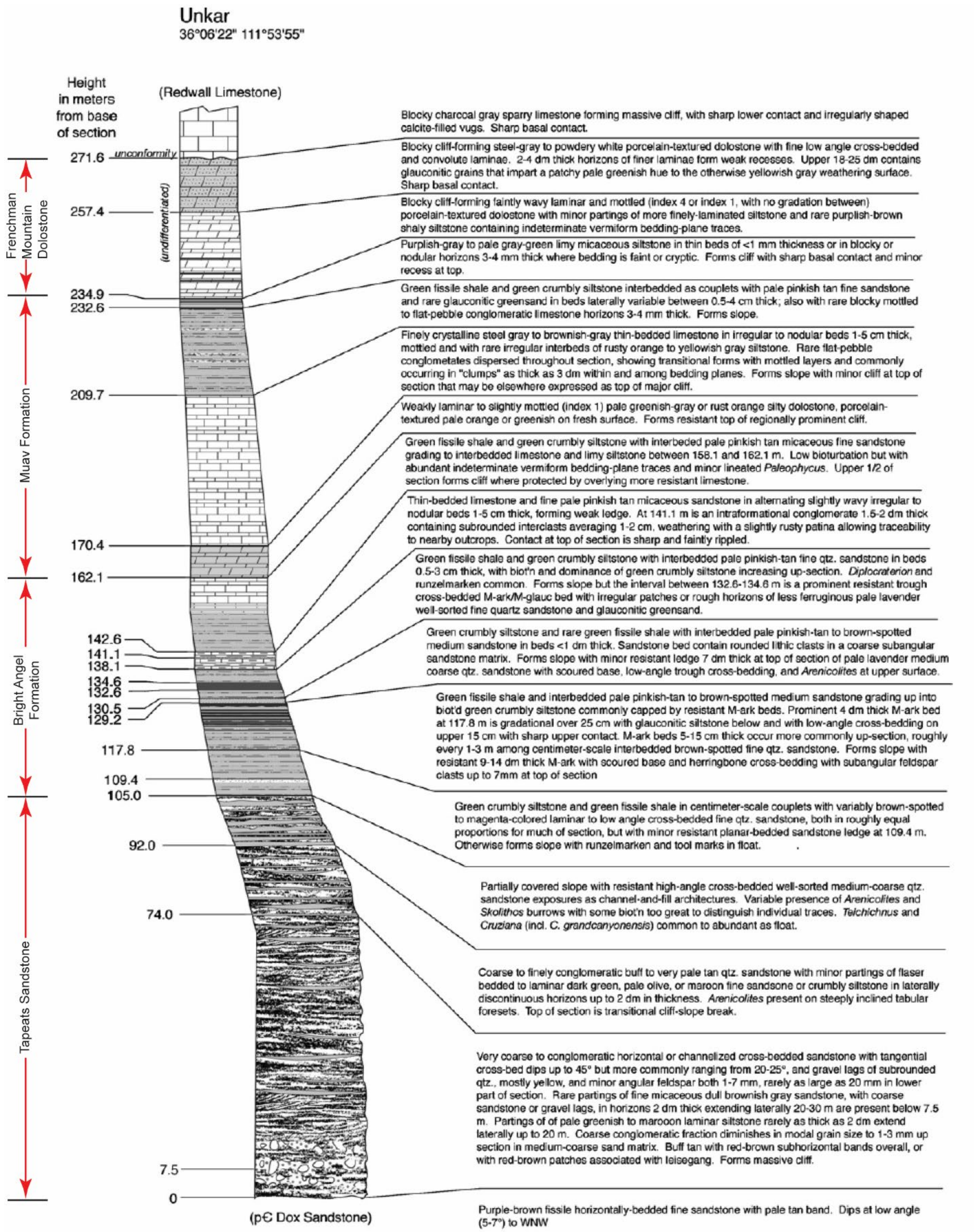
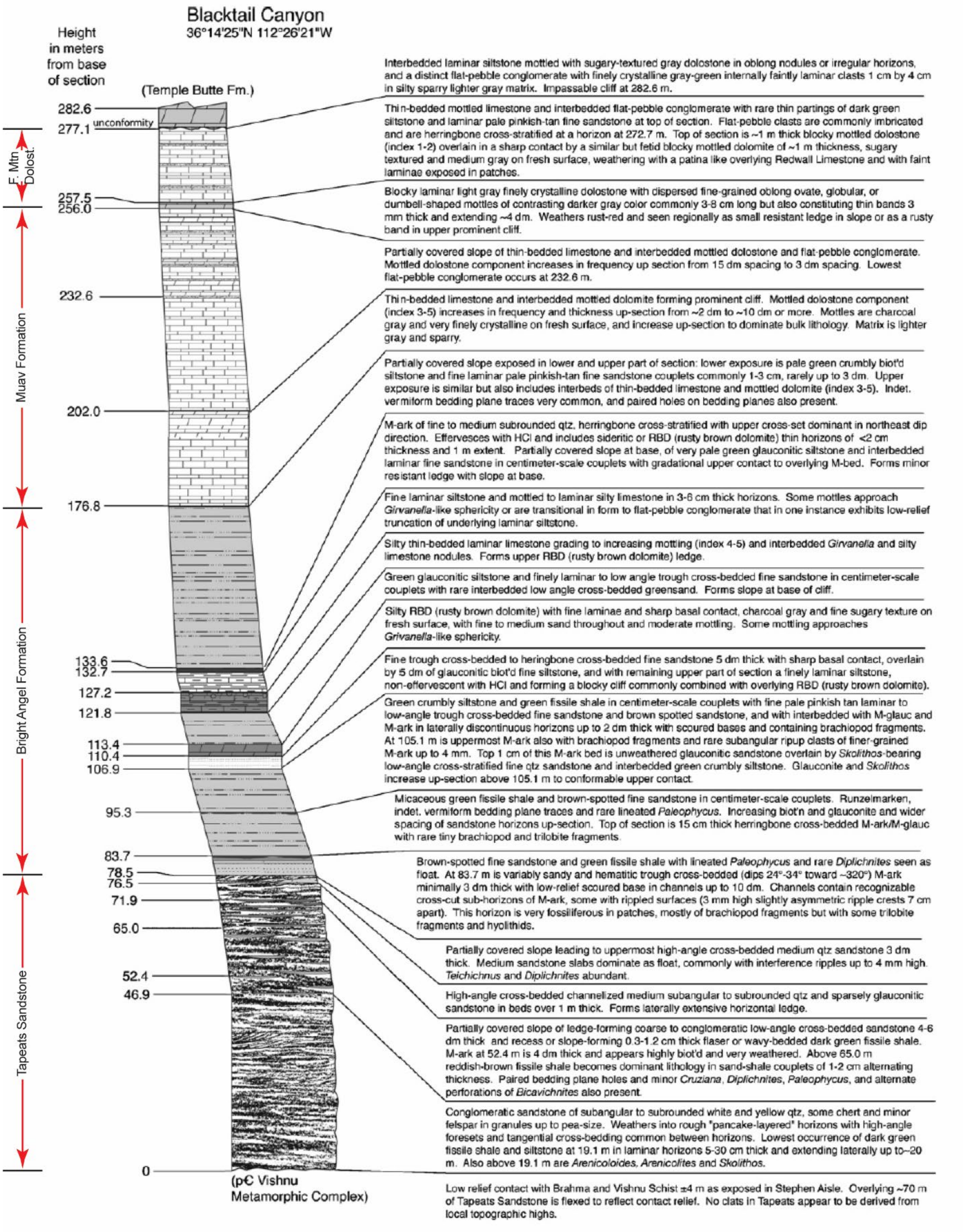
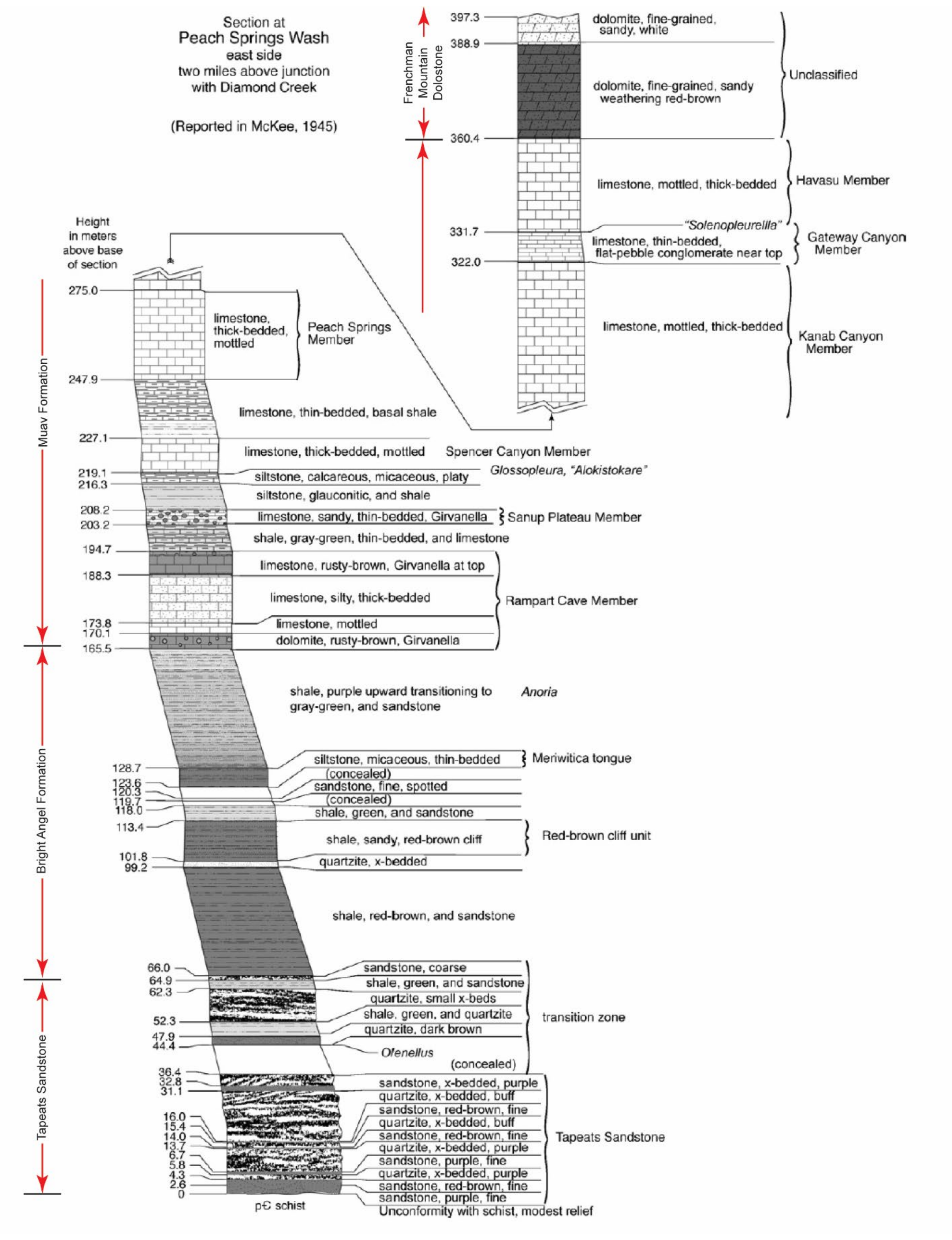
Appendix A – Graphic Stratigraphic Log of the Tonto Group in the Unkar Creek Area (River Mile 73) as Measured by Rose (2003, p. 234, 2006, p.236)



Appendix B – Graphic Stratigraphic Log the Tonto Group in the Blacktail Canyon Area (River Mile 120.5) as Measured by Rose (2003, p. 242, 2006, p.237)



Appendix C – Graphic Stratigraphic Log of the Tonto Group in the Diamond Creek Area (River Mile 226) as Measured by Rose (2003, p.267, 2006, p.239), with data from McKee (1945, p.153)



Appendix D – Locations and Petrographic Descriptions of Bright Angel 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

BAS-01 N 36° 15.322' W 112° 54.439' (N 36.255° W 112.907°)
River Mile 167.9 – river right between National and Fern Glen Canyons (closer to latter).
Glauconitic fissile green sandstone (fine-grained) (non-calcareous) —burrows, ripple marks
At normal scale, the thin section shows a laminated bedding structure dominated by small quartz grains with subordinate glauconite pellets and occasional K-feldspar grains. This fine-grained glauconitic sub-arkosic sandstone is moderately well-sorted, with a hint of low-angle cross-bedding just above the middle of the thin section.

Under the microscope, a tightly-fitted mosaic predominantly consisting of very small (0.02-0.06 mm, ϕ = +5.71 - +4.05, medium to coarse silt size) and occasional small (0.07-0.22 mm, ϕ = +3.77 - +2.19, very fine to fine sand size), or even medium (0.26-0.29 mm, ϕ = +1.95 - +1.80, medium sand size), angular or euhedral to sub-rounded quartz grains with irregular shapes (sometimes elongated parallel to the bedding) and some grains cracked, and edges often meeting at triple points, with subordinate small (0.05-0.19 mm ϕ = +4.23 - +2.40), and occasionally small-medium (0.20-0.29 mm ϕ = +2.33 - +1.80), olive green-brown, rounded oval-shaped (and sometimes elongated and sometimes also curved, and parallel to the bedding) glauconite pellets and fragments of glauconite pellets. Some quartz cement as overgrowths is evident infilling between quartz grains in optical continuity so as to mold clumps of grains into a tight jigsaw fit with triple point edge junctions. In places there are several medium-sized quartz grains together surrounded by smaller quartz grains. Some larger (0.26-0.29 mm, ϕ = +1.95 - +1.80) quartz grains appear to consist of several sub-grains, often with different extinction angles. In some places other quartz grains are squarish or even rectangular with angular corners, and some grains are very irregularly shaped. In a few quartz grains there is a hint of iron oxide "ghost" outlines of the original detrital grains with overgrowths in optical continuity. A medium-sized quartz grain is euhedral with two sub-grains in optical continuity and is grown around and into other mosaic grains which are thus indented into it. Some of the glauconite pellets have clearly grown around small (0.06-0.09 mm, ϕ = +4.05 - +3.47) quartz fragments or small quartz grains, and also possibly small K-feldspar grains or very small (0.03-0.06 mm, ϕ = +5.01 - +4.05) fragments, or even appear to be a possible alteration product after K-feldspar, for which there is some evidence, such as apparent glauconite alteration along fractures in K-feldspar grains, some cleaved K-feldspar grains (one medium rounded with iron oxide along the cleavages) with the same alteration as seen under crossed polars as glauconite, and K-feldspar remnants in glauconite pellets, or even after muscovite (heavily degraded edge-on "books" of flakes with apparent glauconite or related illite alteration). Some pellets have minor concentric outer edge zoning. Occasionally some adjoining glauconite pellets have a sub-euhedral shape and their edges thus meet at triple points, and some are iron oxide stained. Equally as abundant as the glauconite pellets (and sometimes more abundant) are very small (0.02-0.07 mm, ϕ = +5.71 - +3.77) and small (0.09-0.22 mm, ϕ = +3.47 - +2.19), some angular or euhedral and some rounded, or tabular and elongated, altered K-feldspar grains and laths (a few exhibit partial multiple twinning under crossed polars) that are wedged between the quartz grains and glauconite pellets in the mosaic. In places the quartz cement has clearly grown around K-feldspar grains and between them and quartz grains. It is possible a few feldspar grains (0.07-0.16 mm in size, ϕ = +3.77 - +2.66) that exhibit full multiple twinning under crossed polars are plagioclase. Many small or long-very long (0.06-0.89 mm, ϕ = +4.05 - +0.17), thin, edge-on muscovite flakes, some with one end frayed or very frayed (one with the frayed end also curled), some altered, wedged and some bent in the mosaic between quartz, K-feldspar and glauconite grains and often parallel to the bedding. Some small to very large (0.06-0.77 mm ϕ = +4.05 - =0.38) and very thick, very altered and broken edge-on brachiopod shell fragments consisting of collophane (birefringent cryptocrystalline apatite) are tightly wedged and bent between various grains in the mosaic. One small (0.06 mm ϕ = +4.05) sub-angular to sub-rounded, and one very small tabular, high relief, high birefringent grains are possibly zircon. Some occasional small (0.07-0.17 mm ϕ = +3.77 - +2.57) sub-angular to rounded "dirty" grains or elongated clear fragments may be dolomite (higher relief than quartz and similar to calcite except for possible iron substitution discoloring), are sometimes euhedral with edges meeting other mosaic grains at triple points, and some are perhaps either after calcite or partly replaced by calcite. Some calcite infilling spaces between mosaic grains acts as the cement (significantly so in a few places), and even coats some grain edges or partly replaces or veins K-feldspar, quartz or muscovite, or in one instance replaces the core of a glauconite pellet, is in patches or along fractures in those grains, or in one place as a large area of calcite infilling a former pore and likely replacing mosaic grains. Some minor tiny iron oxide spots and streaks on some glauconite pellets and small blotches/patches or edge linings between mosaic grains. There are very few pore spaces left in the rock fabric, just some cracking and some very small pores likely due to the forced impregnation prior to the thin section being cut, and thus blue dye staining between and sometimes partially covering some grains.

<u>BAS-02</u> N 36° 15.322' W 112° 54.439' (N 36.255° W 112.907°)
River Mile 167.9 – river right between National and Fern Glen Canyons (closer to latter).
Calcareous brown sandstone (fine-grained) — cross beds, ripple marks
At normal scale, part of this sample is a massive fine-grained sandstone consisting of predominantly quartz grains, but with subordinate glauconite pellets and scattered K-feldspar grains. The other part of the sample is finer-grained sandstone with smaller quartz and K-feldspar grains and glauconite pellets in

thin laminae, many marked by iron oxides, which likely covers calcite, and which gives the rock its red color. The irregularity of the dark-colored laminae as banding indicates some of iron oxides and calcite are due to later alteration. This is a glauconitic sub-arkosic sandstone.

Under the microscope, a mosaic consisting of very small (0.03-0.06 mm, ϕ = +5.01 - +4.05, coarse silt size), small (0.07-0.22 mm, ϕ = +3.77 - +2.19, very fine to fine sand size), and the occasional medium (0.25-0.40 mm, ϕ = +2.00 - +1.32, medium sand size), irregularly-shaped angular or euhedral and sub-angular quartz grains usually in contact with one another tightly fitted together with small to medium (0.05-0.29 mm, ϕ = +4.23 - +1.80) olive green-brown, rounded oval-shaped glauconite pellets (possibly after altered K-feldspar, as there are occasional remnants of what appears to be altered K-feldspar within them, including iron oxide lined former cleavages) and small and small-medium (0.10-0.40 mm ϕ = +3.22 - +1.32), sub-angular to sub-rounded calcite grains (sometimes several clumped together), the edges of all these grains often meeting at triple points. There is some cracking of the quartz grains in particular with faint iron oxide staining the cracks, and some quartz grains with irregular edges look like broken fragments, occasionally being somewhat elongated. A few quartz grains have hints of internal iron oxide "ghost" outlines of the original detrital grains with overgrowths in optical continuity that are often euhedral or angular, confirming that there is a quartz cement. Some quartz grains consist of irregularly sized and shaped sub-domains that have different extinction angles, and others exhibit undulose extinction. Some glauconite pellets have concentric zoning around their edges, their cores often marked by iron oxide staining as well as their outer edges, while some glauconite pellets are also elongated and curved, or others appear to be broken edged fragments of rounded oval-shaped pellets. Several rounded glauconite pellets with concentric zoning have very small quartz or K-feldspar grains in their cores. Even the glauconite pellets display a tight molded fit with the mosaic quartz grains, often all edges meeting at triple points. In places quartz grains or glauconite pellets are clumped together in tight molded fits. Small irregular blotches of heavy iron oxide (black) are scattered within the mosaic between and encroaching on the edges of some grains or almost completely covering some grains. Where there are discreet solid black grains with well-defined edges, those may instead be pyrite. Many small (0.07-0.23 mm, ϕ = +3.77 - +2.13) and medium (0.38 mm ϕ = +1.39) dolomite rhombs and sub-angular to sub-rounded grains or irregularly-shaped patches (indicated by iron substitution to give black rhomb outlines and small black patches on grains) are wedged within the mosaic as part of it, some evidently replacing calcite, because of the visible calcite remnants within the dolomite rhombs. The larger (0.38 mm $\phi = +1.39$) dolomite rhomb has a medium-sized, rounded oval-shaped "dirty" core. But in some places very small calcite linings of other grains' edges and patches between other grains, including dolomite rhombs, appear to be possibly calcite replacement or more likely calcite cement. Numerous, prolific in places and being dominant in the mosaic, scattered small tabular and very small-small (0.03-0.15 mm $\phi = +5.01 - +2.75$) sub-angular irregularly-shaped, altered K-feldspar grains and fragments are wedged between other mosaic grains, one being wedged between a medium-sized calcite grain or area of cement and a small heavily iron oxide coated dolomite rhomb. Many small or small-medium (0.04-0.33 mm $\phi = +4.64 - +1.60$), long (0.54-0.67 mm, $\phi = +0.89 - +0.58$) or thin, fresh or altered, edge-on muscovite flakes are wedged, broken and bent between various mosaic grains, usually parallel to the bedding, sometimes also split apart or with frayed ends. Two of the longer thick, broken and bent flakes are partially altered to/replaced by calcite, while a small-medium thin flake is partially wrapped around two adjoining glauconite pellets. Two very thick (0.10-0.14 mm long, $\phi = +3.32 - +2.84$, by 0.05-0.11 mm thick), altered and expanded, sub-rounded and tabular, edge-on muscovite "books" are wedged tightly in the mosaic with triple point junctions. Several long and two shorter (0.09-0.59 mm, $\phi = +3.47 - +0.76$) thick or very thick, broken in places, edge-on brachiopod shell fragments consisting of collophane (birefringent cryptocrystalline apatite) are also wedged between mosaic grains. Some iron oxide linings around some grains appear to act like a cement, and some areas are more heavily iron oxide stained with most grains iron-oxide-coated and perhaps also cemented together. There are virtually no pore spaces left in the rock fabric, just a lot of cracking between grains and some tiny and very small pores, some likely due to the forced impregnation with blue dye staining prior to the thin section being cut.

Whitmore Helipad Fold (River Mile 187.4) Samples

N 36° 9.250'   W 113° 11.400'   (N 36.154°   W 113.190°)
RM 187.4 – river left, cliff behind the scrub-covered slope up from the river-bank.

<u>HF-01</u>

Sandstone (hard, brittle), fine-grained, horizontal, not folded (bottom left).

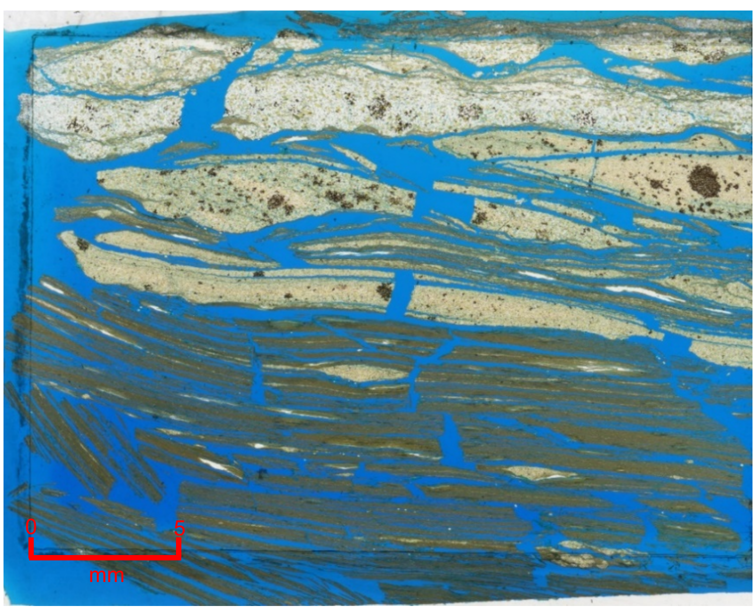
At normal scale, this is a fine-grained sandstone dominated by quartz grains with subordinate K-feldspar grains, scattered glauconite pellets and occasional patches of carbonates (evident from the brown staining). These carbonate patches may be detrital clasts, but that is not easily established as their perimeters/edges are diffuse with respect to the surrounding grains and enclosing matrix. Though generally massive, there is a hint of some bedding traces marked by concentrations of green glauconite pellets. This is a glauconitic sub-arkosic sandstone.

Under the microscope, a tightly fitted mosaic of very small (0.03-0.06 mm, ϕ = +5.01 - +4.05, coarse silt size), small (0.07-0.24 mm ϕ = +3.77 - +2.06, very fine to fine sand size) and small-medium (0.27-0.38 mm, ϕ = +1.90 - +1.39, medium sand size), irregularly-shaped angular or euhedral to sub-rounded quartz grains, some with internal iron oxide "ghost" outlines of original sub-rounded detrital grains and overgrowths in optical continuity, meeting at triple points. Some quartz grains consist of very small irregularly-shaped sub-domains, or sometimes sub-grains, with different extinction angles and some quartz grains display undulose extinction, while others have straight edges and are more euhedral to polygonal due to their overgrowths. In many places the quartz cementation infilling between the quartz

grains is so complete with the original grain boundaries so indistinct that it looks like a solid mass of quartz. Numerous very small (0.03-0.06 mm, ϕ = +5.01 - +4.05), small (0.08-0.23 mm, ϕ = +3.64 - +2.13) and medium (0.25-0.42 mm, ϕ = +2.00 - +1.25) irregularly-shaped angular to sub-rounded K-feldspar grains, tabular laths (some long and relatively thin) and broken fragments (some displaying pseudo multiple twinning and two cross-hatched twinning under crossed polars, and some with the cleavage evident) are scattered through and wedged in the mosaic. A few very small and small-medium sub-rounded K-feldspar grains. and a lath with evident remnant cleavage, are highly altered (to illite?). Many very small to small (0.05-0.21 mm, ϕ = +4.23 - +2.25) sub-angular to sub-rounded and rounded ankerite grains, some being rhombs with the characteristic cleavage evident, while others are oval-shaped and elongated, are scattered through and wedged in the mosaic similar to the other detrital grains. Three larger areas of ankerite (or iron oxide stained dolomite) infill between scattered quartz and K-feldspar grains, encroaching on their edges and perhaps replacing some K-feldspar grains and laths (evident from “ghost” cleavages and lath shapes as well as the apparent K-feldspar grain remnants). Many very small and small (0.05-0.25 mm ϕ = +4.23 - +2.00) sub-rounded to rounded calcite grains are wedged in the mosaic as detrital grains similar to the quartz and K-feldspar grains. Several small and large-very large patches of multiple, iron-oxide-coated, small calcite grains, and sometimes iron-oxide-coated calcite (and perhaps ankerite) infill as cement, between and adjacent to mosaic grains including distinct ankerite grains and often encroaching on the edges of quartz and K-feldspar grains. One probable former small-medium K-feldspar lath appears to have been replaced by calcite. Some irregularly-shaped sub-angular to sub-rounded small (0.07-0.13 mm ϕ = +3.77 - +2.95) grains and rhombs, plus patches, of dolomite are wedged within the mosaic, apparently as part of it, but in several places infill between scattered mosaic grains as cement and probably replace some of them. Many small-medium (0.07-0.35 mm ϕ = +3.77 - +1.50) thin edge-on muscovite flakes, some altered, wedged at various angles between mosaic grains and sometimes bent, in one instance three flakes being stacked together and offset from one another parallel to the bedding. One long (0.45 mm, ϕ = +1.15) thin edge-on muscovite flake is bent multiple times as it weaves parallel to the bedding between various other mosaic grains and ends with a frayed end, while another (0.39 mm, $\phi = +1.36$) is at a steep angle to the bedding wedged between mosaic grains and is broken at right angles as it weaves between other mosaic grains. One small thin edge-on muscovite flake is included in a quartz grain which also has sub-domains with different extinction angles and a tiny K-feldspar grain is also included in it. One small edge-on muscovite flake appears to be totally covered with, or altered to, iron oxide, while a larger (0.11 mm wide, $\phi = +3.19$, 0.11 mm thick) edge-on muscovite "book" is heavily altered to illite (?) with its constituent sheets expanded and splayed. Four very small (0.06-0.08 mm $\phi = +4.05$ - $+3.64$) high relief, high birefringent, sub-rounded grains are probably zircon. There are two small-medium rounded "dirty" rock (?) fragments. One large area of almost total alteration (to illite?) with remnant resorbed tiny-very small quartz grains with fuzzy edges. Occasional small to medium heavy iron oxide patches line parts of some grains, and there are areas of general iron oxide coatings of the edges of most grains, perhaps providing some of the cement. In a small portion of the rock fabric there are a few very small pore spaces, while in most of the rock fabric there are virtually none, just a lot of cracking between grains and some very small pores likely due to the forced impregnation accompanied by blue dye staining prior to the thin section being cut.

<u>HF-02</u>

Green mudstone (not folded, friable) (above sample HF-01).



At normal scale, a friable, extremely fine-grained laminated mudstone or shale occasionally containing selvages and laminae of fine-grained siltstone or sandstone, some of which are dominated by K-feldspar grains and others by quartz grains. The mudstone is dominated by iron-oxide-stained clay, probably illite, while there are a few patches in the siltstone of brown-stained carbonate. Some stringers dominated by green glauconite are occasionally present in the siltstone paralleling the mudstone laminae parallel to the bedding.

Under the microscope, a tightly-fitted, laminated mosaic of tiny-small (0.02-0.23 mm, $\phi = +5.71$ - $+2.13$), and a few medium (0.26-0.38 mm, $\phi = +1.95$ - $+1.39$), predominantly sub-angular (and to a lesser extent sub-rounded), altered K-feldspar grains and laths, and subordinate tiny-very small (0.02-0.06, ϕ = +5.71 - +4.05, medium to coarse silt size), and small-medium (0.07-0.26 mm, ϕ = +3.77 - +1.95), irregularly-shaped angular and sub-angular to sub-rounded quartz grains (sometimes with fuzzy and / or irregular edges), together with abundant tiny-very small (0.02—0.06 mm ϕ = +5.71 - +4.05), and small and / or long (0.07-0.24 mm, ϕ = +3.77 - +2.06), thin edge-on muscovite flakes wedged between the K-feldspar and quartz grains usually parallel to bedding but sometimes at various other angles, and sometimes with slightly frayed ends. In large sections or bands of the rock fabric most of the laminae are dominated by dark brown iron-oxide-stained alteration that is likely to be predominantly illite (and possibly also minor ankerite) after K-feldspar in which grain remnants are so tiny as to be barely distinguishable, although what is visible are blurred/fuzzy-edged, but clearly, remnants of K-feldspar and quartz grains similar to those in the clear patches or bands of the mosaic. Often in these heavily altered and iron-oxide-stained laminae some of these tiny (0.02-0.04 mm, ϕ = +5.71 - +4.64) remnant K-feldspar and particularly quartz grains appear elongated parallel to the bedding and tiny (0.02-0.05 mm, ϕ = +5.71 - +4.23) thin edge-on muscovite flakes parallel to the bedding appear to be abundantly scattered throughout this mosaic. Tiny to very small, irregular heavy iron oxide blotches and small patches are visible scattered through the rock fabric where the altered sections are generally lightly stained with iron oxide to make them colored yellow-brown. In elongated areas or bands and along some laminae the general alteration is less intense and without the iron oxide staining, so the mosaic of tiny-very small K-feldspar and quartz grains and tiny edge-on muscovite flakes generally parallel to the bedding is visible, along with the scattered illite alteration (probably primarily after K-feldspar) and tiny (0.02-0.03 mm, ϕ = +5.71 - +5.01) sub-rounded ankerite grains that appear to be wedged between other mosaic grains as part of the mosaic, and may possibly be also present in stained patches around and between mosaic grains. Some edge-on muscovite flakes appear to be likely altered, probably to illite. The cement appears to be a mixture of quartz and illite alteration, and there are virtually no pores.

The larger section of laminae in the overall rock fabric consists of a coarser-grained tightly-fitted mosaic of predominantly small (0.07-0.25 mm, ϕ = +3.77 - +2.00) angular to sub-rounded quartz grains often meeting at triple points (and sometimes displaying undulose extinction), with subordinate tiny- very small (0.02-0.08 mm, ϕ = +5.71 - +3.64) and small (0.10-0.23 mm, ϕ = +3.32 - +2.13) angular and sub-angular to sub-rounded and rounded K-feldspar grains (many being cracked or cleavages evident with iron oxide within them, and several displaying pseudo multiple twinning under crossed polars), and occasional tiny and small, thin edge-on muscovite flakes (sometimes also bent between mosaic grains), small (0.05-0.24 mm, ϕ = +4.23 - +2.06) and small-medium (0.55-0.29 mm, ϕ = +2.00 - +1.80) rounded greenish glauconite (illite?) grains (or pellets) and small (0.06-0.13 mm, ϕ = +4.05 - +2.95) sub-angular and rounded reddish-brown ankerite grains, all wedged between grains in the mosaic as part of it, cemented in part by quartz and by illite alteration between some mosaic grains (perhaps infilling some former pores), and with occasional tiny to small heavy iron oxide specks and blotches between and on the edges of mosaic grains. One small edge-on brachiopod shell fragment can be identified by its two-layer wall structure and birefringence due to consisting of cryptocrystalline apatite (collophane). In several places the quartz and K-feldspar grains are elongated irregularly-shaped angular fragments that give the mosaic an apparent "sheared" texture. Three tiny-very small (0.03-0.07 mm $\phi = +5.01 - +3.77$) rounded, high relief, high birefringent, iron-oxide-coated grains wedged between mosaic grains are probably zircon. Occasionally there are very large patches or selvages within this coarser-grained mosaic that are similar to the illite-dominated laminae elsewhere in the rock fabric, consisting of iron-oxide-stained brown illite alteration dotted with tiny (0.02-0.04 mm, $\phi = +5.71 - +4.64$) remnant K-feldspar and quartz grains and tiny edge-on muscovite flakes, the illite alteration likely being in part resulting from the very small K-feldspar grains that are predominant in these sections/bands of the rock fabric. The sample was friable and thus was impregnated accompanied by blue dye staining before the thin section was cut, so there are abundant large cracks and gaps between laminae, as well as hairline cracks parallel to the laminae with blue dye staining through the coherent sections of the rock fabric. Only in the siltstone-sandstone selvages are there a few tiny to very small pore spaces.

<u>HF-03</u>

Green mudstone (not folded, not so friable) (to the right of sample HF-02).

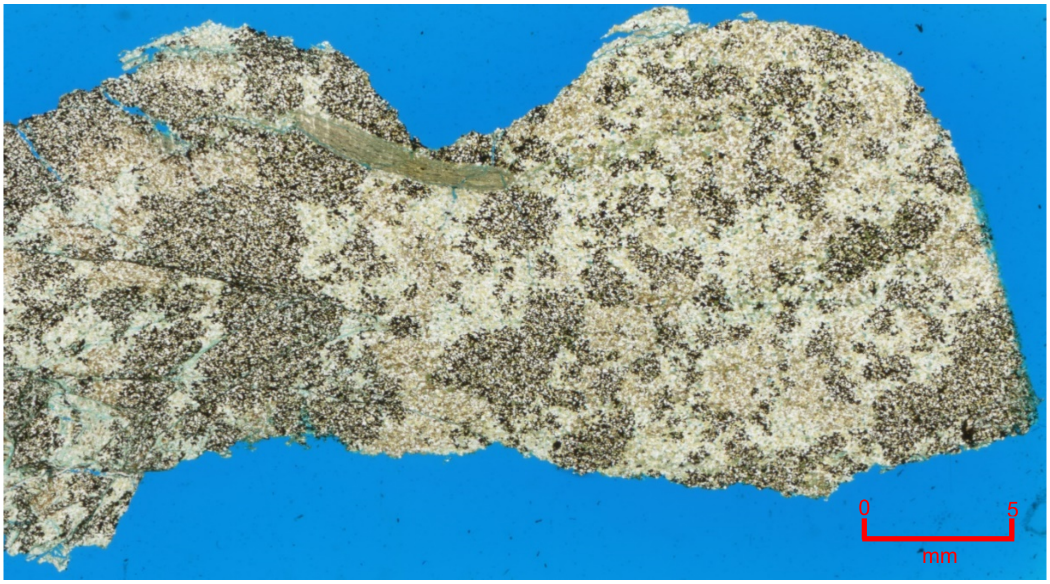
At normal scale, this sample is very similar to HF-02, but is not so friable. It is an extremely fine-grained laminated mudstone or shale occasionally containing selvages, laminae and even "eyes" of the harder fine-grained siltstone or sandstone, some of which are dominated by K-feldspar grains and others by quartz grains. The mudstone is dominated by iron-oxide-stained clay, probably illite, while there are a few patches in the siltstone of brown-stained carbonate. Some stringers dominated by green glauconite are occasionally present in the siltstone paralleling the mudstone laminae parallel to the bedding.

Under the microscope, the rock fabric consists of alternating bands or laminae and selvages of "softer" predominantly iron-oxide-stained, yellow-brown fine-grained illite alteration and "harder" "augen"-like bands or "eyes" consisting of a clear (non-stained) coarser-grained mosaic of quartz and K-feldspar grains. The yellow-brown iron-oxide-stained laminae consist of remnants of predominantly tiny (0.02-0.04 mm, ϕ = +5.01 - +4.64) irregularly-shaped quartz grains with fuzzy edges and tiny (0.02-0.04 mm, ϕ = +5.01 - +4.64) K-feldspar grains that were the dominantly present mineral but have been largely altered to illite which overwhelms the fabric of the mosaic and is pervasive through it. Also present are numerous tiny (0.02-0.05 mm, ϕ = +5.01 - +4.23) thin edge-on muscovite flakes at various angles but mostly inclined parallel to the bedding, some tiny irregularly-shaped blotches of greenish glauconite (?), and many scattered very tiny-tiny specks, blotches and streaks of heavy iron oxide (sometimes appearing to be possibly replacing or coating edge-on muscovite flakes), as well as the pervasive iron oxide staining. The predominant harder "augen"-like, less-stained and altered bands or "eyes" consist of a tightly-fitted mosaic of tiny-small (0.02-0.19 mm, ϕ = +5.71 - +2.40), and a few medium (0.29-0.47 mm, ϕ = +1.80 - +1.09) irregularly-shaped to tabular, mostly sub-angular and partly altered (to illite?) K-feldspar grains and subordinate scattered very tiny-very small (0.005-0.06 mm, ϕ = +7.72 - +4.05, fine to coarse silt size), and small (0.07-0.23 mm, ϕ = +3.77 - +2.13, very fine to fine sand size) irregularly-shaped angular-euhedral and sub-angular to sub-rounded quartz grains with some fuzzy edges (and some displaying undulose extinction), cemented by the pervasive illite alteration. There are also occasional tiny-small (0.03-0.20 mm, ϕ = +5.01 - +2.33) sub-angular to sub-rounded greenish glauconite (?) grains, numerous tiny-small (0.02-0.26 mm, ϕ = +5.71 - +1.95) and a few long-very long (0.29-0.87 mm, ϕ = +1.80 - +0.20), thin edge-on muscovite flakes (sometimes altered or sometimes expanded with frayed ends) at various angles but usually inclined close to being parallel to the bedding and sometimes bent between and around mosaic grains, and a few tiny-small (0.03-0.09 mm, ϕ = +5.01 - +3.47) and small (0.16-0.18 mm, ϕ = +2.66 - +2.48) sub-angular to sub-rounded ankerite grains (sometimes iron oxide stained or coated). Very tiny specks, thin edge linings and small blotches and large patches of heavy iron oxides are also present, the latter spreading around and between many mosaic grains and in many places inclined close to being parallel to the bedding. Sometimes the quartz grains are together in "clumps" where they meet at triple points, whereas elsewhere they have K-feldspar grain remnants, the pervasive illite alteration, and occasional edge-on muscovite flakes and iron oxide blotches and streaks between them. Quite a few possible small (0.10-0.16 mm, ϕ = +3.32 - +2.66) altered edge-on biotite flakes (or perhaps they are iron-oxide-coated altered muscovite flakes) are wedged between small edge-on muscovite flakes and between mosaic quartz and K-feldspar grains, while there are several tiny-small (0.04-0.07 mm, ϕ = +4.64 - +3.77) high relief, high birefringent, sub-angular to sub-rounded, partially iron-oxide-coated grains that are likely to be zircon, and also several small (0.07-0.17 mm, ϕ = +3.77 - +2.57), fresh-looking, irregularly-shaped, sub-angular to sub-rounded grains that may be plagioclase because they exhibit multiple twinning under crossed polars, plus several small-medium possible face-on muscovite flakes. There are two possible medium-length (0.41-0.47 mm, ϕ = +1.29 - +1.09), edge-on brachiopod shell fragments identifiable by their two-layer wall structure and birefringent cryptocrystalline apatite (collophane). Some of the harder less-stained and less-altered bands are coarser-grained, especially with some small (0.07-0.16 mm, ϕ = +3.77 - +2.66) and small-medium (0.19-0.28 mm, ϕ = +2.40 - +1.85) angular and sub-angular to sub-rounded quartz grains predominating over the tiny (0.02-0.04 mm, ϕ = +5.71 - +4.64) quartz grains and tiny-small (0.02-0.13 mm, ϕ = +5.71 - +2.95) illite(?)-altered K-feldspar grains, still with occasional small (0.05-0.09 mm, ϕ = +4.23 - +3.47) and small-medium (0.15-0.27 mm, ϕ = +2.75 - +1.90) sub-angular to sub-rounded glauconite (?) and ankerite grains, the various grains also often meeting at triple points. Where quartz grain edges are fuzzy is where the illite alteration has encroached on those edges. In these coarser-grained harder bands are occasional thin softer and brown-stained, illite-alteration-dominated selvages that define the laminae. Occasionally the harder quartz-dominated mosaic sections of the rock fabric are lens-shaped or even circular "eyes" with the softer brown illite-alteration-dominated laminae "wrapped" around them. Sometimes the brown intense illite-alteration-dominated laminae/selvages contain prolific thin edge-on muscovite flakes that are strongly parallel to the laminations, helping to define them in the rock fabric. There are virtually no pores as the original mosaic was already tightly fitted and the pervasive illite alteration is now the predominating cement, perhaps along with the occasional patches of heavy iron oxides. The sample was friable and thus was impregnated accompanied by blue dye staining before the thin section was cut, so there are abundant large cracks and gaps between laminae, as well as hairline cracks parallel to the laminae with blue dye staining through the coherent sections of the rock fabric, often facilitated by the boundaries between the alternating softer and harder bands/laminae, and also where there are more edge-on muscovite flakes parallel to the bedding in very thin selvages of dense brown iron-oxide-stained illite alteration which also define the laminae.

HF-04

A green mudstone with sand in it, intensely folded, very friable as a sandy unit making the hinge of a very small fold (kink) (above sample HF-02).

At normal scale, this sample (pictured above) looks like a fine-grained sandstone rather than a mudstone/shale. It appears to be dominated by fine quartz grains and subordinate K-feldspar grains and has brown patches/blotches containing carbonate between the sand grains. Between these brown patches are patches of the rock fabric dominated by quartz grains and other patches dominated by K-feldspar grains. A large elongated clast of mudstone/siltstone with rounded ends is very visible. Sparse small glauconite pellets are difficult to see. This is a glauconitic sub-arkosic sandstone.

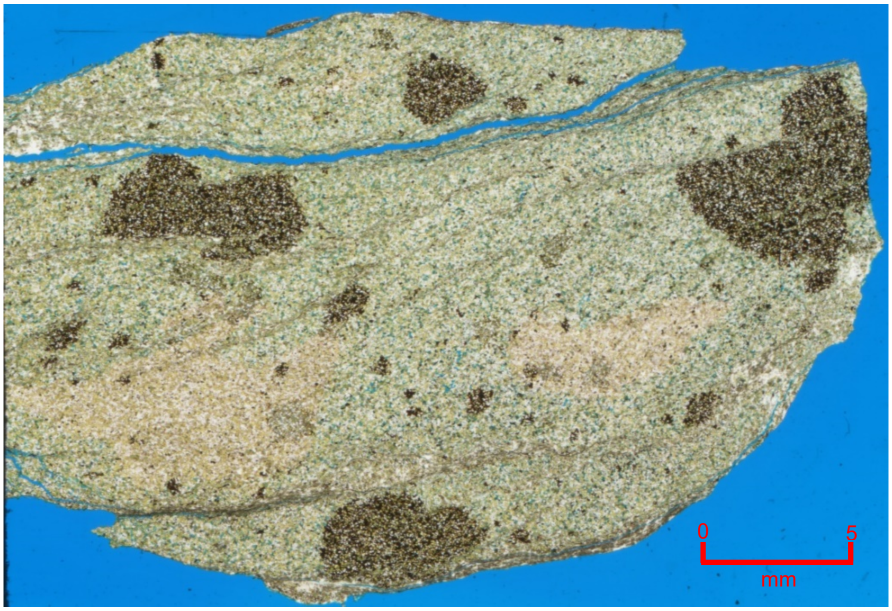


Under the microscope, a tightly fitted mosaic of tiny-very small (0.02-0.06 mm, ϕ = +5.71 - +4.05, medium to coarse silt size) to small (0.09-0.13 mm, ϕ = +3.47 - +2.95, very fine sand size)) and small-medium (0.14-0.24 mm, ϕ = +2.84 - +2.06, fine sand size) angular to sub-rounded and rounded quartz grains (sometimes irregular edges that may have been resorbed? or alternately polygonal shapes), subordinate very small (0.03-0.06 mm, ϕ = +5.01 - +4.05) to small (0.07-0.24 mm, ϕ = +3.77 - +2.06) sub-rounded to sub-angular and angular, mostly altered K-feldspar grains, angular fragments and tabular laths (some displaying cross-hatched twinning under crossed polars), and small (0.07-0.17 mm ϕ = +3.77 - +2.57) and small-medium (0.19-0.21 mm, ϕ = +2.40 - +2.25) rounded and generally elongated or sub-euhedral greenish glauconite grains (or pellets?), these grains sometimes meeting at triple points, while in some places the various grains almost all meet at triple points. There has to be some early quartz cement as there are quartz grains that must have overgrowths as cement because they are molded around other grains, such as a sub-euhedral glauconite grain. Some quartz grains consist either of smaller sub-grains with distinct boundaries or irregularly-shaped sub-domains with more subtle boundaries, in each case with different extinction angles, while other quartz grains exhibit undulose extinction. Several feldspar grains exhibit multiple twinning under crossed polars, so they may be plagioclase. Some small (0.08-0.23 mm, ϕ = +3.64 - +2.13) subangular ankerite rhombs and sub-rounded grains appear to be detrital, and there are apparently later pervasive small scattered or large extensive patches consisting of very small (0.06 mm, ϕ = +4.05) sub-angular ankerite grains between mosaic grains forming the cement between them, sometimes encroaching on and beyond grain edges (perhaps replacing quartz and particularly K-feldspar, for which there is visible evidence in places) and often colored light brownish due to iron oxide staining or totally coated by heavy iron oxide. Many tiny or long (0.04-0.32 mm, ϕ = +4.64 - +1.65), thin (some thicker) edge-on muscovite flakes (some with frayed ends) are wedged and bent between mosaic grains, sometimes parallel to the bedding, and several small (0.10 mm, ϕ = +3.32) face-on muscovite flakes are also wedged between mosaic grains. There is one medium length (0.41 mm, ϕ = +1.29), thick edge-on brachiopod shell fragment with a double layer composed of collophane (birefringent cryptocrystalline apatite). Two small (0.09 mm, ϕ = +3.47) rounded, oval-shaped, moderate relief, birefringent carbonate (?) grains (calcite?) wedged between mosaic grains are clearly detrital, and a very small (0.08 mm, ϕ = +3.64) sub-rounded but elongated, high relief, high birefringent, iron-oxide-stained grain is probably zircon. There is minor possibly illite alteration after K-feldspar. Scattered small and very large extensive heavy iron oxide patches between mosaic grains encroach on grain edges and totally coat some grains, including ankerite grains. There has been cracking of some K-feldspar and quartz grains. In one location a small thin carbonate (ankerite?) veinlet cross-cuts the mosaic, some grains and the iron-oxide-stained ankerite cement, at a steep angle for a short distance. Several cross-cutting fractures are evident in portions of the overall rock fabric, at least one potentially having laterally dislocated heavy iron stained areas. A huge (8.75 mm, ϕ = -2.79), thick and long, curvilinear area in the overall rock fabric appears to be a rip-up shale/mudstone clast. It consists of iron oxide stained brown intense illite alteration permeated through a mosaic of tiny angular to sub-rounded quartz grains and remnants of altered K-feldspar grains with very thin but long edge-on muscovite flakes parallel to the strong laminations which are parallel to the long axis of the clast. The sample was impregnated accompanied by blue dye staining before the thin section was cut, so there are abundant hairline cracks parallel to the laminae with blue dye staining through the coherent rock fabric. There are virtually no pore spaces in most of the rock fabric.

<u>HF-05</u>

Red mudstone with sandstone unit through it, close to intense kink-folded section in the hinge of the fold (above sample HF-03, to the right of the ladder).

At normal scale, this sample is very similar to HF-04, except there appears to be a lot more obvious green glauconite grains/pellets scattered through what is a fine-grained sandstone/siltstone rather than a mudstone. It appears to be dominated by fine K-feldspar grains and subordinate quartz grains and has brown patches/blotches of various sizes containing clay/illite and carbonate (?) between the sand grains. There is a hint of cross-laminations at varying steep to shallow angles through the center section of the sample, in part delineated by linear streaks of more concentrated green glauconite grains. There ia also a hint of a possible fracture or fault in the lower part of the sample (see below). This is a glauconitic sub-arkosic sandstone.



Under the microscope, an interlocking, tightly fitted mosaic of very small to small (0.03-0.18 mm, ϕ = +5.01 - +2.48), angular and sub-euhedral to sub-rounded, irregularly-shaped, variably altered K-feldspar grains and tabular laths, with subordinate tiny-very small (0.02-0.06 mm, ϕ = +5.71 - +4.05, fine to coarse silt size) and small-medium (0.07-0.26 mm, ϕ = +3.77 - +1.95, very fine to fine sand size), angular and euhedral to sub-rounded, irregularly-shaped quartz grains, sometimes with hint of "ghost" outlines of the original detrital grains surrounded by overgrowths in optical continuity. There has clearly been growth of quartz cement because the quartz grains are dominantly euhedral and angular, the overgrowths not always being discernible but the quartz grains have often grown to mold themselves around the K-feldspar grains, with edges usually meeting at triple points with adjoining quartz and K-feldspar grains. The K-feldspar grains and laths in particular are dusted with iron oxide specks and streaks, and most mosaic grains have their edges outlined by iron oxide. Some K-feldspar grains would seem to have "ghost" outlines within them too, perhaps suggesting there have been overgrowths of K-feldspar, although the latter have different extinction so may be differently altered. Some feldspar grains also exhibit pseudo multiple twinning under cross polars so may even be plagioclase. Often the K-feldspar grains and laths tend to clump together so that the quartz grains also tend to clump together. Some quartz grains give the impression of consisting of one or two, or sometimes several, sub-grains or sub-domains, often with different extinction angles. One quartz grain includes a tiny (0.02 mm, ϕ = +5.71) thin edge-on muscovite flake. Numerous small and long (0.05-0.39 mm, ϕ = +4.23 - +1.36), thick and thin, some stacked on top of one another, edge-on muscovite flakes are wedged (and sometimes bent or even broken) between mosaic K-feldspar and quartz grains at various angles to the bedding, though they are often parallel or sub-parallel to the bedding. In places numerous long and thin edge-on muscovite flakes are bent and weave their way around mosaic grains (and some have frayed ends) and together they are at the same angle effectively cross-cutting through the rock fabric aligned along what thus became planes of weakness. Sometimes there has been apparent growth of quartz cement against the edge-on muscovite flakes. There are also several small (0.05-0.08 mm ϕ = +4.23 - +3.64) face-on muscovite flakes. One long (0.29 mm ϕ = +1.80) and thick edge-on brachiopod shell fragment consisting of two layers composed of collophane (birefringent cryptocrystalline apatite) is wedged between mosaic grains parallel to the bedding. Numerous very small and small (0.04-0.18 mm ϕ = +4.64 - +2.48), sub-rounded and sub-angular greenish glauconite (or illite) grains (some are elongated) are wedged between mosaic K-feldspar and quartz grains and appear to have been detrital rather than a product of selective alteration. There is one tiny (0.03 mm ϕ = +5.01) rounded and iron-oxide-coated, high relief and high birefringent zircon grain. Numerous very small and small (0.04-0.14 mm ϕ = +4.64 - +2.84), sub-angular and sub-rounded to rounded, red-brown ankerite grains, either lightly or heavily stained with iron oxide, are wedged between mosaic grains and so appear to have been detrital. Additionally, in some areas there is some minor ankerite forming the cement and / or patches between some tightly-packed-together mosaic grains, or numerous small grains side-by-side between more scattered mosaic grains, again lightly or heavily stained with iron oxide. In most places where the mosaic is clean, a few tiny to very small iron oxide patches and grains are scattered between mosaic grains. In a few other places the mosaic is so heavily coated with iron oxide that all mosaic grains are either totally covered or have their edges covered, giving them irregular shapes, or even partially covered making the grains red-brown so that it is difficult to discern whether they are quartz (which is most likely) or ankerite. Some selvages or laminae of intense illite alteration are evident from the heavy dusting of iron oxide associated with it that also covers the remnant mosaic grains, primarily quartz grains, as it appears that the K-feldspar grains have been altered to illite. These illite alteration laminae are also accompanied within them by numerous small to long, thin edge-on muscovite flakes. Other areas of illite alteration are less dusted with iron oxide and the illite alteration can be seen to be after K-feldspar grains. There are virtually 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 some grains (that can make some look like pore spaces), as well as along hairline cracks parallel to the laminae through the otherwise coherent rock fabric.

<u>HF-06</u>

Vertical bed of fine-grained sandstone (hard) (above sample HF-04 and to the left of the top of the ladder).

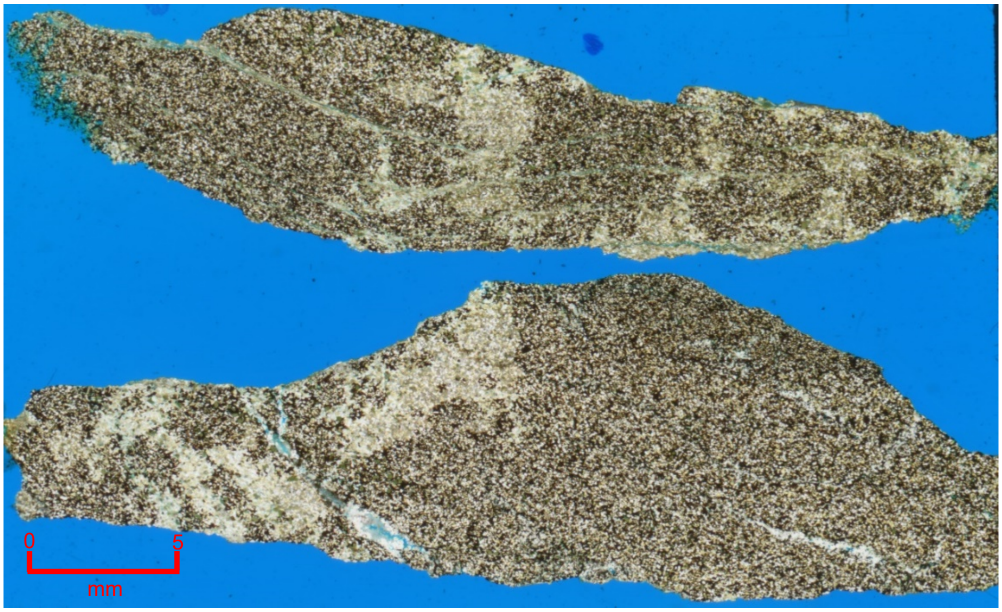
At normal scale, this is a fine-grained sandstone dominated overwhelmingly by quartz grains, but also has very minor subordinate K-feldspar grains and possible green glauconite grains and some brown carbonate

(dolomite) grains, which together in linear streaks hint at cross-bedding laminae. This is a sub-arkosic quartz sandstone.

Under the microscope, a tightly fitting, interlocking mosaic of generally very small (0.05-0.07 mm, ϕ = +4.23 - +3.77, coarse silt size), small (0.08-0.24 mm, ϕ = +3.64 - +2.06, very fine to fine sand size), and medium (0.26-0.33 mm, ϕ = +1.95 - +1.60, medium sand size) irregularly-shaped and polygonal-shaped, sub-euhedral, angular and sub-angular to sub-rounded quartz grains with "ghost" outlines of the original detrital grains and overgrowths in optical continuity that meet at triple points, having grown as the cement to infill all pores. Occasionally some quartz grains consist of sub-grains or sub-domains of different shapes and sizes and with different extinction angles, while a few quartz grains exhibit undulose extinction, particularly near fracture planes and zones. A few quartz grains appear to have very tiny inclusions within them, while one euhedral quartz grain contains two tiny K-feldspar grains. Numerous very small (0.04-0.06 mm, ϕ = +4.64 - +4.05, coarse silt size), small (0.07-0.24 mm, ϕ = +3.77 - +2.06, very fine to fine sand size), and medium (0.26-0.33 mm, ϕ = +1.95 - +1.60, medium sand size) sub-angular to sub-rounded, altered K-feldspar grains and laths (some quite elongated), and very small, irregularly-shaped angular, altered fragments, some grains exhibiting cross-hatched twinning or pseudo multiple twinning under crossed polars, are wedged between the predominating mosaic quartz grains. Some small (0.10-0.26 mm, ϕ = +3.32 - +1.95) K-feldspar grains (usually rounded) and elongated laths have been heavily altered to illite (glauconite), and the impregnation blue dye staining makes them look greenish (like glauconite), while others are also heavily iron oxide stained making them also brownish. Many small or long (0.09-0.60 mm, ϕ = +3.47 - +0.74), thin and thick, edge-on muscovite flakes (some degraded/altered, one with a bent end, and some with frayed ends), a small (0.08 mm, ϕ = +3.64) face-on muscovite flake, and an edge-on thick "book" of degraded and expanded, altered muscovite flakes, are all wedged tightly (and sometimes bent) between mosaic quartz grains. Two tiny (0.02-0.04 mm, ϕ = +5.71 - +4.64) thin edge-on muscovite flakes are included in a small-medium irregularly-shaped quartz grain. Two thick edge-on brachiopod shell fragments composed of collophane (birefringent cryptocrystalline apatite) are wedged between mosaic grains. Many small (0.09-0.23 mm, ϕ = +3.47 - +2.13) rounded dolomite grains, and a lath-like rhomb, variously colored red-brown due to iron oxide staining of different intensities, and small patches of iron-oxide-stained dolomite act as cement between mosaic grains. In one place iron-oxide-stained dolomite cements a large clump of quartz and K-feldspar grains together with a degraded edge-on muscovite flake. In another place a very large area of irregularly-shaped small iron-oxide-stained dolomite grains coalesce to form widespread cement between scattered quartz and K-feldspar mosaic grains, often encroaching on those grains' edges and over the grains themselves. Iron-oxide-stained dolomite replaces a thick edge-on muscovite flake (?). A small (0.07 mm $\phi = +3.77$), high relief, high birefringent tabular grain stained with iron oxide streaks is probably zircon. Two small rounded grains consisting of extremely tiny quartz sub-domains, one speckled with iron oxide, appear to be possible rock fragments. There is variable iron oxide staining or dusting of grains as specks and streaks, very thin iron oxide linings around some grains, and very small and small patches of iron oxide surrounding a few K-feldspar grains. Linear zones of variable thickness are where there has been fracturing, and recementing with a mosaic of tiny angular quartz grains, often with lots of iron oxide staining. In several places, blocks of the regular mosaic of small quartz grains have been offset along fracture planes, some quartz grains having also been fractured and slightly offset. In other places, small patches of a mosaic of tiny quartz grains, often lightly dusted with iron oxide, are between the quartz grains in the regular mosaic, although some of those quartz grains are fractured and/or exhibit undulose extinction, and others are remnants with fuzzy (resorbed?) edges, all indicating the effects of the fracturing and recementing. There are virtually 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 some grains (that can make some look like pore spaces), sometimes covering grains and thus distorting their colors.

<u>HF-07</u>

Green mudstone (vertical) with sandstone running through it (to the right of sample HF-06, just to the right of the top of the ladder).
At normal scale, this sample is a very fine-grained siltstone with brown patches that give the rock the appearance of mudstone. It consists of very small K-feldspar and quartz grains, the former probably slightly more dominant, with subordinate carbonates and clay minerals, likely illite after K-feldspar, and iron oxides. The illite (often referred to as glauconite) probably gives the rock a greenish sheen. Some thin veins of carbonate (?) cross-cut the rock fabric.



Under the microscope, a mosaic of tiny-very small (0.02-0.06 mm, ϕ = +5.71 - +4.05, medium to coarse silt size) and small (0.07-0.18 mm, ϕ = +3.77 - +2.48, very fine to fine sand size) irregularly-shaped, angular to sub-rounded quartz grains, and very small (0.03-0.06 mm ϕ = +5.01 - +4.05) and small (0.10-0.24 mm ϕ = +3.32 - +2.06) irregularly-shaped, sub-angular to sub-rounded K-feldspar grains and laths whose edges are often ill-defined due to encroachment on them of the partial iron oxide or siderite and iron-oxide-covered dolomite cement. In areas clear of iron-oxide-dominated cement the quartz grains meet at triple points and seem to be more prevalent than the K-feldspar grains, some of which exhibit cross-hatched twinning or pseudo multiple twinning under crossed polars, while in other areas the K-feldspar grains appear to predominate. The shapes of the quartz grains suggest that there were early quartz overgrowths to infill pores and cement the mosaic of grains. Some larger quartz grains consist of sub-grains or sub-domains often at different extinction angles, while some quartz grains exhibit undulose extinction. Numerous very small (0.05 mm, ϕ = +4.23), small (0.08-0.23 mm ϕ = +3.64 - +2.13) and medium (0.33 mm, ϕ = +1.60), sub-euhedral, angular and sub-rounded to rounded greenish grains appear to be very fine-grained illite (glauconite?) alteration of K-feldspar, though some of the rounded grains and fragments, and larger elongated irregularly-shaped grains, definitely appear to be detrital. Many K-feldspar grains likewise appear to be partially altered to illite, perhaps best evident under crossed polars because in plane polarized light they have retained their K-feldspar habit and appearance. Numerous small or long (0.06-0.48 mm, ϕ = +4.05 - +1.06), thin and thick, edge-on muscovite flakes (sometimes degraded, bent, weave around mosaic grains, or are broken, and/or have frayed or broken ends) are wedged tightly at various angles between mosaic grains but in some areas are parallel to the bedding. Several short and thick edge-on brachiopod shell fragments (easily confused for muscovite flakes) consisting of collophane (birefringent cryptocrystalline apatite) are also wedged between mosaic grains.

Many very small (0.04-0.06 mm, ϕ = +4.64 - +4.05), small (0.08-0.18 mm, ϕ = +3.64 - +2.48) and small-medium (0.23mm, ϕ = +2.13) sub-angular to sub-rounded dolomite grains and rhombs are visible (sometimes in clumps) when not fully covered by the dominating iron-oxide coating which still often encroaches on their edges, and since some of these grains appear to be wedged in the mosaic, they may be detrital grains. It is unclear whether any of the very small to small-medium (0.06-0.27 mm, ϕ = +4.05 - +1.90) siderite grains might also be detrital, since the siderite may have resulted from replacement of dolomite. Several very small rounded oval-shaped grains and angular or polygonal fragments have slightly higher relief and birefringence and are wedged in the mosaic so could be detrital carbonate, probably calcite. Also, several very small (0.04-0.05 mm, ϕ = +4.64 - +4.23) iron-oxide-coated, very high relief, birefringent, tabular-to-rounded grains/crystals of zircon are wedged in the mosaic. Much of the rock fabric is coated with iron oxide, though the iron oxide appears to preferentially coat the K-feldspar grains, perhaps accompanying the illite alteration, but sometimes just encroaches on the edges of the quartz and K-feldspar grains. Most of the mosaic is cemented with a combination of illite alteration or dolomite partially covered with iron oxide and siderite, that is between, and sometimes in patches between, the quartz and K-feldspar grains. In several areas not coated and obscured by iron oxide there are abundant small sub-angular to sub-rounded dolomite and/or siderite grains and cement areas (with streaks and light dustings of iron oxide) between the scattered quartz, K-feldspar and greenish illite after K-feldspar grains. In another area not coated by iron oxide there is a linear zone cross-cutting the regular mosaic and adjacent patches within the regular mosaic consisting of a tightly-interlocking mosaic of tiny carbonate grains, likely siderite with some sections of them lightly dusted with iron oxide and other patches with tiny quartz grains and illite alteration. Another obliquely cross-cutting linear zone appears to be a fracture with fractured grains and abundant illite alteration. 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 some grains, sometimes covering grains and thus distorting their colors.

<u>HF-08</u>

Red sandstone (horizontal), close to fold hinge and fault, harder unit (kink folded), part of sandstone sample folded (to the right of, and a little below, sample HF-07).

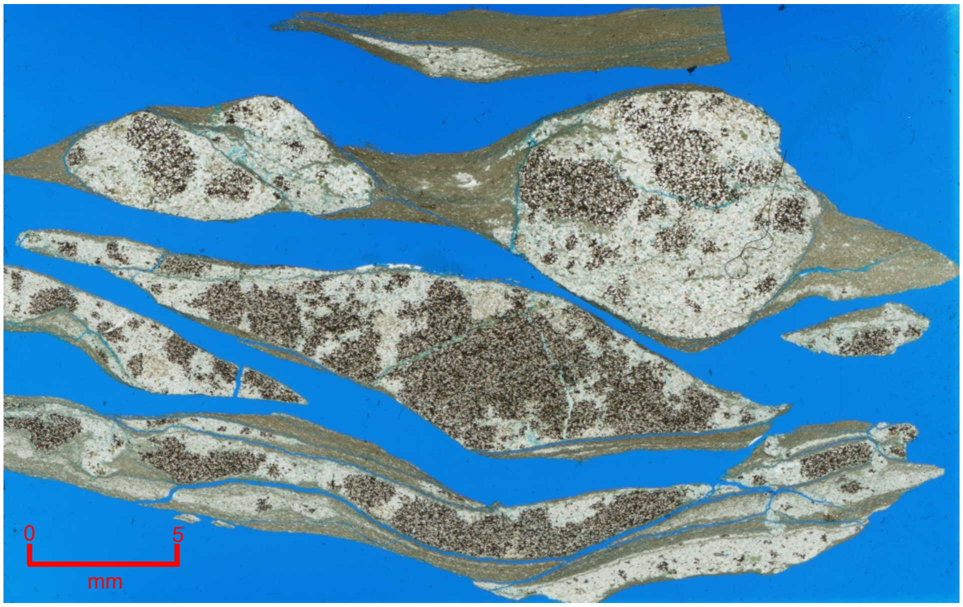
At normal scale, a fine-grained sandstone consisting of small quartz grains with subordinate K-feldspar grains, and patches of brown iron-oxide stained carbonate (which could be detrital carbonate clasts given their rounded shape and reasonably defined edges) and scattered iron-oxides that give the rock a red color overall. Barely visible glauconite (illite) grains provide some greenish tinge. There is also a hint of trough cross-laminations. Overall, this is a glauconitic sub-arkosic sandstone.

Under the microscope, an interlocking, tightly-fitted mosaic of very small (0.03-0.06 mm, ϕ = +5.01 - +4.05, coarse silt size) to small (0.07-0.23 mm, ϕ = +3.77 - +2.13, very fine to fine sand size), irregularly-shaped, euhedral, angular and sub-angular to sub-rounded and rounded quartz grains and very small (0.03-0.06 mm, ϕ = +5.01 - +4.05) to small (0.07-0.15 mm, ϕ = +3.77 - +2.75), irregularly-shaped sub-angular to sub-rounded and rounded K-feldspar grains and former laths, a few of which exhibit pseudo multiple twinning or cross-hatched twinning under crossed polars. The shapes of the quartz grains, and some in large to very large patches of quartz "molded" around some scattered K-feldspar grains, indicate quartz subsequently grew over and around detrital grains, sometimes as euhedral overgrowths, to infill pores and to cement the mosaic of grains by often meeting at triple points. Occasionally the quartz grains contain internal "ghost" outlines of the original detrital grains. Some quartz grains and larger patches of quartz consist of irregularly-shaped sub-domains sometimes with fuzzy boundaries, and with different extinction angles and even exhibiting undulose extinction. Numerous small (0.05-0.23 mm, ϕ = +4.23 - +2.13) rounded greenish-brown grains and sub-angular fragments, and irregularly-shaped patches, sometimes with associated iron oxide outlining and/or patches, appear to be very fine-grained illite (glauconite?) alteration of K-feldspar and sometimes may have been originally detrital. Some very small to small (0.06-0.14 mm, ϕ = +4.05 - +2.84), slightly higher relief and birefringence, sub-angular and sub-rounded dolomite grains, usually finely outlined by iron oxide with internal light iron oxide speckling and streaks, are wedged between the mosaic grains and thus are likely to be detrital. Numerous very small (0.06-0.09 mm, ϕ = +4.05 - +3.47), small (0.11-0.24 mm ϕ = +3.19 - +2.06) or long-very long (0.27-0.30 mm, ϕ = +1.90 - +1.75), thin and thick edge-on muscovite flakes, which are sometimes bent and even broken around mosaic grains, sometimes altered / degraded and sometimes also expanded to become very thick, and sometimes have frayed ends, are wedged at various angles between mosaic grains, though many of the flakes are oriented at the same preferred orientation that is oblique to the bedding. In one instance, several small thin edge-on muscovite flakes are stacked on top of one another along with a parallel band of iron oxide between two of them, while another two stacked very long, thin edge-on muscovite diverge as they bend and weave their separate ways between mosaic grains, one of them broken at one point. Some possible small (0.08 mm, ϕ = +3.64) irregularly-shaped face-on muscovite flakes. Several small, thick, edge-on brachiopod shell fragments, often with two internal layers that distinguish them from muscovite flakes and consisting of collophane (birefringent cryptocrystalline apatite), are wedged between mosaic grains. Several very small (0.04-0.06 mm, ϕ = +4.64 - +4.05) rounded, oval-shaped or tabular, high relief, high birefringent grains are likely to be zircon. Small and large patches of heavy iron oxide occur between mosaic grains and sometimes cover some mosaic grains, in places are associated with illite alteration of former K-feldspar, and sometimes appear to cover or replace edge-on muscovite flakes. Large areas where the mosaic quartz and K-feldspar grains are scattered apart are cemented between them and some greenish "detrital" illite (glauconite) grains and edge-on muscovite flakes by a network of merged small sub-angular dolomite grains (with iron oxide streaks and dustings, and accompanying iron oxide patches), which seem to have in part replaced some of the mosaic quartz and primarily K-feldspar grains. In other areas, the mosaic is partially covered / coated by heavy iron oxide so that many grains and the cement (which in some cases is the network of merged dolomite grains) are obscured and the remainder are scattered apart with the heavy iron oxide between them and encroaching on their edges. In yet other areas, where the illite alteration has extended beyond the greenish grains (after K-feldspar?) to infill between them and between some of the mosaic quartz grains and coupled with an included medium, thick edge-on muscovite flake, or where there is extensive illite alteration between the mosaic grains, it would appear that the illite alteration has facilitated some fracturing and possible shearing of some mosaic grains along linear zones. There are virtually 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 some grains (that can make some look like pore spaces), sometimes covering grains and thus distorting their colors.

HF-09

Green mudstone, friable, hinge of fold (top left, well above sample HF-06).

At normal scale, the rock is a very fine-grained laminated mudstone with "eyes" or lenticular selvages of fine-grained siltstone. The mudstone is dominated by the clay mineral illite, likely due to diagenetic alteration of K-feldspar and thus likely giving the mudstone its greenish color in outcrop. The siltstone consists of very small grains of K-feldspar and quartz, the latter occurring concentrated in "eyes" or lenticular selvages between the mudstone laminae which wrap around the hard quartz accumulations. The siltstone also has blotched areas of brown iron-oxide-stained carbonate (which could be detrital carbonate clasts given their rounded shape and reasonably defined edges) and probably illite and K-feldspar grains, many of which occur in the quartz "eyes" and lenses.



Under the microscope, the rock fabric consists of alternating bands or laminae and selvages of apparently "softer" predominantly iron oxide stained dark brown fine-grained illite alteration and apparently "harder" "augen"-like bands and rounded "eyes" consisting of a clean fine-grained mosaic of quartz and K-feldspar grains. The dark brown iron-oxide-stained laminae consist of remnants of tiny (0.01-0.05 mm, ϕ = +6.72 - +4.23, medium to coarse silt size) irregularly-shaped quartz grains with fuzzy edges, while the tiny (0.02-0.06 mm, ϕ = +5.71 - +4.05) K-feldspar grains that were the dominant mineral present but have been largely altered to illite which now overwhelms the fabric of the mosaic and is pervasive through it. Also present are numerous small or long (0.05-0.37 mm, ϕ = +4.23 - +1.43), thin edge-on muscovite flakes, sometimes bent, mostly inclined parallel to the laminae and thus the bedding, some tiny-very small (0.03-0.06 mm, ϕ = +5.01 - +4.05) irregularly-shaped blotches of greenish glauconite (illite and/or after K-feldspar?), and many scattered very tiny-tiny specks, blotches and streaks of heavy iron oxide (sometimes appearing to be possibly replacing or coating edge-on muscovite flakes), as well as the pervasive iron oxide staining. In some places these iron-oxide-stained dark brown laminae of predominantly illite alteration with thin edge-on muscovite flakes end abruptly against, and partially merge into, the clean (non-iron-oxide-stained) fine-grained mosaic of quartz and K-feldspar grains. The predominant harder "augen"-like non-iron-oxide-stained bands and "eyes" consist of a tightly fitted mosaic of tiny to very small and sometimes small (0.02-0.16 mm, ϕ = +5.71 - +2.66), irregularly-shaped, angular to sub-rounded, partly altered (to illite?) K-feldspar grains (under crossed polars the alteration bands appear like multiple twinning), and subordinate scattered tiny to small-medium (0.02-0.27 mm, ϕ = +5.71 - +1.90), irregularly-shaped, angular-euhedral and sub-angular to sub-rounded quartz grains with some fuzzy edges (and sometimes displaying undulose extinction). They are cemented by pervasive illite alteration, but with occasional tiny-small (0.03-0.20 mm, ϕ = +5.01 - +2.33), sometimes irregularly-shaped, but otherwise sub-angular to sub-rounded greenish glauconite (illite?) grains, numerous tiny-small (0.05-0.25 mm, ϕ = +4.23 - +2.00), thin edge-on, and some tiny and very small (0.05-0.09 mm, ϕ = +4.23 - +3.47) face-on, muscovite flakes usually inclined close to being parallel to the bedding wedged between the mosaic grains, and very tiny specks, thin edge linings and small blotches of heavy iron oxide, the latter sometimes appearing to coat or replace edge-on muscovite flakes so in many places those are also inclined close to being parallel to the bedding. Where several quartz grains are still clumped together their edges usually meet at triple points, which suggests that this rock was originally quartz cemented by overgrowths built around the original detrital grains, whereas the rock is now dominated by the illite alteration of K-feldspar and occasional dolomite forming the cement/matrix. In numerous areas of these "augen"-like bands and "eyes" there are networks of merged numerous, very small-small (0.05-0.20 mm, ϕ = +4.23 - +2.33), sub-angular to sub-rounded dolomite grains (many with just iron oxide streaks and dustings, but others often, perhaps preferentially, heavily coated by iron oxide in patches), which seem to have in part replaced some of the mosaic quartz and primarily K-feldspar grains and left the muscovite flakes untouched. In other areas of the non-heavily iron-oxide-stained mosaic the K-feldspar grains have been totally altered to illite (as is evident under crossed polars) leaving remnant untouched tiny sub-angular quartz grains and edge-on muscovite flakes. In several places the illite alteration has extended beyond the greenish grains (after K-feldspar?) to infill in an irregular pattern between them, so that in one place this illite alteration and many linearly-aligned edge-on muscovite flakes have produced a linear weaknesses in the rock fabric that have facilitated fractures, but no obvious shearing or fracturing of mosaic grains is evident so no movement has occurred. In another place the rock fabric is cut almost perpendicular to the bedding by a narrow fracture-filling vein of very tiny irregularly-shaped quartz grains and possibly some illite (?). And in several other places the mosaic of fine-grained K-feldspar and quartz grains is cut by fractures parallel to the bedding and the intense brown iron-oxide-stained laminae, facilitated by the illite alteration and especially by numerous thin edge-on muscovite flakes that obviously weakened the rock fabric in those planes. A very small (0.03 mm, ϕ = +5.01) sub-rounded, high relief, high birefringent grain may be zircon. There are virtually no pores as the original mosaic was already tightly fitted probably due to the earlier quartz cementing, but the pervasive illite alteration is now the predominating cement, perhaps along with the occasional patches of heavy iron oxide. The sample was friable and thus was impregnated accompanied by blue dye staining before the thin section was cut, so there is abundant blue dye staining between and encroaching on some grains (that can make some look like pore spaces), as well as along hairline cracks parallel to the laminae and in large cracks and gaps between laminae and through the coherent sections of the rock fabric, often facilitated by the boundaries between the alternating softer and harder bands / laminae, and also where there are more edge-on muscovite flakes parallel to the bedding in laminae of intense brown iron-oxide-stained illite alteration.

<u>HF-10</u>

Red sandstone (hard), thin vertical bed within red mudstone (top right, to the right of sample HF-09).

At normal scale, a fine-grained sandstone dominated by small quartz and K-feldspar grains with occasional brown patches of iron-oxide-stained carbonate (which could be detrital carbonate clasts given their rounded shape and reasonably defined edges) and clay (illite) alteration. The scattering of the mixture of quartz and K-feldspar grains gives the rock a well-sorted appearance. Some cross-cutting fine fractures appear to be filled with greenish illite. This is a sub-arkosic sandstone.

Under the microscope, a tightly fitted, interlocking mosaic of almost equal proportions of very small-small (0.03-0.16 mm, ϕ = +5.01 - +2.66, coarse silt to fine sand size), irregularly-shaped, sub-euhedral and angular to sub-rounded and rounded K-feldspar grains and former laths (some exhibit crossed-hatched twinning or pseudo multiple twinning under crossed polars), and very small (0.03-0.06 mm, ϕ = +5.01 - +4.05, coarse silt size) and small (0.07-0.19 mm, ϕ = +3.77 - +2.40, very fine to fine sand size), irregularly-shaped, sub-euhedral and sub-angular to sub-rounded and rounded quartz grains. The quartz and k-feldspar grains are accompanied by numerous small, long and very long (0.05-0.38 mm ϕ = +4.23 - +1.39), thin or sometimes thick, edge-on muscovite flakes (sometimes with frayed ends or one even frayed along its entire length) at various angles (though usually parallel to the bedding) wedged between, and sometimes bent or weaved around, the mosaic K-feldspar and quartz grains, and also many very small to small (0.06-0.20 mm ϕ = +4.05 - +2.33), sub-angular to sub-rounded and rounded greenish glauconite grains (illite after K-feldspar? and often outlined by heavy iron-oxide staining), along with occasional small heavy iron oxide patches and steaks between the mosaic grains and sometimes encroaching on them, and sometimes the patches are somewhat aligned and even form a vein cross-cutting the mosaic. In a few large areas a network of coalesced very small to small (0.04-0.14 mm ϕ = +4.64 - +2.84) dolomite grains has cemented together the mosaic between the scattered grains, the dolomite probably replacing some K-feldspar grains as in those areas quartz grains predominate, unlike in other areas of the mosaic. Neither the edge-on muscovite flakes nor the glauconite grains (illite) have been replaced by dolomite, but iron oxide patches are between the mosaic grains or on some of the dolomite grains which are also usually iron-oxide dusted. Sometimes the dolomite cement grains are small, scattered, irregularly-shaped and not stained by iron oxide. In other areas the heavy iron-oxide coating is intense and covers most of the mosaic grains (so their sizes and shapes are irregular and the mosaic grains appear very scattered), and probably also covers the dolomite and/or quartz cement but does not cover the edge-on muscovite flakes. Sometimes small and tiny, iron-oxide-lined, sub-rounded or lath-like dolomite grains and rhombs are wedged in between the mosaic grains so they may have been detrital, as is evidenced by such dolomite grains being different to the dolomite sometimes cementing them in the mosaic. Generally though the rock fabric consists of tightly-fitted K-feldspar and quartz grains in an interlocking mosaic due to overgrowths on the quartz grains, some of which have internal "ghost" outlines of the original sub-angular to rounded detrital grains, while other overgrowths are molded around and between other mosaic grains, so that quartz grain edges often meet at triple points with other quartz grains and the K-feldspar grains, indicating the rock was initially quartz cemented by infilling of the pores. Some quartz grains consist of smaller sub-grains or sub-domains usually with different extinction angles, and some quartz grains exhibit undulose extinction. A thin long (0.30 mm, ϕ = +1.75) edge-on muscovite flake is sharply bent and broken, weaved around and between blocks of mosaic grains almost parallel to the bedding, with a short thick flake paralleling one nearby, in what became fracture zones due to the muscovite flakes providing planes of weakness, in one instance accompanied by dolomite alteration. A small (0.08 mm, ϕ = +3.64) edge-on muscovite flake is included in a small quartz grain, while several small (0.11 mm, ϕ = +3.19) face-on muscovite flakes are wedged in the mosaic. A very thick, very long, and several smaller, edge-on brachiopod shell fragments (discernable due to their two-layer wall construction) consist of collophane (birefringent cryptocrystalline apatite). Several very small and small (0.03-0.08 mm ϕ = +5.01 - +3.64), high relief, high birefringent, rounded and iron-oxide-stained grains wedged in the mosaic are likely zircon. Thin veins of dolomite partially coated with, and accompanied by, heavy iron oxide cross-cut the mosaic almost perpendicular to the bedding. There are only a few tiny and very small pores apparent in sone sections of the rock fabric, with no pore spaces left elsewhere. 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 some grains (that can make some look like pore spaces), sometimes covering grains and thus distorting their colors as well as along hairline cracks through the otherwise coherent rock fabric.