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# PART A

## Stratigraphic context of petrographic samples, Katherine Group and Mount Clark Formation, eastern Mackenzie Mountains, Northwest Territories

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## Introduction

In the Northwest Territories, basal Cambrian sandstone is a hydrocarbon reservoir facies in the Colville Hills (Hamblin, 1990; Dixon and Stasiuk, 1998; Janicki, 2004; Price and Enachescu, 2009) and may be an exploration target beneath Mackenzie Plain (MacLean, 2011) and elsewhere (Hannigan et al., 2011). In the eastern Mackenzie Mountains, a long-standing problem has been the need to distinguish Cambrian sandstone (Mount Clark Formation) from Proterozoic sandstone (Katherine Group). This has bedevilled both industry and government geologists undertaking bedrock mapping and regional stratigraphic studies (N. Wilson, pers. comm., 2011; MacNaughton et al., 2013; Serié et al., 2013). An accurate understanding of the characteristics of both ages of sandstone is necessary to avoid inaccurate geological reconstructions or the incorrect stratigraphic attribution of petrographic and petrophysical data. Pyle and Gal (2011) presented petrographic descriptions for select samples from a number of localities around Mackenzie Plain, but published petrographic descriptions of these units are otherwise rare.

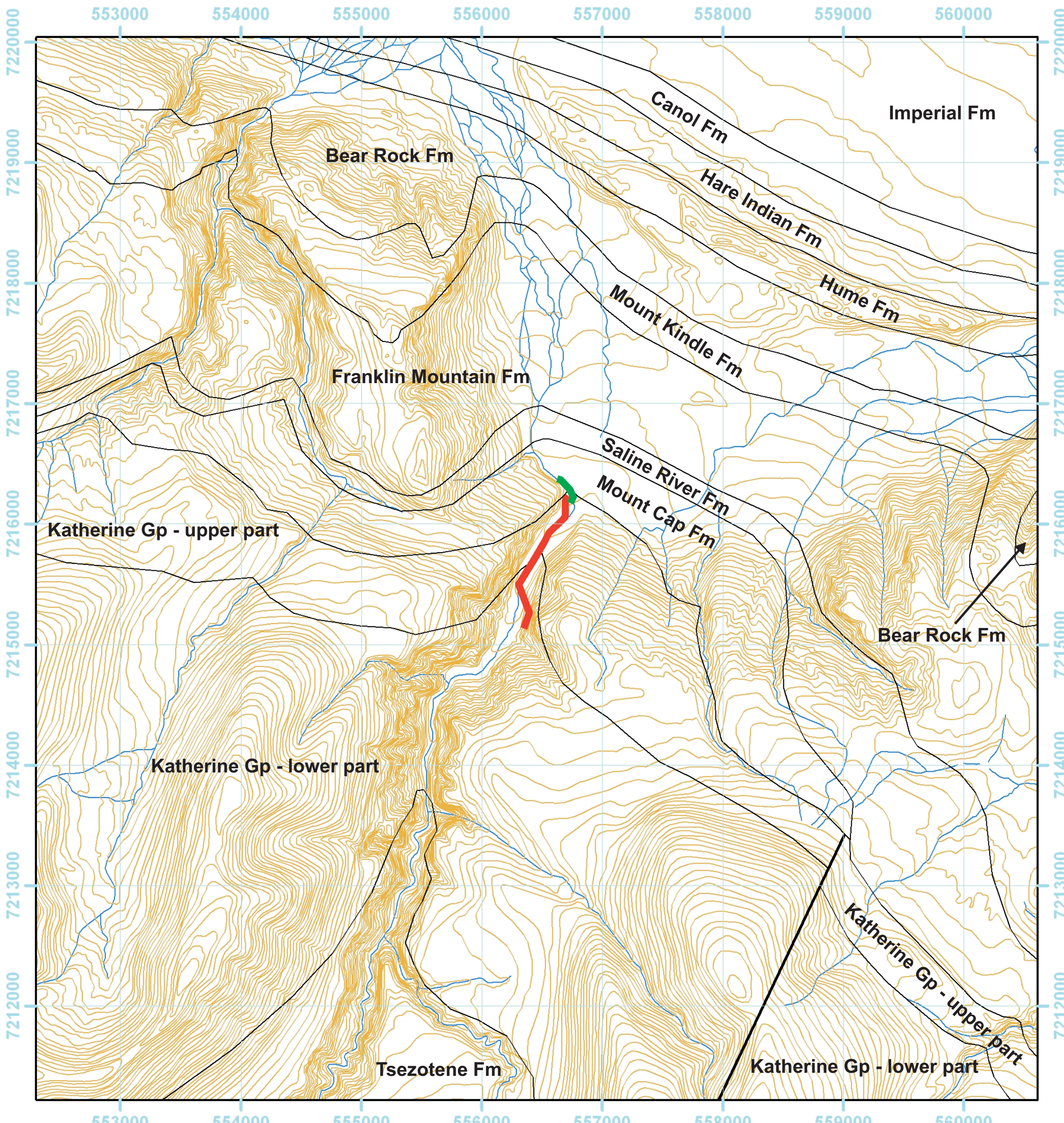
The present report provides stratigraphic and petrographic data for Neoproterozoic and Cambrian sandstone collected from measured sections along an unnamed creek in the easternmost Mackenzie Mountains (Fig. 1), adjacent to the Mackenzie Plain hydrocarbon exploration region. At this location, it was thought that Proterozoic and Cambrian sandstone-bearing units could be clearly distinguished (see discussion in Fallas and MacNaughton, 2012, their p. 8). The locality has also been adopted as field-trip site due to its excellent exposure and relative ease of access (Gal and Pyle, 2011). The primary goal of the work was to obtain detailed petrographic descriptions of Cambrian vs. Proterozoic sandstones, thereby adding to data available to geologists trying to distinguish them in areas where stratigraphic relationships are less clear. The study also provides data on the cementation history and porosity of the sandstones, which will be useful in interpreting their respective potentials as hydrocarbon reservoirs.

The report is in two parts. Part A (by MacNaughton) documents the stratigraphic succession, ties studied samples to measured sections, and comments briefly on stratigraphic implications of the petrographic work. Part B (by Hamel) makes up the main body of the report; it describes and interprets thin-section photomicrographs prepared from collected hand samples.

## Geologic Context

Proterozoic-Cambrian stratigraphy in the eastern Mackenzie Mountains is summarized in Figure 2. Cambrian strata lie with subtle angular unconformity upon the Neoproterozoic Mackenzie Mountains Supergroup (Aitken et al., 1973; Aitken and Cook, 1974). In ascending order, Mackenzie Mountains Supergroup consists of the Tabasco Formation (formally the informal H1 map unit; see Turner and Long, 2012), the Tsezotene Formation, the Katherine Group, and Little Dal Group (see Long et al., 2008, for a recent summary and overview of units).

Older reports divided the Katherine Group into seven informal units of formational rank (units K1 to K7; see, e.g., Aitken et al., 1978; Long et al., 2008). Long and Turner (2012) recently formalized the formational nomenclature of the Katherine Group, as follows:



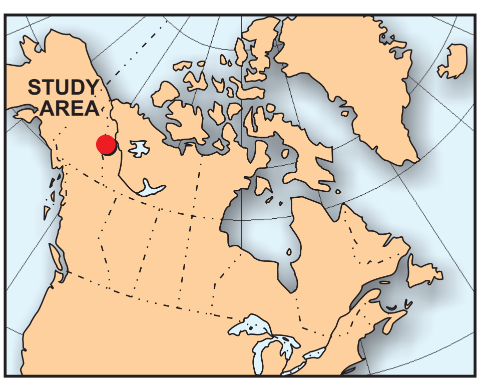




**Figure 1: Location map of measured sections 11MWBs01 (heavy green trace) and 0901S (heavy red trace). Study area is in NTS map area 96E04. Map projection and reference grid are in NAD83, UTM Zone 9; contour interval is 50ft. See text of report for latitude and longitude coordinates for sections. Bedrock geology compilation by Karen Fallas.**

**0901S** **11MWBs01**

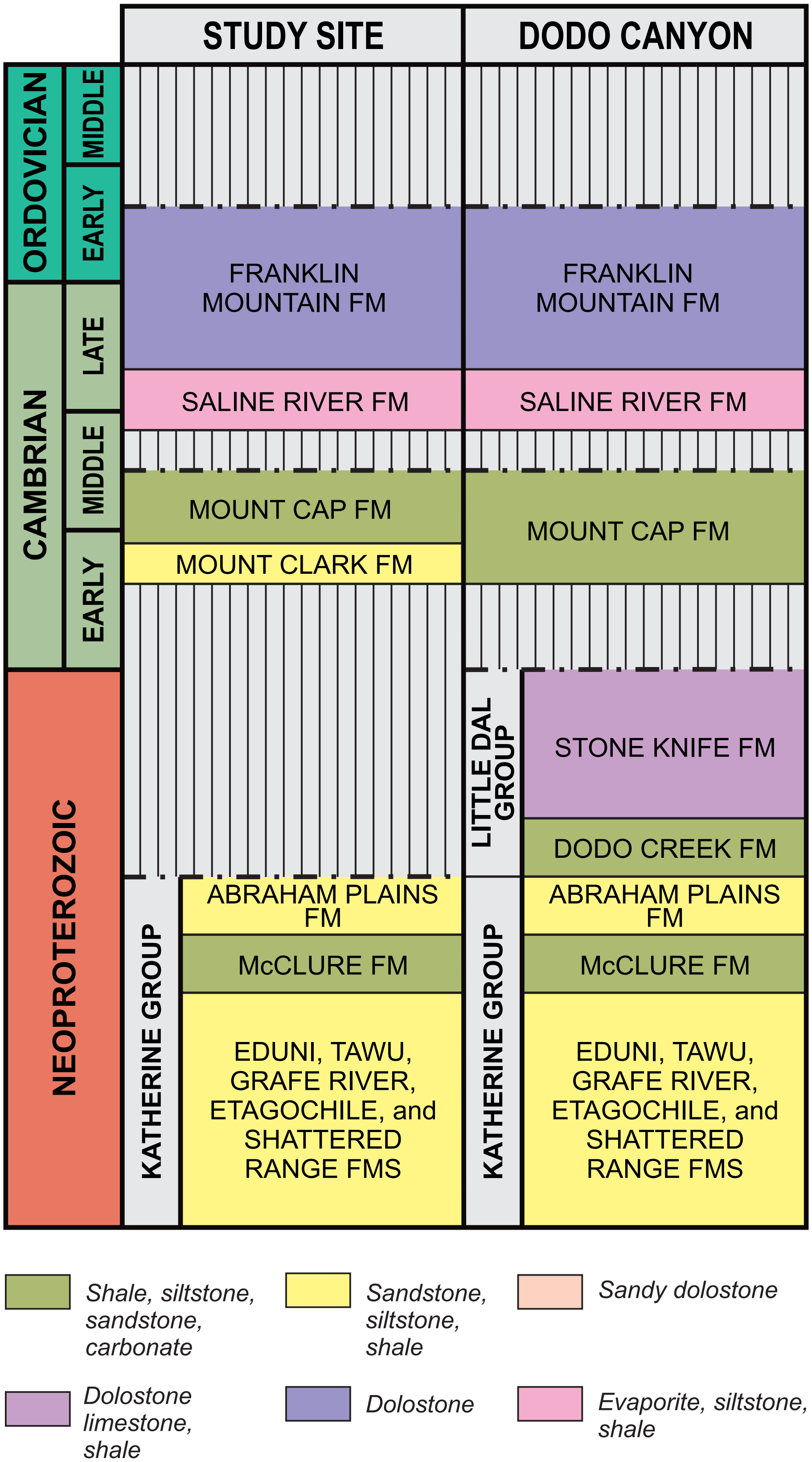



**Figure 2: Neoproterozoic-Cambrian stratigraphy for the study site and for the well-documented succession in Dodo Canyon, approximately 30 km to the southeast. See Aitken et al. (1973) for details of Dodo Canyon stratigraphy.**

K7 = Abraham Plains Formation (sandstone dominated)
K6 = McClure Formation (shale dominated, with stromatolitic dolostone marker)
K5 = Shattered Range Formation (sandstone dominated)
K4 = Etagochile Formation (shale dominated)
K3 = Grafe River Formation (sandstone dominated)
K2 = Tawu Formation (shale dominated)
K1 = Eduni Formation (sandstone dominated)

Because the present petrographic study began before the publication of the new Katherine Group nomenclature, the earlier informal names are used herein.

The Little Dal Group is not preserved at the study site of this report but see Turner and Long (2012) for its formalized internal stratigraphy.

A number of studies have discussed the regional distribution and character of Lower and Middle Cambrian formations on the northern mainland (e.g., Aitken et al., 1973; Dixon and Stasiuk, 1998; MacLean, 2011). In the eastern Mackenzie Mountains, Cambrian units are, in ascending order, the Mount Clark, Mount Cap, Saline River, and Franklin Mountain formations. Mount Clark Formation is dominated by quartz arenite, but also can contain lesser conglomerate and minor amounts of siltstone (Dixon and Stasiuk, 1998; Serié et al., 2009; Fallas and MacNaughton, 2012). Mount Cap Formation is dominated by fine-grained siliciclastics (shale, mudstone) but is heterolithic and locally can contain significant amounts of sandstone, siltstone, dolostone, and limestone (Aitken et al., 1973; Dixon and Stasiuk, 1998; Série et al., 2009). Saline River Formation consists mainly of shale, dolostone, and anhydrite; a middle member of salt is present in the subsurface (Meijer Drees, 1975; Dixon and Stasiuk, 1998). Franklin Mountain Formation is a thick succession of carbonates, mainly dolomite (Aitken et al., 1973; Norford and Macqueen, 1975; Turner, 2011).

Present-day distribution of Proterozoic and Cambrian formations was controlled by the Mackenzie Arch, an elongate region of intermittent Neoproterozoic and early Paleozoic uplift (Aitken et al., 1973; Cecile et al., 1997). Uplift on the arch caused the regional erosional beveling of the Mackenzie Mountains Supergroup (Aitken et al., 1973). In the eastern Mackenzie Mountains, the sandstone-dominated Mount Clark Formation was deposited as a shallow-water facies that fringed the eastern flank of Mackenzie Arch, adjacent to deeper-water facies beneath Mackenzie Plain (MacNaughton et al., 2013).

## Measured Stratigraphic Sections

During the Mackenzie Delta and Corridor Project, two stratigraphic sections were measured along an unnamed creek in the easternmost Mackenzie Mountains (Fig. 1). As explained below, there is overlap in the stratigraphic coverage of the sections. For petrographic analysis of samples from the two sections, see Part B of this report.

### *Section 11MWBs01*

Section 11MWBs01 (Fig. 3A) was measured in detail through strata thought to include the upper part of the Katherine Group (uppermost part of K6 and entirety of preserved K7) and the entirety of the Cambrian Mount Clark Formation. Strata of Mount Cap Formation are poorly exposed immediately above Mount Clark Formation. Section

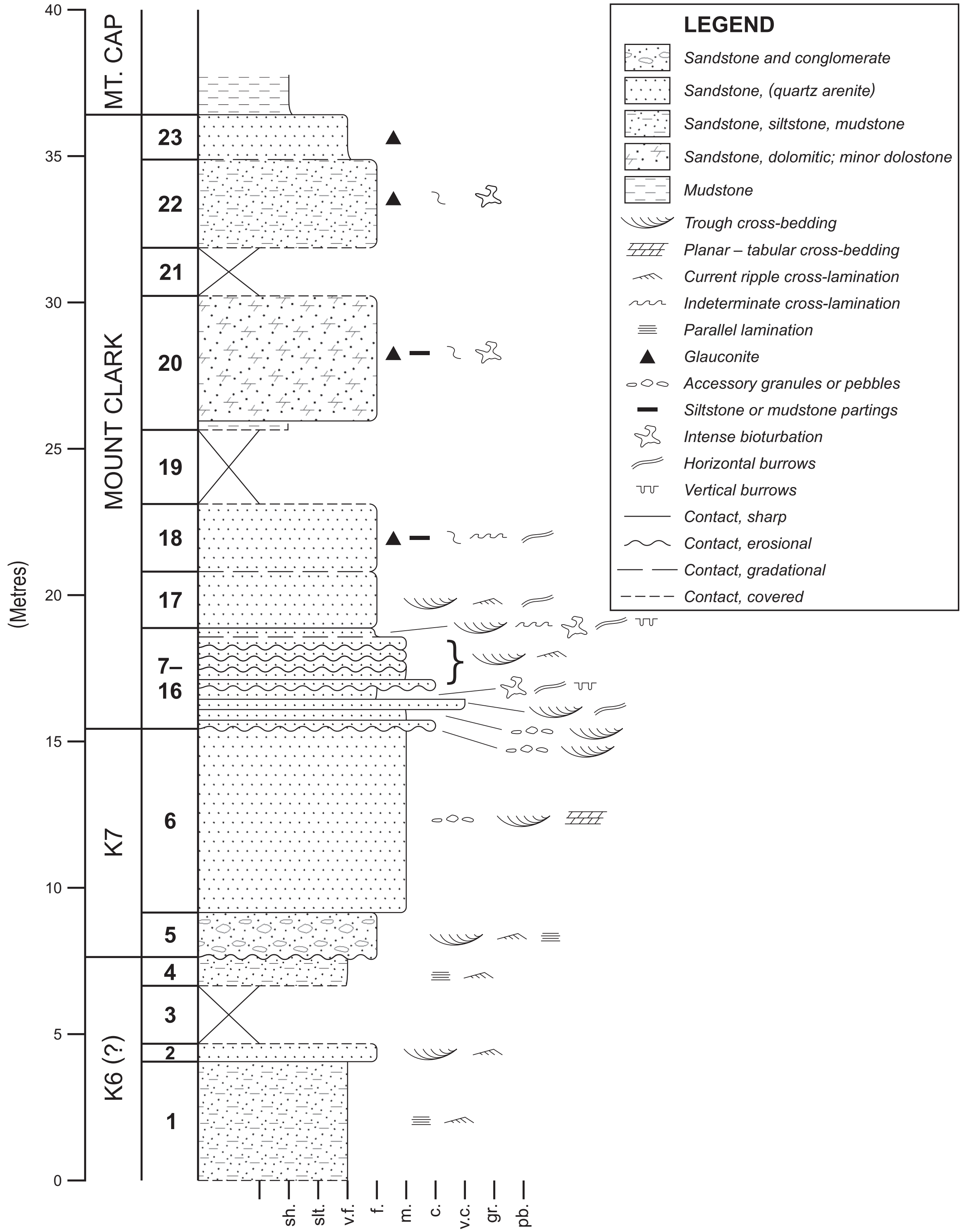



**Figure 3A:** **Graphic log of measured section 11MWBs01 showing details of sedimentary structures and bioturbation.**

11MWBs01 was documented by Robert MacNaughton, assisted by Thomas Proks, on July 16, 2011. The six lowest intervals of section 11MWBs01 overlap with the uppermost three intervals of section 0901S. Coordinates (NAD83) for base of section are: 65.0647° N; 127.7948° W; coordinates for top of section are: 65.0661° N; 127.7961° W. Except for three covered intervals, exposure and access are excellent. Detailed descriptive notes for this section are provided in Appendix A-1, at the end of Part A of the report.

Thirteen outcrop samples from this section were chosen for thin section study. Of these, two came from strata assigned to the uppermost part of map unit K6 during field work, with a further four collected from strata assigned to map unit K7. Seven came from strata mapped as Mount Clark Formation. See Fig. 3B for sample horizons. Outcrop photographs of Section 11MWBs01 are provided in Figure 4.

### *Section 0901S*

Section 0901S (Fig. 5) is the stratigraphically lower of the two sections. It was measured at reconnaissance scale to document gross lithologic packaging in the upper part of the Proterozoic succession along the creek (Fig. 6). It was documented by Matthew Sommers, assisted by Derrick Midwinter and supervised by Robert MacNaughton, on July 31, 2009. Coordinates (NAD83) for base of section are: 65.0551° N, 127.8026° W; coordinates for top of section are: 65.0649° N; 127.7942° W. Although access was generally good at creek level, there were several intervals where tree cover made it necessary to infer lithology based on uphill views of inaccessible cliffs. Because of the necessity of sighting across a fast-flowing stream and measuring through long covered intervals, some interval thicknesses may be inaccurate. During measuring, only gross lithologies were recorded, and so only a graphic log is presented for this section.

Section 0901S encompasses several hundred metres of Katherine Group (Fig. 5). It includes the uppermost beds of K3 (sandstone-dominated), and the entirety of K4 (shale and sandstone) and K5 (sandstone). It encompasses most or all of the shale-dominated K6, including a distinctive package of orange-weathering, stromatolitic dolostone that is a useful interregional marker bed (see Long et al., 2008). In section 0901S, units 15-17 overlap with section 11MWBs01. (Unit 15 = uppermost K6; unit 16 = basal K7; and unit 17 = upper K7; see Figs. 4A, B.) All samples from this interval were collected during measurement of section 11MWBs01, and are keyed to that section.

Two specimens were collected from the Katherine Group along the line of section 0901S. Sample C-490762 was collected from the uppermost 8.0 m of the sandstone-dominated K3 map unit (Interval 1 in Fig. 5). Sample C-490761 was collected from Interval 7 of the section (Fig. 5), a 22.5 m thick package of sandstone.

## Stratigraphic Implications of Petrographic Results

Certain petrographic observations presented in Part B of this report may be relevant to stratigraphic questions. These are commented upon briefly here.

### *1. Possible burrows in Katherine Group?*

Three samples from Section 11MWBs01 preserve features that resemble burrows or bioturbate textures. These are C-490728 (section unit 1, K6 map unit), C-490729

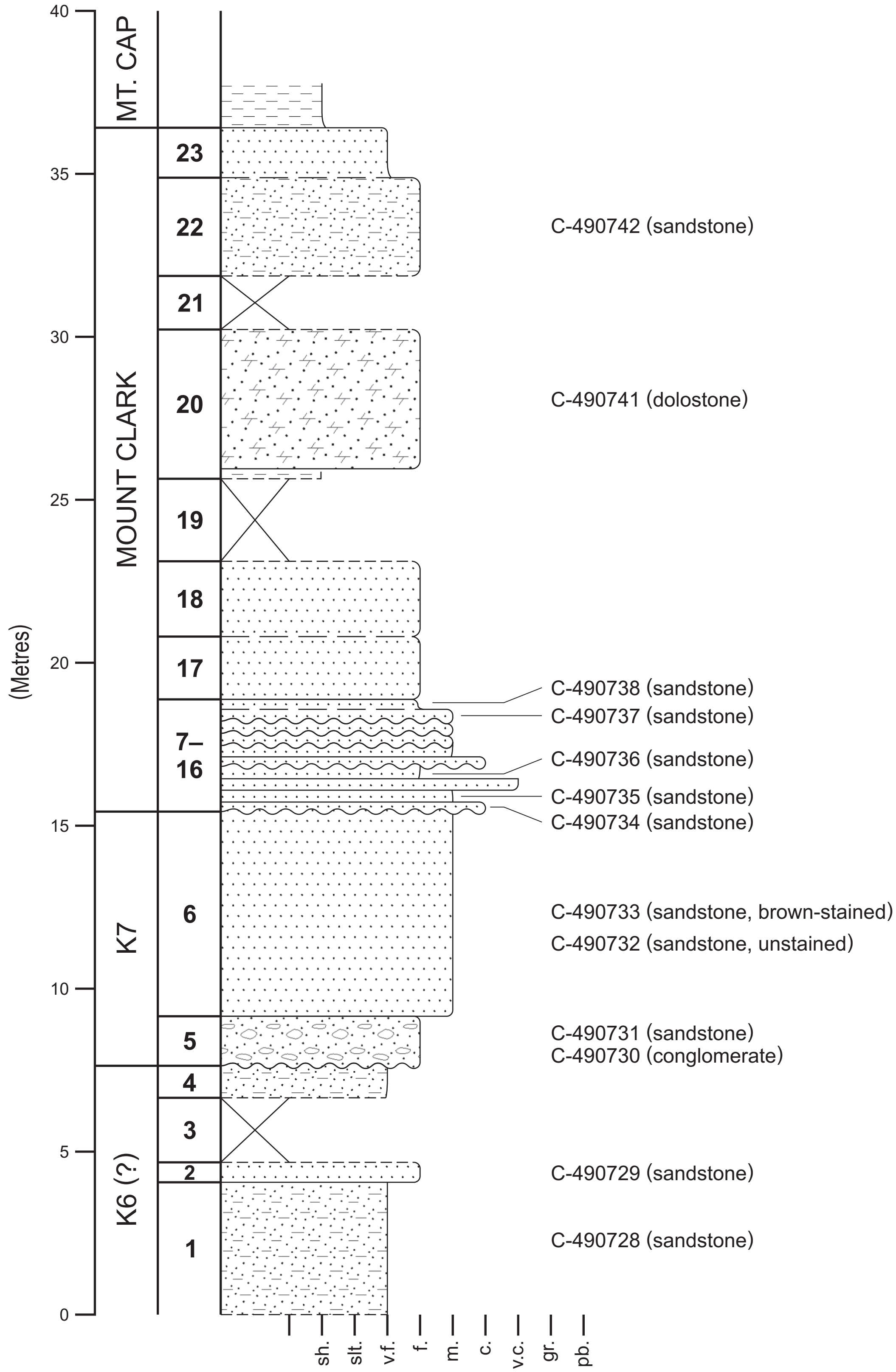



**Figure 3B: Graphic log of measured section 11MWBs01 showing sampling levels for petrographic study.**

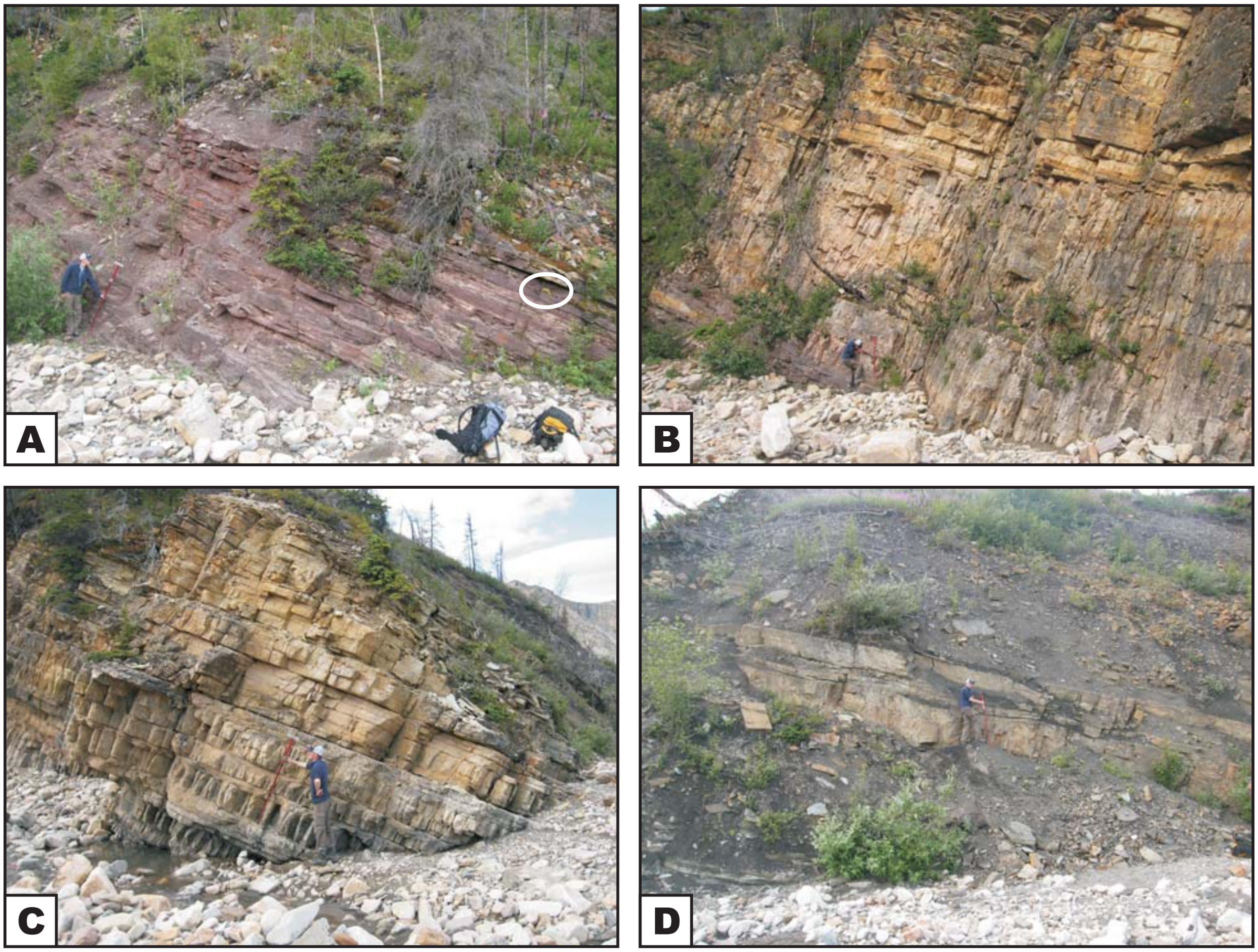
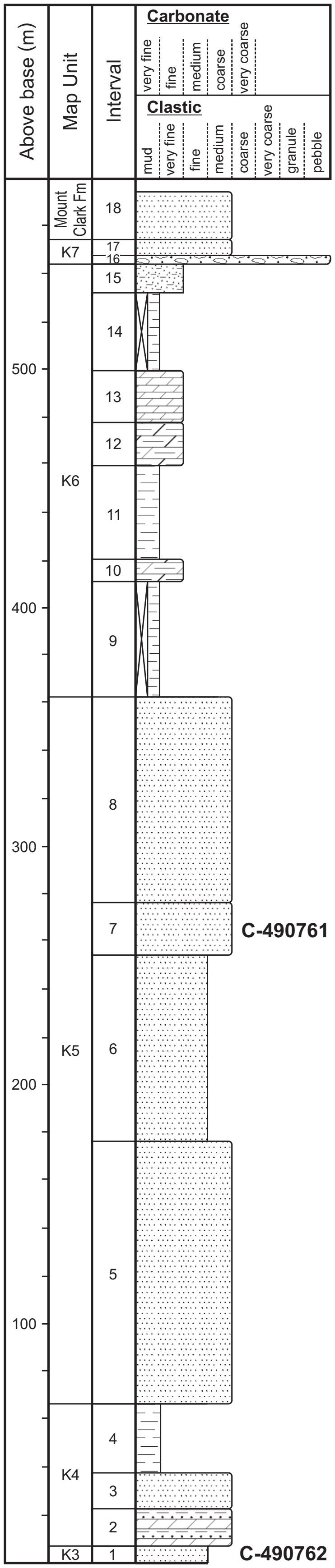



**Figure 4:** Photographs of measured section 11MWBs01. In all photographs, red measuring staff is 1.5 m long. (**A**) View of intervals 1 and 2; flagging tape at right (circled) marks contact between the two units. Lower part of covered unit 3 overlies this outcrop. (**B**) View of probable contact between Katherine Group and Mount Clark Formation. Grey-weathering unit with strong vertical joint set (lower two-thirds of photograph) is unit 6, which is interpreted as uppermost part of Katherine Group. Above this, thinner-bedded, tan-weathering sandstone contains bioturbation and belongs to Mount Clark Formation. At lower left, maroon-weathering strata belong to units 5 and 6. (**C**) Basal succession of Mount Clark Formation. Base of formation is at level of pool (lower left). Assistant's feet are beside unit 11. Top 2.3 m of cliff is unit 18. Above this is a covered interval (unit 19 in the measured section). (**D**) Assistant stands beside lower part of sandstone-dominated, relatively resistant unit 20. Outcrop at lower left is sandstone of unit 18; intervening covered interval is unit 19. Uppermost part of section was measured through generally poor exposure uphill and to the right. Contact with Mount Cap Formation is probably in the covered zone higher up the hillside.



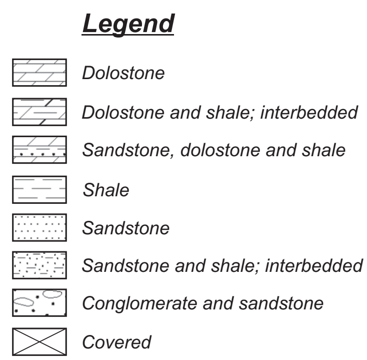




**Figure 5: Graphic log of measured section 0901S, showing horizons sampled for petrographic study.**


**Figure 6: Aerial view of upper part of section 0901S, along unnamed creek in eastern Mackenzie Mountains. View is to north, looking toward Mackenzie Plain. Major divisions of Katherine Group are shown. Position of base K5 unit is poorly exposed on this side of stream. Lower part of section was measured on opposite bank of stream. Cambrian crops out immediately above K7. Asterisk shows collection site of sample C-490761.**

(section unit 2, K6 map unit), and C-490731 (section unit 5; K7 map unit). Thin sections of these samples are illustrated in Part B. This came as a surprise during the present study because no evidence for burrows was noted in these units when the section was measured—the lowest burrows being recorded from unit 9, where bioturbation is intensely and clearly developed.

If the identification of bioturbation in units 1, 2, or 5 is correct, this implies that these units must be of late Ediacaran age or younger. This is because convincing examples of metazoan burrowing are not known from older rocks (e.g., Mángano et al., 2012). The Mackenzie Mountains Supergroup is Cryogenian or older (Long et al., 2008; Long and Turner, 2012) and thus, if the presence of burrows can be verified, the strata assigned to Katherine Group in Section 11MWBs01 cannot belong to that unit. Instead, they would likely be a basal unit of the Mount Clark Formation, or perhaps a sub-Mount Clark unit that post-dates deposition of Mackenzie Mountain Supergroup.

Dr. Gabriela Mángano (pers. comm., 2013) has examined thin-section photomicrographs for C-490728 and C-490729. She offered the opinion that although an argument could be made that the structures in C-490728 are of biogenic origin, they appear “like any synsedimentary deformation of laminae, very common in tempestites . . . produced by simply physical processes (related to rapid sedimentation)”. Regarding C-490729, Dr. Mángano notes that the putative burrows have “apparently more defined structures in cross section” but that “the shape of the sections is awkward, there are engulfments and angularities in the outline that are not typical of burrows in cross section”.

In view of these cautions, and the lack of outcrop-scale evidence for bioturbation, units 1, 2, and 5 of section 11MWBs01 are provisionally left within the Katherine Group. However, more detailed examination of this interval would be appropriate.

### *2. Base of Mount Cap Formation?*

Regionally, the contact between the Mount Clark and Mount Cap formations is a conformable facies boundary that may be markedly diachronous (Dixon and Stasiuk, 1998; MacNaughton et al., 2013). Mount Clark Formation is sandstone dominated, with lesser volumes of shale and siltstone, whereas Mount Cap Formation is shale-dominated but markedly heterolithic, encompassing also sandstone and carbonates (Dixon and Stasiuk, 1998; Fallas and MacNaughton, 2012). During recent bedrock mapping by GSC in the eastern Mackenzie Mountains, is has been found to be “…most effective to treat the change from sandstone-dominated to heterolithic strata as the contact. This corresponds well to a mappable, upward change in weathering character from resistant to semi-resistant or recessive…” (Fallas and MacNaughton, 2012, p. 7).

During field work, the base of the Mount Cap Formation in section 11MWBs01 was considered to be at or just above the top of the section, corresponding to an upward change from sandstone to shale-dominated, very recessive strata. At least one unit assigned to the Mount Clark Formation contains carbonate facies, however. Sample C-490741 (section unit 20) is a silty glauconitic dolostone (see description in Part B), and the possibility of placing the base of the Mount Cap within unit 20 should be considered. In some sections, the first appearance of carbonates does correspond closely to the appearance of abundant shale at the base of the Mount Cap Formation (R.B. MacNaughton, work in progress). However, in Section 11MWBs01, the first carbonate appears within an otherwise sandstone-dominated succession, below the most pronounced change in lithology and weathering character. Therefore, the base of the Mount Cap Formation is still considered to be at or just above the top of the measured section. The presence of one or more carbonate beds in the uppermost Mount Clark Formation emphasizes the gradational and variable character of the Mount Clark-Mount Cap contact.

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## Appendix A-1: Descriptive Notes for Measured Section 11MWBs01

**Measured Section 11MWBs01:** Section measured through uppermost Katherine Group and overlying Mount Clark Formation along the west side of an unnamed creek in easternmost Mackenzie Mountains. Base of section is at coordinates: 65.0647° N; 127.7948° W. From base, route of section proceeded to north and then to northwest around a promontory of sandstone, ending at the last reliable outcrop of Mount Clark Formation. Coordinates for top of section are approximately: 65.0661° N; 127.7961° W. (All coordinates given using NAD83 as datum.) Section described by R.B. MacNaughton and measured by T. Proks on July 16, 2011. Except as noted, all beds are resistant.

| Section summary: | | |
|---|---|---|
| | K6 map unit | 7.7 m (incomplete) |
| | K7 map unit | 7.8 m |
| | Mount Clark Fm | 20.9 m (nearly complete) |
| | Total thickness | 36.4 m |

| Unit | Description | Thickness | Height Above Base |
|---|---|---|---|
| | *Section lost in cover upsection; shale float indicates Mount Cap Formation. Next outcrops stratigraphically upsection include dark-weathering shale and dark-weathering, fetid, lime mudstone.* | | |
| 23 | Base gradational? Poorly exposed, very fine-grained glauconitic quartzose sandstone; thin-bedded. Weathers brownish grey. | 1.5 | 36.4 |
| 22 | Base covered. Outcrop semi-resistant. Quartzose sandstone, glauconitic, very fine to fine grained. Beds 5-10 cm thick, in bedsets 30-60 cm thick; bedding diffuse. Bedsets are separated by very dark grey shale or mudstone, silty, in beds 5-12 cm thick. Abundant bioturbation is locally very intense, making it hard to distinguish individual traces; mainly horizontal burrows. **Sample: C-490742 (sandstone)** | 3.0 | 34.9 |
| 21 | Covered. | 0.8 | 31.9 |
| 20 | Base covered. Outcrop semi-resistant. At base of unit is 30 cm of thin-bedded, dark grey shale. Balance of unit is mainly very fine to fine-grained quartz arenite with numerous glauconitic horizons, especially in upper half of unit. May locally have dolomitic cemented sandstone or dolomite. Bedding irregular and undulatory. Beds are 20-50 cm thick; bedding is thinner in upper half of unit. Lower half of unit has shale-draped erosional surfaces (amalgamation surfaces?), and some intervals with grey mud seams and wavy bedding. In upper half of unit there are interbeds of dark grey shale with suggestions of nodular bedding. Trace fossils are common (mainly horizontal burrows; also poorly preserved *Rusophycus*); some bedding surfaces intensely reworked. **Sample: C-490741 (dolostone)** | 5.5 | 31.1 |

| | | | |
|---|---|---|---|
| 19 | Covered. | 2.5 | 25.6 |
| 18 | Base gradational. Outcrop semi-resistant. Fine-grained quartz sandstone, with trace glauconite in some beds; pale grey or pale greenish grey on fresh surface, weathers tan or pale greenish grey. Beds 1-10 cm thick. Rare ripple cross-lamination (internal structure of beds is difficult to discern). Some grey mudstone or siltstone partings and drapes. Trace fossils include two varieties of *Planolites* (small, and small and short), *Palaeophycus*, and *Teichichnus*. | 2.3 | 23.1 |
| | *Outcrop quality deteriorates above this level.* | | |
| 17 | Base sharp. Fine-grained and lesser medium-grained quartz sandstone. Weathers tan. Beds 2-10 cm thick, commonly with a few millimetres of coarse to very coarse-grained sandstone between them (lags?). Small-scale trough cross-bedding in many beds, also current ripple cross-lamination. Tops of some beds reworked by horizontal burrows. | 1.9 | 20.8 |
| 16 | Base diffuse and gradational. Fine-grained quartz sandstone. Intensely bioturbated. Horizontal burrows abundant and well developed, some stained maroon or pink. Some burrows with good wall linings (therefore *Palaeophycus*). Rare, possible *Teichichnus* and vertical burrows. Rare zones with preserved primary sedimentary structures display trough cross-bedding or large-scale ripple cross-lamination.<br>**Sample: C-490738 (sandstone)** | 0.3 | 18.9 |
| 15 | Base sharp to erosional. Fine to medium-grained quartz sandstone. As for unit 14, but basal coarse-grained horizon is 2 cm thick and cross-beds are closer to 10 cm thick.<br>**Sample: C-490737 (sandstone)** | 0.5 | 18.6 |
| 14 | Base sharp to erosional. Fine to medium-grained quartz sandstone. Locally at base is up to 1 cm of very coarse-grained quartz sandstone. Trough cross-bedding in sets 2-10 cm thick. Some parallel bedding (or possibly dune bottomsets) at unit base. | 0.4 | 18.1 |
| 13 | Base sharp to erosional. Medium-grained quartz sandstone. Small-scale trough cross-bedding and ripple cross-lamination. | 0.2 | 17.7 |
| 12 | Base sharp. Fine to medium-grained quartz sandstone. Trough cross-bedding, in sets up to 20 cm thick. | 0.4 | 17.5 |
| 11 | Base sharp to erosional. Coarse-grained quartz sandstone with some very coarse grains and granules. Trough cross-bedded in sets 3-10 cm thick that wedge out laterally. Passes laterally along outcrop into a single set of trough cross-bedding. | 0.3 | 17.1 |

| | | | |
|---|---|---|---|
| 10 | Base sharp. Unit forms an overhang along route of section. Fine-grained quartz sandstone. Light grey on fresh surface, weathers pale tan. Intensely bioturbated, with very little of original bedding preserved. Mainly simple horizontal burrows, including excellent examples (*Palaoephycus*?) on base of unit. Some suggestion of horizontal burrows with vertical spreite (*Teichichnus*?) in cross-section. Rare *Skolithos*? | 0.4 | 16.8 |
| 9 | Base sharp and irregular. At base of unit is up to 2 cm of coarse to very coarse-grained quartz sandstone. Balance of unit is fine to coarse-grained quartz sandstone. Light grey on fresh surface, weathers pale tan. Trough cross-bedded in sets 5-10 cm thick. Top 1-3 cm of unit is heavily bioturbated by horizontal traces and may be very thin-bedded. **Sample: C-490736 (sandstone)** | 0.4 | 16.4 |
| 8 | Base irregular to erosional. Fine to medium-grained, lesser coarse-grained quartz sandstone. Light grey on fresh surface, weathers pale tan. Basal 1 cm of unit is very coarse grained with granules. Balance of unit is three beds of roughly equal thickness: basal bed is medium to coarse grained; medial bed mainly fine grained; upper bed mainly medium grained. Trough cross-bedding is present in all three of these but especially well developed in the basal one. **Sample: C-490735 (sandstone)** | 0.4 | 16.0 |
| 7 | Base sharp to erosional, locally with at least 2 cm erosional relief. Medium to coarse-grained quartz sandstone, with small quartz pebbles, locally as a lag a single grain thick. Deeply iron-stained; fresh colour is dark grey to rusty. Grains well rounded. Very thin to thin beds with trough cross-bedding. Bed is up to 15 cm thick. **Sample: C-490734 (sandstone)** | 0.1 | 15.6 |
| | *Base of Mount Clark Formation* | | |
| 6 | Base sharp. Cliff-forming unit. Quartz sandstone, mainly fine grained, commonly medium grained, and locally up to coarse or very coarse grained. Small pebbles and granules locally present; these are commonly of quartz, rarely of lithic fragments (possibly green shale). Fresh surfaces white, pale grey; weathers pale pink, pale tan, pale grey. Local brownish-purple staining. Beds 10-50 cm thick, most commonly 10-30 cm. Some outcrop surfaces show trough cross-bedding or planar tabular cross-bedding. Sets pinch out laterally although this is not especially clearly developed. Quartz pebbles and granules concentrated along cross-bed set boundaries. Very well cemented. Well-developed, closely space joint set. **Samples: C-490733 (sandstone, brown-stained); C-490732 (sandstone, not stained)** | 6.3 | 15.5 |

| | | | |
|---|---|---|---|
| 5 | Base sharp to erosional. Cliff-forming unit. Quartz sandstone and conglomerate, in three lithofacies. (1) Very fine-grained quartz sandstone, maroon on fresh and weathered surfaces. Beds 2-5 cm thick, with current-rippled tops, some parallel lamination. Some silty sandstone partings between beds. (2) Very fine to (possibly) fine-grained quartz sandstone. Fresh surface is pinkish-tan, weathers pinkish tan or tan; some rusty staining. One bed is 40 cm thick, possibly with reactivation surfaces. Other beds are 5-10 cm thick, with more maroon staining. (3) Conglomerate, polymictic, consisting of granules and small pebbles of quartz and lithic fragments in a matrix of very fine to fine sand. Clasts subround to round but generally of low sphericity. Maroon on fresh and weathered surfaces. Maroon diagenetic haloes extend beyond boundaries of conglomerate into the enclosing sandstone. Present as small channel fills, up to 30 cm thick, or as "stringers" of conglomerate between foresets in sandstone.<br>**Samples: C-490731 (sandstone); C-490730 (conglomerate)** | 1.5 | 9.2 |
| | *Base of K7 map unit* | | |
| 4 | Base covered. Recessive. Roughly half of unit is siltstone to silty sandstone (description as for lithology 1 in unit 1), maroon on fresh and weathered surfaces, with reduction zones. Basal 20 cm of unit is very fine grained quartz sandstone, maroon on fresh and weathered surfaces (description as for lithology 3 in unit 1). At top is 20-30 cm of very fine-grained quartz sandstone, possibly hematitic, with planar parallel lamination, possible parting lineation. | 1.0 | 7.7 |
| 3 | Covered. | 2.0 | 6.7 |
| 2 | Base sharp. Fine-grained quartz sandstone with silica and ?hematite cement. Some zones maroon (fresh and weathered), others are cream to pinkish grey (fresh and weathered). Beds 3-10 cm thick, with some lateral thickness variation, possibly due to relict bedforms. Current ripple cross-lamination, small-scale trough cross-bedding.<br>**Sample: C-490729 (sandstone)** | 0.6 | 4.7 |
| 1 | Base covered. Resistant to semi-resistant. Three main lithologies. Fresh and weathered colours for all rock types are maroon, less commonly brick red, with local pale green reduction zones. (1) Siltstone to silty sandstone or silty very fine-grained sandstone. Irregular to parallel lamination. Makes up 40% of unit. (2) Very fine-grained quartz sandstone, silty, possibly with hematite cement. Beds 1-5 cm thick; lamination and bedding irregular. Makes up 20% of unit. (3) Very fine-grained quartz sandstone, possibly with hematite cement. Bedding roughly parallel, 1-5 cm thick. Roughly parallel lamination or current-ripple cross-lamination within beds. Current ripples cap one bed. Makes up 30% of unit. Rock types interbedded in packets 10-60 cm thick. Proportion of lithology 2 increases upsection; unit may be sandier upward.<br>**Sample: C-490728 (sandstone)** | 4.1 | 4.1 |
| | *Section begins at base of exposure of red-weathering K6 map unit* | | |

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# PART B

## Petrographic assessment of the Neoproterozoic and Cambrian sandstones, eastern Mackenzie Mountains, Northwest Territories: (Based on outcrop samples) Sections 11MWBs01 and 0901S

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2013

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## Summary of Findings

1. The K6? Formation is represented by the lowermost Units 1 and 2 taken from outcrop samples at section 11MWBs01. These hematite cemented bioturbated, laminated, very fine grain, moderately well sorted subarkoses are considered non-reservoir quality due to the lack of macroporosity. The contact between the Mount Clark sandstones, based on outcrop observations, is between Units 6 and Unit 7. Common burrows in Units 1 and 2 would suggest that the Mount Clark Formation boundary be lowered below Unit 1.
2. Four texturally and diagenetically variable, non-reservoir quality outcrop samples taken at section 11MWBs01 represent Units 5 and 6 from the K7? Formation. Common pore filling and grain rimming organic material plus quartz cement has occluded macropores in the polymictic conglomeratic sublitharenite recovered in the lower portion of Unit 5. Laminated, quartz cemented lower fine grained quartz arenites characterize the upper Unit 5 sandstones.
3. Bitumen plugged, patchily distributed, non-ferroan dolomite cemented, poorly sorted, very fine to granule grain sized quartz arenites characterize the upper portion of Unit 6 taken from the K7? Formation. In contrast, the underlying Unit 6 sandstones are recognized as quartz cemented, laminated, poorly sorted, very fine to very coarse grained quartz arenites. Minor loosely packed kaolinite and chlorite diagenetic clays have precipitated into open pores. These pore filling authigenic clays appear to be characteristic to this interval.
4. Mount Clark sandstones, represented by outcrop sample taken from Unit 7, are recognized as a non-reservoir quality, poorly sorted, very fine to very coarse grained, bitumen plugged and ferroan dolomite cemented quartz arenites. Note that the carbonate is ferroan in composition which contrasts with the underlying non-ferroan carbonate cemented sandstone of Unit 6.
5. Units 8, 10, 15 and 16 are quartz cemented quartz arenites with variable reservoir quality. Two phases of quartz cementation are observed petrographically; this is particularly evident in Unit 8. Mottled texture in Units 8, 10 and 16 suggest

bioturbation is common in these intervals. Open, discontinuous vertical microfractures are found in minor volumes.

6. The best reservoir quality was recovered from a porous and permeable, well sorted, upper fine grained quartz arenite taken from Unit 10. Thin section porosity is well developed in this interval with modal analysis yielding 7.3% effective macroporosity; estimated permeability ranges from 0.5 to 1 md.
7. A silty glauconitic tightly packed argillic very finely crystalline dolostone was encountered in Unit 20. Common sand sized subrounded inclusion-rich glauconitic peloids, silt sized subangular quartz grains and pyritized organic material, plus rare phosphatic grains (fish debris) and muscovite flakes are scattered in the non-ferroan dolomitic matrix Hydrocarbons, in the form of bitumen, commonly rim the subhedral dolomite crystals.
8. Extensively bioturbated, chaotic textured, very poorly sorted, ferroan dolomite cemented argillic litharenites are recognized from outcrop sample C-490742 representing Unit 22 taken from the Mount Clark Formation at Section 11MWBs01.
9. Subarkoses were recognized in the two lowermost sandstones at Section 11MWBs01 and 0901S. Plagioclase dominates the feldspar composition observed in Units 1 and 2 at Section 11MVBs01. In contrast, K-feldspar is the dominant feldspar characterizing the two outcrop samples in Section 0901S.

# Introduction

## Objectives

This report contains the results and conclusions of a petrographic study of selected outcrop samples taken from the Katherine Group and Mount Clark Formation at two sections located in the eastern Mackenzie Mountains of the Northwest Territories. The study was performed on behalf of the Geological Survey of Canada and was undertaken by CMH Petrology Consultant Inc. The main objectives of the study are:

**(i)** Investigate if there are notable differences in mineralogy and cementation history between the Katherine Group and Mount Clark Formation by using thin section microscopy.

**(ii)** To characterize the distribution of porosity and permeability in an effort to understand the controls on reservoir quality development.

## Methods of Analysis

The Katherine Group and Mount Clark Formation sandstones are represented by fifteen outcrop samples taken from two measured sections in the eastern Mackenzie Mountains, Northwest Territories including: 11MWBs01 (13 samples) and 0901S (2 samples).

Thin section analysis provides compositional and textural information necessary to assess reservoir quality. Petrographic analysis also provides interpretation of paragenesis, porosity evolution, reservoir quality and fluid sensitivity. The outcrop samples, provided by the Geological Survey of Canada, were prepared for thin section description by impregnation with blue epoxy to identify porosity. They were half-stained with Alizarin Red (to distinguish calcite – pink, from dolomite) plus potassium ferricyanide (to distinguish ferroan carbonate – dark blue, from non-ferroan carbonate). Note that outcrop sample C-4907433, taken for the upper portion of Unit 6, was re-stained for carbonate identification. The thin sections were also half-stained with sodium cobaltinitrate to identify alkali feldspar (yellow stain on orthoclase and microcline).

The thin section samples, summarized in Tables 1a and 1b, were examined under a Nikon E600 polarizing microscope and up to a 300-point count mineral and grain size inventory was obtained. Grain size analysis consisted of long-axis measurement of up to 300 competent grains. Petrographic results, detailing mineralogical data are summarized in Tables 2a and 2 b and statistical grain size measurements are presented in Tables 3a and 3b.

## Documentation

Petrographic results, detailing mineralogical data are summarized in the following tables, figures and photomicrographs:

- Tables 1a and 1b: Petrographic Sample Summary
- Tables 2a and 2b: Point Count Data and Mineralogy
- Figures 1a-1p: Sandstone Composition Ternary Diagram (QFR)
- Tables 3a and 3b: Grain Size Data
- Grain Size Histograms H1 – H9
- Overviews
- Plates 01 to 13 – Section 11MWBs01 Thin Section Photomicrographs and Descriptions
- Plates 14 and 15 – Section 0901S Thin Section Photomicrographs and Descriptions

# Petrographic Results

## Section 11MWBs01

The Katherine Group outcrop samples (8) were taken from two sections including 11MWBs01 and 0901S. The Mount Clark is represented by seven outcrop samples taken from section 11MWBs01.

### *?K6, Units 1 and 2*

Non-reservoir quality, K6? sandstones taken from Units 1 and 2 are recognized as very fine grained moderately well sorted hematite cemented subarkoses. Grain contacts are predominantly tangential and point-point. Average grain size in these units is 96 µm or very fine grained. Framework grains are comprised mainly of subangular to subrounded monocrystalline quartz with subordinate amounts of plagioclase, trace muscovite flakes, heavy minerals and polycrystalline quartz. The main pore occluding authigenic phase is pervasive hematite cement. Very poorly developed quartz overgrowths have precipitated on the host monocrystalline quartz grains. Unit 2 is commonly laminated and both thin section Overviews of Units 1 and 2 illustrate common bioturbation. The latter would suggest that the Cambrian boundary should be lowered to below this Unit. Unevenly distributed matrix clays in Unit 2 have high birefringence suggesting a smectitic mixed clay composition. X-ray diffraction analysis would ascertain clay composition.

### *?K7, Unit 5*

The lower K7? Formation Unit 5 sandstone, consists of a very poorly sorted, texturally immature conglomeratic sublitharenite. Grain sizes vary from lower very fine to pebble-size clasts floating in a sandstone matrix. The rounded to subangular granular to pebble sized polymictic grains consist of oolitic chert clasts, chert, quartz-rich sedimentary grains (reworked sandstones), organic-rich silty argillaceous lithoclasts and polycrystalline quartz grains. Medium grained matrix sandstone is dominated by subrounded to subangular monocrystalline quartz with accessory polycrystalline quartz, chert, muscovite, plagioclase, organic material, clay-rich sedimentary grains and metamorphic rock fragments. Unevenly distributed mixed clays are found in minor volumes. Diagenetic phases include common syntaxial quartz overgrowths precipitated on host quartz lithoclasts.

Extensively bioturbated, texturally mature to submature, very fine to medium grained quartz arenites characterize outcrop sample C-490731 taken from Unit 5 in the K7? interval. Overall, average grain size is 147 μm or mid-fine grained. Subrounded to subangular monocrystalline quartz dominates the framework constituents with subordinate plagioclase, minor argillic lithoclasts and heavy minerals. Pore occluding authigenic cements include common syntaxial silica overgrowths precipitated on host monocrystalline quartz grains. Light brown matrix clays are concentrated along laminae as observed in the thin section overview. Petrographic characteristics of these matrix clays suggest a smectite-illite-kaolinite composition. However, X-ray diffraction analysis would ascertain clay composition in this interval.

***?K7, Unit 6***

Two non-reservoir quality sandstones, representing Unit 6, are considered diagenetically different. The underlying outcrop sample C-490732 representing Unit 6 consists of a laminated, texturally submature, subrounded to rounded, very fine to very coarse grained quartz cemented quartz arenite. Overall average grain size is 147 μm or mid-fine grained. Framework constituents are dominated by monocrystalline quartz with lesser amounts of polycrystalline quartz, plagioclase, fish debris and heavy minerals. Quartz overgrowths are commonly occluding macroporosity with common unevenly distributed loosely packed mixed authigenic clays precipitated within open pores. Petrographic characteristics of these mixed authigenic clays indicate a kaolinite-chlorite composition.

In contrast, poorly sorted, silt to granule-sized, bitumen and carbonate cemented quartz arenites are recognized from outcrop sample C-490733, taken from the upper portion of Unit 6, in the K7 interval. Minor open, vertical, discontinuous micro-fractures cross cut framework grains and cements. Overall average grain size is 365 μm or medium grained. Subrounded monocrystalline quartz dominates the framework components with minor polycrystalline quartz and plagioclase. Organic material, argillic lithoclasts, metamorphic lithoclasts and quartz-rich sedimentary grains (reworked siltstones) are considered accessory framework constituents. The main pore occluding authigenic cement is patchily distributed non-ferroan dolomite plus bitumen. Rare very poorly developed quartz overgrowths have precipitated on host quartz grains.

**Mount Clark**

Seven outcrop samples representing seven units were taken from the Mount Clark Formation at Section 11MWBs01.

***Unit 7***

A ferroan dolomite cemented, bitumen plugged, poorly sorted, very fine to very coarse grained quartz arenite is recognized as Mount Clark sandstones taken from outcrop sample C-490734 representing Unit 7. Framework constituents are dominated by subrounded to subangular monocrystalline quartz with accessory plagioclase, polycrystalline quartz and rare heavy minerals. Brown matrix clays are unevenly distributed. Common patchily distributed ferroan dolomite cement plus bitumen are the main pore occluding phases with rare poorly developed quartz overgrowths precipitated on host monocrystalline quartz grains.

***Unit 8***

Unit 8 is characterized by quartz cemented, moderately sorted, upper very fine to lower coarse grained quartz arenites recovered from outcrop sample C-490735. Overall, average grain size is 247 μm or upper fine grained. Monocrystalline quartz grains dominate the framework components in this non-reservoir quality interval. Common quartz cement is the main pore occluding authigenic cement precipitated on host monocrystalline quartz grains. The latter are outlined by common “dust rims”. Note that there appears to be several phases of quartz cementation whereby two distinct syntaxial quartz cements occlude macropores.

***Unit 10***

Porous, moderately well sorted, upper fine grained quartz arenites are recognized from Mount Clark outcrop sample C-490736 taken from Unit 10. Subrounded to subangular monocrystalline quartz comprises the main framework grains with accessory plagioclase and rare heavy minerals. Minor brown matrix clays are unevenly distributed in this interval. Poorly developed, unevenly distributed syntaxial quartz overgrowths have precipitated on host monocrystalline quartz grains with trace non-ferroan calcite cement. Macroporosity is well developed in this interval.

***Unit 15***

Unit 15 represented by outcrop sample C-490737 is recognized as a poorly sorted, silica cemented very fine to coarse grained quartz arenite. Subrounded to subangular monocrystalline quartz dominates the framework lithoclasts with subordinate plagioclase and polycrystalline quartz. Rare brown matrix clays are unevenly distributed. Diagenetic phases are dominated by pore occluding syntaxial silica cement, precipitated on host quartz grains plus rare unevenly distributed non-ferroan dolomite cement. Macroporosity is poorly developed with thin section modal analysis yielding 3% effective porosity.

***Unit 16***

Outcrop sample C-490738, representing Unit 16, consists of a poorly sorted, very fine to upper coarse grained quartz arenite. Subrounded to subangular monocrystalline quartz dominates the framework components with lesser amounts of polycrystalline quartz, plagioclase, organic material, micas and heavy minerals. Minor brown matrix clays are unevenly distributed. Authigenic phases are comprised mainly of poorly developed quartz overgrowths, precipitated on host quartz grains with rare non-ferroan calcite cement. Thin section (effective) porosity is poorly developed and unevenly distributed with point count analysis yielding 2.2%. Hydrocarbons, in the form of bitumen, partially line micro-fractures.

***Unit 20***

Outcrop sample C-490741 representing Unit 20 is a silty glauconitic tightly packed argillic very finely crystalline dolostone. Common sand sized subrounded inclusion-rich glauconitic peloids, silt sized subangular quartz grains and pyritized organic material, plus rare phosphatic grains (fish debris) and muscovite flakes are scattered in the dolomitic matrix. Hydrocarbons, in the form of bitumen commonly rim the subhedral dolomite crystals as shown by the red arrows.

***Unit 22***

Extensively bioturbated, chaotic textured, very poorly sorted, ferroan dolomite cemented argillic litharenites are recognized from outcrop sample C-490742 representing Unit 22 taken from the Mount Clark Formation at Section 11MWBs01. Very fine to coarse grained framework grains are scattered in the ferroan dolomite matrix. They consist of inclusion-rich glauconite, subangular to subrounded quartz grains, plagioclase, K-feldspar, phosphatic grains (fish debris) and heavy minerals. The matrix surrounding the clastic grains consists of tightly packed, inclusion-rich, very fine to medium crystalline, subhedral argillaceous ferroan dolomite. The uneven distribution of the framework grains throughout the matrix may be due to extensive bioturbation of the soft sediment prior to burial and lithification. Pyrite is present in small amounts, occurring as discrete framboidal crystallites, dispersed throughout the matrix. Bitumen is found in rare amounts.

**Section 0901S**

Laminated, moderately well sorted, fine grained subarkoses were recovered from outcrop sample C-490762, representing Interval 1 of the K3 mapping unit. Subrounded to subangular monocrystalline quartz dominates the framework constituents with lesser amounts of K-feldspar, plagioclase, polycrystalline quartz, plus rare argillic lithoclasts and glauconite. Common silica cement is the main pore occluding diagenetic cement in this interval with rare pyrite. The partial dissolution of unstable framework lithoclasts.

Moderately well sorted, upper fine grained, silica cemented subarkoses characterize the sandstones taken from Outcrop Sample C-490761 from Interval 7, Unit K5 at Section 0901S. Framework constituents are dominated by subrounded to subangular monocrystalline quartz with common K-feldspar, plagioclase and polycrystalline quartz. Accessory framework grains include glauconite, clay-rich sedimentary grains and heavy minerals. The main pore occluding authigenic phase consists of quartz cement precipitated on host quartz grains with rare patchily distributed ferroan dolomite cement. Dust rims are commonly observed separating the quartz grains from the diagenetic silica overgrowth. Note hydrocarbon, in the form of bitumen, within the carbonate cleavage surfaces.

## Paragenesis and Reservoir Development

Reservoir quality, in these Neoproterozoic and Cambrian sediments, is a function of a complex interrelationship of both depositional and diagenetic processes that modified the various sandstone pore systems. The authigenic minerals are volumetrically significant in some of the units and in most cases completely occlude the pore system. The most commonly observed diagenetic phases include hematite cementation in the lower Units, quartz, dolomite (both ferroan and non-ferroan), and clay. The latter includes a mixture of chlorite and kaolinite.

Original depositional properties of the sandstones, such as framework grain composition and grain size, exert an effect on reservoir quality. Post-depositional diagenesis such as compaction, cementation and dissolution events overprint the original depositional controls of the reservoir quality in these sediments.

The following diagenetic sequence is suggested for the sandstones in the study samples:

- Deposition and mechanical compaction, reorientation of sand grains, plus minor ductile deformation of labile grains characterized by concavo-convex grain contacts, slightly to moderately reduced effective porosity and permeability. (Overviews)
- Incipient chemical compaction and pressure solution at grain contacts. Slight to moderate reduction of primary intergranular porosity.
- Early precipitation of hematite cement. Complete occlusion of primary intergranular porosity. (Plates 01 and 02, View B)
- Early precipitation of syntaxial quartz cement partially to completely occludes macropores. Thin clay coatings, of undetermined composition, commonly outline framework grains from authigenic cement. Moderate to complete occlusion of primary intergranular porosity. (Plates 5 , small black arrows)
- Precipitation of non-ferroan dolomite cement as pore fill. (Plate 6, Views C and D)
- Precipitation of ferroan dolomite cement as pore fill. (Plate 7, Views C and D)
- Partial to complete dissolution of carbonate cement created solution enlarged intergranular pore system that significantly improved reservoir quality of the

sandstones. Dissolution of carbonate cement in acidic waters that preceded migration of hydrocarbon enhanced porosity and reservoir quality. (Plate 09, View A)

- Minor precipitation of kaolinite-chlorite clays. (Plate 05, View B, “K + Chl”)
- Microfracture development. (Overview Unit 8)
- Migration of hydrocarbon into solution enhanced reservoir. (Plates 06 and 07, small red arrows)

## Reservoir Quality Assessment

The outcrop study samples consist mainly of non-reservoir quality cemented sandstones and carbonates. The best reservoir quality was encountered in Unit 10 from the Mount Clark Formation at Section 11MWBs01. Total (calculated) porosity is comprised of effective porosity and microporosity preserved in authigenic clays, in leached grains, and in clay clasts. Overall, effective (thin section) porosity ranges from 0 to 7.3%, whereas calculated (total) porosity ranges from 0.3 to 7.6%. Intergranular porosity dominates the effective pore system in the porous and permeable interval. Non-effective microporosity is associated with clay fabrics and partially leached framework components. Generally, estimated permeability is very low (<0.01 md) reflecting the lack of effective macropores. Estimated permeability in Unit 10 from the Mount Clark Formation at Section 11MWBs01 ranges from 0.5 to 1 md. Average grain sizes range from 0.094 to 0.415 mm or very fine to upper medium size grains. Maximum grain sizes range from 0.207 to 4.133 mm or fine to pebble size grains. Minimum grain sizes range from 10 to 118 μm or clay to upper very fine size.

In most sandstones, permeability generally increases with increasing mean grain size. However, the effect of grain size on permeability decreases if the rock is characterized by moderate mechanical compaction and a solution enhanced pore system, as shown in the outcrop study samples. A slightly better correlation between permeability and GSPI (Grain Size Pore Index), derived by multiplying average grain size and effective porosity, has been determined in these solution enhanced sandstones.
GSPI values, range from 0 to 1.619.

**Project:** Geological Survey of Canada
Petrographic Assessment
Neoproterozoic and Cambrian Sandstones, eastern Mackenzie Mountains, NWT

**Sections:** 11MWBs01 and 0901S

**Date:** February 2013

**Professionals:** Cathy M. Hamel, M.Sc., P.Geol.

| | |
|---|---|
| Stamped in Original Report | Stamped in Original Report |

**Company:** Geological Survey of Canada

**Formation:** Various

**Section:** 11MWBs01

## Table 1a: Petrographic Sample Summary

| Formation | Unit | Sample # | Lithology | Calculated Porosity (%) | Estimated Permeability (md) | TS (effective) porosity (%) | Mean Grain Size (mm) | GSPI |
|---|---|---|---|---|---|---|---|---|
| Mount Clark | 22 | C-490742 | Dolomitic Litharenite | 0.4 | <0.01 | 0 | 0.172 | 0.000 |
| Mount Clark | 20 | C-490741 | Dolostone | 0.3 | <0.01 | 0 | na | na |
| Mount Clark | 16 | C-490738 | Quartz Arenite | 2.5 | 0.05-0.1 | 2.2 | 0.161 | 0.354 |
| Mount Clark | 15 | C-490737 | Quartz Arenite | 3.1 | 0.1-0.2 | 3 | 0.214 | 0.641 |
| Mount Clark | 10 | C-490736 | Quartz Arenite | 7.6 | 0.5-1 | 7.3 | 0.222 | 1.619 |
| Mount Clark | 8 | C-490735 | Quartz Arenite | 0.6 | <0.03 | 0.6 | 0.247 | 0.148 |
| Mount Clark | 7 | C-490734 | Quartz Arenite | 0.6 | <0.01 | 0 | 0.244 | 0.000 |
| K7? | 6 | C-490733 | Quartz Arenite | 0.1 | <0.01 | 0.0 | 0.365 | 0.460 |
| K7? | 6 | C-490732 | Quartz Arenite | 1.5 | <0.03 | 0.6 | 0.290 | 0.174 |
| K7? | 5 | C-490731 | Quartz Arenite | 1.4 | <0.01 | 0 | 0.147 | 0.000 |
| K7? | 5 | C-490730 | Conglomeratic Sublitharenite | 0.3 | <0.01 | 0 | 0.415 | 0.000 |
| K6? | 2 | C-490729 | Subarkose | 0.4 | <0.01 | 0.3 | 0.098 | 0.029 |
| K6? | 1 | C-490728 | Subarkose | 0.6 | <0.01 | 0.3 | 0.094 | 0.028 |

**Company:** Geological Survey of Canada

**Formation:** Various

**Section:** 0901S

**Table 1b: Petrographic Sample Summary**

| Formation | Unit | Sample # | Lithology | Calculated Porosity (%) | Estimated Permeability (md) | TS (effective) porosity (%) | Mean Grain Size (mm) | GSPI |
|---|---|---|---|---|---|---|---|---|
| K5 | 7 | C-490761 | Subarkose | 0.7 | <0.01 | 0 | 0.198 | 0.000 |
| K3 | 1 | C-490762 | Subarkose | 0.5 | <0.01 | trace | 0.170 | 0.000 |

**Company:** Geological Survey of Canada
**Formation:** Various

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## TABLE 2a: POINT COUNT DATA AND MINERALOGY

MODAL ANALYSIS (%) - EXCLUDES POROSITY

| Formation | Unit | Depth (meters) | Framework Grains | | | | | | | | | Accessory | | | | | Clays | | | | Cement | | | | | | Mineralogy | | | | | | Porosity | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MQ | PQ | Ch | Plag | K-spar | CRF | QRF | Glauc | VRF | OM | Micas | MRF | Phos | HM | Mtx | Mxd | Kaol | Chl | Si | Ca | Do | FeD | Hem | Py | Sil | Ca | Dol | Hem | Clays | Other | HC | Inter | Intra | Moldic |
| Mount Clark | 22 | C-490742 | 47.4 | 2 | - | 1.6 | 1 | - | - | 11 | - | 3.2 | - | - | 0.3 | tr | 6.6 | - | - | - | tr | - | tr | 26.3 | - | 0.6 | 0.494 | 0.000 | 0.263 | 0.000 | 0.176 | 0.067 | 1 | - | - | - |
| | 20 | C-490741 | 1.3 | - | - | - | - | - | - | 0.3 | - | 0.3 | tr | - | - | - | 3.3 | - | - | - | - | - | 93.5 | - | - | 1.3 | 0.013 | 0.000 | 0.935 | 0.000 | 0.036 | 0.016 | - | - | - | - |
| | 16 | C-490738 | 85.6 | 2 | - | 1.6 | - | - | - | - | - | 0.2 | tr | - | - | tr | 2.3 | - | - | - | 8.3 | tr | - | - | - | - | 0.959 | 0.000 | 0.000 | 0.000 | 0.023 | 0.018 | - | 2.2 | - | - |
| | 15 | C-490737 | 84 | 0.6 | - | 2.3 | - | - | - | - | - | - | - | - | - | - | 0.6 | - | - | - | 12.3 | - | 0.2 | - | - | - | 0.969 | 0.000 | 0.002 | 0.000 | 0.006 | 0.023 | - | 3 | - | - |
| | 10 | C-490736 | 78.2 | | - | 2.6 | - | - | - | - | - | - | - | - | - | tr | 2.3 | - | - | - | 15.6 | tr | - | - | - | - | 0.950 | 0.000 | 0.000 | 0.000 | 0.023 | 0.026 | 1.3 | 7.3 | - | - |
| | 8 | C-490735 | 80.6 | 0.3 | - | 1.6 | - | - | - | - | - | - | - | - | - | 0.3 | | - | - | - | 16.6 | 0.3 | - | - | - | - | 0.978 | 0.003 | 0.000 | 0.000 | 0.000 | 0.019 | 0.3 | 0.6 | - | - |
| | 7 | C-490734 | 80.6 | 0.3 | - | 1.3 | - | - | - | - | - | - | - | - | - | tr | 5.3 | - | - | - | 1.6 | - | - | 4.6 | - | - | 0.880 | 0.000 | 0.049 | 0.000 | 0.057 | 0.014 | 6.3 | - | - | - |
| K7? | 6 | C-490733 | 60 | 3 | - | 1 | - | - | tr | - | - | 0.3 | - | - | - | - | - | - | - | - | 3 | - | 18.4 | - | - | - | 0.770 | 0.000 | 0.215 | 0.000 | 0.000 | 0.015 | 14.3 | - | - | - |
| | 6 | C-490732 | 79.6 | 4 | - | 2.3 | - | 3.6 | | - | - | - | - | - | tr | tr | - | tr | - | - | 10.2 | - | - | - | - | - | 0.941 | 0.000 | 0.000 | 0.000 | 0.036 | 0.023 | 0.3 | - | 0.6 | - |
| | 5 | C-490731 | 77.3 | | - | 1 | - | 0.3 | | - | - | - | - | - | - | tr | - | 6.5 | - | - | 14.3 | - | - | - | - | - | 0.922 | 0.000 | 0.000 | 0.000 | 0.068 | 0.010 | 0.6 | - | - | - |
| | 5 | C-490730 | 63 | 0.6 | 1.3 | 2 | - | 5 | tr | - | - | 8.5 | 4 | 0.6 | - | - | - | 1 | - | - | 14 | - | - | - | - | - | 0.789 | 0.000 | 0.000 | 0.000 | 0.100 | 0.111 | - | - | - | - |
| K6? | 2 | C-490729 | 78.3 | 0.6 | - | 3.6 | - | - | - | - | - | - | - | - | - | tr | 0.3 | - | - | - | 5.6 | - | - | - | 11.6 | | 0.845 | 0.000 | 0.000 | 0.116 | 0.003 | 0.036 | - | 0.3 | - | - |
| | 1 | C-490728 | 68 | 0.3 | - | 4 | - | - | - | - | - | - | 0.3 | - | - | tr | - | - | - | 0.3 | 1.5 | - | - | - | 25.6 | | 0.698 | 0.000 | 0.000 | 0.256 | 0.006 | 0.040 | - | 0.3 | - | - |

MQ - monocrystalline quartz
PQ - polycrystalline quartz
Ch - chert
Plag - plagioclase
K-spar - potassium feldspar
CRF - clay rock fragments
QRF - quartz rock fragments

Glauc - glauconite
VRF - volcanic rock fragments
OM - organic material
Micas - muscoivte, biotite, chloritized micas, sericite
MRF - metamorphic rock fragments
Phos - fish debris
HM - heavy minerals

Mtx - matrix
Mxd - mixed clays
Kaol - kaolinite
Chl - chlorite

Si - silica
Ca - calcite
Do - dolomite
FeD - ferroan dolomite
Hem - hematite
Py - pyrite

HC - hydrocarbon (bitumen)
Inter - intergranular
Intra - intragranular

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**Formation:** Various

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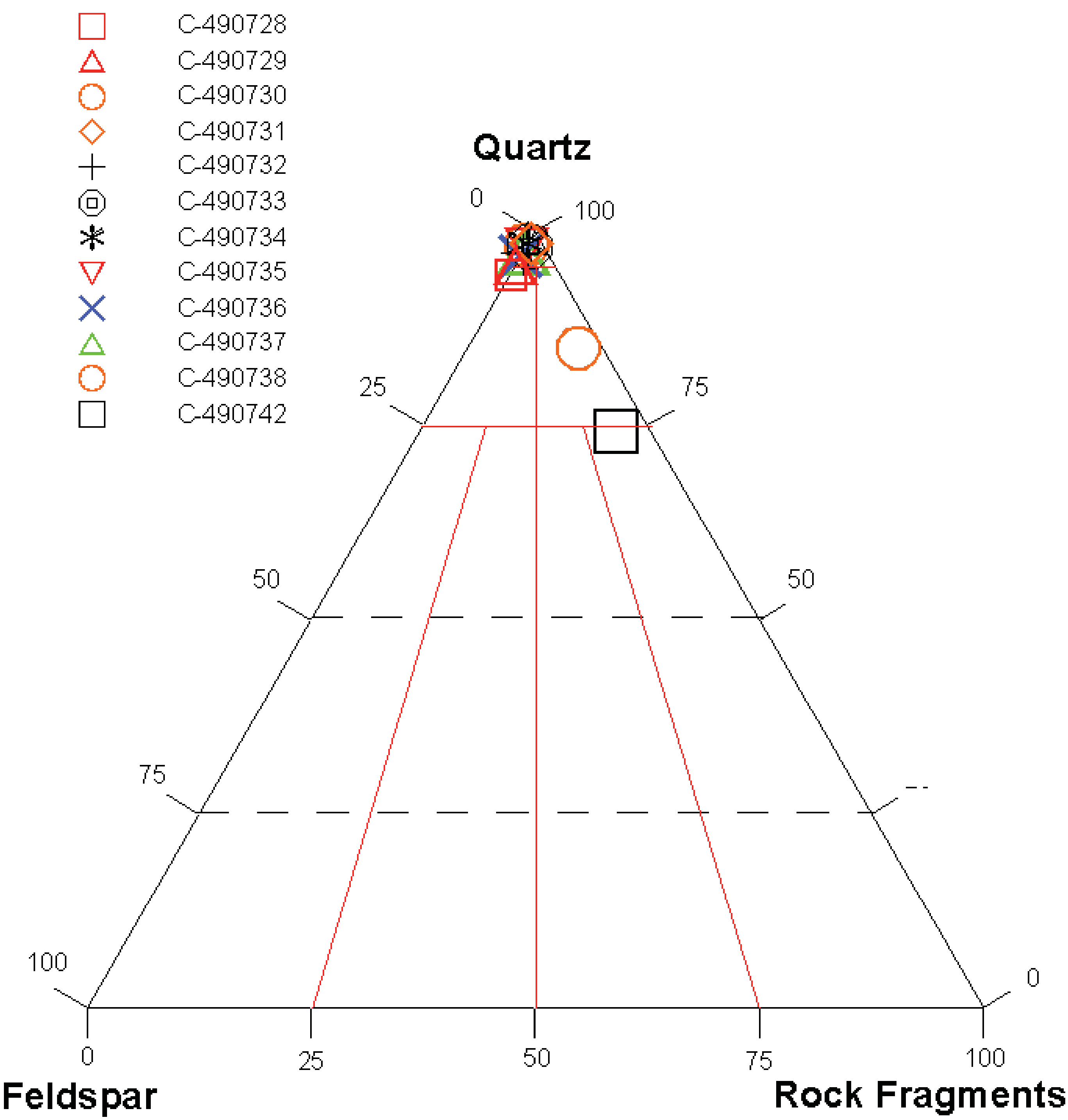
## TABLE 2b: POINT COUNT DATA AND MINERALOGY

| | | | MODAL ANALYSIS (%) - EXCLUDES POROSITY | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Formation | Unit | Depth (meters) | Framework Grains | | | | | | | | | Accessory | | | | | Clays | | | | Cement | | | | | | Mineralogy | | | | | | Porosity | | | |
| | | | MQ | PQ | Ch | Plag | K-spar | CRF | QRF | Glauc | VRF | OM | Micas | MRF | Phos | HM | Mtx | Mxd | Kaol | Chl | Si | Ca | Do | FeD | Hem | Py | Sil | Ca | Dol | Hem | Clays | Other | HC | Inter | Intra | Moldic |
| K5 | 7 | C-490761 | 59 | 5 | tr | 4.6 | 5.6 | 0.6 | | tr | | | | | | tr | | | | 0.3 | 22 | | 3 | | | 0.3 | 0.860 | 0.000 | 0.026 | 0.000 | 0.009 | 0.105 | | | tr | |
| K3 | 1 | C-490762 | 66.6 | 5.6 | | 3 | 6.2 | 0.3 | | tr | | | | | | | | | | | 18 | | | | | 0.3 | 0.902 | 0.000 | 0.000 | 0.000 | 0.003 | 0.095 | | | | |

| | | | | |
|---|---|---|---|---|
| MQ - monocrystalline quartz | Glauc - glauconite | Mtx - matrix | Si - silica | HC - hydrocarbon (bitumen) |
| PQ - polycrystalline quartz | VRF - volcanic rock fragments | Mxd - mixed clays | Ca - calcite | Inter - intergranular |
| Ch - chert | OM - organic material | Kaol - kaolinite | Do - dolomite | Intra - intragranular |
| Plag - plagioclase | Micas - muscoivte, biotite, chloritized micas, sericite | Chl - chlorite | FeD - ferroan dolomite | |
| K-spar - potassium feldspar | MRF - metamorphic rock fragments | | Hem - hematite | |
| CRF - clay rock fragments | Phos - fish debris | | Py - pyrite | |
| QRF - quartz rock fragments | HM - heavy minerals | | | |

# Figure 1a: Composition Ternary Diagram
## Section 11MWBs01 – All Units





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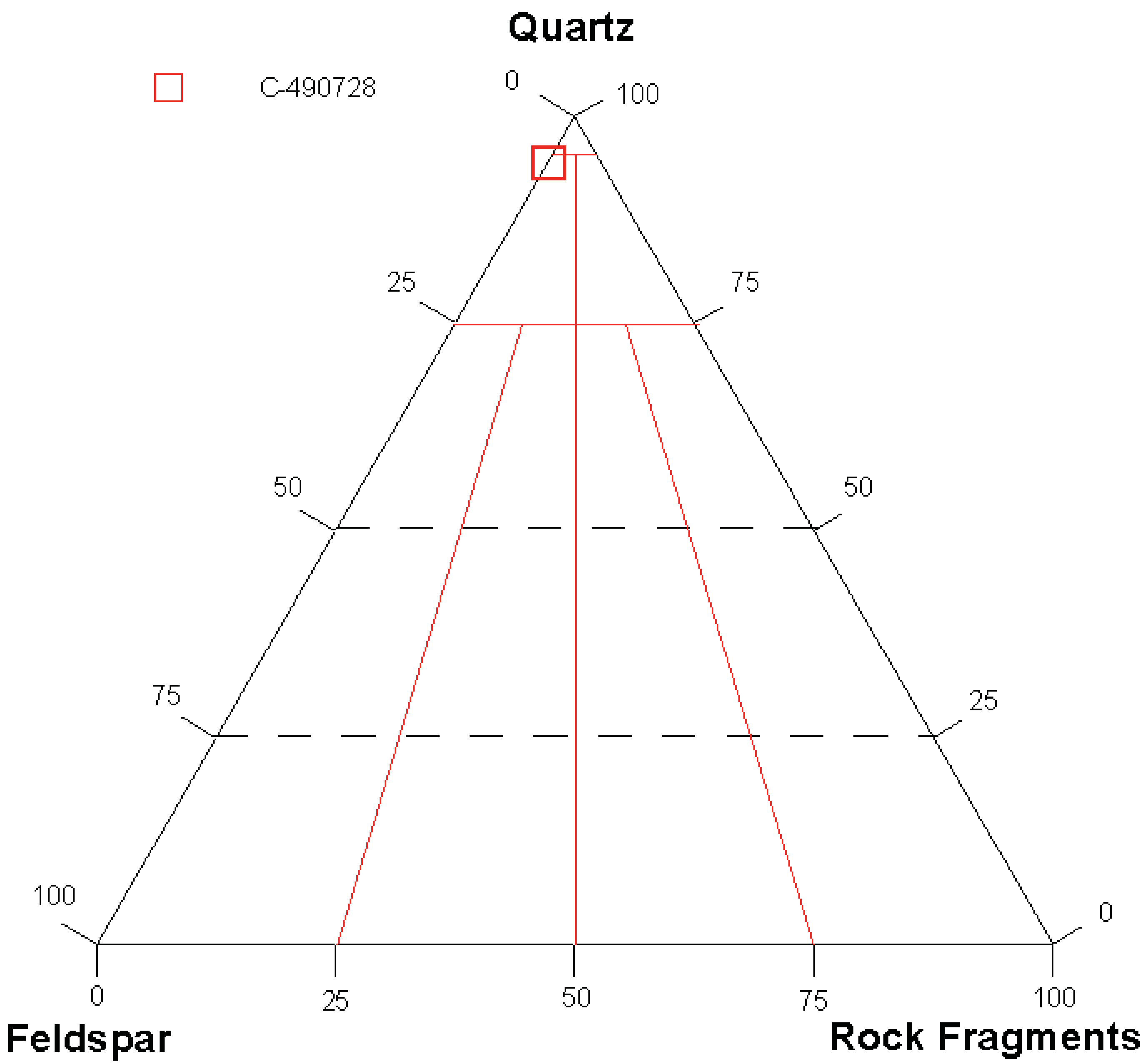
# Figure 1b: Composition Ternary Diagram
# Section 11MWBs01 – Unit 1

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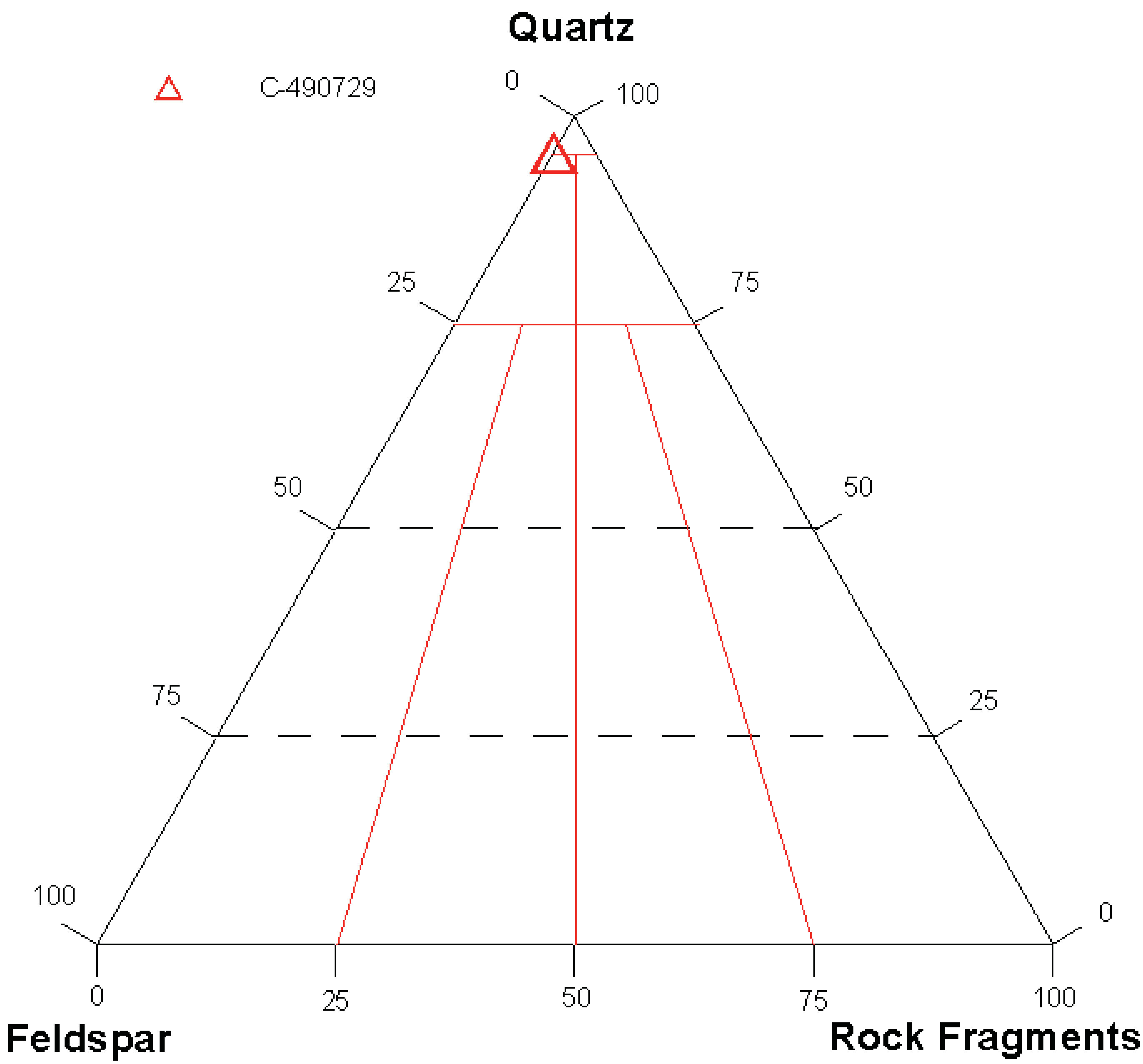
# Figure 1c: Composition Ternary Diagram
## Section 11MWBs01 – Unit 2

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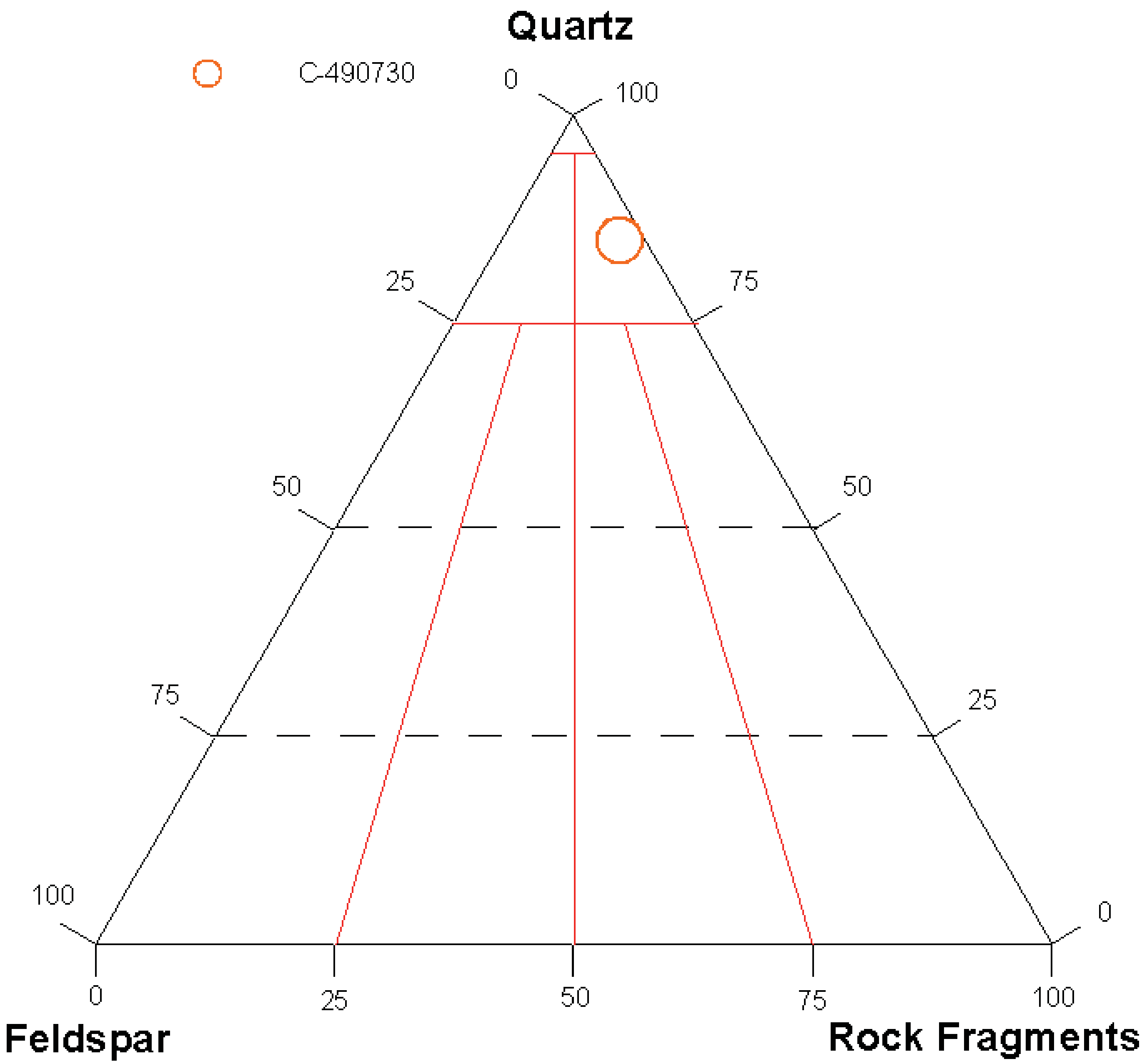
# Figure 1d: Composition Ternary Diagram
## Section 11MWBs01 – Unit 5

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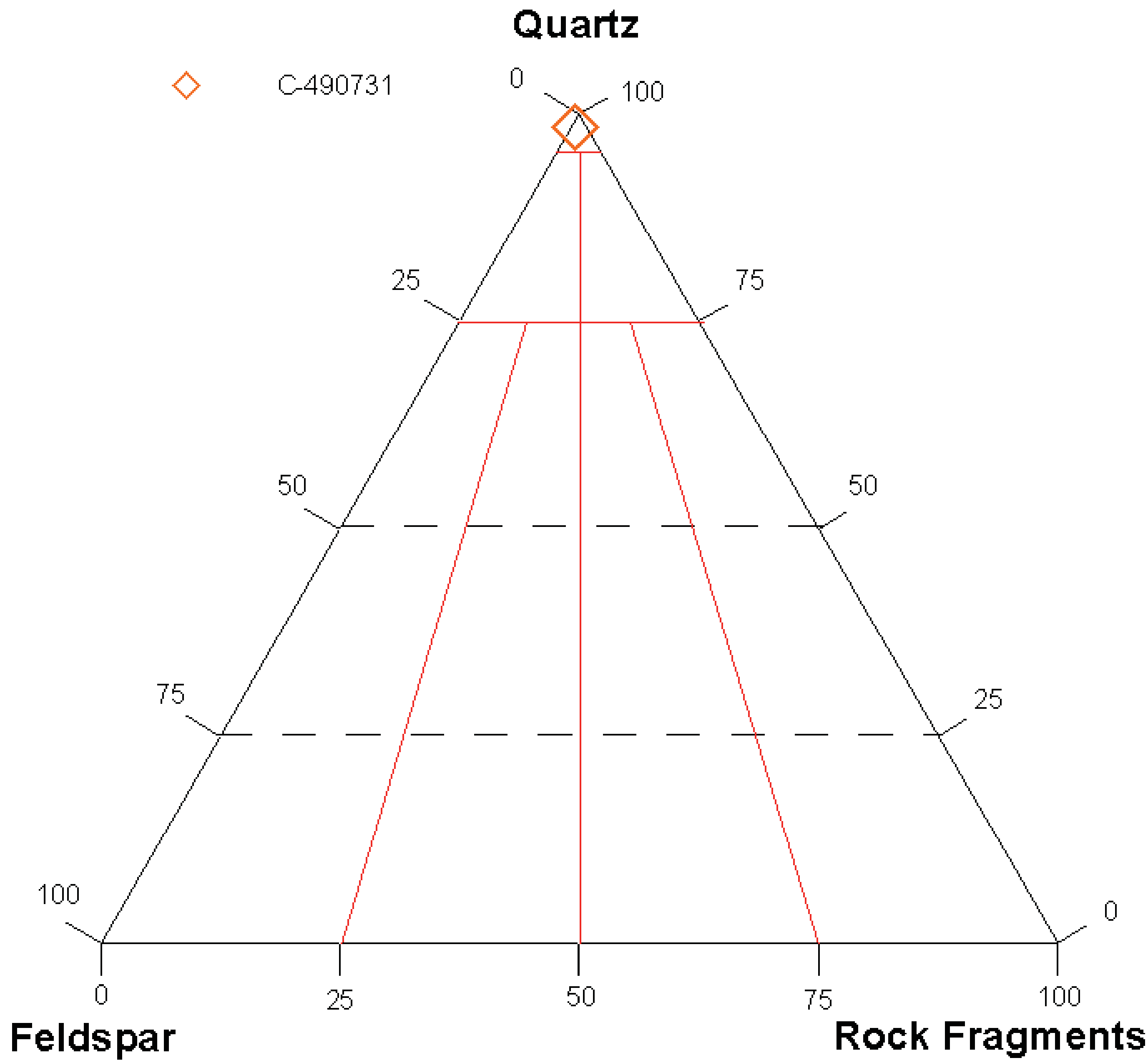
# Figure 1e: Composition Ternary Diagram
## Section 11MWBs01 – Unit 5





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# Figure 1f: Composition Ternary Diagram
## Section 11MWBs01 – Unit 6

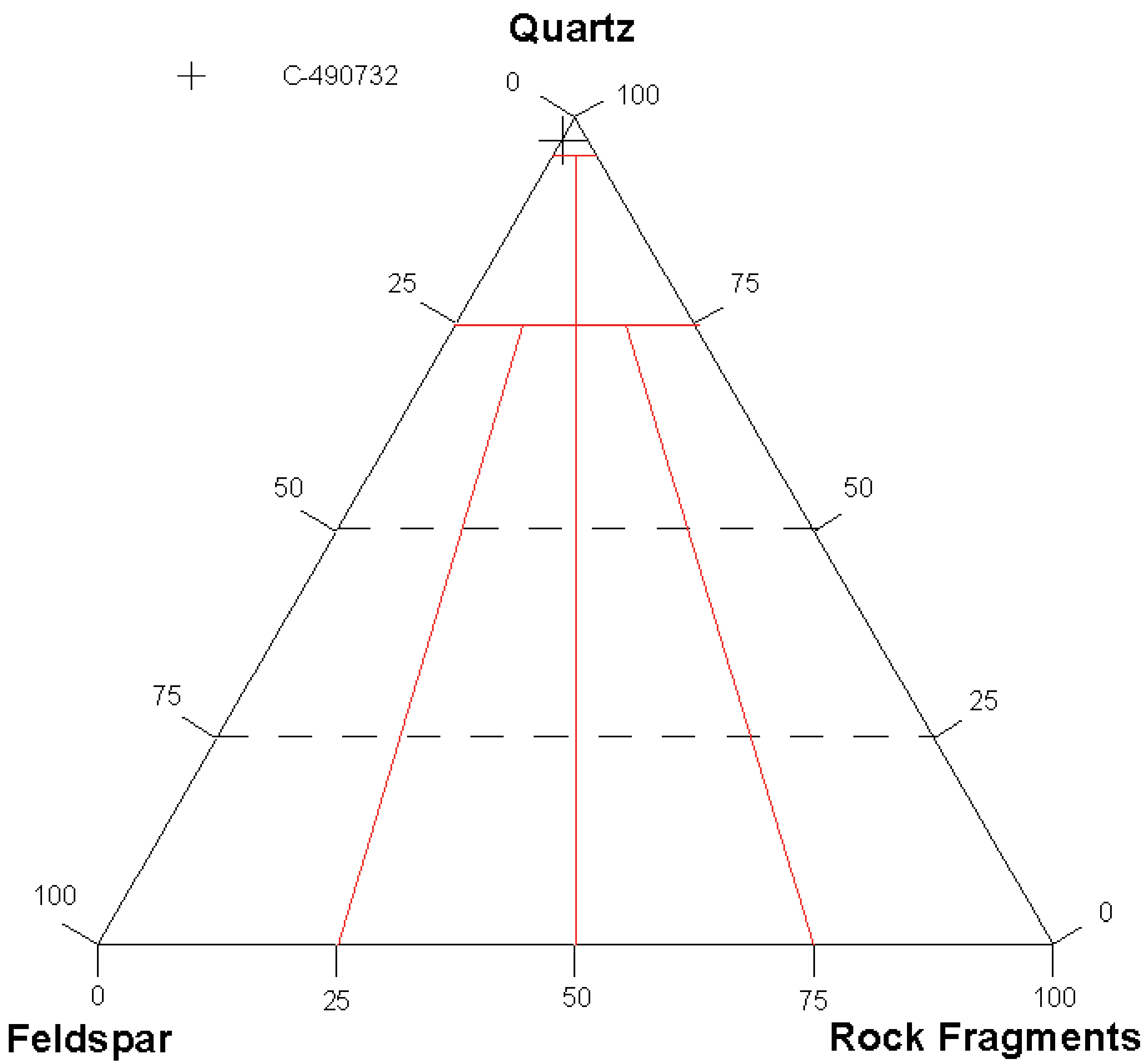



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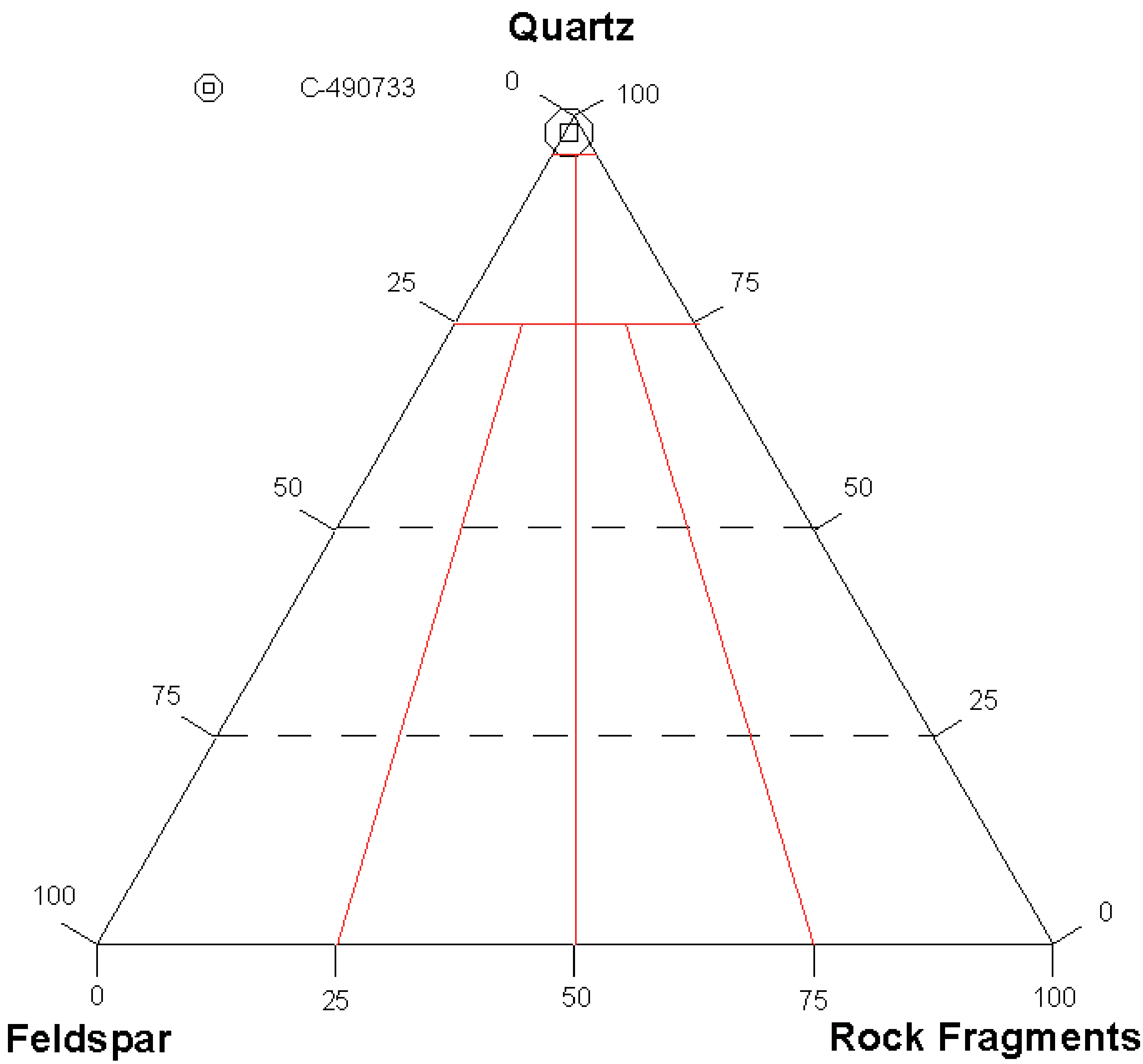
Figure 1g: Composition Ternary Diagram
Section 11MWBs01 – Unit 6

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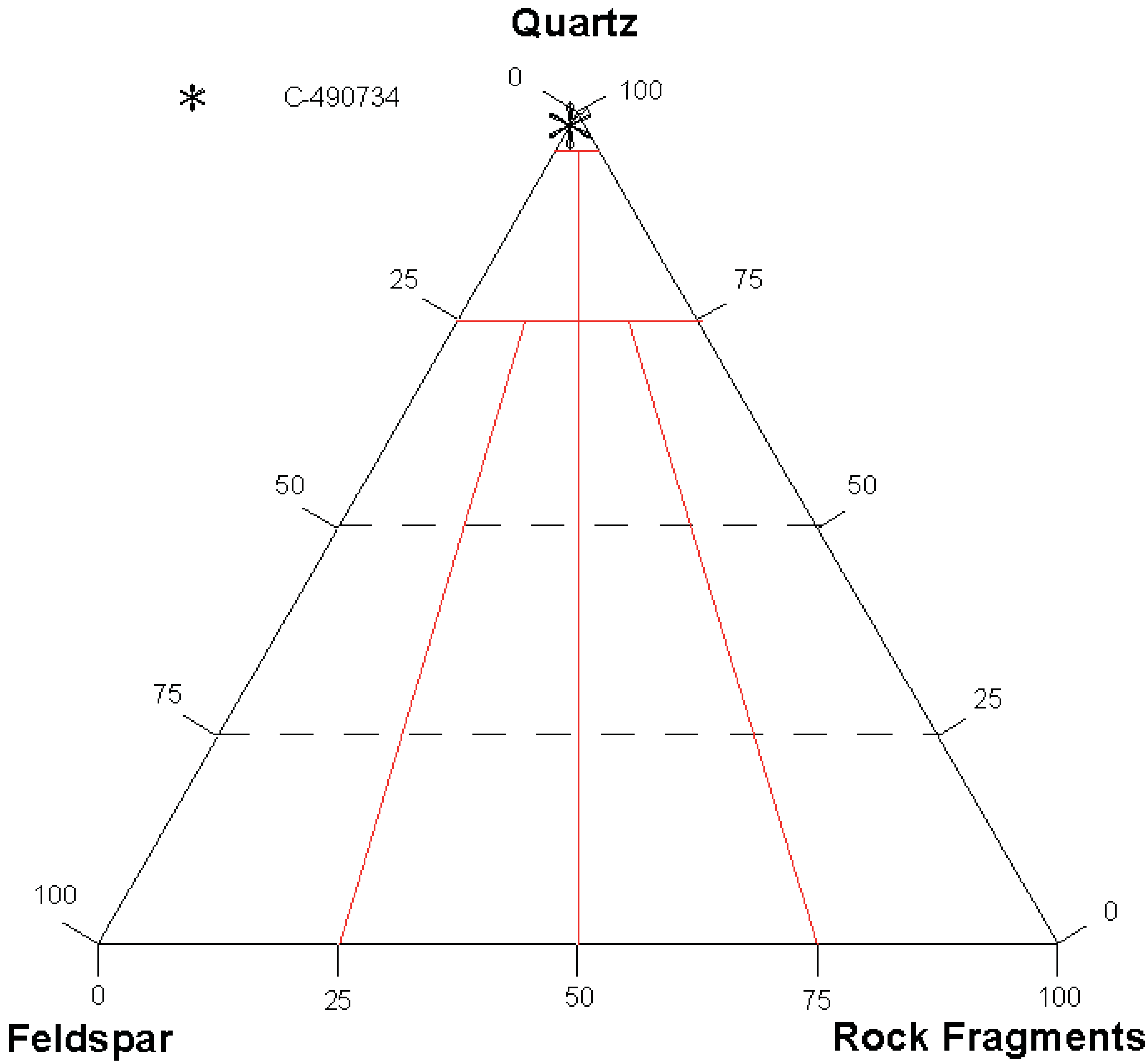
# Figure 1h: Composition Ternary Diagram
## Section 11MWBs01 – Unit 7





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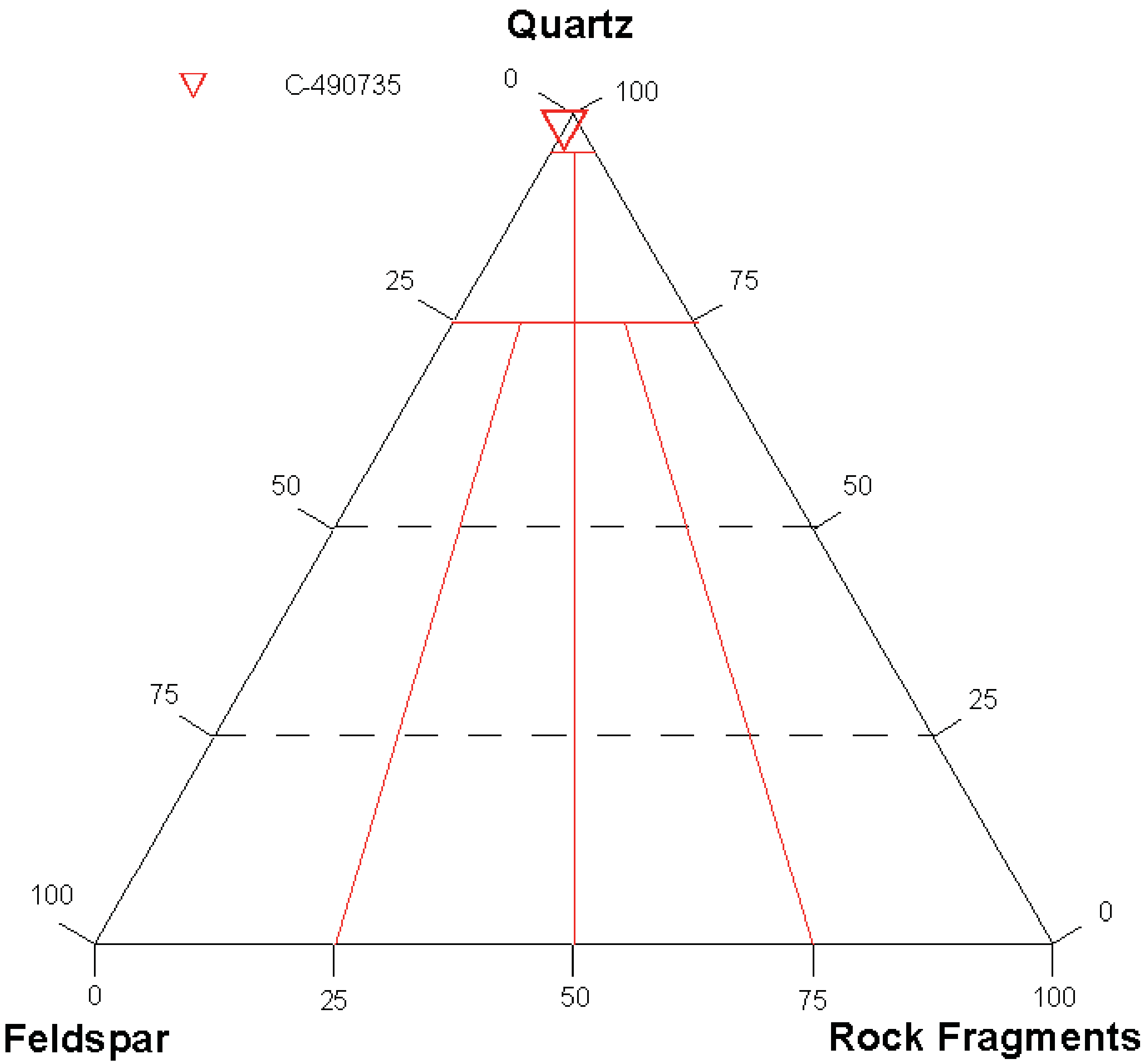
# Figure 1i: Composition Ternary Diagram
## Section 11MWBs01 – Unit 8





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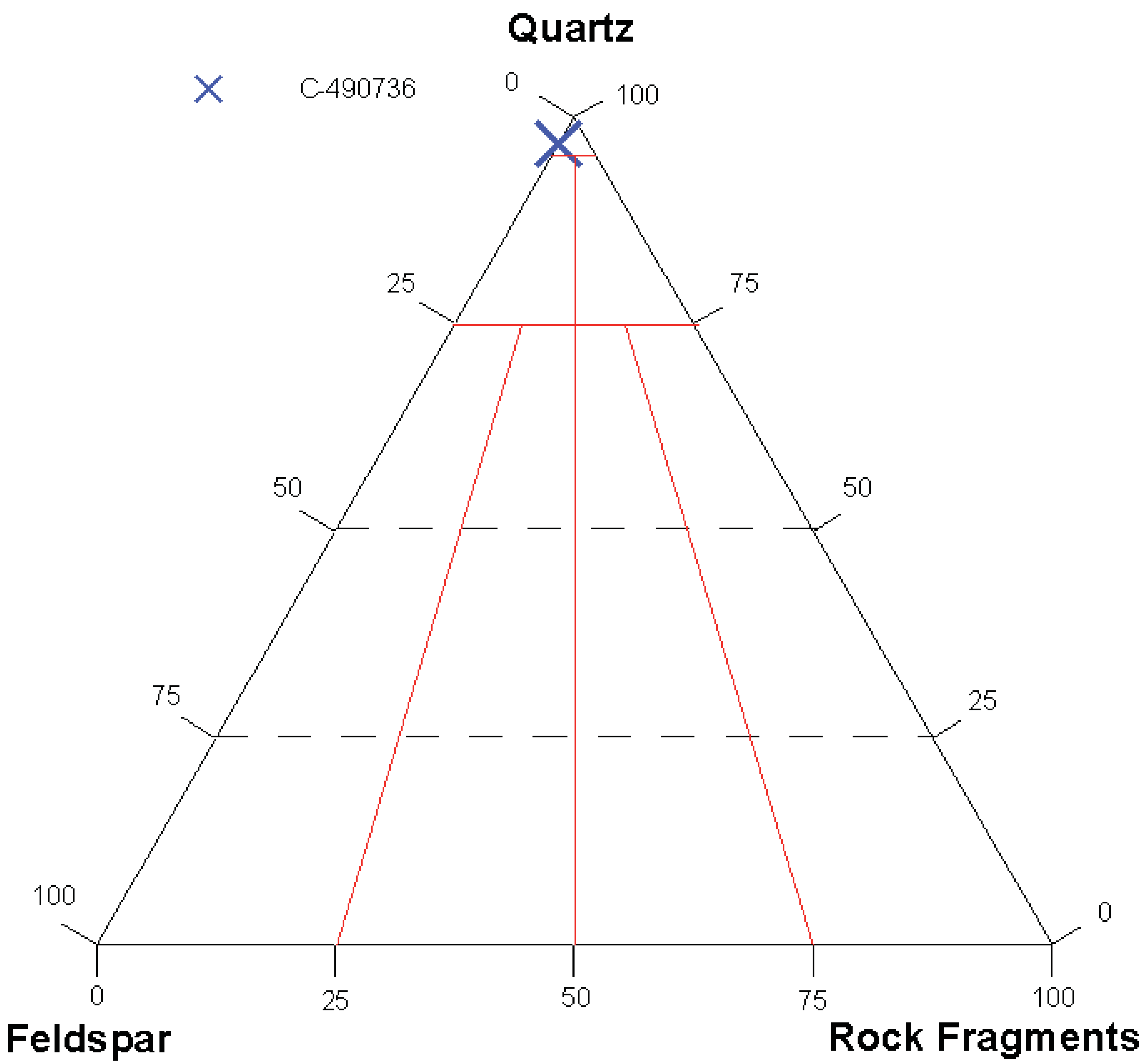
# Figure 1j: Composition Ternary Diagram
## Section 11MWBs01 – Unit 10

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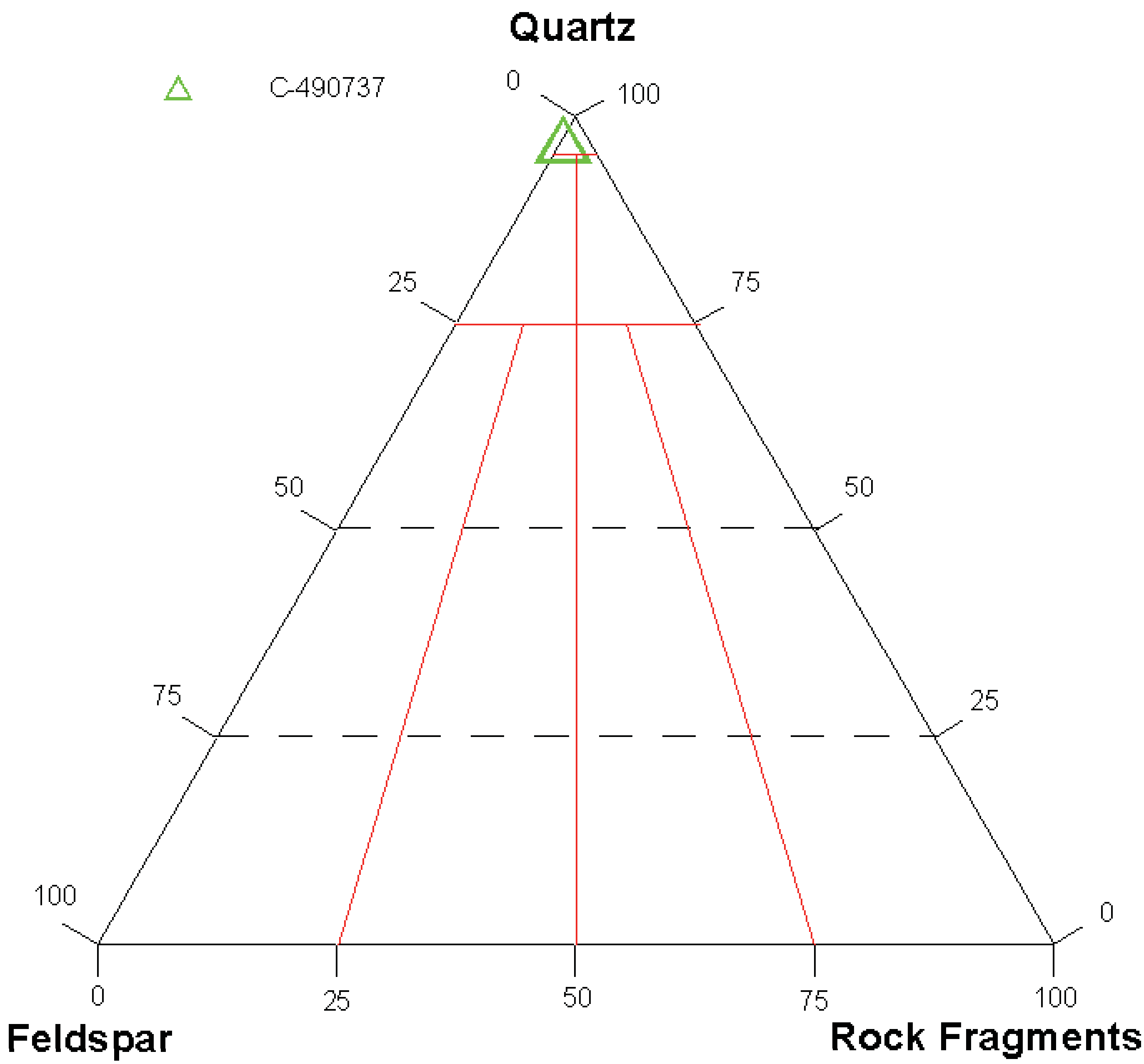
# Figure 1k: Composition Ternary Diagram
## Section 11MWBs01 – Unit 15





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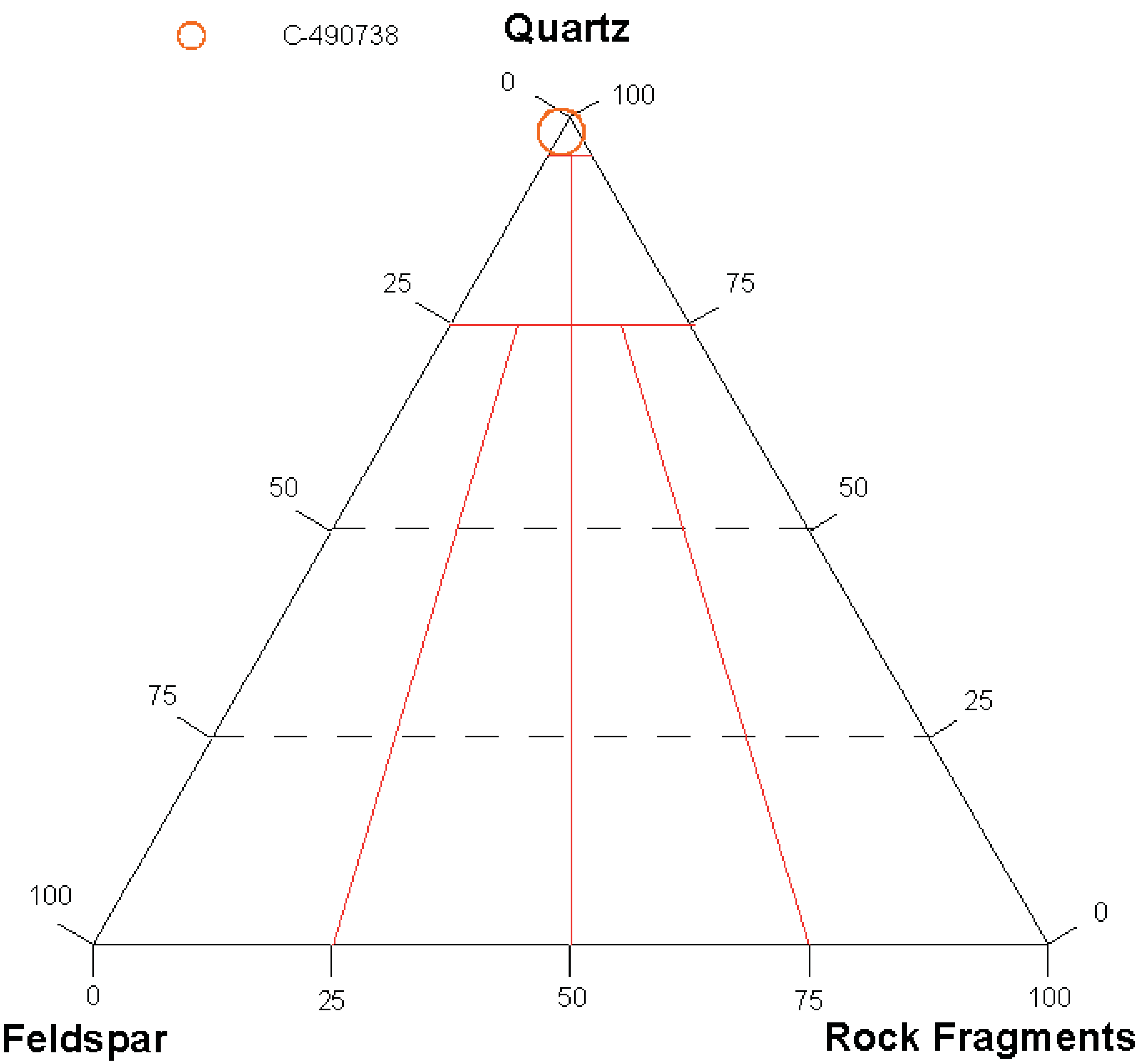
# Figure 1l: Composition Ternary Diagram
## Section 11MWBs01 – Unit 16





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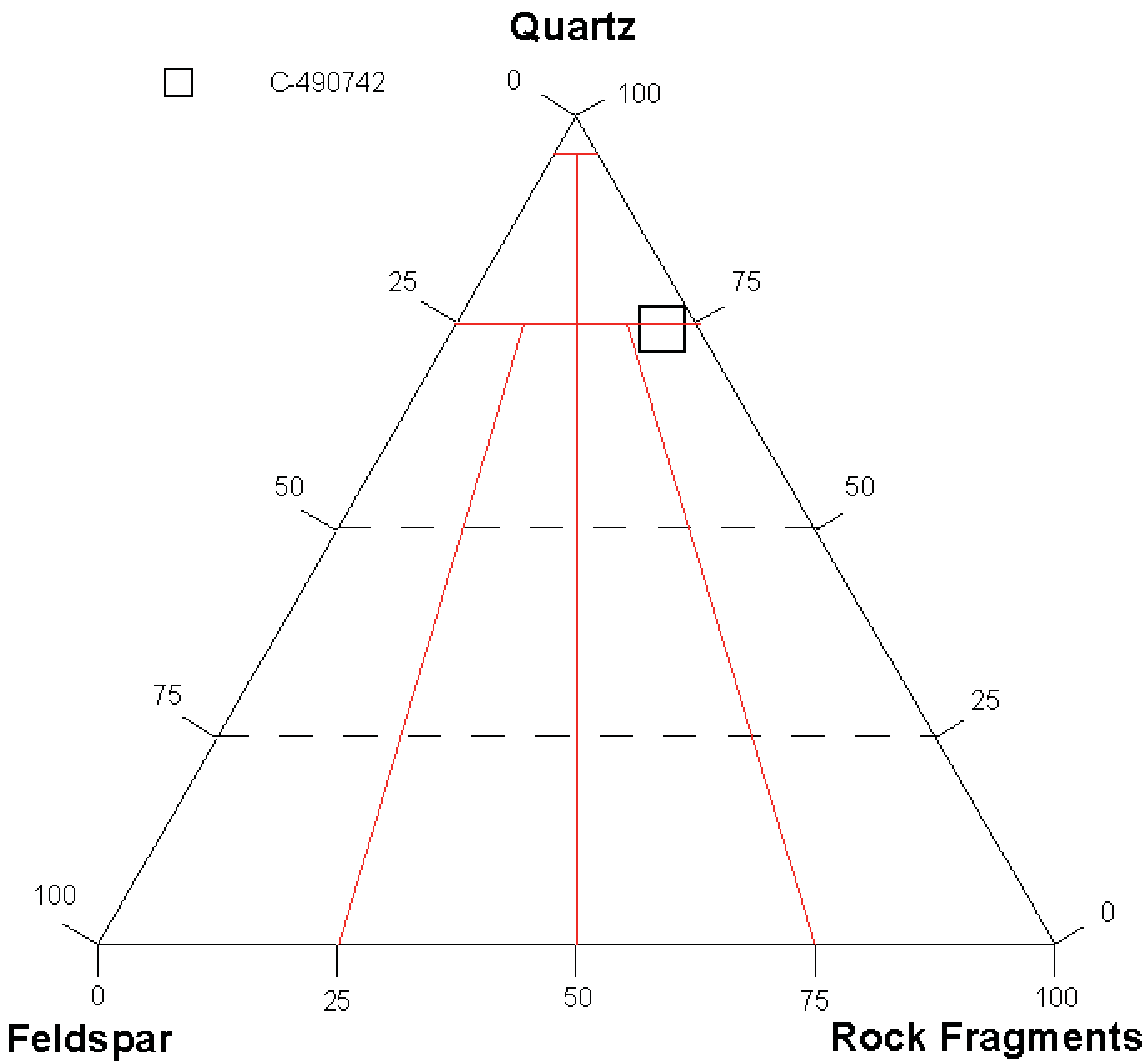
# Figure 1m: Composition Ternary Diagram
## Section 11MWBs01 – Unit 22

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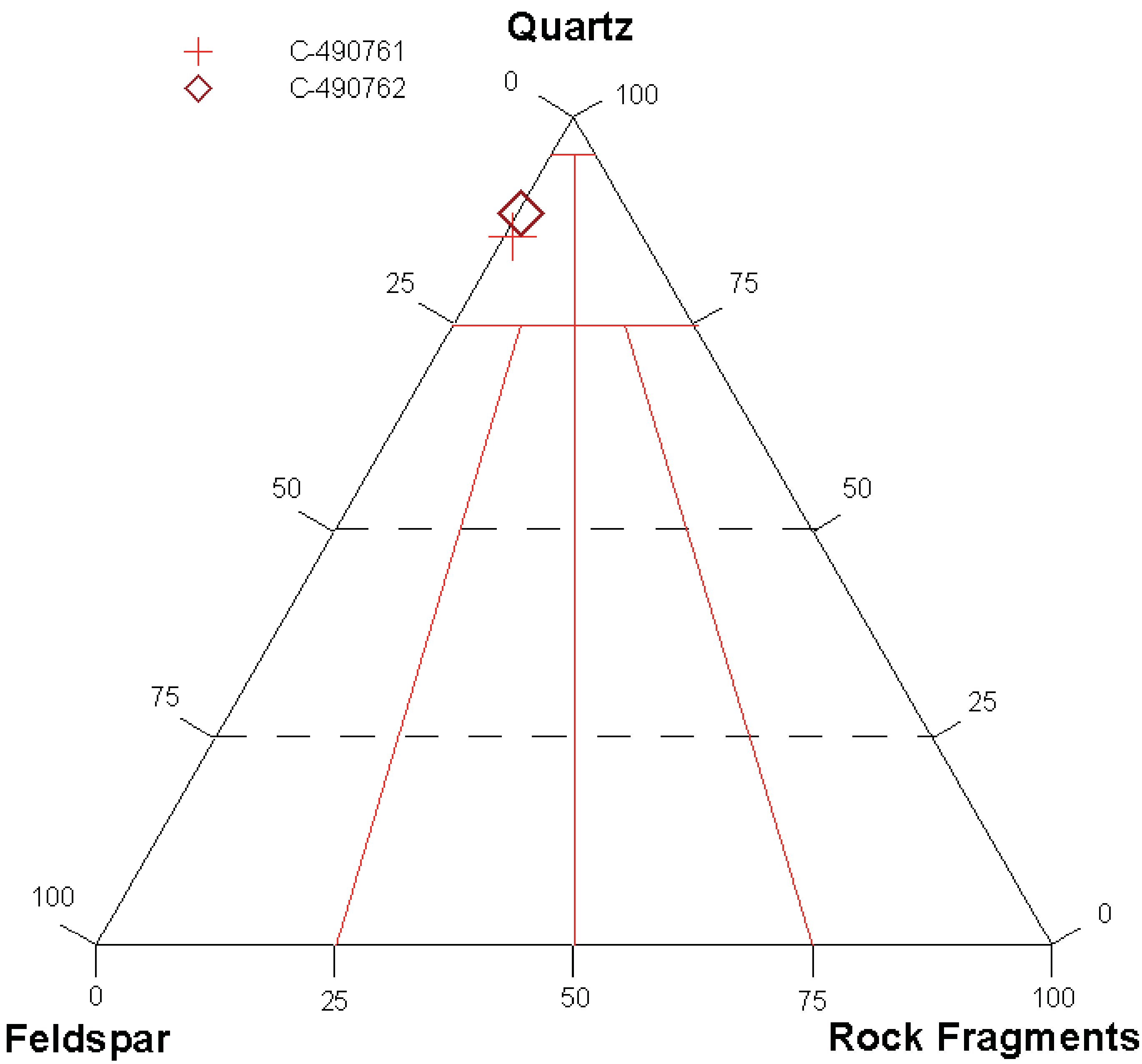
# Figure 1n: Composition Ternary Diagram
## Section 0901S – Units 1 and 7

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# Figure 1o: Composition Ternary Diagram
## Section 0901S – Unit 1

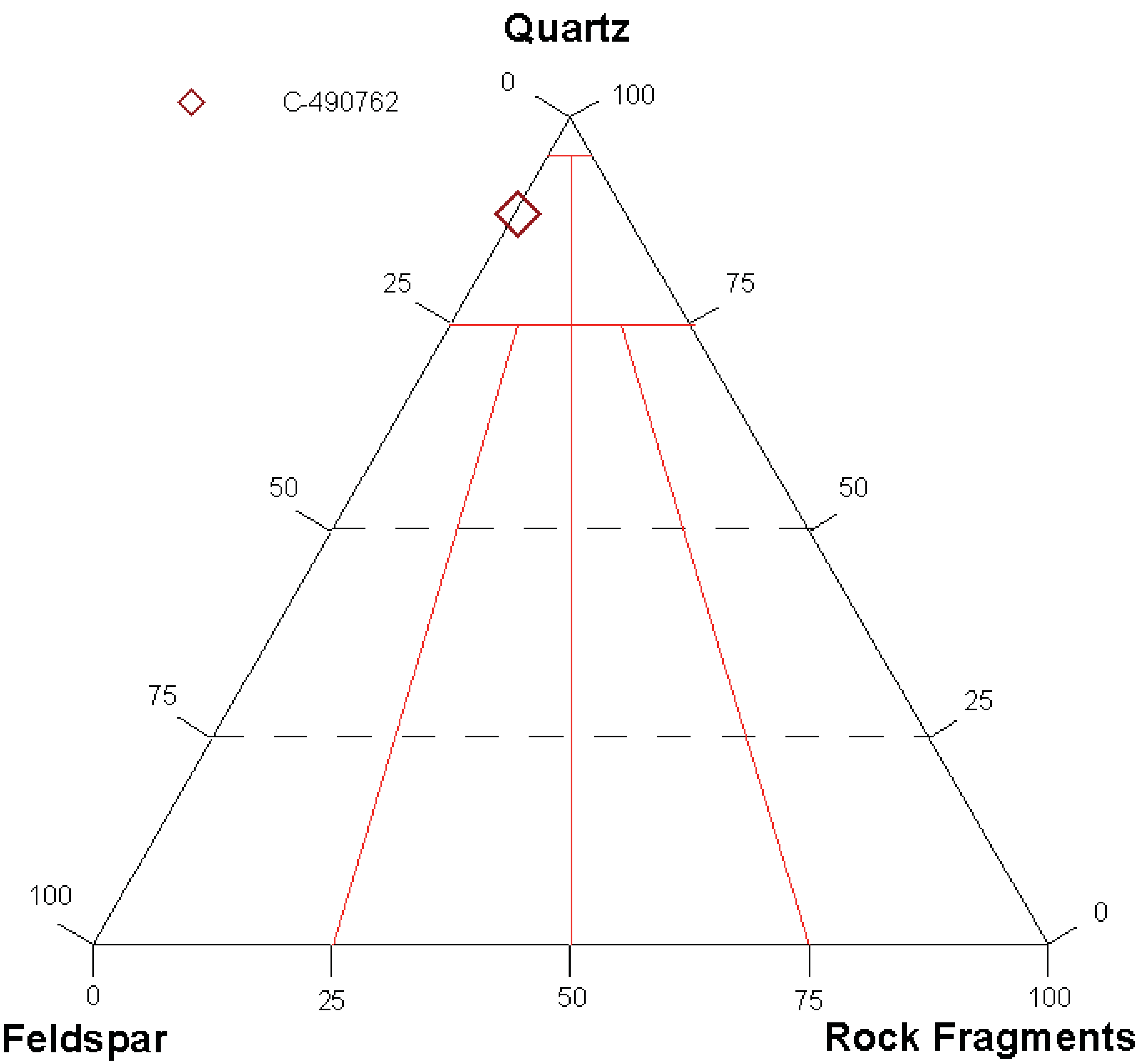



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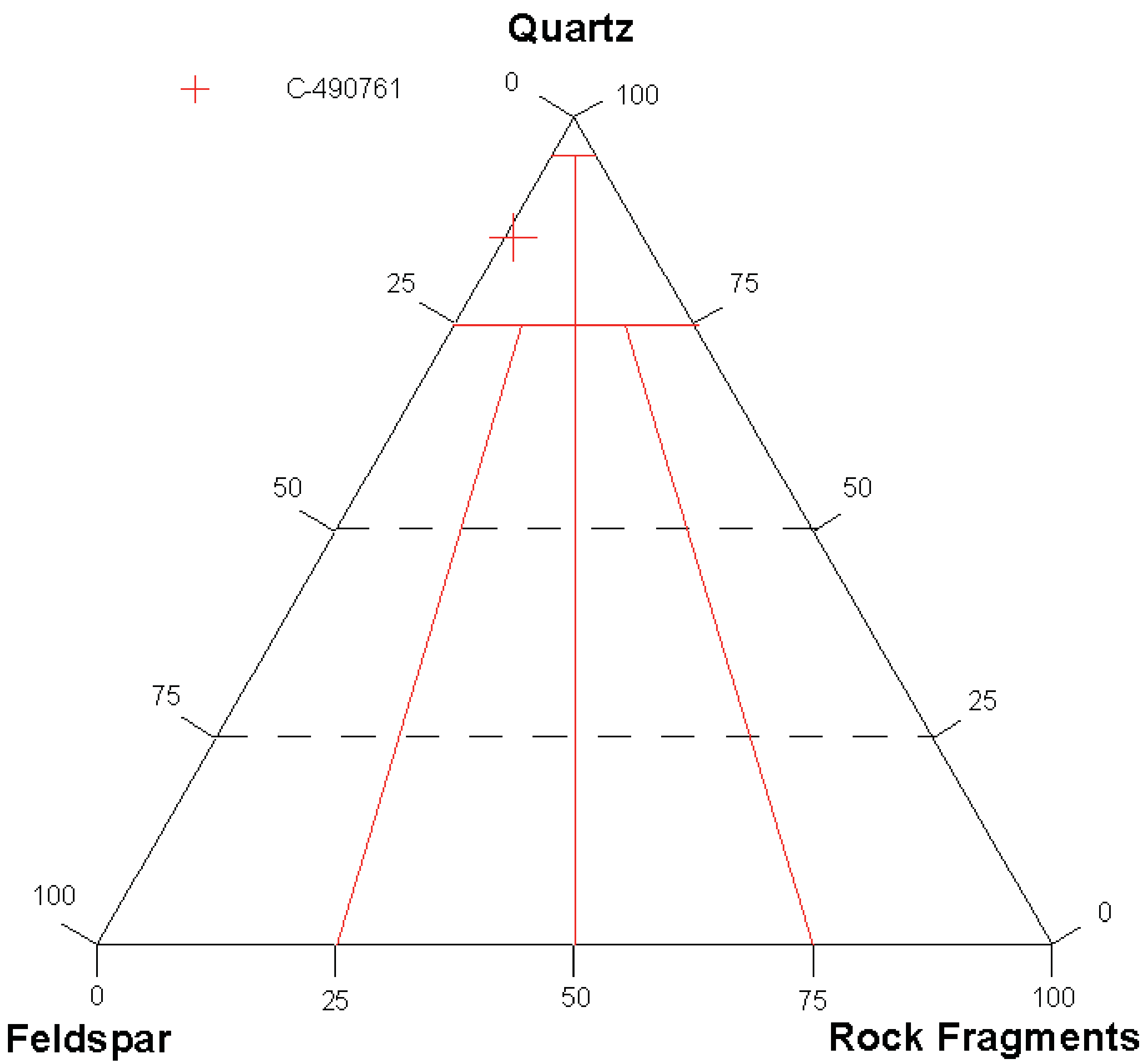
Figure 1p: Composition Ternary Diagram
Section 0901S – Unit 7

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**Formation: Various**
**Section: 11MWBs01**

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**TABLE 3a**

**GRAIN SIZE DATA**

| Formation | Unit | Sample # | Mean (mm) | Max (mm) | Min (mm) | Standard Deviation |
|---|---|---|---|---|---|---|
| Mount Clark | 22 | C-490742 | 0.172 | 0.738 | 0.077 | 0.085 |
| | 16 | C-490738 | 0.161 | 0.911 | 0.076 | 0.102 |
| | 15 | C-490737 | 0.214 | 0.912 | 0.094 | 0.122 |
| | 9 | C-490736 | 0.222 | 0.949 | 0.102 | 0.085 |
| | 8 | C-490735 | 0.247 | 0.530 | 0.118 | 0.075 |
| | 7 | C-490734 | 0.244 | 1.044 | 0.085 | 0.134 |
| K7? | 6 | C-490733 | 0.365 | 4.133 | 0.010 | 0.344 |
| | 6 | C-490732 | 0.290 | 1.649 | 0.091 | 0.242 |
| | 5 | C-490731 | 0.147 | 0.325 | 0.070 | 0.035 |
| | 5 | C-490730 | 0.415 | 4.771 | 0.083 | 0.579 |
| K6? | 2 | C-490729 | 0.098 | 0.165 | 0.060 | 0.017 |
| | 1 | C-490728 | 0.094 | 0.207 | 0.061 | 0.019 |

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**Formation: Various**
**Section: 0901S**

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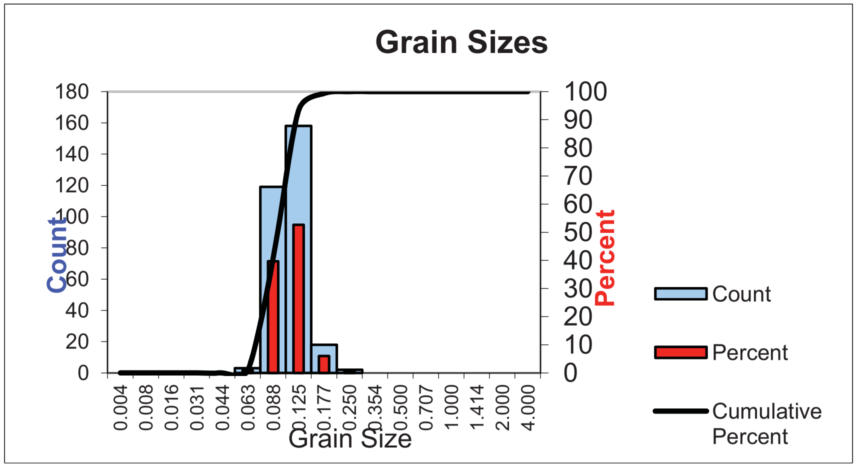
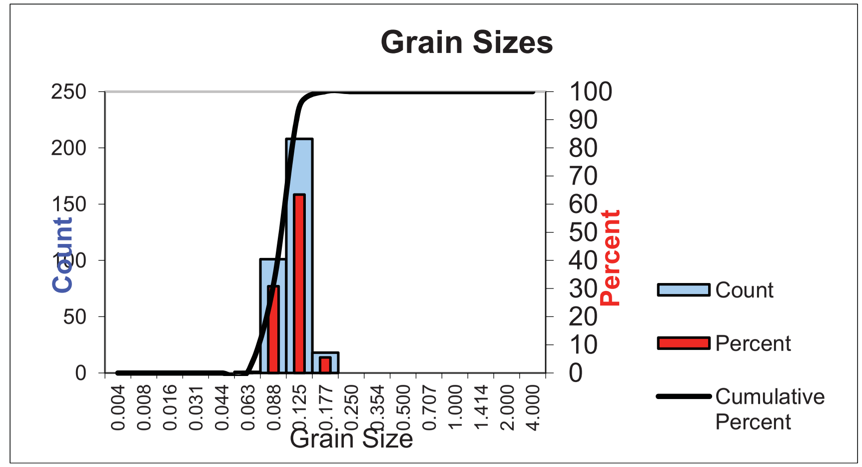
## TABLE 3b
## GRAIN SIZE DATA

| Formation | Unit | Sample # | Mean (mm) | Max (mm) | Min (mm) | Standard Deviation |
|---|---|---|---|---|---|---|
| K5 | 7 | C-490761 | 0.198 | 0.473 | 0.096 | 0.051 |
| K3 | 1 | C-490762 | 0.170 | 0.350 | 0.091 | 0.042 |

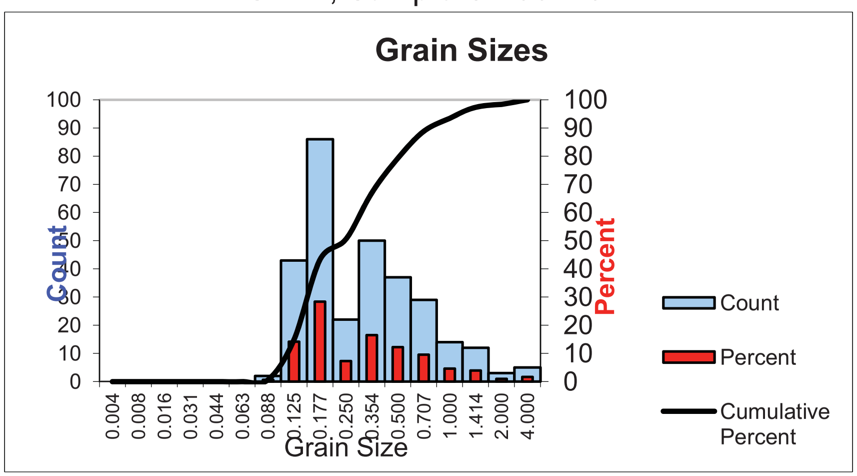
# Figure H1: Section 11MWBs01



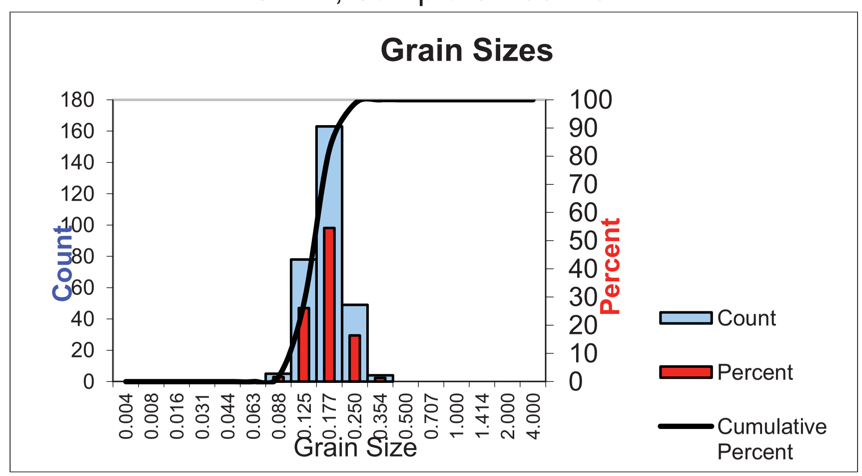

Unit 1, Sample C-490728




Unit 2, Sample C-490729

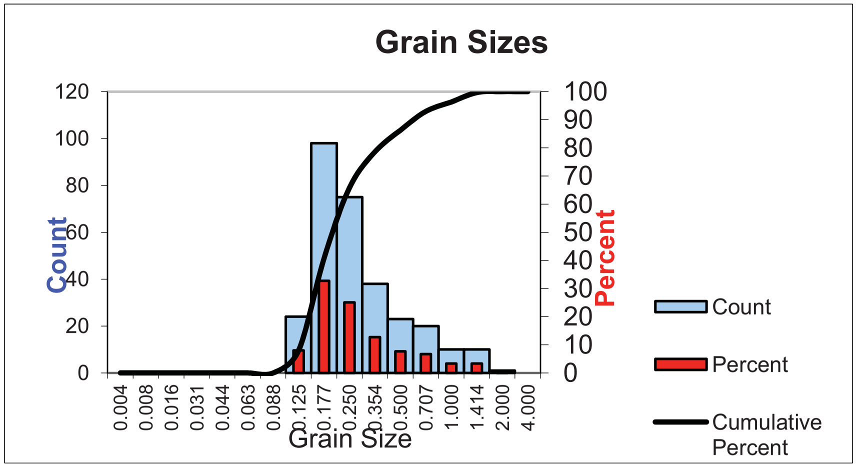



Unit 5, Sample C-490730

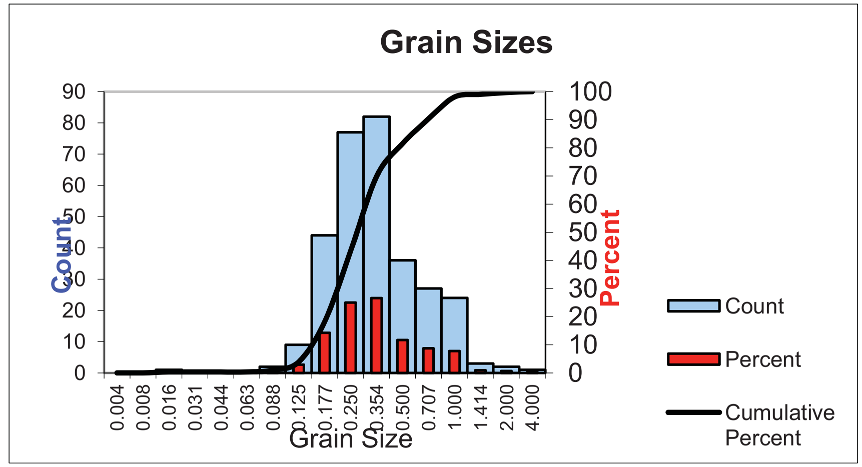



Unit 5, Sample C-490731

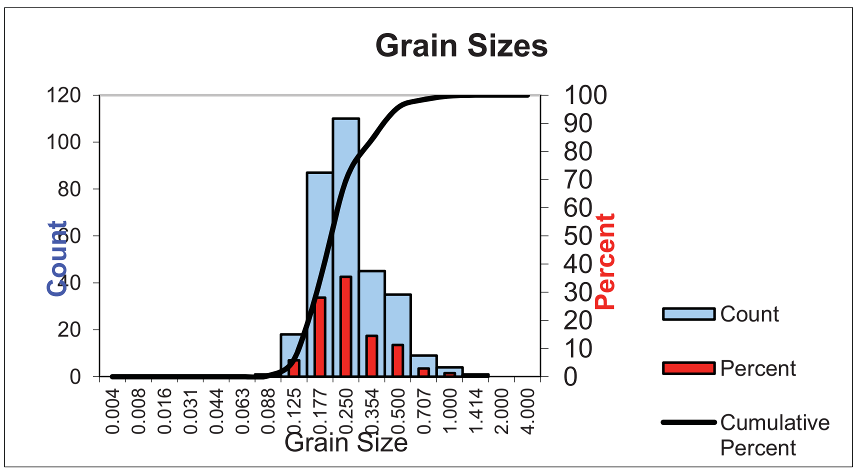
# Figure H2: Section 11MWBs01



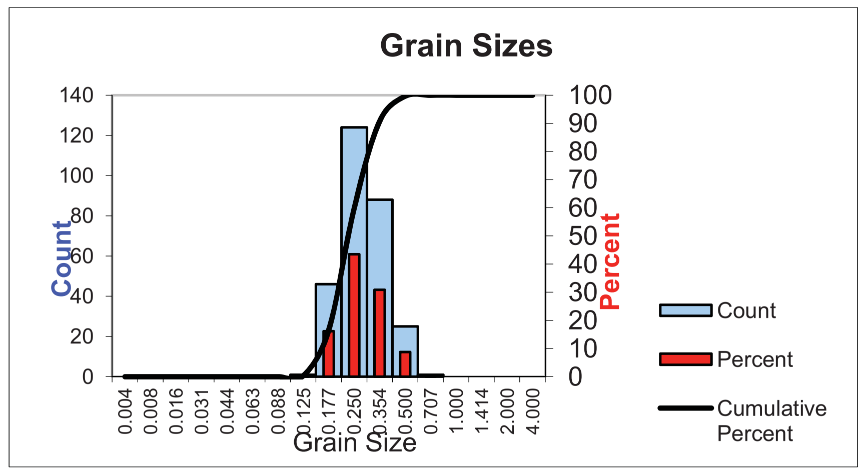

Unit 6, Sample C-490732




Unit 6, Sample C-490733

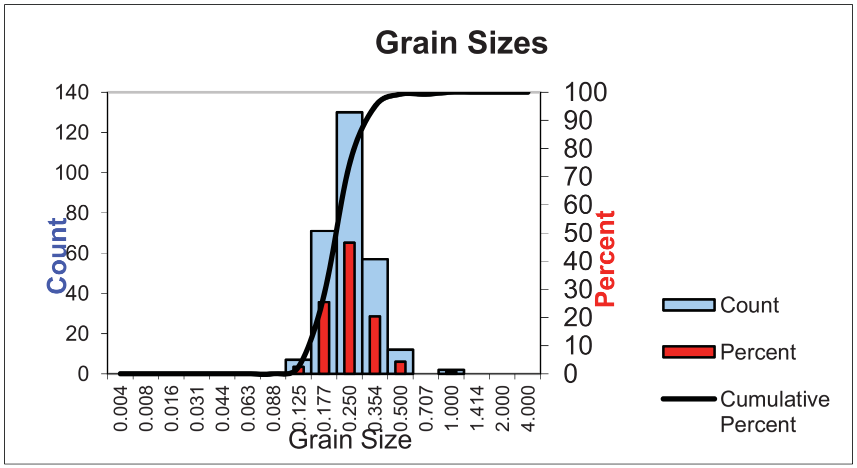



Unit 7, Sample C-490734

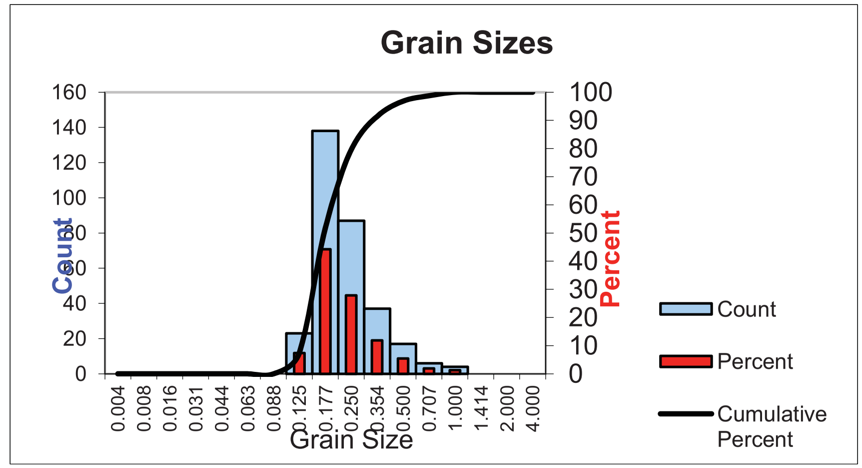



Unit 8, Sample C-490735

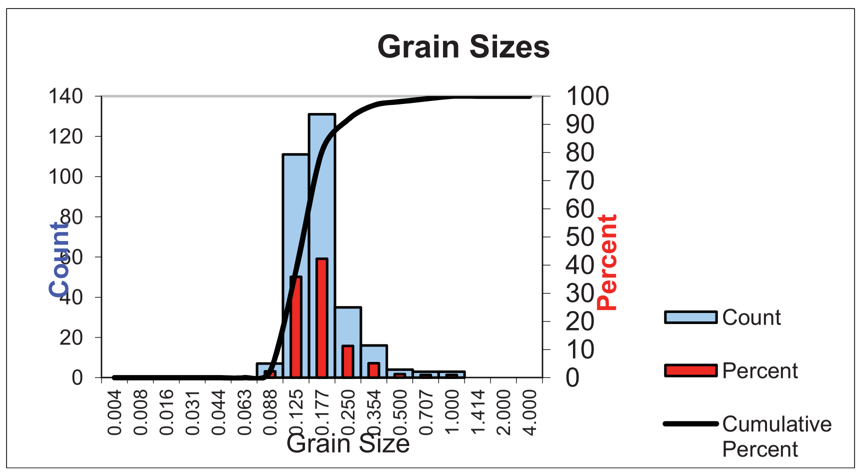
# Figure H3: Section 11MWBs01




Unit 10, Sample C-490736

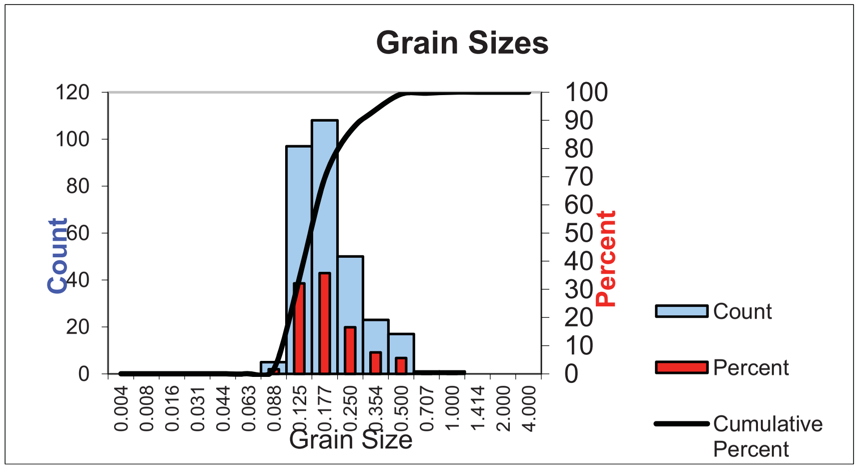



Unit 15, Sample C-490737



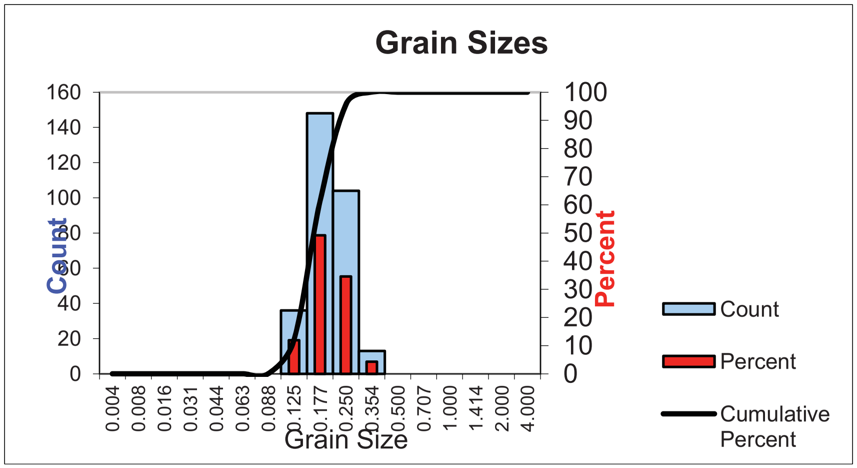

Unit 16, Sample C-490738

# Figure H4: Section 11MWBs01

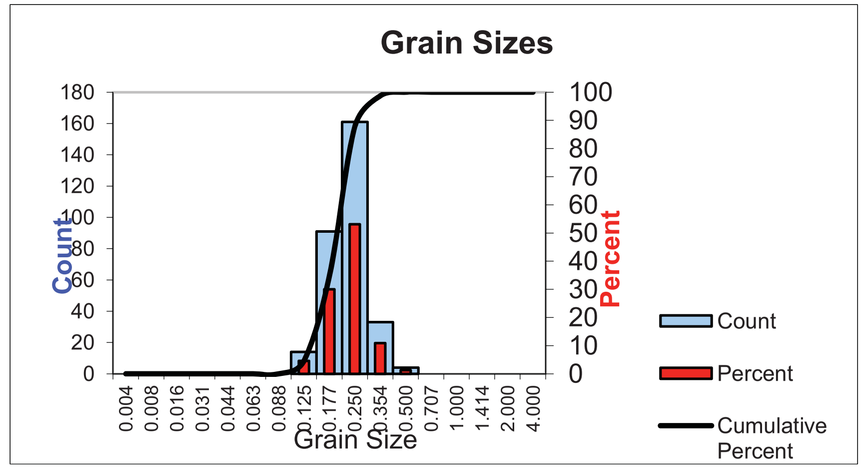



Unit 22, Sample C-490742

# Figure H5: Section 0901S




Unit 1, Sample C-490762




Unit 7, Sample C-490761

# Thin Section Overview

## Section 11MWBs01
## K6 (?)
## Subarkose (Bioturbated)

**Unit:** 1
**Sample #: C-490728**

# Section 11MWBs01

Unit 1

2 mm

**K6(?)**

C-490728

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# Thin Section Photomicrograph Descriptions – Plate 01

## Section 11MWBs01
## K6 (?)
## Subarkose

**Unit:** 1
**Sample #: C-490728**

Extensively bioturbated and laminated, moderately well sorted, very fine grained subarkoses characterize the K6? outcrop sample C-490728 taken from Unit 1. Framework constituents are dominated by subangular to subrounded monocrystalline quartz (Q) with lesser amounts of plagioclase, trace muscovite flakes (Views C and D), heavy minerals and polycrystalline quartz. Hematite cement is pervasive occluding macroporosity in this interval. Thin section photomicrograph View B illustrates hematite cement in reflected light. Quartz overgrowths (Views C and D, small black arrows), precipitated on host monocrystalline quartz grains, are very poorly developed.

**Photo A: 40X PPL, Photo B: 200X RL, Photo C: 100X PPL, Photo D: 100X XPL**



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Section 11MWBs01 K6(?) Unit 1

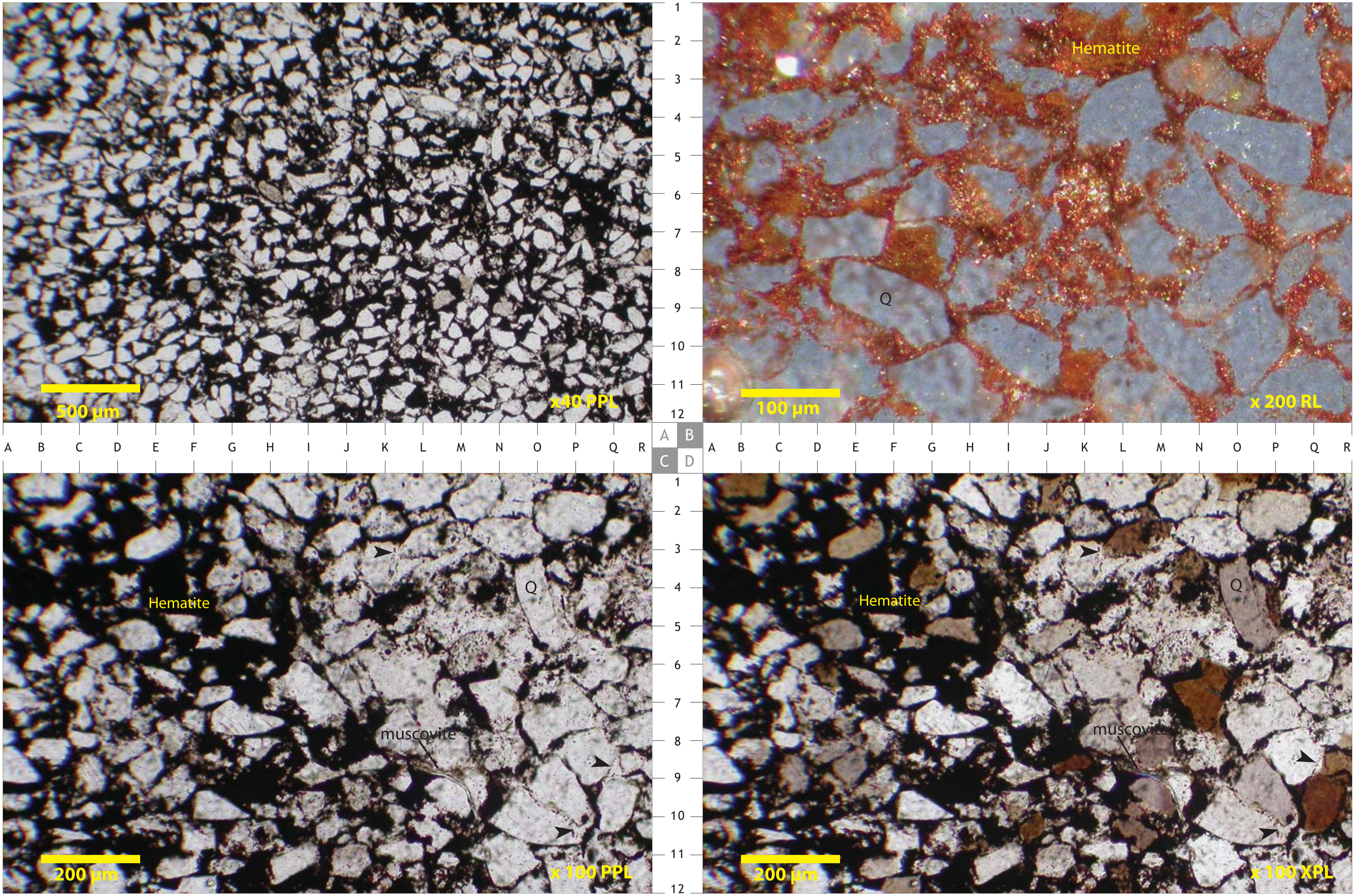


**Plate 01**
C-490728
CMH 2013-01

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# Thin Section Overview

## Section 11MWBs01
## K6(?)
## Subarkose (Laminated and Bioturbated)

**Unit:** 2
**Sample #:** C-490729

*Note red arrows highlight burrows

# Section 11MWBs01

**Unit 2**

**K6(?)**

C-490729

CMH 2013-01

2 mm

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# Thin Section Photomicrograph Descriptions – Plate 02

## Section 11MWBs01
## K6(?)
## Subarkose

**Unit:** 2
**Sample #:** C-490729

The K6? Unit 2 interval is represented by Outcrop sample C-490729. It is recognized as laminated and commonly bioturbated subarkoses. Very fine grained, moderately well sorted framework components are dominated by subangular to subrounded monocrystalline quartz (Q). Subordinate framework grains include plagioclase, polycrystalline quartz and heavy minerals. High birefringence matrix clays are unevenly distributed. Petrographic characteristics of these clays suggest a smectite-illite-kaolinite composition. However, clay X-ray diffraction analysis would ascertain the clay composition in this interval. Authigenic cements include pervasive hematite, as illustrated in thin section photomicrograph View B, and poorly developed syntaxial quartz cement (small black arrows). The latter has precipitated unevenly on host monocrystalline quartz grains.

**Photo A: 40X PPL, Photo B: 200X RL, Photo C: 100X PPL, Photo D: 100X XPL**



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## Section 11MWBs01 K6(?) Unit 2

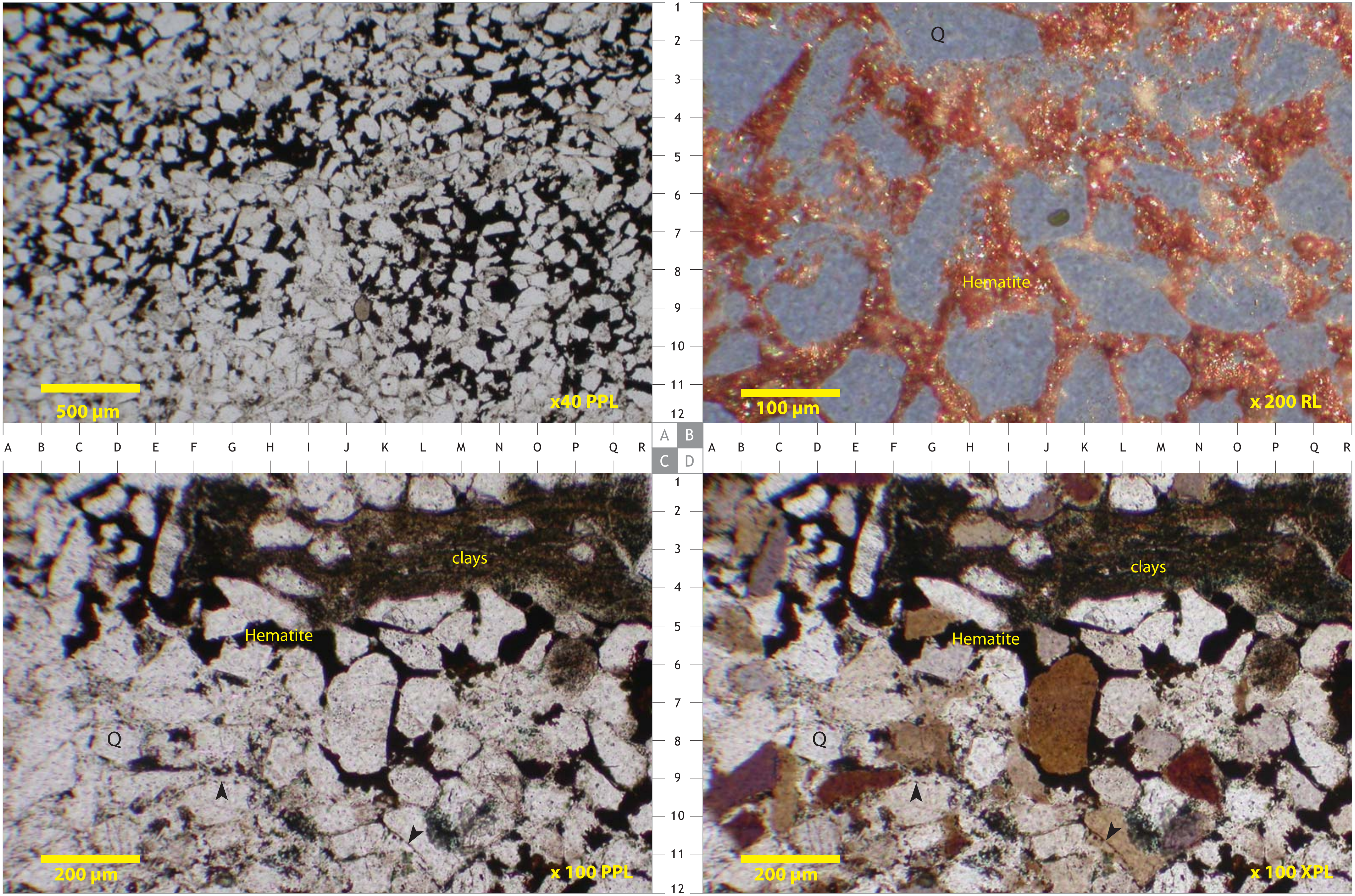


**Plate 02**
C-490729
CMH 2013-01

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# Thin Section Overview

## Section 11MWBs01
## K7?
## Conglomeratic Sublitharenite

**Unit:** 5
**Sample #:** C-490730

K7?

C-490730

CMH 2013-01

2 mm

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# Thin Section Photomicrograph Descriptions – Plate 03

## Section 11MWBs01
## K7?
## Conglomeratic Sublitharenite

**Unit:** 5
**Sample #:** C-490730

Very poorly sorted, texturally immature conglomeratic sublitharenites were encountered by Outcrop sample C-490730, representing Unit 5 in the lower K7? interval. Framework grains vary in size from 0.083 to 4.771 mm, or lower very fine to pebble size clasts. The rounded to subangular granule to pebble sized polymictic grains are composed of oolitic chert sandstones, shales, chert, quartz-rich sedimentary grains (reworked sandstones), organic-rich silty argillic lithoclasts, and polycrystalline quartz grains. Matrix sandstone is dominated by monocrystalline quartz with accessory polycrystalline quartz, chert, muscovite, plagioclase, organic material (OM)l, and metamorphic rock fragments. Unevenly distributed mixed clays are found in minor volumes. Diagenetic phases include common syntaxial quartz overgrowths (small black arrows) precipitated on host quartz lithoclasts.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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## Section 11MWBs01

## K7 Unit 5

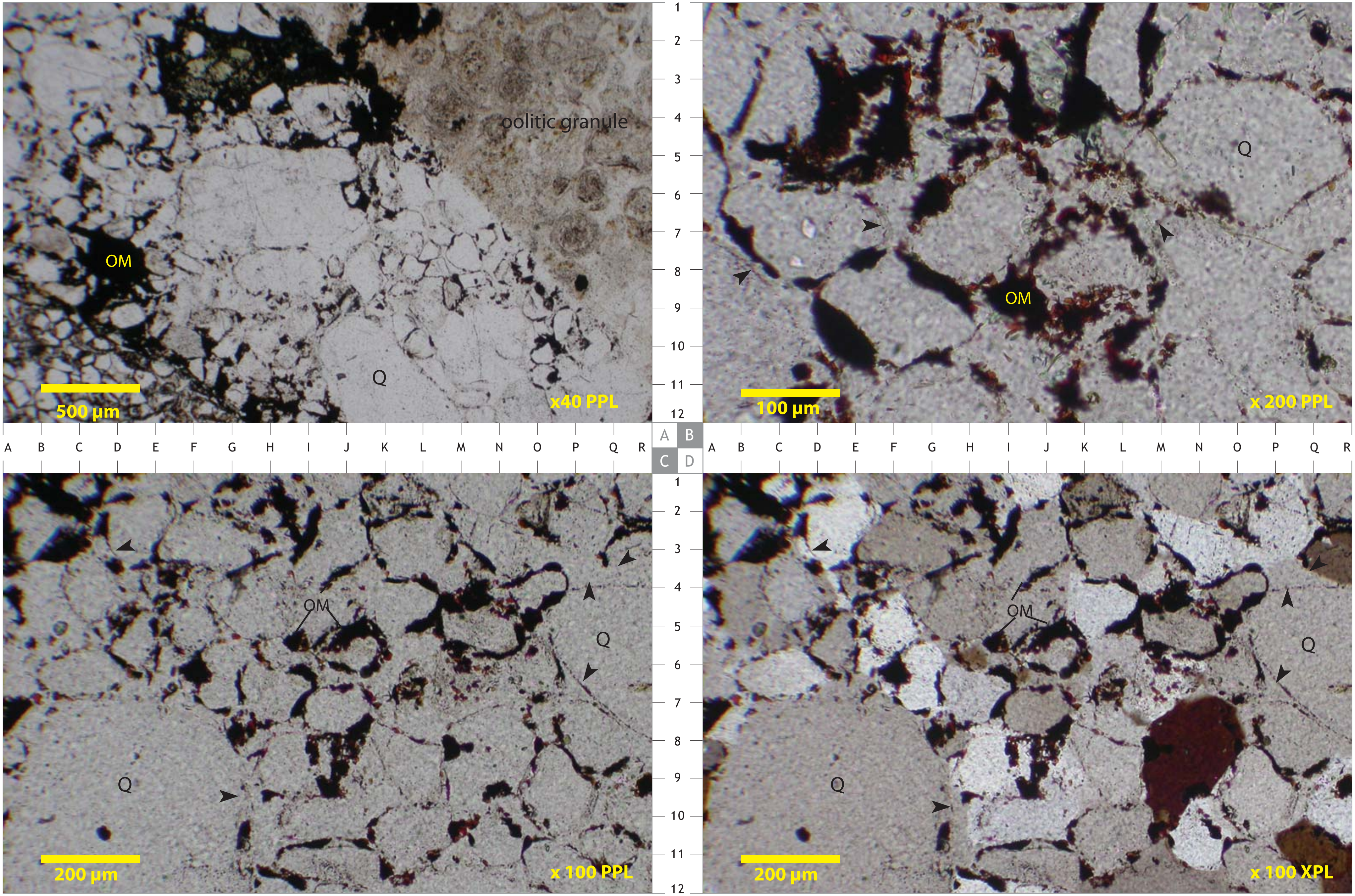


**Plate 03**
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# Thin Section Overview

## Section 11MWBs01
## K7?
## Quartz Arenite

**Unit:** **5**
**Sample #:** C-490731

## Section 11MWBs01

## Unit 5

**K7?**

C-490731

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2 mm

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# Thin Section Photomicrograph Descriptions – Plate 04

## Section 11MWBs01
## K7?
## Quartz Arenite

**Unit: 5**
**Sample #:** C-490731

Extensively bioturbated, texturally mature to submature, very fine to medium grained quartz arenites characterize outcrop sample C-490731 taken from Unit 5 in the K7? interval. Overall, average grain size is 147 μm or mid-fine grained. Subrounded to subangular monocrystalline quartz (Q) dominates the framework constituents with subordinate plagioclase, minor argillic lithoclasts (View A, CRF) and heavy minerals. Pore occluding authigenic cements include common syntaxial silica overgrowths (small black arrows) precipitated on host monocrystalline quartz grains. Light brown matrix clays are concentrated along laminae as observed in the thin section overview. Petrographic characteristics of these matrix clays suggest a smectite-illite-kaolinite composition. However, X-ray diffraction analysis would ascertain clay composition in this interval.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**


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## Section 11MWBs01

## K7 Unit 5

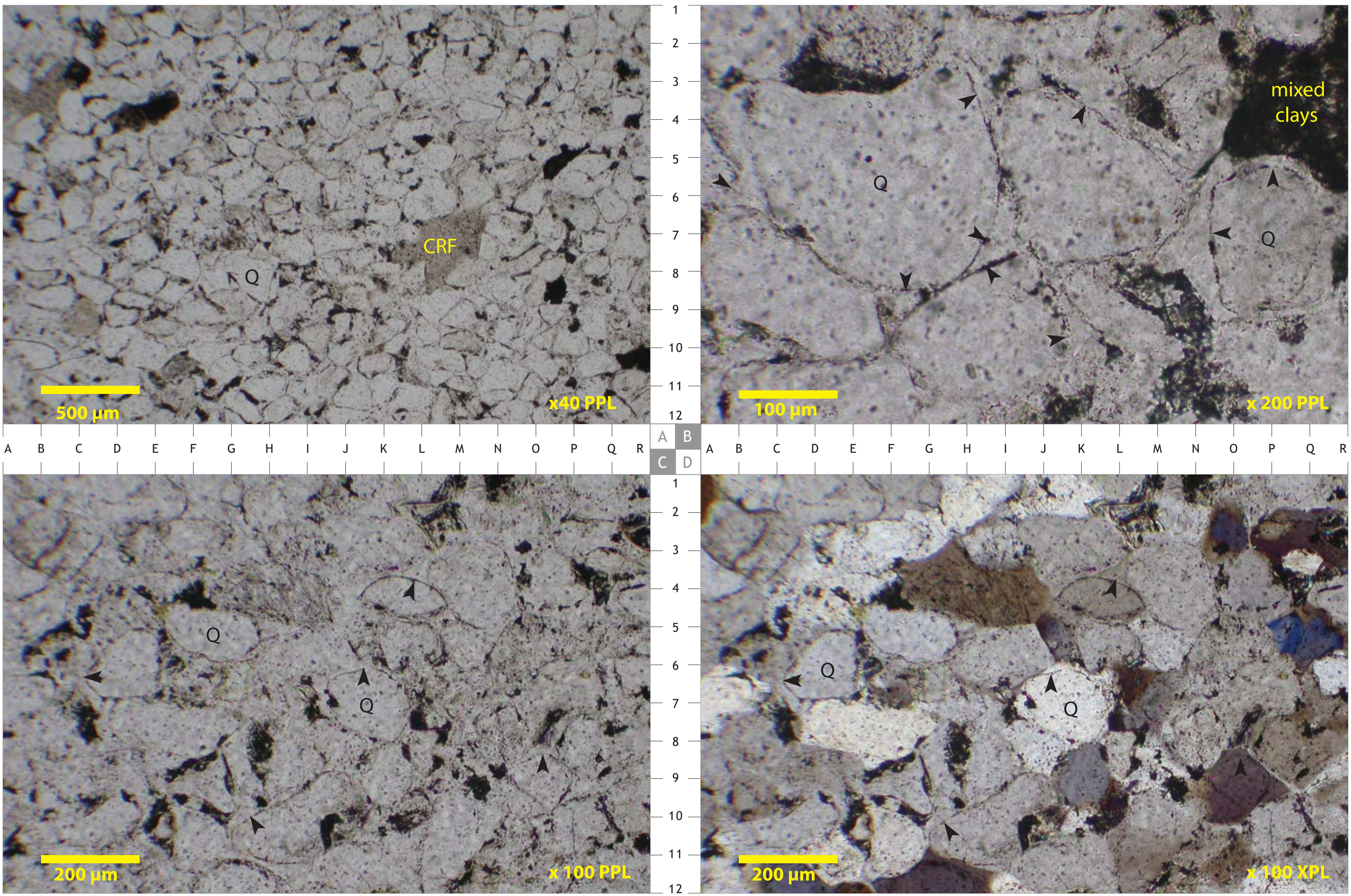


**Plate 04**
C-490731
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# Thin Section Overview

## Section 11MWBs01
## K7?
## Quartz Arenite (Laminated)

**Unit:** 6
**Sample #:** C-490732

# Section 11MWBs01

# Unit 6

**K7?**

C-490732

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2 mm

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# Thin Section Photomicrograph Descriptions – Plate 05

## Section 11MWBs01
## K7?
## Quartz Arenite

**Unit:** 6
**Sample #:** C-490732

A laminated, texturally submature, subrounded to rounded, very fine to very coarse grained quartz cemented quartz arenite are recognized from outcrop sample C-490732 taken from the K7? interval, Unit 6. Framework constituents are dominated by monocrystalline quartz (Q) with lesser amounts of polycrystalline quartz, plagioclase, phosphate (fish debris) and heavy minerals. Quartz overgrowths (small black arrows) are commonly occluding macroporosity with common unevenly distributed loosely packed mixed authigenic clays precipitated within open pores. Petrographic characteristics of these mixed authigenic clays indicate a kaolinite-chlorite (K + Chl) composition. Note the bitumen (small red arrows) lined moldic pore in View A.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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## Section 11MWBs01

## K7 Unit 6

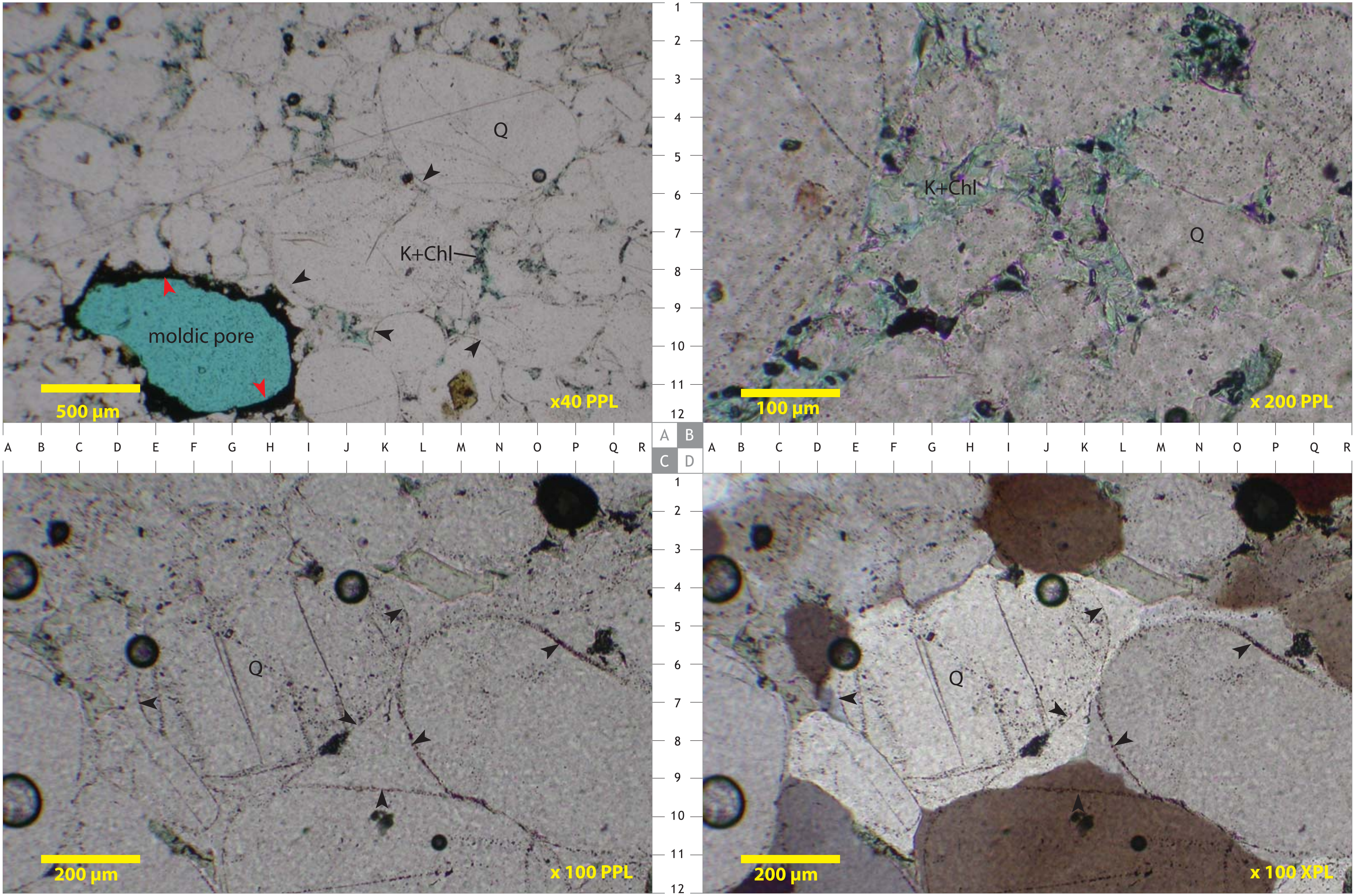


**Plate 05**
C-490732
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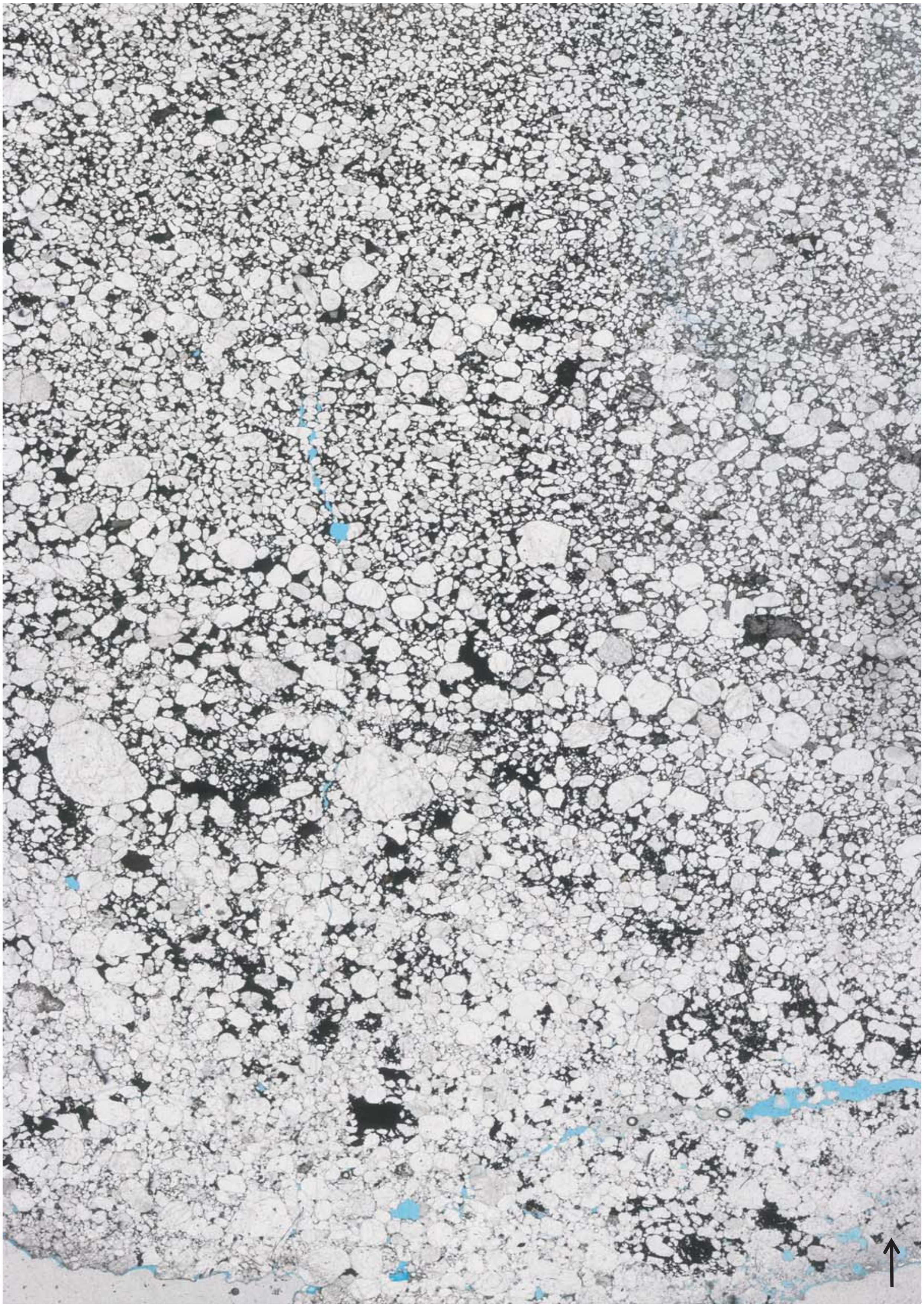
# Thin Section Overview

## Section 11MWBs01
## K7?
## Quartz Arenite

**Unit: 6**
**Sample #:** C-490733

Section 11MWBs01

Unit 6



K7?

C-490733

CMH 2013-01

2 mm

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# Thin Section Photomicrograph Descriptions – Plate 06

## Section 11MWBs01
## K7?
## Quartz Arenite

**Unit: 6**
**Sample #:** C-490733

Poorly sorted, silt to granule-sized, bitumen and carbonate cemented quartz arenites were recovered from Outcrop Sample C-490733, Unit 6, in the K7 interval. Overall average grain size is 290 µm or medium grained. Subrounded monocrystalline quartz (Q) dominates the framework components with minor polycrystalline quartz and plagioclase. Organic material, argillic lithoclasts, metamorphic lithoclasts and quartz-rich sedimentary grains (reworked siltstones) are considered accessory framework constituents. The main pore occluding authigenic cement is patchily distributed non-ferroan dolomite plus bitumen (small red arrows). Note thin section photomicrograph View A illustrates a collapsed partially leached feldspathic lithoclasts (L:7) filled with bitumen. Rare very poorly developed quartz overgrowths have precipitated on host quartz grains (View B, L:3) . The Overview illustrates minor open, vertical, discontinuous microfractures cross cut framework grains and cements.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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Section 11MWBs01

K7 Unit 6

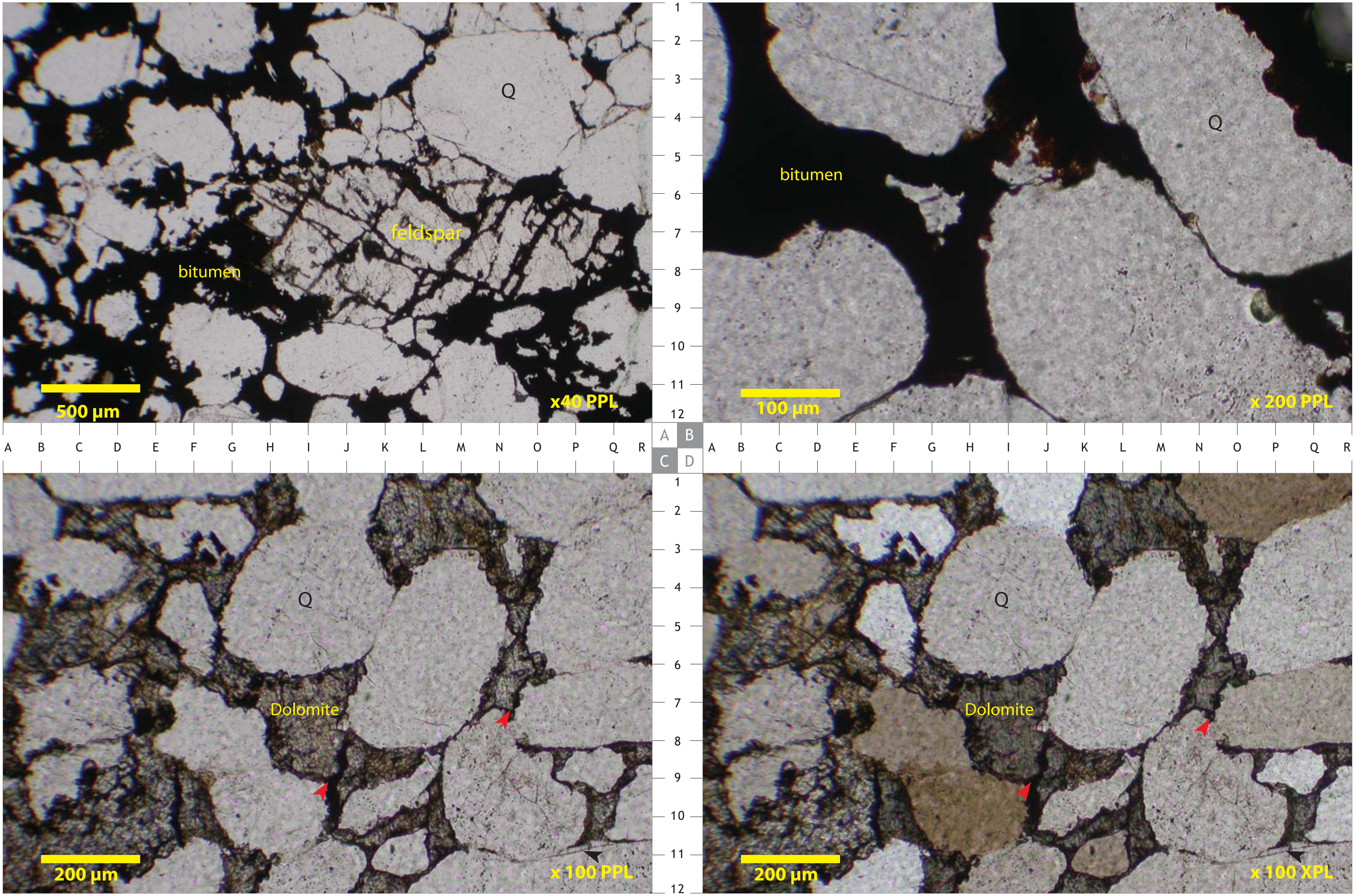


**Plate 06**

C-490733

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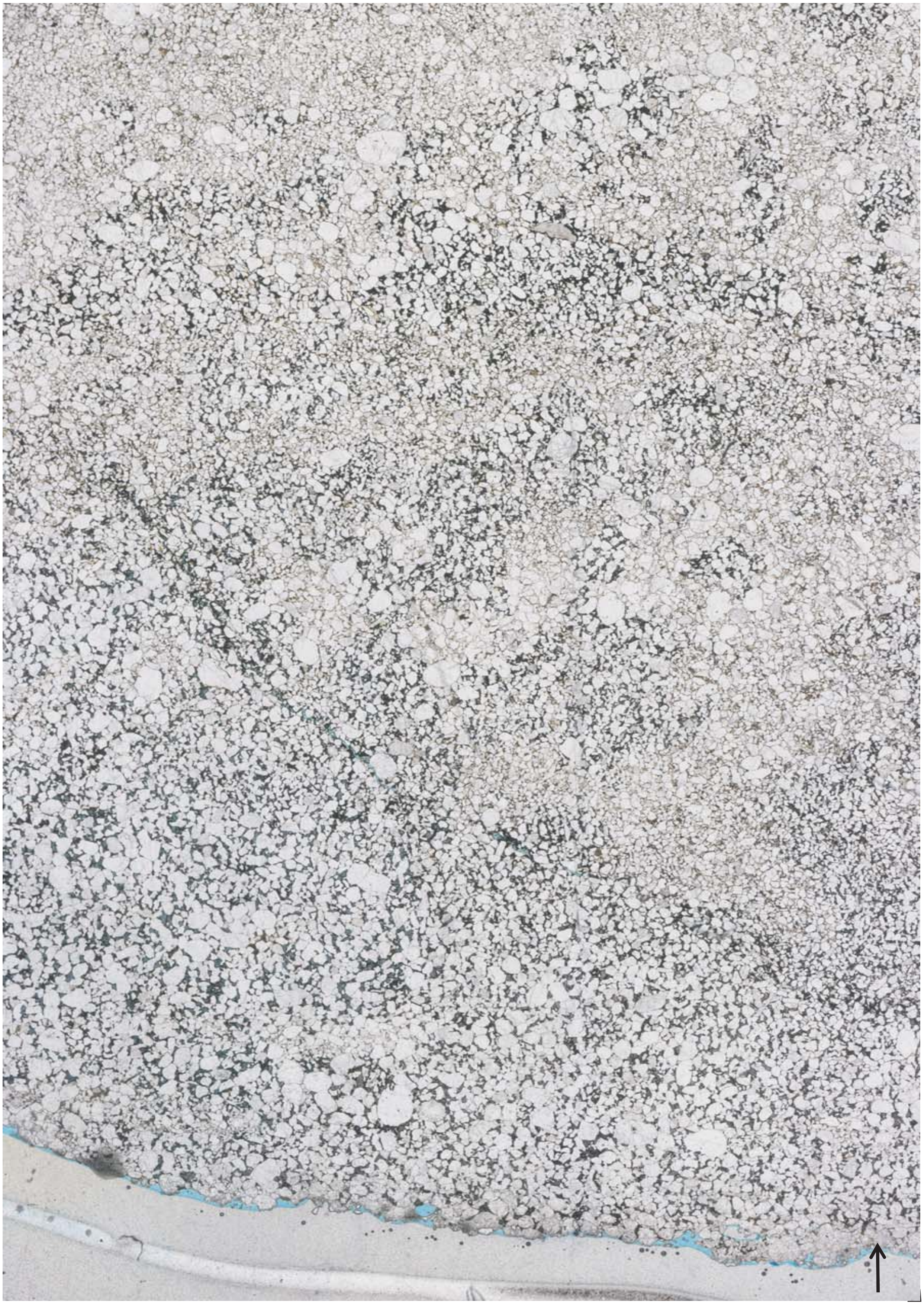
# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Quartz Arenite

**Unit:** 7
**Sample #:** C-490734

# Section 11MWBs01

# Unit 7



## Mount Clark

C-490734

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2 mm

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# Thin Section Photomicrograph Descriptions – Plate 07

## Section 11MWBs01
## Mount Clark
## Quartz Arenite

**Unit:** 7
**Sample #:** C-490734

Ferroan dolomite cemented, poorly sorted, very fine to very coarse grained quartz arenites are recognized as Mount Clark sandstones taken from outcrop sample C-490734 representing Unit 7 at Section 11MWBs01. Framework constituents are dominated by subrounded to subangular monocrystalline quartz (Q), with accessory plagioclase, polycrystalline quartz and rare heavy minerals. Brown matrix clays are unevenly distributed. Common patchily distributed ferroan dolomite (FeD) cement plus bitumen (small red arrows) are the main pore occluding phases with rare poorly developed quartz overgrowths (small black arrows) precipitated on host monocrystalline quartz grains.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**


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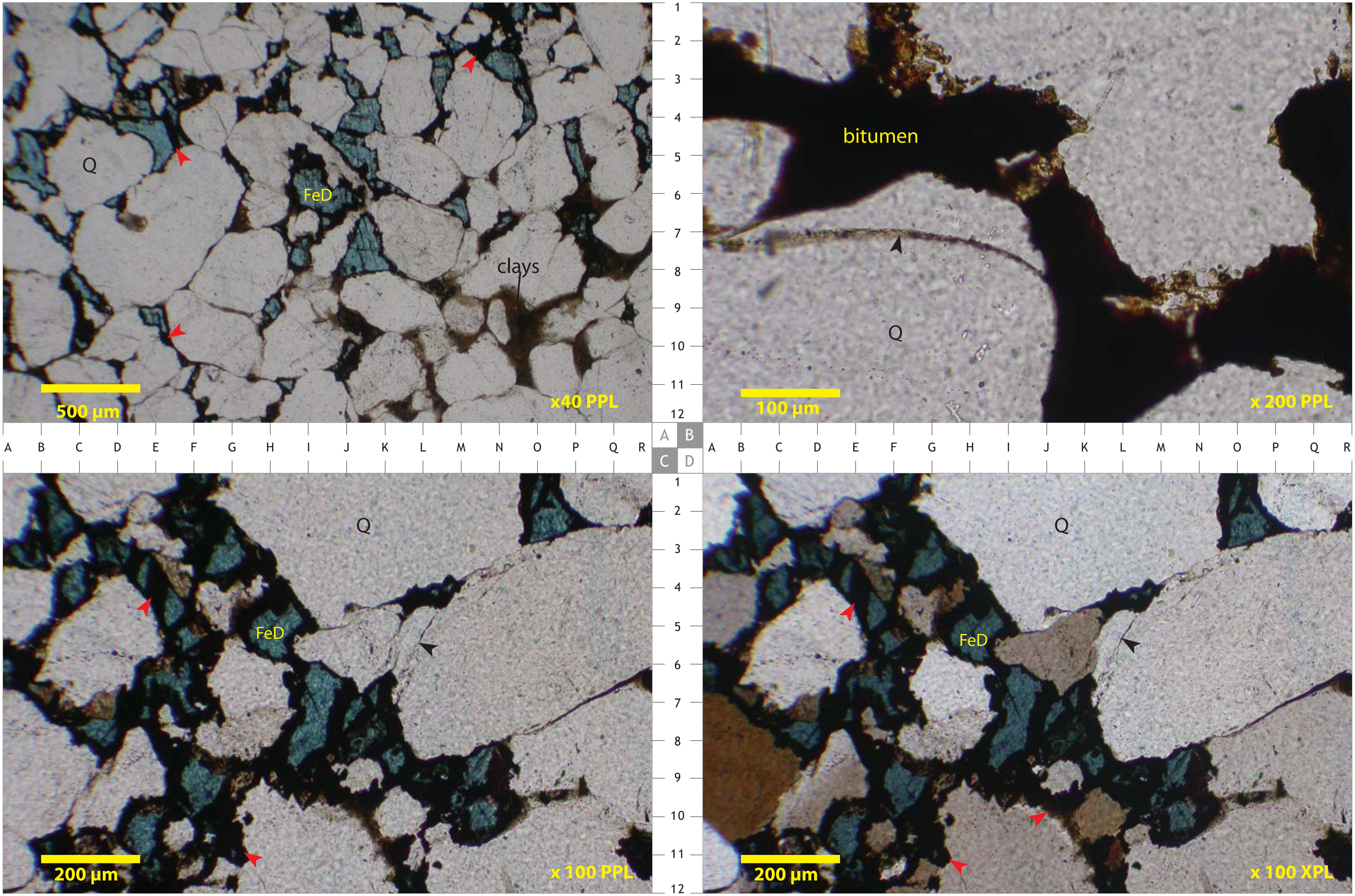


**Plate 07**
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# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Quartz Arenite (Bioturbated)

**Unit: 8**
**Sample #:** C-490735

*Note red arrows highlight discontinuous microfractures

**Section 11MWBs01** **Unit 8**

2 mm

**Mount Clark**

C-490735

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# Thin Section Photomicrograph Descriptions – Plate 08

## Section 11MWBs01
## Mount Clark
## Quartz Arenite

**Unit: 8**
**Sample #:** C-490735

Quartz cemented, moderately sorted, upper very fine to lower coarse grained quartz arenites characterize the Mount Clark sandstones recovered from outcrop sample C-490735, representing Unit 8. Overall, average grain size is upper fine grained. Monocrystalline quartz grains (Q) dominate the framework components in this relatively “tight” interval. Common quartz cement (small black arrows) is the main pore occluding authigenic cement precipitated on host monocrystalline quartz grains. The latter are outlined by common “dust rims”. Note that there appears to be several phases of quartz cementation as observed in View B (J:6) whereby two distinct syntaxial quartz cements (small black arrows) occlude macropores.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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## Section 11MWBs01

## Mount Clark Unit 8

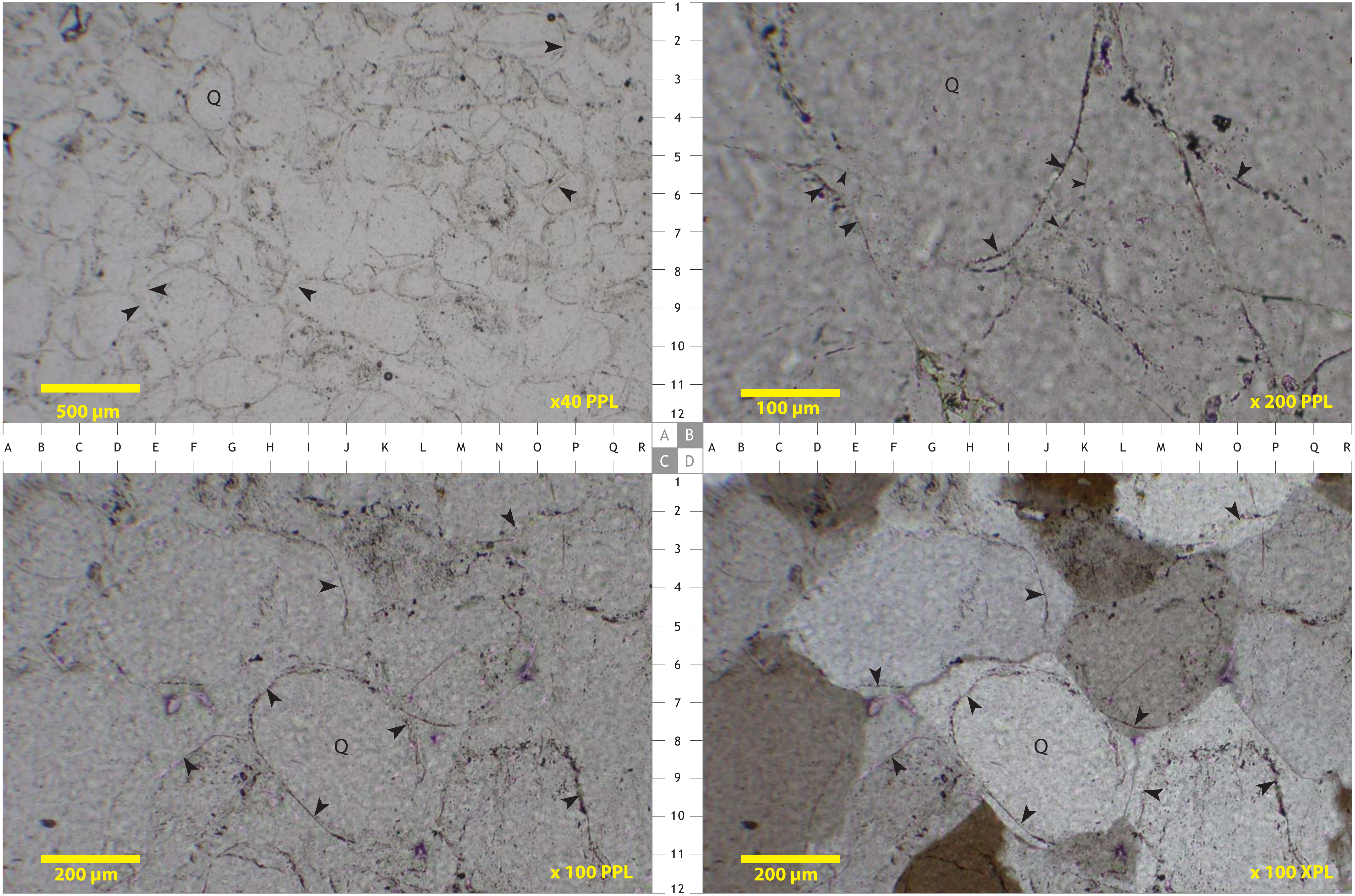


**Plate 08**
C-490735
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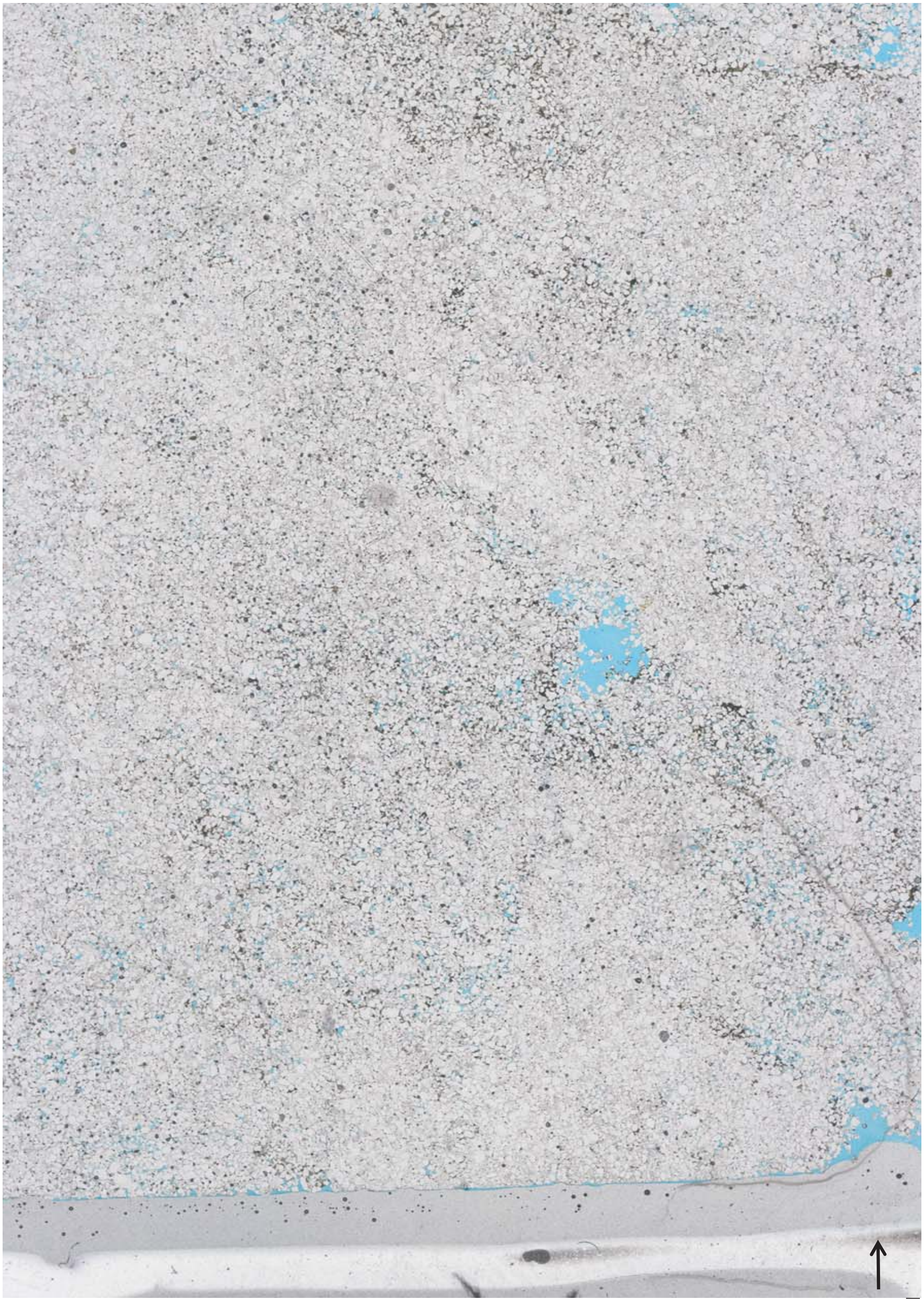
# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Quartz Arenite (?Bioturbated)

**Unit:** 10
**Sample #:** C-490736



Mount Clark

C-490736

CMH 2013-01

2 mm

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# Thin Section Photomicrograph Descriptions – Plate 09

## Section 11MWBs01
## Mount Clark
## Quartz Arenite

**Unit:** 10
**Sample #:** C-490736

Porous, moderately well sorted, upper fine grained quartz arenites are recognized from a Mount Clark outcrop sample C-490736 taken from Unit 10. Subrounded to subangular monocrystalline quartz (Q) comprises the main framework grains with accessory plagioclase and rare heavy minerals. Minor brown matrix clays are unevenly distributed in this interval. Poorly developed, unevenly distributed syntaxial quartz overgrowths (small black arrows) have precipitated on host monocrystalline quartz grains with trace non-ferroan calcite cement. Macroporosity (small yellow arrows) are well developed in this interval.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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## Section 11MWBs01

## Mount Clark Unit 10

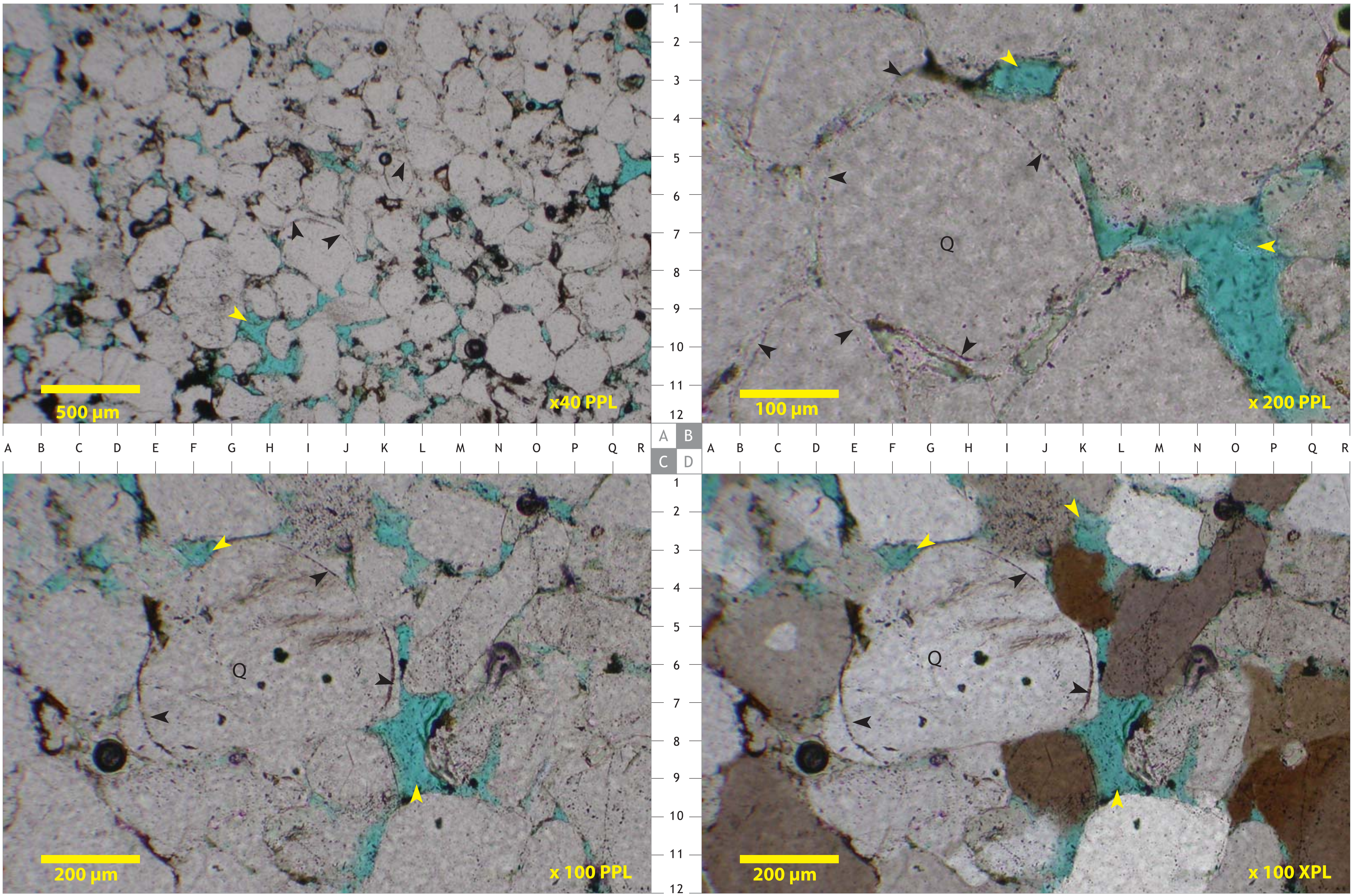


**Plate 09**
C-490736
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# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Quartz Arenite

**Unit:** 15
**Sample #:** C-490737

# Section 11MWBs01

# Unit 15

**Mount Clark**

C-490737

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2 mm

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# Thin Section Photomicrograph Descriptions – Plate 10

## Section 11MWBs01
## Mount Clark
## Quartz Arenite

**Unit:** 15
**Sample #:** C-490737

Unit 15 represented by outcrop sample C-490737 is recognized as a poorly sorted, silica cemented very fine to coarse grained quartz arenite. Subrounded to subangular monocrystalline quartz (Q) dominates the framework lithoclasts with subordinate plagioclase and polycrystalline quartz. Rare brown matrix clays are unevenly distributed. Diagenetic phases are dominated by pore occluding syntaxial silica cement (small black arrows), precipitated on host quartz grains plus rare unevenly distributed non-ferroan dolomite cement (Views C and D). Macroporosity (small yellow arrows) is poorly developed with thin section modal analysis yielding 3% effective porosity.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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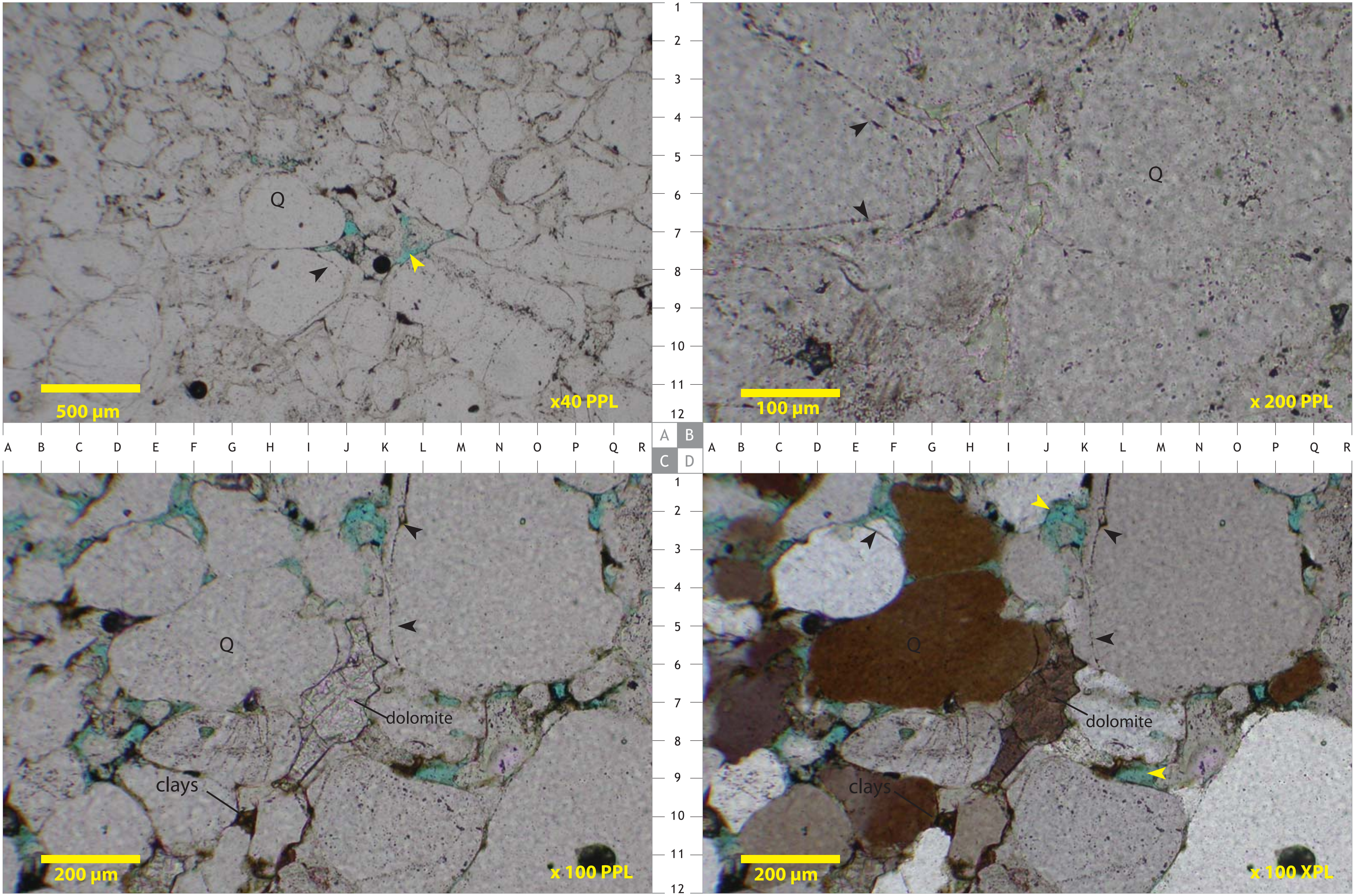


**Plate 10**
C-490737
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# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Microfractured Quartz Arenite

**Unit:** 16
**Sample #:** C-490738

## Section 11MWBs01

## Unit 16


2 mm

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## Mount Clark

C-490738

CMH 2013-01

# Thin Section Photomicrograph Descriptions – Plate 11

## Section 11MWBs01
## Mount Clark
## Microfractured Quartz Arenite

**Unit:** 16
**Sample #:** C-490738

Outcrop sample C-490738, representing Unit 16 taken from the Mount Clark Formation, consists of a poorly sorted, very fine to upper coarse grained quartz arenite. Subrounded to subangular monocrystalline quartz (Q) dominates the framework components with lesser amounts of polycrystalline quartz, plagioclase, organic material, micas and heavy minerals. Minor brown matrix clays (View A) are unevenly distributed. Authigenic phases are comprised mainly of poorly developed quartz overgrowths, precipitated on host quartz grains with rare non-ferroan calcite cement. Thin section (effective) porosity is poorly developed and unevenly distributed with point count analysis yielding 2.2%. Note hydrocarbons, in the form of bitumen (small red arrow), partially lining microfracture in Views C and D.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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## Section 11MWBs01 — Mount Clark Unit 16

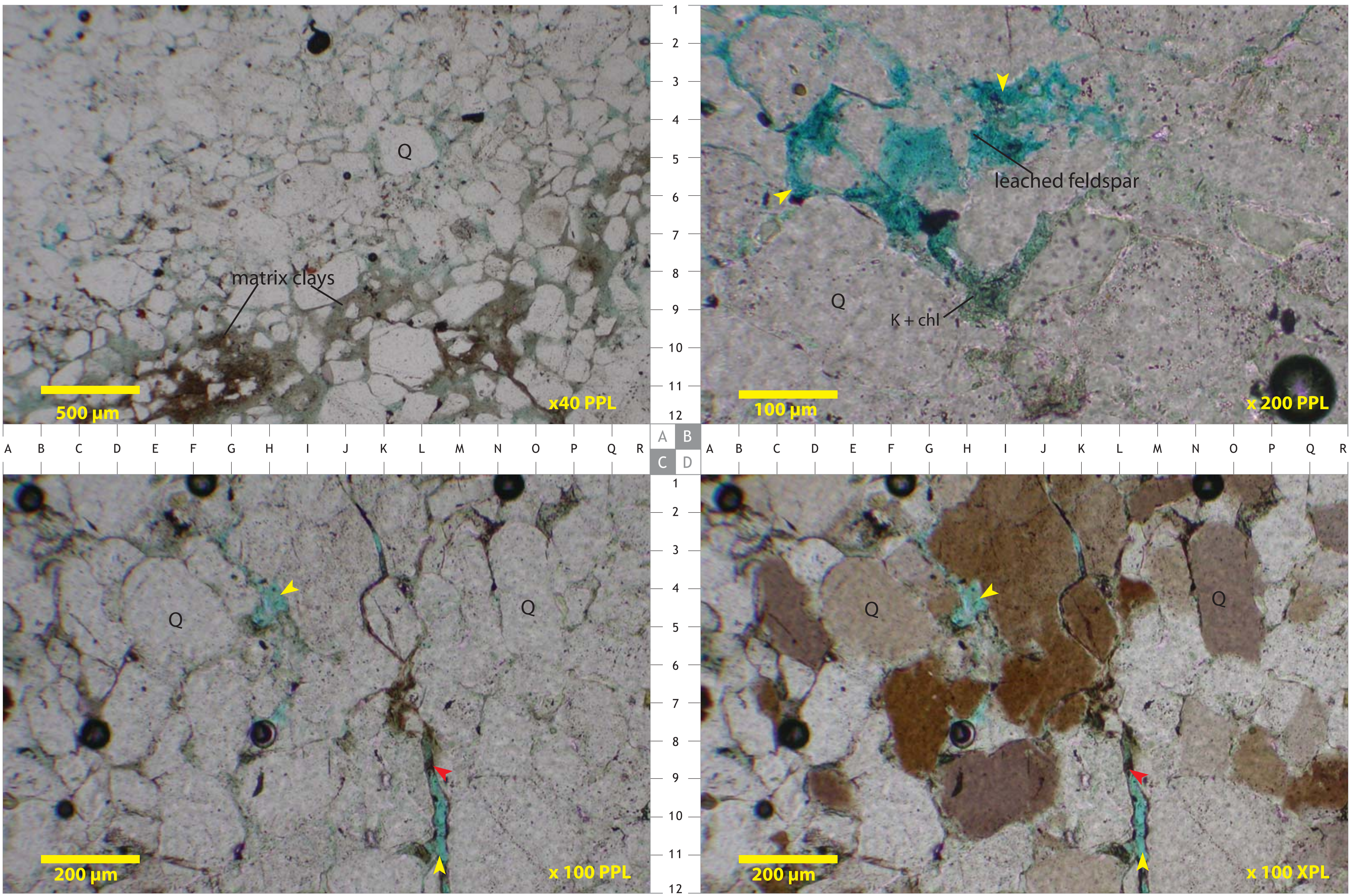


**Plate 11**
C-490738
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# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Silty Glauconitic Dolostone

**Unit:** 20
**Sample #:** C-490741

# Section 11MWBs01

# Unit 20



## Mount Clark

C-490741

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# Thin Section Photomicrograph Descriptions – Plate 12

## Section 11MWBs01
## Mount Clark
## Silty Glauconitic Dolostone

**Unit:** 20
**Sample #:** C-490741

Unit 20 taken from outcrop sample C-490741 is a silty glauconitic tightly packed argillic very finely crystalline dolostone. Common sand sized subrounded inclusion-rich glauconitic peloids, silt sized subangular quartz grains and pyritized organic material, plus rare phosphatic grains (fish debris) and muscovite flakes are scattered in the dolomitic matrix (Dol). Hydrocarbons, in the form of bitumen (small red arrows) commonly rim the subhedral dolomite crystals as shown by the red arrows.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**


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Section 11MWBs01

Mount Clark Unit 20

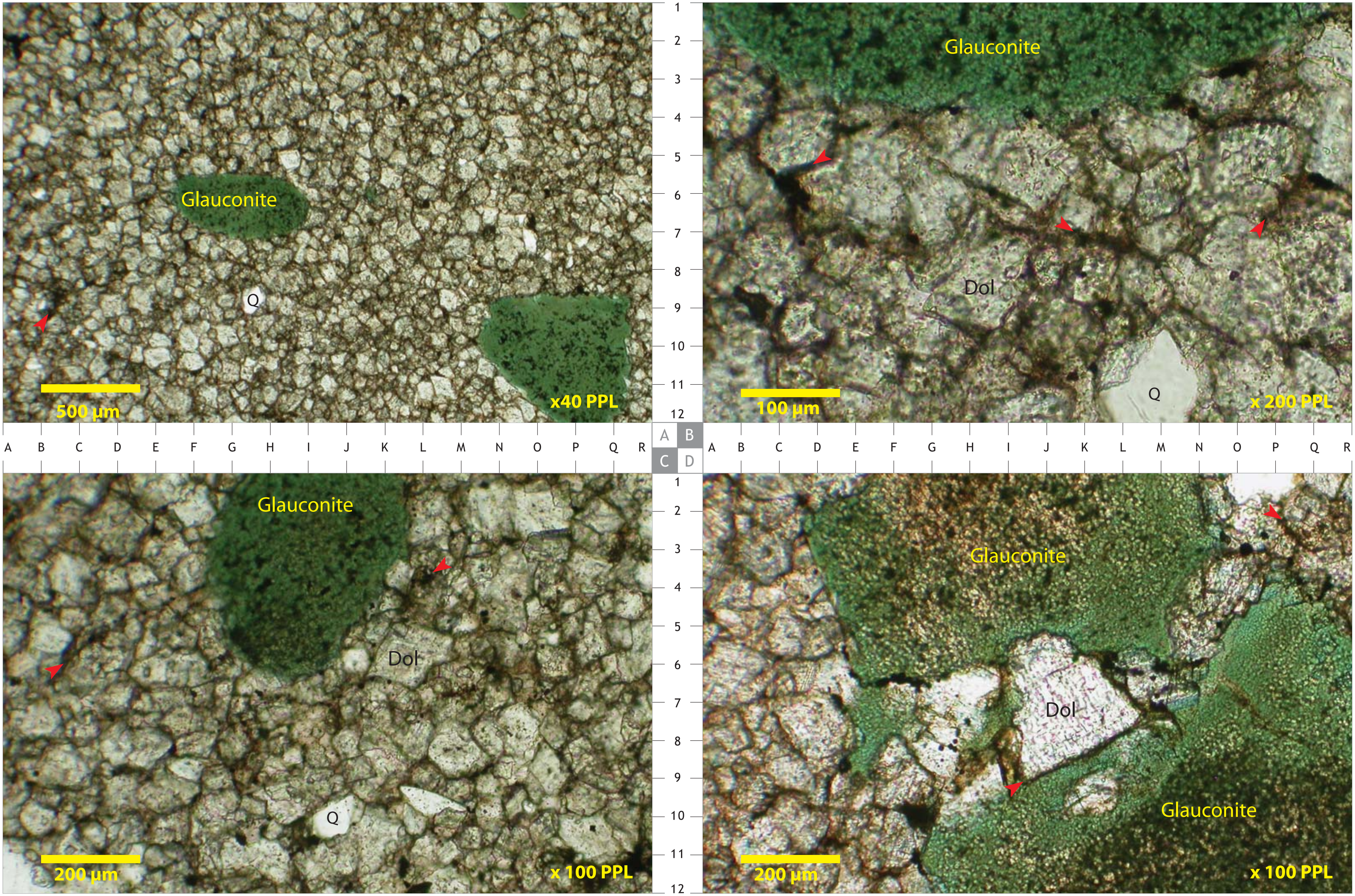


**Plate 12**
C-490741
CMH 2013-01

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# Thin Section Overview

## Section 11MWBs01
## Mount Clark
## Dolomitic Litharenites

**Unit:** 22
**Sample #:** C-490742

# Section 11MWBs01

# Unit 22

2 mm

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## Mount Clark

C-490742

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# Thin Section Photomicrograph Descriptions – Plate 13

## Section 11MWBs01
## Mount Clark
## Dolomitic Litharenites

**Unit:** 22
**Sample #:** C-490742

Extensively bioturbated, chaotic textured, very poorly sorted, ferroan dolomite cemented argillic litharenites are recognized from outcrop sample C-490742 representing Unit 22 taken from the Mount Clark Formation at Section 11MWBs01. Very fine to coarse grained framework grains are scattered in the ferroan dolomite matrix. They consist of inclusion-rich glauconite (Glauc), subangular to subrounded quartz grains (Q), plagioclase, K-feldspar, phosphatic grains (fish debris) and heavy minerals. The matrix surrounding the clastic grains consists of tightly packed, inclusion-rich, very fine to medium crystalline, subhedral argillaceous ferroan dolomite (FeD). The uneven distribution of the framework grains throughout the matrix may be due to extensive bioturbation of the soft sediment prior to burial and lithification. Pyrite is present in small amounts, occurring as discrete framboidal crystallites, dispersed throughout the matrix. Note small red arrows highlighting bitumen.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**


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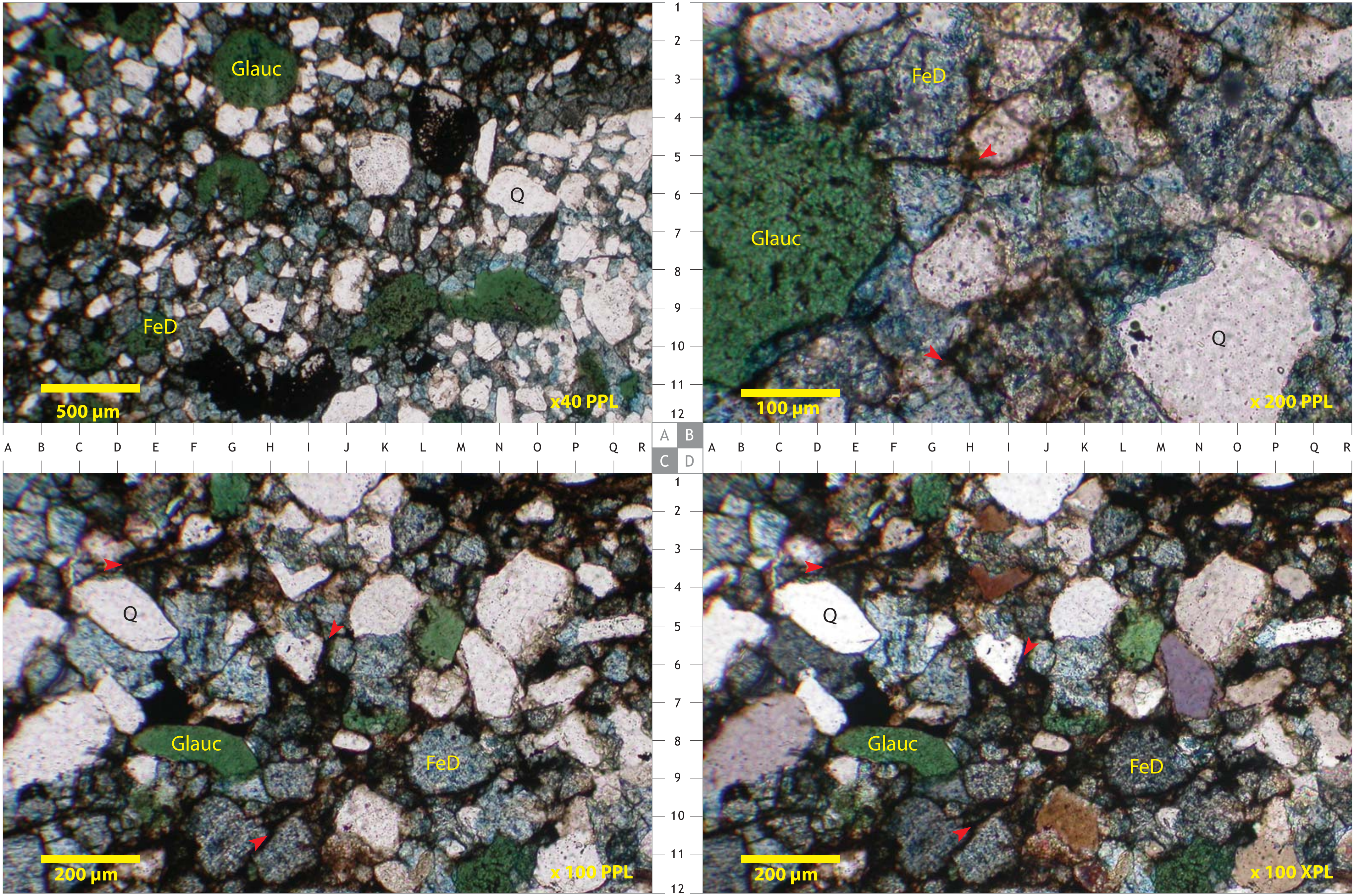


**Plate 13**
C-490742
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# Thin Section Overview

## Section 0901S
## K3
## Subarkose (Laminated)

**Unit:** 1
**Sample #:** C-490762

## Section 0901S

## Unit 1

**K3**

C-490762

CMH 2013-01

2 mm

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# Thin Section Photomicrograph Descriptions – Plate 14

## Section 0901S
## K3
## Subarkose

**Unit:** 1
**Sample #:** C-490762

Laminated, moderately well sorted, fine grained subarkoses were recovered from outcrop sample C-490762, representing Unit 1 of the K3 Formation. Subrounded to subangular monocrystalline quartz dominates the framework constituents with lesser amounts of K-feldspar, plagioclase, polycrystalline quartz, plus rare argillic lithoclasts and glauconite. Common silica cement is the main pore occluding diagenetic cement in this interval with rare pyrite. The partial dissolution of unstable framework lithoclasts, such as feldspars, has resulted in isolated intragranular macropores such as shown in Views C and D, H:6.

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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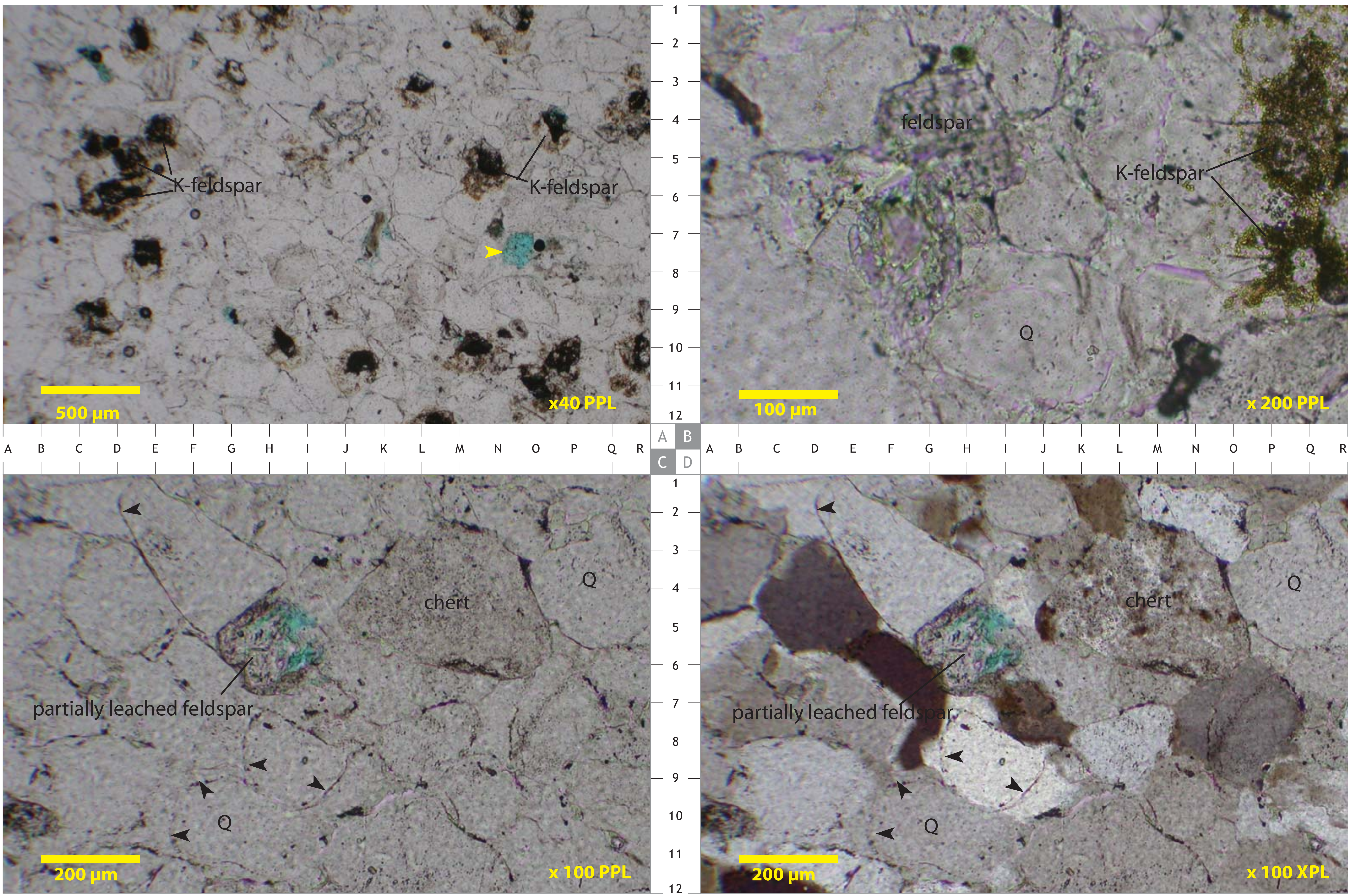


**Plate 14**
C-490762
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# Thin Section Overview

## Section 0901S
## K5
## Subarkose

**Unit:** 7
**Sample #: C-490761**

Section 0901S

Unit 7

K5

C-490761

CMH 2013-01

2 mm

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# Thin Section Photomicrograph Descriptions – Plate 15

## Section 0901S
## K5
## Subarkose

**Unit:** 7
**Sample #: C-490761**

Moderately well sorted, upper fine grained, silica cemented subarkoses characterize the sandstones taken from Outcrop Sample C-490761 from Unit 7, K5 at Section 0901S. Framework constituents are dominated by subrounded to subangular monocrystalline quartz (Q) with common K-feldspar, plagioclase and polycrystalline quartz. Accessory framework grains include glauconite, clay-rich sedimentary grains and heavy minerals. The main pore occluding authigenic phase consists of quartz cement (small black arrows) precipitated on host quartz grains with rare patchily distributed ferroan dolomite cement. Dust rims are commonly observed separating the quartz grains from the diagenetic silica overgrowth. Note hydrocarbon, in the form of bitumen, within the carbonate cleavage surfaces (small red arrows).

**Photo A: 40X PPL, Photo B: 200X PPL, Photo C: 100X PPL, Photo D: 100X XPL**



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Section 0901S

K5 Unit 7

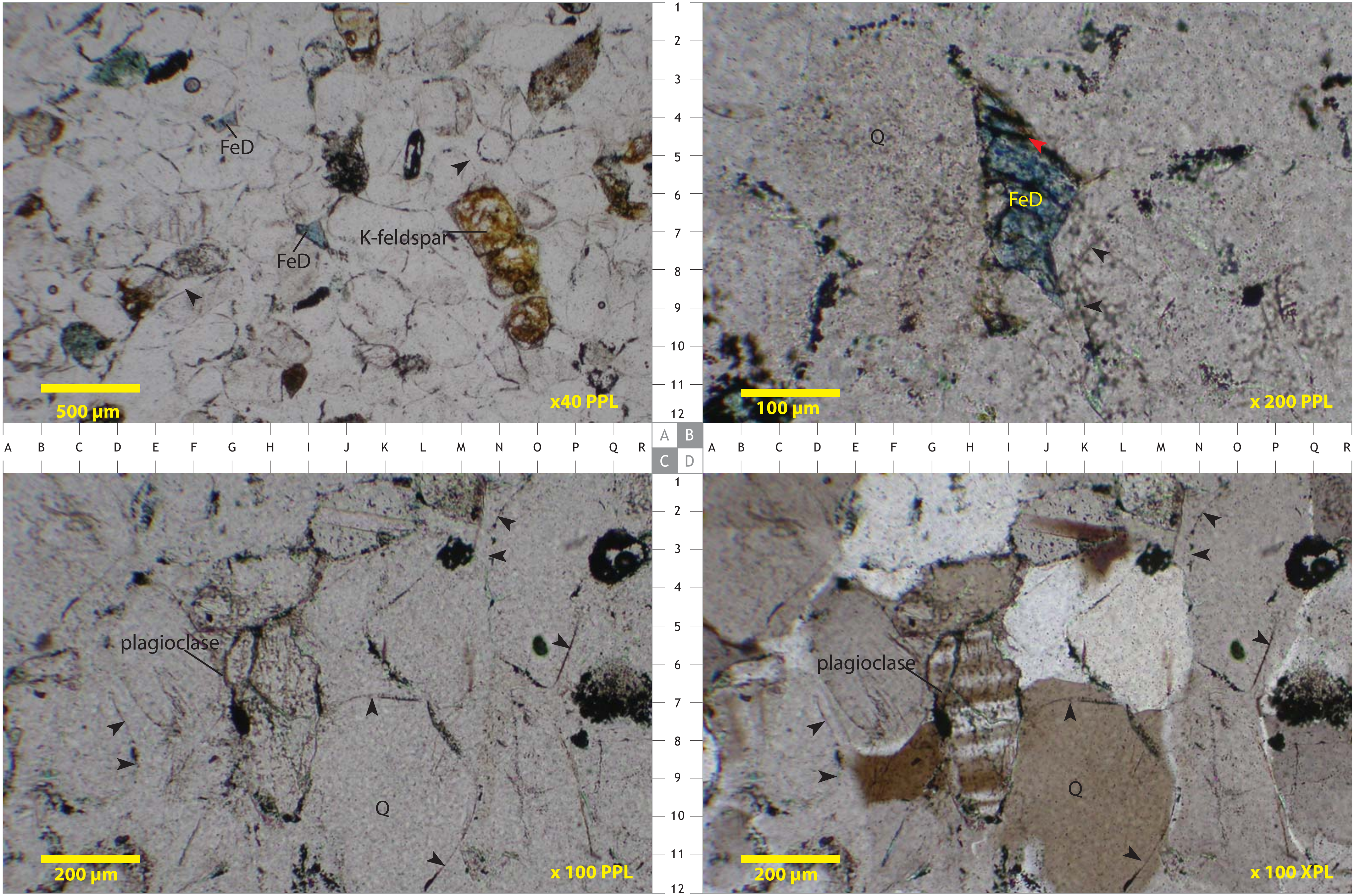


**Plate 15**
C-490761
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