feldspar and quartz grains are clustered together in lensoid and ovoid shapes within the calcite matrix, sometimes clearly outlined as distinctive features (maybe former clasts?), sometimes with the immediately adjoining calcite matrix at the same crystallographic orientation as a thin "halo", and sometimes as a much larger selvage, along with subangular to subrounded greenish glauconite grains, occasional long, iron-oxides-stained or fresh thin edge-on muscovite flakes (parallel to the axes of the lensoids or bent around the clumped grains), and very small iron oxides blotches or stringers of iron oxides with alteration (illite?), but the grains barely touch one another even though they are clustered closely with the regular calcite matric between them, or if they do clump their edges often meet at triple points. Larger (0.19-0.20 mm, ϕ = +2.40 - +2.33), probably former sub-euhedral K-feldspar laths that has been altered to greenish glauconite (illite) are seen broken apart into some very small and small angular and sub-angular fragments that are dislocated but not disconnected within the surrounding calcite matrix. Several the larger former sub-rounded or sub-euhedral K-feldspar grains or laths have been altered to illite (glauconite) and surrounding them and a few adjoining tiny altered K-feldspar grains and tiny quartz grains in the calcite matrix are "halos" of iron oxides staining. There are no pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains, occasionally covering grains and thus distorting their colors.

MFTB-06 N 36° 20.399' W 112° 40.578' (N 36.340° W 112.676°)

Bottom of the Havasu Member of the Muav Formation about 6 m (19.5 feet) west/downstream from sample MFTB-05. Difficult to get to the bend in the fold. This sample is not bent much.
At normal scale, this rock in the thin section appears totally different from the neighboring sample MFTB-05 from the same stratigraphic level only 6 m away laterally through the fold. Its greenish tinge

suggests the presence of illite alteration, which is confirmed by the x-ray diffraction analysis of ~2% glauconite in this sample, which also contains quartz (~5%) and K-feldspar (~6%) grains and muscovite (<1%) flakes. Thus, the glauconite is likely due to illite alteration of K-feldspar grains. Otherwise, in outcrop this appears to be a limestone, but it is actually dominated by dolomite (~82%) with subordinate calcite (~4%), the latter being evident as rounded and irregular visible patches in the rock fabric, marked by their pinkish stain. One such rounded calcite patch is surrounded by iron oxides and then dolomite (right hand side of photo). The dolomite is otherwise only visible as scattered somewhat coarser grains, as selvages surrounding iron oxides selvages, and in a thick concentrated band of somewhat coarser grains running vertically through the rock fabric. Since the bedding is perpendicular to that band, being left to right in the photo of the thin section, this suggests that the dolomite is later alteration of an initially calcite-dominated rock, which is supported by the visible somewhat coarser dolomite grains. Thus, the scattered calcite patches may well be unaltered remnants. Since dolomite grains now dominate the rock, it might be regarded as a dolostone, though initially it was likely a limestone. However, the added presence of >10% silicate grains defines this rock as a silty carbonate, or more technically as a mud-supported wackestone.

Under the microscope, sparsely-scattered occasional tiny to very small (0.01-0.5 mm, ϕ = +6.72 -+4.23) sub-angular K-feldspar grains, and tiny to very small (0.01-0.09 mm, ϕ = +6.72 - +3.47) sub-angular to sub-rounded quartz grains (all with fuzzy edges due to encroachment of the carbonate matrix on them) and angular fragments, set dispersed within a mosaic matrix of predominant tiny to very small (0.02-0.08 mm, ϕ = +5.71 - +3.64) dolomite rhombs and grains that are heavily iron-oxides-stained (heavily around their edges) with subordinate occasional tiny to very small (0.01-0.08 mm, ϕ = +6.72 - +3.64) calcite grains and rhombs (pink-stained), scattered tiny and very small blotches and streaks of iron oxides, and a few very small (0.04-0.12 mm, ϕ = +4.64 - +3.06), thin edge-on muscovite flakes at various angles. A large thick linear section or band of the rock fabric consists of many more tiny to very small sub-euhedral and sub-angular K-feldspar grains and former laths, and many more subordinate tiny sub-angular quartz grains, often touching one another and/or clumped together, with variously dominating (~65%) or subordinate (~35%) interstitial tiny to very small calcite grains and occasional scattered tiny iron-oxides-stained dolomite rhombs, possibly representing an original limestone remnant, and with a huge patch of iron oxides partly covering this band, or elsewhere a few scattered tiny to very small iron oxides blotches and streaks. There are often sharp lines of demarcation between this band and the regular dolomite-dominated-matrix that predominates the rock's fabric. A few occasional very small (0.03-0.06 mm, ϕ = +5.01 - +4.05) sub-angular and sub-rounded greenish glauconite grains and fragments (illite-altered K-feldspar former laths?) are evident between quartz and K-feldspar grains where the interstitial calcite matrix dominates. In many places though the boundaries between the subordinate calcite-dominated matrix and dominant dolomite-dominated matrix textures and compositions are blurred and gradational as dolomite grains and rhombs are scattered among the calcite interstitial to the K-feldspar and quartz grains, suggesting variable incomplete dolomitization. In many other places, there are indistinct areas of the rock fabric, adjoining the dominant areas of dolomite-dominant matrix with only a few scattered K-feldspar and quartz grains, where the interstitial matrix is about equally calcite and dolomite grains and rhombs between the more numerous (larger) K-feldspar and quartz grains, perhaps suggesting complete dolomitization has not occurred. Sometimes there are a few very small "clean" (iron-oxides-"free") and "skeletal" structured dolomite rhombs (larger than the iron-oxides-stained rhombs in the "normal" matrixes) scattered within both the calcite and dolomite dominated matrixes, which may suggests some recrystallization of dolomite has occurred, though these dolomite rhombs are often partially outlined by iron oxides. Numerous very small (0.04-0.12 mm, ϕ = +4.64 - +3.06), or longer (014-0.17 mm, ϕ = +2.84 - +2.57), thin edge-on muscovite flakes are scattered throughout the rock fabric (sometimes wedged between and bent around mosaic grains) without regard to whether dolomite or calcite is the dominant cement, at various angles often only (but not exclusively) in the calcite-dominated-matrix areas, though everywhere else they are usually parallel to one another and parallel to apparent fractures and other lineations which are all perpendicular to the denoted bedding, while a few very small edge-on muscovite flakes may be iron-oxides-coated or even replaced by iron oxides. Sometimes there are medium and large, irregularly ovoid patches or "lenses" consisting of almost only tiny calcite grains/crystals, which may have been due to recrystallization, with the adjoining rock fabric dominated by scattered K-feldspar and quartz grains with interstitial calcite more dominant than dolomite suggestive of incomplete dolomitization, and sometimes the irregular edges display progressively increasing dolomite grains and rhombs between calcite grains and rhombs away from the patches suggesting progressive dolomitization has "eaten" into the calcite patches. Occasional very long anastomosing and branching iron oxides streaks wind across the rock fabric similarly to hairline fractures generally and approximately perpendicular to the denoted bedding. A huge ovoid patch of recrystallized calcite with widely-spaced characteristic cleavage surrounded by a thick iron oxides border occurs within a slightly larger ovoid area of coarser-grained K-feldspar-quartz- ~65% interstitial calcite with an edge-on muscovite flake, in turn surrounded by the predominant dolomite-dominant-matrix rock fabric, but adjoining the thick linear band of coarser-grained K-feldspar-quartz-interstitial calcite (mentioned above) with numerous small-longer very thin edge-on muscovite flakes parallel to the long axis of the band which is perpendicular to the denoted bedding. There are no remaining pores apparent, but the sample was impregnated accompanied by blue dye staining before the thin section was cut, so there is some blue dye staining between and encroaching on some grains (particularly dolomite rhombs), occasionally covering grains and thus distorting their colors, as well as associated with hairline fractures, some of which were likely induced during sample impregnation.